

HDM Halswell Flood Model

Model Status Report

Prepared for Christchurch City Council

Prepared by Beca Limited

20 February 2026



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Revision History

Revision N°	Description	Date
A	First release to accompany delivery of Existing Development 2016 model.	09/12/2022
B	Updated to reflect Existing Development 2021 model – at Peer Review stage.	16/12/2022
C	Updated for delivery of 2021 model	20/10/2023
D	Updated for delivery of 2024 model	08/12/2025
E	Updated based on DHI and Council Comment	20/02/2026

Document Acceptance

Action	Signed	Date
Approved On behalf of Beca Ltd		20/02/2026

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1 Introduction

1.1 Purpose of this Report

The purpose of this report is to outline the method, tools and processes used in the model build of the HDM Halswell flood model 2024. The HDM Halswell flood model 2024 represents the Halswell River catchment of the Citywide Flood Modelling (CFM) project. In line with the structure of other catchment reports within the CFM project, this document detailed the staged development of hydrological and hydraulic modelling for the Halswell River catchment.

The reference model, which previously depicted the catchment conditions of 2021, was updated at the request of the Council to reflect the catchment conditions for 2024. This update also incorporated the Maximum Probable Development (MPD) or Future Development (FD) scenario for the catchment. The updates included addressing existing anomalies, integrating new developments, and enhancing the representation of various structures.

The 2024 model was developed using the 2021 model as its foundation. The following tasks were undertaken, and key deliverables included in the updated model, supporting documentation, and result files:

- Transitioned the model's vertical reference system from Christchurch Drainage Datum (CDD) to New Zealand Vertical Datum (NZVD)
- Existing issues within the base model were identified and addressed
- Model boundaries were revised to align with 2024 development extents
- All small diameter pipes (less than 300 mm) that were not included in the previous model have been added
- Templeton and its catchment were integrated into the model
- Representations of existing basins were enhanced
- New subdivisions developed after 2021 were incorporated
- The representation of groundwater and its influence on rainfall losses was refined

1.2 Citywide Flood Modelling (CFM) Project

The CFM project is a three-way coupled hydraulic modelling project being undertaken by Christchurch City Council (CCC).

The purpose of the CFM project was to develop updated river catchment models for the 'flat land' Christchurch, combined with a single hydraulic model of the city's waterways and pipe networks, that can be used. At the time of writing this report, this schema is partially superseded, with a new schema underway.

- By the Land Drainage Recovery Programme (LDRP) to support identification and prioritisation of repair and remedial options.
- By CCC to investigate resiliency of the city against climate change and sea level rise.

1.3 Specifications

The HDM Halswell flood model was developed using the following specifications and reference documents:

- CFM (LDRP044) Model Schematisation – Avon/Estuary, Heathcote, and Sumner (GHD\AECOM, 2018)
- Waterways and Wetland Design Guide (WWDG) (CCC, 2011)
- Stormwater Modelling Specification for Flood Studies (GHD, 2012)
- Christchurch City Council MIKE FLOOD Technical Specifications (DHI, 2015)
- HDM Halswell Flood Model (Beca, 2023)

1.4 Model Developer

The HDM Halswell flood model has been developed by Beca Ltd (Beca) from their Christchurch Office; details listed in Table 1-1.

Table 1-1: Contact details

Name	Beca Ltd
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Phone	+64 3 366 3521
Fax	0800 578 967 (inside NZ)

1.5 Peer Review

DHI conducted a peer review of the Existing Development 2024 model at the end of 2024, providing advice to address several specific features. DHI also provide a review of the calibration of the model against the historic event. Their recommendations were compiled in a Microsoft Excel spreadsheet, with each item's importance clearly indicated; this spreadsheet is included in Appendix I. For all items identified as *concerns* or *minor issues*, Beca either updated the Existing Development 2024 model in line with DHI's comments or provided an explanation for why no action was taken.

Additionally, advice from DHI's peer review of the Existing Development 2021 model was incorporated during the transition to the 2024 model.

2 Modelling Software

The DHI MIKE software suite is the primary software used to build the HDM Halswell model 2024. The suite was used as MIKE can model a variety of hydrologic and hydraulic processes, including rainfall-runoff, river behaviour, pipe networks, 2D flood flows.

There are two main components of the HDM Halswell model 2024: the hydrology and the hydraulics. Table 2-2 outlines the software used for each component and the methods that were adopted under the software. Further details for each software are provided in the following sections below.

Table 2-1 HDM Halswell model summary

Process	Software	Method
Rainfall-Runoff (Hillside)	RORB	Concentrated Non-linear Storages
Rainfall-Runoff (Flat Land)	MIKE 21 FM	Rain on Grid
Flood Plains	MIKE 21 FM	2D Shallow Water Equations
Pipe Network	MIKE Urban	MOUSE 1D St Venant and Continuity Equations
Channel Flow	MIKE 11 Classic	St Venant and Continuity Equations

2.1 Hydrology Software

The hydrology was modelled using two methods in two software packages: 2D rain on grid in MIKE 21 and RORB rainfall-runoff. The use of this software was determined based on the topography of the Halswell catchments, shown in Figure 2-1, where:

- The flat land hydrology was modelled as rain on grid. Rain on grid applies a rainfall time-series directly to each active mesh element in MIKE 21. As water accumulates in each mesh cell, water will move to the adjacent element based on the amount of rain and losses applied to that element. In the 2021 model, an infiltration map within MIKE 21 utilized Horton's equation to apply a spatially varying decay time series across the entire catchment area. However, in the updated 2024 model, the infiltration module now incorporates groundwater capacity as the method for managing infiltration. The rain on grid method is consistent with the methodology outlined in CFM (LDRP044) Model Schematisation (GHD/AECOM, 2018).
- The hillside (Port Hills) catchments were modelled using RORB. RORB is a runoff and streamflow routing program that calculates flood hydrographs from rainfall and channel inputs. It subtracts losses (initial loss and continuing loss) from the rainfall to produce excess-rainfall and routes this through catchment storage to produce runoff hydrographs at specified locations. RORB was used to produce outflow hydrographs for each hillside catchment which were used as point inflows to the MIKE 21 model. More information on the development and background theory of the runoff-routing method employed in RORB is contained in Appendix A¹. Section 3.3 provides the detail of the hydrology used within the HDM Halswell model.

¹ The concepts and information provided in this Appendix A are taken from the RORB Version 6 User Manual which is copyright of Monash University and Hydrology and Risk Consulting Pty Ltd. Any material copied or otherwise reproduced from that manual must give due acknowledgement of its source.

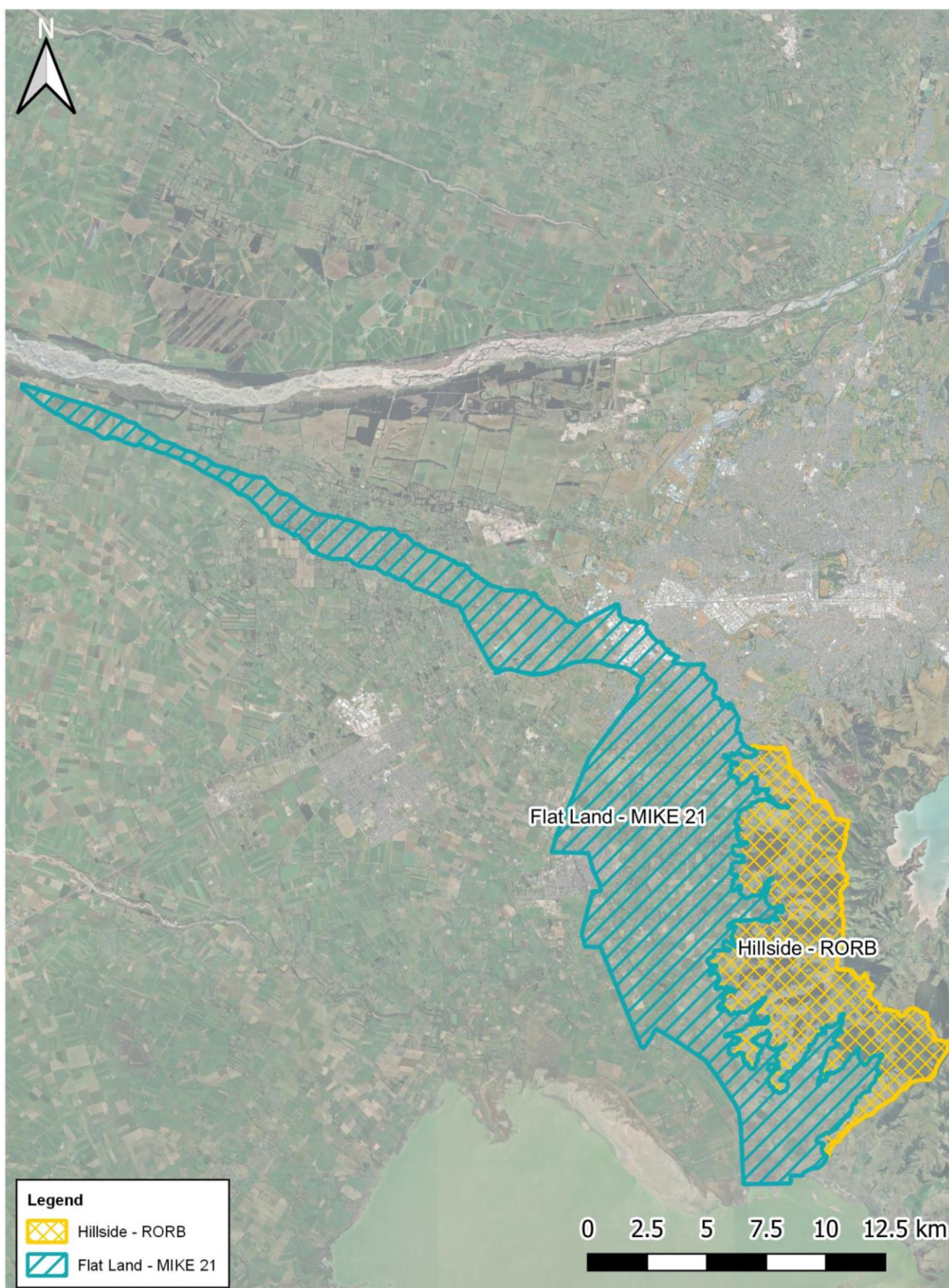


Figure 2-1 Hydrology methods applied to model extents. *Image source: Map data © 2025 Google*

2.2 Hydraulics Software

The HDM Halswell model consists of the three component models which are coupled together with MIKE FLOOD. Figure 2-2 shows this structure and it is listed below.

- The one-dimensional (1D) pipe flow was modelled using MIKE URBAN,
- the 1D river flow was modelled using MIKE 11, and
- the 2D overland flow was modelled using MIKE 21.

The blue arrows in Figure 2-2 represent transfer of water and momentum between the three component models accommodated by MIKE FLOOD.

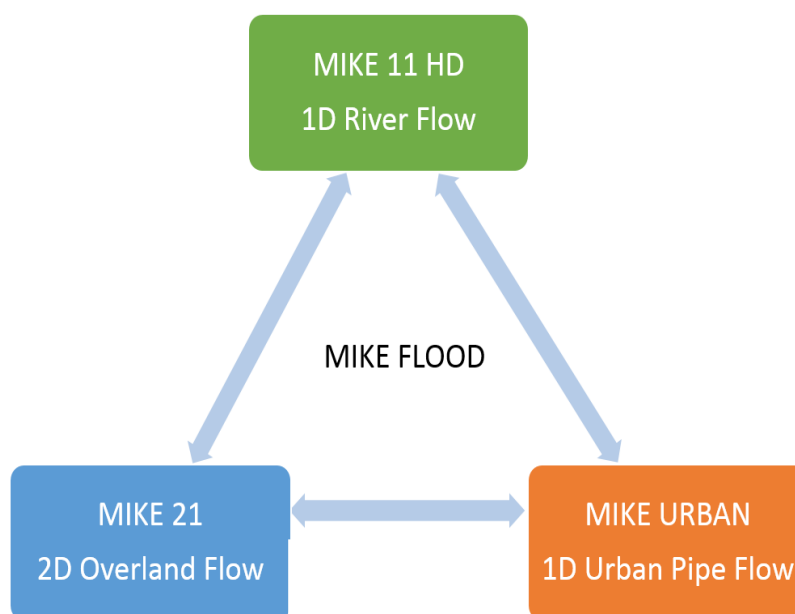


Figure 2-2 Structure of coupling in MIKE FLOOD

2.3 Software versions adopted within model

The software versions that are currently used for the development of the HDM Halswell model are outlined in Table 2-2. This model has been developed over several years and hence has moved through preceding software versions.

Table 2-2 HDM Halswell model software versions

Model Component	Software Version
MIKE 11	v.2020
MIKE 21	v.2020
MIKE FLOOD	v.2020
MIKE URBAN	v.2020
RORBwin	v.6.52 (2023)

2.4 Hardware Specifications

The HDM Halswell model was run on a dedicated modelling PC to speed up the total time required for the simulations. Table 2-3 outlines the hardware used to run the HDM Halswell model. The model was run using the MIKE 21 graphics processing unit functionality which increases performance, substantially reducing simulation run times.

Table 2-3 HDM Halswell model hardware specifications

Computation Element	Hardware Specification
Processor	Intel(R) Core (TM) i7-14700K 3.40 GHz
Memory (RAM)	64.0 GB
Operating System	64-bit operating system, x64-based processor
GPU Computing Processor	NVIDIA RTX 4000 SFF Ada Generation
Dedicated Memory	20 GB

3 Model Build Introduction

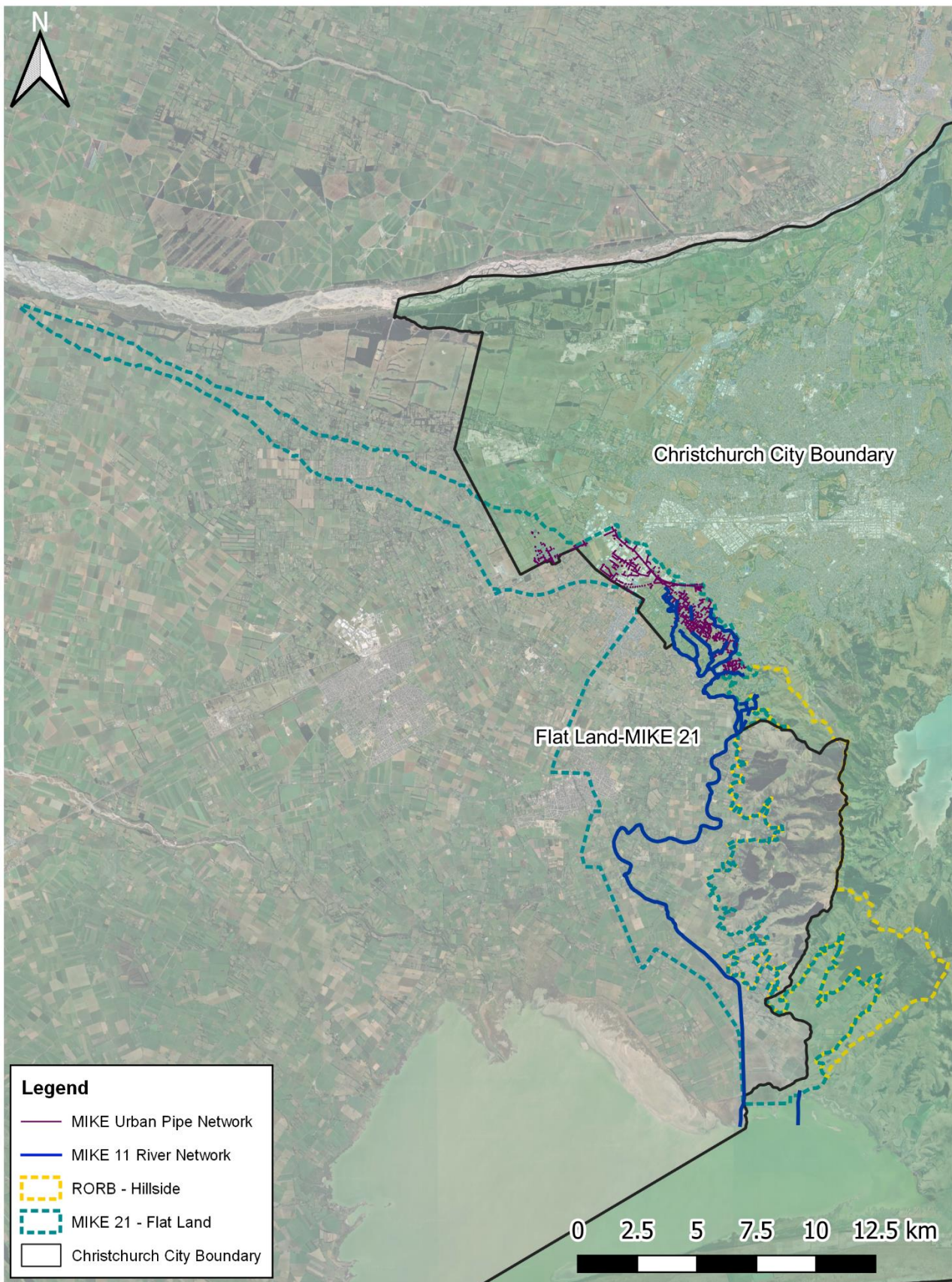
3.1 Catchment Description

The Halswell River catchment is located to the south of Christchurch (Figure 3-1). The catchment is increasingly urbanised in the north and remains predominately rural in the south. It is characterised by:

- Spring-fed headwaters, rising in the commercial, industrial, and residential suburbs of south-west Christchurch (for example Hornby and Halswell).
- Steep, rain-fed headwaters draining from the Port Hills to the east.
- Extensive, flat alluvial plains throughout the mid-course of the river dominated by agriculture and low-density rural properties.
- Low lying areas bordering the river where it drains into Te Waihora/Lake Ellesmere. These areas are reclaimed wetlands and prone to flooding from the lake. The river flows through a canal in its last 6km to reduce flooding issues.

The catchment area is approximately 158 km² including the rural catchment south of the Waimakariri River. This area encompasses the residential of Templeton and is located to the north of the model. The Halswell catchment is predominantly 70% flat and the remaining 30% is the steep hillside area of the Port Hills. Only a small percentage (15%) of the total catchment area is within the Christchurch City Council boundary. Soil type on the plains varies from free-draining Waimakariri sandy loams to poorer-draining Tai Tapu silt loams. Loess covers the slopes of the Port Hills. Overall, the soils are considered to be relatively poor draining with high groundwater levels (Opus, 2016).

The upper Halswell catchment has been identified for future residential developments, with new developments already commenced and likely to continue over several decades (Christchurch City Council, 2020).



3.2 Data Sources

To provide a level of detail to sufficiently quantify the effects of flooding and to support future investigation, the data required for the HDM Halswell model 2024 has been obtained from and provided by CCC and several other sources including the Stronger Christchurch Infrastructure Rebuild Team (SCIRT), Landcare Research, Environment Canterbury (ECan) and the National Institute of Water and Atmospheric Research (NIWA). The information received has included MIKE models, drainage asset information, detailed feature survey information, CCC reports and CFM memorandums. The data has been reviewed and gaps identified. The following section provides an overview of the data provided and any infill undertaken. Table 3-1 (page 11) summaries the data inputs for the HDM Halswell model.

3.2.1 Documentation

The primary documents received and reviewed include, but are not limited to:

- CFM (LDRP044) Model Schematisation – Avon/Estuary. Heathcote and Sumner (GHD/AECOM, 2018),
- Christchurch City Council MIKE FLOOD Technical Specifications (DHI, 2015),
- Land Drainage Recovery Programme Survey Specification (CCC, 2015),
- Waterways, Swamps and Vegetation of Christchurch in 1856 and Baseflow Discharge in Christchurch City Streams (ECan, 2007),
- Restoring Knights and Nottingham Stream Report, (CCC, 2014),
- Halswell River/Huritini floodplain investigation Report (ECan, 2013),
- Halswell River Hydraulic Model Status Report (DHI, 2015),
- Knights and Nottingham Stream: Background and Modelling Log (CCC, 2013),
- Christchurch Flood Areas March 2014 (Jacobs SKM, 2014),
- Citywide Flood Modelling: “2014 Simplified” Pre-Quake Variation Description Memo (GHD, 2015),
- Citywide Flood Modelling: Proposed Technical specification for model runtimes (GHD, 2015),
- Citywide Flood Modelling: 2041 Runoff Methodology (GHD, 2015),
- Citywide Flood Modelling: Avon Calibration Approach Draft (GHD, 2017),
- LDRP044 Citywide Flood Modelling: Rain on mesh hillside hydrology/stability Memo (GHD/AECOM, 2018).

3.2.2 LDRP044: Developing sub-catchment rainfall events Memo (AECOM, 2015). Existing MIKE Models

The following MIKE models were supplied by CCC:

- Halswell River Hydraulic Model (DHI, 2015), modelled in MIKE FLOOD (1D MIKE 11/2D Mike 21).
- Halswell River/Floodplain investigation model (ECan, 2013), modelled in MIKE FLOOD (1D MIKE 11/2D Mike 21).
- Nottingham Stream Model (CCC, 2013), model in 1D MIKE 11.
- Knights Stream Model (CCC, 2013), modelled in 1D MIKE 11.
- HDM Halswell Model (2023), modelled in MIKE suite.

These models were used to provide supporting information and cross reference for asset information, pipe connectivity, sub-catchments, terrain features and linkages.

3.2.3 Topographical Data (Rivers and Streams)

On behalf of CCC, GHD provided the processed Citywide Flood Modelling DEM developed with CCC post-quake 2011 LiDAR. For information on the development of the DEM, refer to CFM (LDRP044) Model Schematisation (GHD/AECOM, 2018). The extent of the post-quake LiDAR used in the Halswell model is shown in Figure 3-2. Beca updated the DEM in the recently developed areas in Knight Stream and Longhurst using LiDAR supplied by CCC that was recorded 2019.

River and stream cross-sectional survey were provided by CCC for:

- Halswell River,
- Nottingham Stream,
- Knight Stream,
- Halswell Outfall Drain,
- Minsons Drain,
- Cases Drain,
- Greens Stream,
- Paynes Drain,
- Quaifes Drain,
- Talbots Drain,
- Creamery Drain, and
- Creamery Ponds 1 and 2.

3.2.4 Topographical Data (Roads and Railways)

Terrain features for road and rail were provided by CCC and Selwyn District Council (SDC) as a GIS database. The SDC dataset is clean with no identifiable spatial alignment issues. The CCC dataset needed refining due to issues with the digitising of the road centrelines and other digital inconsistencies. Methodology for refining the CCC road centre lines were as detailed in CFM (LDRP044) Model Schematisation (GHD/AECOM, 2018).

3.2.5 Drainage Assets

Beca downloaded stormwater pipe network information from CCC's GIS database. Supplementary data for the stormwater pipe assets were provided by SCIRT from their GIS database (2015). Drawings and as-builts were provided by CCC for the following stormwater ponds:

- Halswell Junction Detention Basin,
- Creamery Ponds,
- Owaka Basin,
- Knight Stream Park Basin, and
- Murphy's Drainage Basin.

Drawings of additional basin were provided in 2022:

- Cloverden Basin (now filled in),
- Knights Stream Wetland (including an inlet pumpstation),
- Lee's Basin,
- Maize Maze Basin,
- Ramp Basin,
- Mushroom Basin,
- Westlake Reserve Soakage Basin, and
- Wilmer's Basin.

3.2.6 Rainfall, River flow and Rainfall records

Spatially varying rainfall depths from NIWA's HIRDS v4 were used to create rainfall depths for each ARI, duration, and climate change emissions pathway. For the MIKE 21 rain on grid model, a 500 m spaced *.dfs2 file was generated for each rainfall event. The RORB model had the HIRDS v4 rainfall depths applied at the centroid of each sub-catchment.

Rainfall records and river flow records were collected from E-Can and NIWA that were used in the model validation (see Section 6). Rainfall radar data in the form of accumulation plots was provided by CCC for the RORB model calibration.

Table 3-1 Data collected for the model

Data Type	Source	Comment
CCC LiDAR 2003	GHD on behalf of CCC	Pre-quake data.
CCC LiDAR 2011	GHD on behalf of CCC	Post-quake data, compiled from a range of post-quake flyovers (Aug 2011 and Feb 2012).
CCC GIS network data	CCC	Asset data downloaded from CCC GIS database (2023).
SCIRT supplementary survey data	Stronger Christchurch Infrastructure Rebuild Team (SCIRT)	Supplementary survey data for stormwater pipe network assets (2015).
Cross-sectional survey data	CCC	Cross-sectional survey data collected by CCC. Where survey data was not available cross-sections were sourced from the LiDAR, as specified by CFM (LDRP044) Model Schematisation (GHD/AECOM, 2018) and WWDG (CCC, 2011).
Citywide Soil Drainage Map	Landcare Research/CCC	Layer outlining soil drainage across Christchurch City.
Stormwater retarding basins	CCC	Design drawings and as-builts of stormwater basins: Halswell Junction Detention Basin, Creamery Ponds, Owaka Basin, Knight Stream Park Basin, Knights Stream Wetland, Mushroom Basin, Ramp Basin, Lee's Basin Maize Maze, and Murphy's Drainage Basin.
Halswell HIRDS v4 historic and projected rainfall depths	NIWA	Used to generate design rainfall from HIRDS v4 database.
Kaituna River flow record (RORB calibration)	Environment Canterbury (ECan)	Flow record for RORB model calibration at gauge: Site 67702 - Kaituna River at Kaituna Valley Road.

Data Type	Source	Comment
Port Hill rainfall records (RORB calibration)	ECan	Rainfall record for RORB model calibration at gauges: Site 326611 - Coopers Knob. Site 328711 - Kaituna Valley Road.
Port Hill rainfall record (RORB calibration)	NIWA	Rainfall record for RORB model calibration at gauge: Site 327804 Rainfall 4960 Chch-Akaroa Hwy.
Rainfall radar data (RORB calibration)	CCC	Radar dataset provided for RORB model calibration.
Stormwater Assets	Lynker	Supplementary survey data for sump and Land use (2018-2023).

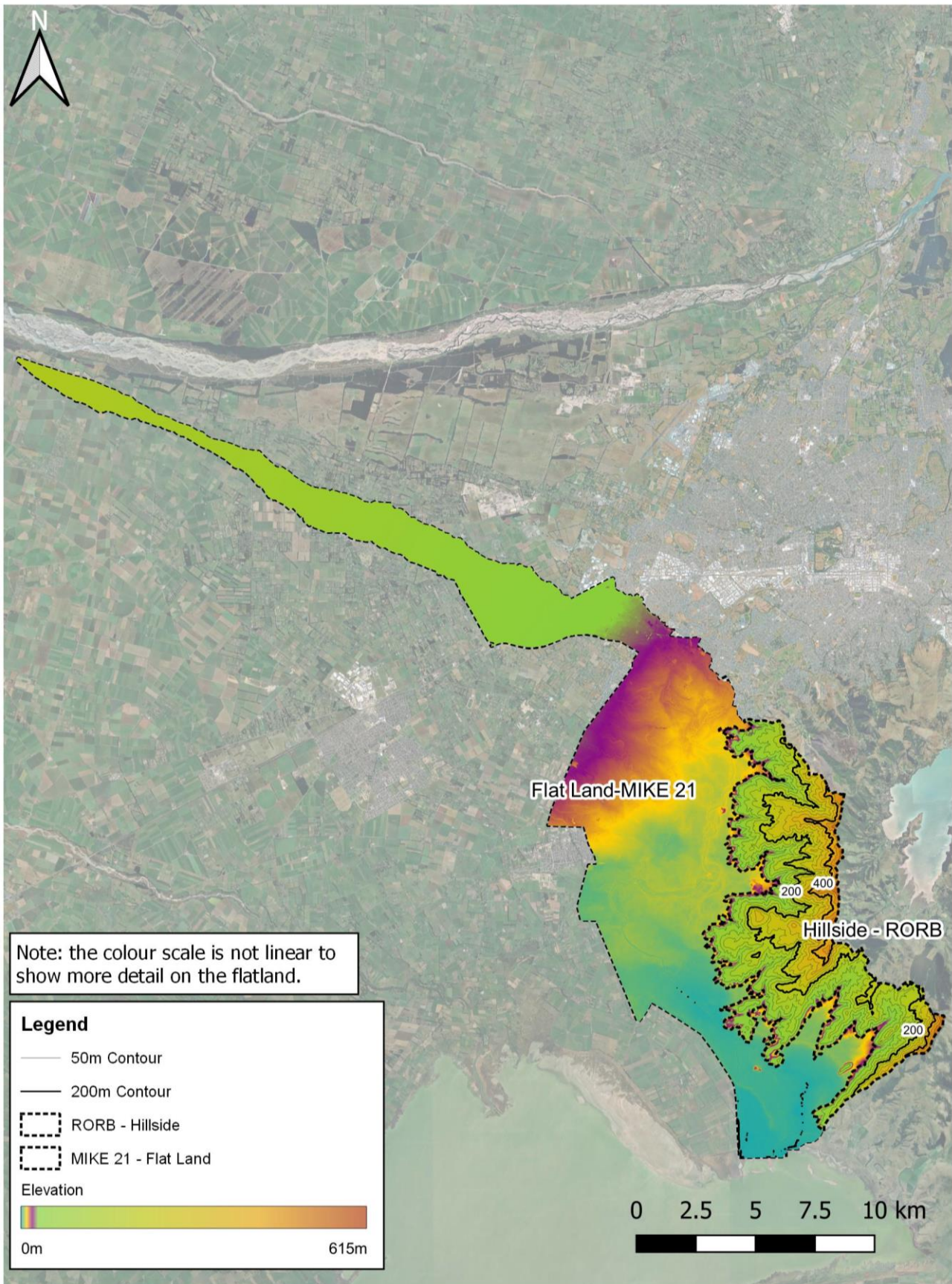


Figure 3-2 Model topography. Image source: Map data © 2025 Google

3.3 Hydrology

Two hydrological methods were adopted. These were Rain on Grid (also known as direct rainfall), and RORB rainfall/runoff routing model. These approaches were applied to the Halswell catchment as shown in Figure 2-1.

Rain on Grid was adopted for the flat lands as specified by the CFM (LDRP044) Model Schematisation (GHDVAECOM, 2018). RORB was used instead of MIKE 21 to model the Port Hills due to instabilities arising in the MIKE 21 rain-on-grid method.

The following sections discuss the design rainfall, design events, base flow, evaporation, imperviousness, wetting loss, and storage loss.

3.3.1 Design Rainfall

As stated in Section 3.2.6, the design rainfall used is spatially varying and was sampled from NIWA's HIRDS v4. The intensity for each duration, frequency, climate change scenario and x-y coordinate was used to create a set of *.dfs2 files that contain:

- The standard triangular hyetograph profiles as prescribed in Chapter 21 of WWDG (2011). These profiles have a peak of twice their average intensity which occurs 70% through the storm. A standard normalised version is shown in Figure 3-3.
- A set of 60-hour centre-weighted nested storms. These are centre-weighted nested storms in which the depth that occurs in the middle 10 minutes matches the depth for 10-minute event in HIRDS v4 (for that point in space with that ARI). The middle 30 minutes matches the depth for 30-minute event in HIRDS v4 and so on. Overall, the depth of the 60-hour nested storm matches the depth of the 60-hour event in HIRDS v4².

A detailed account of how these design rainfall events were created is given in HIRDSv4 data for MIKE and RORB flood modelling (Beca, 2023).

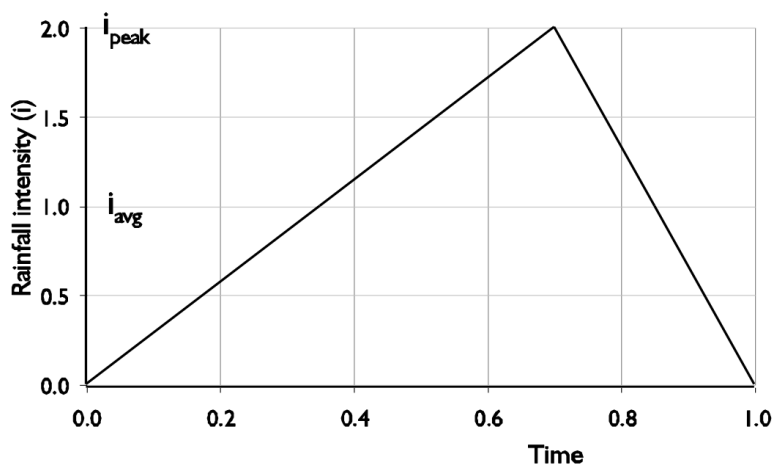


Figure 3-3 Standard dimensionless hyetograph for rainfall intensity from WWDG (2011)

² Actually, HIRDS v4 does not have a 60-hour duration so this has been interpolated using HIRDSv4's seven-parameter depth duration frequency model. For more detail refer to HIRDSv4 data for MIKE and RORB flood modelling (Beca, 2021).

3.3.2 Design Scenarios

The HDM Halswell model 2024 was developed for the ARI events and storm durations outlined in Table 3-2, as agreed with CCC.

Table 3-2 HDM Halswell model 2024 ARI events and storm durations

Existing Development (2024) /Storm duration hours								Rainfall climate scenario	
ARI (years)	0.5	2	6	12	24	48	60	2024	
10	X	X	X	X	X	X	X	X	
50	X	X	X	X	X	X	X	X	
200	X	X	X	X	X	X	X	X	
500	X	X	X	X	X	X	X	X	
Future Development (2074)									
ARI (years)	0.5	2	6	12	24	48	60	2074	
50	X	X	X	X	X	X	X	X	
500						X		X	
Future Development (2124)									
ARI (years)	0.5	2	6	12	24	48	60	2124	Rain 16%
200	X	X	X	X	X	X	X	X	
200	X	X	X	X	X	X	X		X
500	X	X	X	X	X	X	X	X	

3.3.3 Rain-on-Grid (Flat Land)

a. Rainfall

Rain on grid, also known as rain-on-mesh or direct rainfall, works by applying a rainfall timeseries to each active mesh element. The design rainfall was applied directly to MIKE 21 using the 'Specified Precipitation' function. Details on the development of the design rainfall is provided above in Section 3.3.1.

b. Imperviousness

Imperviousness for the Halswell catchment was developed from Lynker data. However, as the Lynker dataset does not fully extend across the Halswell model boundary within the Templeton catchment, supplementary information from the Landcare 2012 impervious dataset and LINZ was used to address the remaining gaps. Further details are provided in the following subsection.

This data set was modified to reflect the impervious values of new roads and buildings as specified by CFM (LDRP044) Model Schematisation (GHD\AECOM, 2018). 90% imperviousness was used for all roads, excluding roads classified as 'non-existent', 'proposed' or 'paper.'

c. Infiltration Losses

The HDM Halswell model 2024 incorporates the updated CCC infiltration method, as applied in the Heathcote model, where infiltration is treated as a function of soil storage.

Infiltration losses were implemented as a series of 2x2 m grids in a multi-layer *.dfs file with constant loss rates in MIKE 21. These grid series were developed, following the methodology described in the LDRP097 Multihazard Baseline Modelling - M21 Infiltration with Groundwater Capacity Report, which was prepared by GHD for Christchurch City Council. The target areas are those where infiltration is expected to be uniform, typically corresponding to regions with a single soil type and consistent land use.

The input file for this approach is a multi-layer *. dfsu file that incorporates the following parameters:

1. Spatially varying infiltration rates (constant for each soil type).
2. Spatially varying depth to groundwater (calculated from groundwater levels and adjusted using the vadose zone approach, considering capillary rise and topsoil properties).
3. Spatially varying model porosity (constant for each soil type).
4. Leakage to the saturated zone (assumed to be null in this methodology).
5. Initial water volume (also assumed to be null in this methodology).

d. Infiltration Zones

The infiltration zones are classified according to soil type, using the soil-type map from Landcare (2013) together with the Imperviousness map developed by Beca (2024).

To create the impervious portion of the infiltration layer, we used the following datasets:

- Lynker impervious dataset (used as the base, as it is the most up-to-date and includes new subdivisions)
- LINZ Building Footprints
- CCC Building Footprints (used for areas not covered by the LINZ dataset)
- LINZ NZ Roads
- LINZ NZ Railway Centrelines

Since some datasets did not fully cover the model domain, these additional steps were taken:

- For areas outside the Lynker dataset, LINZ road center lines were buffered to create a 6m wide carriageway.
- Building footprints were mapped using the CCC layer as a priority, with the LINZ layer filling any gaps.
- In Templeton, we combined the above approaches but buffered roads to 10m after reviewing aerial imagery.
- For other new or developing subdivisions where none of the above data existed, roads were manually delineated based on design surfaces and plans. Buildings were not explicitly included in these areas.

These datasets were also used in the development of the roughness layer.

The three soil drainage types used are poor, moderate, and free draining as outlined in WWDG (2011) and summarised in Table 3-3. The final infiltration zones are shown in Figure 3-4.

Table 3-3 Christchurch standard soil infiltration types (WWDG, 2011)

Infiltration Type	Soil Description	Example of Local Soils
Poor	Poorly drained, low permeability	Tai Tapu silt loams and Port Hills soils
Moderate	Imperfectly drained, medium permeability	Kaiapoi silt loams
Free	Free draining, high permeability	Waimakariri silt loams

e. Infiltration Rates

For each infiltration zone, the constant infiltration rates were calculated by multiplying the infiltration rate per soil type in MIKE to create the required files, as used in the Avon & Heathcote model prepared by GHD. This model specifies infiltration rates according to Drainage classes 1-5 with the imperviousness raster from Lynker (2024), resulting in scaled infiltration rates that account for imperviousness. Table 3-4 summarizes the infiltration rates for each Drainage Class.

Table 3-4 Summary of infiltration rates in the model

Zone ID	Drain Class	Infiltration rate(mm/hr)
Open Space – Poor Draining	1-2	2.8
Open Space – Moderate Draining	3	3.6
Open Space – Free Draining	4-5	5

Figure 3-4 shows the infiltration zones across the Halswell catchment.

We understand that infiltration rates for basins were based on onsite experiments undertaken by CCC, while infiltration rates for soak pits in the Templeton area were calculated using the methodology described in the CCC Mitigation Devices Methodology Soakpits Section Memo (DHI, 2024). According to this methodology, various parameters (as outlined in the table below) need to be determined to estimate infiltration rates for soak pits.

Table 3-5 Soak Pit Parameters

Items	Descriptions
Roof area	Refers to the impervious area contributing runoff to the soak pit.
Infiltration rate	Represents the rate of water entering the soak pit through its inlet pipe(s), distributed across the impervious area
Void volume	Denotes the estimated void space within the soak pit, excluding filler material. Assumes sufficient storage for all runoff during a 1 in 10-year ARI 1-hour event.
Depth to groundwater	Calculated as the ratio of the estimated void space to the roof area.
Leakage rate	Scaled soakage pit infiltration rate based on the roof area.

The basin infiltration rates were generally set to a standard value of 480 mm/day. Except for Carr's Basin (located on the western side of the northern end of the catchment) and the Little River Link Basin (south of the CSM), both of which were assigned an infiltration rate of 1200 mm/day, as recommended by CCC. Higher infiltration values were also applied to buried soakage systems and other relevant mitigation devices where appropriate.

The *.tif output generated from the process was converted into *.dfs2 format using the MIKE Zero tool.

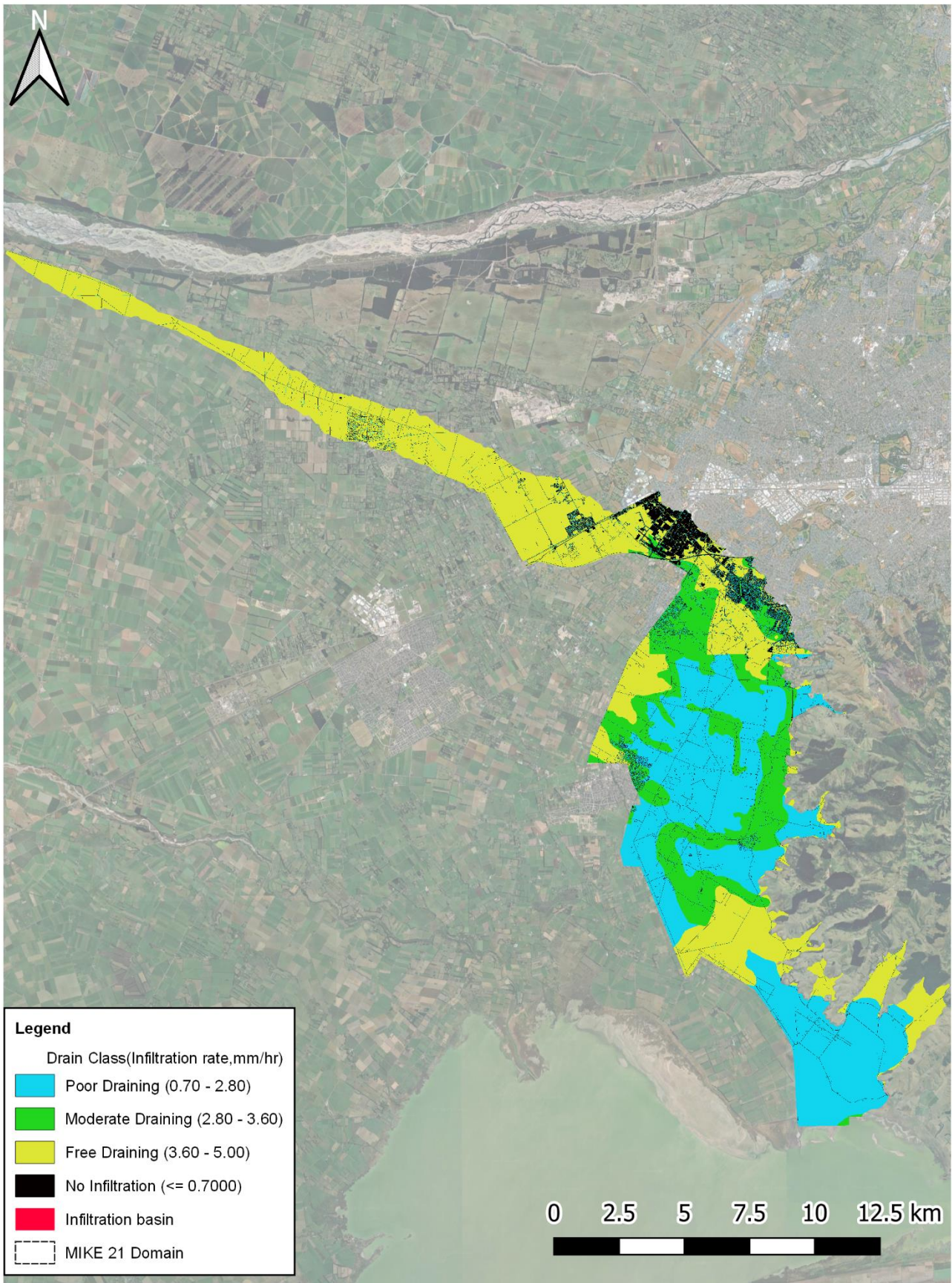


Figure 3-4 HDM Haswell model 2024 infiltration zones. *Image source: Map data © 2025 Google*

f. Groundwater Depth

The depth-to-groundwater layer was created by processing groundwater level surfaces supplied by Aqualinc. Capillary rise values for each soil type were sourced from the LDRP097: Multihazard Baseline Modelling - M21 Infiltration with Groundwater Capacity Report, which references Guymon (1994). These values were then converted to depth to groundwater using the 2D Halswell depth-corrected ground surface. The processing was carried out with the ArcPy tool, producing a *.tif file as output, which was subsequently converted into a *.dfs2 format using the MIKE Zero tool.

g. Porosity

Porosity values were also derived from the LDRP097: Multihazard Baseline Modelling - M21 Infiltration with Groundwater Capacity Report, where they were recommended for use during the calibration process. The ArcPy tool was employed to generate *.tif files for porosity, which were then converted into *.dfs2 format using the MIKE Zero tool. A summary of the used capillary rise and porosity values is provided in the table below Table 3-6.

Table 3-6 Capillary rise and porosity per soil type

Soils classification	Capillarity rise (m)	Porosity
Gravel (C)	0.0125	14.0%
Sand (M)	0.1350	15.0%
Clayey Silts (F)	1.0550	10.0%
Peat (P)	0.5000	15.0%
Fill (X)	0.0250	15.0%
Dummy (W)	0.0000	0.0%

Initial water volume is assumed to be null in this methodology.

All *.dfs2 files generated were converted and combined into a single multilayer *.dfsu file using MIKE tools by DHI.

3.3.4 RORB Model

Two RORB models were developed for the hillside catchments of HDM Halswell model. These are shown in Figure 3-5. Two models were built based on catchment size and types:

- The Halswell CCB model was developed for the hillside catchment located within the Christchurch City Boundary (CCB), with sub-catchments ranging from 0.1 km² to 0.5 km². This provides sufficient detail for the urban/rural catchments. The Halswell CCB model sub-catchments are shown in Figure 3-5. In the figure, all RORB nodes are labelled however only nodes at the boundary of the MIKE 21 domain are inflows into the MIKE 21 model. There are also some nodes that exist in the RORB model that are within the MIKE 21 (for example, DU2 and OUTLET). These are only in the RORB for completeness and are not inflows to the MIKE 21 model.
- The Halswell 02 model was developed for the hillside area located outside the Christchurch City Boundary, with sub-catchments ranging from 0.5 km² to 5.6 km². Larger sub-catchments were used as the hillside area outside the Christchurch City Boundary is rural and does not require the same level of detail. The Halswell 02 model sub-catchments are shown in Figure 3-7. To calibrate the two models, the Kaituna River catchment model was also developed (Figure 3-8). The Kaituna catchment is a gauged rural catchment located further south around the Port Hills. It is a good representation of the characteristics of the hillside area of the HDM Halswell model.

All the RORB models were built using ArcMap and the ArcRORB tool. The RORB model-build and calibration process is outlined in the Halswell RORB Calibration Memo (Beca, 2021) located in Appendix B.

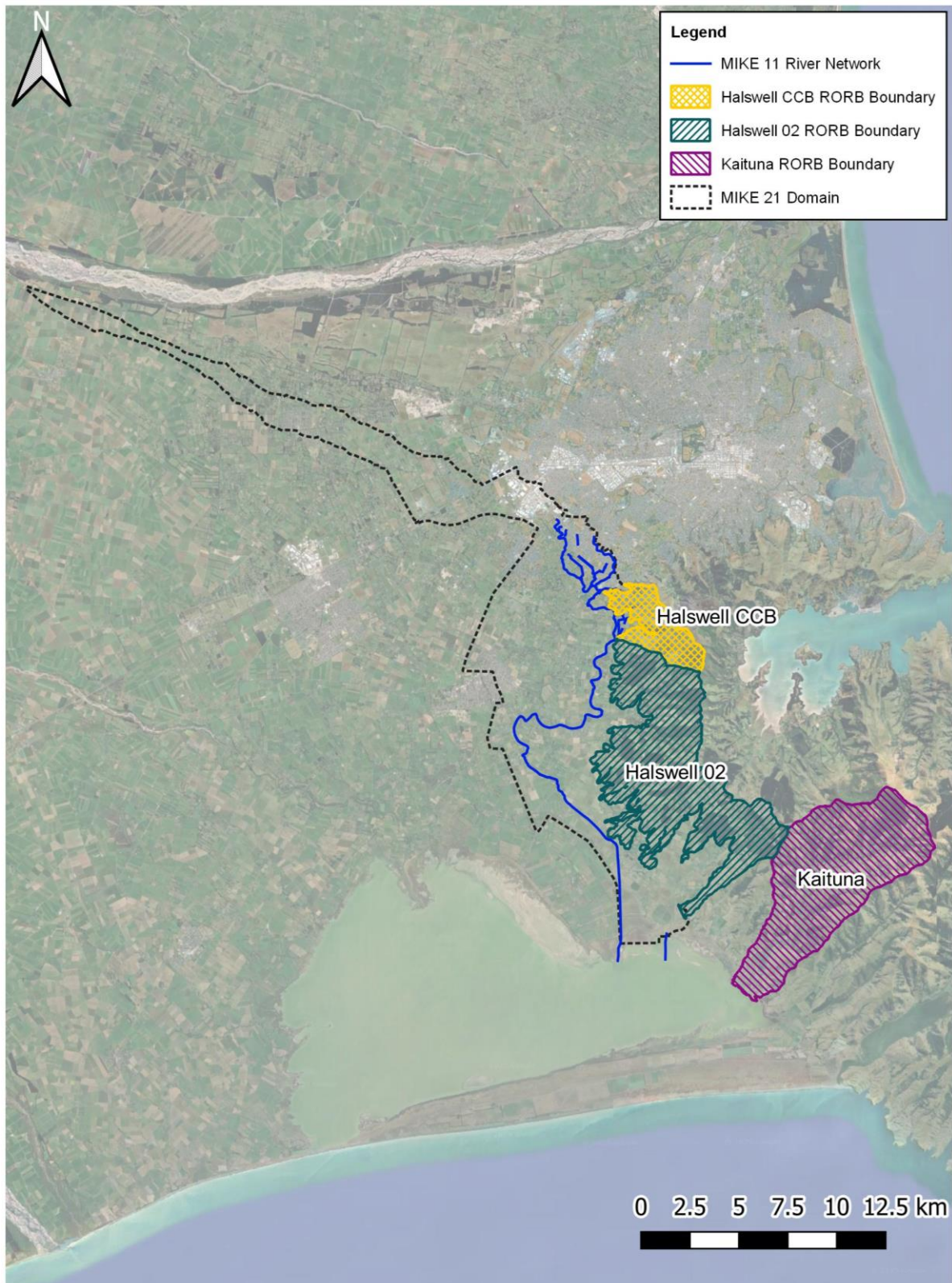


Figure 3-5 Halswell Hillside RORB catchments (Halswell CCB, Halswell 02 and Kaituna Valley). *Image source: Map data © 2025 Google*

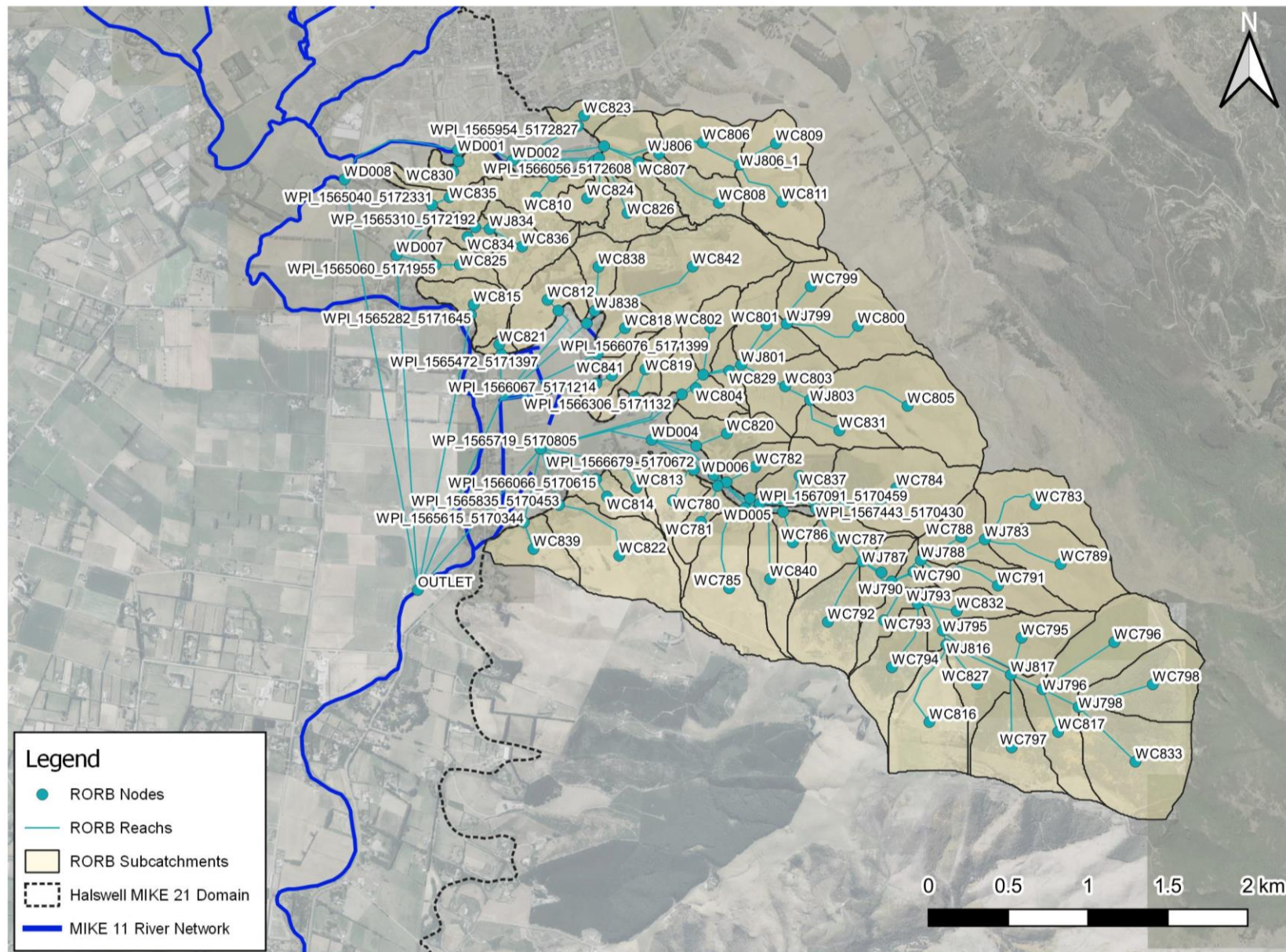


Figure 3-6 Halswell CCB RORB model sub-catchments. *Image source: Map data © 2025 Google*

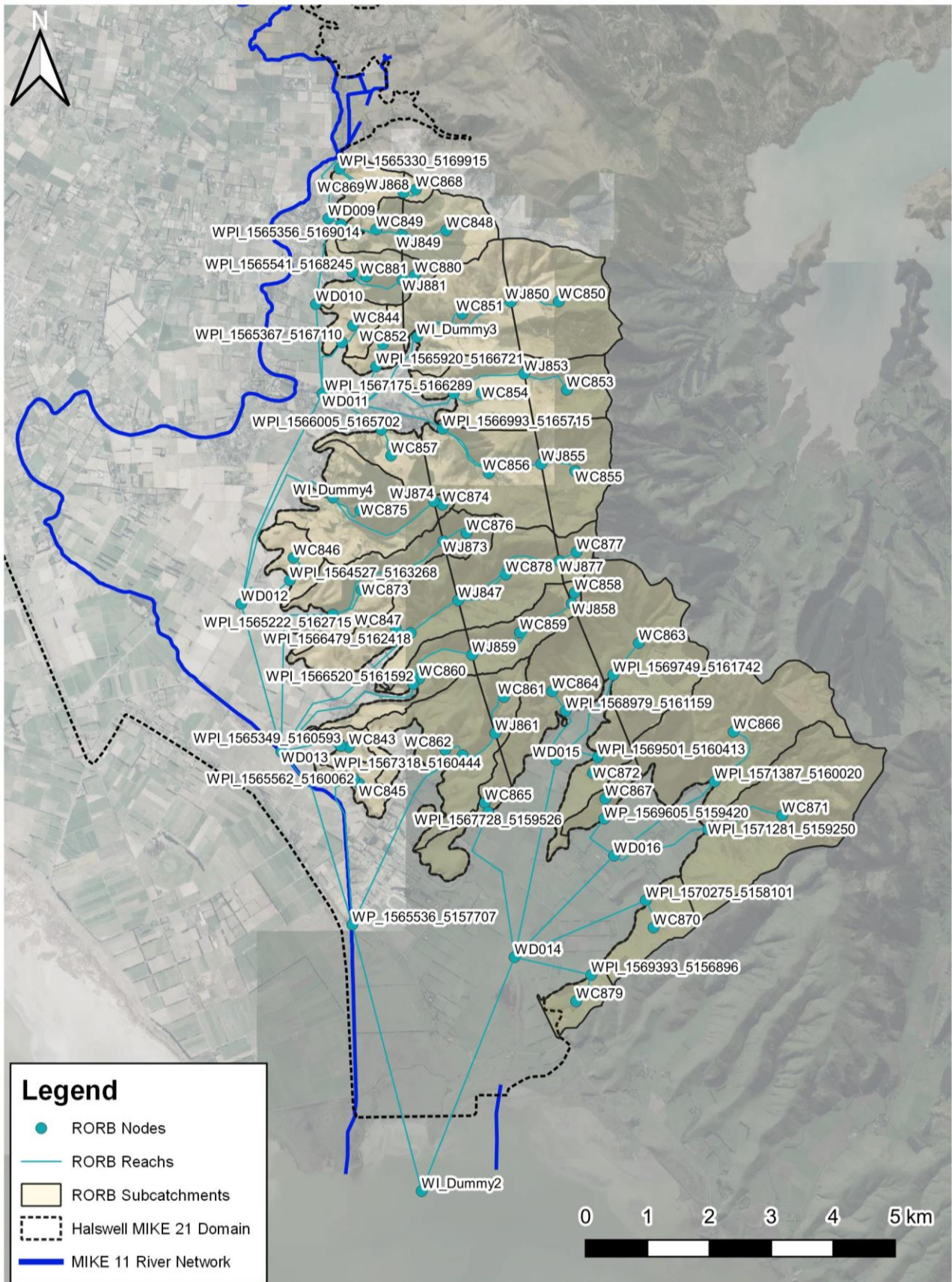


Figure 3-7 Halswell 02 RORB model sub-catchments. *Image source: Map data © 2025 Google*

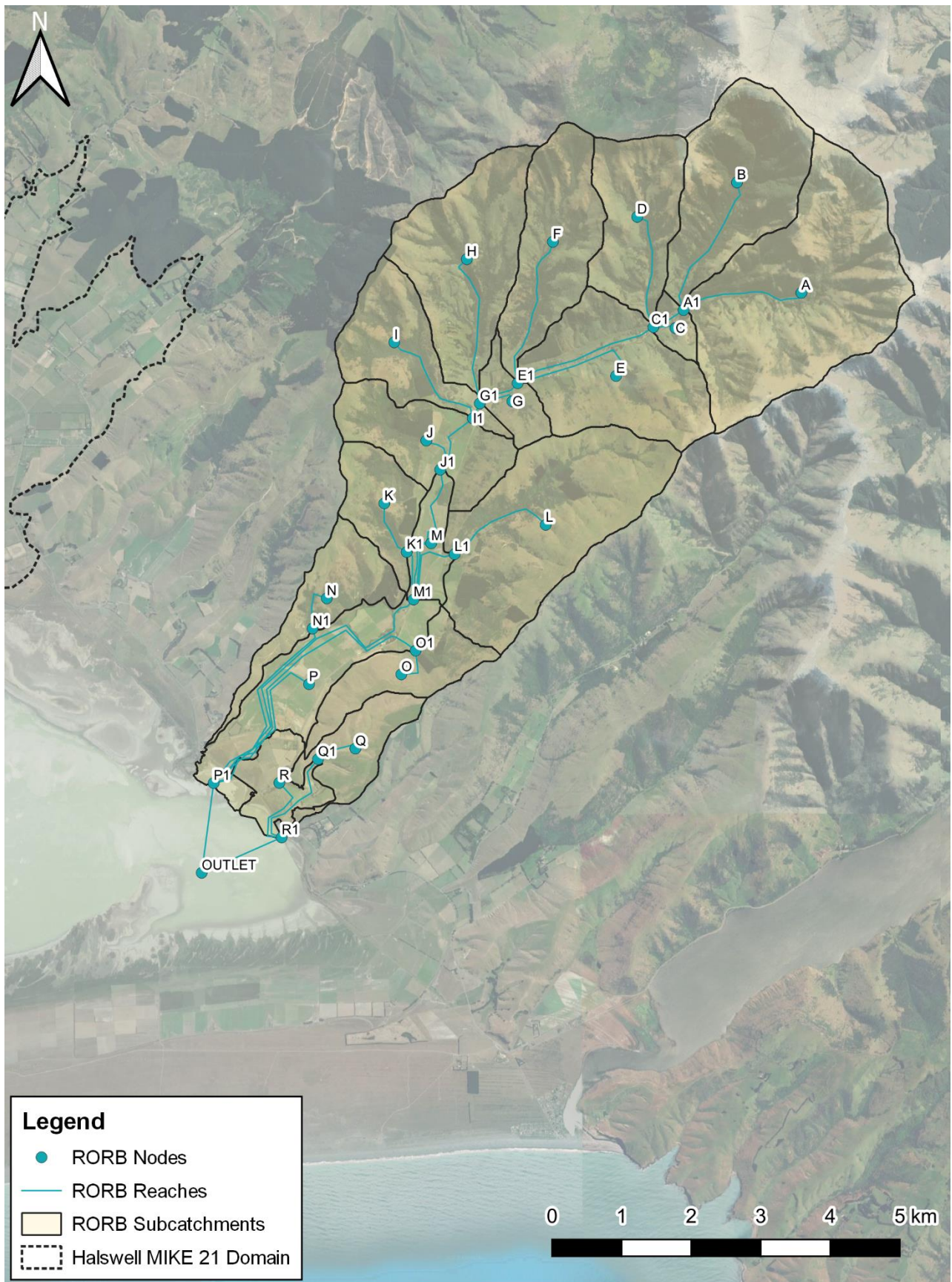


Figure 3-8 Kaituna catchment model sub-catchments. *Image source: Map data © 2025 Google*

a. RORB Imperviousness

Imperviousness for the RORB models was determined based on the Christchurch City District Plan (the district plan) provided by CCC, and Chapter 21 of the WWDG (2011). The district plan was used to create district zone types for each sub-catchment. Based on the types, an average pervious and impervious percentage was applied to each sub-catchment.

The types are Living Hills and Rural – Port Hills. The Living Hills zone average effective pervious and impervious percentages are summarised in Table 3-7. The WWDG does not provide the zone average effective pervious and impervious area percentages for Rural – Port Hills zones. It was assumed that sub-catchments categorised as Rural – Port Hills would be 100% pervious.

Table 3-7 Zone average effective pervious and impervious area percentages (WWDG, 2011)

District Zone	Pervious Area Contribution (%)	Impervious Area Contribution (%)
Residential: Living Hills	50%	90%

The Halswell CCB model had several sub-catchments split between Living Hills and Rural – Port Hills zones. To account for Living Hills zone, the area of Living Hills was measured, and percentage imperviousness was calculated as recommended in Table 3-7. The rest of the sub-catchment was taken to be Rural – Port Hills and set to zero.

The Halswell 02 model and the Kaituna catchment model sub-catchments were categorised as a Rural – Port Hill zone and the fraction imperviousness was set to zero (100% pervious).

b. RORB Reaches

To join sub-catchments to one another reaches are required. Beca set the reach type for Halswell CCB, Halswell 02 and Kaituna catchment models as Reach Type 1. Reach Type 1 is for natural channels and was assumed for all reach types as the Halswell hillside is predominantly rural. Beca determined the slope of the reaches using the 5 m contours generated from the post-quake LiDAR which was provided by CCC.

c. RORB Calibration

Beca calibrated the Kaituna model using four rainfall events (Table 3-8). These events were selected as recommended by CFM (LDRP044) Model Schematisation (GHD\AECOM, 2018). Rainfall records for each event were collected from the Kaituna, Coopers Knob and Akaroa Highway rain gauges. A flow record was used for the Halswell River at Kaituna River. These records were provided by ECan and NIWA as listed in Table 3-1 in Section 3.2.

Table 3-8 Calibration events for the Kaituna RORB model

Calibration Event	Event Dates
October 2000	12th October 2000
May 2006	12th – 13th May 2006
June 2013	15th – 22 June 2013
March 2014	4th – 5th March 2014

Calibration was done through RORB using the design run process and parameters configured by varying routing parameters by intersection area. The process of calibration of the RORB model is provided in Halswell RORB Calibration Memo (Beca, 2018) located in Appendix B.

The RORB model parameters determined through calibration are summarised below.

d. Coefficient k_c

k_c is an empirical coefficient that is the principal parameter of the model. A k_c of 13 was applied to the Halswell hillside models as per the Kaituna model calibration. A k_c of 13 is close to the recommended k_c (from the RORB manual) of 13.9 and aligns the timing of peak river flows with the peak runoff for the October 2000, May 2006, and June 2013 events. The closest alignment occurs for the June 2013 event.

e. Exponent m

Exponent m is a dimensionless exponent and a measure of a catchment's non-linearity, where a value of one implies a linear catchment. A value of 0.8 was taken for m , as recommended by the RORB manual for ungauged catchments.

f. Losses

Loss processes were modelled with an initial loss and a continuing loss rate. These were determined through calibration of the Kaituna model. An initial loss of 17.5 mm and a continuing loss of 1.25 mm/hour were found to be suitable in the Kaituna catchment, and by extension the study catchments within the Halswell model. These values provide the closest alignment of river flows and runoff.

g. Runoff Hydrographs

The RORB models were used to generate runoff hydrographs at junction nodes located on the flat land (2D surface) boundary. Runoff hydrographs were generated for each design event (refer to Section 3.3.2). The RORB hydrographs were converted from *.csv files into *.dfs0 files and the *.dfs0 files were applied as sources in the HDM Halswell MIKE 21 Model.

3.3.5 Future Development (FD)

For future development modelling, all hydrological parameters remained unchanged except for infiltration rates and the future development RORB model results for source points corresponding to the 2074 and 2124 ARI scenarios. RORB runs for 2074 and 2124 were generated using rainfall data for the respective years and the 2068 future development catchments with no mitigation measures applied, all other parameters in the RORB model remained unchanged and consistent with the existing development runs.

The methodology used to develop the future development infiltration layer is outlined below, along with key considerations and issues encountered during its preparation. Throughout this process, any anomalies or concerns identified - such as discrepancies in the imperviousness datasets were promptly communicated to CCC and GHD (as the imperviousness data provider) via email. Decisions regarding data selection and methodology were made collaboratively, with confirmation and guidance received from CCC and GHD. The updated infiltration layer was subsequently peer reviewed by DHI.

Beca utilized impervious layers prepared by GHD, received on 17/10/2025. The unmitigated impervious raster dataset was used to derive future infiltration layers for the 2074 and 2124 Annual Recurrence Intervals (ARI). Notably, the imperviousness data corresponded to the years 2073 and 2103 ARI, as confirmed by both GHD and CCC for use in the FD ARI events.

During the development of the infiltration layer, Beca identified anomalies in the raw files provided by GHD, specifically pixels with higher imperviousness in 2073 than in 2103. This issue was raised with GHD and CCC, and GHD subsequently confirmed the anomalies in the 2103 impervious dataset. Following further investigation and discussion, it was agreed with CCC (confirmed on 12/11/2025) to use the original impervious data for both 2073 and 2103 ARIs, as the bias within the CCC urban area was found to be minimal.

The methodology adopted for developing the future development infiltration layer was as follows:

- Started with the FD imperviousness layers and the raw infiltration rate per soil type raster.
- Multiplied the infiltration rate by the pervious fraction (“1 – impervious”) to obtain updated infiltration rates.
- Warped the infiltration rate layer to align with the imperviousness raster using nearest neighbour interpolation.
- Converted the existing development infiltration *.dfs file into a shapefile and applied zonal statistics to determine the mean updated infiltration rate for each element.
- Retained the infiltration rates for basin elements, as these values were not expected to change in the future development infiltration layer.
- Converted the updated infiltration values into a new *.dfs file.

The updated infiltration layer was subsequently peer reviewed by DHI as part of the HDM Halswell flood model review.

As previously confirmed by CCC (25/09/2025), future development runs assumed no change in groundwater levels, as the difference between 0.0m and 1.2m sea level rise (SLR) scenarios in the Halswell area was negligible. Therefore, only infiltration values were updated for the FD runs; all other parameters remained unchanged.

3.4 MIKE 11

3.4.1 Branches

There are 27 branches modelled in the MIKE 11 component of the HDM Halswell model. These branches represent streams, field drains, open channels, two basins and the Halswell River. To model the connections to main river channel the Halswell River branch was split into three sections.

The MIKE 11 network is shown in Figure 3-9 and Figure 3-10, and includes the following branches:

- | | |
|-------------------------------------|--------------------------------------|
| • Cases Drain, | • Minsons Early Valley Drain, |
| • Creamery Drain, | • Minsons Farm Drain 2, |
| • Creamery Pond 1, | • Minsons Farm Drain 3, |
| • Creamery Pond 2, | • Minsons Farm Drain 1, |
| • Greens Drain, | • Nottingham Stream, |
| • Halswell Junction Outfall, | • Old Channel, |
| • Halswell River 1, | • Paynes Drain, |
| • Halswell River 2, | • Quaifes Drain 1, |
| • Halswell River 3, | • Quaifes Drain 2, |
| • Knights Stream, | • Talbots Drain 1, and |
| • Minsons Branch 1, | • Talbots Drain 2. |
| • Minsons Drain, | |

The branch “Hals.OldChannel” models the downstream end of the historic channel of the Halswell River. The branch does not capture the whole historic channel which extends further north towards Gebbies Valley and Motukarara. The rest of the historic channel is therefore modelled in the MIKE 21FM component.

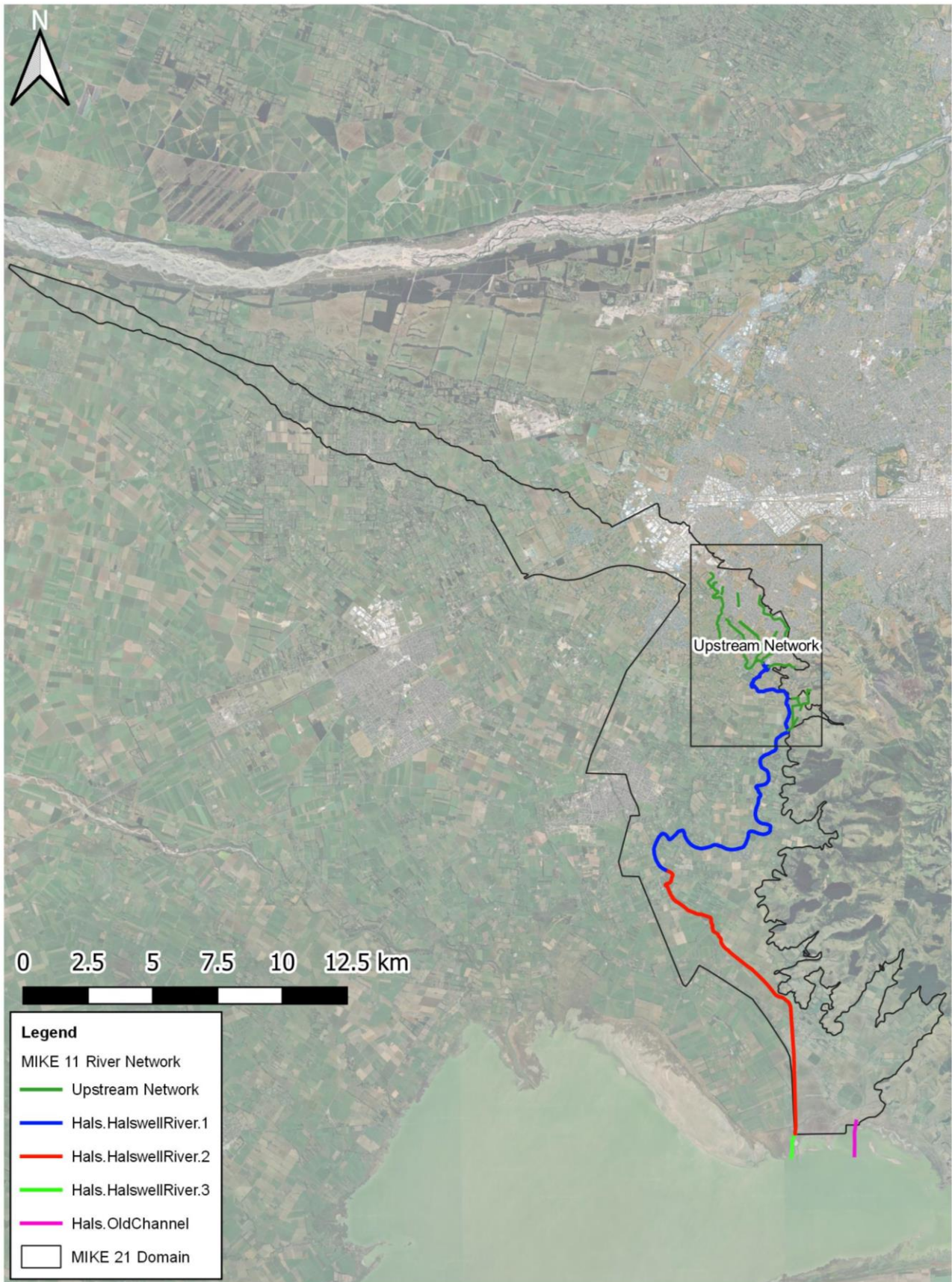


Figure 3-9 HDM Halswell MIKE 11 network – full extent. *Image source: Map data © 2025 Google*

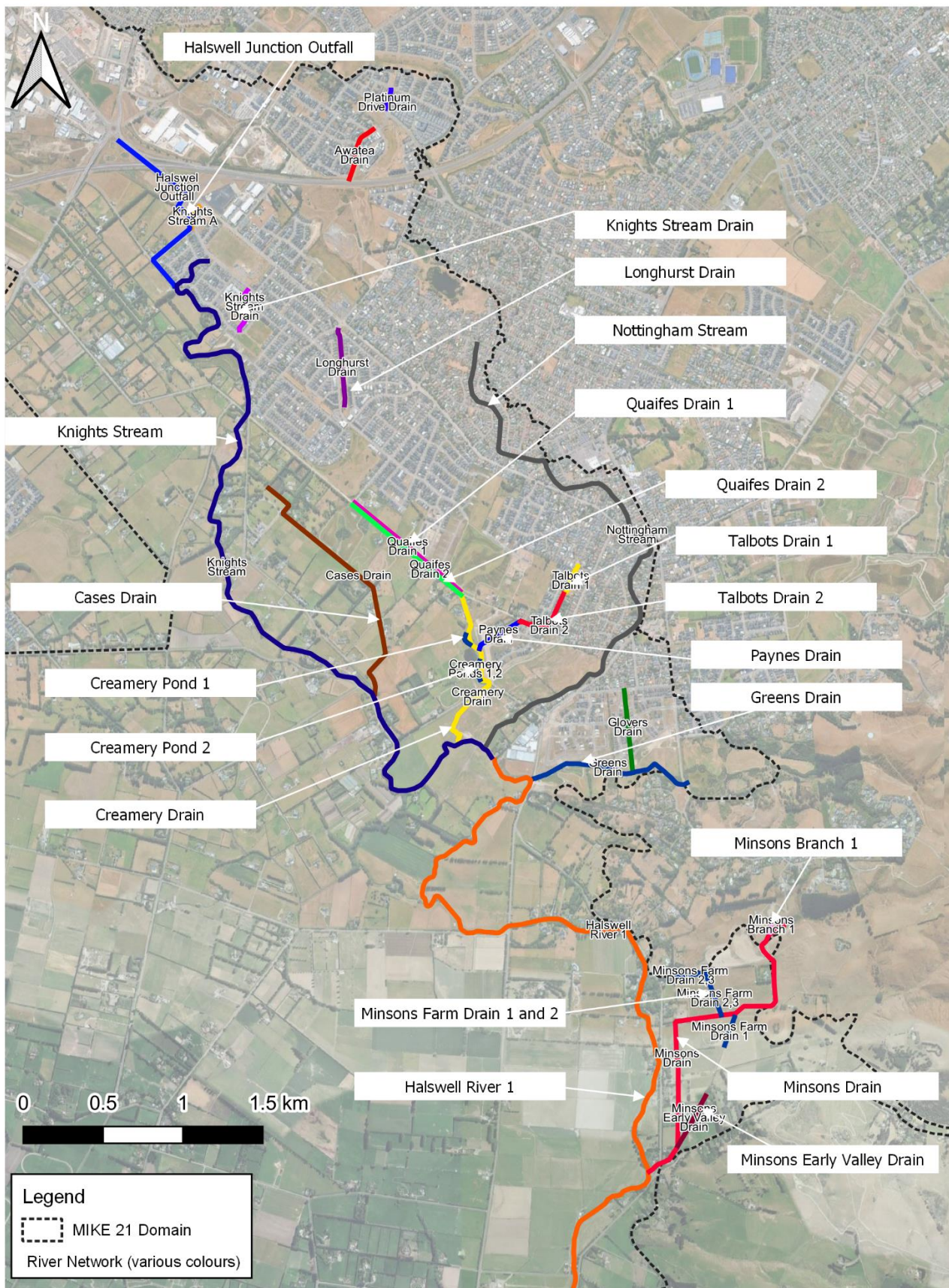


Figure 3-10 HDM Halswell MIKE 11 network - upstream network. *Image source: Map data © 2025 Google*

a. Cross-sections

The MIKE 11 cross-sections used in this model were sourced from detailed ground survey provided by CCC. Where this information was not available, cross-sections were developed from CCC LiDAR. The approach to generate a MIKE 11 cross-section database from the detailed ground survey and LiDAR was as specified in CFM (LDRP044) Model Schematisation (GHD\AECOM, 2018). The cross-sections were applied to the 27 branches defined in the MIKE 11 network. The cross-sections were applied to open channels between the banks to represent 1D flow with the corresponding elements removed from the mesh to avoid double counting flow.

b. Cross-sections from detailed ground survey data

Ground survey cross-sections were imported into MIKE 11 format without interpretation or manipulation of the point-coordinates and levels. The data was reformatted from “x, y, z” format into the MIKE 11 “x, y” format.

The bank markers of the ground survey cross-sections were manually reviewed so that the top of bank represents the top of bank levels (markers 1 and 3) and that these marker locations were suitable for lateral linking to the MIKE 21 mesh.

This process was completed for the branches and detailed ground survey listed in Table 3-9.

Table 3-9 Ground Survey cross-sections used to generate MIKE 11 cross-sections

Branch ID	Survey
Cases Drain	CCC Minson and Cases survey 2016
Creamery Drain	CCC Creamery drain survey 04-08-2015
Glovers Drain	CCC Glovers drain survey 04-08-2015
Greens Drain	CCC Greens drain survey 04-08-2015
Halswell Junction Outfall	CCC HJO drain survey 04-08-2015
Knights Stream	CCC Knight Stream survey February 2013
Minsons Branch 1	CCC Minson and Cases survey 2016
Minsons Drain	CCC Minson and Cases survey 2016
Minsons Early Valley Drain	CCC Minson and Cases survey 2016
Minsons Farm Drain 2	CCC Minson and Cases survey 2016
Minsons Farm Drain 3	CCC Minson and Cases survey 2016
Minsons Farm Drain 1	CCC Minson and Cases survey 2016
Nottingham Stream	CCC Nottingham Stream 2013
Nottingham Stream	CCC Nottingham Stream 2025(Received on 18/7/2025)
Paynes Drain	CCC Paynes drain survey 04-08-2015
Quaifes Drain 1	CCC Quaifes drain No 1 survey 04-08-2015
Quaifes Drain 2	CCC Quaifies drain No 2 survey 04-08-2015
Talbots Drain 1	CCC Talbots drain 1 survey 04-08-2015
Talbots Drain 2	CCC Talbots drain 2 survey 04-08-2015

i. Cross-section from LiDAR

Cross-sections were generated for the lower Halswell River and Old Channel branches, from the 2019 LiDAR provided by CCC. Cross-sectional points were sampled every 1m along the cross-section line and spaced every 10 m along the Halswell River and Old Channel. The initial cross-sections were generated with a width of 30 m, which were then adjusted to reflect and capture wider or narrower sections of these water courses.

The cross-section inverts were identified as the lowest elevation point (or mid-point of the lowest elevation points). The initial top-of-bank markers were identified based on the maximum elevation differences to the true left and true right of the invert. These marker positions were then further refined to match the position of the MIKE 21/MIKE 11 block-out extents, thus producing bank marker positions symmetrical on the centreline.

LiDAR cross-sections were checked against survey cross-section supplied by ECan. These checks were mainly in the lower Halswell river and showed that LiDAR represented the channel reasonably well given the intent of this model to show flooding within the CCC limits.

Further information on the generation of cross-sections from LiDAR is provided in Section 5.2.2 of CFM (LDRP044) Model Schematisation (GHD\AECOM, 2018).

ii. Cross-sections from Drawings

Creamery pond retarding basin cross-sections were taken from as-builts for ponds 1 and pond 2. These cross-sections were imported into the model without interpretation and/or manipulation of the levels. The data was converted into the required MIKE 11 “x, y” format.

iii. Transitional cross-sections

Transitional cross-sections were used in the HDM Halswell model to smooth abrupt changes in flow conveyance between the network branches and to remove the risk of the MIKE 11 computation of structure Q-H relationship failing. Transitional cross-sections were copied from the wider downstream branch and placed as the last cross-section in the incoming stream.

3.4.2 Naming Convention and Data Flagging

The naming convention and data source flagging for rivers, cross-sections and structures in the MIKE 11 model was as specified in Section 5.8, Section 5.9 and 5.10 of CFM (LDRP044) Model Schematisation (GHD\AECOM, 2018).

For example:

river branches “Hals.QuaifesDrain.1”, “Hals.QuaifesDrain.2” and “Hals.HalswellRiver.2”,
cross-sections “Survey.sect_160.07”, “Bridge_US.SF 1280”, “LIDAR2019.INTERPOLATED.3”,
structures “26 John Patterson Drv_Weir”, and “23 Halswell Ryans Bridge”.

The naming convention for cross-sections has many different forms depending on the source of the data so only a subset of examples is provided here.

3.5 MIKE URBAN

3.5.1 Pipe Network

The stormwater reticulation network was modelled in MIKE URBAN. The HDM Halswell MIKE URBAN model network is shown in Figure 3-11, and was developed from CCC and SCIRT GIS. The network includes all pipes except those in the private network. ‘Short’ pipes (less than 10m) and manholes that are close together

were merged except sump leads. Figure 3-11 also shows the locations of basins in the MIKE 21 model, these are discussed in section 3.6.1.

3.5.2 Culverts

Culverts were modelled in the MIKE URBAN model for the cross drainages for roads, such as Christchurch Southern Motorway and Halswell Junction Road, and the culverts connecting upstream and downstream open channels at Longhurst and Knight Stream Park developments.

3.5.3 Naming Convention and Asset Flagging

The naming convention and data source flagging for the MIKE Urban network was as specified in Section 6.10 of CFM (LDRP044) Model Schematisation (GHD\AECOM, 2018).

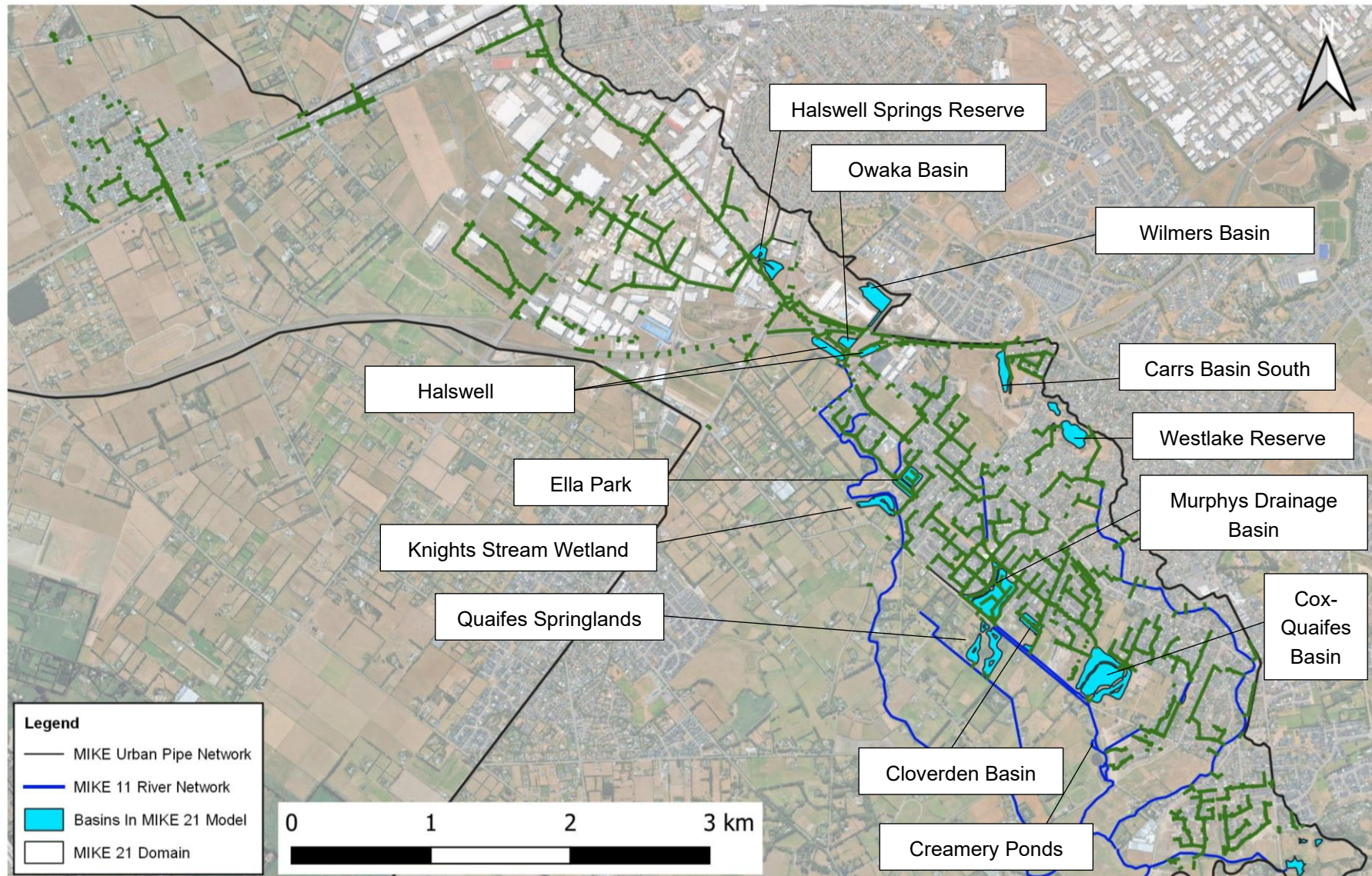


Figure 3-11 HDM Halswell MIKE Urban Network, basins in and out of the Existing Development 2024 model. *Image source: Map data © 2025 Google*

3.6 MIKE 21FM

3.6.1 Mesh

The mesh developed for the HDM Halswell model was based on Section 4 of CFM (LDRP044) Model Schematisation (GHD/AECOM, 2018) and was generated for the flat land of the Halswell catchment. The specific methodology used to generate the mesh is outlined in the Beca Christchurch City Council's Citywide Modelling Methodology Memo (2017) located in Appendix C. The HDM Halswell model mesh is a triangular flexible mesh and was generated with the criteria summarised in Table 3-10.

Table 3-10 HDM Halswell Mesh Generation Criteria

Mesh Generation Criteria	Value
Maximum element area	200 m ²
Smallest allowable angle	26°
Maximum number of nodes	10,0000,000

a. Road and Rail

Roads and rail networks in the Halswell catchment were defined by the 'three row method' outlined in Section 4.3.1 of CFM (LDRP044) Model Schematisation (GHD/AECOM, 2018). This method defines the road as three rows of triangles, with the central row used to represent the centreline crown. For more information on mesh development, see the Beca Road Point Methodology Memo (2021) located in Appendix D. The elevation of the road uses an adaption of the DHI's 'depth correction' function to control the elevation of each element. For more information on depth correction, see Section 3.6.2 below.

b. Mitigation Basins

A total of 10 mitigation basins were represented in the MIKE 21 mesh in the Existing Development 2021 model, including:

- Carr's Basin,
- Ella Park Basin,
- Knights Stream Wetland,
- Halswell Junction Detention Basin,
- Halswell Quarry Pond,
- Knight Stream Wetland,
- Murphy's Drainage Basin,
- Owaka Basin,
- Quaifes Road Springlands, and
- Westlake Ponds.

In the HDM Halswell 2024 model, a further 7 basins were added to the model:

- Cox-quaifes Basin,
- Lee's Basin,
- Maize Maze Basin,
- Mushroom Basin,
- Quaifes Springlands,
- Ramp Basin, and
- Wilmer's Basin.

The locations of these basins are shown in Figure 3-11.

The extent of each basin was defined by triangles for both the top-of-bank and the toe-of-bank. The top-of-bank uses elevations taken from LiDAR. The toe-of-bank locations were drawn at 8m from the inside of the top-of-bank location to avoid small triangle formation and to avoid negative bias in the basis volumes. Elevations for the toe-of-bank were set at drawing/as-built/LiDAR levels. The top-of-basin element could not always be relied on to accurately capture the crest due to being close to the road elements, so dykes were also added. The insertion of dykes better defines the crest level and is as per the CFM scheme. The dykes' crests use 2018-2019 LiDAR. Wilmers, Cox-Quaifes, Mushroom, and Owaka Basin dyke levels were set using 2020-2021 LiDAR as they were constructed after the 2018-2019 LiDAR was flown (and they were added to the existing development 2021 model later in the project). A resulting example is shown in Figure 3-12.

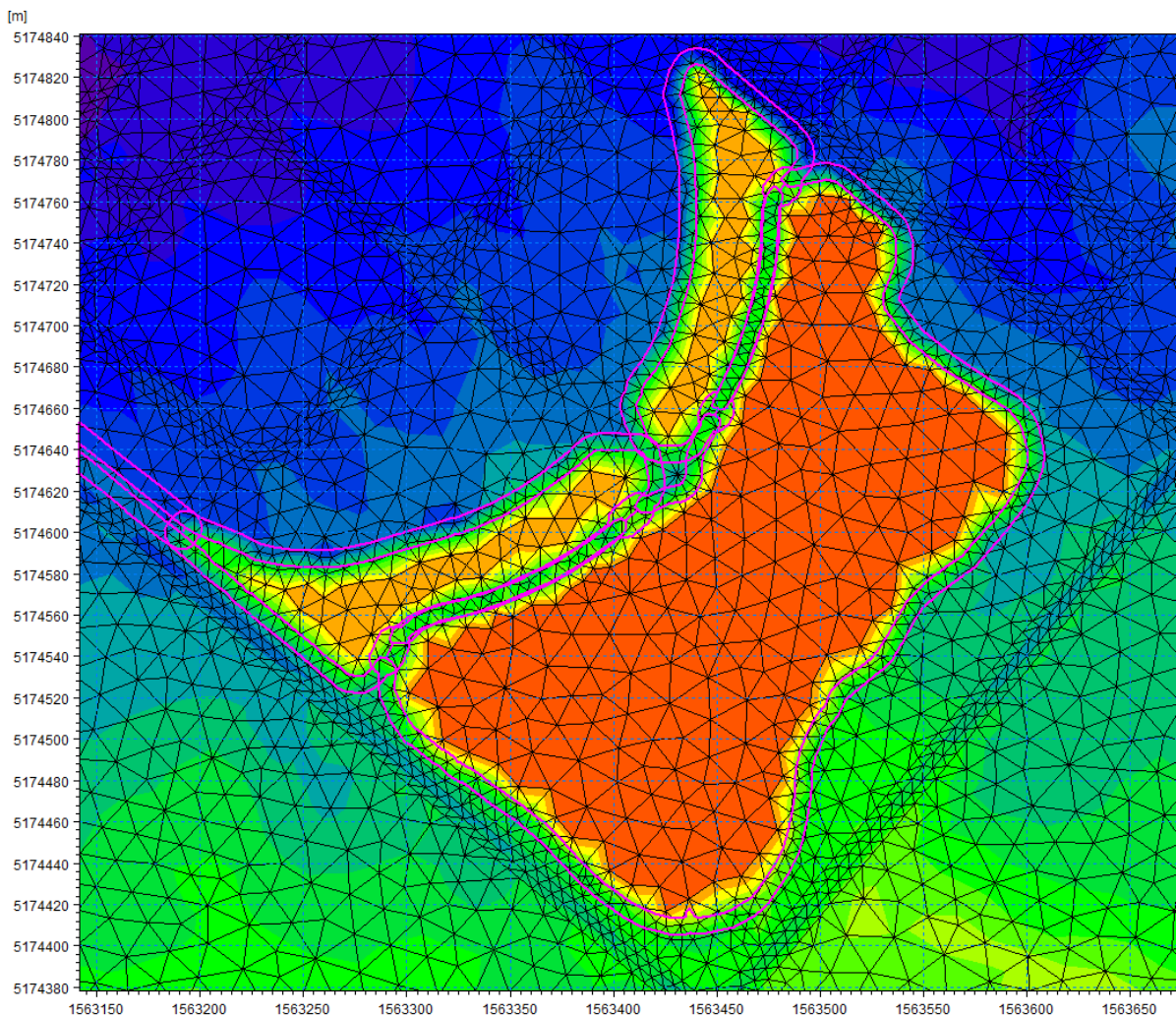


Figure 3-12 Example of basin definition in HDM Halswell model – Murphy's Drainage Basin the pink lines denote the top and toe of the wetland bank.

3.6.2 Surface editing

The DEM surface was generated based on the CCC LiDAR data that was modified to include a variety of real physical features, as outlined in the Section 4.4 of CFM (LDRP044) Model Schematisation (GHDAECOM, 2018). The processed surface is referred to as the "Z4".

The current model utilizes, as a base, the same reviewed DEM Z4 that was used in the 2021 model. However, the 2021 surface was in Christchurch Drainage Datum, while the new HDM Halswell 2024 model is in NZVD.

As a result, the surface has been converted to NZVD. The process completed for updating the datum for each component of the model is summarised below:

- **Raster of change:** The existing LINZ conversion point data was used to convert from Lyttelton 1937 (which CDD is based on) to NZVD2016. To convert the model data, this change point data was developed into a raster of change (from CDD to NZVD2016).
- **CRS links in Mike Urban (MU):** Halswell Model CRS links are set up as a depth below ground level, so no updates were required.
- **General Mike Urban (MU) network** was exported to a shapefile and updated to NZVD2016. A new field in MU of change (based on the change raster) was used to edit levels.
- **Mike11 (M11) cross sections** were changed to point data then converted to NZVD2016 (using the change raster) and re-imported into the model using DHI's script converting from point export to shapefile to make these changes.
- **M11 culverts** were converted manually using the change raster due to the low number of culverts.
- **M11 irregular weirs** locations were exported to a shapefile to find changes required based on the change raster. Then a script was used to make this change as these weirs utilise level/width.
- **Mike21 (M21) dykes** Exported to shapefile, converted using the change raster then re-imported automatically using functions in MIKE+.
- **M21 culverts** manually converted using the change raster due to the low number of culverts.
- **Boundary water level** at lake Ellesmere/Te Waihora will be changed manually using the change raster.

Additionally, modifications were made to incorporate new subdivision surfaces into the datum corrected DEM, received from CCC, reflecting developments post-2021. These updates include Copper Ridge, Sabys Estate, Halswell Prestige, Country Palms, Riverstone, Kennedys Green, The Fields, 62 Quaifes Rd, Country Downs, 42 Gamock Drive, Matai Springs, 63 Quaifes Rd, Cloverden, Oakvale and Templeton.

After setting the level of the depth correction file from the Z4 (using zonal statistics) levels at some locations were set manually. This was to:

- a) for MIKE 21 levels to match coupled outlet levels (this is a requirement for MIKE Flood to work),
- b) set the coupling level of important manholes (for example, at scruffy dome outlets for attenuation basins), and
- c) to lower the surface below water level boundary conditions (for stability, refer to section 4.3.11).

3.6.3 Depth correction

Usually with a flexible mesh, the bathymetry is applied to the mesh elements by assigning an elevation value based on an average of their corner vertices. In this case, the mesh elevation was set through the 'depth correction' function. The 'depth correction' function assigns a given elevation to each flexible mesh element centroid and eliminates the use of the element vertex elevations.

The depth correction file, a *.dfsu, was developed from a digital elevation model (DEM) by overlaying the mesh triangle areas in GIS and using zonal statistics to calculate the average elevations from the DEM for each triangle mesh element. For the detailed process, see the Beca Depth Correction Memo (2021) located in Appendix E.

The process for setting the depth correction levels is as follows:

1. Create a mesh shapefile using the MIKE Zero Toolbox (GIS-Mike2Shp)
2. Calculate zonal statistics using the Z4 and the mesh shapefile
3. Add a new field to explicitly store the ID of each mesh element
This is required because some GIS operations can alter the internally stored shapefile IDs, so explicit tracking is necessary
4. Create a polygon shapefile containing the manually defined depth correction levels
5. Join the manually set levels by location to the zonal statistics shapefile
This produces a dataset containing the zonal statistics, manually set levels, and the explicit element

ID

Note: In QGIS, this step can change the internally stored shape IDs, reinforcing the need for explicit ID tracking

6. Set the bathymetry field so that:
 - a. the manually set level is used where it exists, and
 - b. the zonal statistics value is used where no manual level is defined
7. Join the bathymetry levels back to the original mesh shapefile using the explicit element ID field
8. Update the depth correction *.dfsu file using the DHI tool “**DHI.NZSOL.UpdateDfsuZValueFromShp**”

4 Model Data Summary and Computation Parameters

The key parameters used within each MIKE model component of the HDM Halswell model (MIKE 11, MIKE 21, and MIKE Urban) are discussed in the following sections. These parameters are critical to the model's behaviour and results.

4.1 MIKE 11

The MIKE 11 model of the HDM Halswell model consists of 5 primary files:

- Network File (*.nkw11),
- Cross-section File (*.xns11),
- Boundary Data File (*.bnd11),
- HD Parameters File (*.hd11), and
- MIKE 11 (MIKE11.ini file).

A summary of the parameters and inputs for each of these MIKE 11 files is provided in the sections below.

4.1.1 Network File

The extent of the MIKE 11 network is shown in Figure 3-9 in Section 3.4, with the components of the network summarised below in Table 4-1 and the locations of the structures shown in Figure 4-1 and Figure 4-2.

Table 4-1 Network file breakdown for MIKE 11 model component of HDM Halswell model

Type	Input Parameter	Model count
Network	Branches	27
	Points	1483
Structures	Weirs	49
	Culverts	54

a. Points

Points defined were specified with x and y coordinates, with chainage types a mixture of both “user” and “system defined”. “User” was selected at the start and end of branches and where needed to specify specific coupling locations.

b. Branches

Branches of the model were developed based on the CFM (LDRP044) Model Schematisation (GHDVAECOM, 2018), where:

- All branches were set as “regular,” which is the normal branch type used within MIKE 11 and comprises several calculation points that are defined by the cross-sections specified in the cross-section file.
- The dx values for all branches in MIKE 11 were set to be within a range of 1 to 8 times the element length in MIKE 21. For some branches, this requirement could not be met due to long MIKE 11 structures. Here additional cross sections were added (interpolated) so there are sufficient H points (head points) for proper coupling of lateral links.

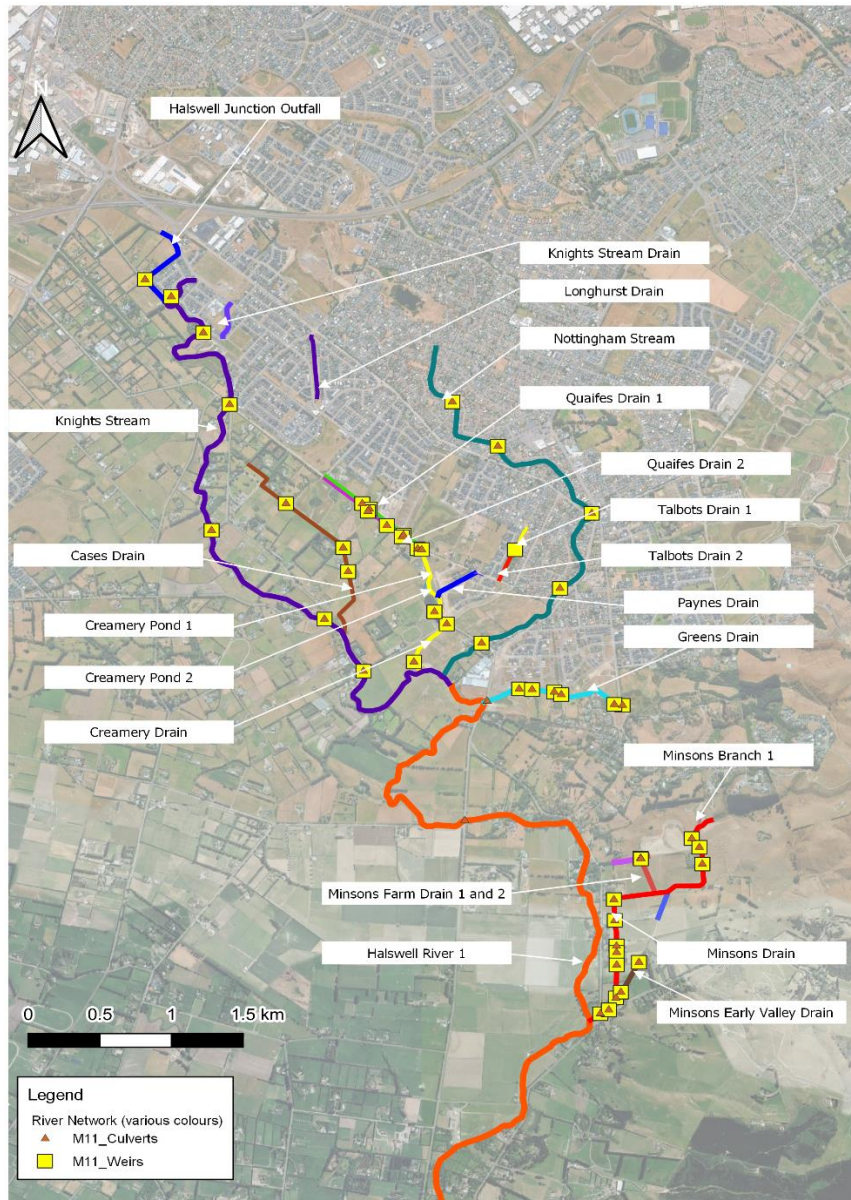


Figure 4-1: Locations of structures (culvert/weir/bridge) for northern section of HDM Halswell Mike 11 model.
Image source: Map data © 2025 Google

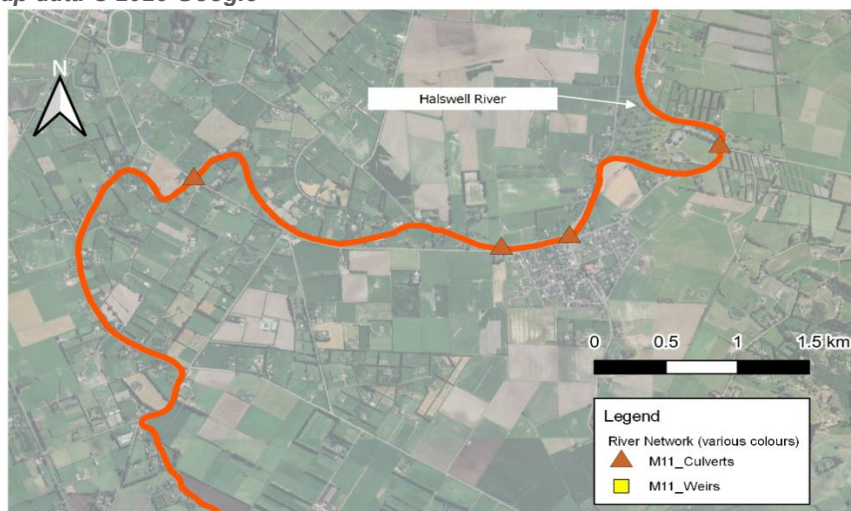


Figure 4-2 Locations of structures(culvert/weir/bridge) for southern section of HDM Halswell Mike 11 model. *Image source: Map data © 2025 Google*

Table 4-2 summarises the upstream (US) and downstream (DS) chainages, topographical identifications and dx values of the HDM Halswell model branches.

Table 4-2 HDM Halswell Model 2024 MIKE 11 Branches

Branch ID	Topo ID	US Chainage (m)	DS Chainage (m)	dx (m)
Hals.CreameryDrain	CREAMERY DRAIN CCC survey 04-08-2015	-4	1173	24
Hals.TalbotsDrains.3	TALBOTS DRAIN 2 CCC survey 04-08-2015	369.21	432.04	10000
Hals.GreenDrain	GREEN DRAIN CCC survey 04-08-2015	-22	1057.5	34
Hals.HalswellRiver.1	Topo	0	17048.7	30
Hals.NottinghamStream	ENHANCEDJUNE2013	0	3873	34
Hals.PaynesDrain	Paynes Drain CCC survey 04-08-2015	0	312	16
Hals.QuaifesDrain.1	Quaifes Drain No 1 CCC Survey 04-08-2015	0	869.45	16
Hals.QuaifesDrain.2	Quaifes Drain No 2 CCC Survey 04-08-2015	0	883	16
Hals.TalbotsDrain.1	TALBOTS DRAIN 1 CCC survey 04-08-2015	0	196.7	24
Hals.TalbotsDrains.2	TALBOTS DRAIN 2 CCC survey 04-08-2015	0	240.149	34
Hals.HalswellJunctionOutfall	HJO CCC survey 04-08-2015 632-end	598.5	1323.6	24
Hals.HalswellRiver.3	Couple	0	1000	16
Hals.OldChannel	Couple	0	500	16
Hals.HalswellRiver.2	XS from ECan LiDAR	17050	29979	16
Hals.MinsonsDrain	CCC Minson and Cases Survey 2016	988	3256	34
Hals.MinsonsFarmDrain.1	CCC Minson and Cases Survey 2016	0	186	16
Hals.MinsonEarlyValleyDrain	CCC Minson and Cases Survey 2016	0	360	16
Hals.MinsonsBranch.1	CCC Minson and Cases Survey 2016	30	104	16
Hals.MinsonsFarmDrain.2	CCC Minson and Cases Survey 2016	0	343	16
Hals.MinsonsFarmDrain.3	CCC Minson and Cases Survey 2016	0	179	16
Hals.CasesDrain	CCC Minson and Cases Survey 2016	0	1693	16
Hals.CreameryPonds.1	DRAWINGS	0	77	16
Hals.CreameryPonds.2	DRAWINGS	0	149	16
Hals.KnightsStream	FEB2013	530	6259	34
Hals.KnightStreamDrain	XS from ECan LiDAR 2019 (1)	0	268	16
Hals.TalbotsPipe	TalbotsPipe	0	4.60	16
Hals.LonghurstDrain	XS from ECan LiDAR 2019 (3)	0	474	16

c. Culverts

A total of 54 culverts were modelled in MIKE 11. They were modelled as closed sections and structures as specified in CFM (LDRP044) Model Schematisation (GHD\AECOM, 2018), with the culvert geometries ranging from Circular, Rectangular, Irregular – Depth-Width Table and Cross Section DB.

The Manning's ' n ' for the majority of culverts was set of 0.013. Default values for the head loss factors were used to model the culverts in MIKE 11 and are summarised in Table 4-3.

Table 4-3 Culverts and bridges head loss factors for HDM Halswell MIKE 11 Model

Head Loss Factor	HDM Halswell MIKE 11 Culverts/Bridges
Inflow Positive	0.5
Outflow Positive	1
Free Flow Positive	1
Bends Positive	0
Inflow Negative	0.5
Outflow Negative	1
Free Flow Negative	1
Bends Negative	0

d. Weirs

A total of 49 weirs were modelled in MIKE 11 and were modelled as Regular and Broad Crested Weir with Level-Width geometries. Default values for the head loss factors were used to model the weir in MIKE 11 and are summarised in Table 4-4.

Table 4-4 Weir Head Loss Factors for HDM Halswell MIKE 11 Model

Head Loss Factor	HDM Halswell MIKE 11 Weir
Inflow Positive	0.5
Outflow Positive	1
Free Flow Positive	1
Inflow Negative	0.5
Outflow Negative	1
Free Flow Negative	1

e. Bridges

A total of 28 single-span bridges were modelled as culverts in MIKE 11. The culvert structure was used for the bridges as specified by CFM (LDRP044) Model Schematisation (GHD\AECOM, 2018). The culvert function forms a uniform cross-section of the span of the bridge, where the bridge's geometries were set as Circular, Irregular – Depth-Width Table or Cross-section DB.

The Manning's ' n ' for the bridges ranged from 0.013 to 0.024. Manning ' n ' value was determined based on the bridge's material, the stream beds roughness, and the bridge opening cross-section shape.

Default values for the head loss were used for all the bridges except for Culvert 8 (Hals.KnightStream Chainage 3392 diameter 1200 mm) and are summarised in Table 4-3. For Culvert 8, the inflow positive and inflow negative factors were set to 0.7.

4.1.2 Cross sections

The MIKE 11 cross sections developed were applied to the 24 branches defined in the MIKE 11 network. The cross-sections were applied to the branches between the banks to represent 1D flow and were spaced to represent the conveyance along the watercourse. The key cross-sectional properties are specified below.

a. Topo IDs

The Topo IDs linking the cross-sections with the MIKE 11 Branches are outlined in Table 4-2.

b. Cross-section ID

Cross-section ID were named as outlined in Section 5.91 of CFM (LDRP044) Model Schematisation (GHDVAECOM, 2018). This specific naming convention has been used to help identify and track cross-section sources and any modifications made to the cross-sections.

c. Cross-section properties

The following properties were applied for all cross-sections in the MIKE 11 of the Halswell model:

- The section types were set as open (for open channels).
- The radius types were set to “Total Area, Hydraulic Radius.”
- No coordinates were applied.
- No correction of the x- coordinates was applied.
- The morphological model has not been used.
- Resistance numbers were set using uniform distribution, with a Manning’s ‘ n ’ of 0.035.

4.1.3 Boundary Data

The 36 boundary conditions used in the MIKE 11 for the HDM Halswell model 2024 are summarised in Table 4-5 and the locations of boundary conditions shown in Figure 4-3. This table outlines the location of the boundary (branch name and chainage), the boundary nature (open, point source, distributed etc.) and the boundary type (namely, inflows, water levels etc.) and the corresponding boundary values.

Boundary 9 and Boundary 29 represent the downstream lake level boundary at Lake Ellesmere. This open water level boundary is a timeseries that varies from 0.153 m RL to 1.252 m RL (NZVD) and was taken from the Halswell River/Huritini Floodplain Investigation (ECan, 2013). The average reoccurrence interval for a lake level of this elevation is 200 years (annual exceedance probability of 0.5%).

Boundary 6 represents the flow of water into the start of Greens drain (from the MIKE 21 model). The water level was set to equal the invert level of the cross-section at chainage -22 m however the actual water level is set based on the current level in MIKE 21 and flow is transferred between the models each timestep. At this location (approximately 80 m north of the Halswell Quarry entrance along Kennedys Bush Rd) there is a wetland which is modelled in MIKE 21. The same type of boundary is also used at boundaries 16 and 20.

Table 4-5 MIKE 11 boundary conditions for HDM Halswell Model

No.	Branch Name	Chainage	Nature	Type	Data Type	Value
1	Hals.TalbotsPipe	4.6	Open	Water Level	Constant Water Level	11.822m NZVD
2	Hals.CasesDrain	0	Open	Inflow	Constant Discharge	0.01 m ³ /s
3	Hals.CreameryPonds.1	56.7	Point Source	Inflow	Constant Discharge	0.05 m ³ /s
4	Hals.CreameryPonds.2	0	Point Source	Inflow	Constant Discharge	0.01 m ³ /s
5	Hals.TalbotsDrains.3	369.2	Open	Inflow	Constant Discharge	0.01 m ³ /s
6	Hals.GreenDrain	-22	Open	Water Level	Constant Water Level	11.07 m NZVD
7	Hals.HalswellJunctionOutfall	598.5	Open	Inflow	Constant Discharge	0.02 m ³ /s
8	Hals.HalswellRiver.1	5612	Distributed Source	Inflow	Constant Discharge	0.5 m ³ /s
9	Hals.HalswellRiver.3	1000	Open	Water Level	Water Level Time Series	0.153 m NZVD to 1.252 m NZVD
10	Hals.KnightsStream	530	Open	Inflow	Constant Discharge	0.01 m ³ /s
11	Hals.KnightsStream	2150	Point Source	Inflow	Constant Discharge	0.07 m ³ /s
12	Hals.KnightsStream	3260	Point Source	Inflow	Constant Discharge	0.15 m ³ /s
13	Hals.KnightsStream	4730	Point Source	Inflow	Constant Discharge	0.12 m ³ /s
14	Hals.KnightsStream	5500	Point Source	Inflow	Constant Discharge	0.081 m ³ /s
15	Hals.KnightStreamDrain	0	Open	Inflow	Constant Discharge	0.01 m ³ /s
16	Hals.KnightStreamDrain	268	Open	Water Level	Constant Water Level	13.77 m NZVD
17	Hals.LonghurstDrain	0	Open	Inflow	Constant Discharge	0.01 m ³ /s
18	Hals.LonghurstDrain	88	Point Source	Inflow	Constant Discharge	0.01 m ³ /s
19	Hals.LonghurstDrain	160	Point Source	Inflow	Constant Discharge	0.01 m ³ /s
20	Hals.LonghurstDrain	474	Open	Water Level	Constant Water Level	13.62 m NZVD

No.	Branch Name	Chainage	Nature	Type	Data Type	Value
21	Hals.MinsonEarlyValleyDrain	0	Open	Inflow	Constant Discharge	0.01 m ³ /s
22	Hals.MinsonsBranch.1	30	Open	Inflow	Constant Discharge	0.01 m ³ /s
23	Hals.MinsonsDrain	988	Open	Inflow	Constant Discharge	0.01 m ³ /s
24	Hals.MinsonsFarmDrain.1	0	Open	Inflow	Constant Discharge	0.01 m ³ /s
25	Hals.MinsonsFarmDrain.2	0	Open	Inflow	Constant Discharge	0.01 m ³ /s
26	Hals.MinsonsFarmDrain.3	0	Open	Inflow	Constant Discharge	0.01 m ³ /s
27	Hals.NottinghamStream	0	Open	Inflow	Constant Discharge	0.016 m ³ /s
28	Hals.OldChannel	0	Open	Inflow	Constant Discharge	0.1 m ³ /s
29	Hals.OldChannel	500	Open	Water Level	Water Level Time Series	0.153 m NZVD to 1.252 m NZVD
30	Hals.LonghurstDrain	17	Point Source	Inflow	Constant Discharge	0.01 m ³ /s
31	Hals.LonghurstDrain	35	Point Source	Inflow	Constant Discharge	0.01 m ³ /s
32	Hals.QuaifesDrain.1	0	Open	Inflow	Constant Discharge	0.021 m ³ /s
33	Hals.QuaifesDrain.2	0	Open	Inflow	Constant Discharge	0.02 m ³ /s
34	Hals.TalbotsDrain.1	0	Open	Inflow	Constant Discharge	0.001 m ³ /s
35	Hals.TalbotsDrains.2	0	Point Source	Inflow	Constant Discharge	0 m ³ /s
36	Hals.TalbotsDrains.2	240.1	Open	Water Level	Constant Water Level	11.64 m NZVD

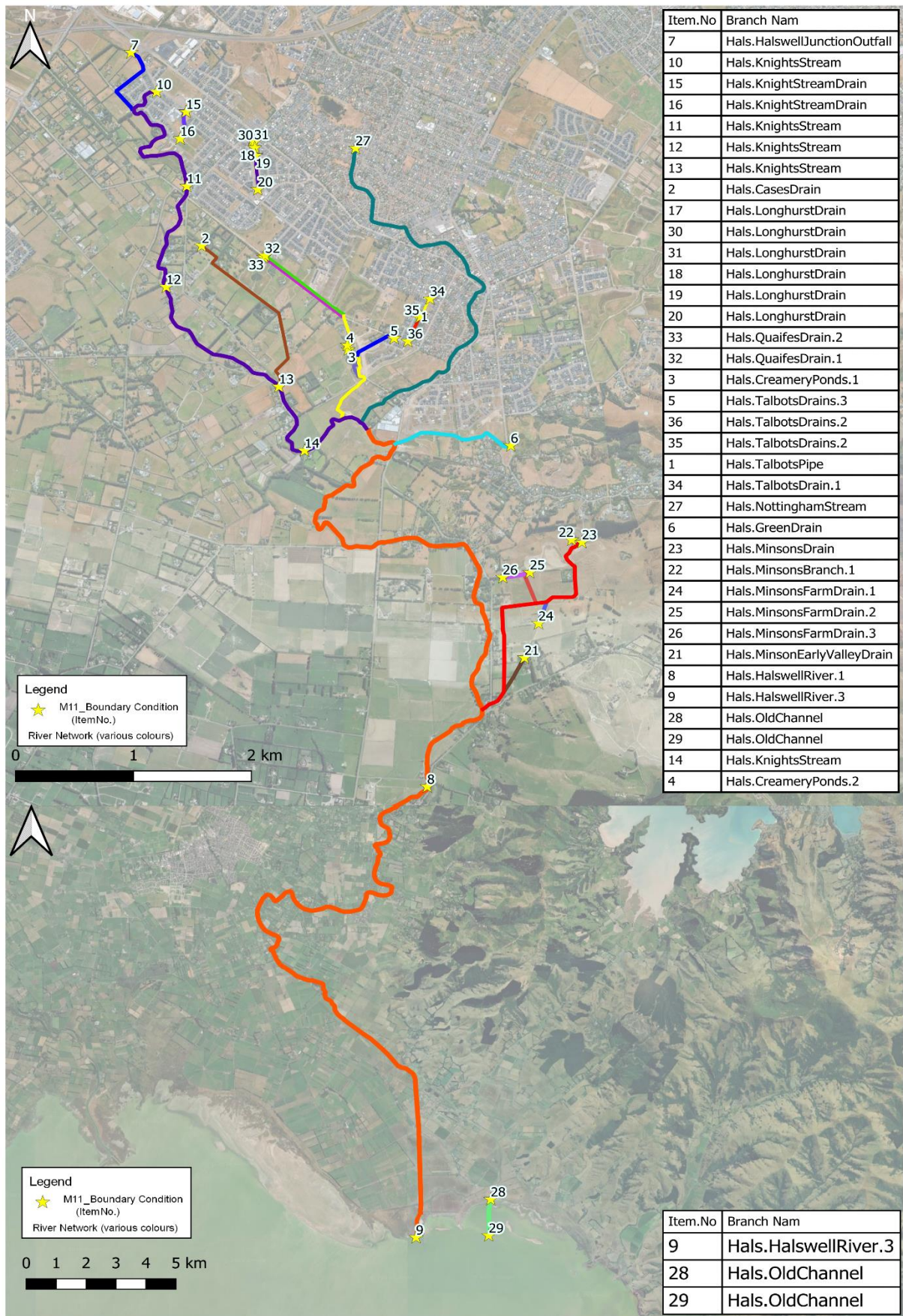


Figure 4-3 Locations of boundary condition for HDM Halswell Mike 11 model. Image source: Map data © 2025 Google

4.1.4 HD Parameters

The hydrodynamic (HD) parameters provided are used for setting supplementary data for model runs. Most of the parameters were set to default values, with many parameters set as global for the entire model. The HD parameters used within the MIKE 11 for the HDM Halswell model are summarised below.

a. Default Computational Parameters

Table 4-6 outlines the default computation parameters used in the MIKE 11 for the HDM Halswell model. These parameters are essential for the computational scheme of MIKE 11 and defaults values were used for all computation parameters except for Delta.

In the HDM Halswell model, Delta was set to 0.9 (default value is 0.5). The Delta value can significantly influence model dynamics as Delta affects the time-centring of the gravity term in the momentum equation. A high value of Delta has a dampening effect. Delta was set to 0.9 to stabilise the linkages from MIKE 11 to MIKE FLOOD. The MIKE 11 manual recommends a Delta of 0.85 for MIKE FLOOD models with small timesteps. The adopted value of 0.9 is slightly higher.

Table 4-6 MIKE 11 HD default computational parameters for the HDM Halswell model

Parameter	Value
Delta	0.9
Delhs	0.01
Delh	0.1
Alpha	1
Theta	1
Eps	0.0001
Dh Node	0.01
Zeta Min	0.1
Stru Fac	0
Inter1Maz	10
Nolter	1
MaxIterSteady	100
Froudemax	-1
FroudeExp	-1

b. Initial Conditions

The initial water depth has been set globally at 0 m in the MIKE 11 component.

c. Wind

Wind factors were not considered in the HDM Halswell model.

d. Bed Resistance

A global Manning's 'M' of 30 has been applied for the MIKE 11 network of the HDM Halswell model. However, since the cross sections use local Manning's n values the global parameter is not used in the simulation.

e. Wave Approximation

The wave approximation uses a High Order Fully Dynamic approximation.

f. Quasi Steady Parameters

The default values for the quasi-steady simulation computational parameters and no steady state options were used in the MIKE 11 model. Table 4-7 outlines the quasi-steady simulation computational parameters used in the MIKE 11 HD file.

Table 4-7 MIKE 11 HD quasi-steady simulation computational parameters

Parameter	Value
Relax	0.5
Beta_Limit	1E-8
Fac_0	2.5
Qconv_factor	0.001
Hconv_factor	0.01
Min_Hconv_In_Branch	1E-5
Q-struc_Factor	0.005
H_stop	0.0001
Steady State Option	Not Used

g. Heat Balance

Heat exchange was not used.

h. Stratification

Stratification parameters used in the MIKE 11 of the HDM Halswell model are summarised in Table 4-8.

These are the default parameters in MIKE 11. There are no stratification branches in the Halswell model so the parameters are not used in the model. Stratification branches are defined in the 'branches' section of the *.nwk11 file.

Table 4-8 MIKE 11 HD Stratification Parameter for HDM Halswell model

Parameter	Value
No of Layers	10
Densities Calculated	Yes
Turbulence model in fluid	k-eps model
Turbulence model Viscosity	0.003
Turbulence model at bed	Drag coefficient
Richardson numbers correction	Yes
Baroclinic Pressure – Factor	1
Baroclinic Pressure – Local Bed Slope	0
Convection / Advection – Factor horizontal momentum	1
Convection / Advection – Factor vertical momentum	1
Convection / Advection – Factor advection	1
Dispersion – Factor horizontal viscosity	1
Dispersion – Factor vertical viscosity	1

i. Groundwater Leakage

Groundwater leakage was not used in the MIKE 11 part of the HDM Halswell model.

j. Flood Plain Resistance

The default value of -99 for flood plain resistance was applied in the MIKE 11 model. A value of -99 indicates that the flood plain resistance should be calculated from the raw data of the cross-sections database (*.xns11 file).

k. Encroachment

Encroachment simulations were not used in the MIKE 11 of the HDM Halswell model.

4.1.5 MIKE 11.ini file

The MIKE11.ini file offers functionality to adjust settings within the numerical engine of MIKE 11. There are 48 variables that can be changed for hydrodynamic simulations. One default was changed for the MIKE 11 component of the HDM Halswell model.

The water level exceedance factor was set to 8 (usually it is 4). This parameter defines the factor at which MIKE 11 will halt and give an error due to a river reach being too deep compared to its bank height. For example, if a bank is 1m tall MIKE 11 will halt with an error when the depth reaches $8 \times 1\text{m} = 8\text{m}$. When the water depth exceeds the height of its banks four times this usually indicates an error in the model set up or that the MIKE 11 model has become unstable. In HDM Halswell model however, Greens Drain has a realistic water level that exceeds the height of its bank by more than 4 times (but less than 8 times) for the large events. These are the 0.5% and 0.2% annual exceedance probability events.

4.2 MIKE Urban

MIKE Urban computation was setup for network run with long term statistics (LTS) simulation. The LTS modelling of the network, with dynamic wave simulation, allows for a time-efficient long-term simulation, covering a long simulation period while providing the computation of relevant statistics for the variables of interest.

4.2.1 Pipes

The updated HDM Halswell model 2024 includes the Christchurch City Council pipes less than 300 mm that were not required in the previous schema. Private pipes are mostly excluded from the model unless required for network connectivity.

a. Roughness

The material classification for the pipes was provided by the CCC and SCIRT GIS data sets. The pipes in Halswell catchment are either concrete or plastic. Concrete was applied as the default classification for pipes where no material classification was provided.

The roughness values for concrete and plastic pipes were taken from Section 6.9 of by CFM (LDRP044) Model Schematisation (GHD/AECOM, 2018) and are summarised in Table 4-9. The plastic pipe roughness provided was a homogenised roughness value for all plastic pipe types used in the CCC GIS data set.

The formation for hydraulic friction losses was set as Mannings explicit.

Table 4-9 Pipe Roughness Parameters for HDM Halswell MIKE Urban Model

Material Type	Manning's ' <i>M</i> '	Manning's ' <i>n</i> '
Concrete	76.9	0.013
Plastic (PE, PVC/uPVC, PP)	90.9	0.011

4.2.2 Manholes

All manholes were specified as 'Normal' type. Manholes that are not inlets have been designated as "type weighted inlet energy" with a loss coefficient (K_m) of 0.25, while a higher loss coefficient ($K_m = 0.5$) has been applied at true inlets, primarily at endpoints, where applicable.

a. Manhole Diameter

The manhole sizes were provided by CCC and SCIRT GIS data sets. Where manhole diameter was unavailable, the standard manhole sizes were used as a default. These standard sizes, based on connecting pipe sizes, are summarised in Table 4-10.

Table 4-10 Standard Manhole Diameter used in HDM Halswell MIKE Urban Model

Connecting Pipe Size (mm)	Standard Manhole Diameter (m)
< D900	1.05
D900 to D1200	1.35
D1200 to D1350	1.5
> D1350	2.3

b. Ground Level

The ground level for all manholes was set from the elevation values from the MIKE 21 mesh.

c. Invert Level

Invert levels were taken from CCC GIS system and checked against SCIRT data the levels are taken in NZVD. As specified in CFM (LDRP044) Model Schematisation (GHD\AECOM, 2018), negative and zero grades in the MIKE URBAN pipelines were removed by raising the upstream invert level of the pipe. Wherever there was a greater than 200 mm difference between the upstream and downstream invert levels, it was assumed that the negative gradient is real and was hence left in the model.

d. Sump inlet coupling

An issue with MIKE Flood was identified by Council in December 2025 where multiple sump inlets coupled to a single manhole only take the highest inlet elevation. In some catchments, this resulted in artificially high flood levels. Beca reviewed this issue in relation to the Halswell Model, and a summary of the findings is included below:

- Sumps and sump leads have been added directly into the model. This occurred for the CCC assets (apart from ~6 sumps), this was not completed for the private networks.

Originally, considerable flooding was observed in the industrial area, outside of the road. To remedy this, some private sumps were coupled directly to the CCC asset (usually a manhole in the street), which in

some places included coupling multiple sump inlets to single manholes. This is shown in



- Figure 4-4.
- The majority of this type of coupling was used in the industrial area with approximately 10 instances in the residential area (usually private laneways).

Given the limited extent of the issue identified in Halswell the decision was made not to make any changes at this stage. The locations have been added to the anomalies register for future updates of the model.



Figure 4-4: Industrial area with multiple sumps coupled to single manholes (Coloured dotted lines denote a coupling link).
Image source: Map data © 2025 Google

e. Dummy Manholes

Dummy manholes were used for the culverts connecting to the open channels. The dummy manhole was a standard diameter selected based on the culvert size (as outlined above). The inlet losses for the culverts were set to 'MOUSE_Sharp_Eged' with a K_m set to 0.5.

4.2.3 Outlets

Outlets that discharge to a river (represented in MIKE 11) or into flood plain (2D surface in MIKE 21) were represented as outlets in the MIKE Urban network. Outlet energy losses were set to 'MOUSE Classic (Engelund)' with a K_m set to 0.5.

4.3 MIKE 21FM

The MIKE 21 model of the HDM Halswell model was set up as a hydrodynamic triangular flexible mesh model. The MIKE 21 model of the HDM Halswell model uses the following key files:

- Mesh file (Hals_ED2024.mesh)
- Depth correction file (Hals_ED2024.dfsu)
- Roughness file (Roughness_citywide_Hals_postEQ_ED2024_5m.dfs2)
- Infiltration files (for example, Hals_ED2024_Infiltration_MD.dfsu)
- Rainfall files (for example, RAIN_Hv4_0200ARI_001HR_HISTORICAL.dfs2)
- Sources files (for example, RORB_CCC_ED2020_RAIN_Hv4_0500ARI_060hr_HISTORICAL_095ARF.dfs0)
- Initial condition file (Hals_ED2024_IC_WSE.dfsu)

4.3.1 Timestep and Solution Technique

The maximum timestep used in the MIKE 21 model was 0.5 second intervals. MIKE 21 uses an explicit variable timestep that requires a Courant-Friedrich-Lévy condition below 1 to be stable.

The solution technique used in the HDM Halswell MIKE 21 model for shallow water technique was low order fast algorithm scheme. The parameters used in the solution technique are outlined in Table 4-11. The Courant-Friedrich-Lévy (CFL) was set to the default value of 0.8.

Table 4-11 Solution technique parameters for HDM Halswell MIKE 21 model

Parameter		Value
Shallow Water Technique	Time Integration	Low order, fast algorithm
	Space discretization	Low order, fast algorithm
	Minimum Time Step	0.01 sec
	Maximum Time	0.5 sec
	Critical CFL number	0.8 sec
Transport Equation – although these are not used in the model	Minimum Time Step	0.01 sec
	Maximum Time	0.25 sec
	Critical CFL number	0.8 sec

4.3.2 Depth

Depth correction file, as described in Section 3.6.2, was applied in the process outlined in the Beca Depth Correction Memo (2021) located in Appendix E.

4.3.3 Drying, flooding, and wetting depths

Drying and wetting depths were set to 1 mm, 3 mm, respectively. These values were advised by DHI and CCC.

4.3.4 Eddy Viscosity

Eddy viscosity in the HDM Halswell model was set to constant, with a value of 0.1 m²/s.

4.3.5 Bed resistance

A 5 m by 5 m roughness grid file (*.dfs2) was generated to apply the roughness (Manning's '*M*') values associated with the land use classifications in the HDM Halswell model 2D domain. The roughness values were derived from the values provided in Table 3 of the CFM (LDRP044) Model Schematisation (GHD\AECOM, 2018) and the land use classification provided from various sources, including Landcare data, CCC City Plan Zoning, CCC Street Centreline, Lynker and CCC Building Footprints. Composite roughness values were developed and applied the residential and commercial/industrial classification based on an assessment of the extent of various elements (driveways, lawns, gardens and so on) in sample areas.

In the HDM Halswell MIKE 21 model, the roughness grid was applied as a Manning's number that was constant in time and varying in space.

The impervious data set was used to generate an impervious 2D grid file (*.dfs2). The grid file was generated with a 2m x 2m spacing and was applied using the 'Bed Resistance' function in MIKE 21 model. Figure 4-5 shows the Mannings *M* across the catchment.

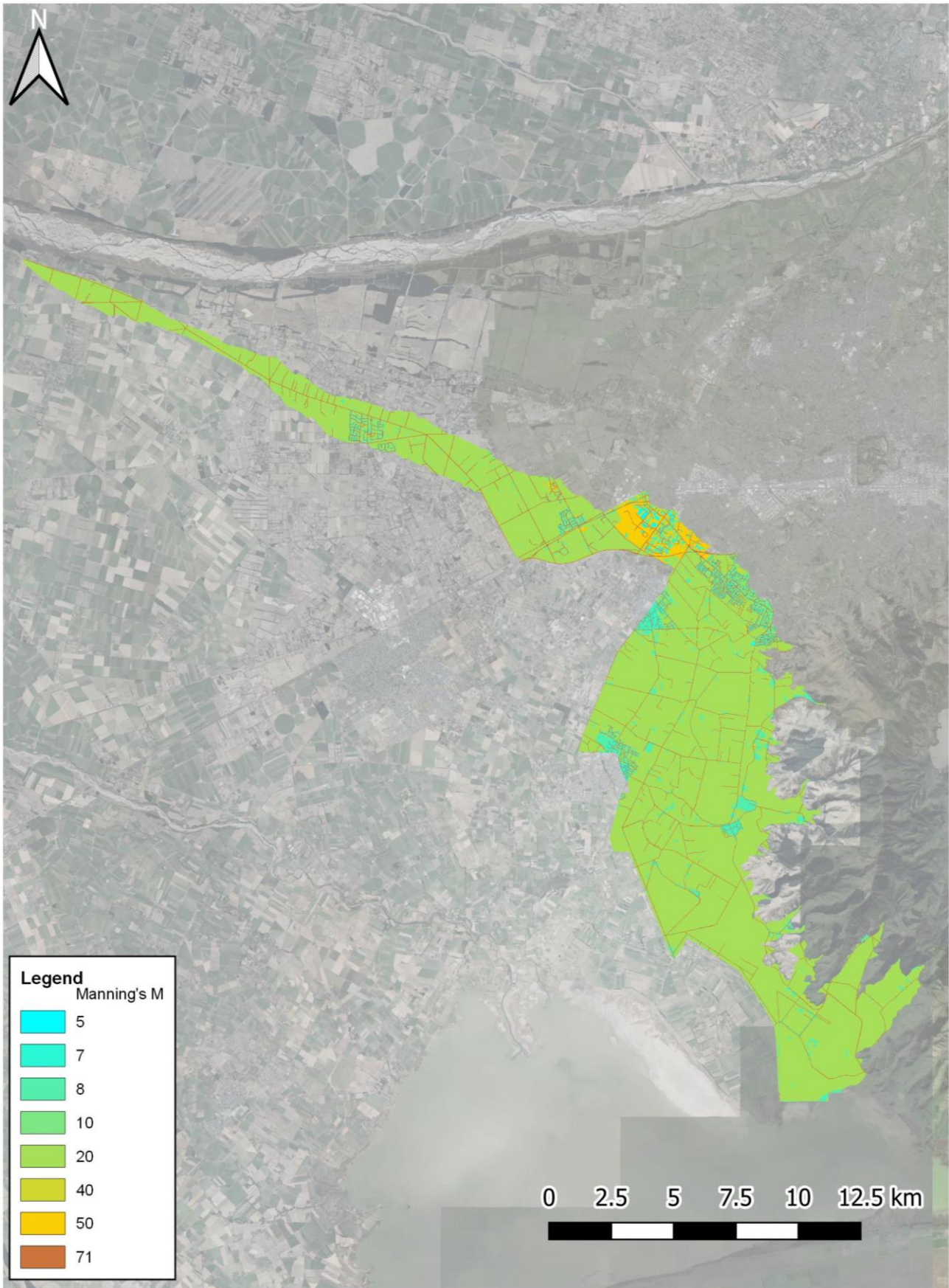


Figure 4-5 Manning's M roughness map (Existing Development 2024 model). Image source: Map data © 2025 Google.

4.3.6 Precipitation Evaporation

The 2D design rainfall grids, described in Section 3.3.3a, were applied using the Precipitation function in MIKE 21. The rainfalls were applied as specified precipitation, varying in time and domain and with a soft start interval of 0 sec (no soft start).

4.3.7 Infiltration

The 2D infiltration grids, described in Section 3.3.3c, were applied using the infiltration module. The infiltration type used in this model is “constant” infiltration with capacity. The infiltration zone extent is defined as a depth.

4.3.8 Culverts

23 culverts have been modelled in MIKE 21. These culverts have a range of culvert geometries including circular, rectangular, irregular, and level-width.

The Manning’s ‘*n*’ for all the culverts was set to 0.013. Default values for the head loss factors were used for all the MIKE 21 culverts. These are summarised in Table 4-12.

Table 4-12 Culverts and bridges Head Loss Factors for HDM Halswell MIKE 21 Model

Head Loss Factor	HDM Halswell MIKE 11 Culverts/Bridges
Inflow Positive	0.5
Outflow Positive	1
Free Flow Positive	1
Bends Positive	0
Inflow Negative	0.5
Outflow Negative	1
Free Flow Negative	1
Bends Negative	0

4.3.9 Sources Nodes

Source nodes have been used to apply the runoff hydrographs from the RORB rainfall runoff model, as described in Section 3.3.4. There is a total of 57 source points applied to the MIKE 21 grid, as shown in Figure 4-6. These 57 source points represent the location of the RORB nodes located on the hillside/flat land boundary and that will provide the runoff onto the 2D surface.

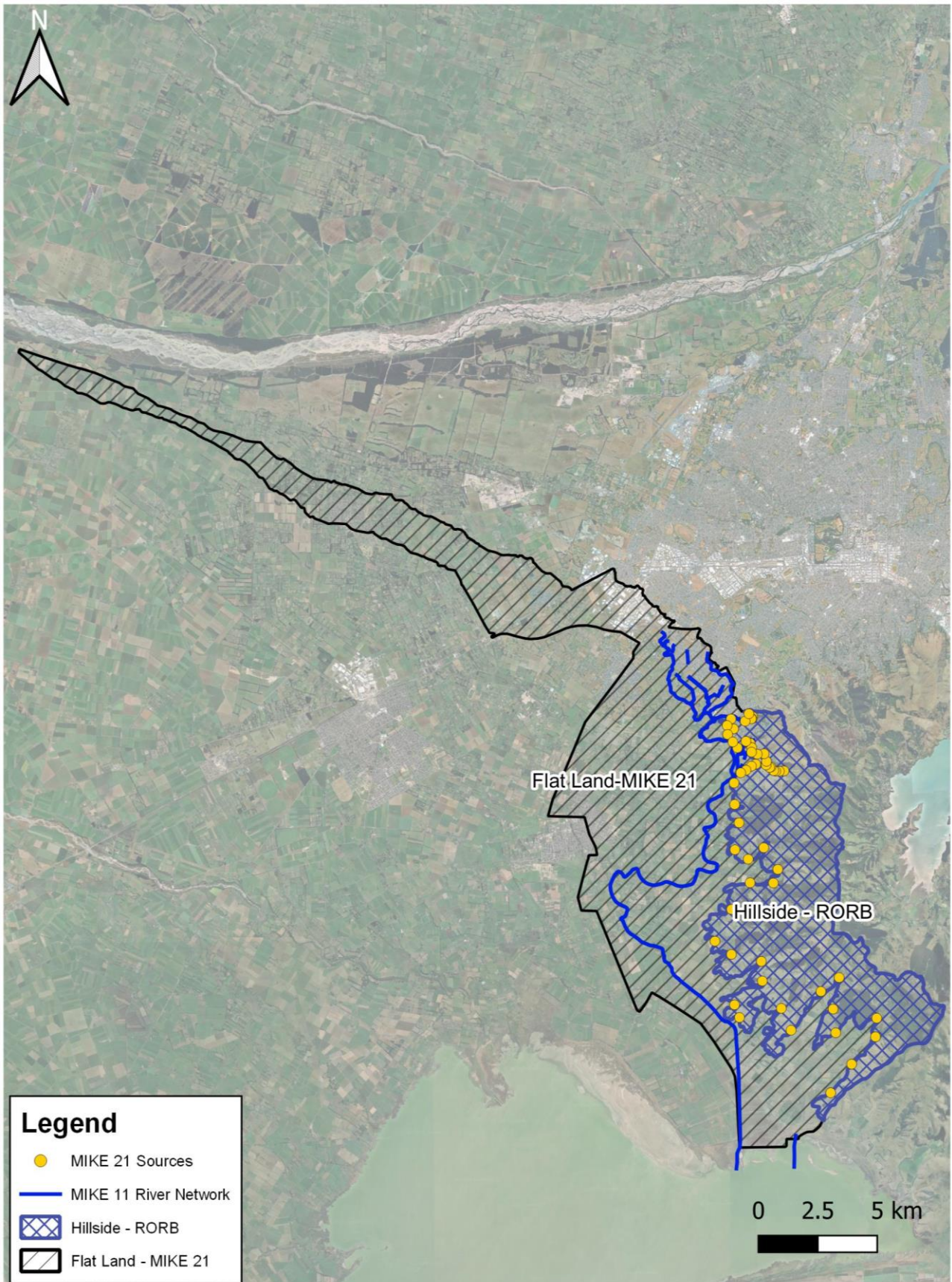


Figure 4-6 HDM Halswell MIKE 21 RORB Hydrograph Source Nodes. *Image source: Map data © 2025 Google*

4.3.10 Other Parameters

Wind, Coriolis forcing, ice coverage, tidal potential and wave radiation were not included as part of the Halswell MIKE 21 model.

4.3.11 MIKE 21 FM Boundary

Most of the edges of the MIKE 21 model have land boundaries. These boundaries do not allow flow into or out of the model and are hence good for walls or areas of the model that remain dry. Initial results showed water was unrealistically pooling against the outside boundary in some locations. In these locations a water level boundary was created to allow water to flow out of the model. To encourage stability at these water level boundaries the depth correction layer (bathymetry) was lowered to be approximately 200mm below the level of the boundary. Figure 4-7 shows the location of these boundaries.

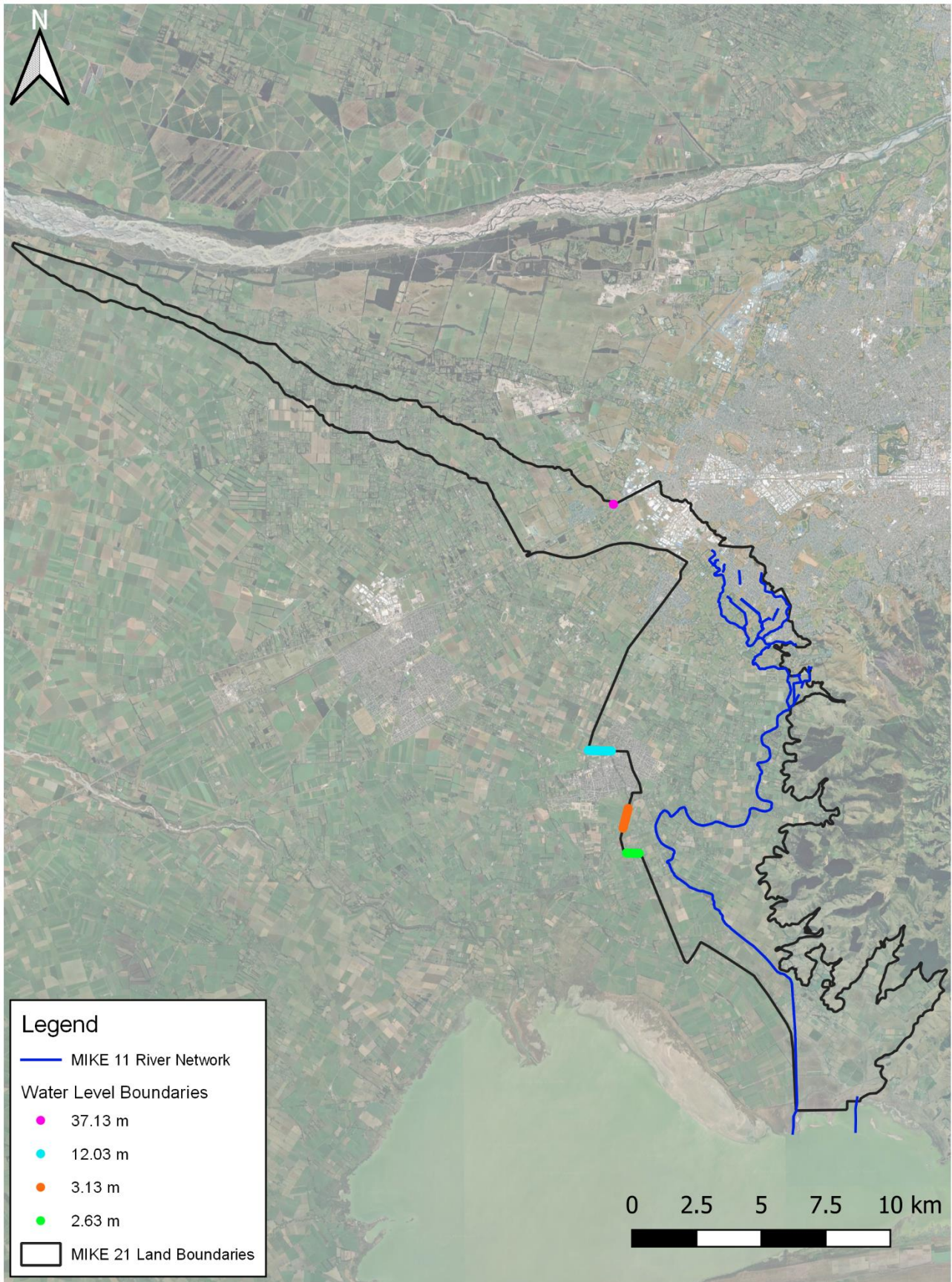


Figure 4-7 Water level boundaries allowing flow out of the model. *Image source: Map data © 2025 Google*

4.4 MIKE FLOOD

MIKE FLOOD was used to couple the MIKE 11, MIKE 21, and MIKE Urban models, allowing for the transfer of water from the 1D engine to the 2D engine vice versa to predict flooding during the design storm events. The sections below summarise the linkages between the three MIKE models.

4.4.1 Lateral Links

Lateral links were used to link all the open channels (rivers, streams, and drains) in MIKE 11 to the 2D surfaces. The lateral links were placed along the banks of each branch using the MIKE 11 1D cross-sections. Table 4-13 summarises the Lateral Link parameters set in the Halswell MIKE FLOOD model.

Table 4-13 Lateral link parameters for HDM Halswell MIKE FLOOD model

Parameter	Setting	Comment
Type	Weir 1	Default value. MIKE 11 Weir Formula 1 with friction term included in the computation.
Source	M21 and HGH	As specified in CFM (LDRP044) Model Schematisation (GHDVAECOM, 2018) these are generally set to MIKE 21 except in locations with known bank levels above the MIKE 21.
Depth tolerance	0.100	Default value.
Weir Coefficient	1.838	Default value.
Friction (Manning's 'n')	0.050	Default value.
Exponential Smoothing Factor	0.2 to 1	Exponential smoothing factor dampens short timescale oscillations; however, it can create a time lag in the transfer of water levels across the link if it is set inappropriately. For links with initial unstable behaviour (oscillates), the MIKE FLOOD user manual suggests a factor between 0.2 to 0.4.

4.4.2 Standard Links

Standard links were used to link the MIKE 11 branches, where the river branch discharges directly to the 2D surface and vice versa. This only applies to Greens Drain which was linked at the start of the drain (at chainage -22). Table 4-14 summarises the standard link parameters used.

Table 4-14 Standard Link parameters for HDM Halswell MIKE FLOOD model

Parameter	Setting/Value	Comment
Momentum Factor	0	Set to zero meaning no momentum is transferred through to the MIKE 11 computation.
Depth Adjust	No	Depth adjustment not active for the link.
Extrapolating Factor	0	Default value.
Exponential Smoothing Factor	0.2	Default value. Factor of 1 represents no smoothing.

4.4.3 Urban Links

Manholes in the HDM Halswell MIKE Urban model were linked to the 2D surface through Urban links, with the 'M21 to inlet' function. Manholes were linked at the location of each connected sump inlet. A sump was considered as 'connected' when it is located within the hydraulic extent, within the mesh extent and within 10 m of the MIKE Urban manhole. The urban coupling linkages for the HDM Halswell MIKE FLOOD model were provided by GHD on 9 November 2017. During peer review DHI identified errors in the coupling linkages provided by GHD. Beca resolved these by reviewing and manually updating them.

The MIKE Urban outlets discharging to the 2D surface via the Urban links using the 'M21 to outlet' type.

Table 4-15 summaries the Urban link parameters set in model.

Table 4-15 Urban Link Parameters for HDM Halswell MIKE FLOOD model

Parameter	Setting/Value	Comment
Max Flow (m ³ /s)	Quad Sump: 0.08 Triple Sump: 0.06 Double Sump: 0.04 Single Sump (& other types): 0.02 Outlets: 10	Based on the inlet capacity defined in CCC GIS.
Inlet Area (m ²)	1.0	Default value.
Inlet Method	Orifice Equation	Default value.
Discharge Coefficient	0.98	Default value.
QdH Factor	0.1	Default value.
Exponential Smoothing Factor	1.0	Exponential smoothing factor dampens short timescale oscillations; however, it can create a time lag in the transfer of water levels across the link if it is set inappropriately. For links with initial unstable behaviour (oscillates), the MIKE FLOOD user manual suggests a factor between 0.2 to 0.4.

4.4.4 River/Urban Links

River/Urban linkages were used to connect the MIKE Urban network to the MIKE 11 river branches. Most links were set to 'MIKE Urban Outlet to Mike 11' type. Five links were set to 'MIKE 11 water level boundary' where a river branch flows into the MIKE Urban. The exponential smoothing factor for River/Urban links were set to 0.4 as MIKE FLOOD user manual suggest a factor between 0.2 to 0.4 for links with initial unstable behaviour.

5 Model Stability Status

This section outlines the stability status of the HDM Halswell model. It provides the stability standard methodology, information on the tools, and the model stability status to date.

Here instability is identified/defined by 'oscillations' in the water level results. An oscillation is calculated to be the smaller of the level changes either side of a local extreme point. For example, if the water level in a manhole jumps up by 20mm in a timestep then down by 25mm in the next, the oscillation recorded for that manhole is 20mm. The max oscillation is the largest such event during the simulation.

5.1 Stability Standard

5.1.1 Stability standard methodology summary

Stability assessments were done in batches that include several events of different ARIs and durations. The 1D and 2D results were analysed and stability was improved to meet agreed standards.

The stabilization process is outlined below.

a. 1D results

For 1D results, the following methodology is to be used:

1. 1D results (MIKE URBAN or MIKE 11) are to be loaded into MIKE view excluding the first 25%.
2. Water level oscillations are to be evaluated within the 1D results file using the MIKE View oscillation tool. The tool is discussed further in Section 5.1.1b (MIKE View oscillation tool). The following process is to be applied:
 - i. All sites with oscillation amplitude greater than 150 mm tabulated and their locations are to be mapped (shapefile).
 - ii. All sites' max oscillation are to be calculated in the XLS and tabulated.
 - iii. All MU sites in this set are to have their associated M21 time series results extracted from the cell above the node. If the node was not coupled, the lowest coupled cell; or if there was any MIKE Urban-MIKE 21 coupling (using "Data Extraction FM" tool with a list of named x-y coordinates) are also to be plotted.
3. Work to reduce instabilities is then to proceed as follows:
 - i. For oscillations between 150mm to 300mm, typically a "do nothing" approach is to be taken and are to be reported except for any MIKE Urban sites where the associated MIKE 21 levels show level oscillations greater than 100mm. For the MIKE Urban sites where the associated MIKE 21 level shows oscillations greater than 100mm, one attempt to fix them is to be taken and the sites are to be reported thereafter whatever the outcome.
 - ii. For oscillations larger than 300mm, an initial attempt to fix them is to be taken. If not solved initially, typically a "do nothing" approach is to be taken and they are to be reported, except for any MIKE Urban sites where the associated MIKE 21 levels show level oscillations larger than 100mm. For these sites, a second attempt is to be taken and they are then to be reported whatever the outcome.

b. MIKE View oscillation tool

The MIKE View oscillation tool evaluates and provides a summary report on instabilities in the MIKE Urban and MIKE 11 model results. It is available under the MIKE View tools, and the stability standard settings are shown in the Table 5-1.

Table 5-1 MIKE View oscillation tools settings

Parameter	Value
Data Type	Node Level for MIKE Urban Water Level for MIKE 11
Calculation Period	All data (the first 25% was not loaded)
Option Selection	Oscillations
Limit for Number of Extremes	0
Duration of Time Interval	Default Value
Min Difference for Extremes	0.15 or 0.30 m

c. 2D results

For the 2D instability assessment, Beca developed its own analysis script, which generates outputs equivalent to those produced by the original DHI tool. The script outputs a *.csv file which contains a set of 'bins' and a corresponding count of how many cells there are whose largest oscillation falls into that bin. For example, one simulation could have 1,000,000 elements whose largest oscillation is smaller than 50 mm, 500 elements whose largest oscillation is between 50 and 100mm, and so on. The bins that are to be used as part of the stability methodology are 0 mm to 50 mm, 50 mm to 150 mm, 150 mm to 300 mm, 300 mm to 500 mm, 500 mm to 1 m, 1 m to 2 m, and 2 m to 5 m. Additionally, the script produces a combined shapefile that shows, for each element, the maximum oscillation observed across all durations and identifies the duration in which that maximum occurred.

5.2 Existing development 2024 Stability Status

Stability testing for the HDM Halswell 2024 model was undertaken as part of the peer-review submission and repeated for the final model deliverable for the ED2024, 200-year ARI storm across all durations. No significant stability issues were identified during this process. The stability status of the Existing Development 2024 model is summarised below.

200-year ARI:

Ten MIKE Urban manholes showed maximum water-level oscillations greater than 300 mm across all durations. They account for roughly 0.4% of all manholes in the model. The locations of these manholes are shown in Figure 5-1. The different marker colours represent oscillations across the various storm durations.

In all cases, the oscillations observed in MIKE Urban did not correspond to water-level fluctuations greater than 50 mm in the MIKE-21 results, nor were any significant oscillations present in MIKE-11. This confirms that the observed MIKE Urban fluctuations are confined to the element-level numerical solution and do not affect overall model behaviour or flood results.

Consequently, these manholes are not considered indicators of model instability.

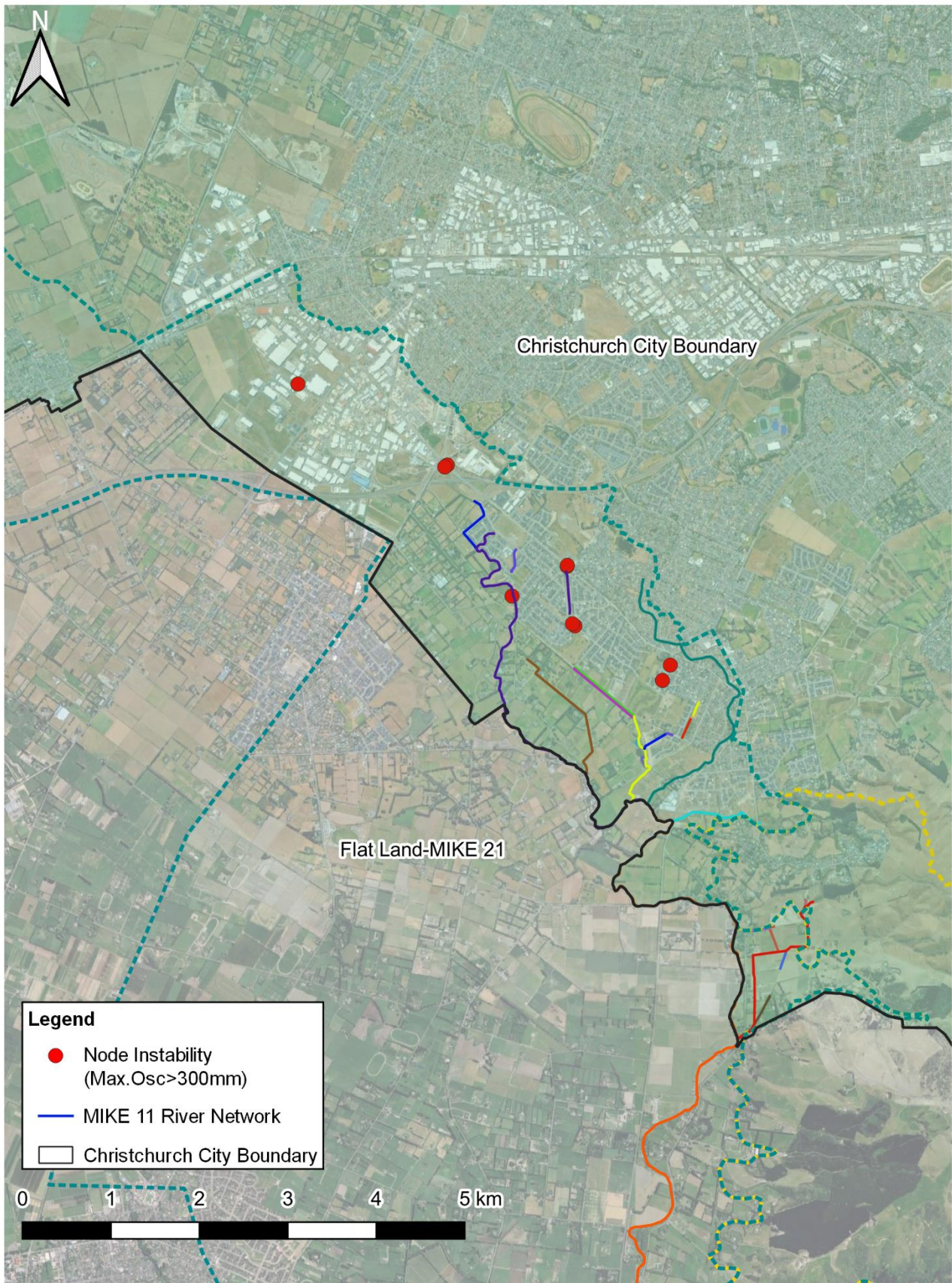


Figure 5-1 MIKE Urban manholes showing water level oscillations (>300 mm) during 200-year ARI simulations (for all durations); *Image source: Map data © 2025 Google*

6 Model Calibration

6.1 Introduction

Following the severe flooding from 29th April to 2nd May 2025, CCC requested Beca to compile rainfall, GIS, and hydrometric data from the May 2025 event and calibrate the RORB and MIKE models before proceeding with design runs. This report sets out the observed data for the event that has been collected from various sources and compares the results of the calibration runs to relevant observed data.

6.1.1 Calibration approach

Model calibration was carried out using the Existing Development 2025 model as the base. Calibration was undertaken using aerial flood extent photographs taken on 2nd May 2025 (ECan) and water level/flow data from key sites, including Halswell Junction Basin, Cox-Quaifes Basin, Nottingham Stream at Nicholls Road, Knight Stream at Sabys Road, and Halswell River at Ryans Road Bridge, as outlined in section 6.2.3 and 6.2.4 respectively.

6.2 Available data summary

Rainfall data for the 29th April to 2nd May 2025 event was collected and analysed from both rain radar and gauge sources. Further details are provided in the following sections.

6.2.1 Rainfall radar

Gauge corrected radar rainfall data for the calibration event was obtained from MetService, with total depths ranging from 65 to 340 mm. Refer to Figure 6-1 for spatial distribution.

6.2.2 Rainfall gauges

Gauge rainfall data for the 29th April to 2nd May event was sourced from NIWA, with data from 29 stations used for spatial extrapolation. Total rainfall depths ranged from 66 to 196 mm. Interpolation was performed using the natural neighbour method, and data was converted to MIKE *.dfs2 format for model input. Gauge locations are shown in Figure 6-2.

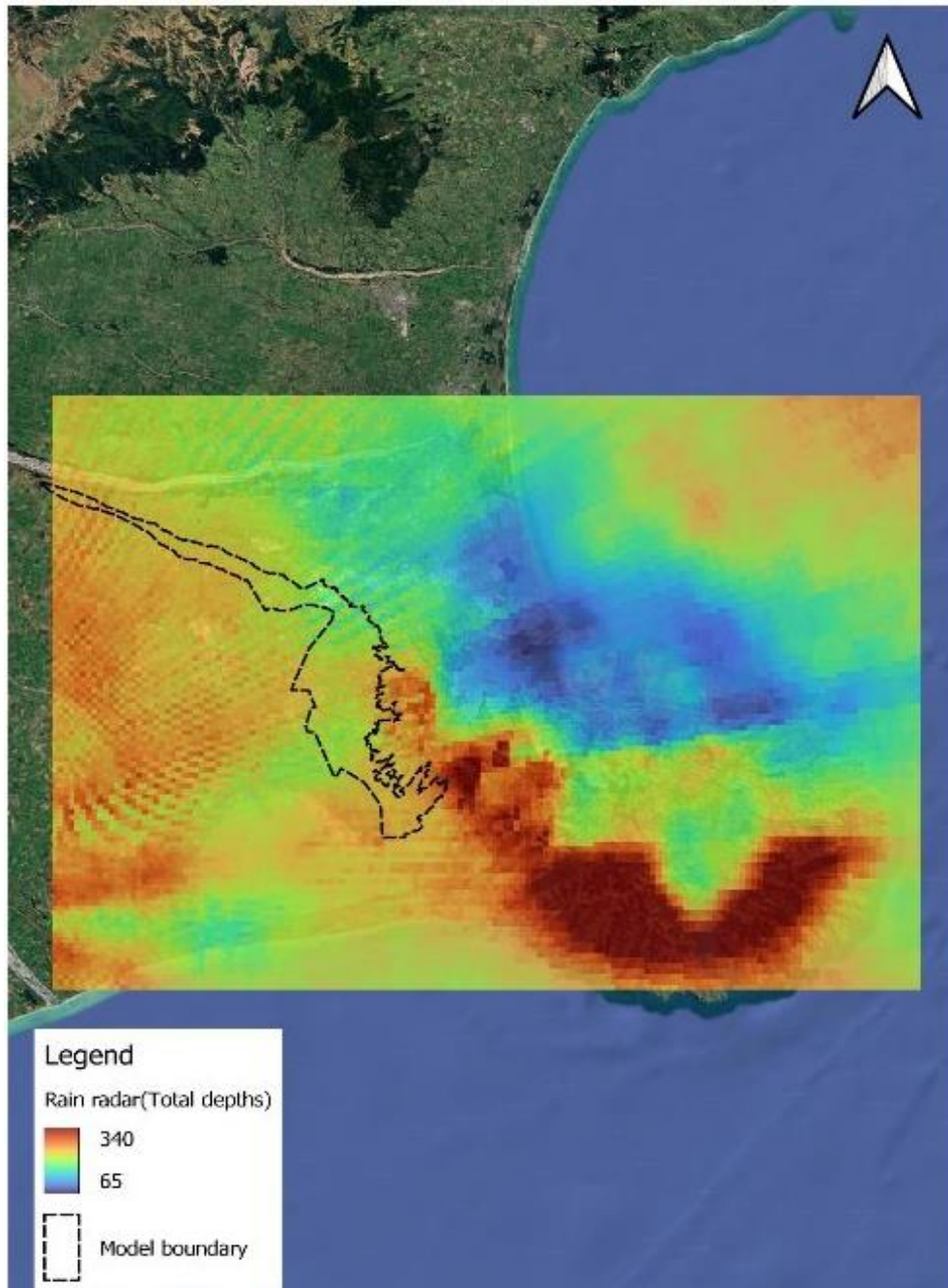


Figure 6-1 Halswell radar rainfall. *Image source: Map data © 2025 Google*

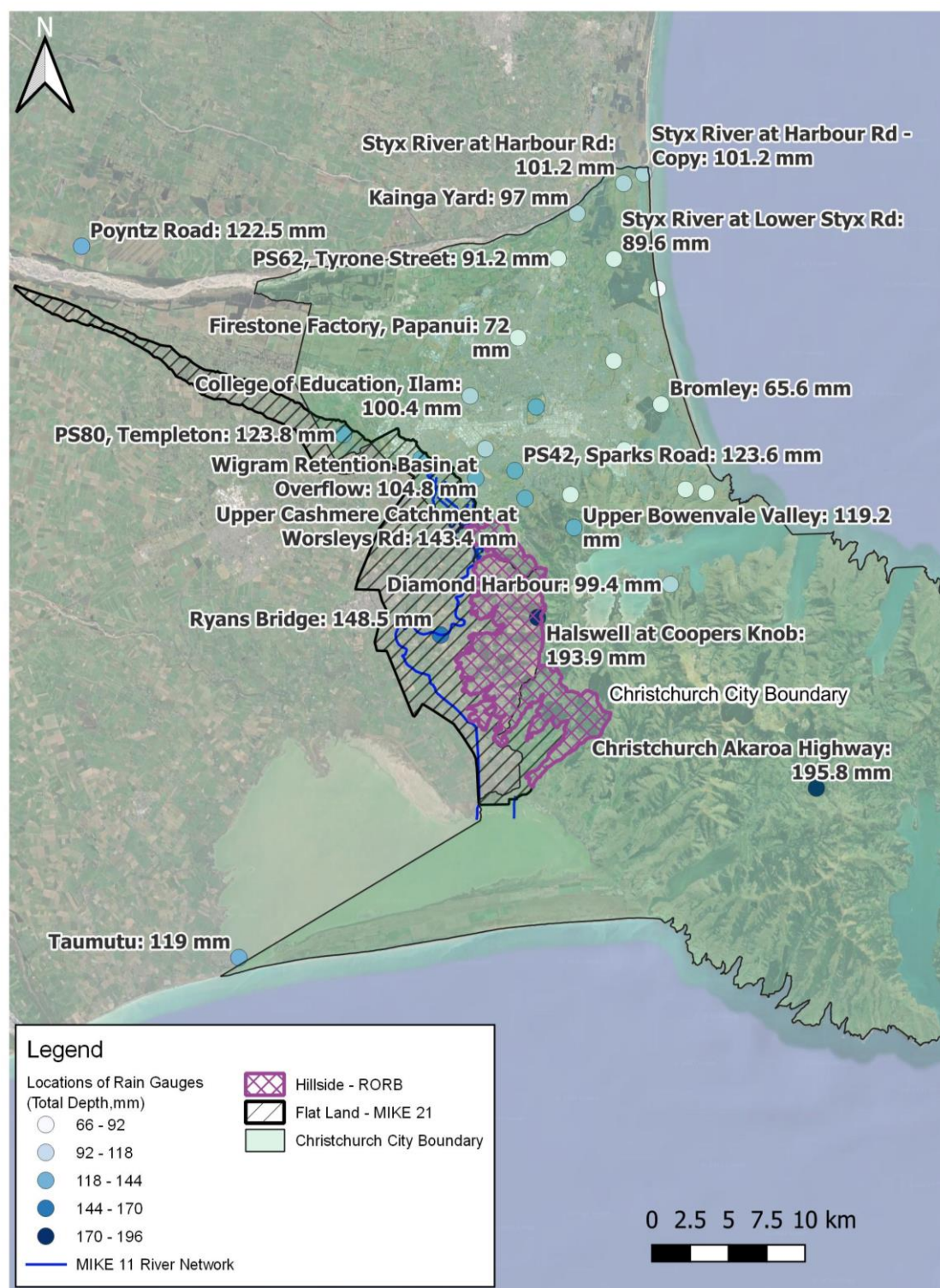


Figure 6-2 Halswell gauge rainfall. Image source: Map data © 2025 Google

Table 6-1 summarises the locations and total rainfall depths of gauges used for calibration, highlighting higher rainfall in the southern and eastern areas of the model boundary.

Comparison of radar and gauge data shows significant differences, with radar consistently reporting 20% to 143% higher values than gauges at the same locations. Smaller differences (36%–49%) were observed for gauges within or near the Halswell catchment (see Figure 6-3). For this reason, gauged rainfall data was used for detailed model comparisons of water levels, discharge, and flood extent.

Table 6-1 Total rainfall depths recorded at calibration gauges.

Name	NZTM X	NZTM Y	Event Total depth (mm)
College of Education, Ilam	1564991.734	5181017.509	100.4
Styx River at Harbour Rd	1575010.672	5194753.504	101.2
Styx River at Harbour Rd - Copy	1576317	5195370	101.2
Wigram Retention Basin at Overflow	1565988.351	5177602.55	104.8
Christchurch Botanical Gardens	1569301.465	5180310.747	118.6
Taumutu	1549900.787	5144720.496	119.0
Upper Bowenvale Valley	1571775.255	5172517.636	119.2
Poyntz Road	1539628.116	5190695.111	122.5
PS42, Sparks Road	1567911.712	5176191.866	123.6
PS80, Templeton	1556726.597	5178519.739	123.8
Ridgens Road	1527199.45	5171236.962	124.0
Halswell Retention Basin, Halswell Junction	1561782.175	5176944.542	133.4
Aidanfield, Dunbars Reservoir	1565361.363	5175695.403	136.6
Upper Cashmere Catchment at Worsleys Rd	1568585	5174400	143.4
Ryans Bridge	1563064.349	5165567.238	148.5
Halswell at Coopers Knob	1569396.691	5166696.504	193.9
Christchurch Akaroa Highway	1587593.916	5155674.363	195.8
Bromley	1577451.726	5180480.075	66
Van Asch St, Sumner	1580405.81	5174773.404	67
Avon River at PS205	1574368.146	5183289.061	72
Firestone Factory, Papanui	1568122.705	5184786.344	72
Bowenvale Flume at Bowenvale Ave	1571548.292	5174633.743	79
Reservoir No.4, Clifton Tce	1579050.445	5174982.102	80
Tunnel Road, Heathcote	1575055.286	5177522.288	87
Styx River at Lower Styx Rd	1574378.683	5189873.025	90
Styx River at Lower Styx Rd - Copy	1577247	5187946	90
PS62, Tyrone Street	1570731.119	5189902.934	91
Kainga Yard	1571973.37	5192819.284	97
Diamond Harbour	1578065.163	5168838.483	99

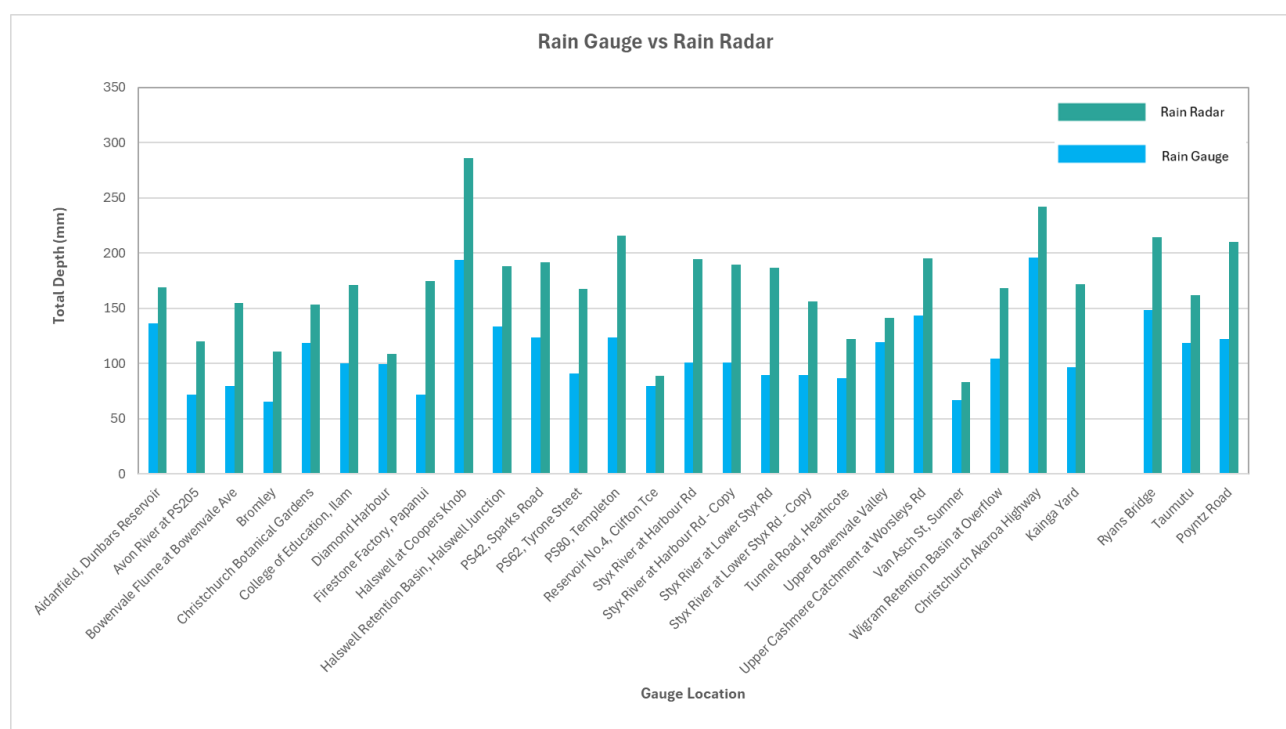


Figure 6-3 Comparison of total rainfall depths between radar and gauge data.

6.2.3 Level gauges

Eight water level stations are available within the model boundary: five in basins (one at Halswell Junction Basin and four in Cox-Quaifes Basin—including three within the basin and one at the outfall culvert); and three in drains (Knights Stream at Sabys Road, Nottingham Stream at Nicholls Road, and Halswell River at Ryans Bridge, 11 km from Halswell).

Water level data for the 29th April-2nd May 2025 event was sourced from Christchurch City Council and ECan for model calibration. For Cox-Quaifes Basin, only two stations were selected to validate simulated levels. Station locations are shown in Figure 6-4 and maximum recorded stages are summarised in Table 6-2

Table 6-2 Recorded maximum stage at water level gauging sites.

Sensor location for water level	Source	Event Max stage (m)
Halswell Retention Basin	CCC	23.107
Nottingham@Nicholls Rd 20001AC5	CCC	13.964
CQ 1st Flush LS1-R 20000F75	CCC	12.395
CQ Detention LS1-R 20001028	CCC	12.391
CQ Wetland LS1-R 200010B8	CCC	11.879
CQ Culvert LS1-R 200010CC	CCC	11.781
Knight Stream at Sabys Rd	CCC	11.273
Ryans Bridge	ECan	6.457

The cross-section at a stream recording site (Knights Stream and Ryans Bridge) can have an effect on the water level recorded. The model relies on LiDAR derived cross-sections at the Ryans Bridge site and surveyed cross sections in Knights Stream at Sabys Rd

6.2.4 Flow gauges

There are two flow gauges in the Halswell area that record both flow and level: Knights Stream at Sabys Road and Halswell River at Ryans Bridge (approximately 11 km from Halswell, with a catchment area of ~76 km²). The Sabys Road gauge, installed after the 2013 event, is near the city boundary and well placed for assessing upper catchment flows although noting that the catchment has very little development at this stage and is mostly pasture. Observed flows from these stations were used for calibration. Gauge locations are shown in Figure 6-4 with maximum event flows summarised in Table 6-3.

Table 6-3 Recorded maximum flows at gauging sites.

Sensor Location for Discharge	Source	Event Max Flow (m ³ /s)
Knight Stream at Sabys Rd	CCC	1.45
Ryans Bridge	ECan	12.633

Both the Knights Stream and Ryan Rd Bridge sites record water level only, the flow comes from a rating to convert water level to flow based on manual flow gaugings. Often there is less confidence in rating (i.e., the flows predicted from the water level) at higher flows as there tend to be less manual gaugings at high flows.

6.2.5 Aerial Photos

Aerial photography supplied by ECan was used to validate the 2D flood extent, with coverage mainly focused south of Halswell and limited imagery in the upper catchment (only two photos within the Christchurch City Boundary). The model extends to Te Waihora/Lake Ellesmere but includes limited detail in the lower reaches, where farm drains and minor culverts (e.g., Dawsons Creek) are not represented. Not all flooded areas may have been captured due to limitations in aerial coverage. Model results were compared with ECan photos at matching timestamps (2/5/2025 8:40 AM), as outlined in Section 0.

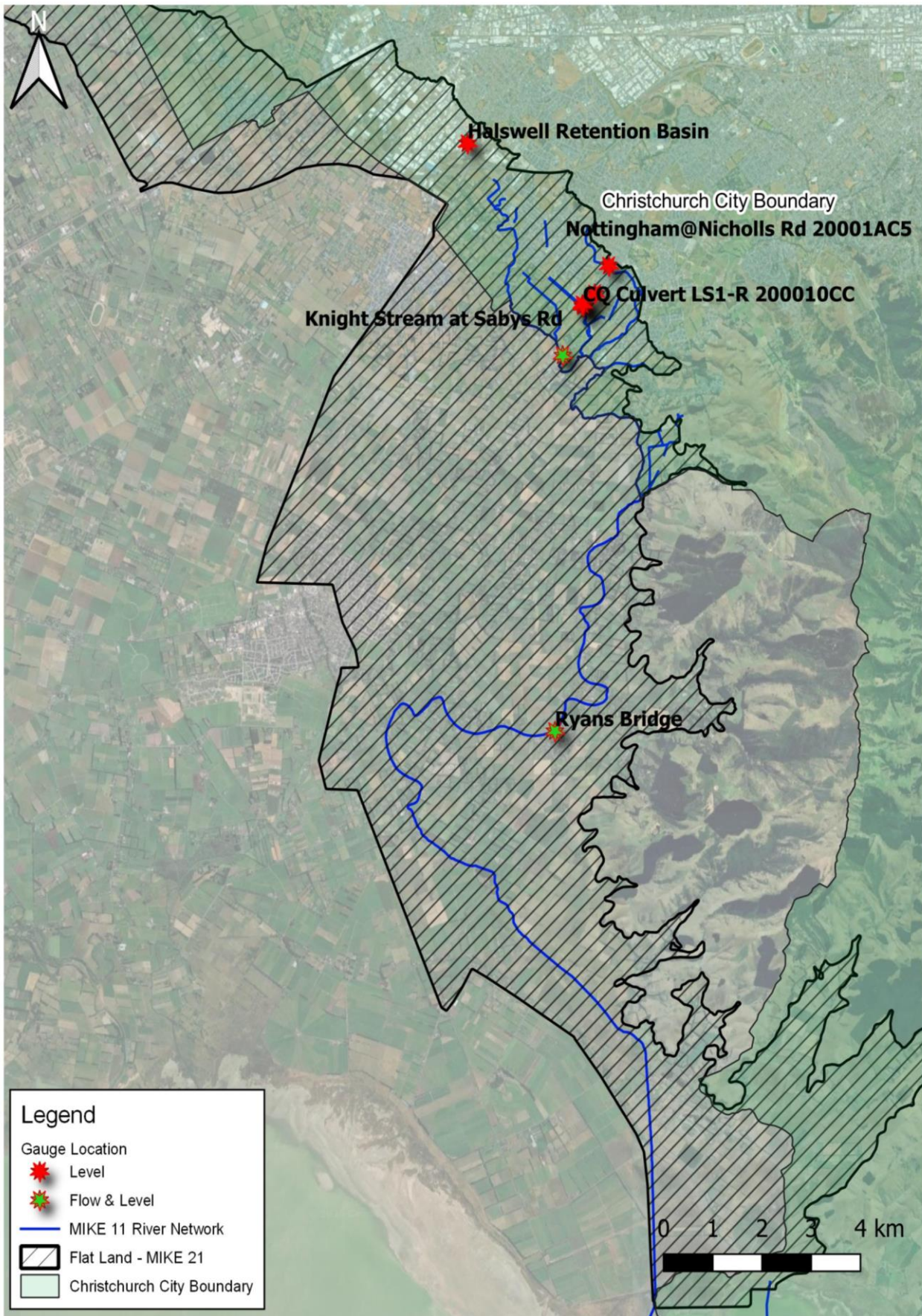


Figure 6-4 Gauging stations location. Image source: Map data © 2025 Google

6.3 29 April – 2 May 2025 Calibration Run

6.3.1 Model geometry changes

No adjustments were made to the model geometry (pipes, elevation model, boundary delineation, etc.)

6.3.2 Boundary Conditions

The RORB model was updated with event rain gauge data to provide flow boundary inputs to MIKE at the Port Hills side. The MIKE coupled model used the April–May, 2025 rainfall file as a boundary, with all other parameters unchanged for baseline comparison. Hydrology (infiltration rates) is based on calibrated variables from the Heathcote model.

6.4 Results

6.4.1 Peak flows and levels at different stations

Table 6-4 summarises calibration results against observed data.

Table 6-4 Recorded maximum flows and water levels at gauging sites.

Location	Peak flows (m ³ /s)			Time at Peak diff. (hour)	Peak WSE (m)		
	Modelled	Gauged	Difference		Modelled	Gauged	Difference(mm)
Halswell Junction Basin	-	NA	-	-	23.09	23.11	-20
Nottingham@Nicholls Rd 20001AC5	-	NA	-	-	13.98	13.96	20
CQ Detention LS1-R 20001028	-	NA	-	-	12.42	12.39	28
CQ Culvert LS1-R 200010CC	-	NA	-	-	11.83	11.78	50
Knight Stream at Sabys Rd	2.98	1.89	58%	3.9	11.56	11.27	290
Halswell River at Ryans Bridge	16.86	12.63	33%	7.05	6.50	6.46	44

Water level comparison at Halswell Junction Basin shows good alignment in peak timing and levels, with a difference of only ~20 mm. The 1D model indicates rapid basin filling and emptying, possibly due to inlet/outlet setup. Differences in initial water levels are due to 2D initial condition issues in the baseline run (see Figure 6-5).

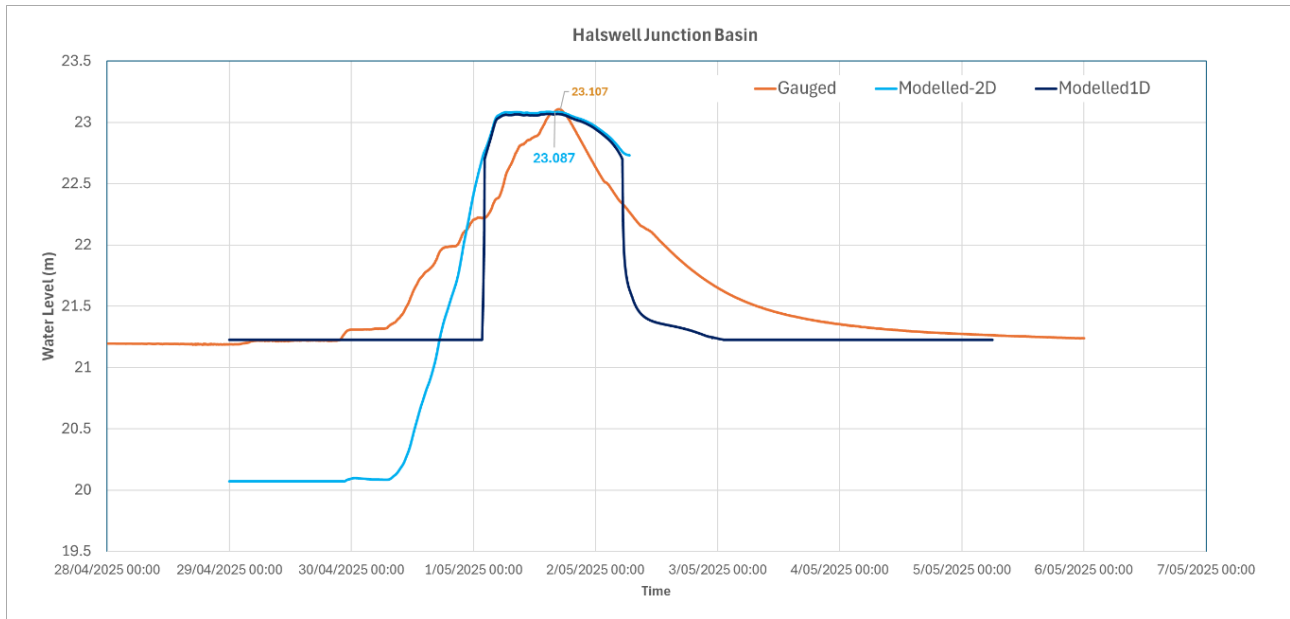


Figure 6-5 Water Level comparison at Halswell Junction Basin

The Nottingham Stream site shows modelled and observed water levels to have good agreement in both shape and timing, capturing multiple peaks effectively. The timing alignment suggests accurate catchment response and flow routing. The high-water levels observed on the rising limb could be attributed to inaccuracies in spatial and temporal rainfall averaging-potentially causing overestimation when interpolating or a cross-section difference. This is shown in Figure 6-6.

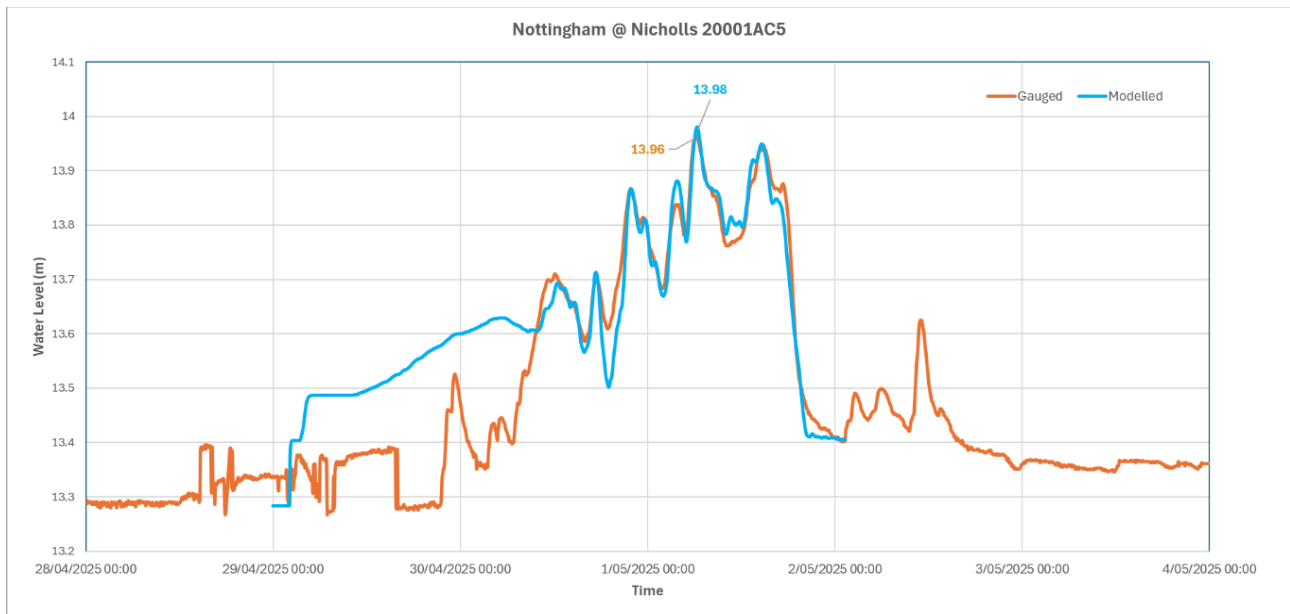


Figure 6-6 Water Level comparison at Nottingham stream at Nicholls Road

Water levels at Cox-Quaifes Detention Basin align well in shape and peak timing, indicating realistic basin operation in the model. However, the model slightly overestimates the volume entering the basin. This is shown in Figure 6-7.

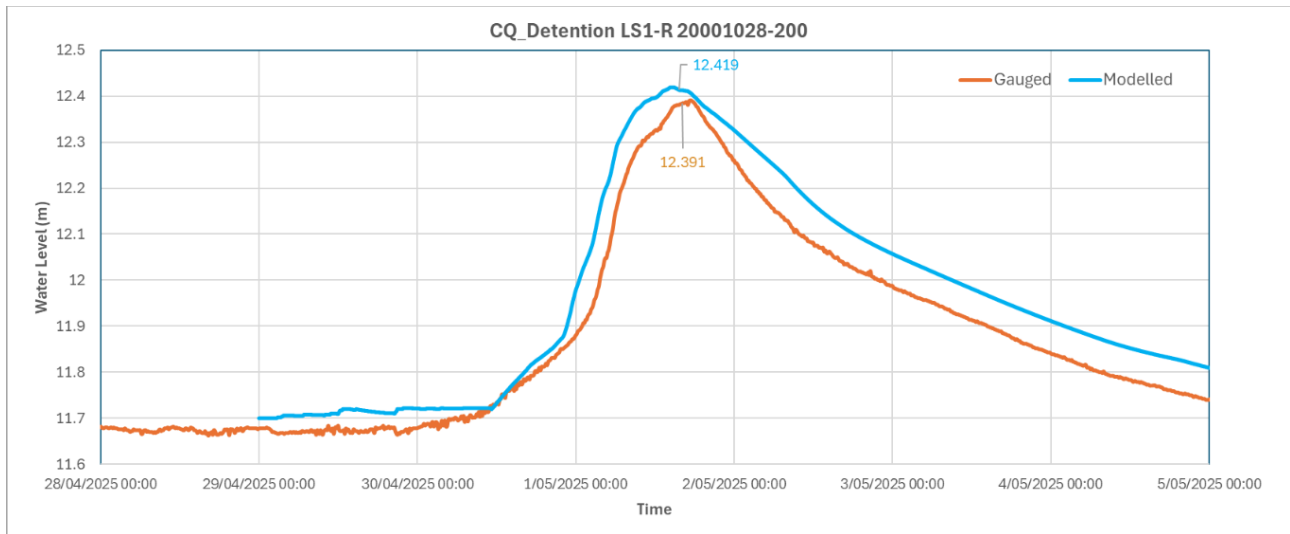


Figure 6-7 Water Level comparison at Cox-Quaifes Detention

Water level comparison at Cox-Quaifes outfall culvert shows good alignment in shape and peak timing. Differences in starting levels may be due to cross-section changes following channel works for the new culvert. As shown in Figure 6 8

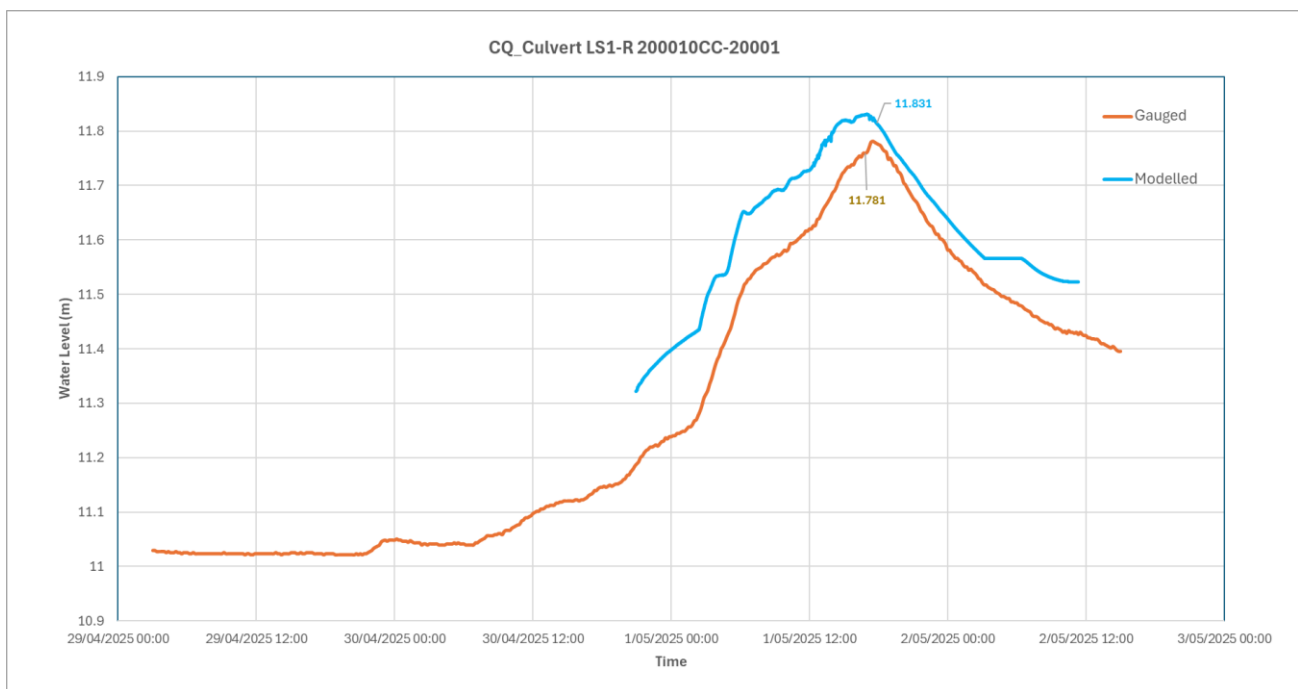


Figure 6-8 Water Level comparison at Cox-Quaifes Culvert

Water level comparison (Figure 6-9) at Knight Stream at Sabys Road shows modelled water level is a similar match to observed records in shape, but peak values are higher. This may be due to outdated cross-sections, increased vegetation, or backwater effects not reflected in the current model.

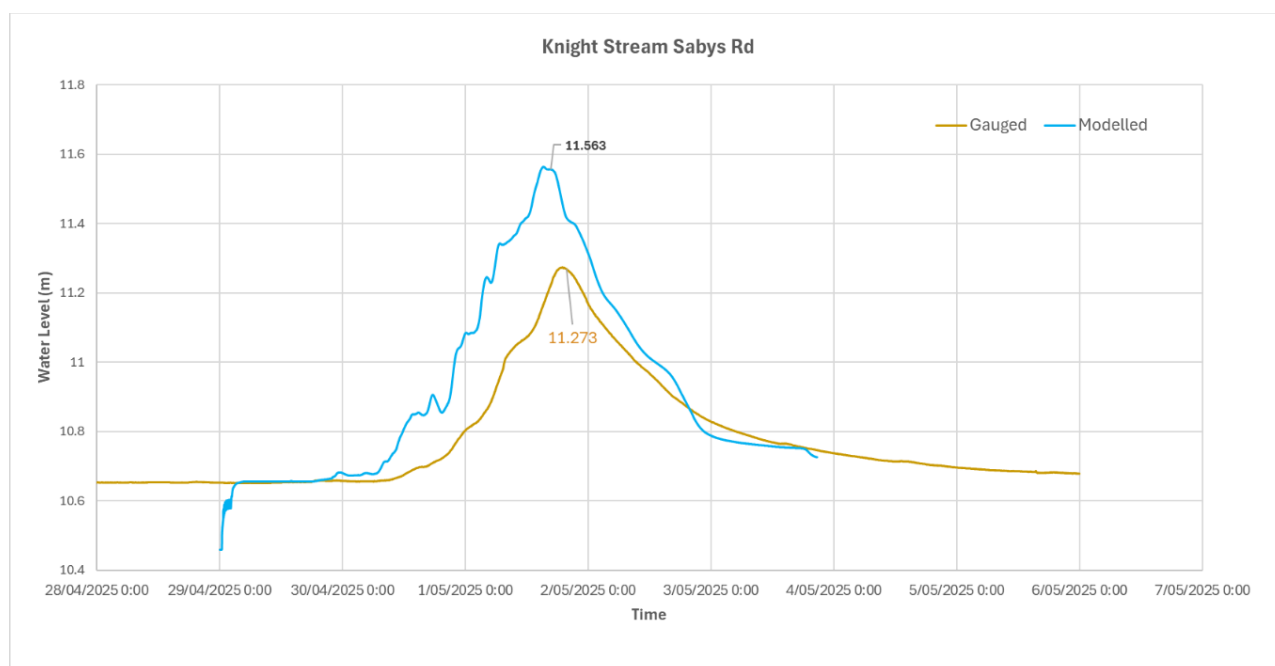


Figure 6-9 Water Level comparison at Knight stream at Sabys Road

Peak flow data was missing at Knight Stream, Sabys Road during the event. The peak was estimated by extrapolating the rating curve and back-calculating from observed water levels. The modelled peak flow is approximately 58% higher than the estimated observed value. This is shown in Figure 6-10.

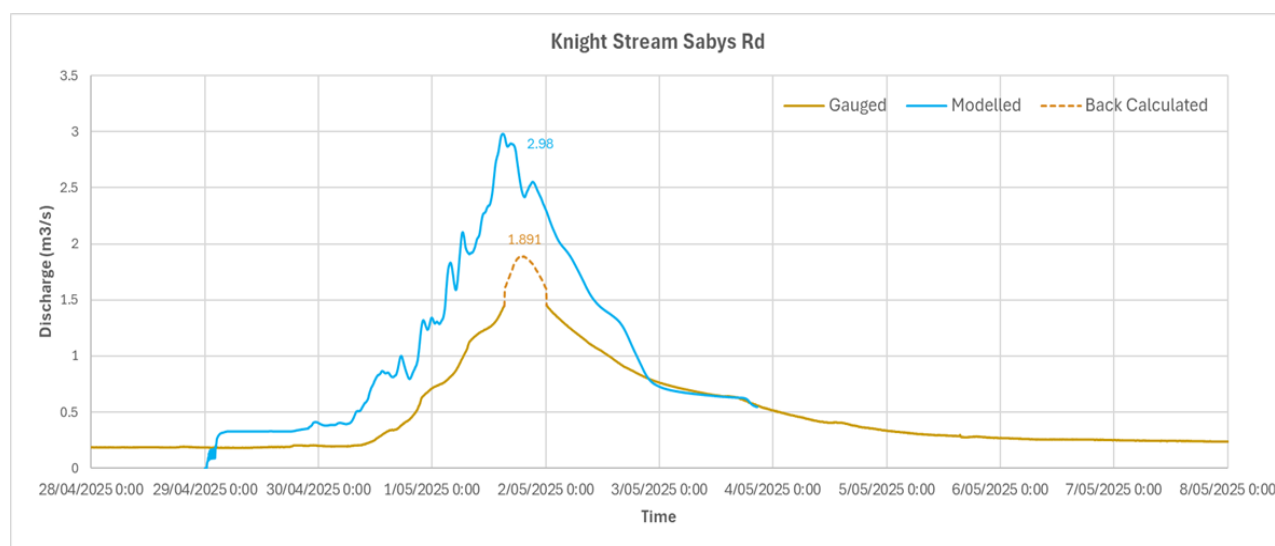


Figure 6-10 Flow comparison at Knight stream at Sabys Road

Water level comparison at Ryans Bridge (Figure 6-11) shows similar peak values, but overall shapes do not match well. The rural catchment response appears to be slower than modelled especially in the falling limb. This is likely due to hydrological factors such as soil water release which is not included in the model hydrological method.

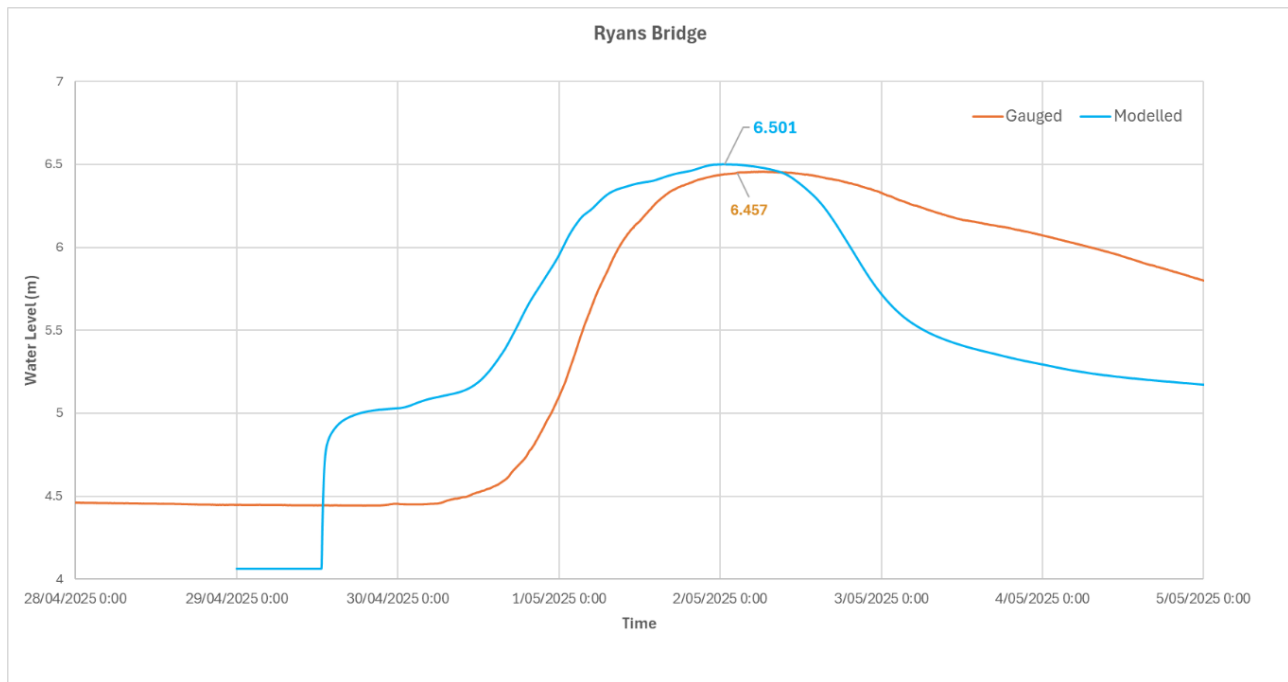


Figure 6-11 Water Level comparison in Halswell River at Ryans Bridge

Comparing flow at Ryans Bridge (Figure 6-12) shows the modelled peak is about 33% higher than observed. Peak water levels are similar, but peak flows differ, likely due to rating curve and cross-section differences.

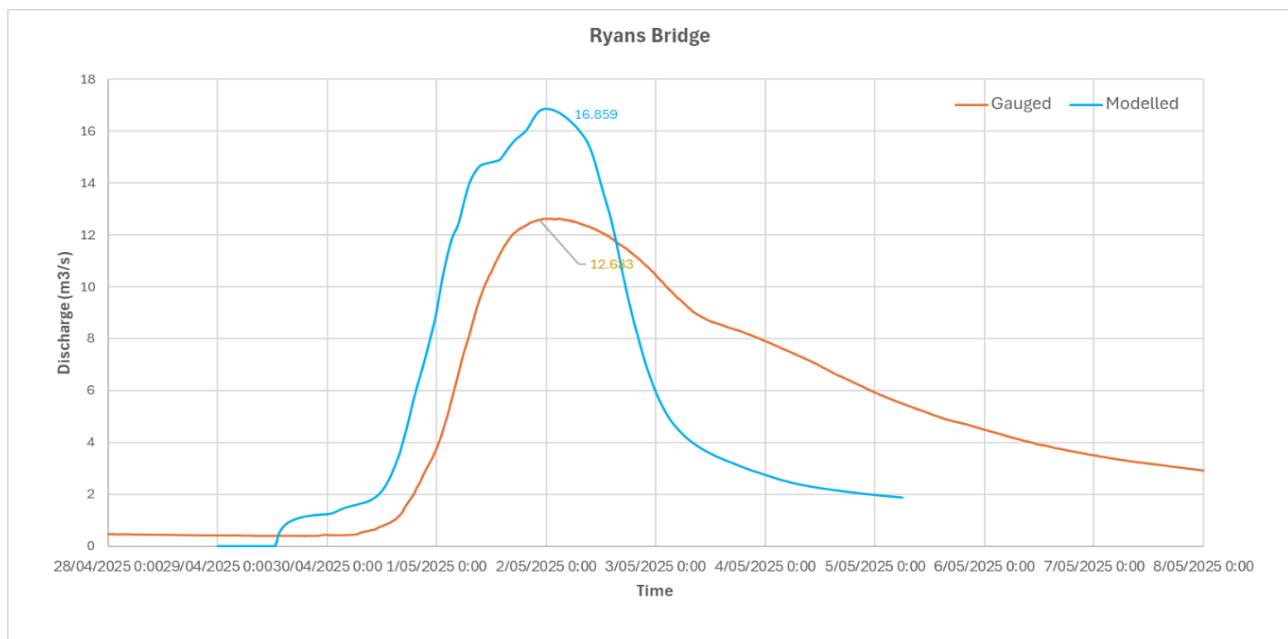


Figure 6-12 Flow comparison at Ryans Bridge

Conclusion Comparison of Aerial Photos with Modelled Flood Extent Figure 6-13 to 6-16 compare modelled maximum flood extent with aerial photos from the May 2025 event. At a catchment scale, the model shows more inundation than the aerials. As the river is modelled in 1D, comparisons focus on the floodplain. The difference in water depth varies across the lower catchment but it generally appears to be 100-150 mm in most places but up to 500 mm in isolated areas. A comparison in knight Stream Subdivision within the city boundary, shows a similar flood extent, with more water (~100 mm) shown in Ella Park and Murphys Drainage reserve, as seen in the flood photos. Flood map and aerial photo comparisons are shown below;

additional comparisons for the lower catchment are provided in the calibration report, which is appended to this document as Appendix F.



Figure 6-13 Flood photo at Murphys Drainage Reserve (Source: ECan) *Image source: Map data © 2025 Google*



Figure 6-14 Modelled flood depth at Murphys Drainage Reserve *Image source: Map data © 2025 Google*



Figure 6-15 Flood photo at Ella Park(Source: ECan). Image source: Map data © 2025 Google

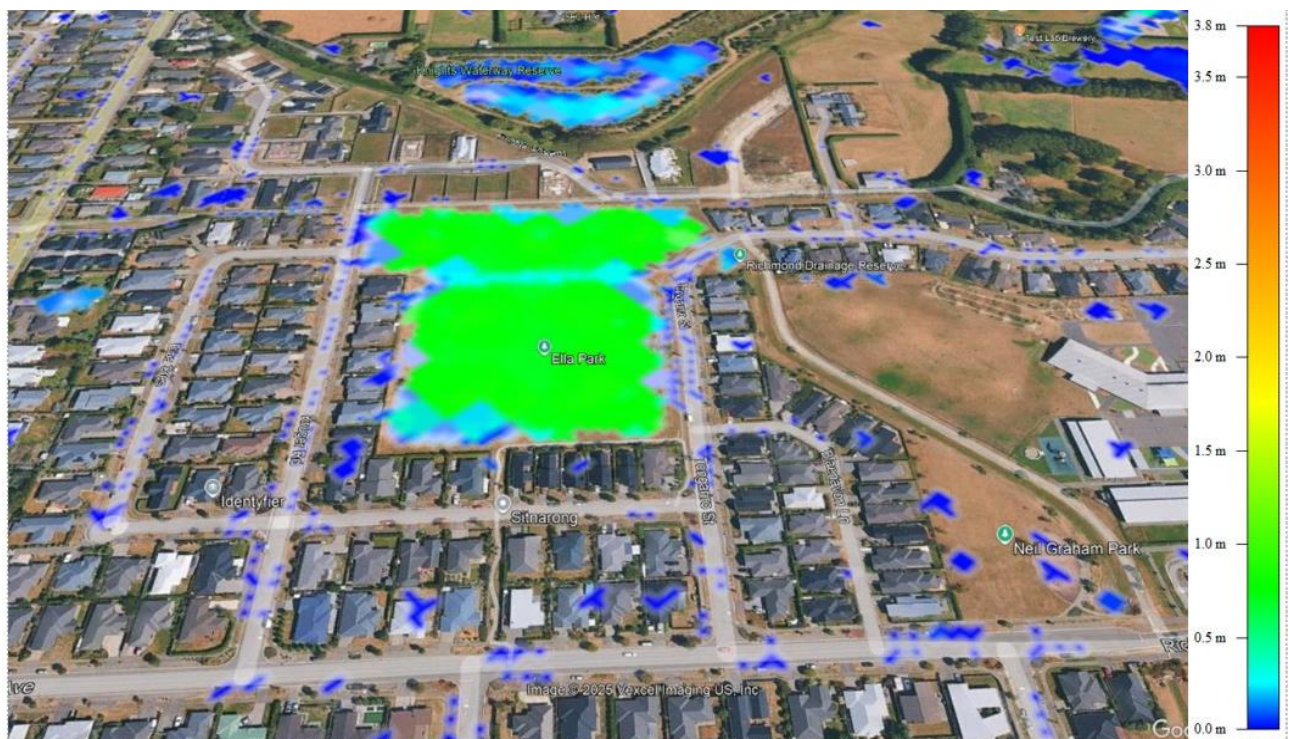


Figure 6-16 Modelled flood depth at Ella Park. Image source: Map data © 2025 Google

6.4.2 Calibration Conclusion

Based on the available calibration data it appears the model predicts more runoff than was observed, especially in rural areas. Water levels in some city basins and channels (like Nottingham Stream) match well, but modelled flows at gauging sites are usually higher than recorded. This could be due to outdated channel data, debris, or rating curve issues.

At Sabys Road bridge, the recorder missed the peak flow, but the back-calculated peak is lower than the simulated. This may be because rural areas respond slower to rainfall than the model predicts.

Aerial photo comparisons show the model predicts more flooding in rural areas than observed. Urban areas match better, but limited photos in the upper catchment make validation difficult.

Calibration shows infiltration rates may be too low and/or groundwater depths too high in the model, which matches peer review advice.

The lack of alignment with the recorded data could be due to:

- Missing rural drainage: The model does not represent small local drains or culverts in rural areas, which may restrict runoff from entering the Halswell River.
- Gauge recorder: The Sabys Road recorder did not capture the peak flow; although the peak was back-calculated, it is not a recorded value, so a direct comparison with reality is not possible.
- Limitations of photo extents: Most photos are for the lower catchment, with only two for the upper area within Christchurch city boundary. It is difficult to determine flood extent from these photos, so only qualitative comparison is possible and using them for direct peak water level comparison is beyond their accuracy.
- The hydrological loss method can't represent the slow response that is seen in the lower catchment.

The peer review recommended a sensitivity test be undertaken to understand how the catchment responds to changes in infiltration rates and ground water level. This is outlined in the following section.

7 Model Sensitivity

7.1 Approach

Following the conclusions from model calibration, the sensitivity checks were determined to be:

- Increasing infiltration rates by 50%
- Reducing the groundwater level by 300 mm

7.1.1 Infiltration

As recommended by the peer reviewer, infiltration rates were increased by 50% as tabulated in Table 7-1. The inlet structure at Halswell Junction Basin was also modified in line with the Christchurch City Council's design memo.

Table 7-1 Infiltration rates used in sensitivity testing

Parameter	Infiltration(mm/hr)	Infiltration increased by 50%
Very Poorly Drained	2.8	4.2
Poorly Drained	3.6	5.4
Imperfectly Drained	5	7.5

7.1.2 Groundwater

The groundwater level was lowered by 300 mm alongside the increase in infiltration due to the design groundwater level (85th percentile level) at ground level in large areas of the lower catchment therefore the infiltration rate alone would have no effect.

The observed depth to groundwater during the April–May event, sourced from ECan, has been compared with the modelled groundwater depth. It shows that the model generally uses higher groundwater levels than those observed. Figure 7-1 shows the monitoring station names along with both observed and modelled groundwater depths in metres. The observed data appears to vary more across the lower catchment than the modelled data.

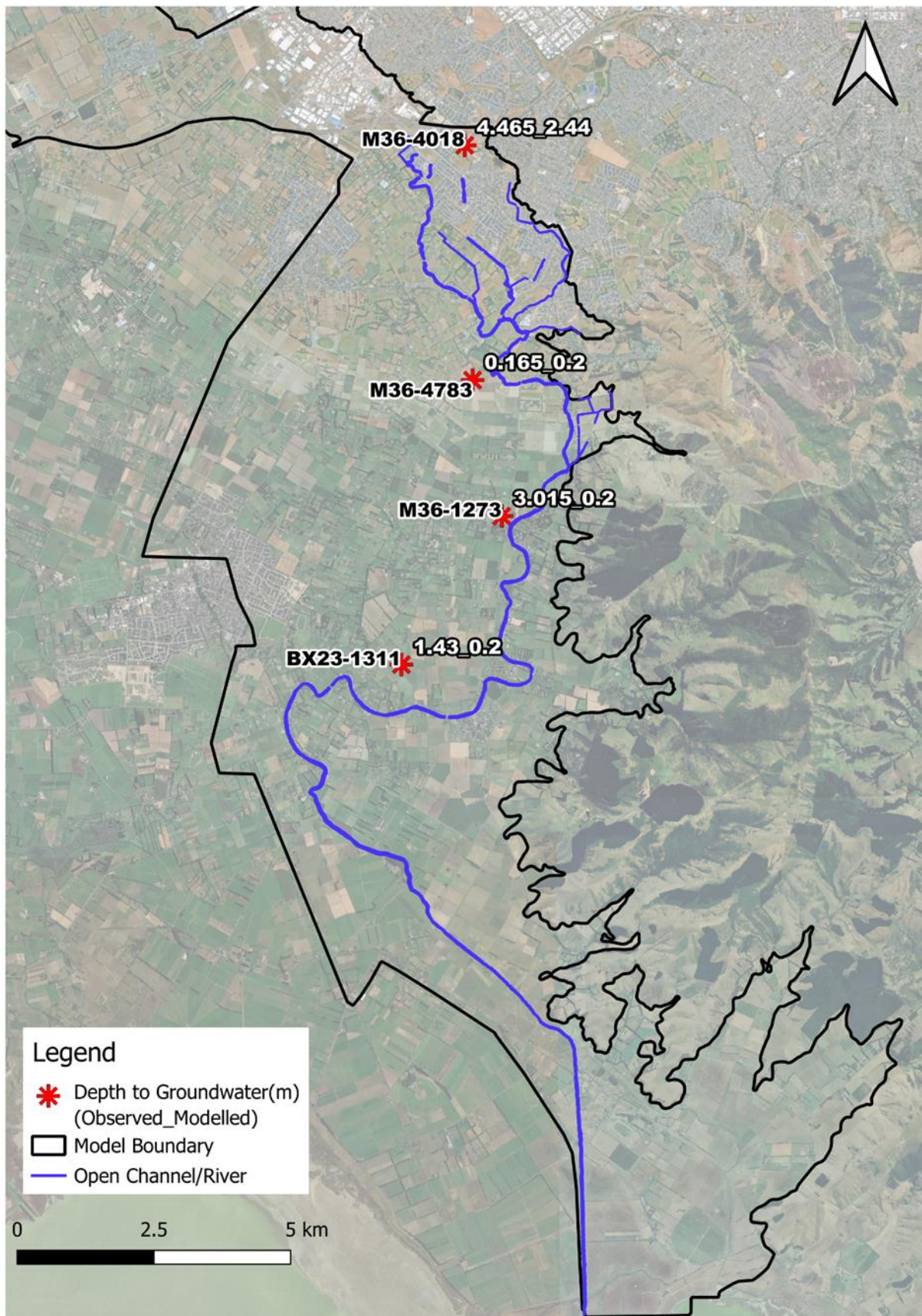


Figure 7-1 Comparison of observed and modelled groundwater depths at monitoring stations (Source: ECan). *Image source: Map data © 2025 Google*

7.2 Results

7.2.1 Infiltration adjustment

Increasing infiltration by 50% and increasing depth to groundwater by 300 mm leads to smaller water level changes in the upper Halswell River catchment and larger changes in the lower reaches compared to baseline model. This comparison is shown in Figure 7-2 to Figure 7-9.

Halswell Junction Basin

The basin outlet structures have been updated according to the design memo (Halswell Junction Road Basin Outlet Improvement Initiation Memo by Victor Wong, dated 13 Dec 2017) from the CCC, and the downstream network arrangement has been checked against the CSM as-built drawings. Results show that the peak water level and the shape at the top of the hydrograph remain largely unchanged. However, the receding limb now responds more closely to observed data, with increased volume in the basin. The rising limb indicates the effect of the higher initial infiltration, but as the basin fills, more volume accumulates. This could highlight that the model has more impervious surface within the upstream catchment. Overall, there is little change in peak water level (see Figure 7-2) due to the change in variables.

Nottingham Stream

The calibrated peak water level matches the modelled water level on both the rising and falling limbs of the hydrograph, but the calibrated peak is 45 mm lower than the baseline model (see Figure 7-3).

Cox Quaifes Detention Basin and Culvert

Initially, water infiltrates and lowers the water level compared to the modelled results, but the basin gradually fills. There is no difference in peak water level, but the recession limb shows a decrease in water level. At the culvert location, the calibrated peak is reduced by 66mm compared to the modelled result. This means the sensitivity result is 16mm lower when compared to the observed value, while the hydrograph shape closely matches the observed data (see Figure 7-4 and Figure 7-5).

Knight Stream at Sabys Road

The calibrated water level is 167 mm lower than the baseline model, but still 125 mm higher than the observed peak. The flow is 0.83 cumecs less than the modelled discharge (see Figure 7-6 and Figure 7-7). Therefore, the sensitivity run in is closer to the observed water level and flow.

Ryans Bridge

The calibrated water level matches the observed values, with no change in the shape of the rising and receding limbs of the hydrograph. The calibrated flow is 1.317 cumecs lower than the modelled values (see Figure 7-8 and Figure 7-9).

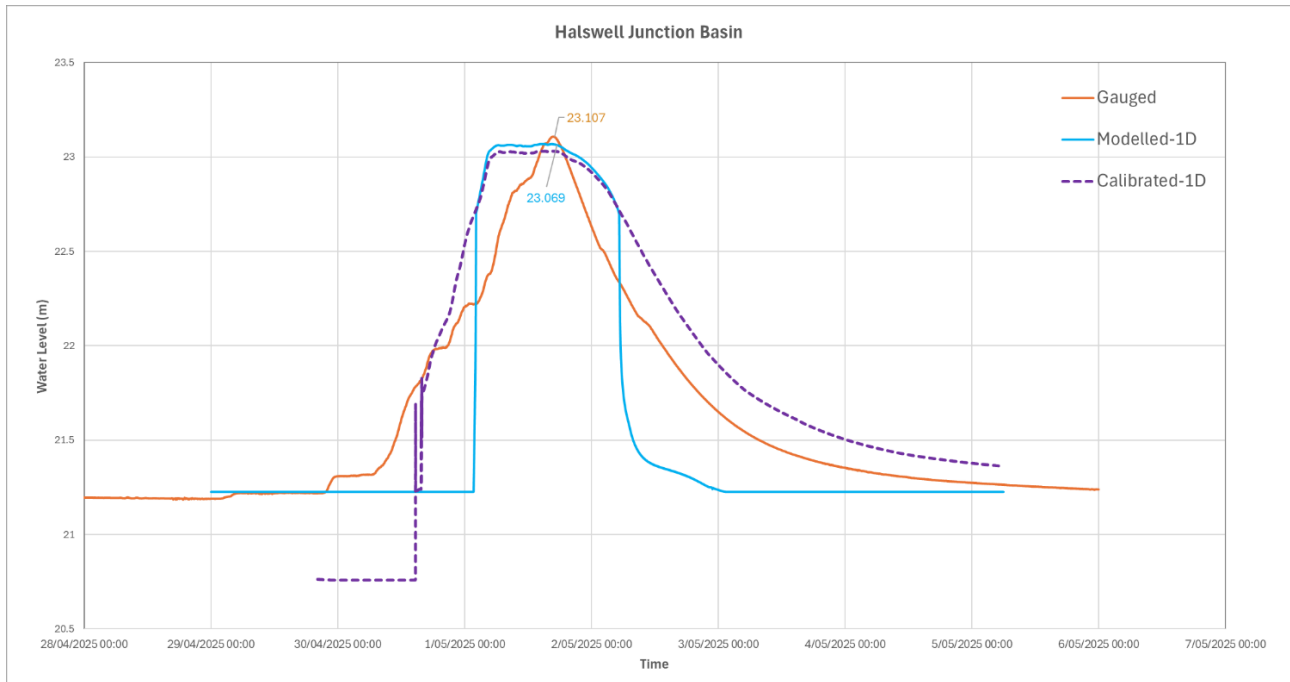


Figure 7-2 Comparison of modelled and calibrated water levels with gauged at Halswell Junction Basin

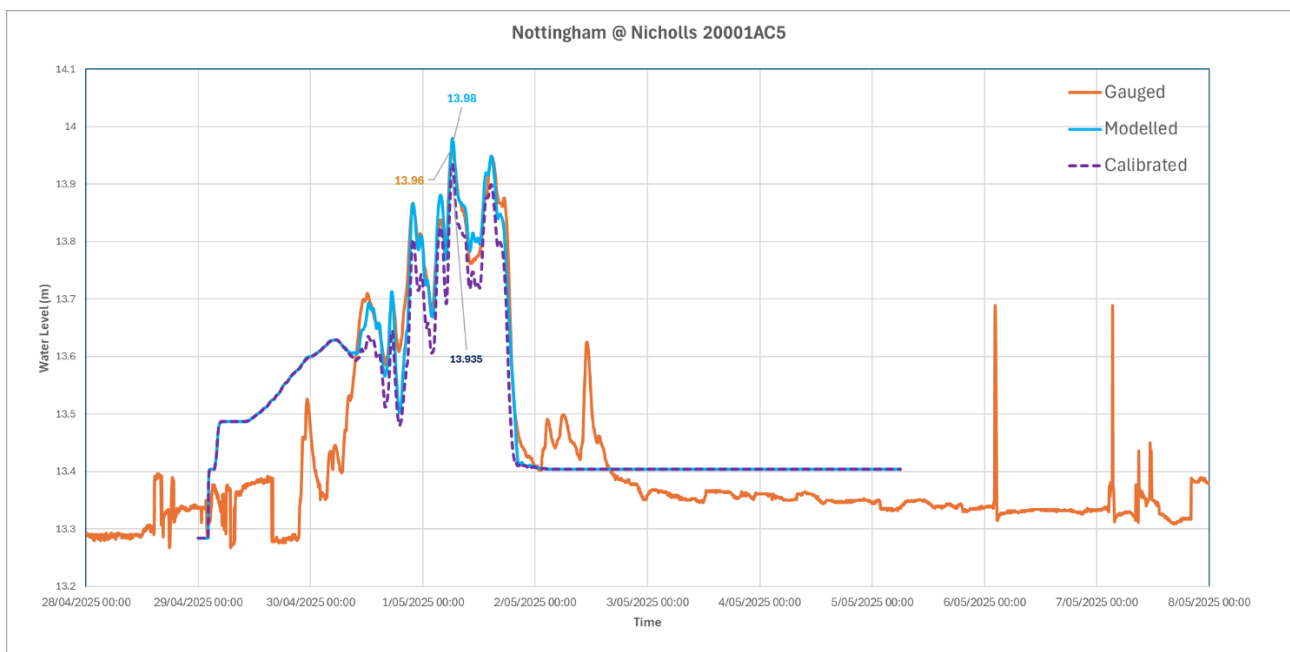


Figure 7-3 Comparison of modelled and calibrated water levels with gauged at Nottingham stream at Nicholls road

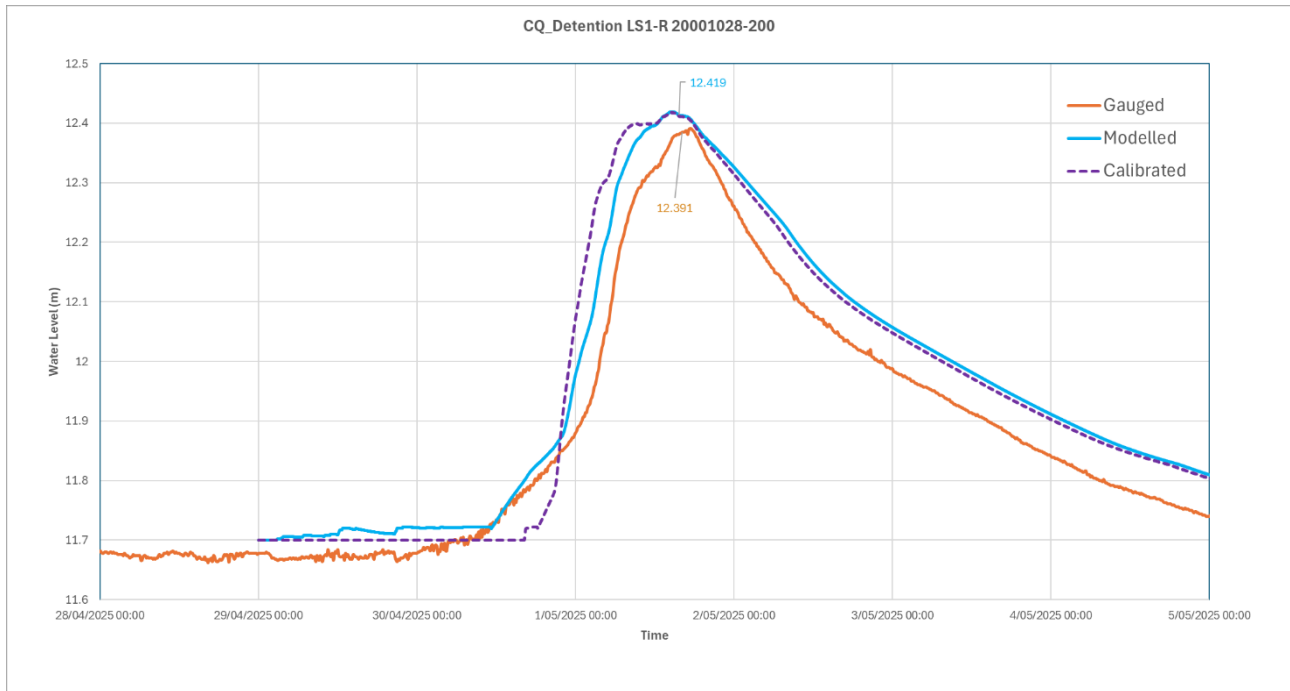


Figure 7-4 Comparison of modelled and calibrated water levels with gauged at Cox-Quaifes detention basin

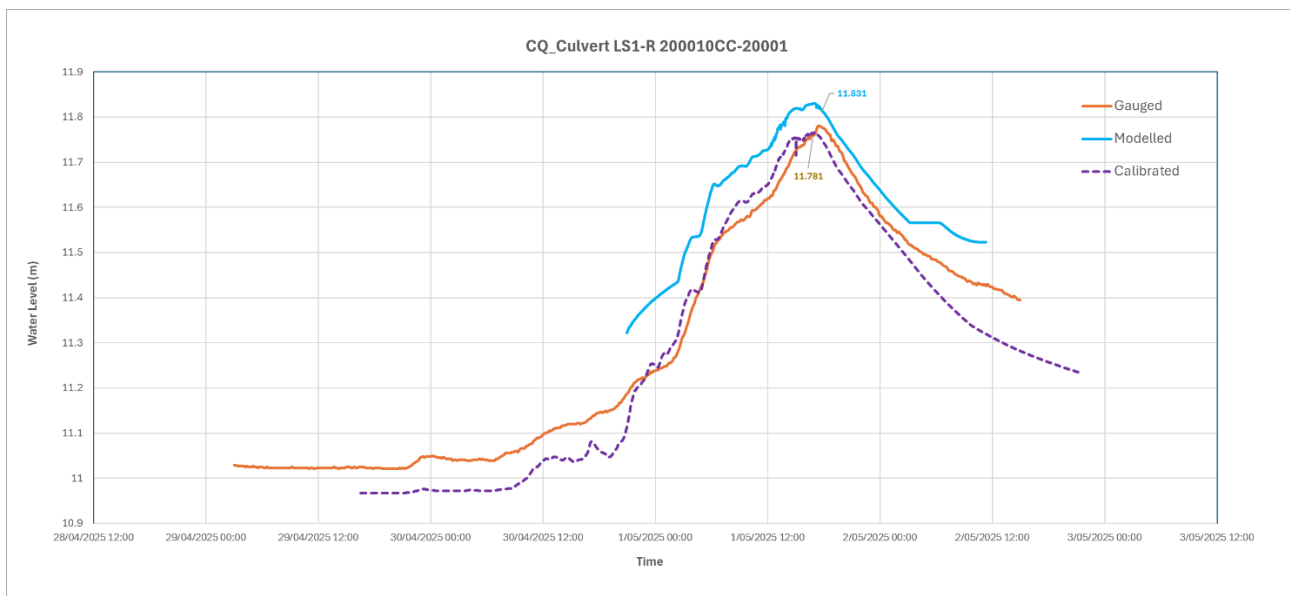


Figure 7-5 Comparison of modelled and calibrated water levels with gauged at Cox-Quaifes Culvert

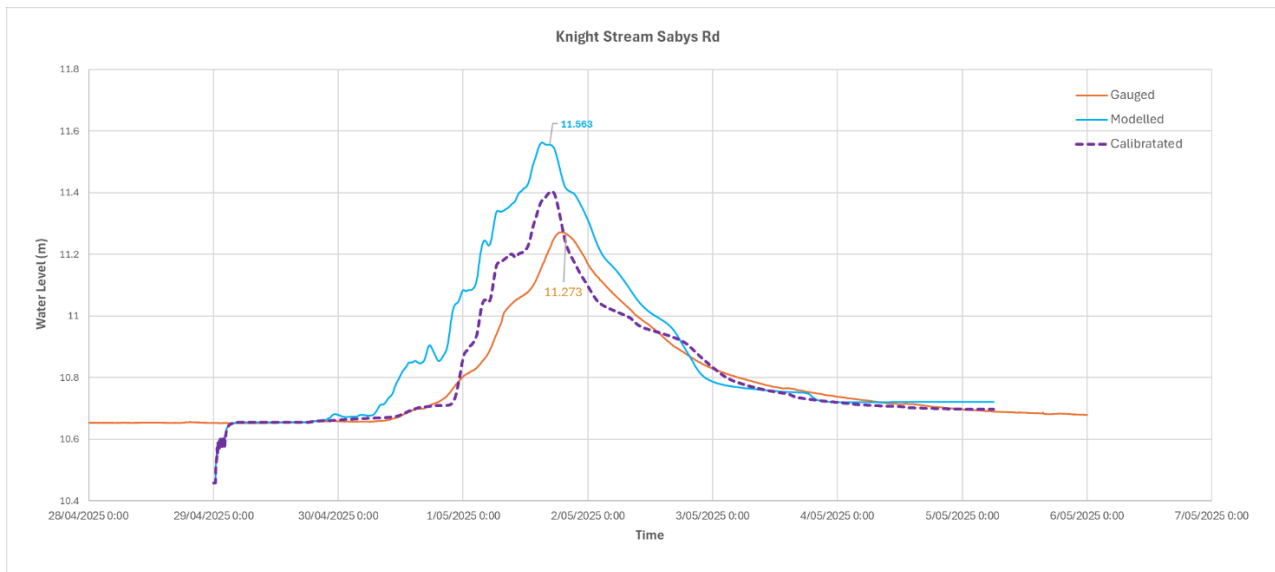


Figure 7-6 Comparison of modelled and calibrated water levels with gauged in Knight stream at Sabys Road

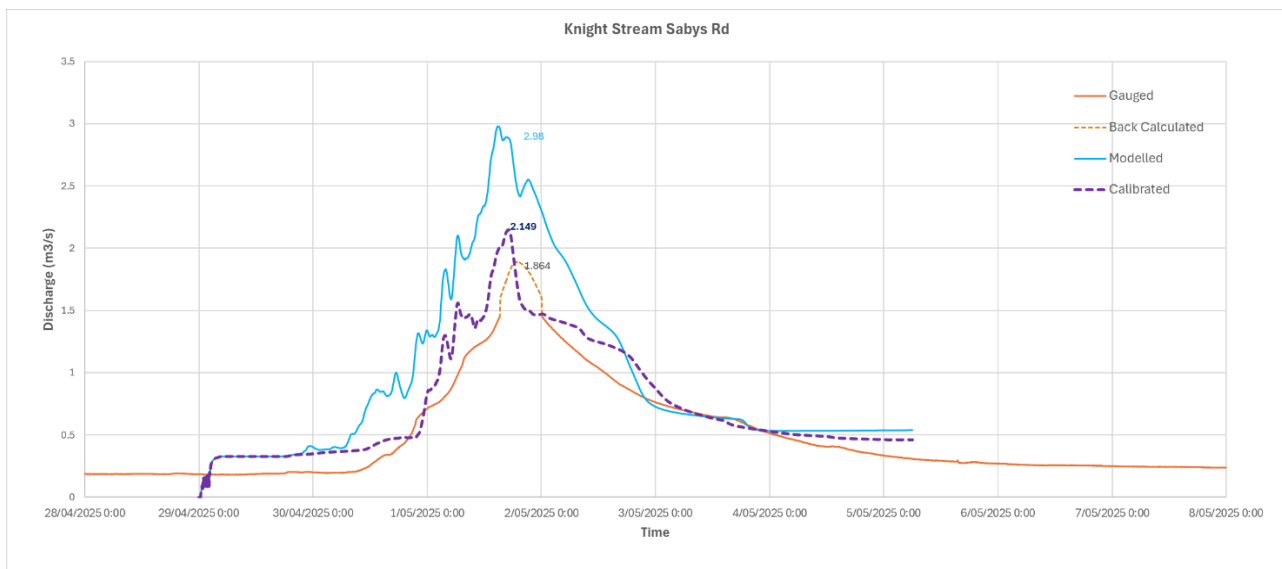


Figure 7-7 Comparison of modelled and calibrated flows with gauged in Knight Stream at Sabys Road

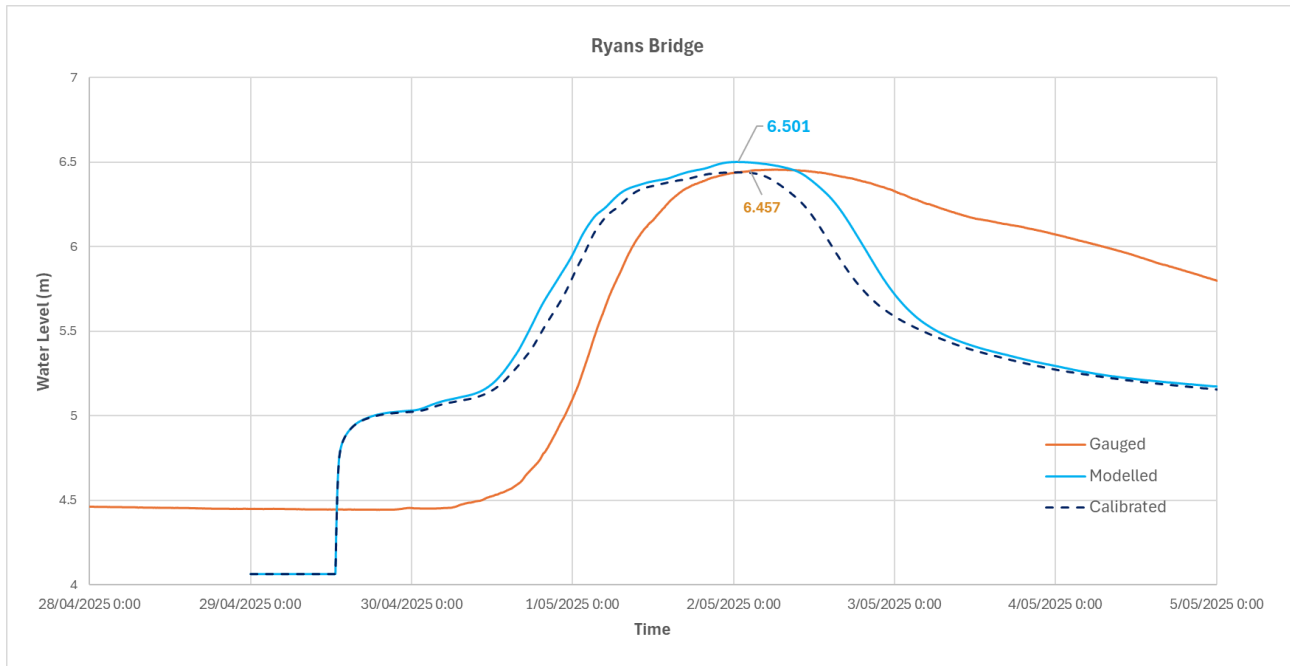


Figure 7-8 Comparison of modelled and calibrated flows with gauged in Halswell River at Ryans Bridge

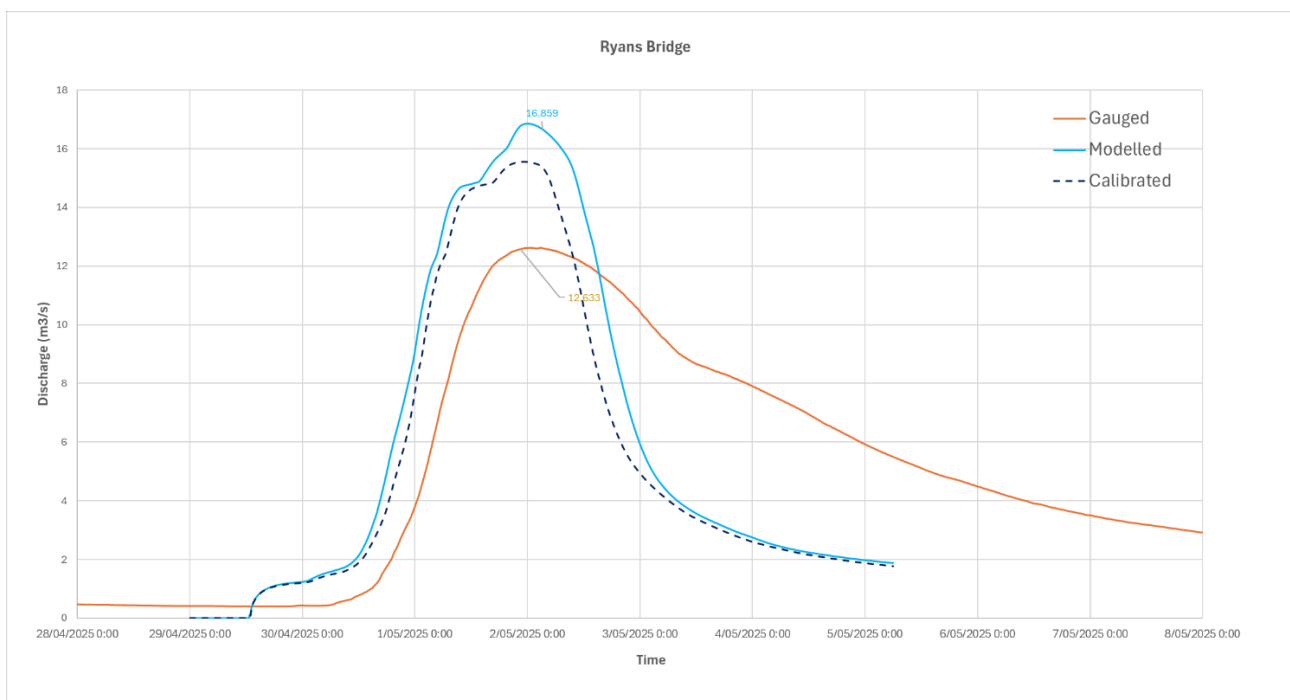


Figure 7-9 Comparison of modelled and calibrated flows with gauged in Halswell River at Ryans Bridge

When comparing the calibrated flood extent with flood photos, the results show good alignment, with a reduced water depth of 70 mm in Murphy's Drainage Reserve showing good match but an almost one-meter reduction in Ella Park Basin - suggesting that more water infiltrated in the model than in reality. The upper figures represent modelled results, while the lower figures are from calibration (see Figure 7-10). Aside from these basins and some low-lying flat areas in the upper catchment, most areas remain unaffected. However, significant changes are evident at the southernmost boundary of the model, as shown in the depth difference map in Figure 7-11. Additional flood photo comparisons related to the sensitivity run for the lower catchment are provided in detail in Appendix F.

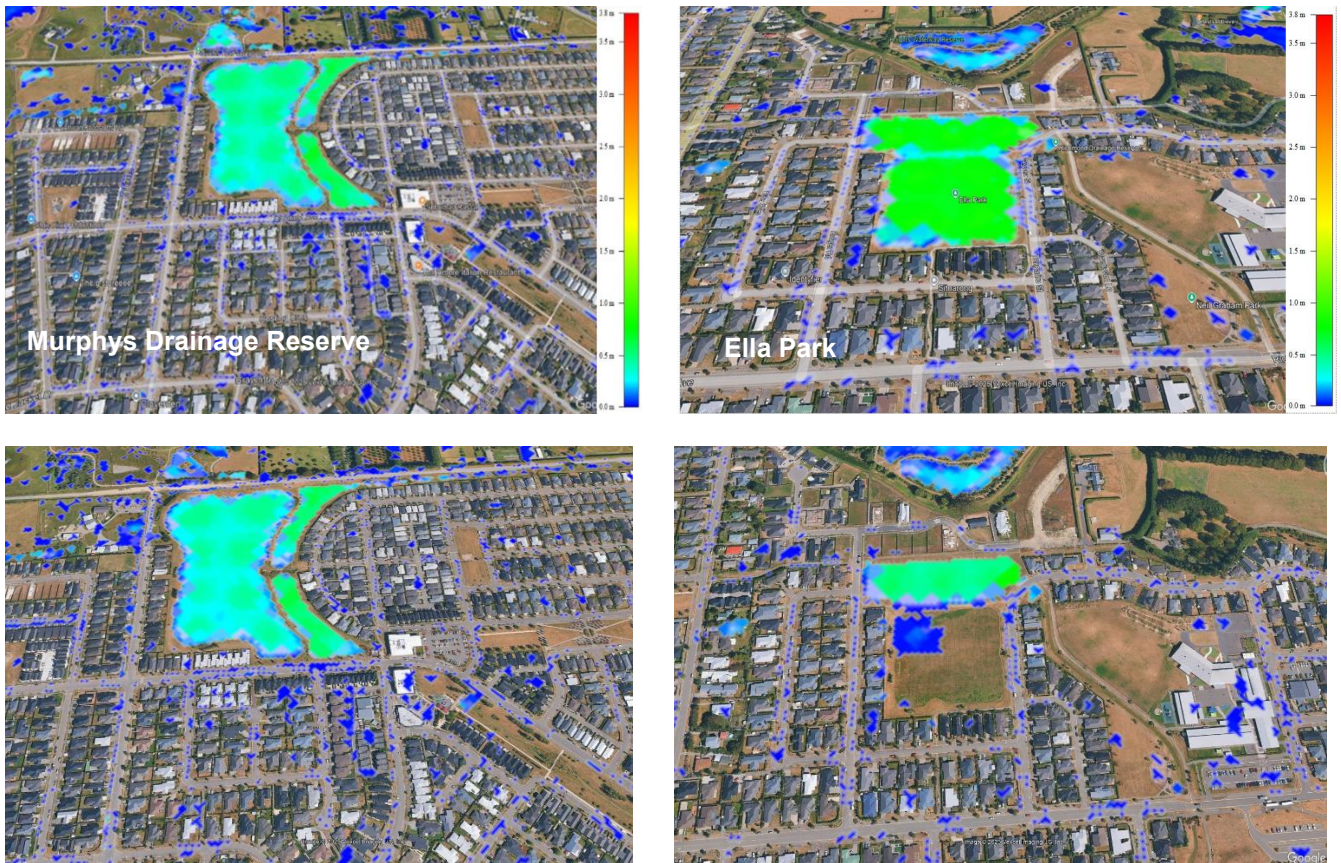


Figure 7-10 Sensitivity Flood extent comparison, top images are the base model and lower images are the sensitivity runs. Image source: Map data © 2025 Google

Comparison of the 2D surface indicates that increasing infiltration rates and lowering groundwater depth have only a minor impact in the upper catchment of the Halswell River, with more noticeable changes observed in the middle and lower catchment. In the upper catchment, basins show water depth changes ranging from 50 mm to 1000 mm (Ella Park), as illustrated in the depth difference map between the calibrated and baseline models (Figure 7-11).

Soil Storage

In the context of infiltration, saturation refers to the point at which the soil can no longer absorb additional water. Once this point is reached, any further rainfall or surface water will accumulate and potentially result in runoff. For the calibrated run, the saturation map indicates that the middle and lower catchments are fully saturated, with no remaining capacity in the subsoil—meaning all subsequent rainfall accumulates and runs off (see Figure 7-12). In contrast, the Templeton catchment area still has some available subsoil capacity, allowing for further infiltration.

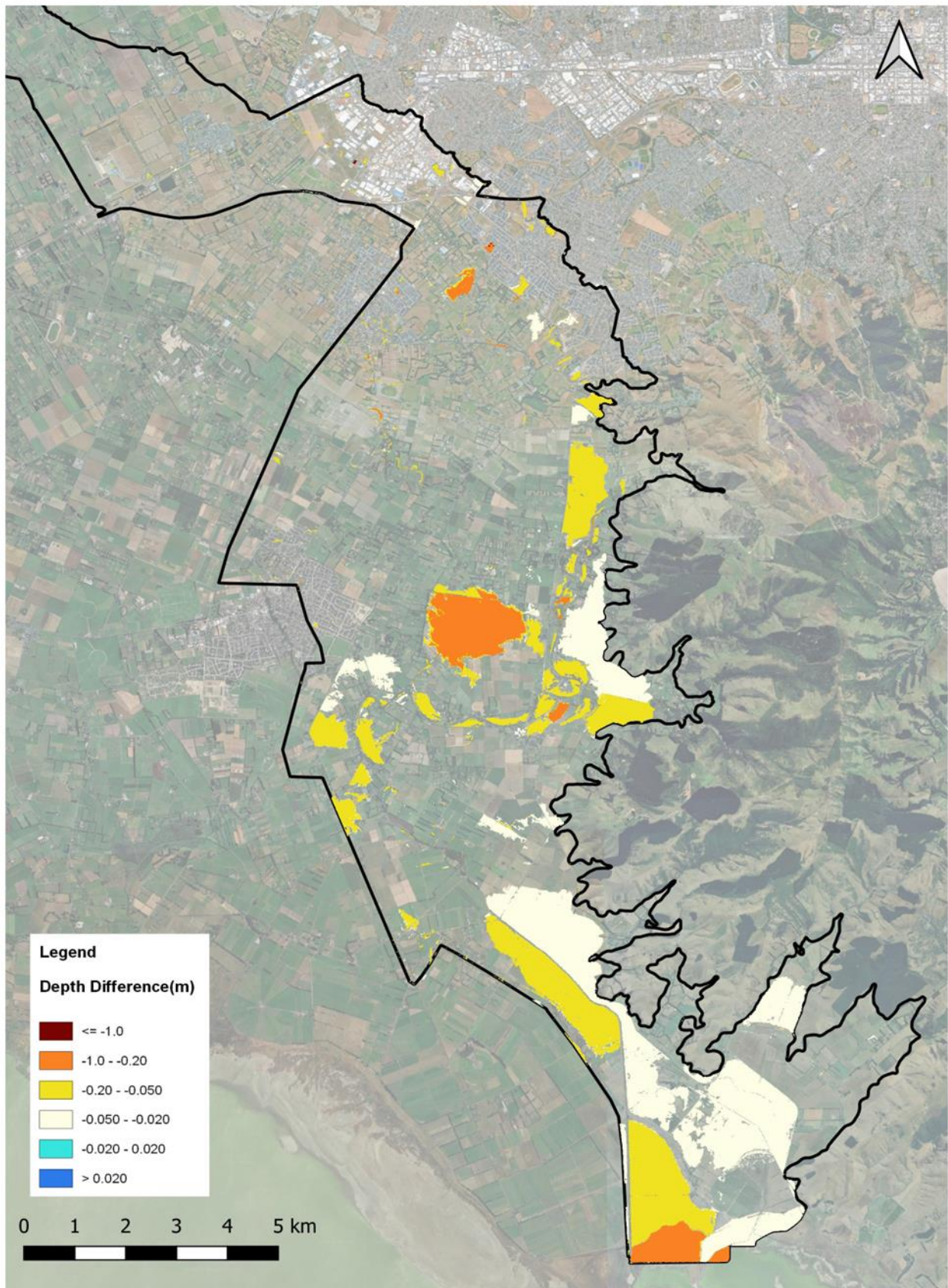


Figure 7-11 Water depth difference between sensitivity and modelled caused by changing the infiltration and groundwater depth. *Image source: Map data © 2025 Google*

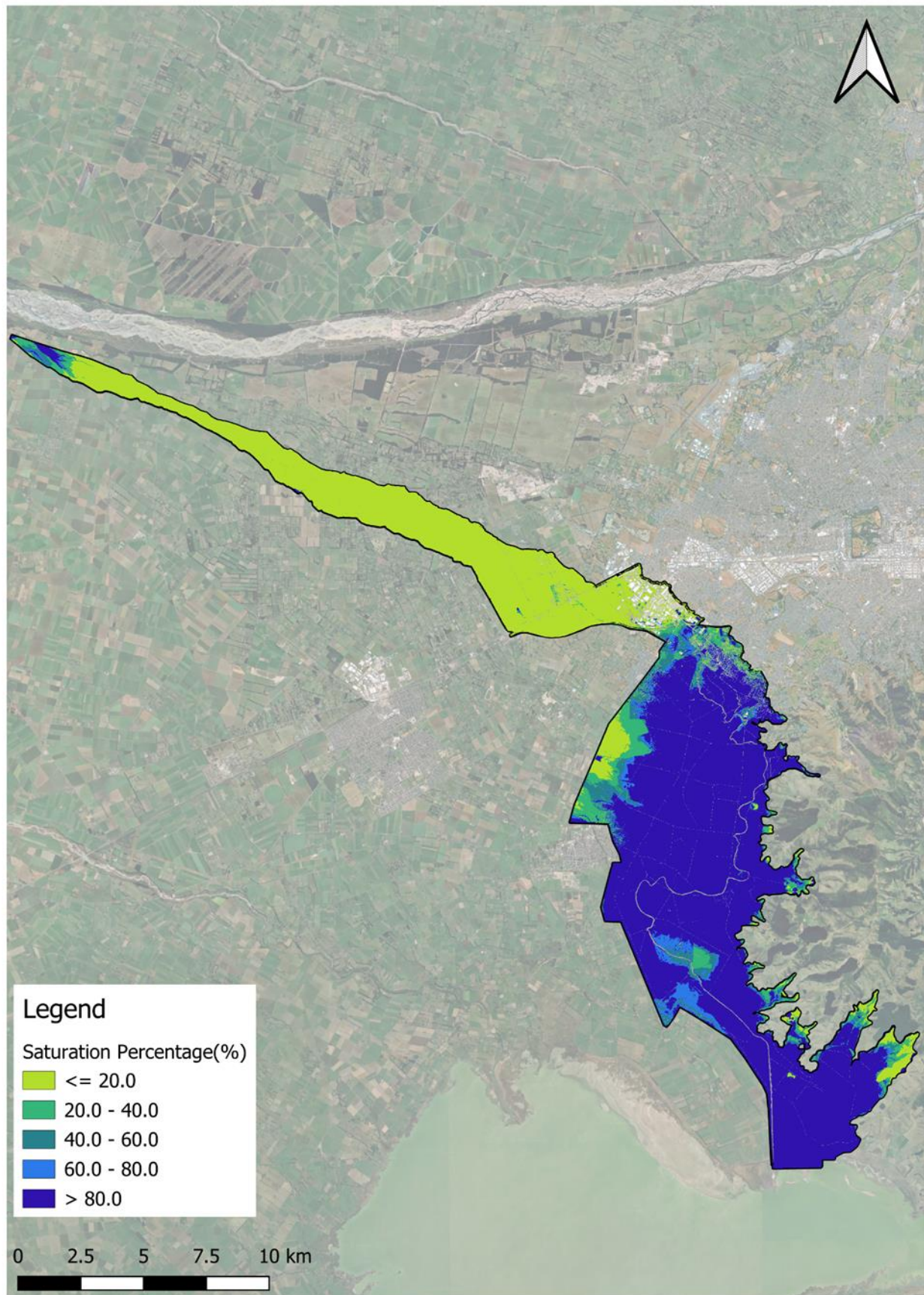


Figure 7-12 Soil saturation map by changing the infiltration and groundwater depth. *Image source: Map data © 2025 Google*

CCC is also testing the viability of using a different hydrological method for catchments on the Port Hills. The NAM method has the ability represent soil storage which represent the slower release of water. We have compared the NAM runoff hydrographs with the RORB hydrographs currently used by the model in two locations. Figure 7-13 is in the upper catchment in Early Valley and Figure 7-14 is in the lower catchment near Motukarara. Both hydrographs show a similar pattern when compared to RORB. The NAM method produces a lower peak flow value and a longer recession (tail). The hydrographs also so less water (volume) has runoff but it should be noted that the variables used in the NAM modelling are calibrated to gauges in the Heathcote catchment.

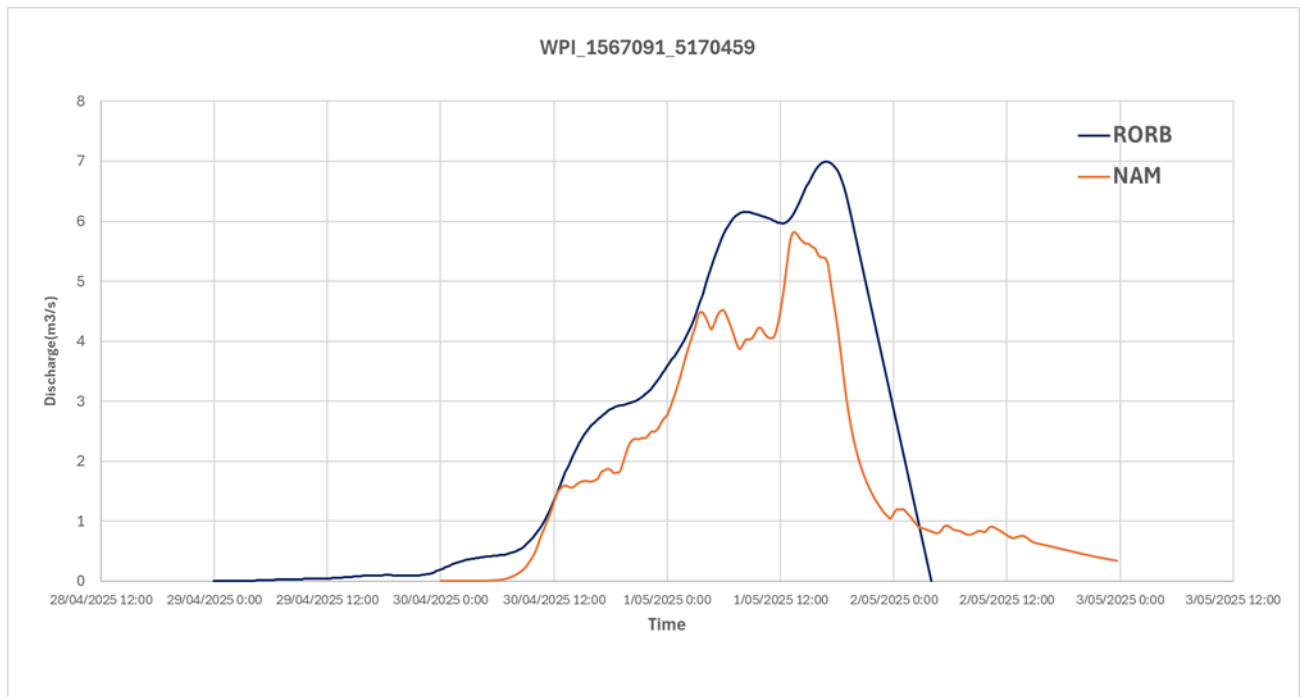


Figure 7-13 Early Valley runoff hydrograph comparison

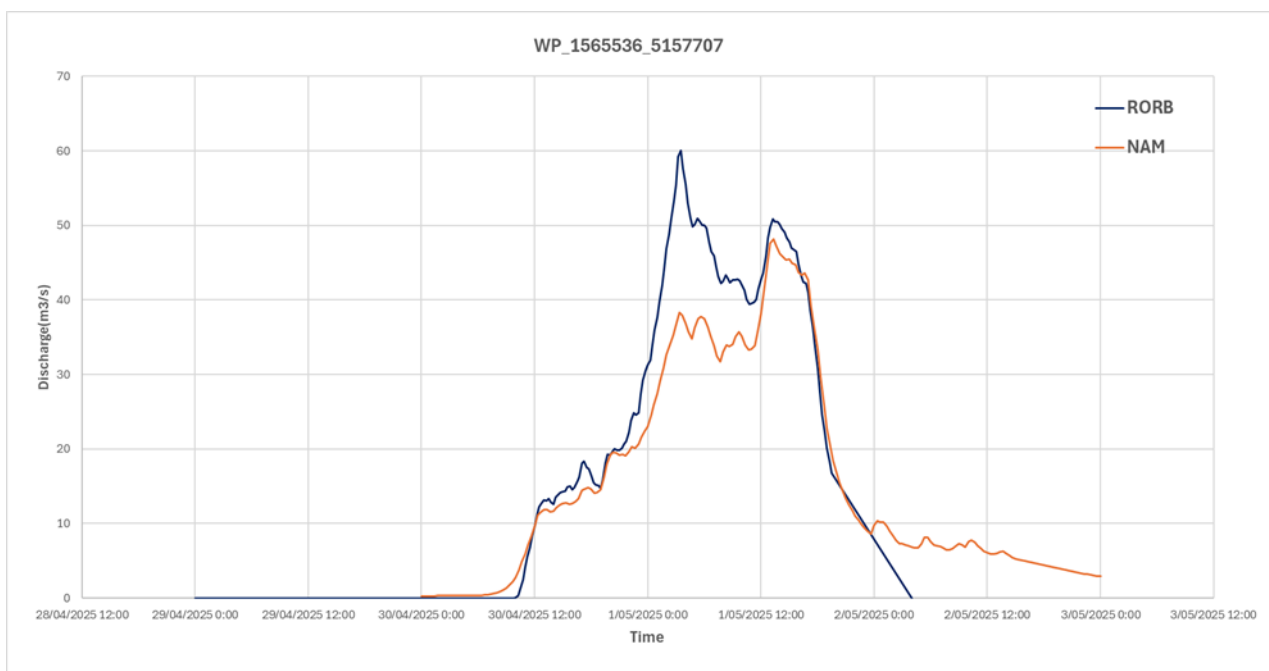


Figure 7-14 Motukarara runoff hydrograph comparison

7.3 Conclusions

Increasing infiltration rates by 50% and lowering groundwater depth by 300 mm led to notable reductions in water levels up to 1000 mm (Ella Park basin), with less change in channels such as Nottingham Stream, and Knight Stream, with more pronounced effects observed in the middle and lower catchments of the Halswell River. In contrast, the upper catchment and most areas within the Christchurch City boundary experienced only minor changes, as confirmed by the 2D surface comparison and flood extent mapping.

The updated basin outlet structures and downstream network arrangements at Halswell Junction Basin resulted in hydrograph recession limb that better matched observed data, while peak water levels reduced.

Sensitivity results at key locations showed improved alignment with observed hydrographs, including reduced peaks at Nottingham Stream (by 45 mm), Cox Quaifes Detention Basin culvert (by 66 mm), and Knight Stream at Sabys Road (by 167 mm compared to baseline).

The use of the NAM model may help align the shape of the hydrograph seen at Ryan Road bridge where a longer recession was recorded than predicted in the model. NAM should be included in future updates of the model.

The saturation map further indicated that the middle and lower catchments are fully saturated, causing additional rainfall to accumulate and run off, whereas the Templeton catchment still retains some infiltration capacity. Overall, aside from localized changes in certain basins and low-lying areas, most regions remain unaffected, with significant differences primarily at the southern boundary of the model.

Summary:

- The base model results show a reasonable response in the May 2025 event which has been confirmed by the peer reviewer in September 2025.
- The sensitivity results show that different parts of the catchment show varying levels of sensitivity to the two variables tested. As expected, infiltration rate changes have an effect where there is capacity for water to infiltrate due to low groundwater level. The infiltration rates also have a more significant effect in subcatchments where impervious areas are limited.
 - There are opportunities for future model refinement by varying groundwater levels and changes in infiltration based on soil type rather than a blanket change.
- Although the groundwater level was lowered in the sensitivity run, the saturation map showed that soil became fully saturated, adding to the runoff volume. Comparison of the recorded groundwater levels shows that some areas of the catchment have groundwater levels lower than those used in the sensitivity runs.
- There is an opportunity to refine the Q-H relationship at Halswell junction basin outlet to better match the water level recorder.

Therefore, the current setup (base model) is conservative and produces results in the calibration event that are reasonable in places. Sensitivity runs show that the area within the city to be less sensitive to the parameters tested.

Although the current model is considered (by the peer reviewer also) to be suitable for its intended purpose, more work is required to better calibrate the model. This additional work will help council understand how hydrological parameter vary across the catchment. Ideally this additional work could be undertaken once a second event suitable for calibration has occurred and should focus on varying groundwater levels and also changes in infiltration based on soil type (rather than a blanket change).

8 Model Runs Setup

8.1 Specification for design run settings

MIKE 21 results were recorded more frequently for shorter duration storms. The results saved are water level, depth, east velocity, north velocity, current speed, and Courant Friedrichs Lewy number (CFL number). Table 8-1 provides the storm durations, their overall run duration (total duration simulated), and the number of time steps saved.

Table 8-1 storm duration, run duration and number of time steps saved for each design storm simulation

Storm duration [hours]	Run duration [hours]	Number of time steps saved
0.5	6.5	78
2	8	96
6	12	144
12	18	108
24	30	120
48	54	162
60	66	198

The events simulated include the durations given in Table 8-1 and a Future development storm combined with the average recurrence interval (ARI) 10 years, 50 years, 200 years and 500 years.

No other parameters were changed between the different runs, aside from the duration, rainfall, and event-specific inflows. For example, infiltration parameters remained consistent across all design simulations for the Existing Development scenario. However, for the Future Development scenario, infiltration parameters were updated to reflect changes in the future impervious layer.

9 Model Runs Results

9.1 Runtime performance

A memo written by GHD titled Citywide Flood Modelling - Proposed technical specification for model runtimes dated (15 July 2015) outlines the runtime objectives for the city-wide modelling projects.

The time taken to simulate the HDM Halswell models depends on:

- The hardware of the machine used to run the simulations,
- The software environment that the runs are simulated in (for example, the operating system and MIKE Flood specific settings),
- The other processes that are running on the machine in parallel. In particular, the proportions of the graphics processing unit (GPU) and central processing unit (CPU) that are available to be used by MIKE Flood, and
- Several other simulation/event specific factors (for example, flow velocity and its impact on Courant number).

The Halswell model was executed on a virtual modelling machine to reduce overall simulation time. Hardware specifications for the machine are provided in section 2.4. Figure 9-1 illustrates the simulation times for each design event using the Existing Development 2024 model. Most events were completed in under 20 hours, with only a few exceptions. Generally, events with longer durations or higher rainfall (i.e., higher average recurrence intervals) required more time to simulate. This is likely because increased rainfall results in more water on the MIKE 21 surface, which demands more computational effort and, in some cases, necessitates smaller timesteps.

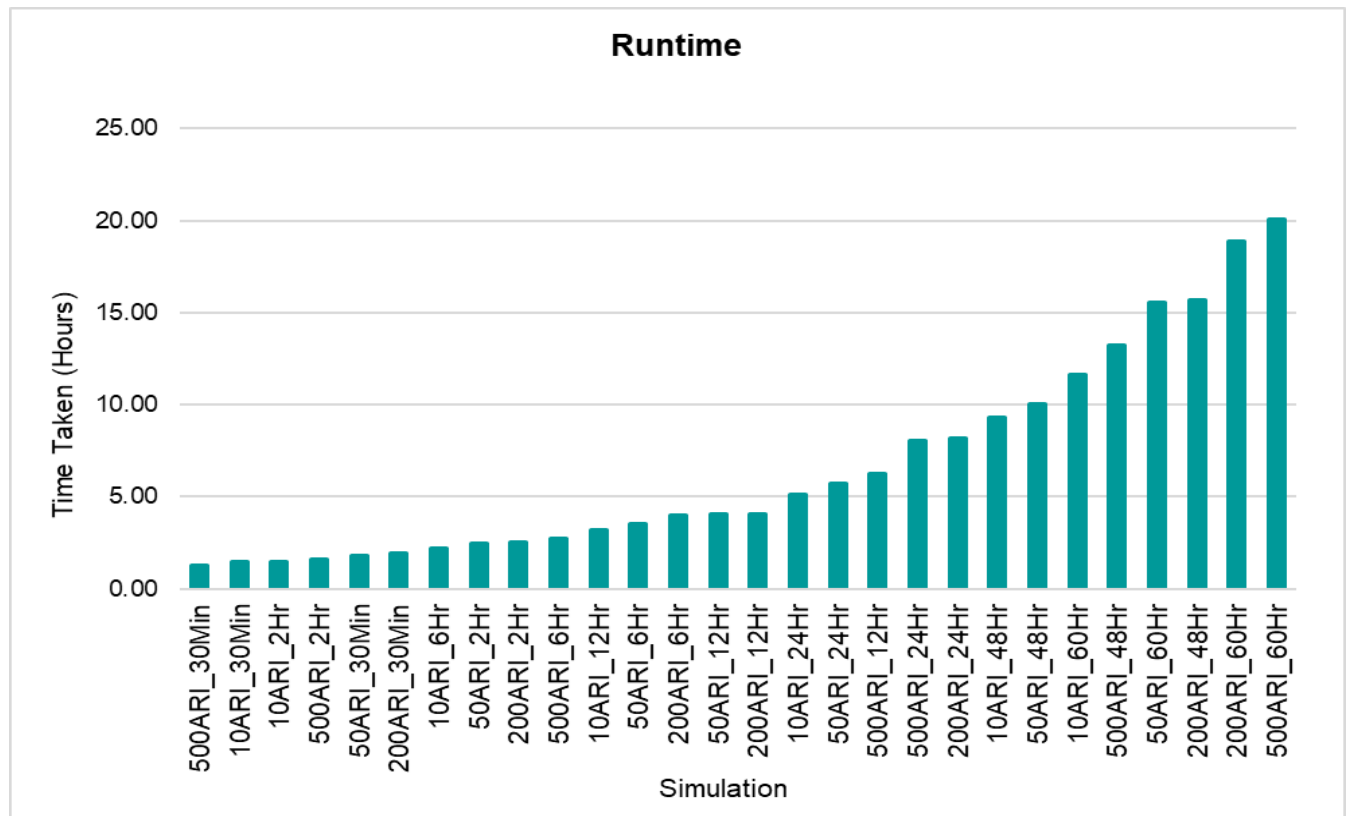


Figure 9-1: Runtime performance for the Existing Development 2024 model

9.2 Comparison between 2021 and 2024 Model results

The comparative assessment between the 2021 Halswell model and the updated 2024 model was carried out using difference mapping of the max of max flood depths for the 10-year, 50-year and 200-year ARI events. Differences were evaluated only for existing development areas, as the 2021 model did not include future development scenarios within its scope. In Figure 9-2, blue shading indicates locations where the 2024 model predicts more water, while orange shading represents areas where the 2021 model showed greater depths.

Overall, the 2024 model produces deeper water along the main water stem and central floodplain, which aligns with the additional inflow from the newly added northern Templeton catchment and the presence of a more complete stormwater pipe network. These updates improve connectivity and route flows more efficiently into the primary conveyance system. Another key contributor to the observed differences is the change in hydrological methodology between the two models. The 2021 model applied infiltration using Horton's equation, assigning a spatially varying Horton decay time series across the entire catchment whereas the 2024 model incorporates infiltration directly within groundwater storage processes. This integrated approach allows infiltration losses to vary spatially based on depth to groundwater. In the central part of the catchment, where groundwater levels are relatively shallow, the capacity for infiltration is reduced. This results in more surface runoff, which partly explains the deeper depths (blue in Figure 9-2) observed in these areas. Also, some of the darker blue areas represent basin ponding, reflecting that basin outlets and network connections have been updated and now convey water into these storage areas.

The inclusion of the Templeton catchment in the 2024 model introduces higher peak flows and larger runoff volumes, which can be traced downstream as a continuous blue band extending through rural areas and confluence zones. In contrast, areas where the 2021 model previously showed greater ponding now exhibit shallower depths (orange) due to the effects of added basins, revised network links, and improved conveyance, which collectively reduce peak spreading and remove false ponding.

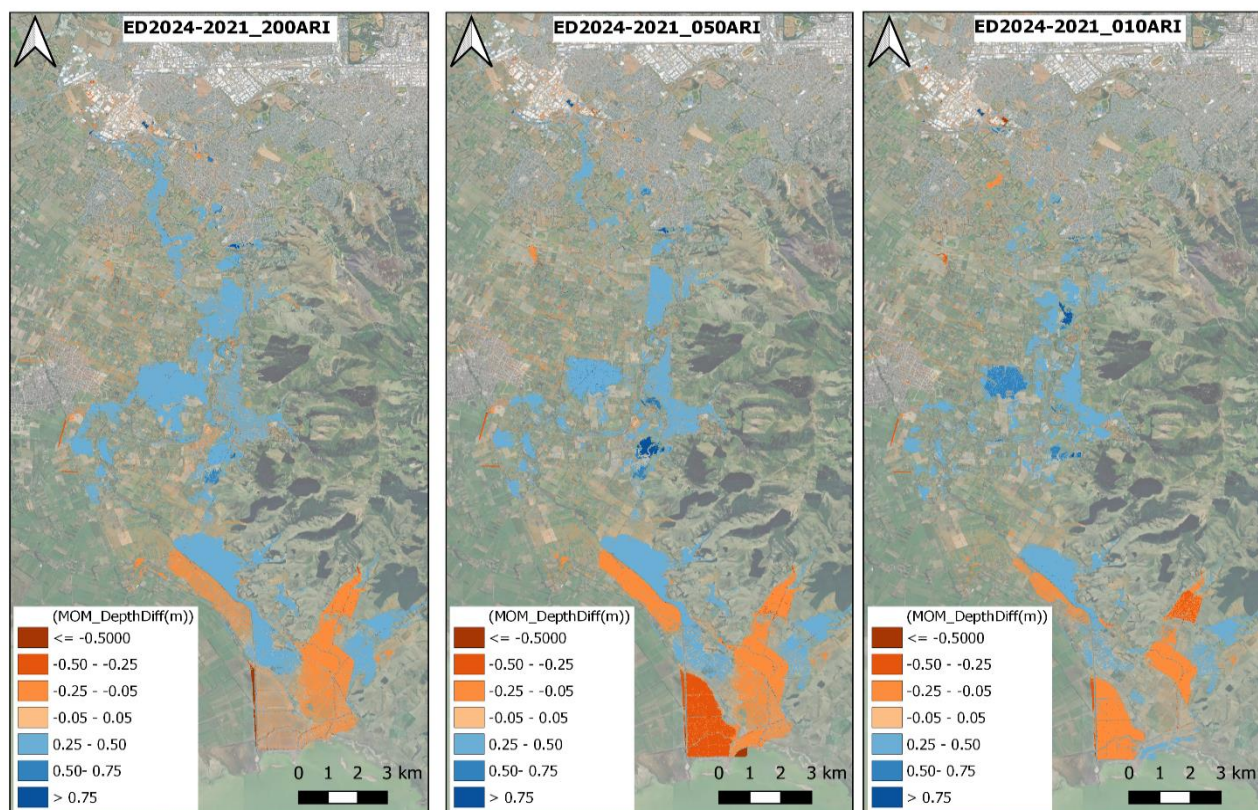


Figure 9-2: Difference mapping of max of max flood depths between the 2021 and 2024 Halswell models (i.e. 2024 minus 2021) in the 200-year, 50-year and 10-year ARI events. *Image source: Map data © 2025 Google*

9.3 Additional Quality Assurance Checks

Additional quality assurance (QA) checks were undertaken to validate the reliability of the updated model per user requirements specifications. These checks included:

1. Differencing of maximum 2D and 1D outputs across 100% of model runs to ensure consistency in peak responses.
2. Verification of event scaling by differencing the maximum water levels between the 200 year and 50year events, and between the 50year and 10year events, to confirm that smaller events consistently produce lower water levels and reduced inundation extents. -year and 50-year events, and between the 50-year and 10-year events, to confirm that smaller events consistently produce lower water levels and reduced inundation extents.
3. Differencing of maximum and end-of-run rasters across water level and depth for each event to demonstrate the extent to which water levels remained higher after the peak ('past-the-peak' conditions).
4. Polygon shape showing the areas of effect of instabilities identified in the stability standards work.

The differences between the higher and lower ARI events indicate the presence of a small amount of numerical noise, with variations typically around 0.01 m. This level of variation is well within acceptable limits for large scale hydraulic modelling. These minor discrepancies reflect numerical artefacts generated by the model solver rather than any meaningful hydraulic behaviour. Consequently, this noise has no material effect on the interpretation of flood levels, inundation extents, or event scaling, and does not compromise overall model reliability.

10 Compliance with Specifications

10.1 Identified issues of low importance

While building the HDM Halswell model and upon reviewing the results some minor issues were identified. Generally, as issues were found they were resolved but those that required significant effort with little improvement were instead recorded in anomalies register (*Halswell Model Review_RevB(Anomalies Tab)*). This was done to keep the project moving and allow important results to be provided in a timely manner without spending too much time on inconsequential details. The issues are listed in the Table 10-1 below and also provided in the Anomalies tab under User requirement documents.

Table 10-1 Summary of identified modelling issues, associated risks, and recommended actions

Issue Description	Risk/Impact	Recommended Action
Several manhole invert levels were missing in the Asset GIS dataset.	Low impact due to flat terrain; minimal influence on model performance.	Gaps have been filled by interpolating values from adjacent manholes; however, if surveyed invert levels for these manholes become available in the future, they should be incorporated into the model.
Farm drain culverts in the southern catchment (outside Christchurch City Boundary) were incorrectly located.	Potential for ponding and road overtopping, leading to deeper upstream flooding and reduced downstream flooding.	Update culvert locations in future model revisions.
Buildings missing from the roughness layer.	Incorrect roughness representation around built-up areas; local flow patterns may be affected.	Update roughness layer when an updated buildings dataset becomes available.
M21 initial condition WSE uses an old model boundary, continuing to reference the ED2016 boundary.	No impact on model results but may cause confusion during QA checks.	Update the initial condition coverage to match the current model extent.
Early Valley drain representation in M-21 is limited due to low mesh resolution in MIKE 21.	Mesh resolution insufficient to capture local flow behaviour; potential inaccuracies in the immediate drain vicinity.	Consider incorporating a 1D model in future upgrades to better represent flow along Early Valley Drain.
Solver instability occurs where mesh elements are very steep, as the solver reorders mesh elements. This makes it difficult to identify the exact elements causing the issue.	Steep elements may cause velocity spikes and Courant violations, as they are few and mostly outside the urban area so have little influence on the model outcomes.	This issue may be resolved in a future software upgrade by doing mesh smoothing or local refinement.
M21 culverts causing inflow and outflow correction	Inflow and outflow correction-The inflow and outflow correction is associated with M21 culverts.	No immediate action is necessary since the culverts are away from the area of interest as per reviewer advise. Knights stream drain stability is improved.

Issue Description	Risk/Impact	Recommended Action
Asset naming convention	Intermediate names such as “inserted” or “manhole” have been assigned to some assets instead of the actual CCC asset names. This is partly due to network simplification and the absence of defined names in GIS when these assets were added to the model.	The updates should be implemented in future model revisions.
Pipe asset data source flagging	Reviewer feedback indicates that pipe asset data requires flagging	Update source flagging in future model revisions
Node/ Manhole Data source flagging	Reviewer feedback indicates that pipe asset data requires flagging	Update source flagging in future model revisions
Spot check pipe attributes.	Peer reviewer recommended additional spot checks for pipe attributes be completed for GIS accuracy.	Some spot check were completed during the model build phase. A full model check could be completed.
Inter basin weirs to be introduced in Mesh	Dikes have correctly been used to define pond banks; however, some inter-basin weirs are also represented as dikes. This may cause instability at high water levels due to unintended barrier effects.	Refine representation of inter-basin weirs in future mesh updates to prevent unintended hydraulic separation between basins.
The Q-H relationship for Halswell junction basin outlet has not been verified as part of calibration run.	Risk that the modelled outlet performance may be misrepresented, as the rising-limb water levels do not align with the council’s gauged data. The discrepancy may relate to inlet issues or basin infiltration rate; however, comparison of calculated and modelled.	This review can be completed during the next phase of model run.
Missing private sumps not included in model, CCC sumps largely included except few missing.	Some private sumps are missing from the model, leading to property flooding (mostly commercial) Including these sumps would help to mitigate those risks.	Include missing sumps and refine coupling arrangements during the next model update.
Instability at model boundary by the intersection of Waterloo Rd and Barbers Rd.	Very localised to the corner, also the flow is boxed in by the raised railway to the immediate south, which reduces the impact away from the location.	The model boundary could be extended a bit further away from this location to a natural drainage point, or some other way.
A seam exists in the ground model around Hornby South where 2023 Selwyn LiDAR DEM was only available in a limited region at the time when the model was being built.	Some new roads and basins in Hornby South area are not represented in the previous DEM but are in the new one and there is a visible cut off.	To be corrected in the next model update, using the new 2025 Christchurch city LiDAR DEM from LINZ.

10.2 Recommendations for Model Improvement

Based on the sensitivity analysis and calibration results, several targeted actions are recommended to enhance the accuracy and reliability of the Halswell model. These changes will help address areas where the model is currently conservative or less responsive to parameter adjustments, and support more effective calibration in future events.

- At this stage, further calibration is not recommended (unless an event suitable for calibration should occur), as the model already provides conservative results relative to the available gauged records. Instead, it would be advantageous to collect more gauged data across the catchment particularly in the middle of catchment areas, which showed greater sensitivity to the variables tested in the sensitivity assessment. This will help future calibration work capture the full catchment behaviour that may have been missed in earlier events. Figure 10-1 shows four possible gauge locations, marked with river or basin names with chainages. These sites were chosen based on the city boundary extent and the calibrated flood results with known flood prone reaches.
- In future updates, the NAM model should be incorporated to better match observed hydrograph recession patterns, especially at locations like Ryan Road bridge.
- To incorporate NAM the Halswell model should be converted to MIKE+. This will help with ongoing software support. Newer versions of MIKE+ will also have various engine optimisations, bug fixes, and new modelling features.
- New cross-section survey is also recommended, as the current model uses survey data collected nearly ten years ago. Channel geometry is likely to have changed significantly in places since then and updating the model with new cross-section data would improve its accuracy.
- Future model improvements should focus on updating key components such as the roughness layer to include newly constructed buildings. Small drains such as the Early Valley Drain should be added to the 1D network where the existing mesh resolution does not capture flow pathways well, inter basin weirs should be built directly into the model mesh, as representing them with dikes can cause instability at higher water levels.
- Any missing private sumps that connect directly with CCC manholes should be included to improve the overall inlet capacity representation.
- Culvert performance should be checked in HY8 to confirm structure conveyance performance.

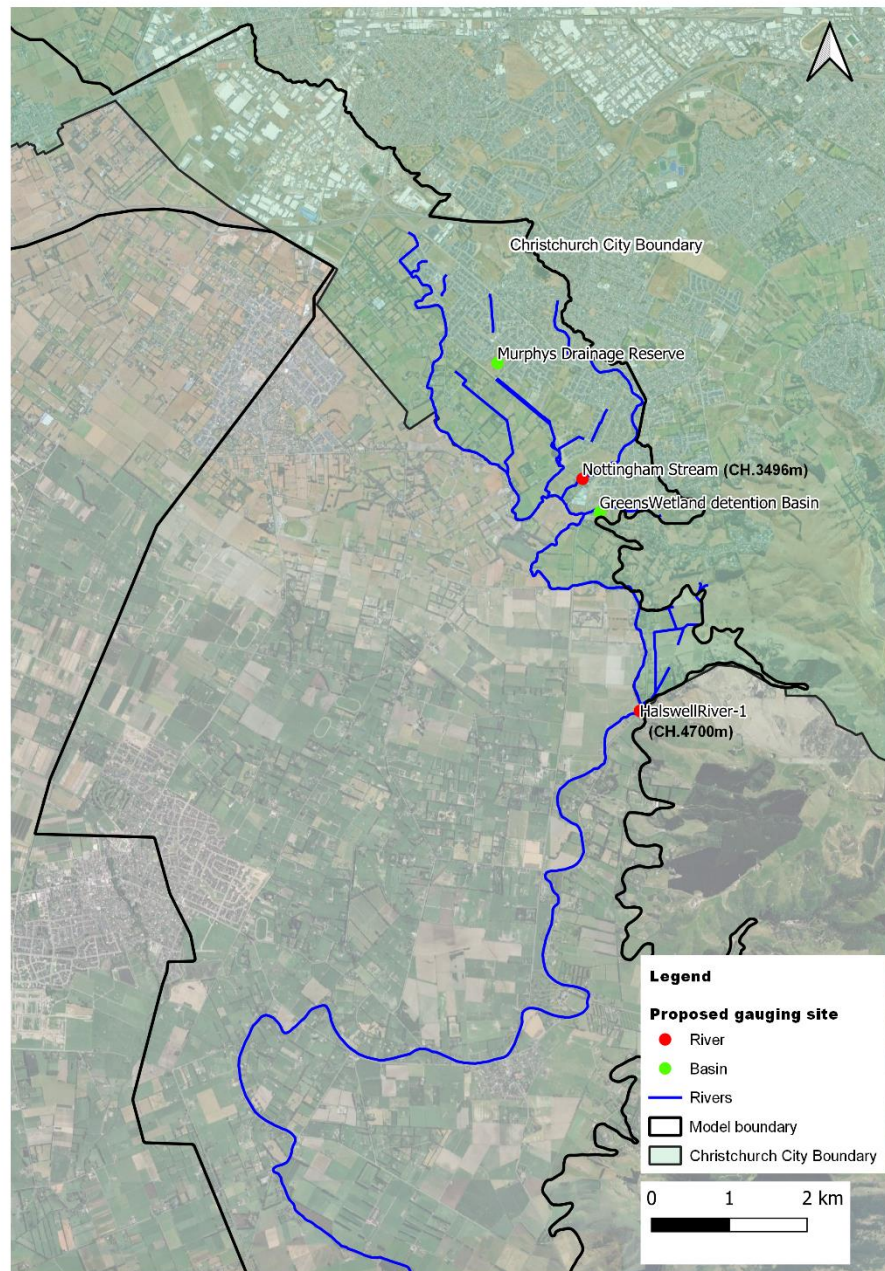


Figure 10-1 Proposed locations for new monitoring gauges. *Image source: Map data © 2026 Google*

11 References

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Appendix A – RORB Manual Runoff Concepts

APPENDIX A: RUNOFF ROUTING CONCEPTS

The purpose of this appendix is to introduce readers to some of the concepts of runoff-routing as they apply to RORB, i.e. to help explain why the model was formulated the way it was. It begins ([Section A.1](#)) by showing how a series of concentrated storages can represent the attenuation and translation effects of a catchment on the rainfall-excess hyetograph. [Section A.2](#) provides theoretical and empirical justification of the power function equation $S = kQ^m$ used to simulate reach storage-discharge behaviour and indicates the factors affecting k values. Some justification for splitting the parameter k into catchment (k_c) and reach (k_r) components is given in [Section A.3](#), along with the ideas behind the use of d_{qv} as an intermediate parameter in the model. To conclude, [Section A.4](#) summarizes the main advantages of the approach adopted in the RORB program.

A.1 Simulation of Catchment Behaviour

We begin by considering a storm large enough to produce runoff at the outlet of a catchment. If the hyetograph of rainfall-excess (i.e. the rainfall hyetograph less the losses due to infiltration, etc.) is plotted *on the same scale as* the observed hydrograph at the catchment outlet, the resulting figure shows the relationship of one to the other. [Figure A-1](#) shows typical 'input' and 'output' curves in hydrograph units.

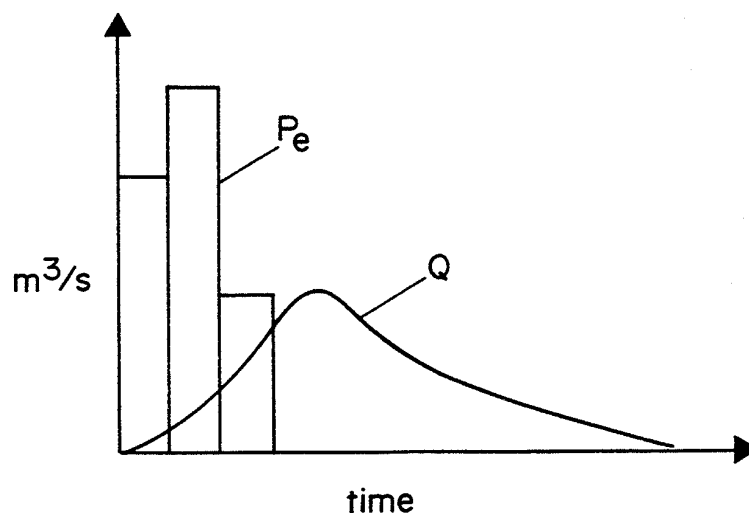


Figure A-1 The Effect of Catchment Storage

In [Figure A-1](#), the volumes beneath the rainfall-excess hyetograph and the runoff 'hydrograph' are equal. However, the latter is much flatter than the former, and its peak occurs later in

time. That is, the effect of a catchment on the input hydrograph is like that of a storage in that it causes:

- *attenuation* of the input pattern; and
- *translation* of peak flows in time.

As shown in [Figure A-2](#), the attenuation and translation effects of a catchment on the rainfall-excess hyetograph can be *simulated* by routing the input through a series of concentrated storages. The first routing through such a storage produces a hydrograph which peaks on the falling limb of the input hyetograph. The routing through the second storage produces further attenuation, and a peak more remote from the original input. Additional routings continue to flatten the hydrograph and to shift its peak further to the right. The routing of the rainfall-excess hyetograph through a string of concentrated storages thus can be seen to simulate the effect of a catchment on its rainfall-excess input.

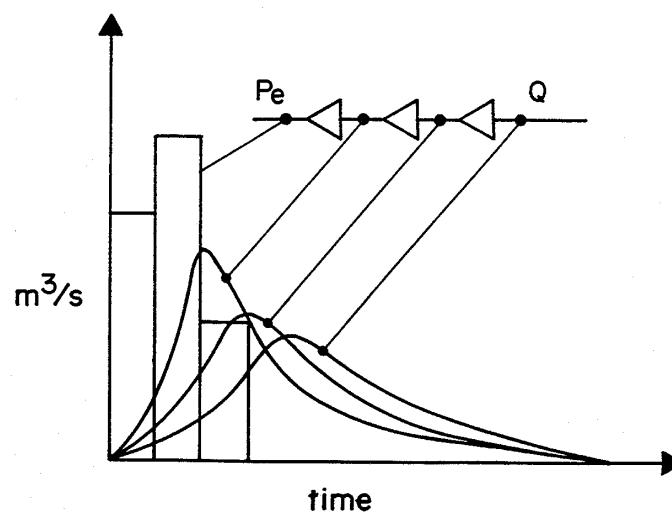


Figure A-2 Simulation of Catchment Effect with a Series of Concentrated Storages

Consider now [Figure A-3](#), in which the concentrated storages have been placed on the major stream reaches of the catchment, which itself has been divided into a number of sub-areas draining to the stream system. The figure shows that the rainfall-excess for sub-area A, entered at the node on A, is routed through a series of storages on its way to the catchment outlet; runoff from sub-area B is acted on by the storages which lie on the streams between it and the outlet. Similarly for C, D, and E. With this formulation, the rainfall-excess hyetographs from different parts of the catchment are routed through an amount of concentrated storage which depends on the remoteness of each area from the outlet.

As will be explained in [Section A.4](#), such subdivision of the catchment provides the opportunity to model spatial variability of rainfall and losses, different reach characteristics, and separate allowance for major storages which may exist (or are proposed) on the catchment.

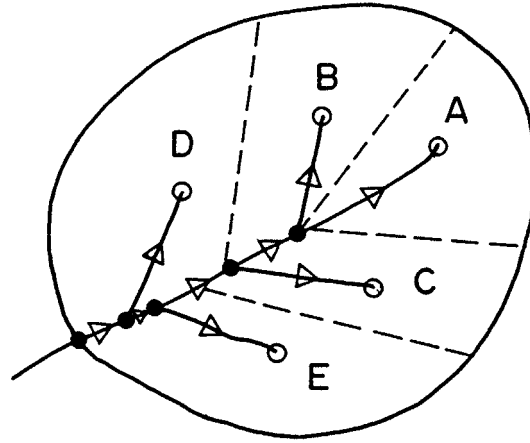


Figure A-3 Distributed Storage Network to Represent a Catchment

A.2 Representation of Reach Storage ($S = kQ^m$)

The form of the storage equation $S = kQ^m$ is justifiable by both theoretical and empirical means. Theoretically, application of a uniform flow equation in a prismatic channel will yield an equation of this form as shown below.

Consider [Figure A-4](#) which shows a reach (length, L) of a channel with a triangular cross-section. The depth of flow in the channel is y , the Manning roughness is n , the bed slope is S_b and the channel side slopes are z horizontal to 1 vertical. The water 'stored' in the channel is given by the product of the cross-section (area A) and the length, i.e.

$$S = AL = zy^2L \quad \text{Equation A-1}$$

Using Manning's equation, the discharge Q can be expressed as

$$Q = vA = \frac{1}{n} \left(\frac{zy^2}{2y\sqrt{1+z^2}} \right)^{2/3} S_b^{1/2} zy^2 \quad \text{Equation A-2}$$

[Equation A-1](#) and [Equation A-2](#) can be combined to eliminate y . The result is an equation in the form $S = kQ^m$ where $m = 0.75$ and

$$k = \frac{n^{0.75} (2\sqrt{1+z^2})^{0.5} L}{z^{0.25} S_b^{0.375}} \quad \text{Equation A-3}$$

Similar analyses can be made for other cross-section shapes (e.g. Ref. [1](#))

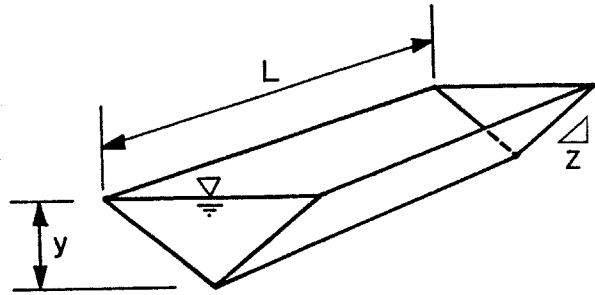


Figure A-4 Uniform Flow in a Prismatic Channel of Triangular Cross-section

A.2.1 Value of exponent m

Analyses like the one above, can be performed for other cross-section shapes to produce the following exponent values:

Triangular cross-section	$m = 0.75$
Trapezoidal cross-section	$m = 0.74$
Parabolic cross-section	$m = 0.69$
Wide rectangular channel	$m = 0.60$

The results are for *uniform flow* in open channels. However, similar m values, ranging from 0.68 to 0.8, have been reported in *field studies* using natural catchments (Ref. [1](#)); these studies included two events with overbank flow. More recent experience with runoff-routing models has led the authors to adopt an 'average' m value of 0.8, although other values in the range 0.6-1.0 are frequently encountered. [It might be noted here that an m value of 1.0 implies a *linear* model of catchment response.]

A.2.2 Value of k

The relation for k given by [Equation A-3](#) shows the nature of its dependence on channel roughness, cross-section shape, bed-slope, and length. Such a relationship could be of use for routing in *prismatic* channels where these parameters can be estimated. In *natural* river channels the effects of slope and roughness often tend to be compensatory; in such cases, the k value can be taken as proportional to L . In *urban* catchments with lined channels, this compensating effect is missing so the effect of slope on reach storage must be specifically included.

A.3 Splitting k into k_c and k_r

The time between the occurrence of a particular element of rainfall-excess at a particular point on the catchment and its effect at the outlet is called the storage delay time for that point. On a linear catchment, it is constant for any point but on a nonlinear one it varies with discharge.

It was proposed by Laurenson (Ref. [2](#)) that the *lag* of a catchment (i.e. the time between the centroid of rainfall-excess and the centroid of the resulting surface runoff) was equal to the *average storage delay time* for all elements of rainfall-excess throughout the storm and over

the entire catchment. Assuming areally uniform rainfall-excess, this means that lag is equal to the storage delay time of points on the catchment corresponding to the centroid of the time-area diagram. On nonlinear catchments, both the lag and the storage delay times of all points were assumed to vary with discharge. It was also assumed that the storage-delay time value of the centroid of the time-area diagram varied with outlet discharge in the same way that lag varied with mean outlet discharge of the flood from which it was derived. This latter relation was found empirically to have the form

$$t = k_c Q^p \quad \text{Equation A-4}$$

where $t = \text{lag}(h)$ and $Q = \text{mean outlet discharge } m^3/s$ and k_c and p are constants, p having a value of the order of -0.25. Adopting a catchment storage model of the form shown in [Figure A-3](#), the storage delay time (in hours) of a storage i is thus assumed to have the form

$$k_i = k_c k_r Q^p \quad \text{Equation A-5}$$

implying a storage function

$$S_i = 3600 k_c k_r Q^{p+1} \quad \text{Equation A-6}$$

where k_r is the *relative* delay time of storage i , i.e. the ratio of its delay time to that of the centroid of the time-area diagram and S_i is in m^3 .

The RORB program computes the catchment mean travel distance (the distance from the outlet to the centroid of the time-area diagram) from the reach lengths input in the catchment data file. If there are n sub-catchments and the i^{th} one has area a_i (km^2) and a travel distance to the *catchment* outlet d_i (km), then the mean travel distance d is given by:

$$d_{av} = \sum_{i=1}^n (a_i d_i) / A \quad \text{Equation A-7}$$

where A is the total catchment area (km^2). Considering the catchment storage between two adjacent nodes of the model, i upstream and j downstream, its k_r value is given in dimensionless form by

$$k_r = (d_i - d_j) / d_{av} \quad \text{Equation A-8}$$

Such relative delay times will have values of the order of 0.1.

With k_r expressed in its dimensionless form, k_c becomes equal to the coefficient of the formula for delay time of the centroid of the time-area diagram and of the lag-mean discharge formula ([Equation A-4](#)). The advantage of this is that k_c can be estimated directly from lag formulae.

A.4 Advantages of the Runoff Routing Approach

The main advantage of the runoff-routing procedure over methods which are based on unitgraphs is its **flexibility**; the catchment formulation adopted in RORB can easily account for:

- variability of rainfall depth over the catchment;
- variability of rainfall pattern over the catchment; variability of losses over a catchment;
- nonlinearity of catchment response;

- the modelling of existing or proposed storages in the catchment, using equations appropriate to each specific storage;
- the modelling of the effects of reaches 'drowned out' by reservoir inundation;
- the modelling of flows in branched networks;
- the effects of urbanization of all, or part of, the catchment; and,
- the ability to represent other forms of runoff-routing model.

This flexibility comes from the subdivision of the catchment into sub-areas (assumed homogenous), the routing of the runoff from each part of the catchment through the appropriate amount of reach storage, and the separate modelling of significant artificial or natural storages . The formulation allows for the output of calculated hydrographs at any point in the catchment, and thus for the user to compute design flows for any region of interest.

Authors' Note: The power function form of the storage-discharge relation ([Section A.2](#)), while valid for most applications, may not always be the most suitable for a stream reach. The user should decide – using FIT runs and judgement - whether the formulation is suited for the task at hand.

B

Appendix B – Halswell RORB Calibration

Memorandum

To: Elliot Tuck
From: Natasha Webb
Copy: Mike Law
Subject: Halswell Calibration

Date: 9 May 2018
Our Ref: 3361713

This memorandum outlines the Halswell Hillside RORB modelling. The modelling was split into three RORB models, where two models for the Halswell Hillside catchment area and one calibration model of the Kaituna catchment. The memo sets out the catchment delineation, model build, calibration and calibration results.

1 Catchment Delineation

The three RORB models developed are shown in Figure 1 and the following section outlines the catchment delineation for each model.

1.1 Halswell Hillside Catchments

The Halswell Hillside area modelled in RORB, as shown in Figure 1, has a total catchment area of 67.41km². To simplify the model, the hillside area was split into two separate RORB models based on catchment size and type.

For the hillside area located within Christchurch City Council boundary, the sub-catchments were sized from 0.1km² to 0.5km² to provide sufficient detail for urban/rural catchments. This level of detail is the same used in the City Wide Model currently under construction. This RORB model was called Halswell CCB and is shown in Figure 2. Halswell CCB has a total catchment area of 10.49km².

For the hillside area located outside the Christchurch City boundary, the sub-catchments were sized from between 0.5km² to 5.6km². The larger sub-catchment sizes were used as the hillside area of the city is rural and does not require the same level of detail. The second RORB model is called Halswell 02 and is shown in Figure 3. Halswell 02 has a total catchment area of 56.58km².

1.2 Kaituna Catchment

The Kaituna catchment was selected to calibrate the Halswell RORB model because it is a rural catchment located further south around the Port Hills from the catchment used to calibrate the Heathcote River model. The Kaituna catchment provides a better representation of the hillside area within the Halswell River Model. The Kaituna catchment, shown in Figure 4, has a total catchment area of 39.93km² and is a gauged catchment (operated by Environment Canterbury, ECan), with flow recorder and rainfall gauge located in the valley floor at Kaituna Road (located at node M1). As the Kaituna catchment is located outside the city boundary, the sub-catchments were sized from 0.5km² to 5.6km².

Memorandum

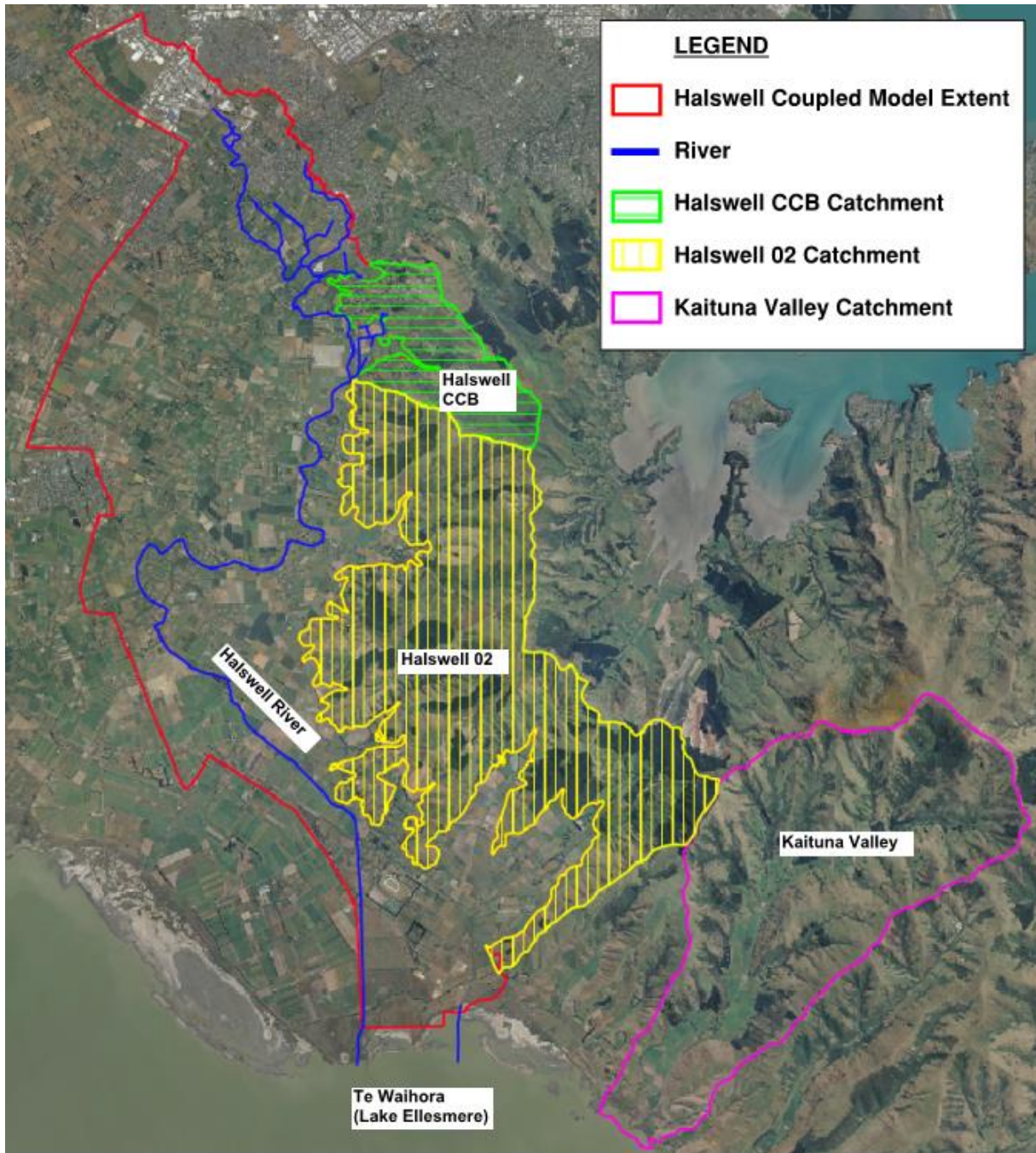


Figure 1 – Halswell Hillside RORB model catchments (Halswell CCB, Halswell 02 and Kaituna Valley)

Memorandum

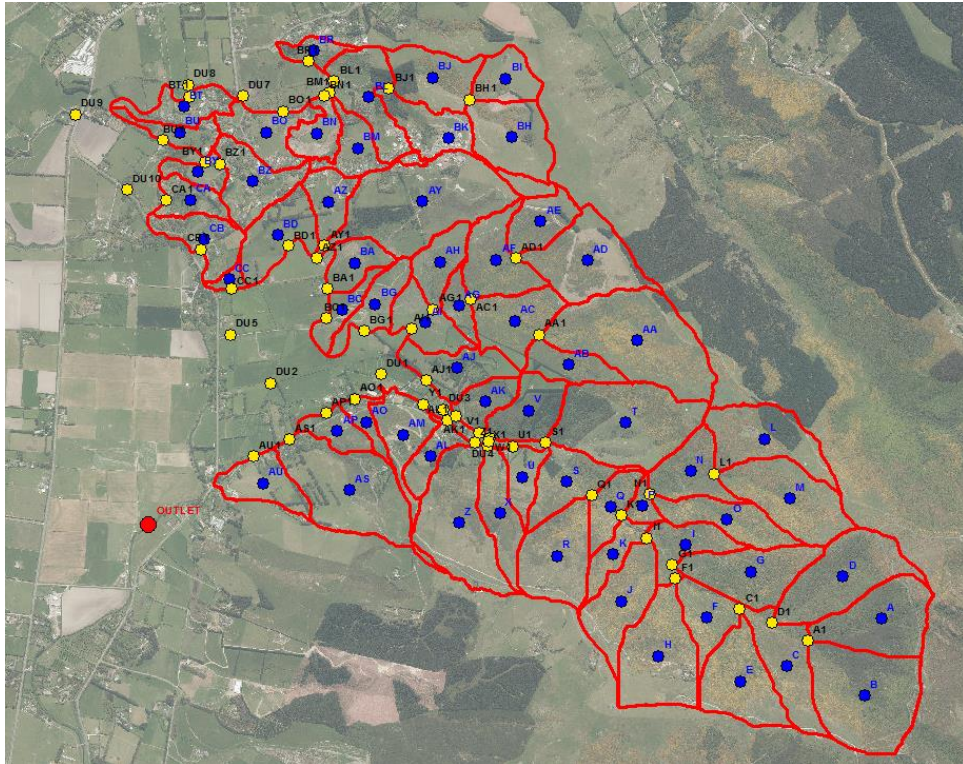


Figure 2 – Halswell CCB RORB Model Sub-catchments

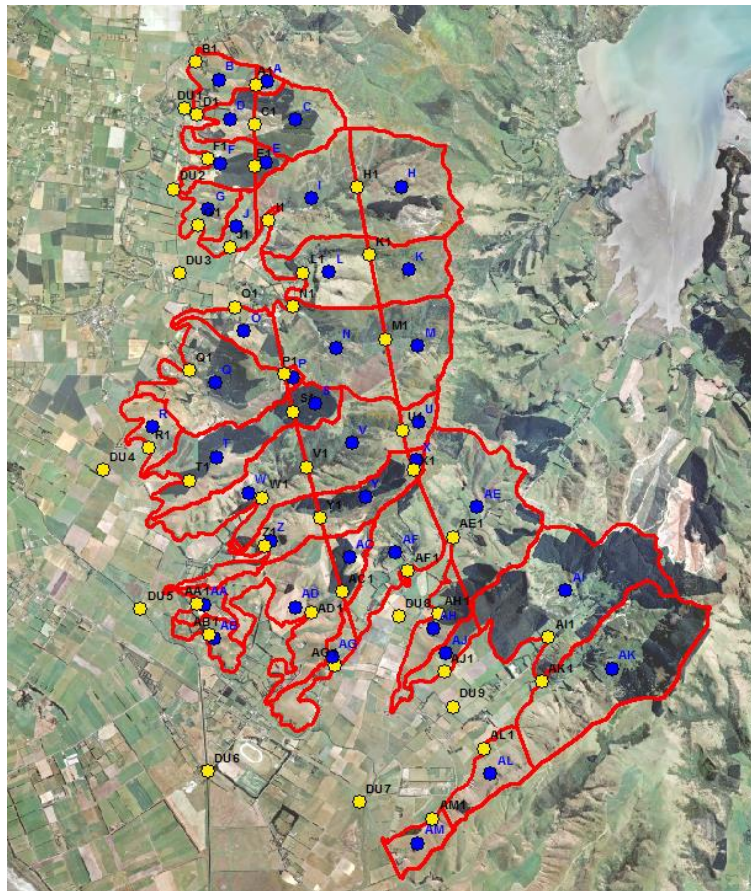


Figure 3 – Halswell 02 RORB Model Sub-catchments

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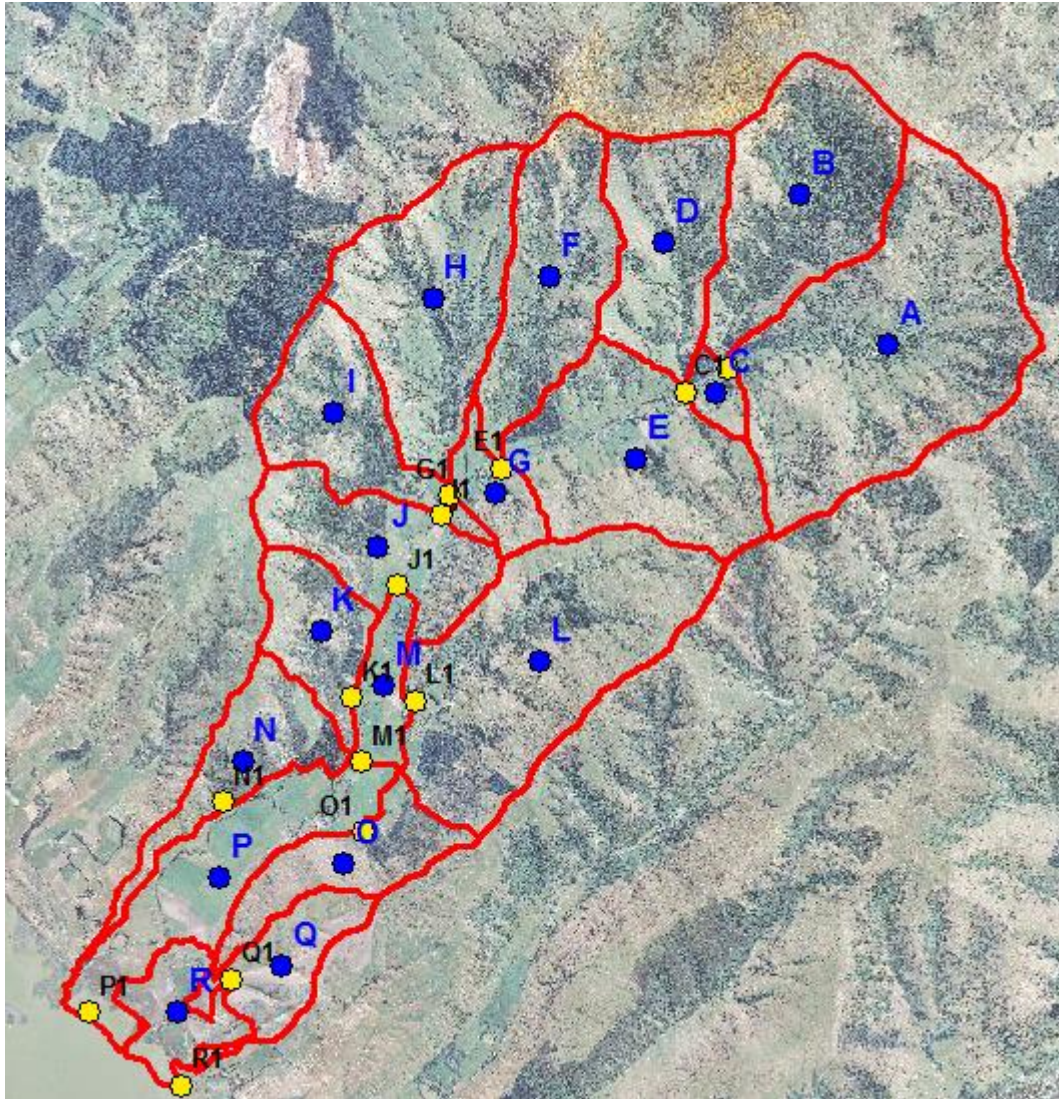


Figure 4 – Kaituna Catchments

2 RORB Model Build

All the RORB models were built using ArcMap and the arcRORB tool. Using the arcRORB tool, the sub-catchments were converted into RORB and the reaches, catchment centroids (shown as Blue dots) and junctions (shown as Yellow dots) were defined. In both RORB models, the reaches were defined as natural channels, where reach slope was generated by arcRORB tool using the equal area method and 5m contours.

For the urban sub-catchments in Halswell CCB model, the fraction impervious was calculated based on the Christchurch City Council's Waterways, Wetland and Drainage Guidelines (WWDG, 2003) for district zone LH. As the Halswell 02 model and Kaituna model are rural catchments, the sub-catchments were set as 100% pervious.

Memorandum

3 Calibration

The Kaituna RORB model was calibrated for the four calibration events listed in Table 1. For each of these events, the Kaituna River flow and Kaituna rainfall records were collected from Ecan. The rainfall records were processed into a RORB storm file and run through RORB to generate the runoff hydrographs at the flow recorder location (see M1 in Figure 4).

Table 1 – Calibration Events for Kaituna RORB Model

Calibration Event	Event Dates
October 2000	12th October 2000
May 2006	12th – 13th May 2006
June 2013	15th – 22 June 2013
March 2014	4th – 5th March 2014

However, initial calibration runs showed that for all of the calibration events, the rainfall depth recorded at the Kaituna gauge was too low to generate the runoff volumes required to meet Kaituna River flow volumes¹. We confirmed that there was insufficient rainfall in the Kaituna record by calculating the expected total rainfall depth required to produce the required river flow volume (see Table 2). Some of this volume may be accounted for as base flow, which cannot be added to the RORB model.

The Kaituna rainfall gauge is located on the valley floor and may not be representative of the rainfall the catchment receives, especially on the upper slopes. For this reason the decision was taken to, use additional rainfall gauges located at higher altitudes nearby thereby providing a comparison to the Kaituna rain gauge and to calibrate the RORB model. The two additional gauges selected are Coopers Knob (Ecan site) and Akaroa Highway (NIWA site).

At both sites, the rainfall record was processed for each event, run through the Kaituna RORB model and the total rain depth calculated (shown in Table 2). Coopers Knob gauge did not have a complete record for October 2000 event and this was event was not include in the calibration runs. Akaroa Highway gauge open in November 2012 and accordingly, the October 2000 and May 2006 events were not included in the calibration run.

3.1 Calibration Results and Discussion

Table 2 summaries the expected excess rainfall (Total rainfall minus losses) depth calculation and the total rainfall depths for each gauge. As mentioned above, the excess rainfall depth at the Kaituna flow recorder is lower than expected. Although Cooper's Knob shows similar rainfall depths to the expected rainfall depth, Cooper's Knob gauge rainfall may not have enough rainfall to meet river flow volumes since this depth calculation does not take into account infiltration losses across the catchments. Akaroa Highway has recorded a lot more rainfall than either the Kaituna or Coopers Knob gauges.

¹ Note that this approach assumes that the flow rating for the Kaituna flow recorder is accurate, especially at high flows.

Memorandum

Table 2 – Total Rainfall Depth Comparison

Calibration Events	Expected Excess Rainfall Depth – calculated from Kaituna River flows (mm)	Total Rainfall Depth (mm)		
		Kaituna Rainfall Gauge	Coopers Knob Gauge	Akaroa Highway Gauge
October 2000	37.8	59.5		
May 2006	42.3	38.5	54	
June 2013	230.2	168	225	294
March 2014	60.6	70	88	341.2

Figure A1 to Figure A8 (see attachments) show the best fit of the runoff hydrographs for the each calibration event at each of the gauge sites. Table 3 outlines the design parameters for each event at each gauge site. Figure A1 to Figure A8 show that both the Kaituna rainfall and Cooper's Knob rainfall do not have enough rainfall to meet river flow volumes. Conversely, the Akaroa rainfall provides too much rainfall, which requires large unrealistic initial losses (up to 30 mm) and continuing losses (up to 11.25 mm/h) for the March 2014 event.

These figures also show the runoff hydrographs of AECOMs proposed RORB design parameters for a k_c of 2, m of 0.8, an initial loss of 17mm and a continuing loss of 1.25 mm/h. From these graphs, it can be seen that AECOMs values of a k_c of 2 has generated hydrograph peaks higher and quicker than what was recorded and therefore does not provide a good fit for the Kaituna catchment. This is true for all of the calibration events.

Table 3 suggests that the Kaituna catchment requires a k_c between 11.9 to 13 (for the June 2013 and March 2014 events) or a k_c between 5 to 7 for (October 2000 and May 2006 events) to match up the peak discharge and timing from the catchments. In the RORB manual, the calculation for k_c for a catchment area of 39.93km² is 13.9. Therefore, a k_c of 13 would be reasonable for the Kaituna catchment.

Similarly, if the Akaroa rainfall runs are not used, the initial losses are between 13mm to 17.5mm and the continuing losses are between 0.3mm/h to 1.27mm/h, which are similar to AECOMs proposed loss parameters. Therefore, an initial loss of 17.5mm and a continuing loss of 1.25mm/h would be reasonable for the Kaituna catchments.

Memorandum

Table 3 – Design Parameters for each Calibration event

Calibration Event	Gauge	k_c	m	Initial Loss (mm)	Continuing (mm/h)
AECOM	AECOM	2.0	0.8	17.5	1.25
Oct-00	Kaituna	5.0	0.8	17.5	1.27
May-06	Kaituna	7.0	0.8	15.0	0.30
	Coopers Knob	6.3	0.8	17.0	1.72
Jun-13	Kaituna	12.5	0.8	25.0	0.00
	Coopers Knob	11.9	0.8	25.0	0.45
	Akaroa Highway	12.5	0.8	13.0	1.00
Mar-14	Kaituna	13.0	0.8	30.0	0.00
	Coopers Knob	11.9	0.8	30.0	0.00
	Akaroa Highway	16.25	0.8	30.0	11.25

Using these design parameter selections, the calibration events at each rainfall gauge were rerun. Figure 5 to Figure 8 show the runoff hydrographs for the each calibration event at the gauge site that provided the best fit. The June 2013 event runoff hydrograph shows the best match to the Kaituna river flow (see Figure 7). Although there is not enough rainfall in the Kaituna rainfall record, using the selected design parameter has matched up the timings of the peaks for the June 2013 event. For the other events, the selected design parameters will not match the Kaituna river flow hydrograph. However, the resulting runoff hydrograph match the timings of the peak river flows for the October 2000 and May 2006 events.

Memorandum

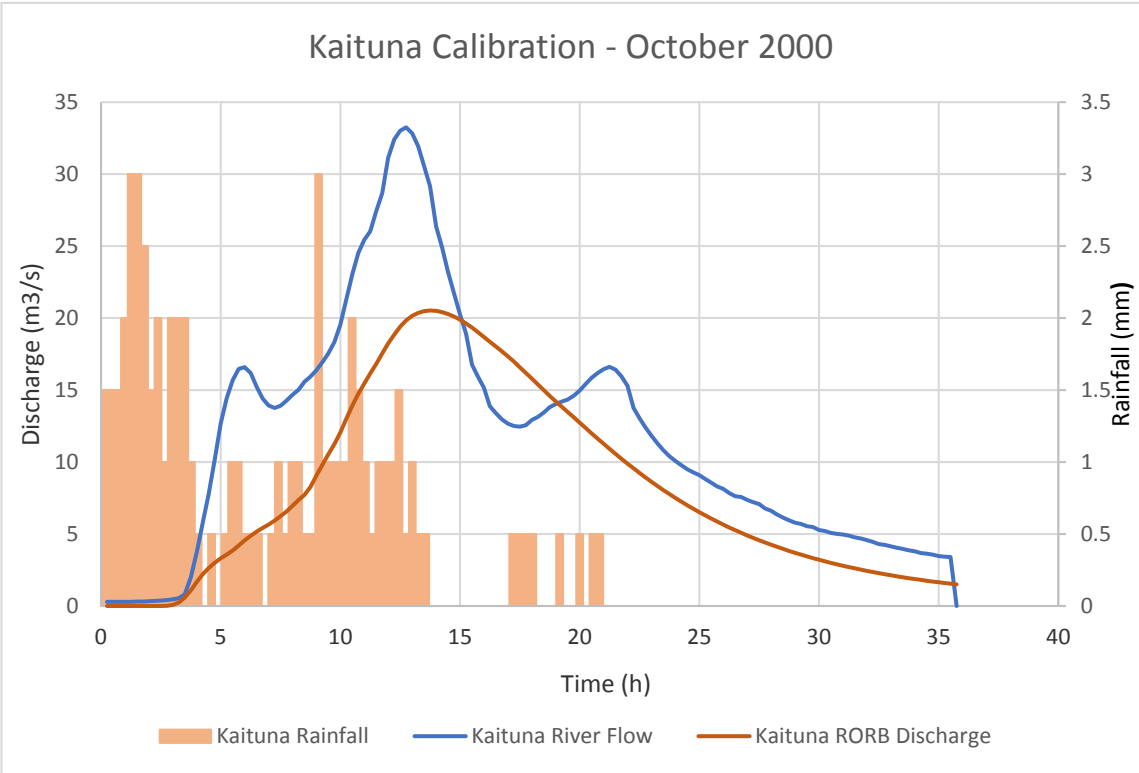


Figure 5 – October 2000 – Kaituna Gauge

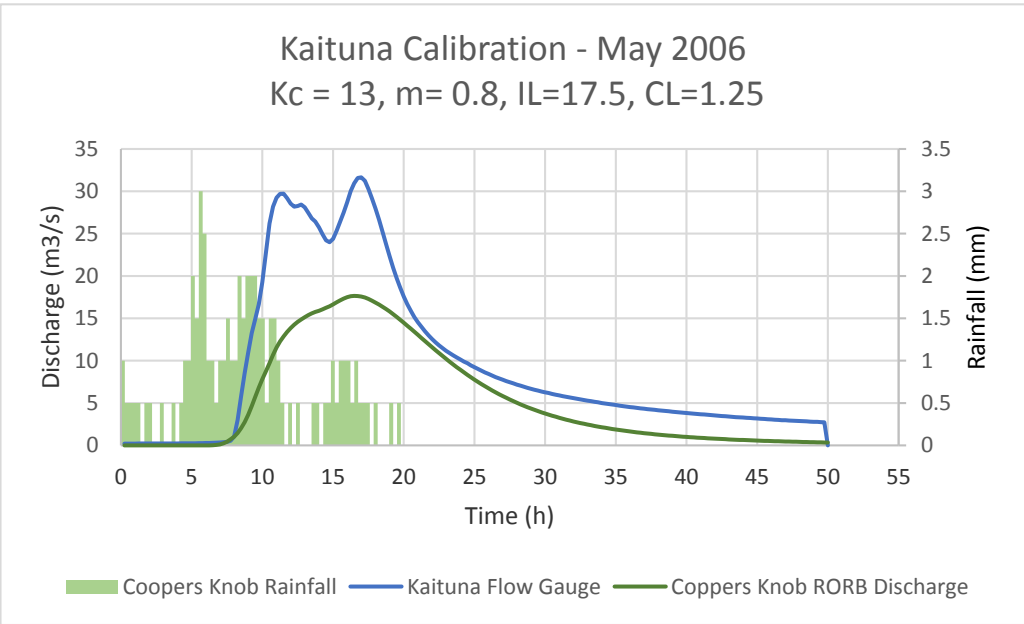


Figure 6 – May 2006 Calibration Event – Coopers Knob Gauge

Memorandum

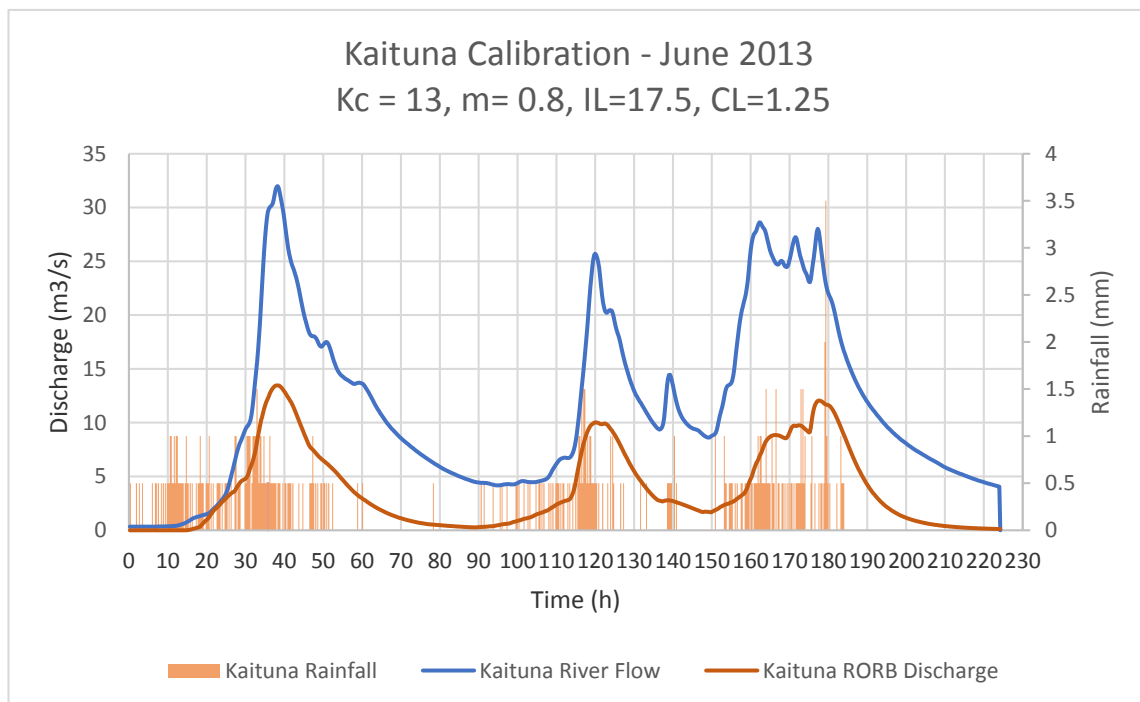


Figure 7 – June 2013 Calibration Event – Kaituna Gauge

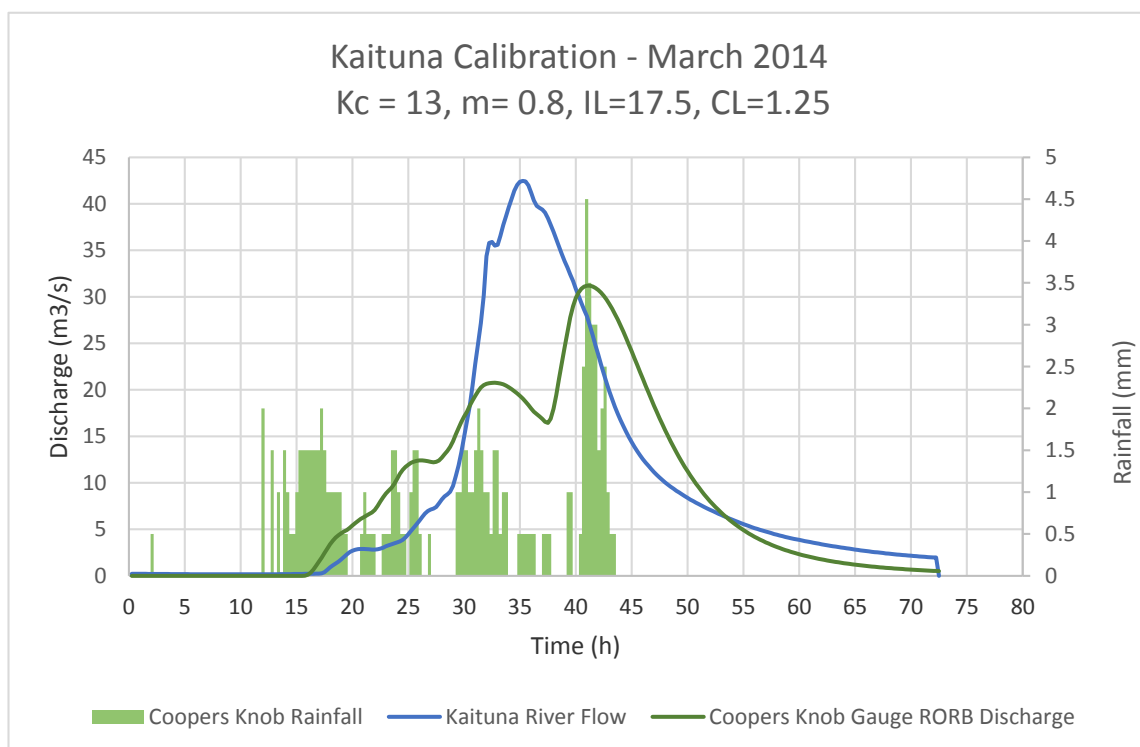


Figure 8 – March 2014 Calibration Event – Coopers Knob Gauge

Memorandum

4 Conclusion

The Kaituna catchment was selected to calibrate the Halswell Hillside RORB models. The Kaituna model was run for four calibration events and with the rainfall records from the Kaituna, Coopers Knob and Akaroa Highway gauges. The runoff results were compared with the Kaituna River flow record. From these calibration runs, the following conclusions were made:

- The Kaituna rainfall gauge under estimates rainfall depths for all calibration events. Lower rainfall has meant that in comparison to the Kaituna river flow gauge, the runoff does not match the peak river flows. Similarly, Coopers Knob rainfall gauge also underestimates the runoff required to meet the Kaituna river flows for all calibration events.
- The Akaroa highway rain gauge over estimates the rain in the Kaituna Valley and consequently, produced unrealistic loss parameters during calibration.
- A k_c of 2, as suggested by AECOM, is too low for rural catchments that include a flat area at the base of the hills. In the Kaituna model, it creates faster and peakier runoff hydrographs and cannot be used for the Halswell Hillside catchments.
- A k_c of 13 should be applied to the Kaituna and the Halswell hillside model. A k_c of 13 is close to the recommend k_c (from the RORB manual) of 13.9 and aligns the timing of peak river flows with the peak runoff for the October 2000, May 2006 and June 2013 events. The closes alignment occurring for the June 2013 event.
- The initial loss of 17.5mm and a continuing loss of 1.25mm are reasonable to be used for Halswell hillside models. These loss values provide the closes alignment of river flows and runoff. They are the same values as AECOM's proposed loss parameters.

The under estimating and over estimation of rainfall depths has made calibration of the model difficult. Consequently, the selected parameters do not provide a good fit with recorded flows for all calibration events. However, the selected parameters are robust, aligning peaks and are close to the expected RORB values.

Natasha Webb

Civil Engineer

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Email: natasha.webb@beca.com

Memorandum

Attachments

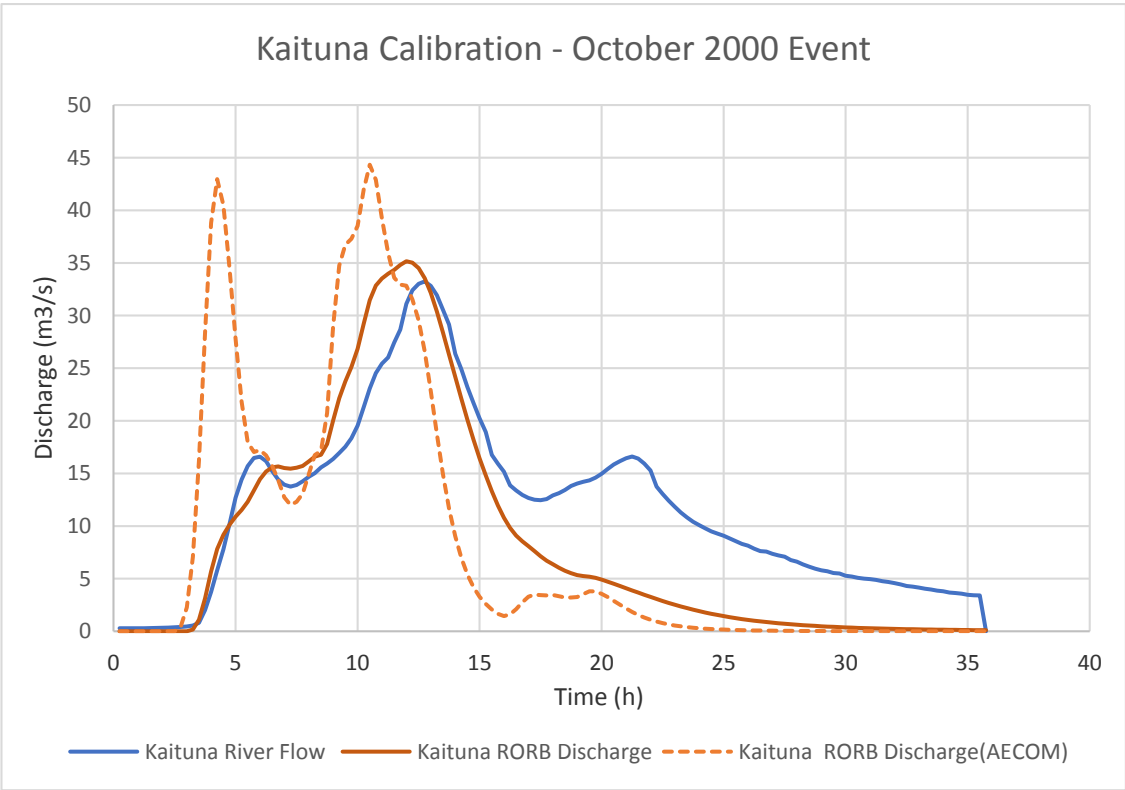


Figure A1 – October 2000 Calibration Event

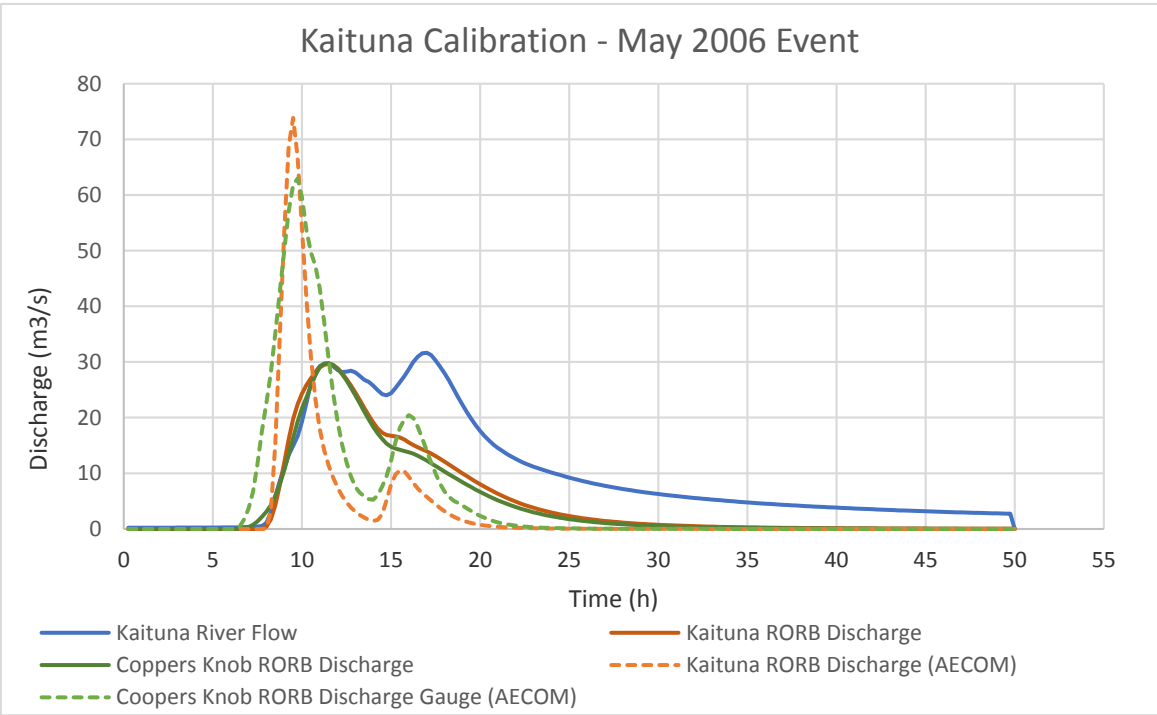


Figure A2 - May 2006 Calibration Event

Memorandum

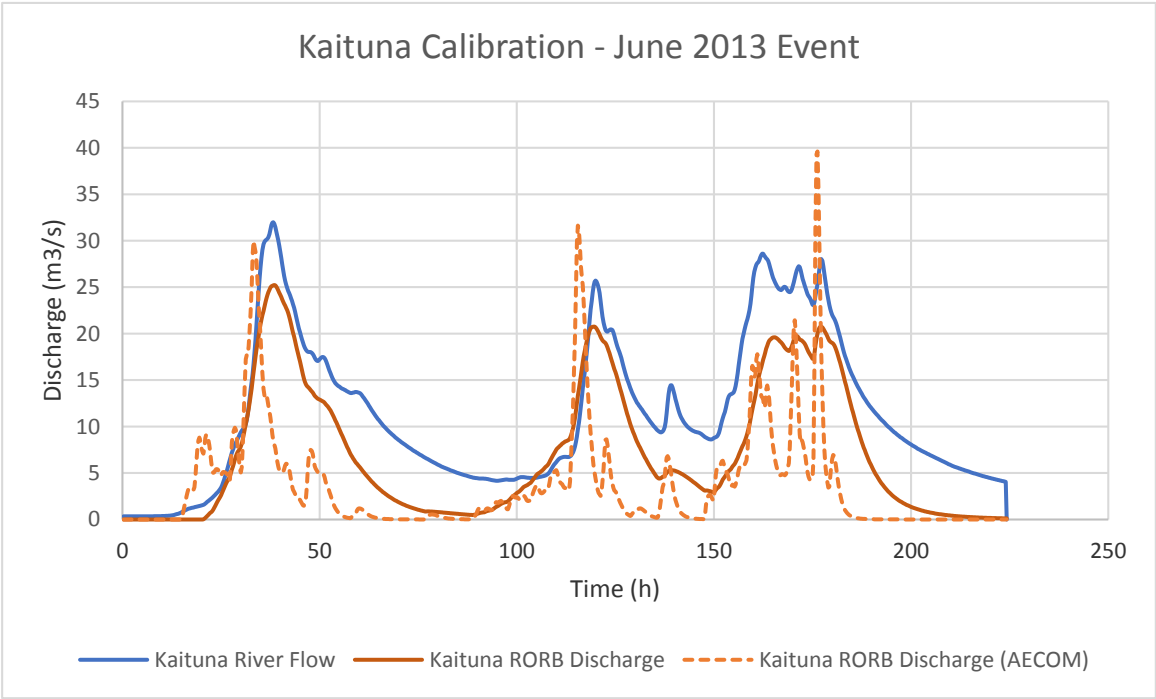


Figure A3 – June 2013 Calibration Event – Kaituna Gauge

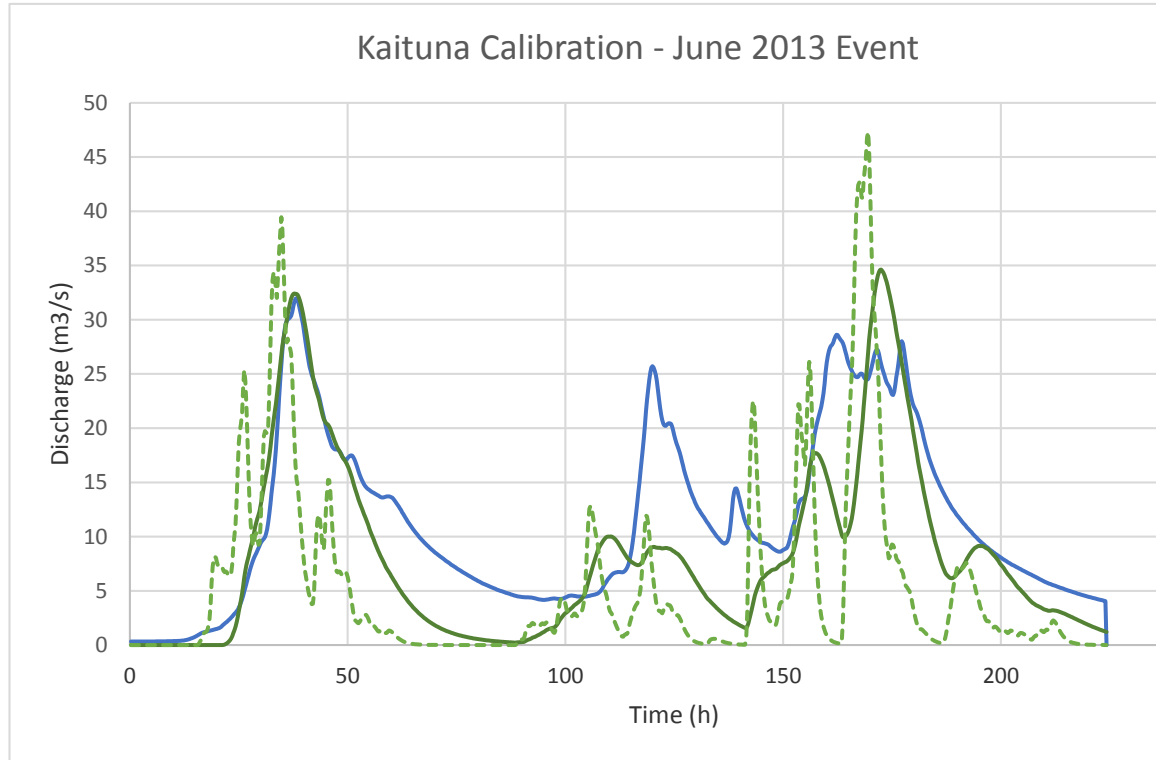


Figure A4 –June 2013 Calibration Event – Coopers Knob Gauge

Memorandum

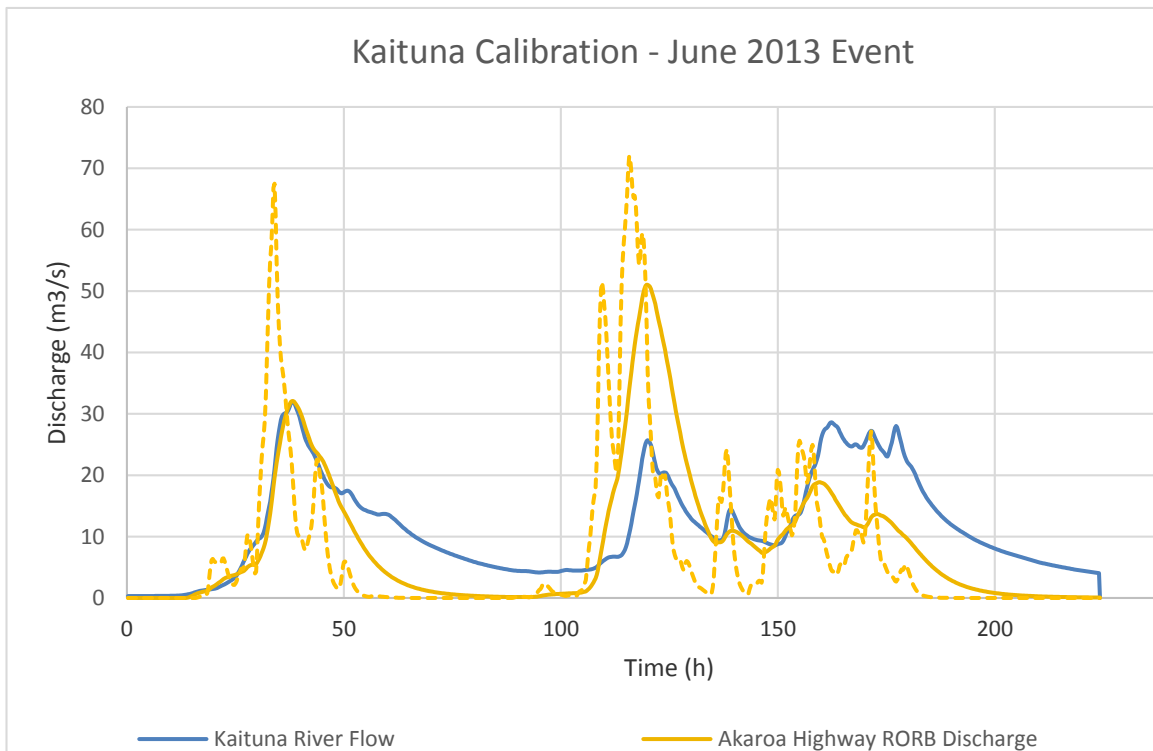


Figure A5 – June 2013 Calibration Event – Akaroa Highway Gauge

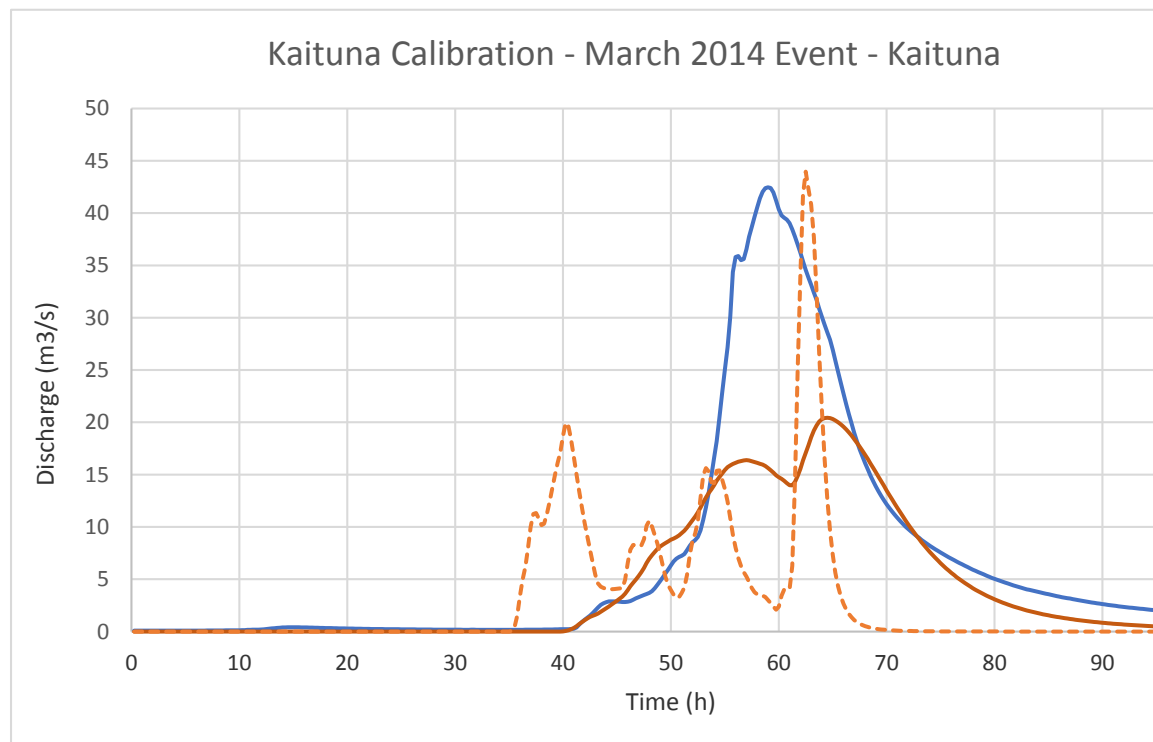


Figure A6 – March 2014 Calibration Event – Kaituna Gauge

Memorandum

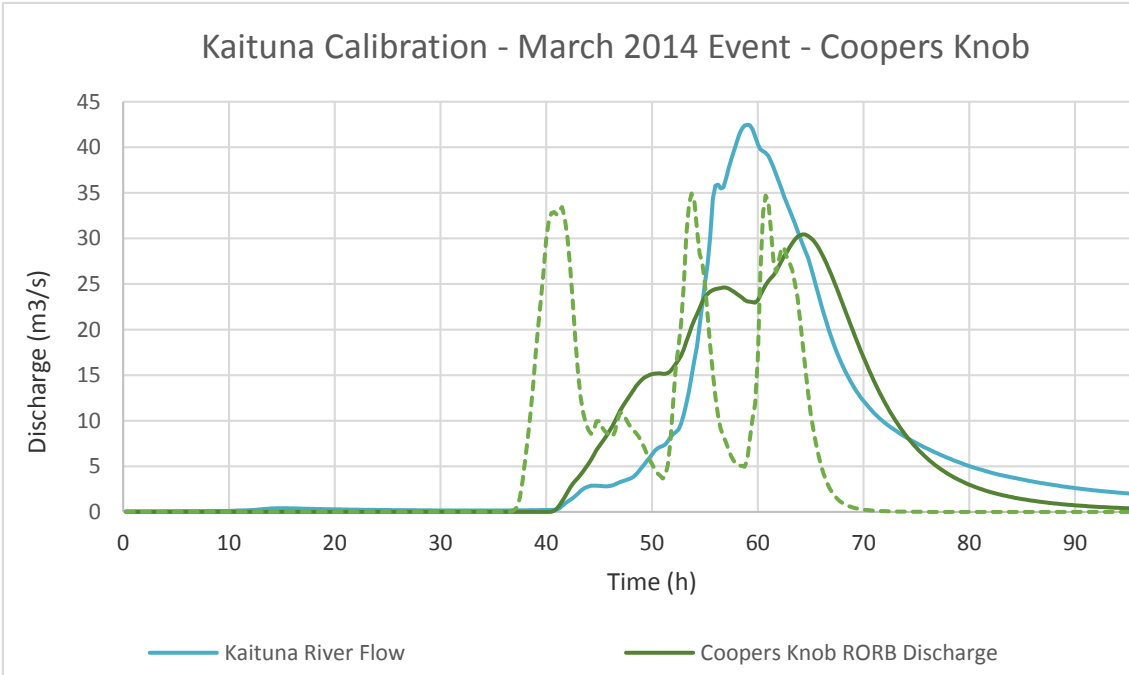


Figure A7 – March 2014 Calibration Event – Coopers Knob Gauge

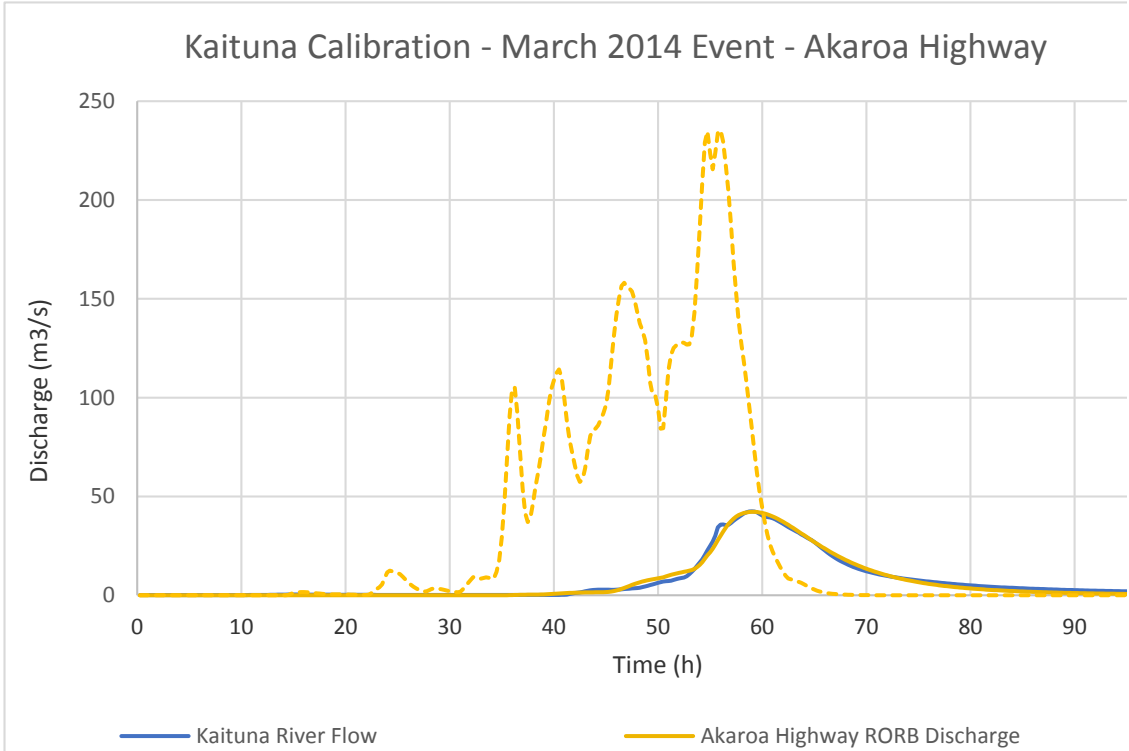


Figure A8 – March 2014 Calibration Event – Kaituna Gauge



Appendix C – CCC Citywide Methodology, A Simplified Approach

Memorandum

To: Elliot Tuck
From: Sher Khan
Copy: Graham Levy; Kate Purton
Subject: Christchurch City Council's Citywide Modelling Methodology. A Simplified Approach

Date: 22 September 2017
Our Ref: 3361713

1 Background

Christchurch City Council introduced a new citywide modelling approach (CCC-Citywide Flood Modelling (LDRP 044), 2017). The purpose was to keep the modelling work consistent throughout CCC area and increase the level of details in Mike by DHI models. At the time of this memo the modelling methodology was still in draft form and changes were expected in the final report.

The relevant specifications to this Citywide Flood Modelling Methodology are:

- Waterway and Wetland Design Guide (2011), CCC
- Stormwater modelling Specification for Flood Studies (2012), GHD
- Christchurch City Council MIKE FLOOD Technical Specification (2015), DHI

2 Purpose of this memo

The purpose of this memo is to simplify the Mike 21FM mesh generation process. The memo list the steps to generate the flexible mesh in an easy to understand way. This method does not require Spatial Analyst Tool of ArcGIS or GHD code to write DEM values onto mesh instead it uses QGIS which is available for free.

3 Generating Mesh as per Citywide Modelling Requirements

The following are the steps to generate the mesh as per citywide requirement

3.1 Generating mesh polygons

- Convert shapefiles of catchment boundary, roads, railways and channels to produce *.xyz files
- Open *.MDF file and set it projection.
- Import the catchment file in *.MDF file to define the mesh boundaries as follows:
 - Data →import boundary. Import the catchment boundary with the option of X,Y and Connectivity / NZTM/ [m]/[m]/use connectivity information/discard arc <2 vertices.
 - Define the polygons to exclude or include in the mesh and set the mesh triangles area. For Halswell area, set the maximum mesh element size for flat area and hillside to 200 m² and 1000 m² respectively.
- Import the river boundaries (1D) as above
- Import the road and rail boundaries as follows:
 - Data→Manage scatter data→Add and brows to the road/rail point (xyz) data.
 - Now convert the above road/rail points to mesh nodes. Convert→Convert scatter data file to Mesh nodes.

Memorandum

- Import the hill streams' data and convert it to mesh nodes same as road/rail data.
- Import correction points (if any) and convert it to mesh nodes same as road/rail data.
- Generate the mesh with the criteria given in Table 1

Maximum element area	1000 m ²
Smallest allowable angle	26
Maximum number of nodes	10,000,000

- Smooth mesh by 10 iterations and tick the box for "constrained by mesh criteria".
- Export mesh and DFSU files (**Don't assign Z values to mesh at this stage**). When exporting DFU set the item type to "Bed level change". You can change ITEM type at any stage by opening the DFSU file in Data Manager and browsing under View→Items
- Convert DFSU file to GIS using Mike Zero tool "Mike2Shp" available under Mike Zero Tool Box. Always convert DFSU file to shape file not the MESH file.

3.2 Mapping Z values on shape file

- For mapping Z values on shape file use QGIS.
- Load shape file generated from DFSU file
- Load DEM data (tiff or asci)
- In QGIS under raster Tab, use zonal statistics to calculate the mean values within each triangle as shown in Figure 1. Note that a column "mean values" will be add in the attribute table. You need to give it same name as was used for the ITEM type in the DFSU file. At the end multiply the values with -1. Syntax is (Bathymetry * -1).

3.3 Mapping Z values on DFSU file

For mapping Z values on the DFSU file use the DHI tool "update_dfsu_z_value_from_shp".

- Open DHI tool and run the "DHI.NZSOL.UpdateDfsuZValueFromShp.exe" file and brows to SHP file (section 3.1) and DFSU file.
- Hit process and wait until word "Success!" appears
- A copy of the DFSU will be generated in the same folder where the original DFSU files was placed.
- Note that you could run this tool from any drive and all files do not need to be in the same folder.

4 Assigning Depth Correction in Mike21FM

- In MIKE 21 FM, go to Hydrodynamic Module →Depth and set the depth correction type to specified bed level change. Browse to the newly created DFSU file containing additive inverse topography values. Save the MIKE 21 setup.
- Open the Mike21FM (*.m21fm) file in a text editor. Search for DEPTH and Change the type from 1 to 2 as shown in Figure 2. This will ensure that the values in the mesh are ignored and overwritten by the depth correction values.
- Note that the depth correction type will be greyed out when you will open the Mike 21 model. If it is not then make sure that the parameter "Type" is set to 2. Refer to Figure 3.

Memorandum

Sher Khan

Modeller

Phone Number: +64 3 366 3521

Email: sher.khan@beca.com

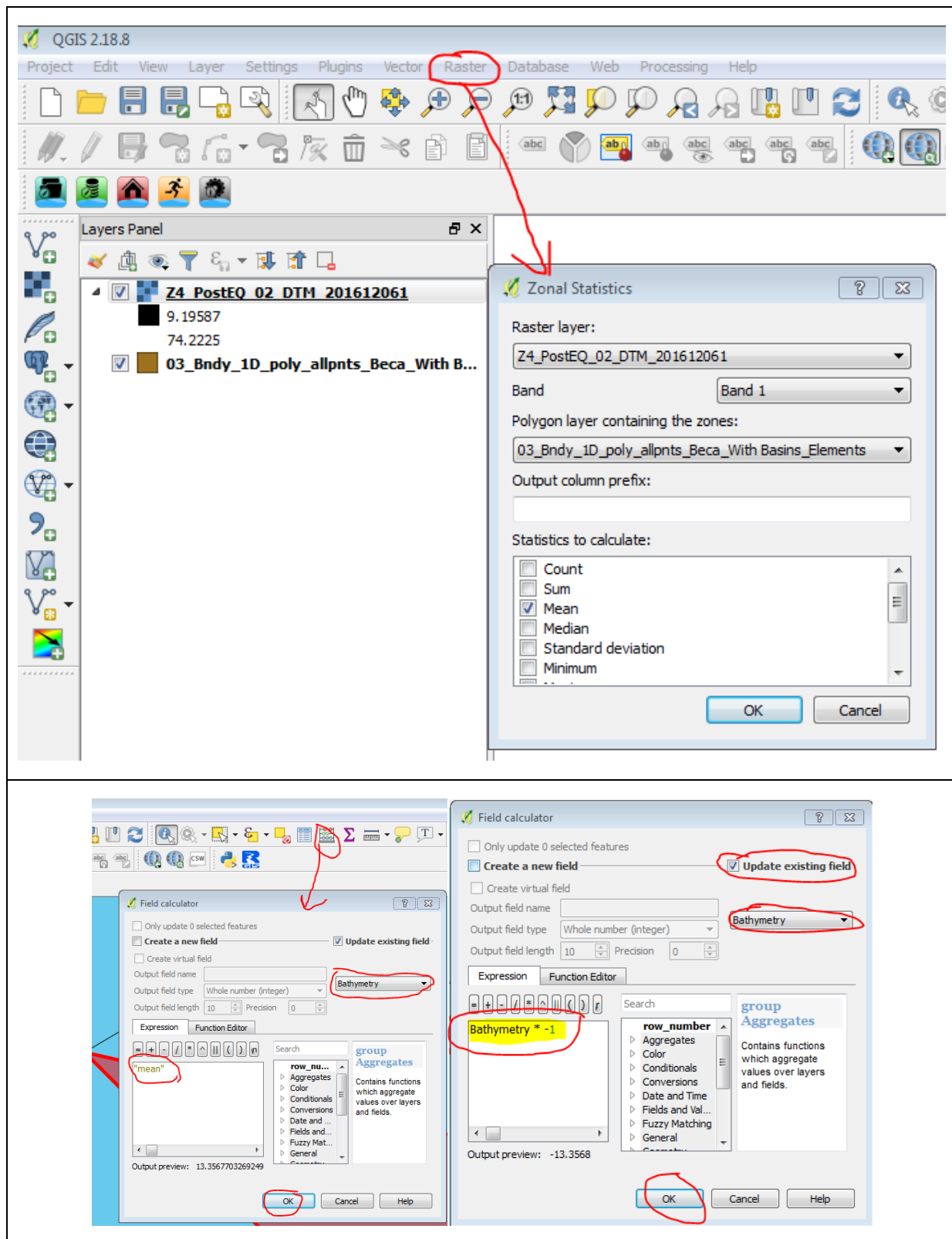


Figure 1: Zonal Statistics in QGIS

Memorandum

```
[DEPTH]
  Touched = 1
  type = 2
  format = 2
  file_name = |.\BedLevelChange.dfsu|
  item_number = 1
EndSect // DEPTH

[FLOOD_AND_DRY]
  Touched = 1
  type = 2
  drying_depth = 0.02
  flooding_depth = 0.05
```

Figure 2: Mike 21 FM edits in text editor

The screenshot shows the 'Depth' dialog box in Mike 21 FM. It has a title bar 'Depth' and a 'Depth correction type' dropdown menu. Below this is a 'Depth correction' section containing a 'Format' dropdown menu set to 'Varying in space, constant in time'. Underneath, there are two rows of input fields: 'Data file and item' with a text box containing 'C:\Users\noba\Desktop\MIKE21\BedLevelChange.dfsu' and a 'Select...' button, and 'Item: Bed level change' with a 'View...' button.

Figure 3: Mike 21 FM depth correction

D

Appendix D – Road Mesh Points Memorandum

Memorandum

To:	Stephen Holder	Date:	12 May 2021
From:	Josh Cumberland	Our Ref:	3364860-1092705358-240
Copy:	Tyler McMillan		
Subject:	Revised methodology for mesh road point development in the Huritini/Halswell River flood model		

Introduction

Christchurch City Council have requested more detail on how the road points were generated for the 2D mesh in the Huritini/Halswell River Model.

Road points for the mesh are required to generate mesh elements that reasonably represent the road features, particularly road crests and gutters. The Citywide Flood Modelling (CFM) Model Schematisation Report (GHD, 2018) outlines how road points were generated for the Citywide mesh. We encountered issues following the CFM guidelines, mainly due to a lack of detail on establishing points at intersections and inoperative GIS tools that were supplied to automate the process. As a result, we have agreed with Council that an alternative method can be adopted for the Huritini/Halswell River Model. We have laid out this procedure below.

Methodology

Road points were developed in accordance with the CFM Model Schematisation Report (GHD, 2018). Deviations from the CFM methodology are *italicised* below:

1. NZ road centreline shapefiles were buffered by 6.5 m (Local Road classification in the CFM Model Schematisation Report) to produce gutterline alignments.
2. Road centre outlines were produced to form the centre row of mesh triangles by buffering the road centreline by one-third of the buffer distance for the gutterlines (i.e. 4.33 m).
3. Points were created along the buffered lines at an average spacing of 7.9 m.
4. *Intersection centre points were created using the 'Intersection' function in QGIS (a function that extracts the overlapping portions of features [in this case, the road centrelines] in the Input and Overlay layers).*
5. Internal intersection circles were created at a 6.9 m radius buffer from the centre points.
6. External intersection circles were created at a 13.5 m radius buffer from the centre points.
7. Points closer than 4 m apart were merged to a single point.

The points automatically generated in Step 3 did not adequately define the layout of each road junction. The points were therefore moved so that the junction could be defined as per Figure 1. Because the spread of points at each junction differed this process was done manually by snapping points to intersections, as follows:

- a. *At the main intersection node*

Memorandum

b. At intersections of the road centrelines and the internal intersection circles

c. At intersections of the road centre-outlines and the external intersection circles

An intersection produced from this methodology is shown in Figure 1. An example intersection from the CFM mesh produced by GHD is shown in Figure 2.

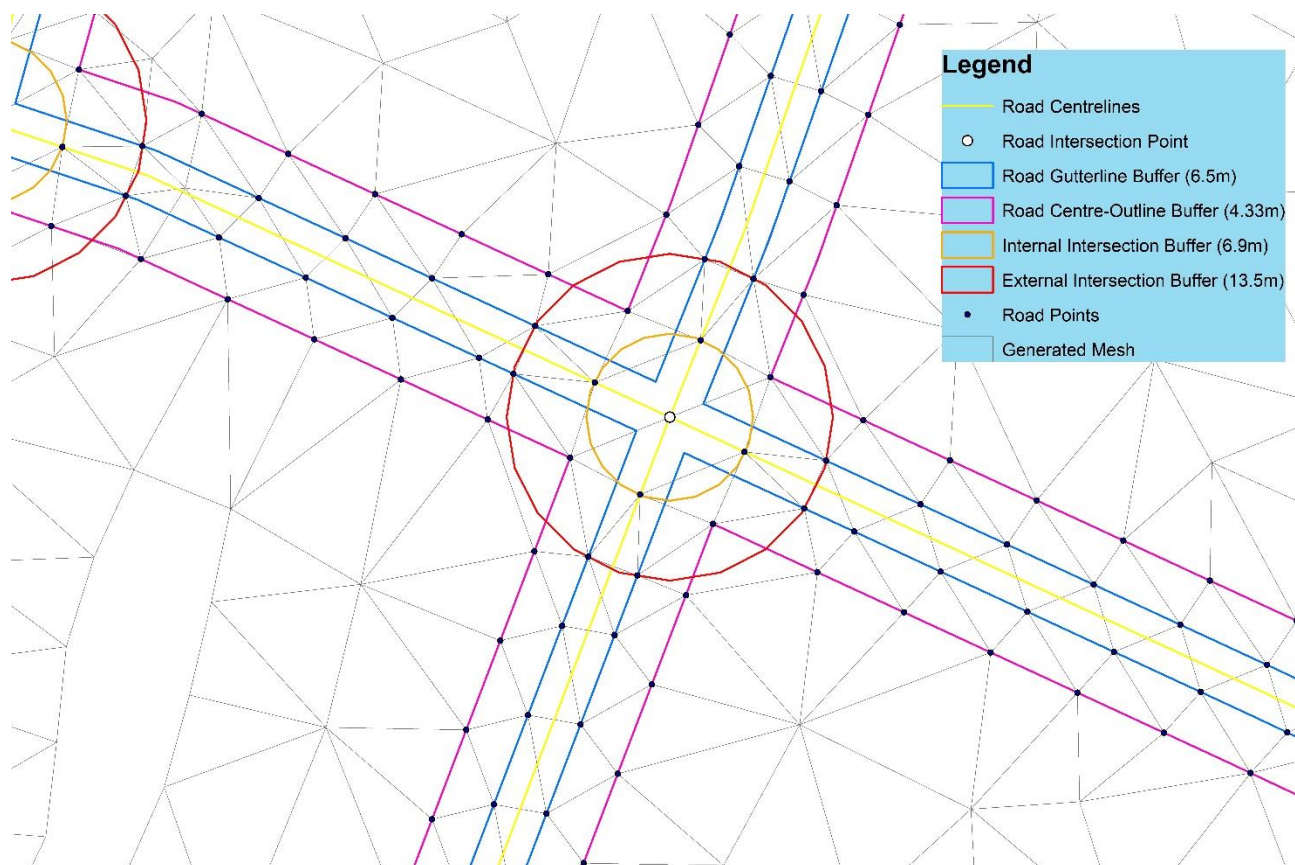


Figure 1 Example intersection

Memorandum

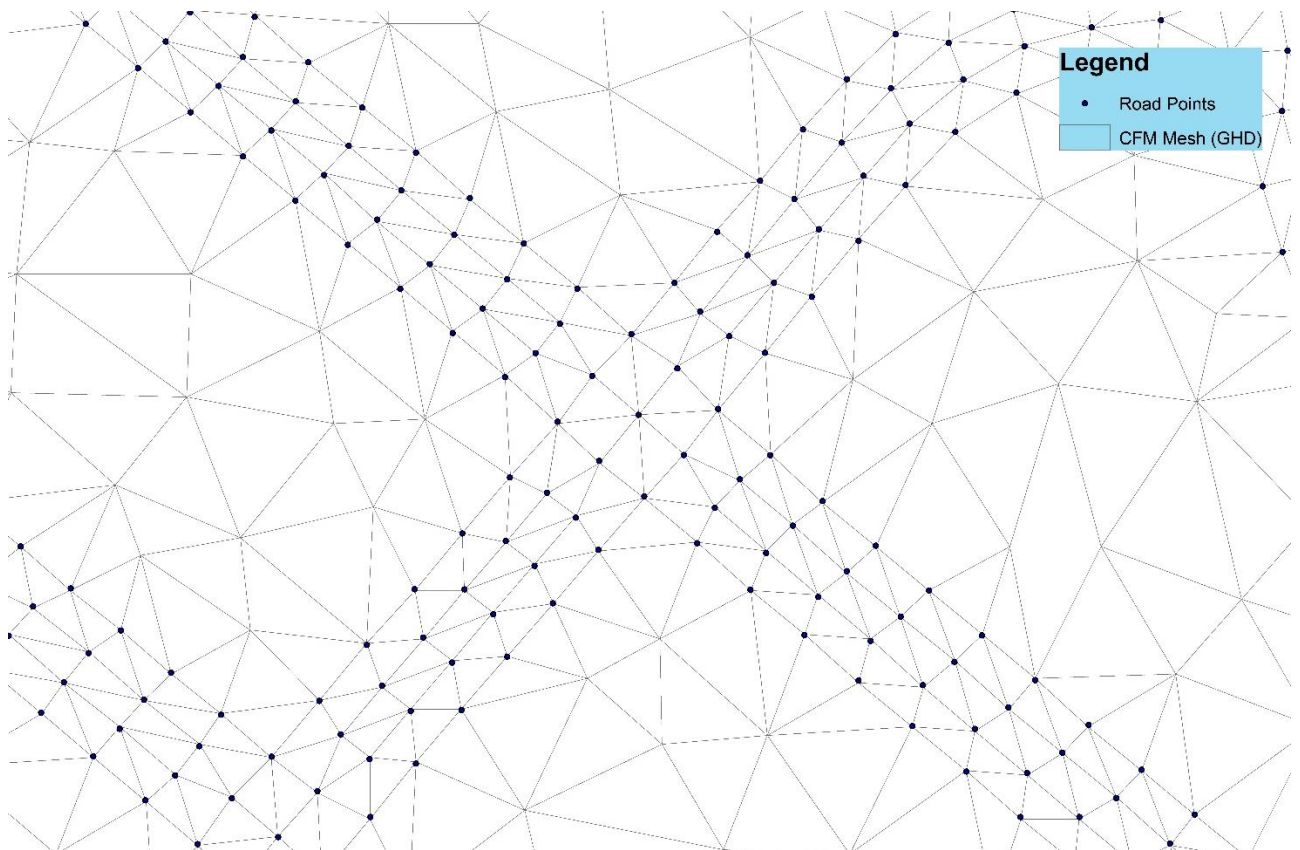


Figure 2 CFM mesh intersection (GHD)

Deliverables

Deliverables from this method will include a road point shapefile, and all shapefiles used to create the road points (road network centrelines, intersection points, road and intersection buffer-lines).

E

Appendix E – Beca Response to DHI Review of Road Methodology

14 May 2021

Attention: Antionette Tan (DHI)

Dear Antoinette,

Thank you for your review of Beca's proposed revisions to the mesh generation and depth correction layer for the Halswell model. The reviewed documents were "Depth Correction Memo – Variation Request 6b" and "Road Mesh Points Memo – Variation Request 6b" both dated 9th April 2021. Below is a response to the points raised in your review. We have attached revised versions of the methodology memorandums, as well as your review letter.

Road mesh points method

Your review did not provide any comments on the methodology or the accompanying memorandum and therefore we have finalised these in their original form.

Depth correction method

Your review highlighted several potential methodology issues, asked for clarification in the text, and posed additional questions. Our response to your review is provided below.

1.1 Methodology issues

Issue 1 - Under the section titled "Implications of the methodology and changes from the original CWM schematisation" you raised a concern that if a large difference existed between the road crest and the gutter point elevation, the MIKE21 v2016 flooding and drying algorithm could produce instabilities in the model. The original CFM methodology limited the road crossfall slope to 6 % to improve model stability. You suggested that the v2020 algorithm is more stable in this regard, but without running the model these stability issues could not be assessed.

Outcome - We agree there is a potential stability issue, which should be limited to rural roads due to the location of the buffer lines. We do not propose to change the model to v2020 at this stage, rather we will continue with v2016. We propose to resolve any instabilities associated with this issue during the model stabilisation step (ie we will treat any instabilities in the same way we would treat instabilities from other model components). We therefore do not propose any further modifications to the methodology. This could be revisited if there is widespread instability that stops the model from running and effects large areas within the city boundaries.

Issue 2 - You identified a limitation of our proposed methodology relating to larger roundabouts. For such structures you rightly point out that they are poorly represented as mesh sizes become larger near the wider edges of the roundabouts. As you have indicated this was also a limitation in the original methodology also.

Outcome – We have discussed this matter with Council and have agreed that matching the level of detail in the original methodology is sufficient for their purposes. We therefore propose to continue with the methodology as described.

1.2 Text clarifications

All comments in the section titled “Clarifications in the text” have been addressed. Updated versions of these memorandums have been attached.

1.3 Additional questions

Clarification was requested about the extent of change for the depth correction layer update (i.e. only updating the new model areas and new roads and leaving the remaining areas with previous values vs. updating all areas of the model). Our proposed methodology is to update all depth correction values for the model extent because a new mesh had to be generated for the entire model domain. There will be slight discrepancies in the mesh element alignment between the previous model mesh and the updated model mesh (even for older areas in the model that haven't been changed), so all of the model mesh depth correction values have to be updated.

A question was raised about generating a DEM for the model extent, similar to the CWM DEM showing the overlayed road surface DEM. Given that our methodology doesn't create a separate road surface DEM, but only returns various zonal statistic values for each mesh element (mean, minimum and maximum), the only DEM that can be delivered was the .tiff shared during the initial review (i.e. a TIN with elevation values assigned to each element centroid).

Closure

Based on the above we intend to proceed with the model development and subsequent stabilisation runs. If there are any points you feel have not been address appropriately please contact us to discuss.

Yours sincerely



Josh Cumberland

Hydraulic Modeller

on behalf of

Beca Limited

Phone Number:

Email: Josh.Cumberland@beca.com

Copy

Stephen Holder, Christchurch City Council (CCC)



Appendix F – Calibration & Sensitivity analysis report

HDM Halswell Flood Model - Model Calibration Report

29 April to 2 May 2025 event Prepared for Christchurch City Council

Prepared by Beca Limited

5 September 2025



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everyday
better.

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1 Introduction

1.1 Scope

Following the severe flooding from **29th April to 2nd May 2025**, Council requested Beca to compile rainfall, GIS, and hydrometric data from the May 2025 event and calibrate the RORB and MIKE models before proceeding with design runs. This report sets out the observed data for the event that has been collected from various sources and compares the results of the calibration runs to relevant observed data.

1.2 Calibration Approach

Model calibration was carried out using the Existing Development 2025 model as the base. Calibration was undertaken using aerial flood extent photographs taken on 2nd May 2025 (ECan) and water level/flow data from key sites, including Halswell Junction Basin, Cox-Quaifes Basin, Nottingham Stream at Nicholls Road, Knight Stream at Sabys Road, and Halswell River at Ryans Road Bridge, as outlined in section 2.3 and 2.4 respectively.

2 Available Data

Rainfall data for the 29th April – 2nd May 2025 event was collected and analysed from both rain radar and gauge sources. Further details are provided in the following sections.

2.1 Rainfall Radar

Gauge corrected radar rainfall data for the calibration event was obtained from MetService, with total depths ranging from 65 to 340 mm. Refer to Figure 2-1 for spatial distribution.

2.2 Rainfall Gauges

Gauge rainfall data for the 29th April–2nd May event was sourced from NIWA, with data from 29 stations used for spatial extrapolation. Total rainfall depths ranged from 66 to 196 mm. Interpolation was performed using the natural neighbour method, and data was converted to MIKE *.dfs2 format for model input. Gauge locations are shown in Figure 2-2.

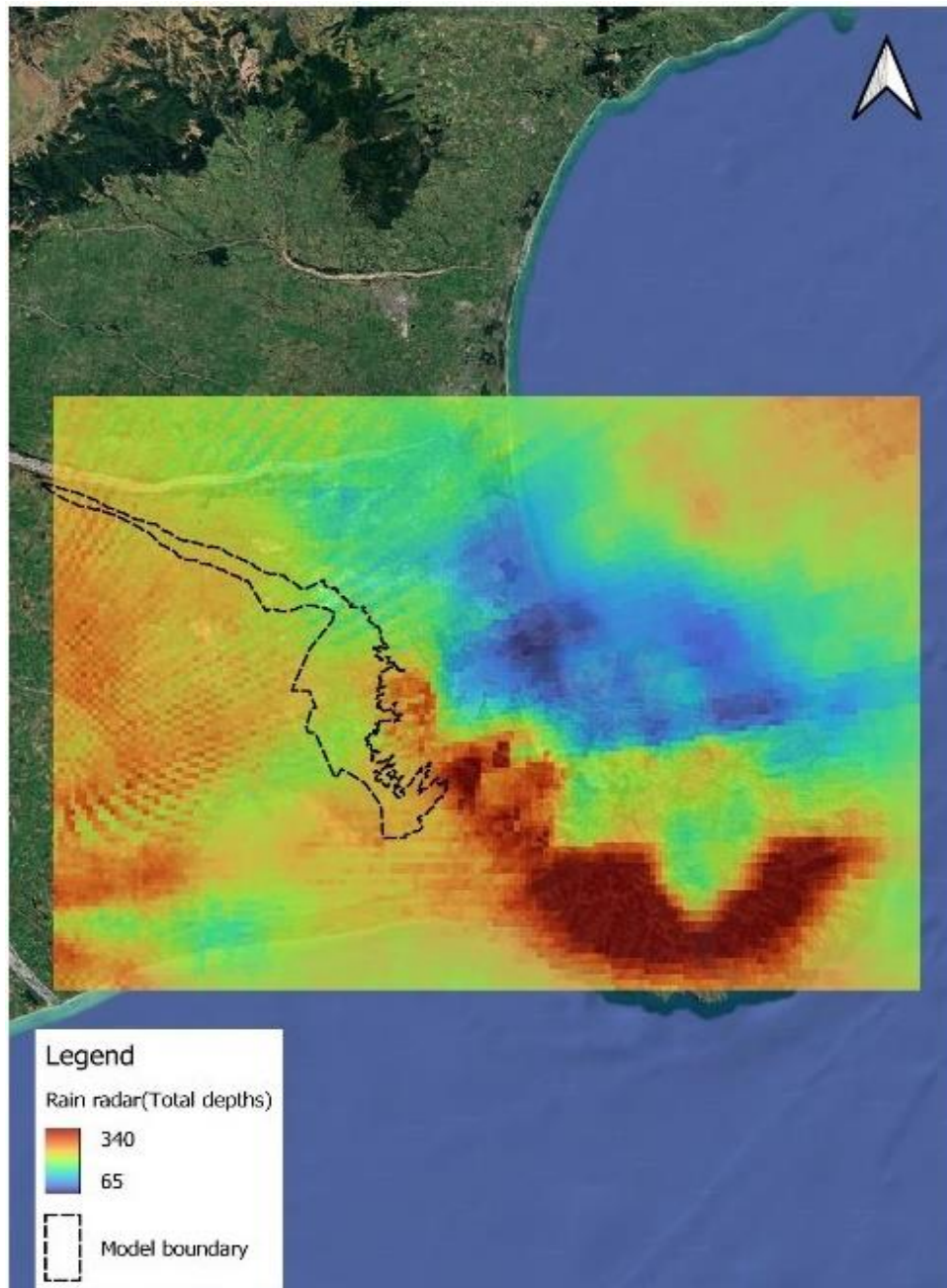


Figure 2-1 Halswell radar rainfall

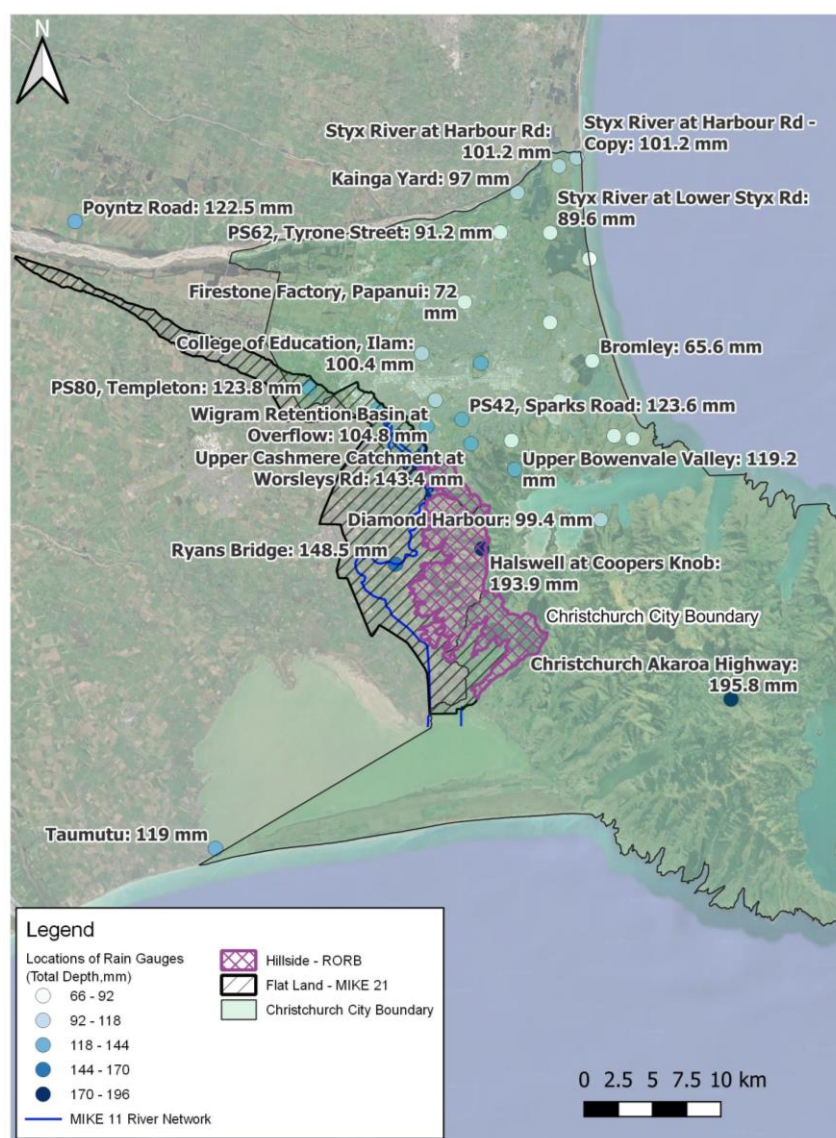


Figure 2-2 Halswell gauge rainfall

Table 2-1 summarises the locations and total rainfall depths of gauges used for calibration, highlighting higher rainfall in the southern and eastern areas of the model boundary.

Comparison of radar and gauge data shows significant differences, with radar consistently reporting 20% to 143% higher values than gauges at the same locations. Smaller differences (36%–49%) were observed for gauges within or near the Halswell catchment (see Figure 2-3). For this reason, gauged rainfall data was used for detailed model comparisons of water levels, discharge, and flood extent. The methodology for preparing data for RORB and MIKE inputs are provided in Appendix 1.

Table 2-1 Total rainfall depths recorded at calibration gauges.

Name	NZTM X	NZTM Y	Event Total depth (mm)
College of Education, Ilam	1564991.734	5181017.509	100.4
Styx River at Harbour Rd	1575010.672	5194753.504	101.2
Styx River at Harbour Rd - Copy	1576317	5195370	101.2
Wigram Retention Basin at Overflow	1565988.351	5177602.55	104.8
Christchurch Botanical Gardens	1569301.465	5180310.747	118.6
Taumutu	1549900.787	5144720.496	119.0

Name	NZTM X	NZTM Y	Event Total depth (mm)
Upper Bowenvale Valley	1571775.255	5172517.636	119.2
Poyntz Road	1539628.116	5190695.111	122.5
PS42, Sparks Road	1567911.712	5176191.866	123.6
PS80, Templeton	1556726.597	5178519.739	123.8
Ridgens Road	1527199.45	5171236.962	124.0
Halswell Retention Basin, Halswell Junction	1561782.175	5176944.542	133.4
Aidanfield, Dunbars Reservoir	1565361.363	5175695.403	136.6
Upper Cashmere Catchment at Worsleys Rd	1568585	5174400	143.4
Ryans Bridge	1563064.349	5165567.238	148.5
Halswell at Coopers Knob	1569396.691	5166696.504	193.9
Christchurch Akaroa Highway	1587593.916	5155674.363	195.8
Bromley	1577451.726	5180480.075	66
Van Asch St, Sumner	1580405.81	5174773.404	67
Avon River at PS205	1574368.146	5183289.061	72
Firestone Factory, Papanui	1568122.705	5184786.344	72
Bowenvale Flume at Bowenvale Ave	1571548.292	5174633.743	79
Reservoir No.4, Clifton Tce	1579050.445	5174982.102	80
Tunnel Road, Heathcote	1575055.286	5177522.288	87
Styx River at Lower Styx Rd	1574378.683	5189873.025	90
Styx River at Lower Styx Rd - Copy	1577247	5187946	90
PS62, Tyrone Street	1570731.119	5189902.934	91
Kainga Yard	1571973.37	5192819.284	97
Diamond Harbour	1578065.163	5168838.483	99

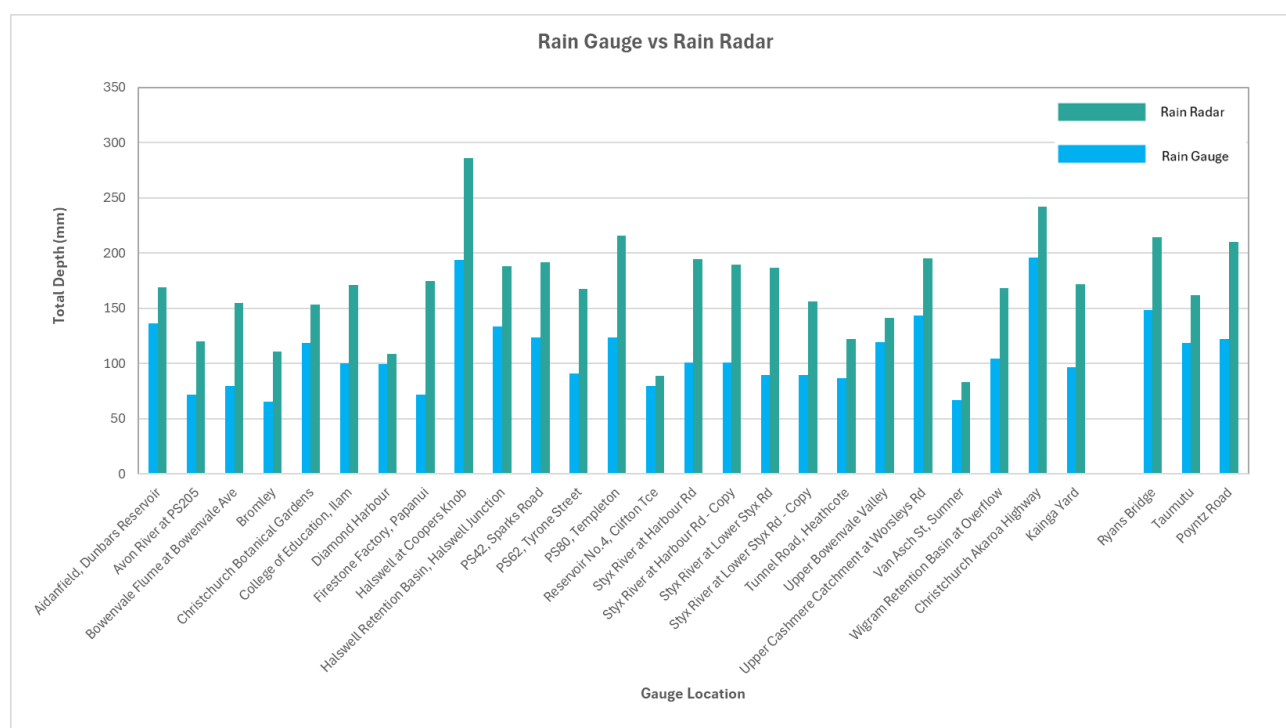


Figure 2-3 Comparison of total rainfall depths between radar and gauge data.

2.3 Level Gauges

Eight water level stations are available within the model boundary: five in basins (one at Halswell Junction Basin and four in Cox-Quaifes Basin—including three within the basin and one at the outfall culvert); and three in drains (Knights Stream at Sabys Road, Nottingham Stream at Nicholls Road, and Halswell River at Ryans Bridge, 11 km from Halswell).

Water level data for the 29th April-2nd May 2025 event was sourced from Christchurch City Council and ECan for model calibration. For Cox-Quaifes Basin, only two stations were selected to validate simulated levels. Station locations are shown in Figure 2-4 and maximum recorded stages are summarised in Table 2-2

Table 2-2 Recorded maximum stage at water level gauging sites.

Sensor location for water level	Source	Event Max stage (m)
Halswell Retention Basin	CCC	23.107
Nottingham@Nicholls Rd 20001AC5	CCC	13.964
CQ 1st Flush LS1-R 20000F75	CCC	12.395
CQ Detention LS1-R 20001028	CCC	12.391
CQ Wetland LS1-R 200010B8	CCC	11.879
CQ Culvert LS1-R 200010CC	CCC	11.781
Knight Stream at Sabys Rd	CCC	11.273
Ryans Bridge	ECan	6.457

The cross-section at a stream recording site (Knights Stream and Ryans Bridge) can have an effect on the water level recorded. The model relies on LiDAR derived cross-sections at the Ryans Bridge site and surveyed cross sections in Knights Stream at Sabys Rd.

2.4 Flow Gauges

There are two flow gauges in the Halswell area that record both flow and level: Knights Stream at Sabys Road and Halswell River at Ryans Bridge (approximately 11 km from Halswell, with a catchment area of ~76 km²). The Sabys Road gauge, installed after the 2013 event, is near the city boundary and well placed for assessing upper catchment flows although noting that the catchment has very little development at this stage and is mostly pasture. Observed flows from these stations were used for calibration. Gauge locations are shown in Figure 2-4 with maximum event flows summarised in Table 2-3.

Table 2-3 Recorded maximum flows at gauging sites.

Sensor Location for Discharge	Source	Event Max Flow (m ³ /s)
Knight Stream at Sabys Rd	CCC	1.45
Ryans Bridge	ECan	12.633

Both the Knights Stream and Ryan Rd Bridge sites record water level only, the flow comes from a rating to convert water level to flow based on manual flow gaugings. Often there is less confidence in rating (i.e., the flows predicted from the water level) at higher flows as there tend to be less manual gaugings at high flows.

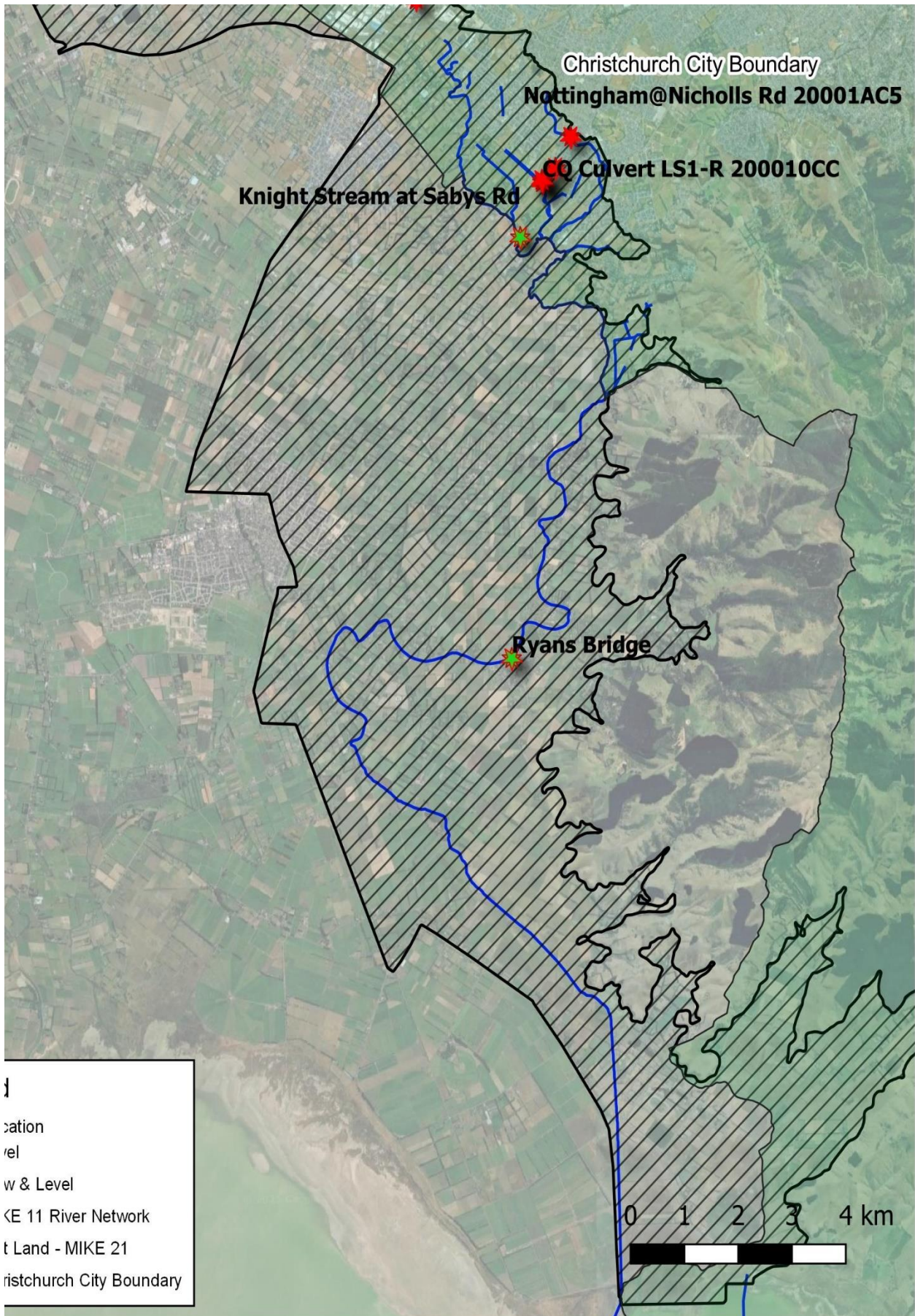


Figure 2-4 Gauging stations location

2.5 Aerial Photos

Aerial photography supplied by ECan was used to validate the 2D flood extent, with coverage mainly focused south of Halswell and limited imagery in the upper catchment (only two photos within the Christchurch City Boundary). The model extends to Te Waihora/Lake Ellesmere but includes limited detail in the lower reaches, where farm drains and minor culverts (e.g., Dawsons Creek) are not represented. Not all flooded areas may have been captured due to limitations in aerial coverage. Model results were compared with ECan photos at matching timestamps (2/5/2025 8:40 AM), as outlined in Section 4.2.

3 29 April – 2 May 2025 Calibration Run

3.1 Model Geometry Changes

No adjustments were made to the model geometry (pipes, elevation model, boundary delineation, and so on)

3.2 Boundary Conditions

The RORB model was updated with event rain gauge data to provide flow boundary inputs to MIKE at the Port Hills side. The MIKE coupled model used the April–May, 2025 rainfall file as a boundary, with all other parameters unchanged for baseline comparison. Hydrology (infiltration rates) is based on calibrated variables from the Heathcote model.

4 Results

4.1 Peak flows and levels at different stations

Table 4-1 summarises calibration results against observed data.

Table 4-1 Recorded maximum flows and water levels at gauging sites.

Location	Peak flows (m ³ /s)			Time at Peak diff. (hour)	Peak WSE (m)		
	Modelled	Gauged	Difference		Modelled	Gauged	Difference(mm)
Halswell Junction Basin	-	NA	-	-	23.09	23.11	-20
Nottingham@Nicholls Rd 20001AC5	-	NA	-	-	13.98	13.96	20
CQ Detention LS1-R 20001028	-	NA	-	-	12.42	12.39	28
CQ Culvert LS1-R 200010CC	-	NA	-	-	11.83	11.78	50
Knight Stream at Sabys Rd	2.98	1.89	58%	3.9	11.56	11.27	290
Halswell River at Ryans Bridge	16.86	12.63	33%	7.05	6.50	6.46	44

Water level comparison at Halswell Junction Basin shows good alignment in peak timing and levels, with a difference of only ~20 mm. The 1D model indicates rapid basin filling and emptying, possibly due to inlet/outlet setup. Differences in initial water levels are due to 2D initial condition issues in the baseline run (see Figure 4-1).

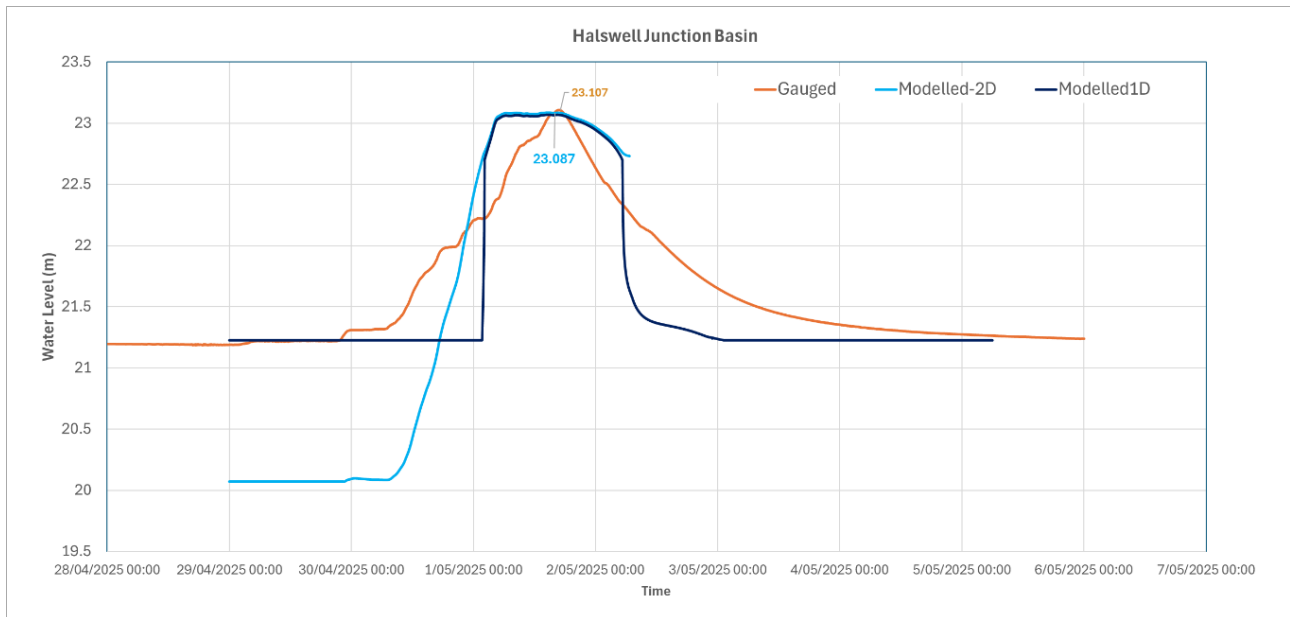


Figure 4-1 Water Level comparison at Halswell Junction Basin

The Nottingham Stream site shows modelled and observed water levels to have good agreement in both shape and timing, capturing multiple peaks effectively. The timing alignment suggests accurate catchment response and flow routing. The high-water levels observed on the rising limb could be attributed to inaccuracies in spatial and temporal rainfall averaging-potentially causing overestimation when interpolating or a cross-section difference. This is shown in Figure 4-2.

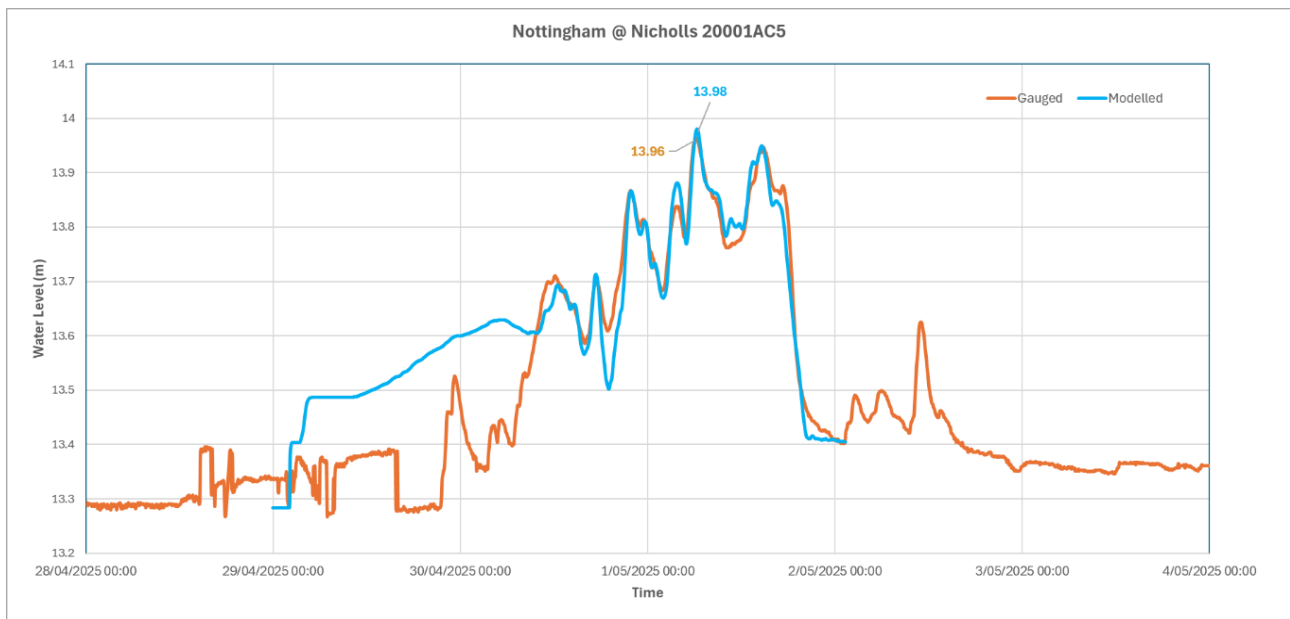


Figure 4-2 Water Level comparison at Nottingham stream at Nicholls Road

Water levels at Cox-Quaifes Detention Basin align well in shape and peak timing, indicating realistic basin operation in the model. However, the model slightly overestimates the volume entering the basin. This is shown in Figure 4-3 .

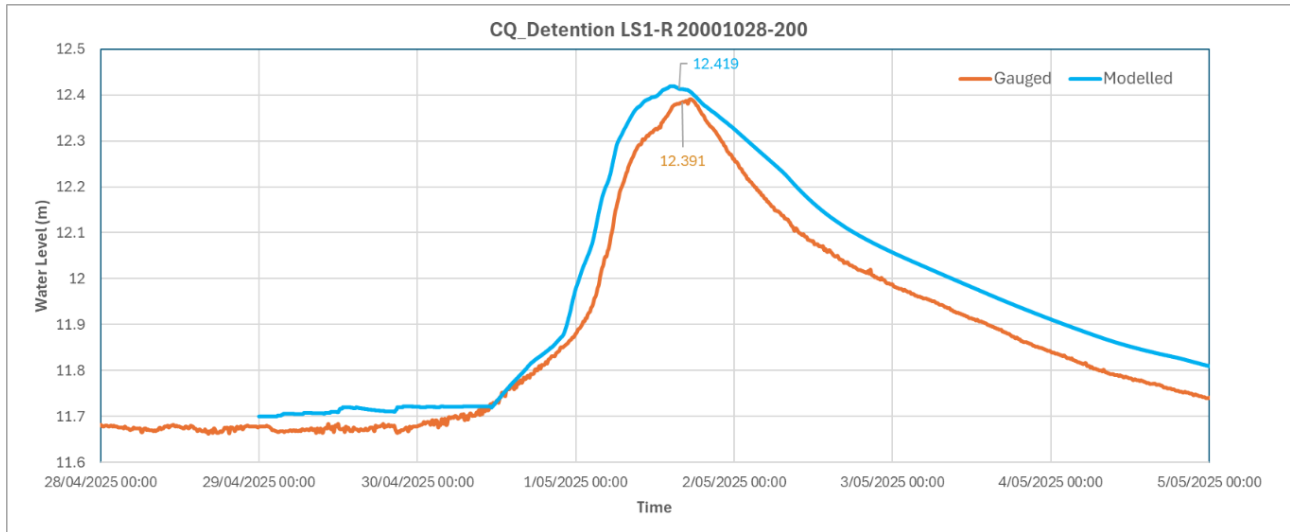


Figure 4-3 Water Level comparison at Cox-Quaifes Detention

Water level comparison at Cox-Quaifes outfall culvert shows good alignment in shape and peak timing. Differences in starting levels may be due to cross-section changes following channel works for the new culvert. As shown in Figure 4-4 .

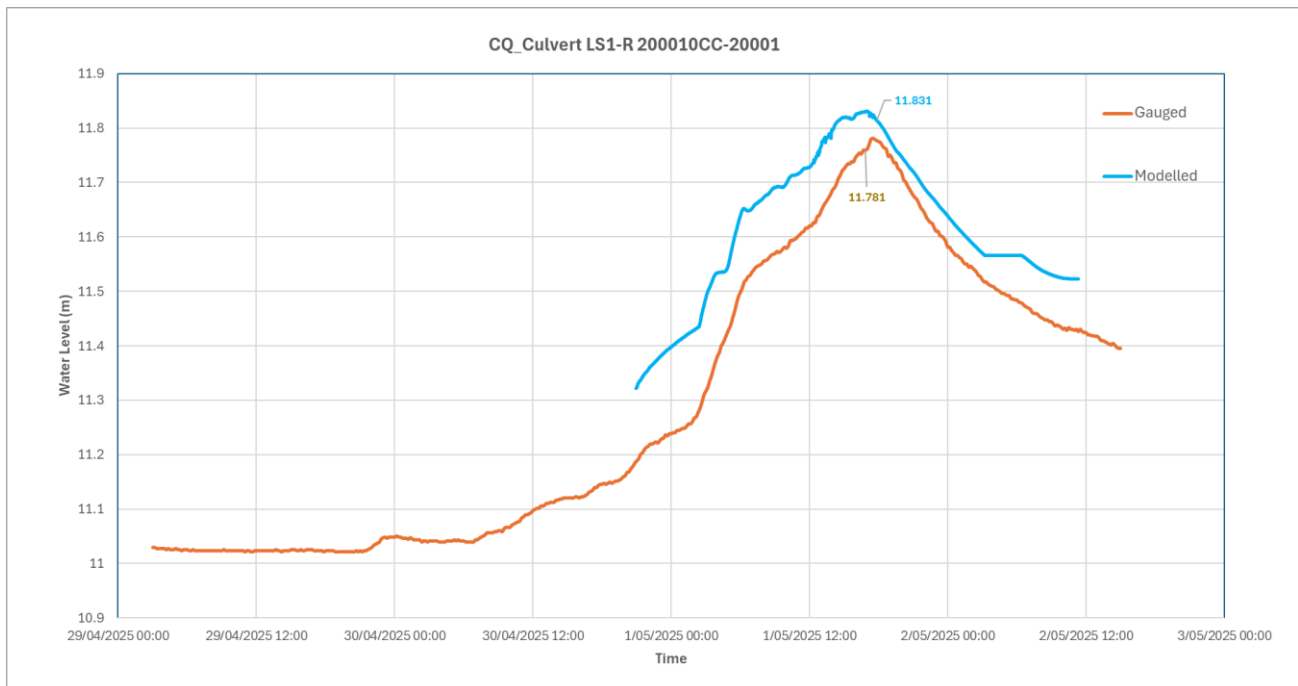


Figure 4-4 Water Level comparison at Cox-Quaifes Culvert

Water level comparison (Figure 4-5) at Knight Stream at Sabys Road shows modelled water level is a similar match to observed records in shape, but peak values are higher. This may be due to outdated cross-sections, increased vegetation, or backwater effects not reflected in the current model.

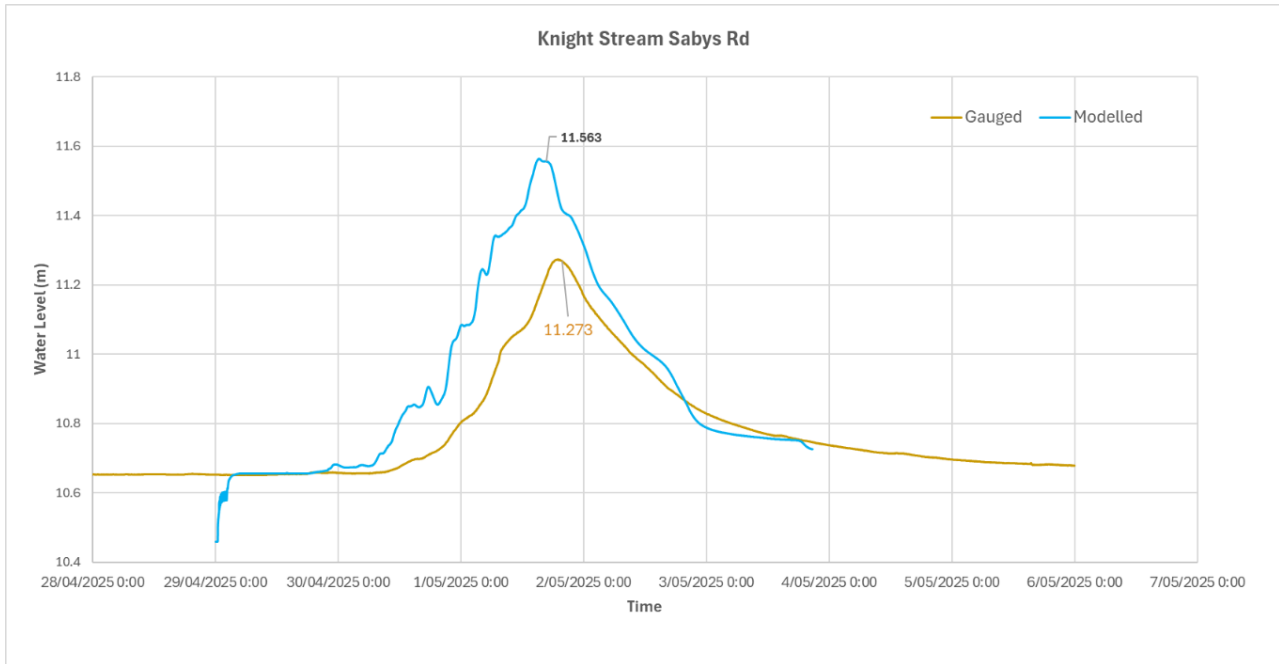


Figure 4-5 Water Level comparison at Knight stream at Sabys Road

Peak flow data was missing at Knight Stream, Sabys Road during the event. The peak was estimated by extrapolating the rating curve and back-calculating from observed water levels. The modelled peak flow is approximately 58% higher than the estimated observed value. This is shown in Figure 4-6.

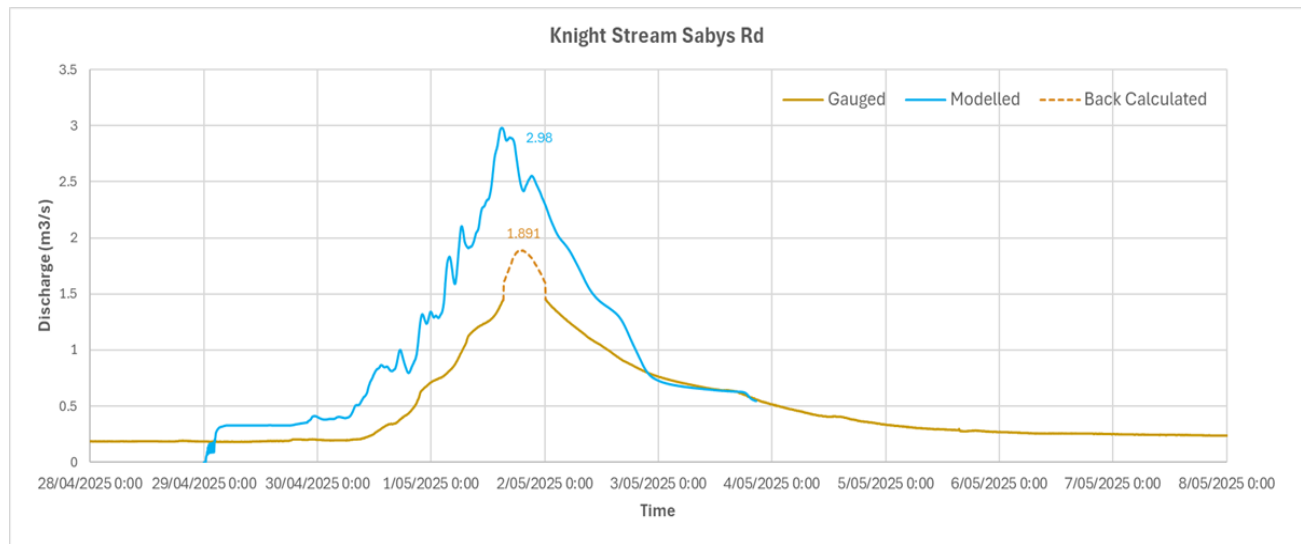


Figure 4-6 Flow comparison at Knight stream at Sabys Road

Water level comparison at Ryans Bridge (Figure 4-7) shows similar peak values, but overall shapes do not match well. The rural catchment response appears to be slower than modelled especially in the falling limb. This is likely due to hydrological factors such as soil water release which is not included in the model hydrological method.

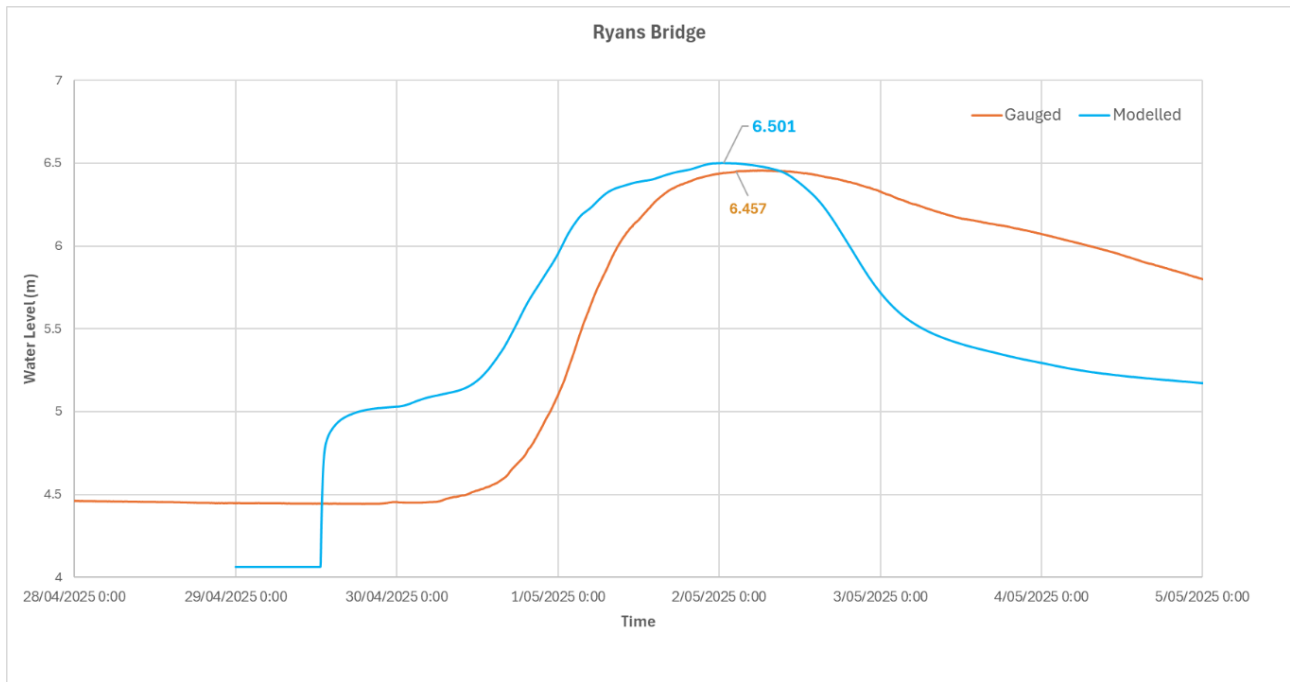


Figure 4-7 Water Level comparison in Halswell River at Ryans Bridge

Comparing flow at Ryans Bridge (Figure 4-8) shows the modelled peak is about 33% higher than observed. Peak water levels are similar, but peak flows differ, likely due to rating curve and cross-section differences.

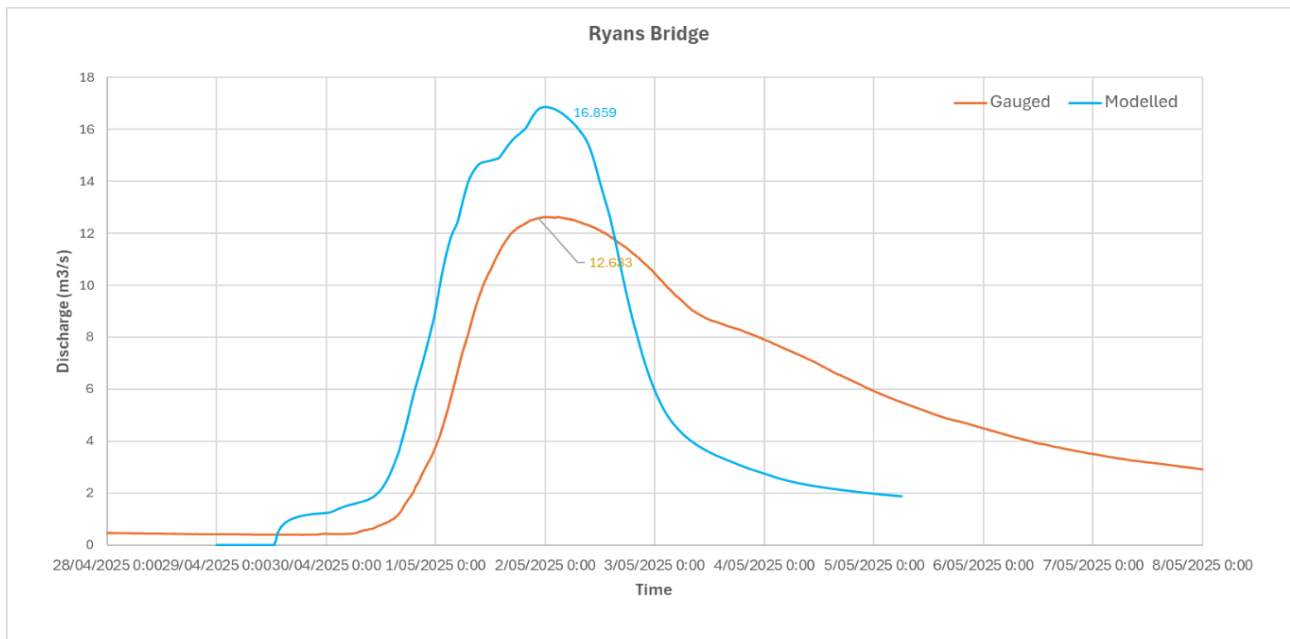


Figure 4-8 Flow comparison at Ryans Bridge

4.2 Comparison of Aerial Photos with Modelled Flood Extent

Figure 4-9 to 4-12 compare modelled maximum flood extent with aerial photos from the May 2025 event. At a catchment scale, the model shows more inundation than the aerials. As the river is modelled in 1D, comparisons focus on the floodplain. The difference in water depth varies across the lower catchment but it generally appears to be 100-150 mm in most places but up to 500 mm in isolated areas. A comparison in knight Stream Subdivision within the city boundary, shows a similar flood extent, with more water (~100 mm) shown in Ella Park and Murphys Drainage reserve, as seen in the flood photos. Flood map and aerial photo comparisons are shown below; additional comparisons for the lower catchment are included in Appendix 2.



Figure 4-9 Flood photo at Murphys Drainage Reserve (Source:ECan)



Figure 4-10 Modelled flood depth at Murphys Drainage Reserve



Figure 4-11 Flood photo at Ella Park (Source: ECan)

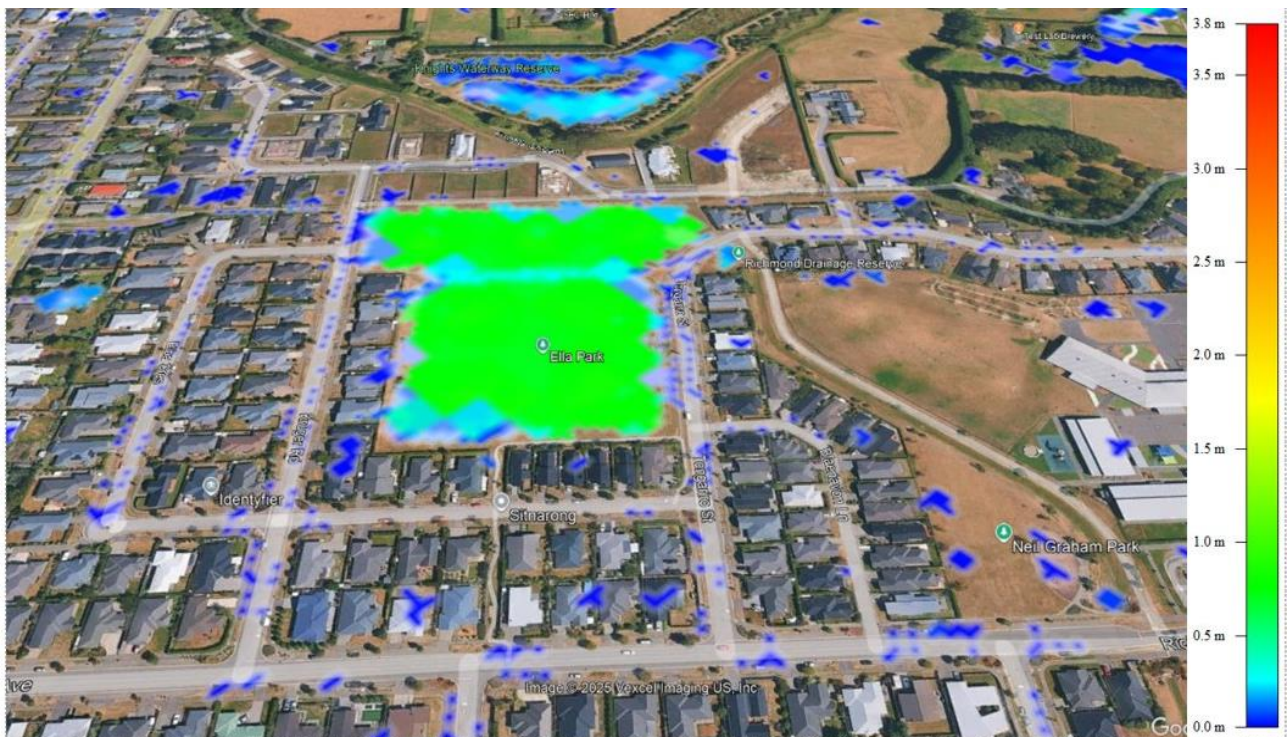


Figure 4-12 Modelled flood depth at Ella Park

Calibration Conclusion

Based on the available calibration data it appears the model predicts more runoff than was observed, especially in rural areas. Water levels in some city basins and channels (like Nottingham Stream) match well, but modelled flows at gauging sites are usually higher than recorded. This could be due to outdated channel data, debris, or rating curve issues.

At Sabys Road bridge, the recorder missed the peak flow, but the back-calculated peak is lower than the simulated. This may be because rural areas respond slower to rainfall than the model predicts.

Aerial photo comparisons show the model predicts more flooding in rural areas than observed. Urban areas match better, but limited photos in the upper catchment make validation difficult.

Calibration shows infiltration rates may be too low and/or groundwater depths too high in the model, which matches peer review advice.

The lack of alignment with the recorded data could be due to:

- Missing rural drainage: The model does not represent small local drains or culverts in rural areas, which may restrict runoff from entering the Halswell River.
- Gauge recorder: The Sabys Road recorder did not capture the peak flow; although the peak was back-calculated, it is not a recorded value, so a direct comparison with reality is not possible.
- Limitations of photo extents: Most photos are for the lower catchment, with only two for the upper area within Christchurch city boundary. It is difficult to determine flood extent from these photos, so only qualitative comparison is possible and using them for direct peak water level comparison is beyond their accuracy.
- The hydrological loss method can't represent the slow response that is seen in the lower catchment

The peer review recommended a sensitivity test be undertaken to understand how the catchment responds to changes in infiltration rates and ground water level. This is outline in the following section.

5 Model Sensitivity

5.1 Approach

5.1.1 Infiltration

As recommended by the peer reviewer, infiltration rates were increased by 50% as tabulated in Table 5-1. The inlet structure at Halswell Junction Basin was also modified in line with the Council's design memo.

Table 5-1 Infiltration rates used in sensitivity testing

Parameter	Infiltration(mm/hr)	Infiltration increased by 50%
Very Poorly Drained	2.8	4.2
Poorly Drained	3.6	5.4
Imperfectly Drained	5	7.5

5.1.2 Groundwater

The groundwater level was lowered by 300 mm alongside the increase in infiltration due to the design groundwater level (85th percentile level) at ground level in large areas of the lower catchment therefore the infiltration rate alone would have no effect.

The observed depth to groundwater during the April–May event, sourced from ECan, has been compared with the modelled groundwater depth. It shows that the model generally uses higher groundwater levels than those observed. Figure 5-1 shows the monitoring station names along with both observed and modelled groundwater depths in metres. The observed data appears to vary more across the lower catchment than the modelled data.

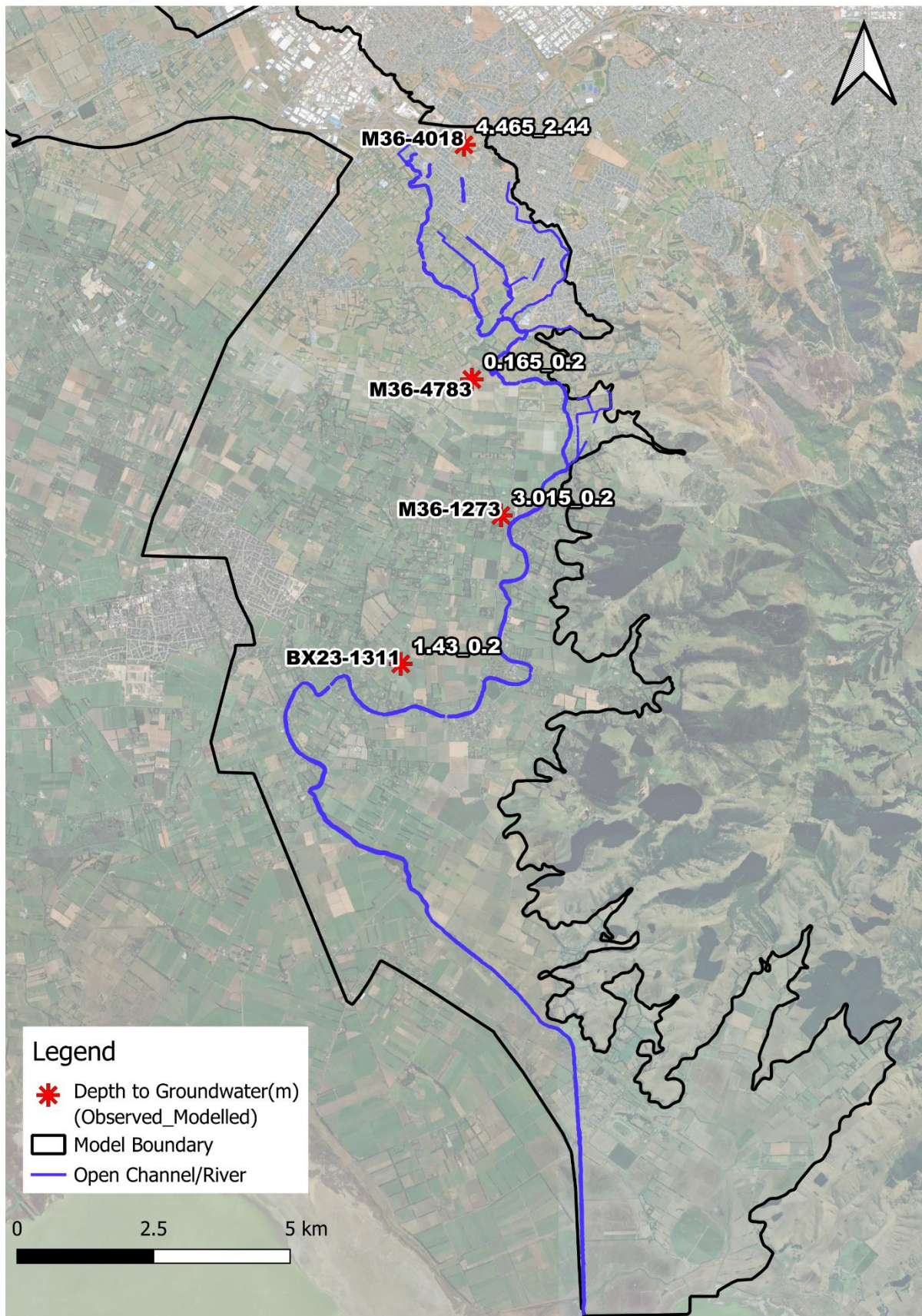


Figure 5-1 Comparison of observed and modelled groundwater depths at monitoring stations (Source: ECan)

5.2 Results

5.2.1 Infiltration Adjustment

Increasing infiltration by 50% and increasing depth to groundwater by 300 mm leads to smaller water level changes in the upper Halswell River catchment and larger changes in the lower reaches compared to baseline model. This comparison is shown in Figure 5-2 to Figure 5-9.

Halswell Junction Basin

The basin outlet structures have been updated according to the design memo (Halswell Junction Road Basin Outlet Improvement Initiation Memo by Victor Wong, dated 13 Dec 2017) from the council (schematic details are provided in Appendix A), and the downstream network arrangement has been checked against the CSM as-built drawings. Results show that the peak water level and the shape at the top of the hydrograph remain largely unchanged. However, the receding limb now responds more closely to observed data, with increased volume in the basin. The rising limb indicates the effect of the higher initial infiltration, but as the basin fills, more volume accumulates. This could highlight that the model has more impervious surface within the upstream catchment. Overall, there is little change in peak water level (see Figure 5-2) due to the change in variables.

Nottingham Stream

The calibrated peak water level matches the modelled water level on both the rising and falling limbs of the hydrograph, but the calibrated peak is 45 mm lower than the baseline model (see Figure 5-3).

Cox Quaifes Detention Basin and Culvert

Initially, water infiltrates and lowers the water level compared to the modelled results, but the basin gradually fills. There is no difference in peak water level, but the recession limb shows a decrease in water level. At the culvert location, the calibrated peak is reduced by 66mm compared to the modelled result. This means the sensitivity result is 16mm lower when compared to the observed value, while the hydrograph shape closely matches the observed data (see Figure 5-4 and Figure 5-4).

Knight Stream at Sabys Road

The calibrated water level is 167 mm lower than the baseline model, but still 125 mm higher than the observed peak. The flow is 0.83 cumecs less than the modelled discharge (see Figures 5-6 and 5-7). Therefore, the sensitivity run in is closer to the observed water level and flow.

Ryans Bridge

The calibrated water level matches the observed values, with no change in the shape of the rising and receding limbs of the hydrograph. The calibrated flow is 1.317 cumecs lower than the modelled values (see Figures 5-8 and 5-9).

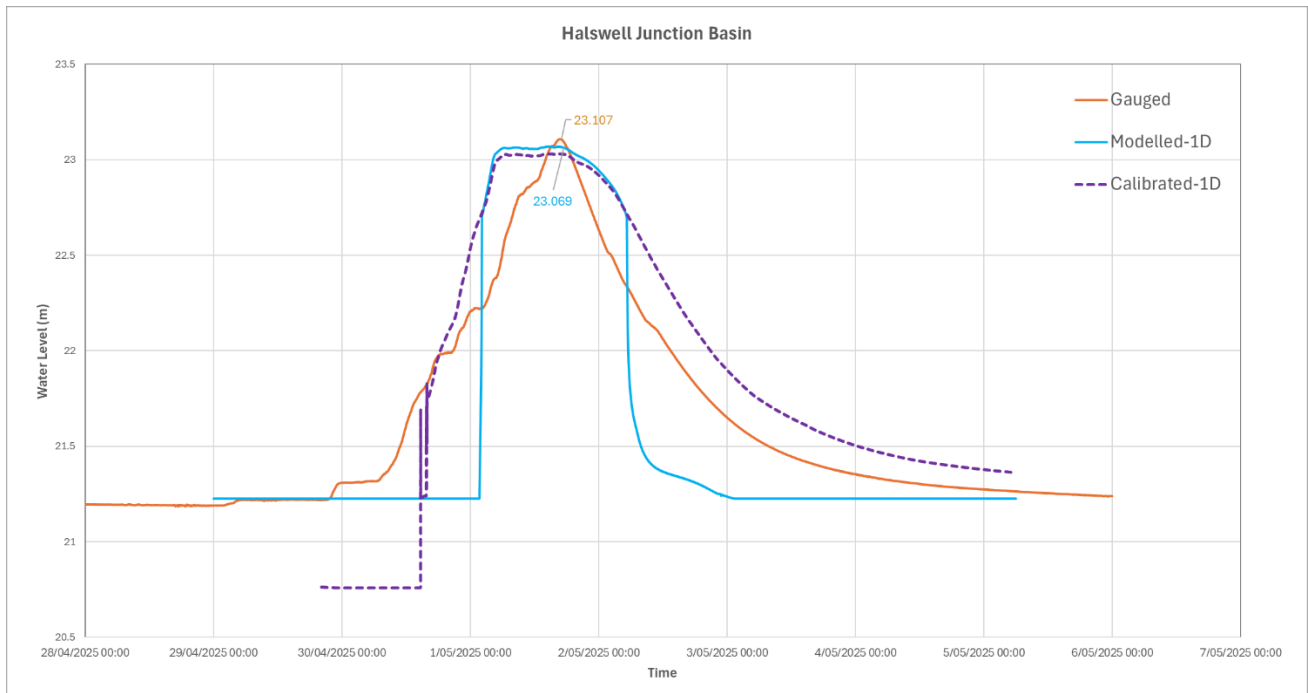


Figure 5-2 Comparison of modelled and calibrated water levels with gauged at Halswell Junction Basin

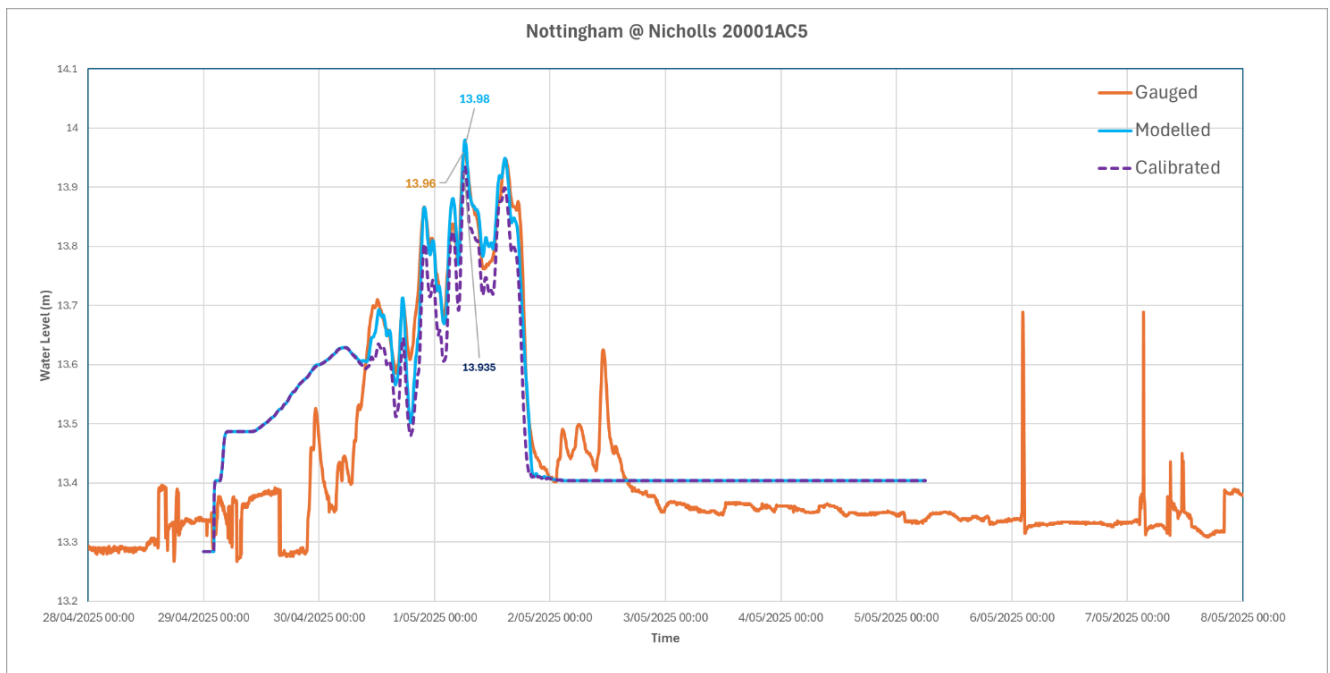


Figure 5-3 Comparison of modelled and calibrated water levels with gauged at Nottingham stream at Nicholls road

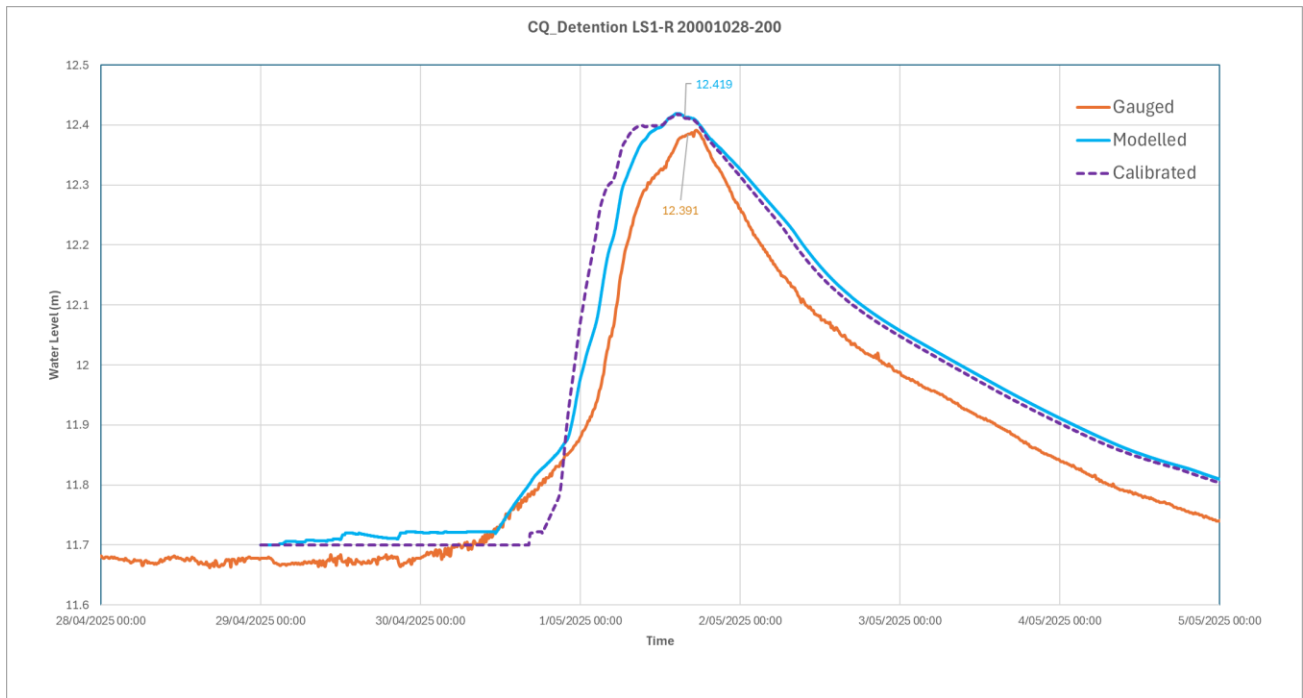


Figure 5-4 Comparison of modelled and calibrated water levels with gauged at Cox-Quaifes detention basin

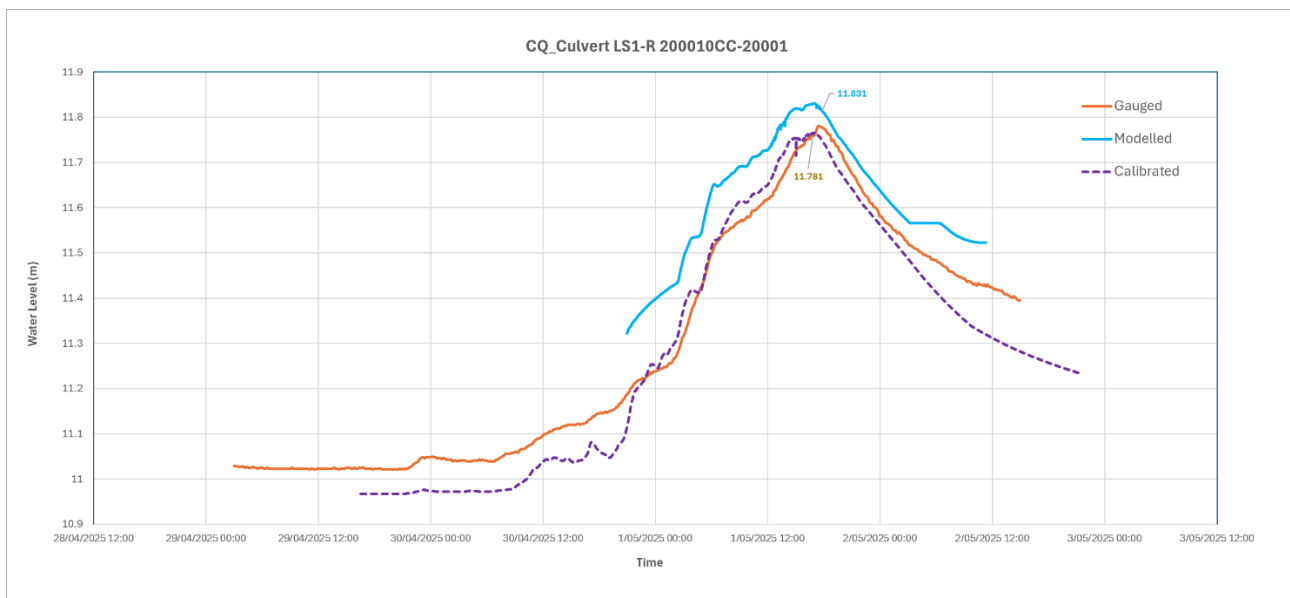


Figure 5-5 Comparison of modelled and calibrated water levels with gauged at Cox-Quaifes Culvert

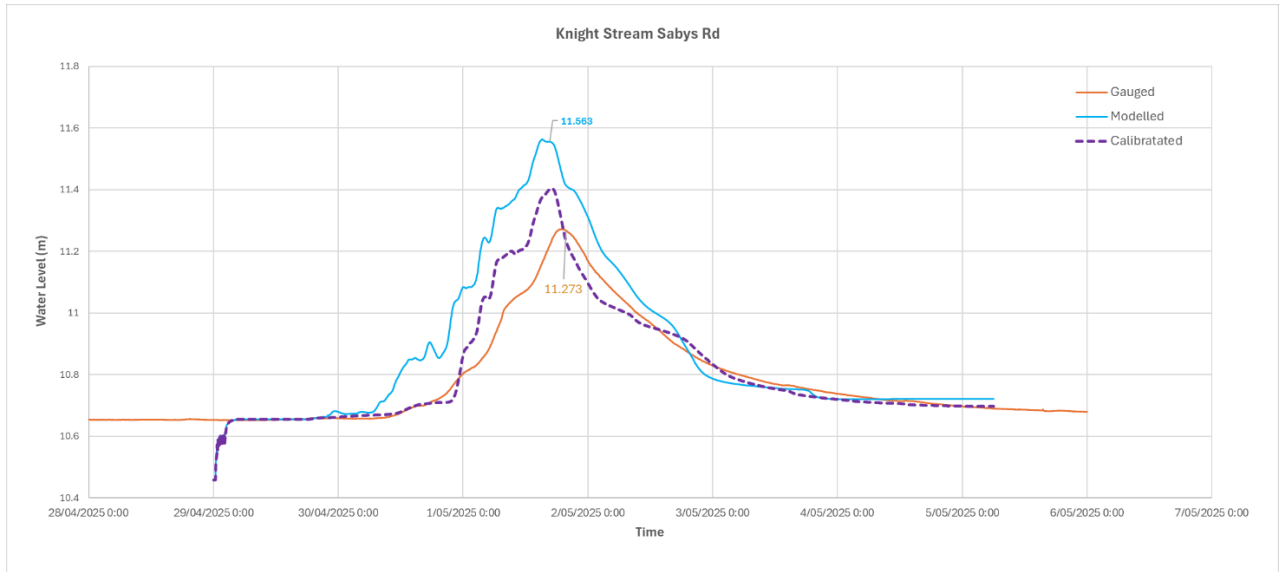


Figure 5-6 Comparison of modelled and calibrated water levels with gauged in Knight stream at Sabys Road

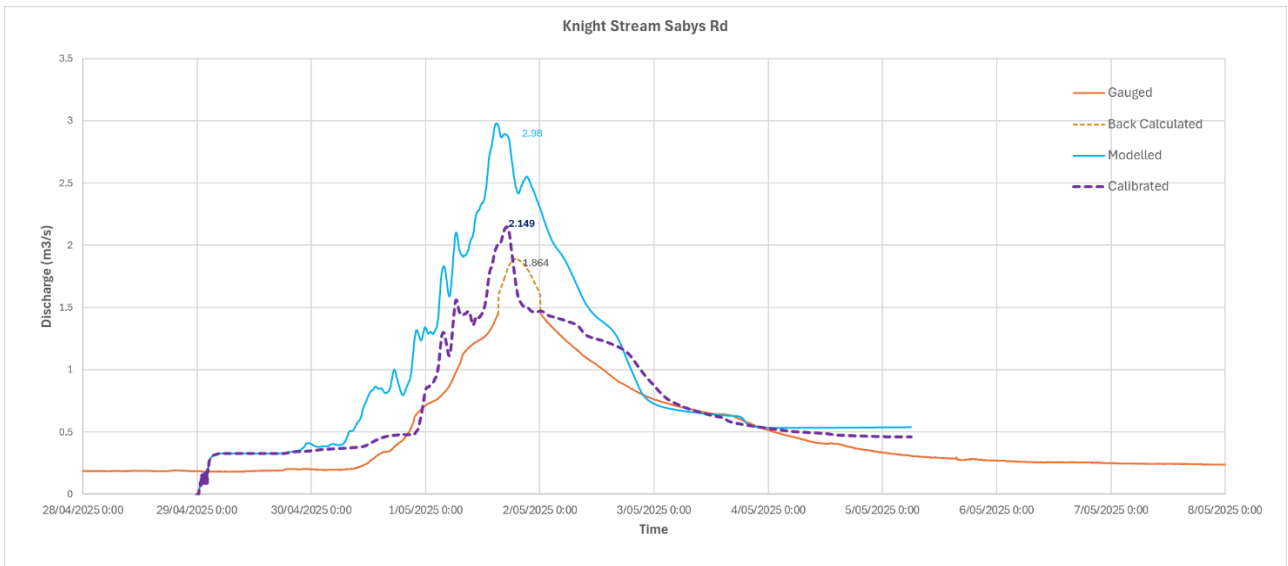


Figure 5-7 Comparison of modelled and calibrated flows with gauged in Knight Stream at Sabys Road

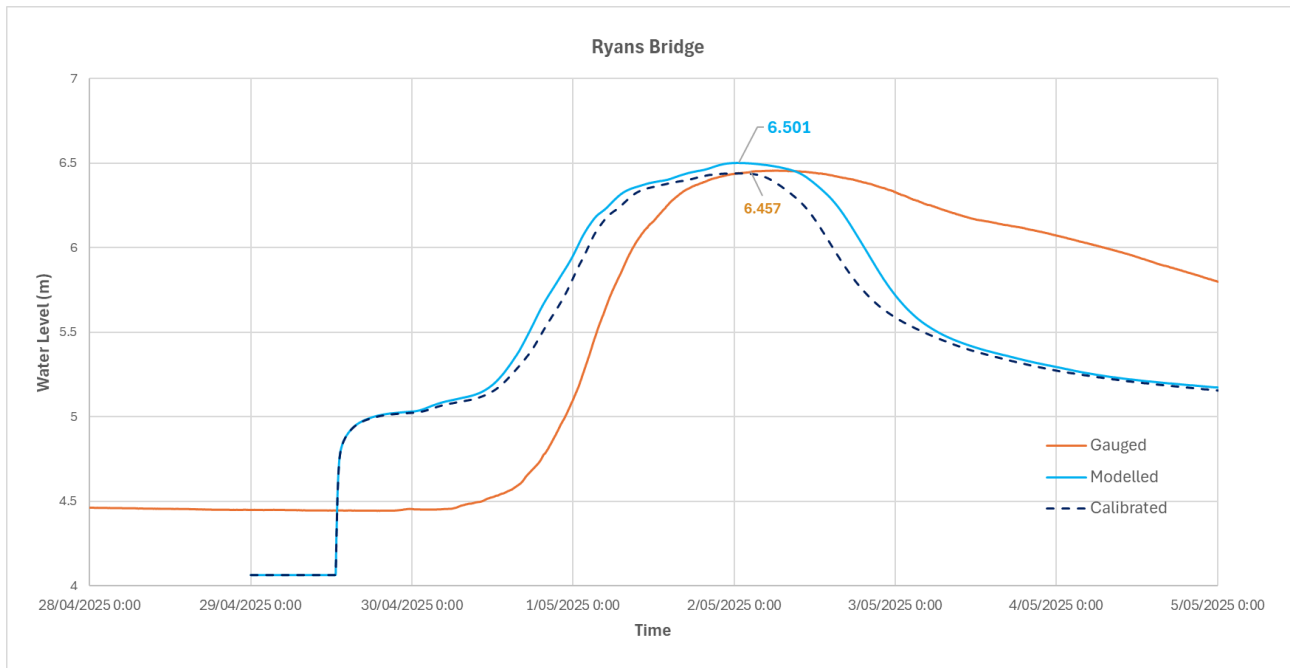


Figure 5-8 Comparison of modelled and calibrated flows with gauged in Halswell River at Ryans Bridge

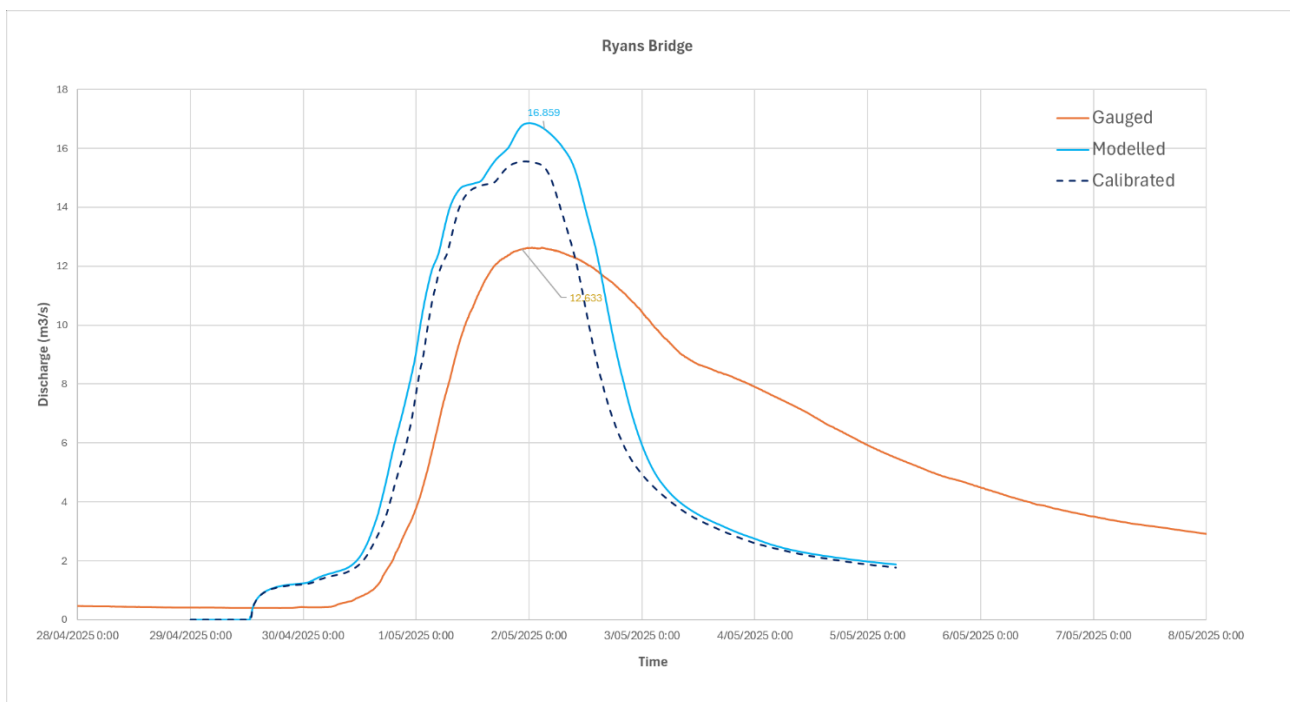


Figure 5-9 Comparison of modelled and calibrated flows with gauged in Halswell River at Ryans Bridge

When comparing the calibrated flood extent with flood photos, the results show good alignment, with a reduced water depth of 70 mm in Murphy's Drainage Reserve showing good match but an almost one-meter reduction in Ella Park Basin - suggesting that more water infiltrated in the model than in reality. The upper figures represent modelled results, while the lower figures are from calibration (see Figure 5-10). Aside from these basins and some low-lying flat areas in the upper catchment, most areas remain unaffected. However, significant changes are evident at the southernmost boundary of the model, as shown in the depth difference map in Figure 5-11. Additional flood photo comparisons related to the sensitivity run for the lower catchment are provided in Appendix 3.

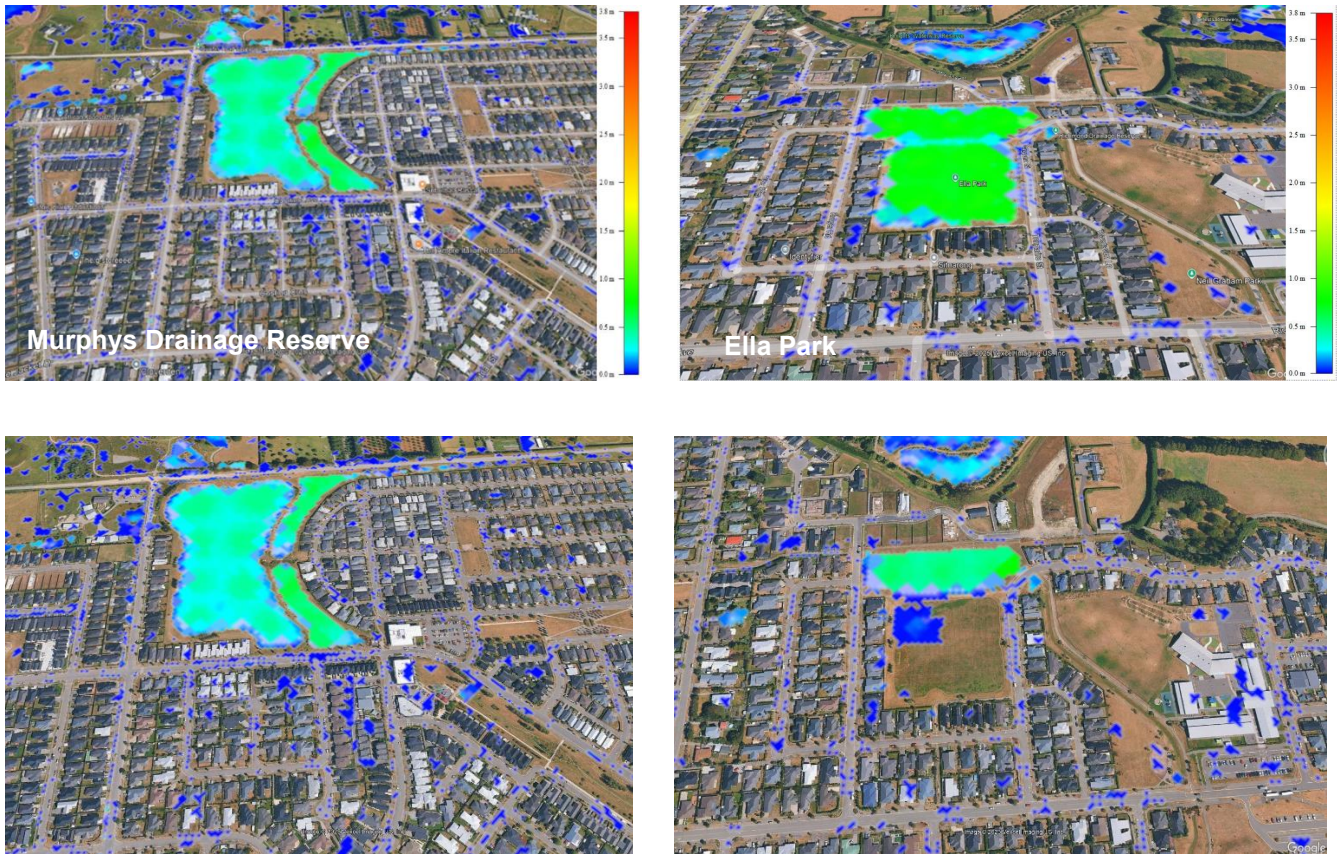


Figure 5-10 Sensitivity Flood extent comparison, top images are the base model and lower images are the sensitivity runs

Comparison of the 2D surface indicates that increasing infiltration rates and lowering groundwater depth have only a minor impact in the upper catchment of the Halswell River, with more noticeable changes observed in the middle and lower catchment. In the upper catchment, basins show water depth changes ranging from 50 mm to 1000 mm (Ella Park), as illustrated in the depth difference map between the calibrated and baseline models (Figure 5-11).

Soil Storage

In the context of infiltration, saturation refers to the point at which the soil can no longer absorb additional water. Once this point is reached, any further rainfall or surface water will accumulate and potentially result in runoff. For the calibrated run, the saturation map indicates that the middle and lower catchments are fully saturated, with no remaining capacity in the subsoil—meaning all subsequent rainfall accumulates and runs off (see Figure 5-12). In contrast, the Templeton catchment area still has some available subsoil capacity, allowing for further infiltration.

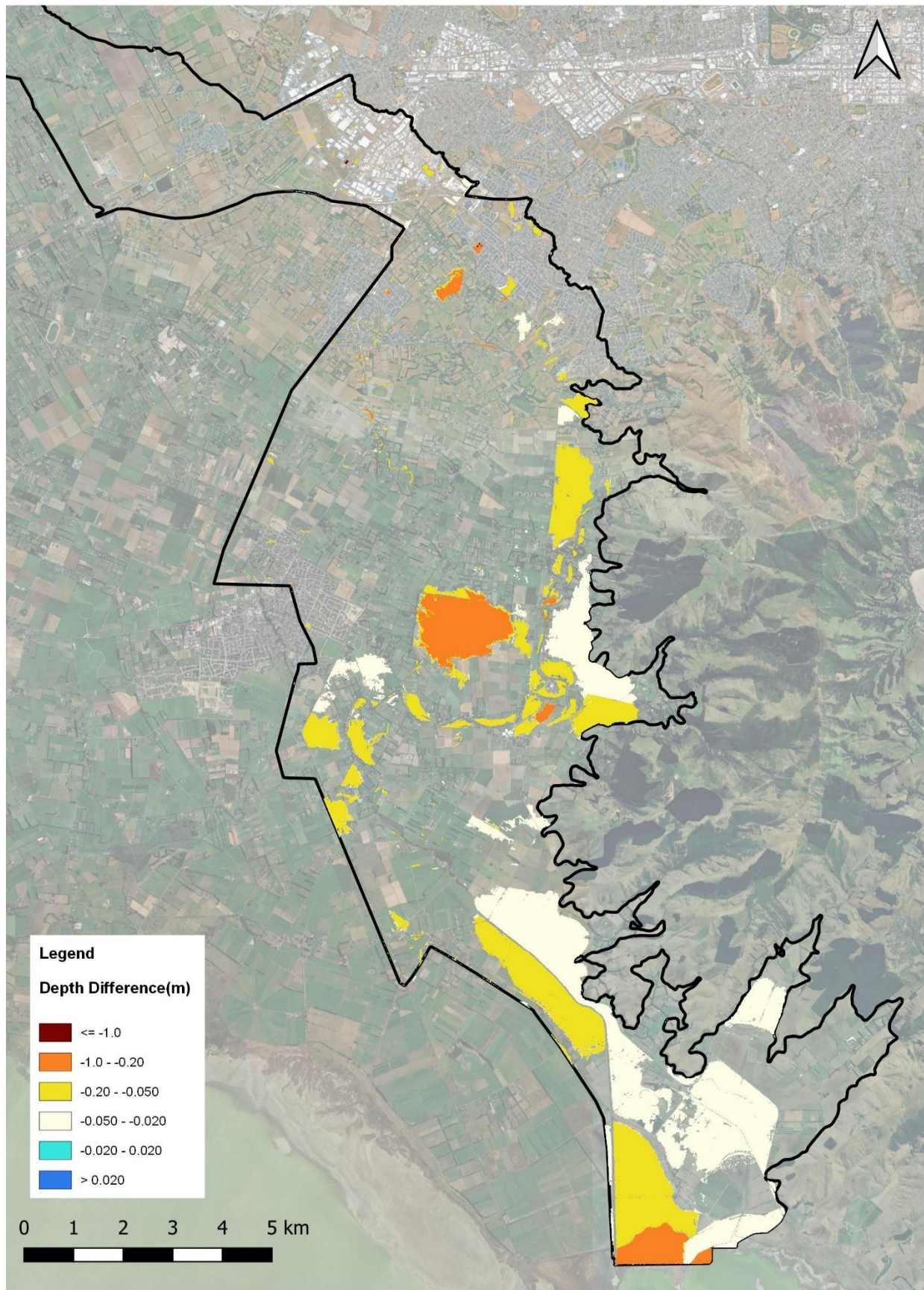


Figure 5-11 Water depth difference between sensitivity and modelled caused by changing the infiltration and groundwater depth

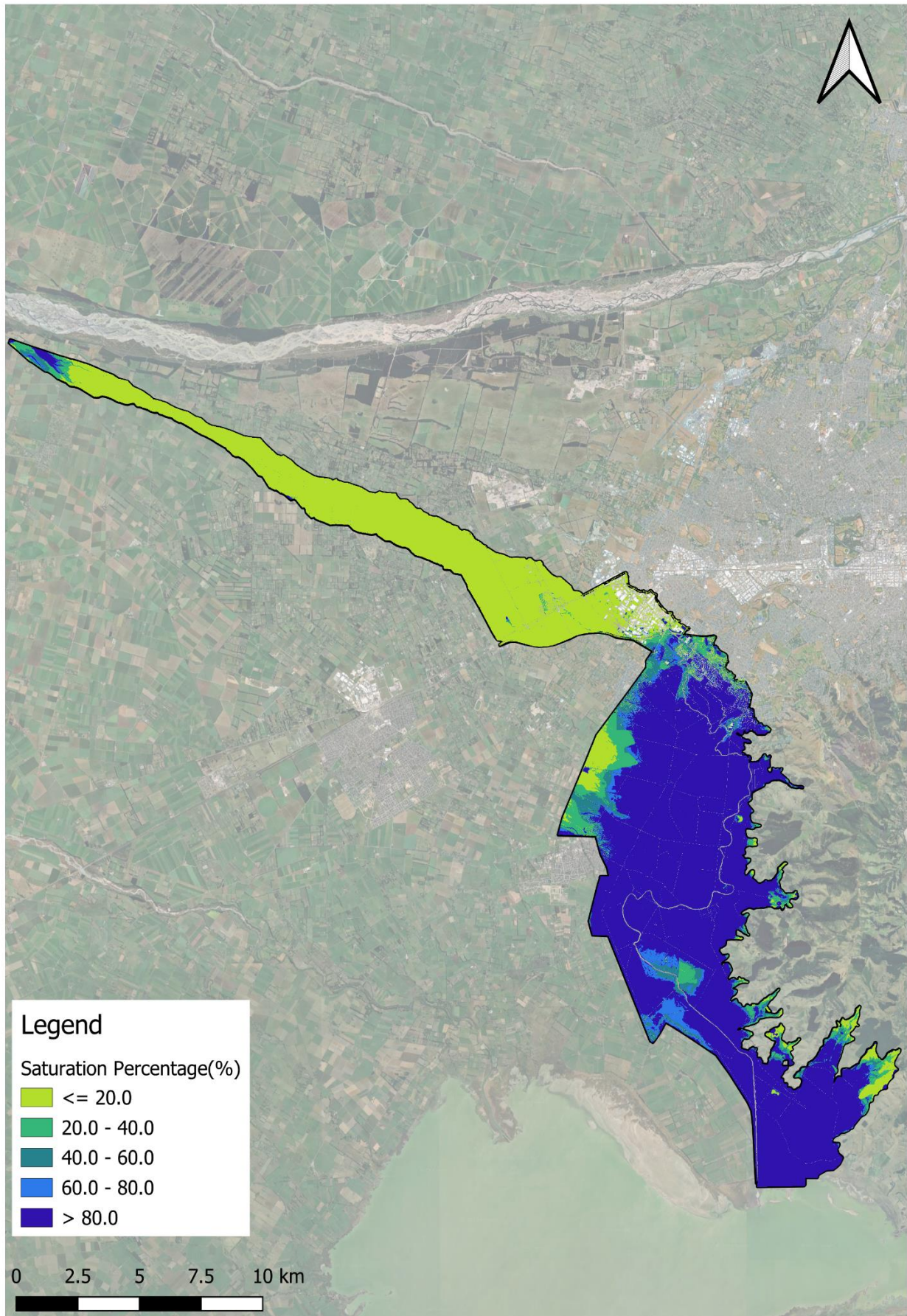


Figure 5-12 Soil saturation map by changing the infiltration and groundwater depth

Council is also testing the viability of using a different hydrological method for catchments on the Port Hills. The NAM method has the ability represent soil storage which represent the slower release of water. We have compared the NAM runoff hydrographs with the RORB hydrographs currently used by the model in two locations. Figure 5-13 is in the upper catchment in Early Valley and Figure 5-14 is in the lower catchment near Motukarara. Both hydrographs show a similar pattern when compared to RORB. The NAM method produces a lower peak flow value and a longer recession (tail). The hydrographs also so less water (volume) has runoff but it should be noted that the variables used in the NAM modelling are calibrated to gauges in the Heathcote catchment.

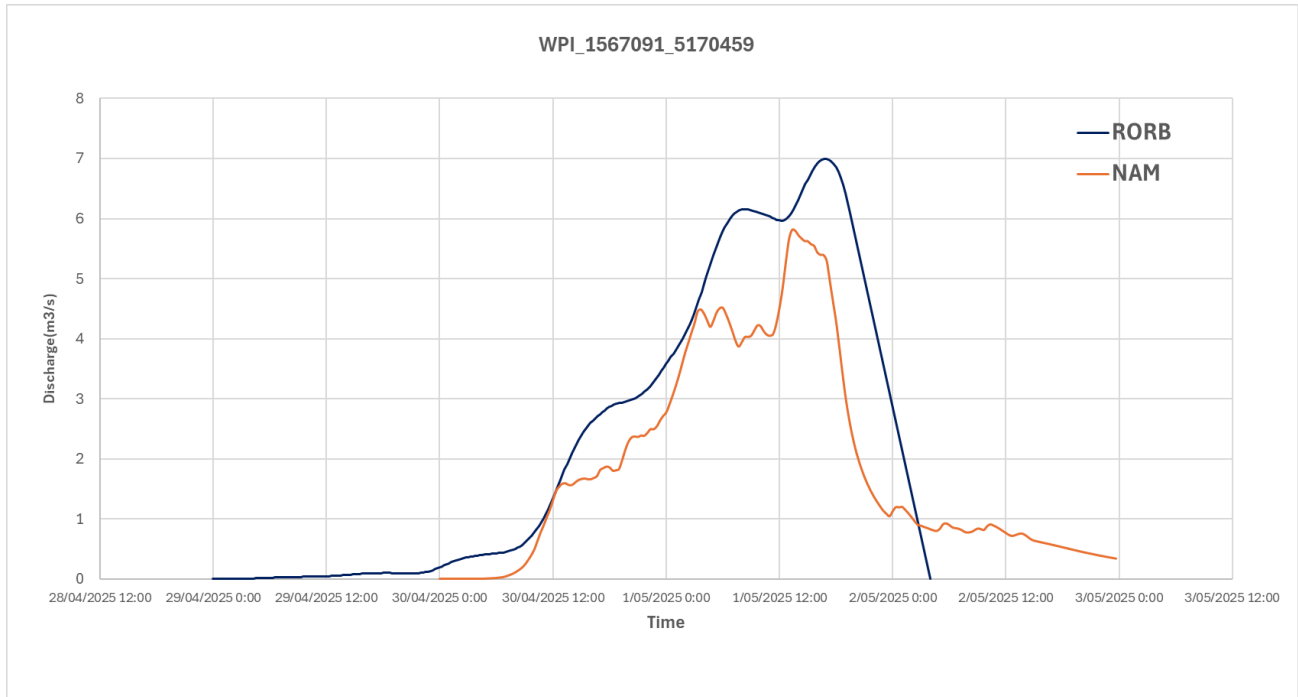


Figure 5-13 Early Valley runoff hydrograph comparison

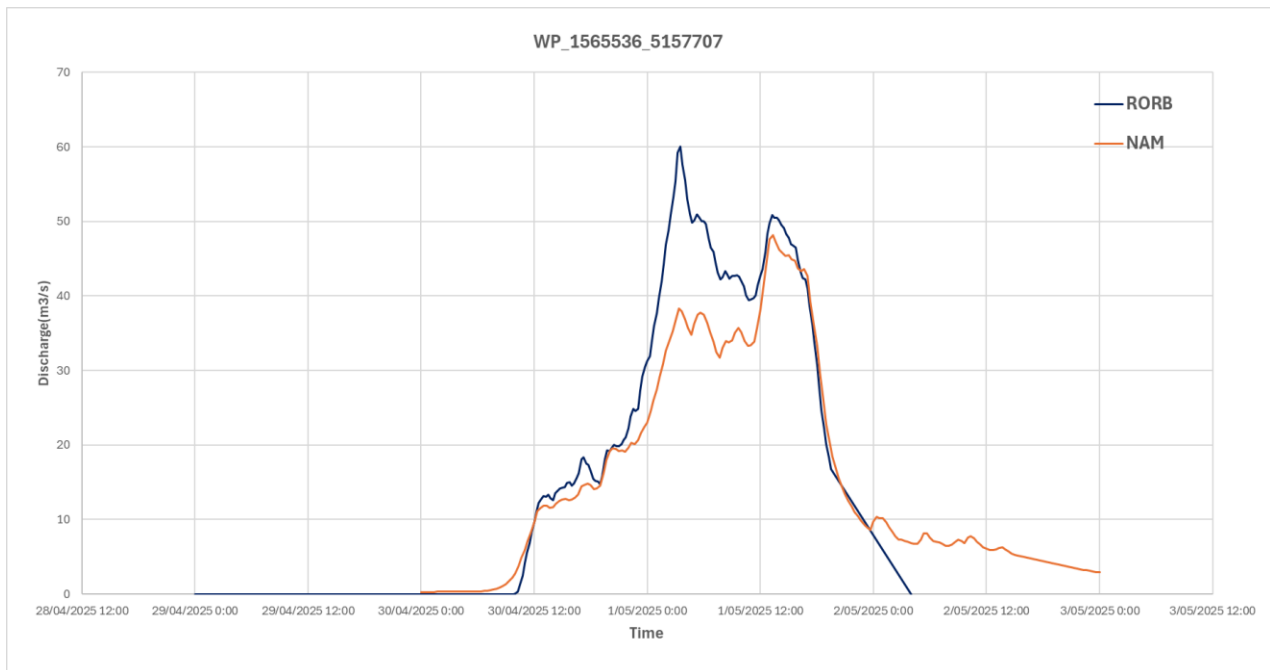


Figure 5-14 Motukarara runoff hydrograph comparison

6 Conclusions

Increasing infiltration rates by 50% and lowering groundwater depth by 300 mm led to notable reductions in water levels up to 1000 mm (Ella Park basin), with less change in channels such as Nottingham Stream, and Knight Stream, with more pronounced effects observed in the middle and lower catchments of the Halswell River. In contrast, the upper catchment and most areas within the Christchurch City boundary experienced only minor changes, as confirmed by the 2D surface comparison and flood extent mapping.

The updated basin outlet structures and downstream network arrangements at Halswell Junction Basin resulted in hydrograph recession limb that better matched observed data, while peak water levels reduced.

Sensitivity results at key locations showed improved alignment with observed hydrographs, including reduced peaks at Nottingham Stream (by 45 mm), Cox Quaifes Detention Basin culvert (by 66 mm), and Knight Stream at Sabys Road (by 167 mm compared to baseline).

The use of the NAM model may help align the shape of the hydrograph seen at Ryan Road bridge where a longer recession was recorded than predicted in the model. NAM should be included in future updates of the model.

The saturation map further indicated that the middle and lower catchments are fully saturated, causing additional rainfall to accumulate and run off, whereas the Templeton catchment still retains some infiltration capacity. Overall, aside from localized changes in certain basins and low-lying areas, most regions remain unaffected, with significant differences primarily at the southern boundary of the model.

Summary:

- The base model results show a reasonable response in the May 2025 event.
- The sensitivity results show that different parts of the catchments a sensitivity to the two variables tested. As expected, infiltration rate changes have an effect where there is capacity for water to infiltrate due to low groundwater level. The infiltration rates also have a more significant effect in sub catchments where impervious areas a limited.
- Although the groundwater level was lowered in the sensitivity run the saturation map showed that soil became fully saturated adding to the runoff volume. Comparison of the recorded groundwater levels shows that some areas of the catchment have groundwater levels lower than those used in the sensitivity runs.

Therefore, the current setup (base model) is conservative and produces results in the calibration event that are reasonable in places. Sensitivity runs show that the area within the city to be less sensitive to the parameters tested. To refine the calibration more work is required focusing on varying groundwater levels and also changes in infiltration based on soil type (rather than a blanket change).

1

Appendix 1 – Preparation of Rainfall Data for MIKE and RORB Models

Memorandum

Preparation of Rainfall Input Data for MIKE and RORB Models

1. MIKE (dfs2) Data Preparation

- **Interpolation Method:**
Rainfall surfaces were generated using "natural neighbour" interpolation from rain gauge data (see Table 1 below for gauges used).
- **Model Extent Coverage:**
As the natural neighbour method does not extrapolate beyond the input gauges, duplicates of the 'Styx River at Harbour Rd' and 'Styx River at Lower Styx Rd' gauges were created and shifted westward to ensure full coverage of the Styx model domain. This approach is consistent with the methodology used for the Styx calibration data produced for CCC in November 2023.
- **Temporal Resolution:**
Rainfall depths were re-sampled to a constant 5-minute timestep, assuming constant rainfall intensities between each raw gauge data interval.
- **Simulation Period:**
00:00 on 29 April 2025 to 00:00 on 2 May 2025 (3 days).
- **Spatial Reference:**
 - Coordinate system: NZTM
 - Cell size: 500 m
 - Coverage:
 - x-axis: 1,535,000 to 1,613,000 m
 - y-axis: 5,139,000 to 5,196,000 m
- **Quality Assurance (QA) Processes:**
 - Compared total rainfall depths in raw gauge data with those in the re-sampled 5-minute data to ensure consistency.
 - After creating the dfs2 file, used the MIKE Zero Toolbox "Timeseries from 2D files" to extract hyetographs at gauge locations, and plotted these against original data to confirm consistency.

2. RORB (stm) Data Preparation

- **Interpolation Method:**
Rainfall data was interpolated using the "natural neighbour" method at subcatchment centroids, based on the same rain gauge dataset.
- **Temporal Resolution:**
Rainfall depths were re-sampled to a constant 15-minute timestep, assuming constant rainfall intensities between each raw gauge data interval.
- **Simulation Period:**
00:00 on 29 April 2025 to 19:30 on 1 May 2025 (2.8 days), resulting in 270 timesteps.
- **Quality Assurance (QA) Processes:**

- Verified that total rainfall depths for each subcatchment matched the totals calculated during dfs2 file generation.
- Spot-checked hyetographs for accuracy.

Table-1 Rain Gauge Data Used

Name	Timestep (min)	Total Depth (mm)	NZTM x	NZTM y
Aidanfield, Dunbars Reservoir	5	136.6	1565361	5175695
Avon River at PS205	5	72.0	1574368	5183289
Bowenvale Flume at Bowenvale Ave	5	79.4	1571548	5174634
Bromley	10	65.6	1577452	5180480
Christchurch Akaroa Highway	1	195.8	1587594	5155674
Christchurch Botanical Gardens	5	118.6	1569301	5180311
College of Education, Ilam	5	100.4	1564992	5181018
Diamond Harbour	1	99.4	1578065	5168838
Firestone Factory, Papanui	5	72.0	1568123	5184786
Halswell at Coopers Knob	1	193.9	1569397	5166697
Halswell Retention Basin, Halswell Jn	5	133.4	1561782	5176945
Kainga Yard	1 to 30	97.0	1571973	5192819
Poyntz Road	1 to 30	122.9	1539628	5190695
PS42, Sparks Road	1	123.6	1567912	5176192
PS62, Tyrone Street	5	91.2	1570731	5189903
PS80, Templeton	5	123.8	1556727	5178520
Reservoir No.4, Clifton Tce	1	80.0	1579050	5174982
Ridgens Road	1 to 30	124.0	1527199	5171237
Ryans Bridge	1 to 30	148.5	1563064	5165567
Styx River at Harbour Rd	5	101.2	1575011	5194754
Styx River at Harbour Rd - Copy	5	101.2	1576317	5195370
Styx River at Lower Styx Rd	5	89.6	1574379	5189873
Styx River at Lower Styx Rd - Copy	5	89.6	1577247	5187946
Taumutu	1 to 10	119.0	1549901	5144720
Tunnel Road, Heathcote	5	86.6	1575055	5177522
Upper Bowenvale Valley	5	119.2	1571775	5172518

Name	Timestep (min)	Total Depth (mm)	NZTM x	NZTM y
Upper Cashmere Catchment at Worsleys	5	143.4	1568585	5174400
Van Asch St, Sumner	5	67.0	1580406	5174773
Wigram Retention Basin at Overflow	5	104.8	1565988	5177603

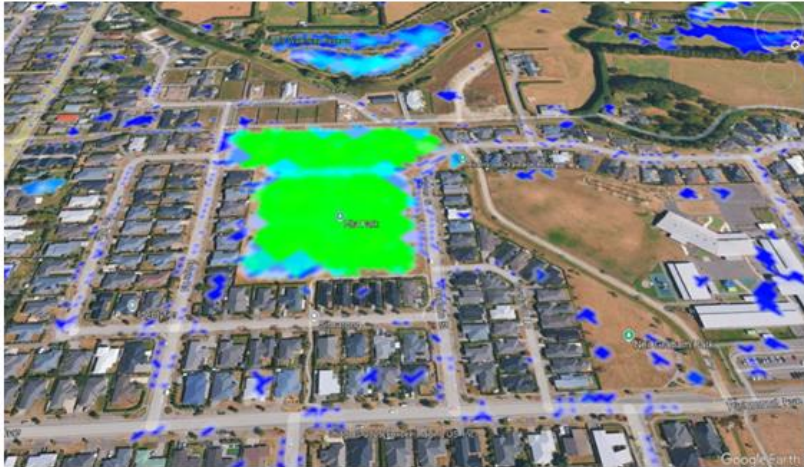
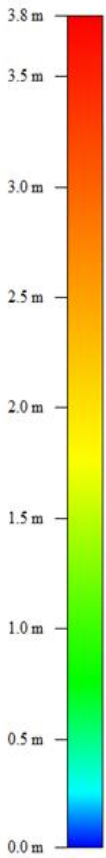
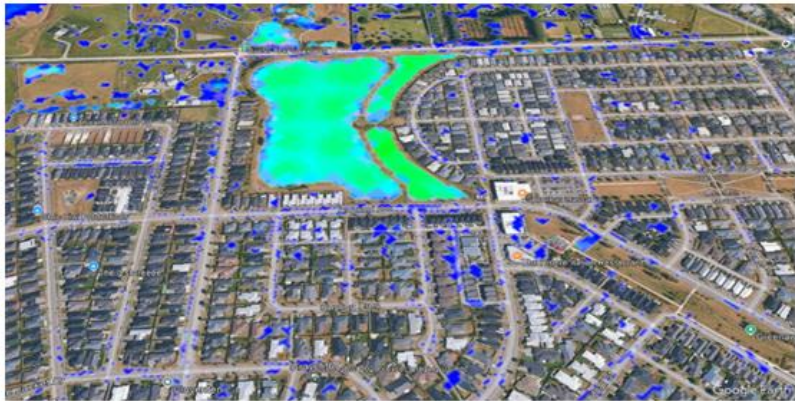
Note:

All QA checks confirmed consistency between original gauge data and the processed rainfall inputs used in both MIKE and RORB models.

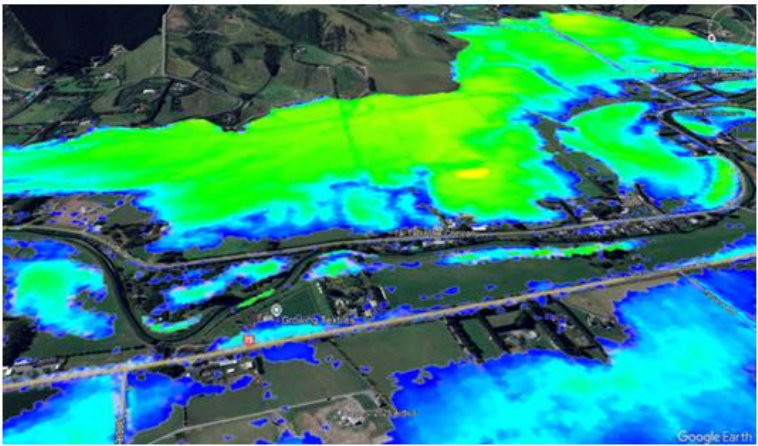
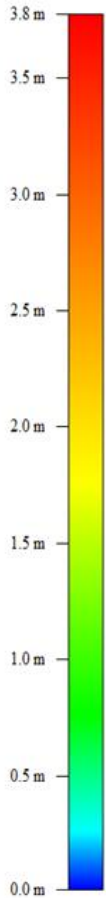
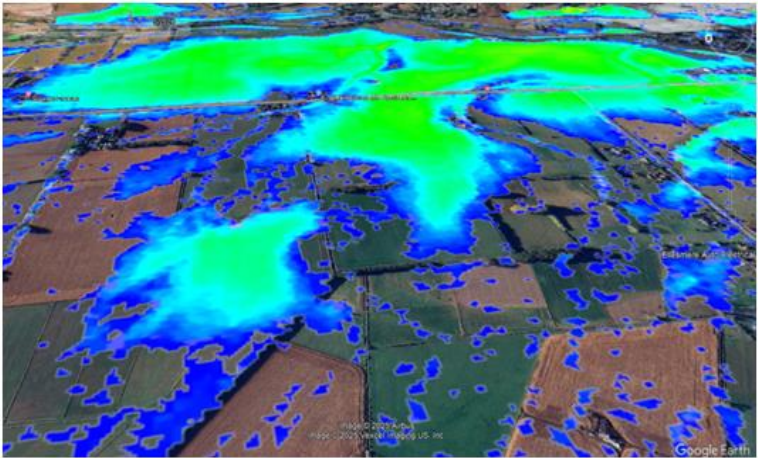
2

Appendix 2 – Calibration Run (Flood map and aerial photo comparisons)

Sensitivity: General

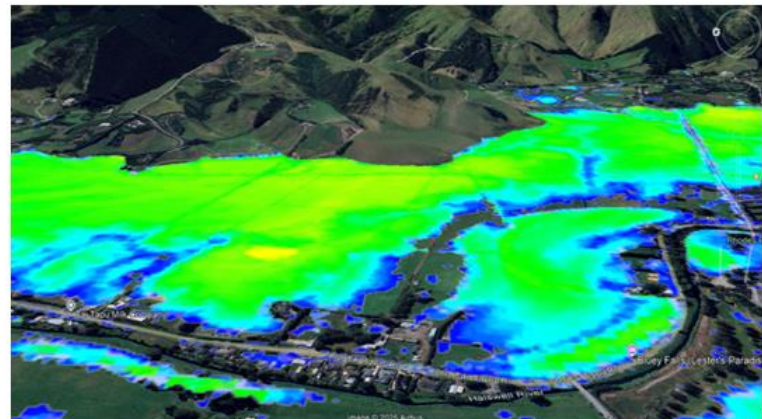
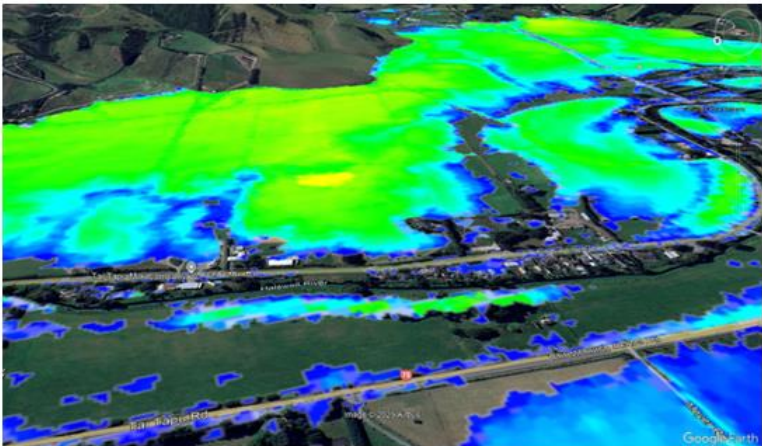


Sensitivity: General



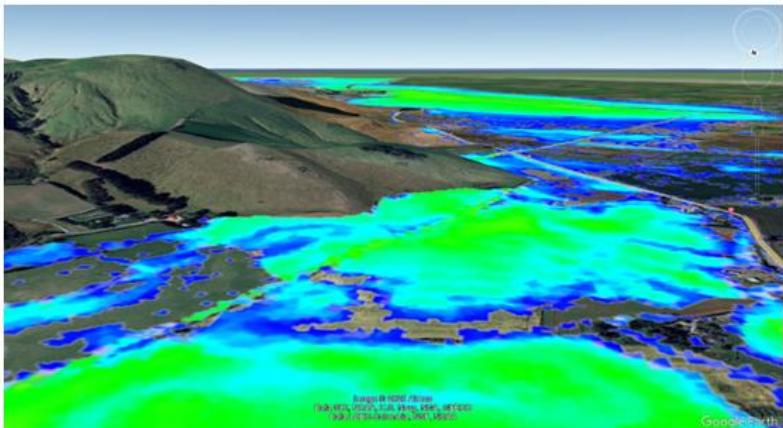
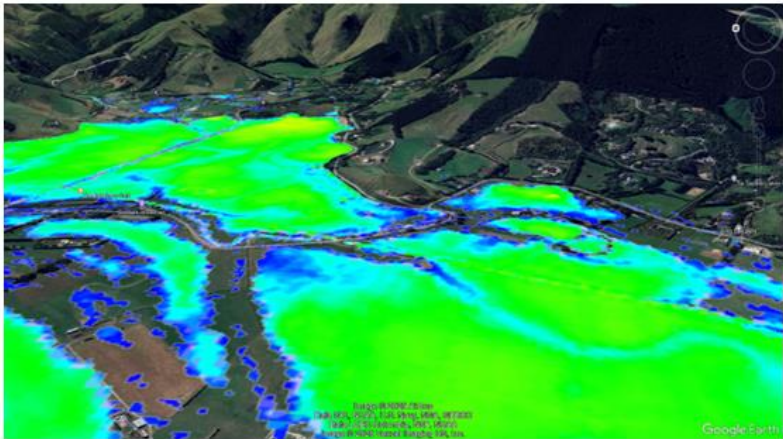
Halswell-Tai Tapu Area

Sensitivity: General

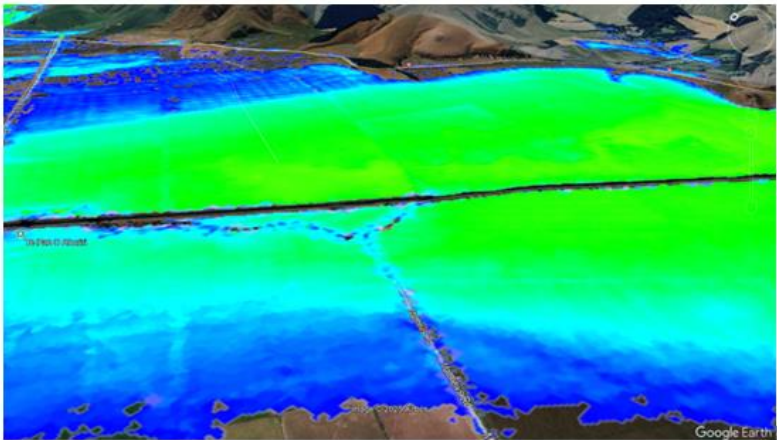
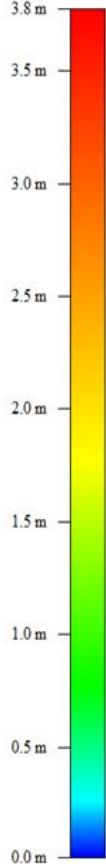
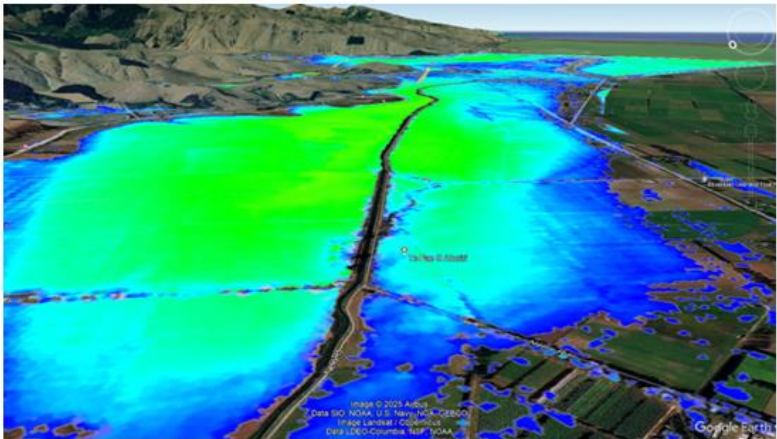


Halswell-Tai Tapu Area

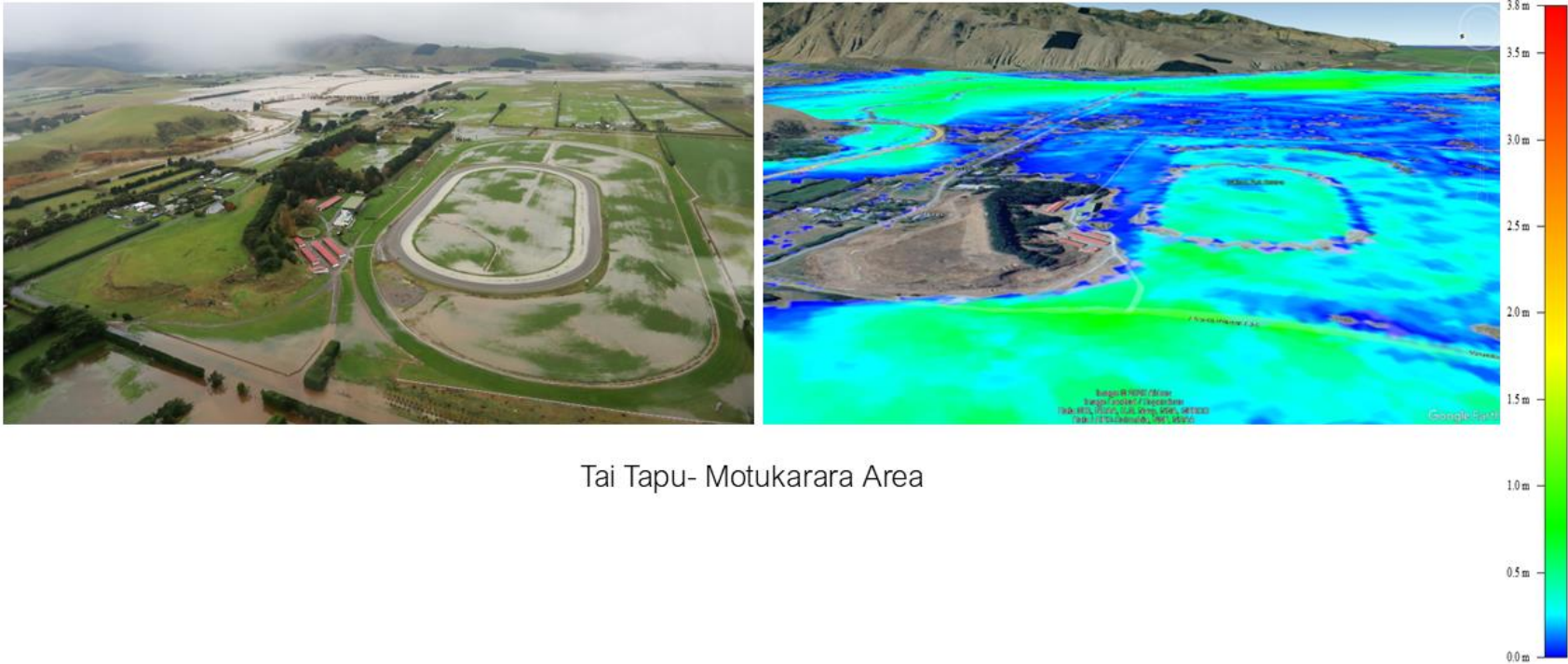
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Halswell-Tai Tapu Area

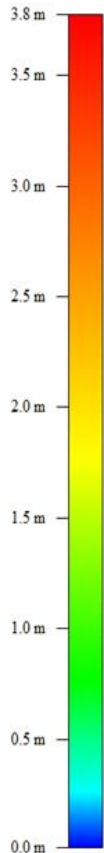
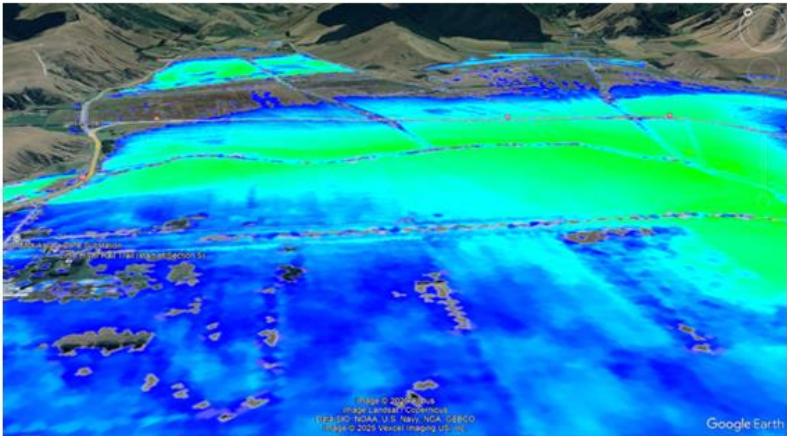
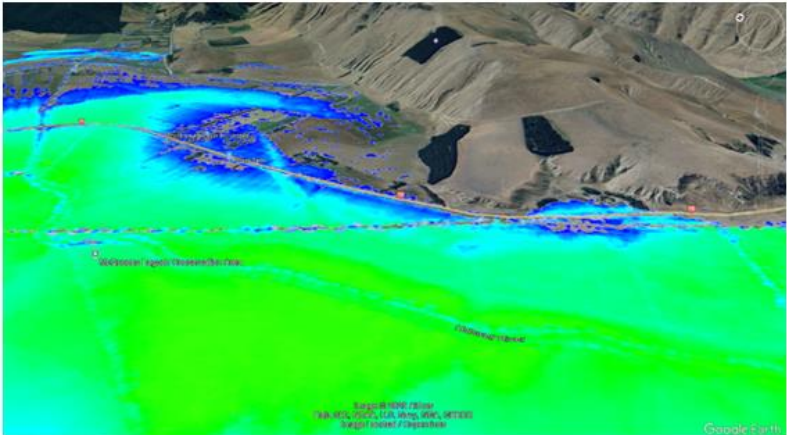


Tai Tapu- Motukarara Area



Tai Tapu- Motukarara Area

Sensitivity: General

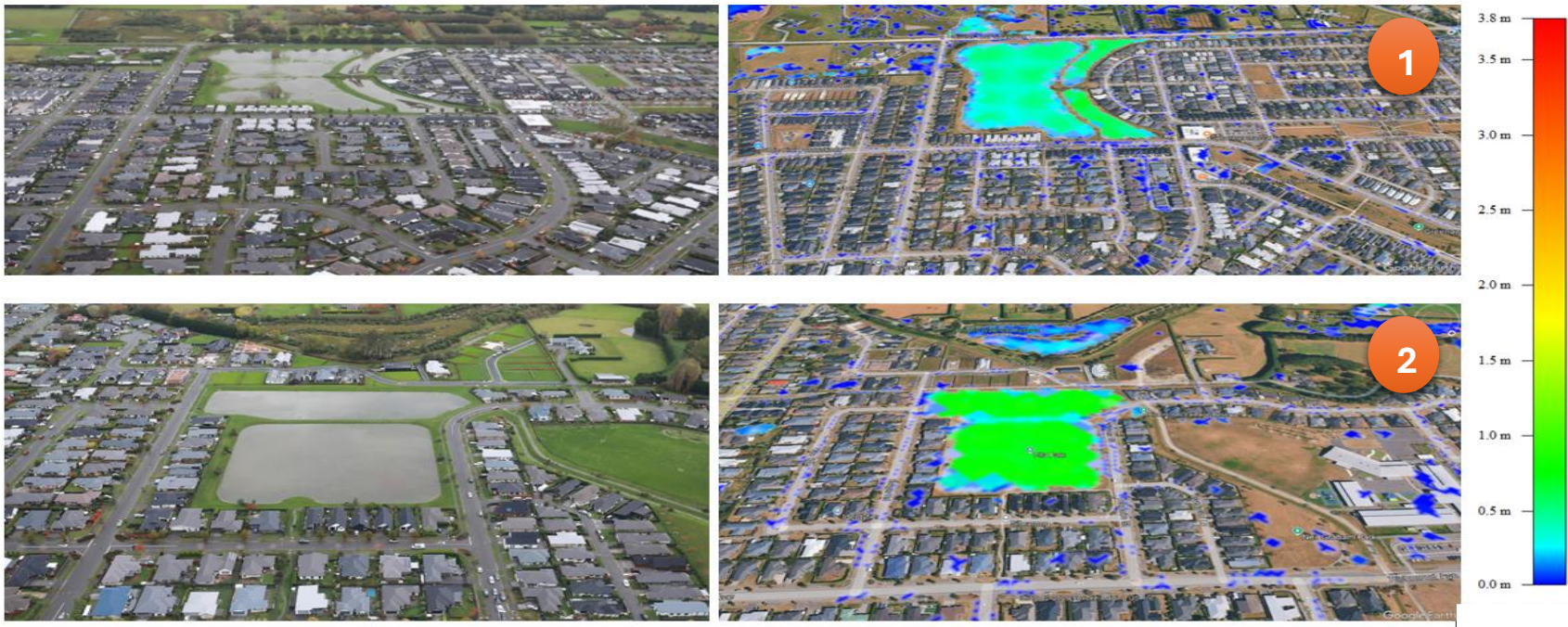


Motukarara Area

3

Appendix 3 – Sensitivity Run (Flood map and aerial photo comparisons)

Baseline Model

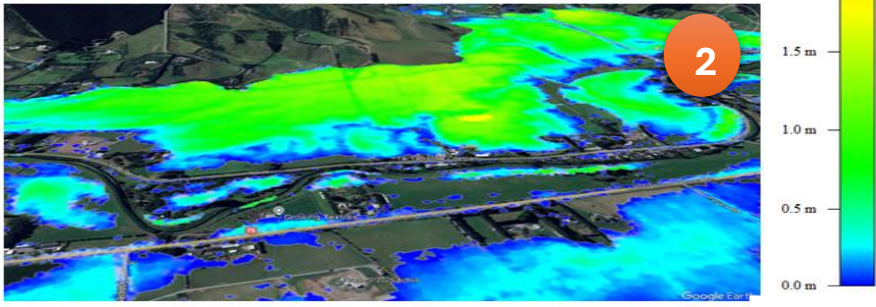
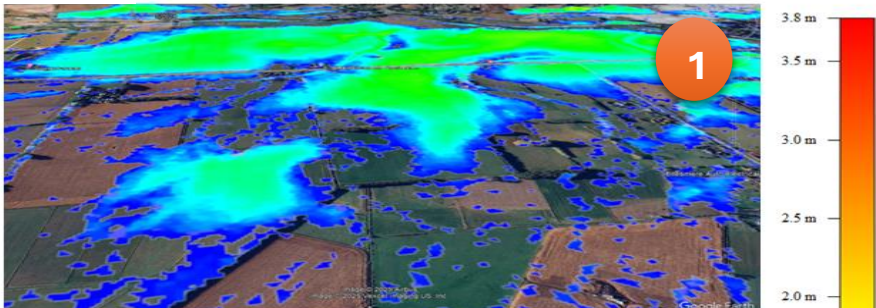


Calibrated

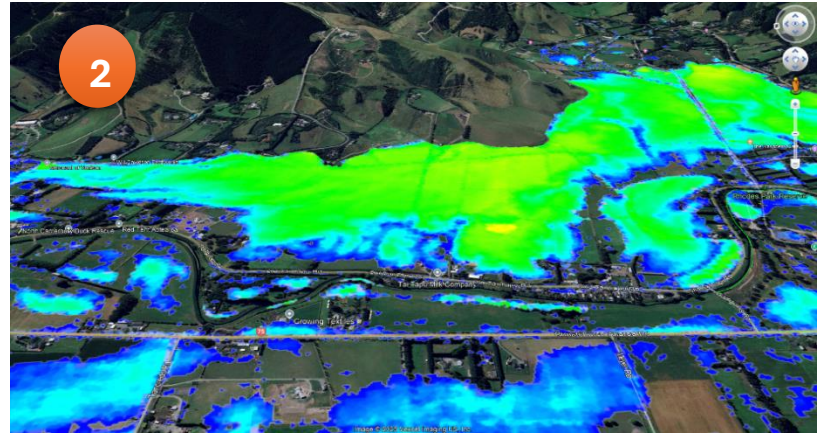
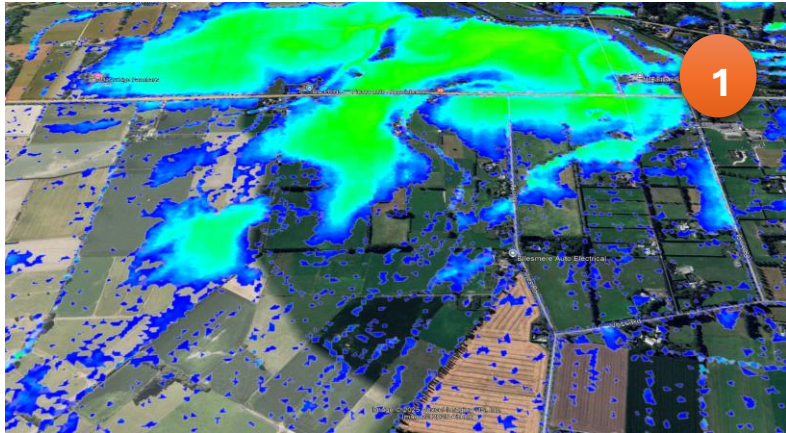
50% increased infiltration and 0.3m reduced GW depth



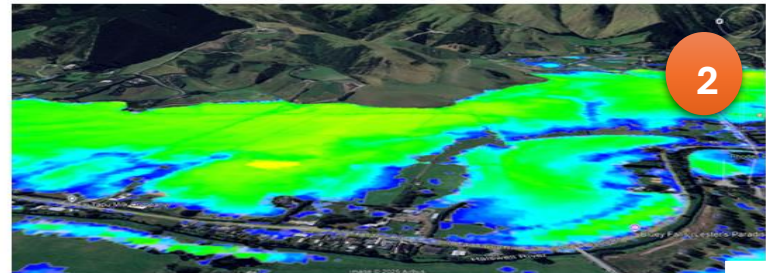
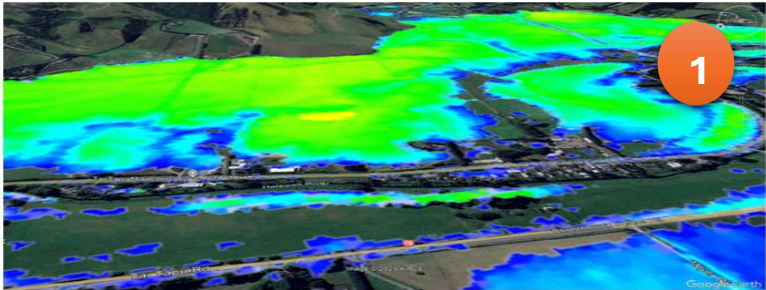
Baseline Model



Calibrated
50% increased infiltration and 0.3m reduced GW depth



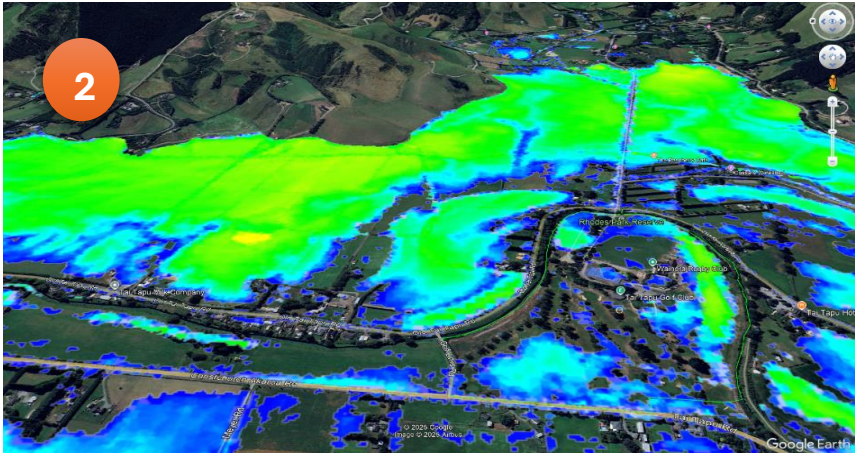
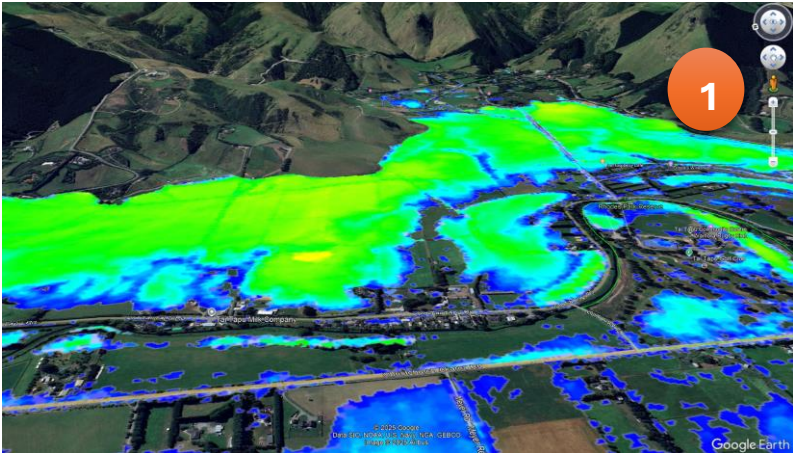
Baseline Model



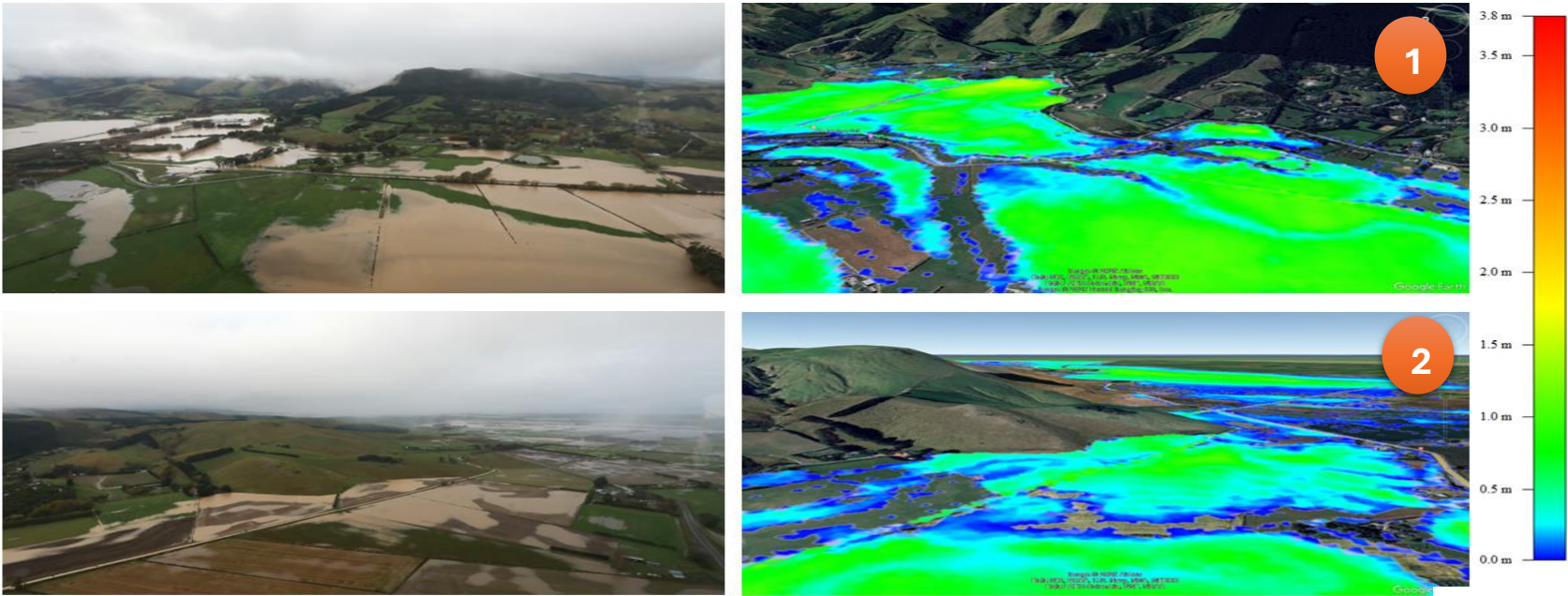
Halswell-Tai Tapu Area

Calibrated

50% increased infiltration and 0.3m reduced GW depth



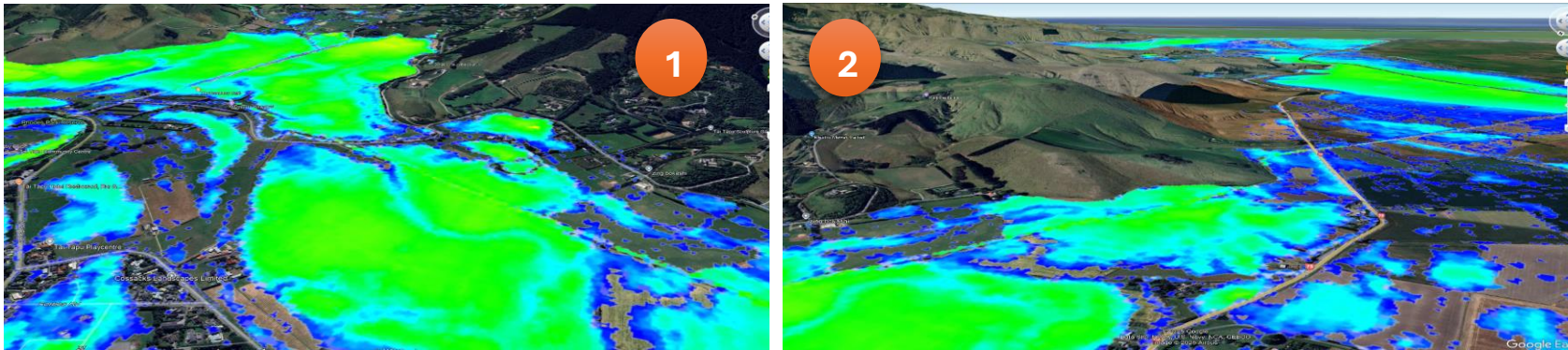
Baseline Model



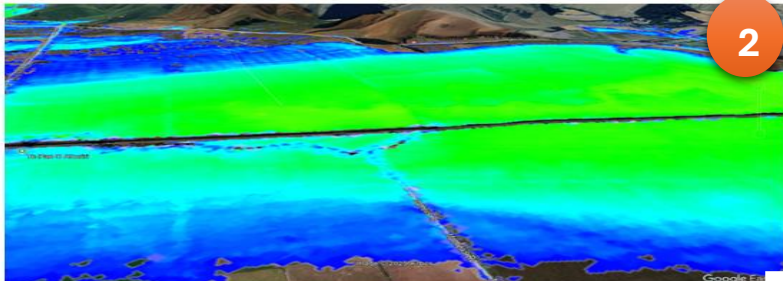
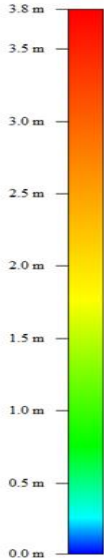
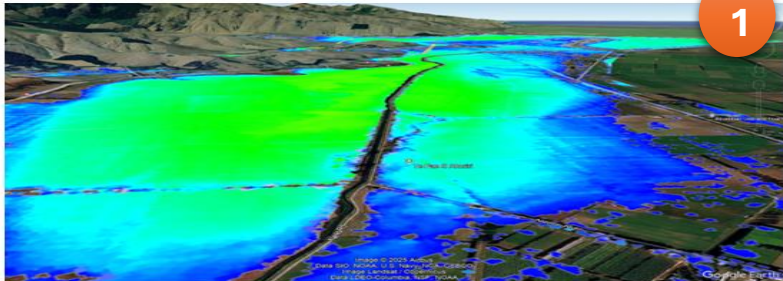
Halswell-Tai Tapu Area

Calibrated

50% increased infiltration and 0.3m reduced GW depth



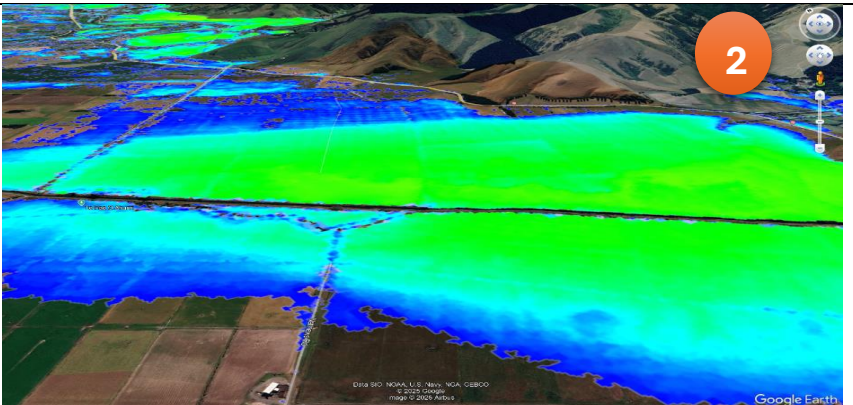
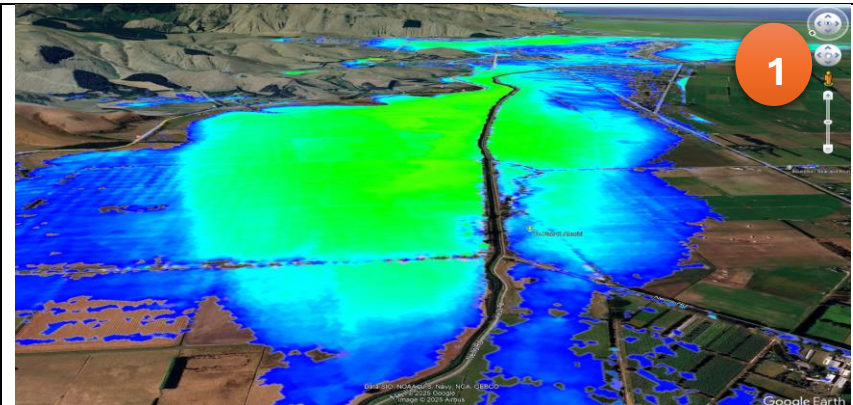
Baseline Model



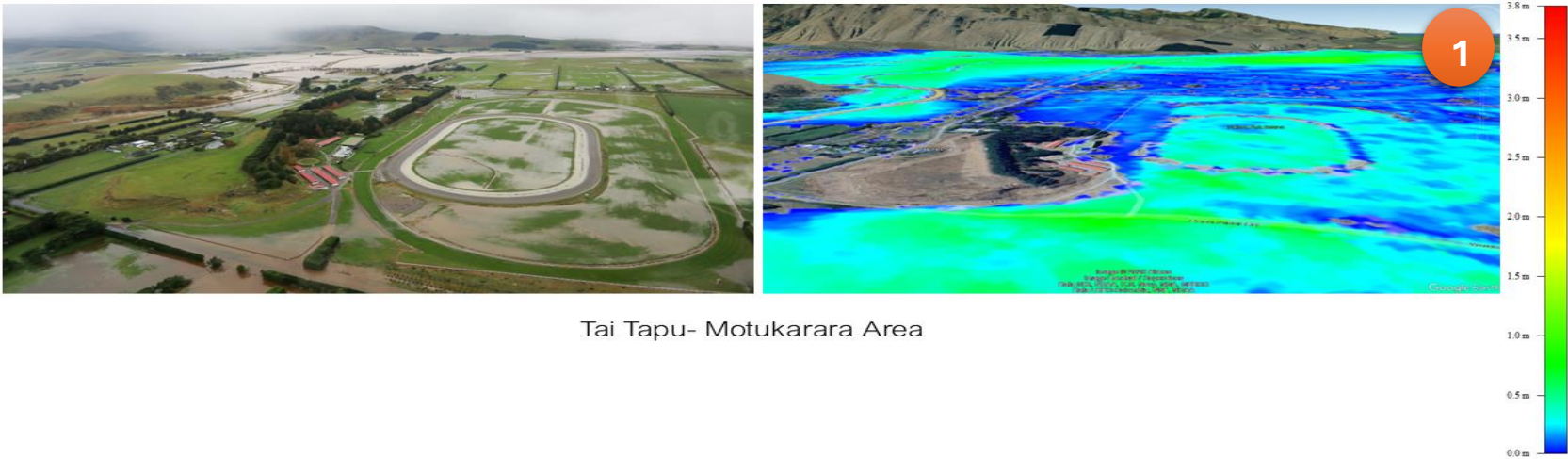
Tai Tapu- Motukarara Area

Calibrated

50% increased infiltration and 0.3m reduced GW depth

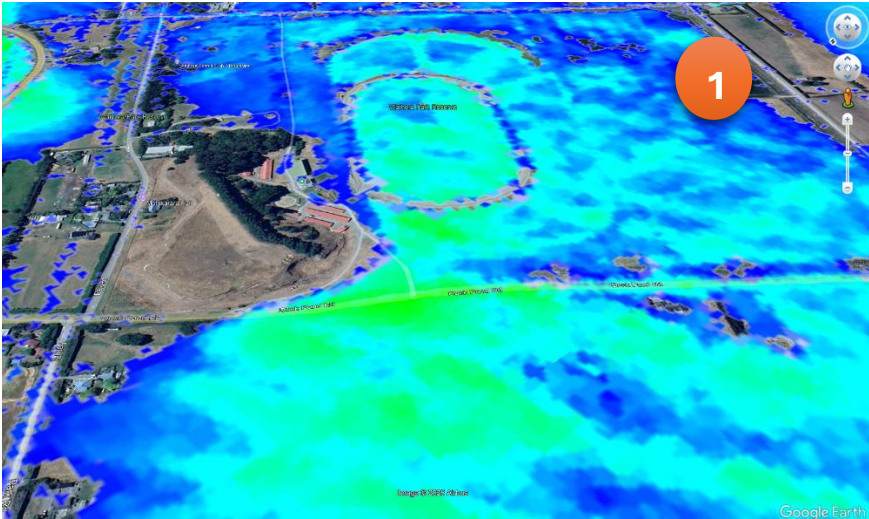


Baseline Model

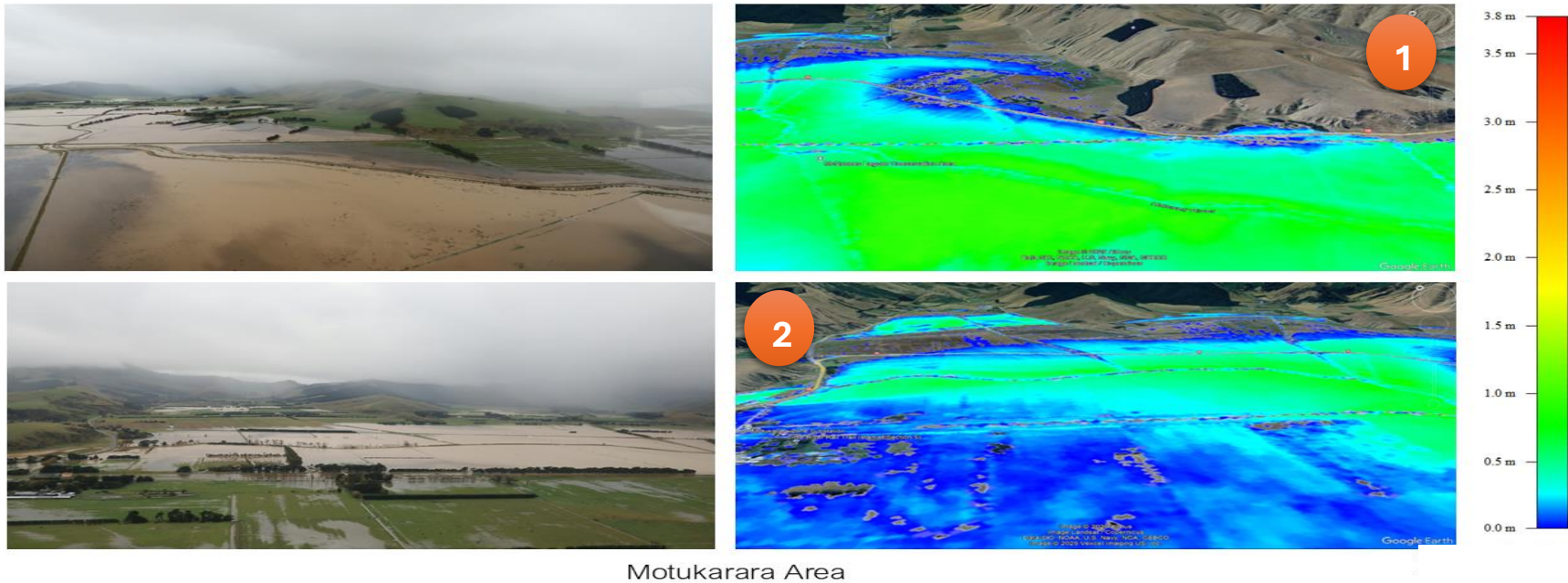


Calibrated

50% increased infiltration and 0.3m reduced GW depth

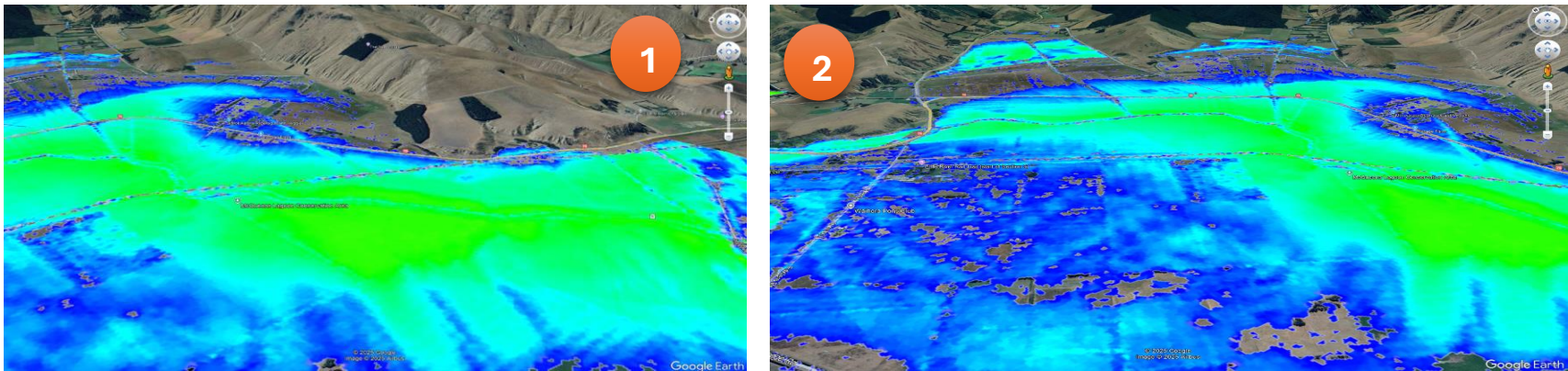


Baseline Model



Calibrated

50% increased infiltration and 0.3m reduced GW depth





Appendix A – Schematic of Halswell Junction Basin outlet

Schematic representation of Halswell Junction Basin Outlet

The schematization of the Halswell Junction basin outlet has been updated based on the design memo, as detailed below. While the memo does not specify the exact number of openings in the octagonal riser 'hood', these have been represented in the model as three rectangular orifices (600 x 600 mm each) and one circular opening with a diameter of 1.6 m (see table below). All levels have been assigned according to the information provided in the design memo, which has been converted from CDD to NZVD.

Orifice ID	Type	Invert Level(m)	Diameter(m)	Width(m)	Height(m)	Discharge Coefficient (m)
HALS.Orifice.DRWG.13519	Rectangular	20.12	-	0.6	0.6	1
HALS.Orifice.DRWG.13520	Rectangular	20.12	-	0.6	0.6	1
HALS.Orifice.DRWG.13521	Rectangular	20.12	-	0.6	0.6	1
HALS.Orifice.DRWG.13522	Circular	22.02	1.6	-	-	0.5*

**As the design memo does not clearly specify the type and arrangement of the outlet, we have assumed that this outlet is fitted with a grate and therefore applied a 50% headloss.*

A dummy node (13520) has been included in the model to connect all these orifices. Additional levels and configurations can be seen in the profile plot (Figure-2). The design memo has been attached to this report for reference.



Figure-1: Plan View

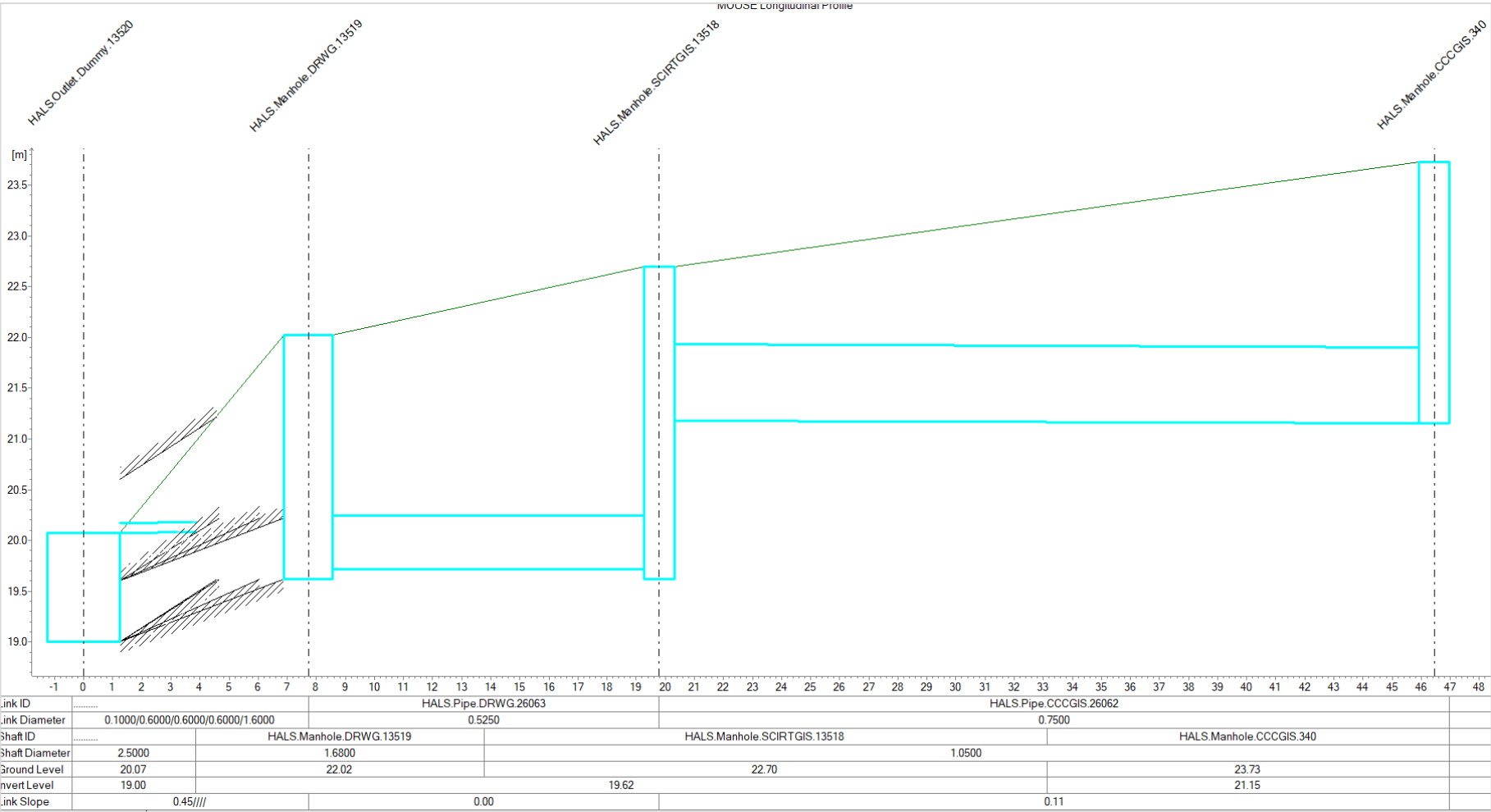


Figure-2: Profile Plot

PROJECT INFORMATION			
Project Name: Halswell Junction Road Basin Outlet Improvement Initiation Memo			
Project number: CP 500935		WBS: 562 / 3424	
PREPARED BY			
	Name	Signature	Date
Author	Victor Wong		13 Dec 2017
Reviewer	N / A		
DELEGATED AUTHORITY SIGN OFF			
	Name	Signature	Date
Team Leader	Howard Simpson		
Client Representative	Mark Penrice		

Summary

Halswell Junction Rd basin (HJR Basin) is a stormwater management facility at the corner of Springs Road and Halswell Junction Road in Hornby, Christchurch. It is a wet detention pond, with permanent water level, and receives surface runoff from nearly 170ha of mostly industrial catchment in Hornby and Templeton (Figure 1).

The existing pond outlet configuration demands physical presence of the operation staff during rain events to manually control the flow of water out of the pond. This is unlikely to happen with resource typically require elsewhere in the city. As a result, the receiving runoff regularly short-circuits the basin and enters the downstream channel without adequate residence time for quality treatment.

This memo outlines a need to resolve the current issue by modifying the existing outlet, so the basin can treat and manage its inflows and outflows more effectively.



Figure 1 – Aerial view of Halswell Junction Road Basin

Background

Halswell Junction Rd Basin is a permanent wet pond at the corner of Springs Road and Halswell Junction

Road. It receives surface runoff from more than 170 ha of mostly industrial catchment in Hornby and Templeton. A wet pond provides temporary stormwater detention during storms, and allows for particles to drop out of the inflows. The basin was completed in 1990 by the former Ministry of Works and Developments.

The capacity of the basin was increased in 2011 during construction of Christchurch Southern Waterway Phase 1. A 2010 Beca investigation report for this expansion is available in TRIM 13/886956. The outlet was not modified in this basin expansion.

For the basin to function effectively, surface runoff from a storm event should be retained until a certain water quality standard was achieved prior to releasing it downstream. Detained water was released by combination of partially opening a gate and pumping through Pump Station 251 (PS 251). As these overflows from HJR Basin has minimal impact downstream, this tedious setup means that the basin is typically ignored by Council staff during heavy rainfall events to attend more pressing flooding issues in other parts of Christchurch. The main flap valve to the 750mm pipe in Halswell Junction Road was left

open after 2011, and permanent pond level dictated by the pipe invert. With no attenuation, the basin becomes a "flow-through" basin with minimal treatment.

To provide water quality treatment for these untreated flows out of HJR Basin, Owaka Basin, a stormwater infiltration basin is to be installed as part of Christchurch Southern Motorway phase 2 to receive and treat 12.5mm of first flush runoff going through HJR Basin. Wilmers Basin, another stormwater management basin at 46 Wilmers Road, will be constructed in 2018 to provide additional treatment and detention when Owaka Basin reaches its capacity.

The Council is required to observe a 1997 agreement with Tangata Whenua that untreated water should not discharge to Knights Stream. If the HJR basin outlet is modified to hold back the water during peak storms, and only release them at a controlled rate after the peak has passed, this should alleviate a lot of concerns on both runoff quality and quantity.

Other Past Issues

Aside from its heavy maintenance scheme, which requires intervention from Council operation staff during each rainfall event, the basin has also suffered leakage problems, which contributed to it not performing to its optimum capacities.

Due to the permeable nature of the insitu ground, the pond was lined with loess when it was constructed. However, exposed portions of ground above the permanent water line dried up and cracked when exposed to heat during summer months. This leads to water seeping to ground instead of being captured by the basin. In addition, there was also a crack in one of the outlet structure. This caused the basin to operate at less than its full potential. The leakage was remediated a few years ago using bentonite and observed seepage had decreased significantly. See memos in Trim 15/93969 and 15/94013.

Existing Setup

Outlet Structure

The existing outlet structure (Figure 2 and 3) consists of:

- A stormwater pump station (PS 251), which would pump excess runoff in the basin to nearby 150mm diameter sewer. There is a walkway to the pump station.
- An octagonal riser 'hood' structure beneath the pump, which has several 600 x 600 openings with gate valves for flow control.

- A deep 10m long 525mm diameter concrete pipe, which is submerged all the time, and serves as the gravity drain for water in permanent wet zone to a large square manhole where the pump is housed.
- A 750mm concrete pipe, also connected to the aforementioned manhole, which serves as a high level outfall to underground stormwater network in Halswell Junction Road. Ken Couling, a former Council engineer, has estimated the 750mm pipe to have a maximum flow capacity of 480L/s.

At present, flat valves for both the ‘hood’ structure and 750mm outlet has been left permanently opened – presumably instructed by Council personnel – since the 2011 basin expansion. Hence, the existing pond level is determined by the pipe invert of RL 30.55 and all water into the basin flows unrestricted to underground pipe network in Halswell Junction Road

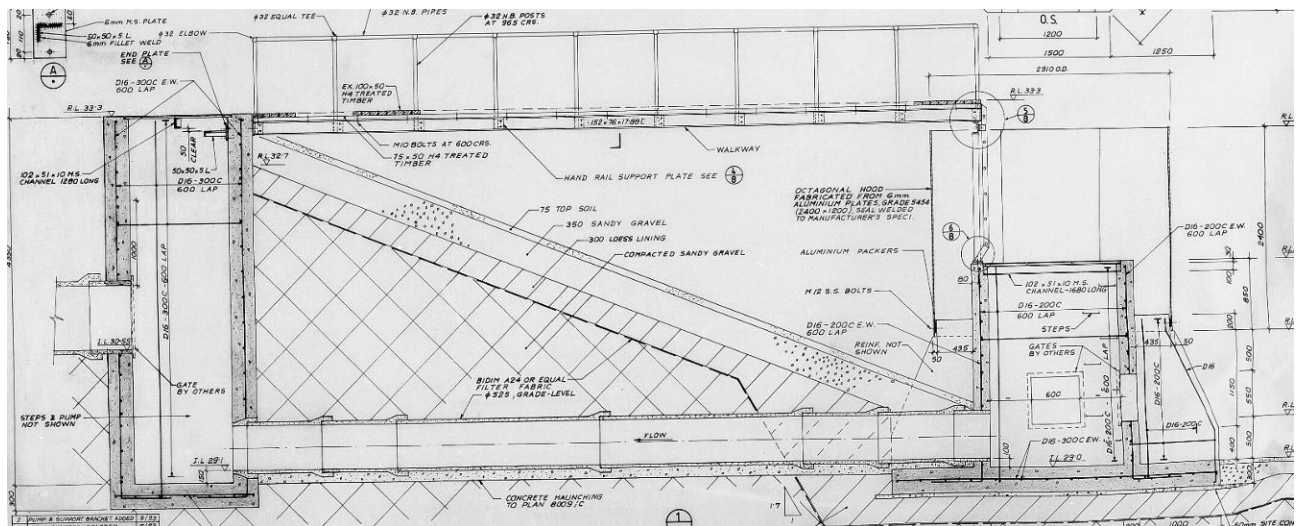


Figure 2 – Outlet manhole and pipes, octagonal ‘hood’ structure and walkway



Figure 3 – Octogonal ‘hood’ structure, which house the pump controls

Volumes

The basin volumes have increased nearly two-fold post 2011 expansion during the motorway construction.

Approximated pre and post expansion volumes obtained from Beca investigation report are listed in Table 1. An elevation vs. volume plot from the same report is available in Appendix B. These quantities were rough estimates only and should be reconfirmed via a topographical survey.

The existing setup means that approximately 40,000m³ of storage above the permanent pond level is not been currently utilised for treatment nor storage.

Table 1 – Pond Volumes Pre and Post 2011

	Pre 2011 Expansion	Post 2011 Expansion
Normal WL (m)	Unknown	30.55 (same as 750mm outlet IL)

Permanent Pond Volume (m³)	16,000	28,400
Top Basin WL (m)	33.0	32.44
Maximum Volume (m³)	38,800*	70,400**

* - The memo 'Halswell Junction Retention Basin Rate of Leakage, TRIM 15/94013' mentioned useable storage volume of 25,000m³ is available above the permanent water.

** - This is the estimated volume up to RL 32.44m, however, it is unlikely the basin will reach this level, as water would start to overtop at RL 32.0m at the south-east corner to Halswell Junction Road. At RL 32.0m, pond volume is estimated to be around 59,000m³.

Existing Operating Procedure

The operational procedure prior to the expansion is as listed in Table 2 (from Engineering Plan 12133). This is also shown figuratively in Figure 4. It is unlikely the procedure has changed prominently, as there was no modification made to the basin outlet.

Table 2 – HJR Basin operating procedures in the original 1990 design

Water Level (m)	Description	Comments
RL 29.0 – 30.0	Permanent wet zone	This can only be emptied using pump.
RL 30.0 – 30.55	Second layer of permanent wet zone	This can only be emptied using pump. This is to be carried out if water quality is acceptable and additional volume required in preparation for the next storm.
RL 30.55 – 31.4	Storage volume 1	This zone was designed to be drawn down <u>after</u> the inflow has been reduced to 10 L/s by adjusting valve B opening. However, in 2011 expansion, valve B was left permanently opened, which allows water to flow through uninterrupted.
RL 31.4 – 33.0	Storage volume 2	The water in this zone will overtop the riser 'hood' structure and discharge freely the 750mm outlet pipe.

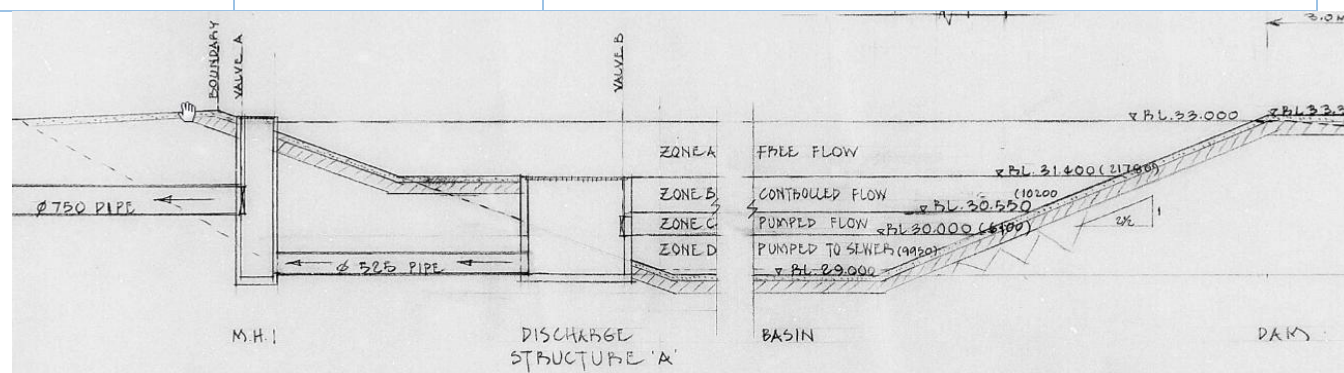


Figure 4 – Operating procedures for HJR Basin in the original 1990 design

Proposal

A 'self-regulating' outlet mechanism will allow Halswell Junction Road Basin to drain at a controlled rate and maximise its full storage capacity ensuring effective treatment of surface runoff received. To achieve these purposes, it was proposed to:

1. Investigate the possibility of reconstructing the basin outlet, including the 525mm diameter low flow pipe and 'hood' structure so that the basin can drain without manual intervention during storms. The new structure should also has a spillway for bypass high storm flows. A potential basin operating procedure is shown in Table 3.
2. Consider installation of another high level outlet at the south-east corner of the pond to the underground network in Halswell Junction Road to serve as the emergency overflow.
3. Investigate other means of removing the permanent ponded water beneath RL 30.22m and if possible, remove PS 251 as a discharge mechanism altogether.
4. Investigate options of installing bypass structures in pond inlets, which allows the basin to be taken offline, and undergoing maintenance work such as sediment or vegetation removal.

Table 3 – Possible basin operating procedures

Water Level (m)	Description	Comments
RL 29.0 – 30.55	Permanent wet zone (water quality volume)	This could be emptied using existing pump at PS 251, or alternative options such as an outlet pipe to Springs Road. The pond might need emptying for maintenance purpose and if additional volume is required in preparation for the next storm.
RL 30.55 – 31.4	Detention storage	This zone could be slowly drawn down at suitable rate by slow flow outlet e.g. orifice. Outlet should be designed with protection of the receiving environment in mind, and to all possible flow conditions.
RL 31.4 – 32.44	Extended detention storage	High flow bypass and secondary flow path should be identified for heavy storms.

Cost Estimates

A summary of estimated project cost is shown in Table 4 below. A detail breakdown of the forecasted cost is attached in Appendix A.

Table 4 – HJR Basin Outlet Improvement Estimated Cost

Description		Estimated Cost
1	Investigation and Design	\$53,350
2	Construction	\$ 153,120
	Total	\$ 206,470

Conclusion & Recommendations

The existing Halswell Junction Road Basin outlet has a maintenance heavy scheme, and as a result the basin is generally left alone during most rain events. A functional outlet control device means an effective stormwater management basin that will improve the overall water quality and quantity in receiving waters of Halswell River.

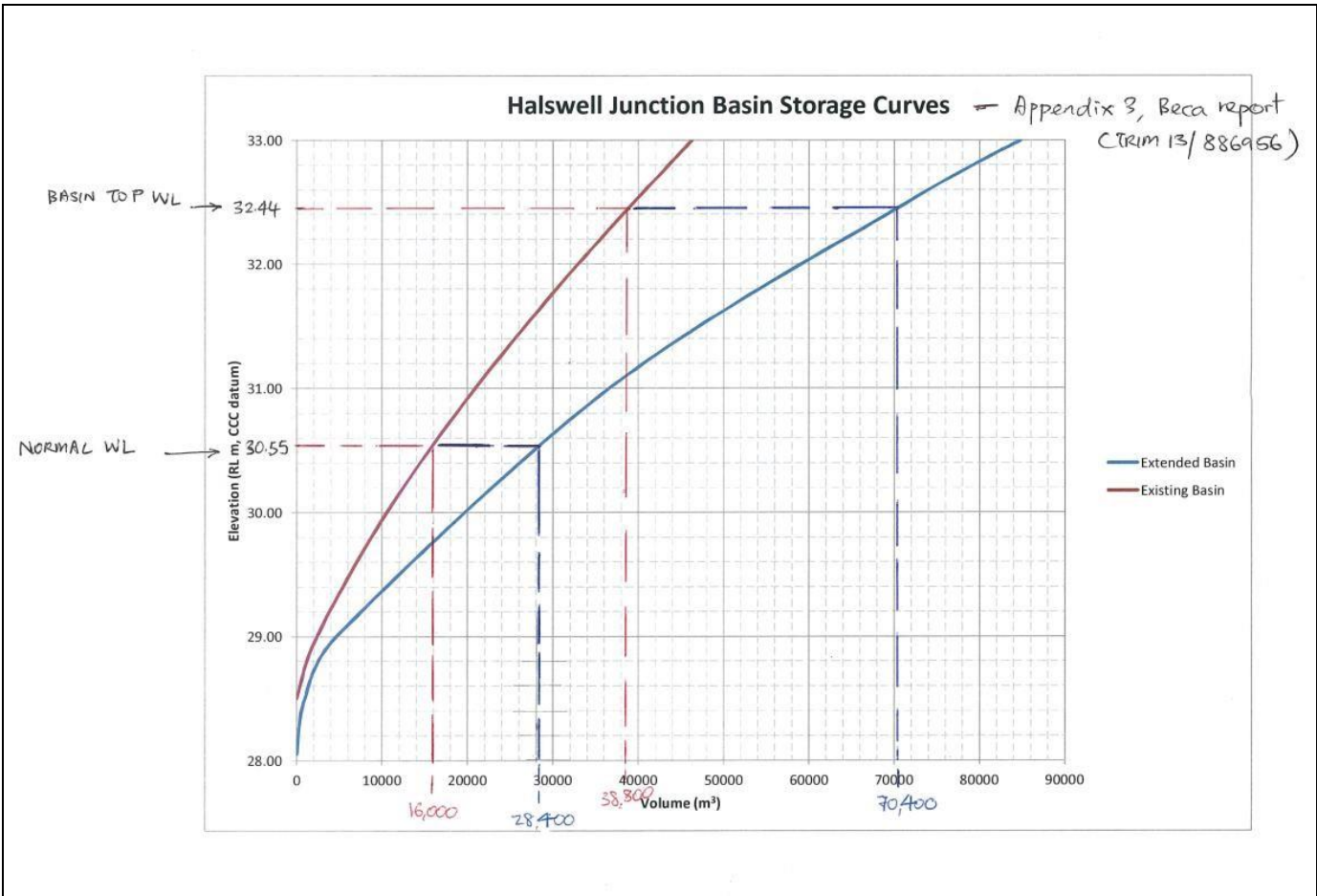
It is therefore recommended that the existing HJR basin outlet be modified so the basin can perform its tasks automatically and effectively as a flood control and pollutant removal device.

Appendix A – Project Cost Estimate

Date	13/12/2017		Revision	1	
Description	HJR Basin Outlet Improvement				
Item	Description	Unit	Quantity	Unit Rate	Amount
Investigation & Design					
1.0	Preliminary Investigations (Engineering plans, scale penetrometers, site visits and desktop studies) Resource Consents (CCC and Ecan)	LS	1	\$2,500	\$2,500
1.1	(Include desktop assessment, report writing and applications etc)	LS	1	\$2,500	\$2,500
1.2	Survey (Topography survey, pickup of all services, 12D processing etc)	LS	1	\$3,500	\$3,500
1.3	Design and Draughting (Detailing, calculations and documentation)	LS	1	\$20,000	\$20,000
1.4	Project Management and Contract Administration	LS	1	\$15,000	\$15,000
1.5	Others (Include ecological studies, hydraulic modelling)	LS	1	\$5,000	\$5,000
				<i>Subtotal</i>	\$48,500
				<i>Design Contingency</i>	<i>10%</i>
					\$4,850
				Investigation & Design Total	\$53,350
Construction					
Site Preparation					
2.0	Preliminary and General	LS	1	\$5,000	\$5,000
2.1	Site Clearance and Establishment (Breakout and dispose of existing structure, vegetation etc)	LS	1	\$25,000	\$25,000
2.2	Site Setout	LS	1	\$1,000	\$1,000
2.3	Erosion and Sediment Control	LS	1	\$5,000	\$5,000
Construction^{1,2}					
3.1	Civil Works (Included earthworks, trench support, dewatering etc.)	LS	1	\$10,000	\$10,000

3.2	Flow Control Structures and Associated Pipeworks <i>(Weir, orifice, bypass channel, erosion control and all pipeworks required for flow control)</i>	LS	1	\$40,000	\$40,000
3.3	Restoration	LS	1	\$5,000	\$5,000
3.4	Landscaping and Planting	LS	1	\$10,000	\$10,000
3.5	Footpath	LS	1	\$3,000	\$3,000
Miscellaneous					
4.1	Salvage and Removal of Pump and Associated Mechanical and Electrical Components <i>(If there is an alternative solution to drain the permanent pond)</i>	LS	1	\$10,000	\$10,000
4.2	Commissioning	LS	1	\$2,000	\$2,000
4.3	Others - Subcontractors Profit & Attendance	%	15%		\$11,600
				<i>Subtotal</i>	\$127,600
	<i>Construction Contingency</i>			<i>20%</i>	\$25,520
				Construction Total	\$153,120
1 - The forecast construction cost does not take into consideration modification of inlets to HJR Basin (If required).					
2 - The cost also does not consider installation of a low flow outlet to pipe network south of Springs Road.					

Appendix B – HJR Basin Volumes (from 2010 Beca Report)





Appendix G –Technical memo on runtime specification



Memorandum

15 July 2015

To	Tom Parsons		
Copy to	Peter Kinley, Greg Whyte, Chris Maguire, Iris Brookland, Graham Harrington, Peter Christensen		
From	Tim Preston	Tel	027-6414301
Subject	Citywide Flood Modelling - Proposed technical specification for model runtimes	Job no.	51/33275/

Hi Tom,

At the technical meeting 19/6, you asked GHD to prepare our recommendations in terms of improving the CCC specification for model runtimes. This memo is produced to meet that objective and we would recommend that the following specifications be adopted for the Citywide Flood Modelling project:

The recommendation specifies runtime requirements for draft (common) model runs. There is a general expectation that on occasions either during or on conclusion of some modelling work that higher specification (slower) model run(s) will be required either as a progress check or as a final design confirmation. Runtime requirements for such runs are not specified because they are much less common and will actually be quite varied according to the modelling need.

For closely related sets of (similar) model runs, evidence of satisfactory stability and accuracy with low order calculations may only need to be thoroughly checked for one selected model run with confidence in the similar model runs inferred. The check run should verify acceptable water balance result, stability through checking velocities and CFL numbers as well as quantifying 2D grid max water level differences between low order and high order calculations. The method of checking results shall be included in reporting associated with the runs and the extent to which suggest inferred confidence is used as a QA tool is at the discretion of the senior modelling person involved.

Table 1 Run specification and runtime parameters

Runtime Parameter Description	Draft model runs	Final design / or check model runs
1. Precision	Single	Single
2. Order of computation engine (both in time and space)	Low order	High order
3. Auto water balance	Off	On (discretionary)
4. Courant number	0.9	0.8

Runtime Parameter Description	Draft model runs	Final design / or check model runs
5. Model stability (2D)	Qualitative inspection of 2D results and sample timeseries results	Qualitative inspection
6. Maximum values calculated at runtime	No	Discretionary
7. Data saving fields	Depth, level, speed, CFL	Discretionary
8. Data saving timesteps	10 minute	Discretionary
9. Rainfall type	Single event	Multiple events batched
10. Rain event duration	Per river catchment critical duration	Up to 72 hours
11. Flood event	50yr ARI, climate change rainfall and sea level rise	Optional
12. Stopbanks	Included in modelling	Optional
13. Computer specification	Refer below except single GPU	Dual or quad GPU
14. Geography	Single river catchment	Single river or Citywide catchment
15. Runtime requirement	7 hours	Not required

Computer specification: A suitable computer is a 16 core Dell Precision T7610 with Intel Xeon processors, 32 GB memory and running 64-bit Windows 7 operating system, with 2 Nvidia GeForce GTX Titan GPUs, with a solid state local hard drive (mostly adopted from DHI specification Mar 2015, issued as App C to the RFP)

GHD Discussion / rationale:

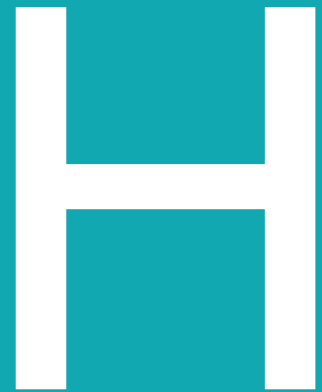
1. For models in Christchurch with small vertical extents (eg: 100m) that single precision 8 sig figs, produces with a minimum vertical resolution for numerical calculations of 0.01mm
2. This relates to the number of terms used in the numerical approximation (computation). Low order should be considered as a 'draft' run, with significant decisions such as design or floor level settings using high order
3. Auto water balance slows down the runtimes significantly and should be used sufficiently to derive confidence in the model stability, but is not required for most model runs
4. The higher 0.9 courant number will accelerate runtimes but increase risks of model instability, reducing the number to 0.8 for final runs should improve outcomes in item 5 below.
5. 2D instabilities are generally identified by high CFL numbers and unreasonably high velocities. To our knowledge there is no way to specify what is considered acceptable, but in general small amounts (both in time and space) of instability that do not appear to affect overall results of interest are considered acceptable. This needs to be judged instinctively by a senior modelling person, in conjunction with 'reasonableness' of the overall results and Council may want to review this.
6. Processing of maximum values post runtime is usually preferred.

7. With FM software it is tedious to post process depth into level (or vica versa), hence specification to produce both and velocity is required in order to assess stability. Sometime other parameters may be required for specific purposes, but generally three should be sufficient for most purposes.
8. Recommendation is consistent with DHI specification and strikes a balance between speed and results files sizes vs the need for resolution driven by the critical use to inspect areas of potential instability
9. Once the critical duration is established for a typical design purpose, a single event should be sufficient for most design runs. Running a 'final proof' using the full suite of storm durations would be recommended for final design runs.
10. Recommendation is essentially following current practice of 60, 18, 48 hrs for the Heathcote, Avon and Styx models respectively. Recommendation to adopt river specific standards will advantage the Avon/estuary model which is likely to be the 'heaviest' in terms of detail and runtime requirements.
11. The 50 year flood event with climate change rainfall and sea level rise will be the most common design model run undertaken. Larger events may be expected to take longer to run.
12. Stopbanks included will be the most common design model run undertaken. Including the stopbanks will reduce wetted cells and be of some benefit to runtimes.
13. We have found that procurement of dual GPU computers is both expensive and administratively onerous as it requires going outside of our IT standard procurement policy in terms of CPU box and potential need to violate suppliers warrantee. We expect this will be a problem for most consultants and hence recommendation for single GPU. We have appended a requirement for solid state local hard drives as these improve results saving performance (prerogative being that results are saved locally to maximise speed).
14. This specification would apply to any of the major CCC river catchments (Styx, Avon, Heathcote or Halswell) individually but not the aggregate Citywide model.
15. Seven hours, includes for model initialisation time and runtime, but excludes any hotstart runtime. This time allows for two runs to be completed per working day (one daytime, one overnight).

Regards

Tim Preston

National Technical Leader Water Planning



Appendix H – Existing Development 2021 stabilization file note

File Note

By: Leif Healy **Date:** 10 November 2022
Subject: Existing Development 2021 stabilization **Our Ref:** 3364860

1 Background

This document records changes made to the HDM Halswell hydraulic model as part of stabilization of the Existing Development 2021 model.

1.1 Batch of runs used

Eight model scenarios were simulated. They are given below along with their abbreviated name:

- 0.5% AEP 0.5-hour design event – V002_Hals_02_ED2020_00p5AEP_00p5hr
- 0.5% AEP 3-hour design event – V002_Hals_02_ED2020_00p5AEP_03hr
- 0.5% AEP 9-hour design event – V002_Hals_02_ED2020_00p5AEP_09hr
- 0.5% AEP 60-hour design event – V002_Hals_02_ED2020_00p5AEP_60hr
- 0.2% AEP 0.5-hour design event – V002_Hals_02_ED2020_00p2AEP_00p5hr
- 0.2% AEP 3-hour design event – V002_Hals_02_ED2020_00p2AEP_03hr
- 0.2% AEP 9-hour design event – V002_Hals_02_ED2020_00p2AEP_09hr
- 0.2% AEP 60-hour design event – V002_Hals_02_ED2020_00p2AEP_60hr

Results for these simulations were analysed according to the city-wide modelling methodology (the methodology, including in Appendix A).

1.2 Pre-stabilisation work

To get the model to run more quickly rational steps were taken to stabilize the model prior to following the city-wide stabilization methodology. This included:

- Setting the exponential smoothing factor to 0.2, 0.4 or 0.8 for lateral links that were known to cause instability in the existing development 2016 model.
- Setting the exponential smoothing factor to 0.2 for River/Urban links.
- Setting the exponential smoothing factor to 0.2 for Urban-Overland links.
- Adding closed cross sections at the downstream end of river branches that are linked to the pipe network and were known to cause instability (as per the city-wide methodology).
- Setting the overall timestep (under 'Time' in the MIKE 21 FM model) to 0.25 seconds. This facilitates frequent hydraulic linking of the 1D and 2D models which should improve the stability of the links. In large events the pipe network becomes completely surcharged so small changes in flow at the river/urban links create large changes in head in the pipe network (compared to when the pipes are partially full). When the pipes are partially full the remaining volume can absorb the fluctuations.
- Locations with CFL violation warnings were mapped in GIS to focus improvements to the mesh. Some small mesh elements were merged where this would not impact the results. This was done in the *.MDF file's nodes and arcs so the new mesh could be easily updated without needing to reapply manual edits.

These steps were successful in preventing the model from becoming unstable and allowed it to run in a practical timeframe.

File Note

2 Stabilization Round One

2.1 MIKE 21 oscillations

As per the city-wide methodology, oscillations in the 'Surface elevation' result were mapped as a set of shapefiles. A Python script was prepared to automatically convert these to raster files (*.tif) for faster visualisation.

There were only three places in the MIKE 21 domain where there were oscillations larger than 100 mm as a result of linkages with the MIKE 11 and MIKE Urban models. The largest was near Ella Park at the downstream (southern) end of the river branch 'Hals.Knightstream.Drain' (Figure 2-1).

The second largest was near the confluence of 'Hals.MinsonsDrain' and 'Hals.HalswellRiver.1' which is near the intersection of Old Tai Tapu Road and Early Valley Road (Figure 2-2). The smallest was on the true left bank of 'Hals.PaynesDrain' near its link to 'Hals.CreameryDrain' (Figure 2-3). The actions taken to resolve these are discussed in section 2.4 and the result is reported in section 3.1.

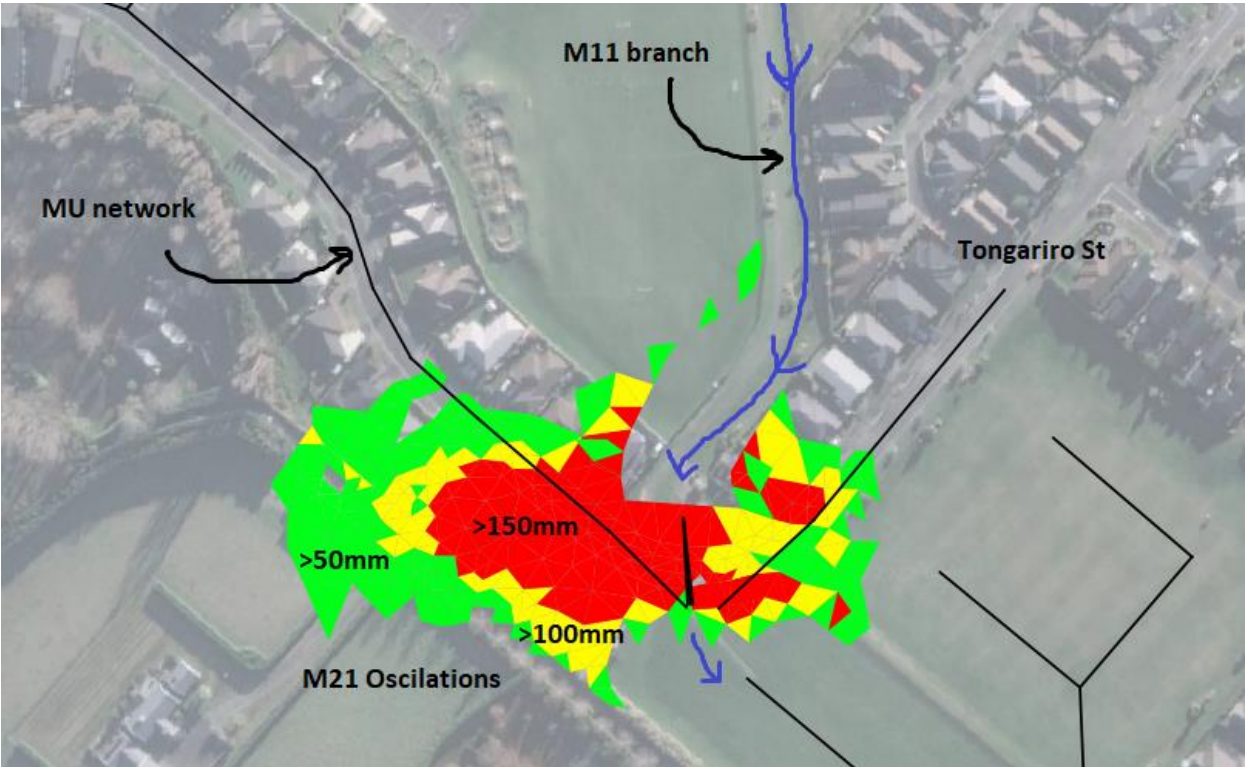


Figure 2-1: MIKE 21 oscillations near Ella Park at the bottom of 'Hals.Knightstream.Drain' river branch. NZ Basemaps by Toitū Te Whenua.

File Note

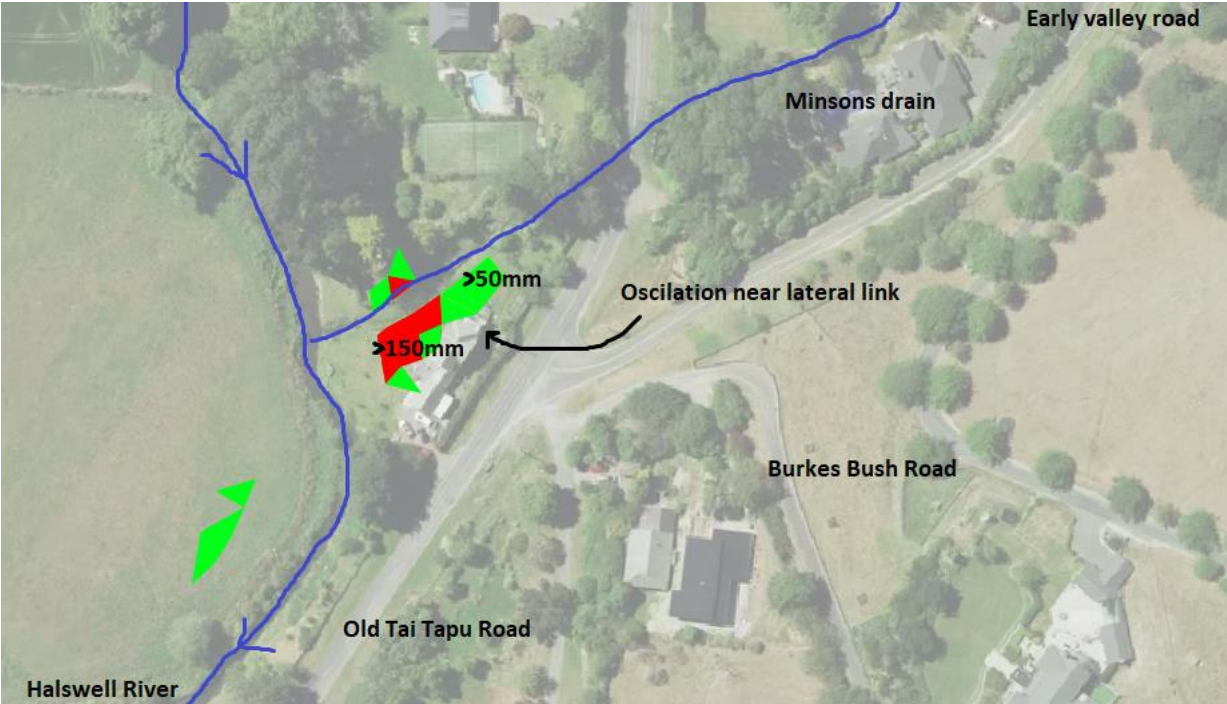


Figure 2-2: Oscillations near confluence of Minsons Drain and Halswell River. NZ Basemaps by Toitū Te Whenua.

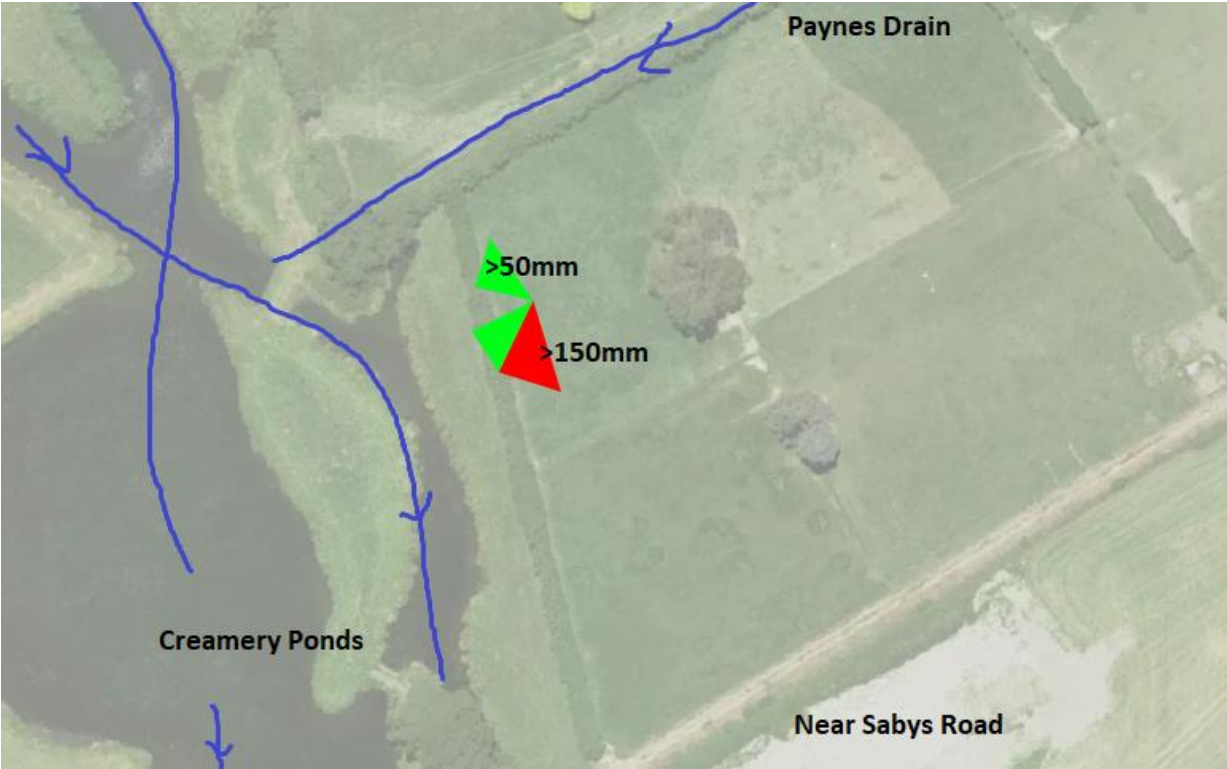


Figure 2-3: Oscillation near Paynes Drain and Creamery Ponds confluence. NZ Basemaps by Toitū Te Whenua.

File Note

There are some other locations where oscillations were observed in the MIKE 21 domain that are not associated the 1D models or coupling. Where Dawson Creek crosses Ellesmere Road there is a culvert in the MIKE 21 model and some associated oscillations (Figure 2-4). Dawson Creek is small and is not modelled in MIKE 11. It is modelled as a simple overland flow in MIKE 21. There were also oscillations observed at the internal dike in Halswell Springs Reserve (Figure 2-5). Oscillations associated with both of these locations were only observed in one simulation: 0.2% AEP 60-hour design event. The MIKE Flood log was checked and there were no CFL violation warnings, indicating they are not associated with small elements and high velocity/wave speed.

The causes were found:

- At Dawson Creek near Ellesmere Road there was a MIKE culvert whose x-y coordinates were not correct. This meant it was connecting two small cells that were next to each other on the road. This was resolved as part of the first round of stabilization.
- At the internal dike in Halswell Springs Reserve, the water level rises and is very similar on both sides of the dike. The dike uses the MIKE ‘empirical formulation’ which has a rapid change in discharge at low water level difference across the dike. The MIKE documentation recommends increasing the critical level difference parameter on the dike if this causes instability.

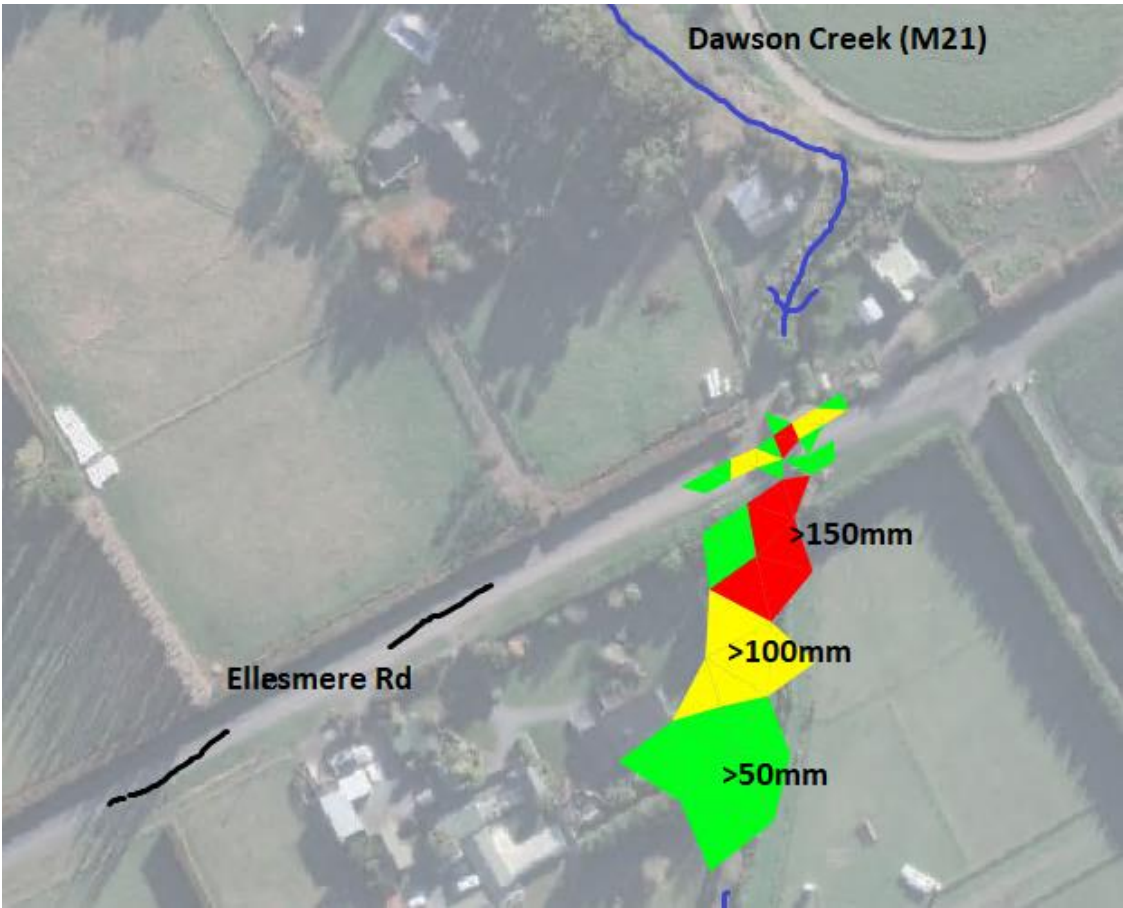


Figure 2-4: Oscillations at Dawson Creek at Ellesmere Road. NZ Basemaps by Toitū Te Whenua.

File Note

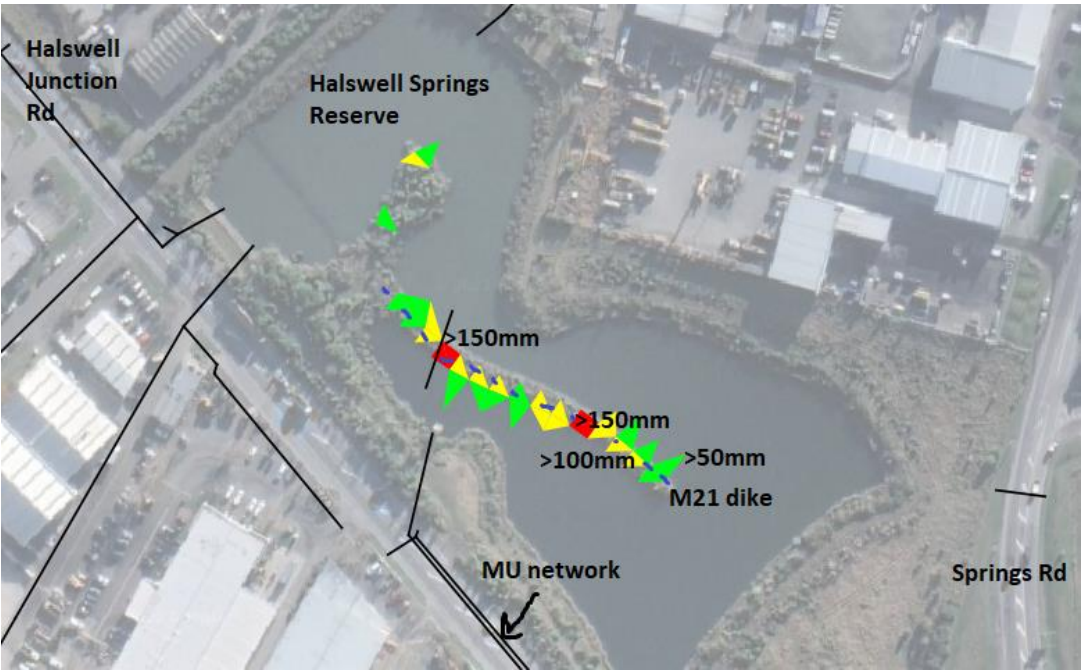


Figure 2-5: Oscillations at internal Halswell Springs Reserve dike. NZ Basemaps by Toitū Te Whenua.

2.2 MIKE Urban oscillations

In round one several manholes showed oscillations greater than 150mm (228 out of 1685 or 13.5%). These were recorded in a shapefile as per the methodology. The methodology says to 'do nothing and report' except where they are associated with a MIKE 21 oscillation greater than 100mm. This only occurred at one location (near Ella Park in Figure 2-1).

Some manholes showed oscillations greater than 300mm (40 out of 1685 or 2.4%). The methodology says one attempt should be made to resolve these and those that are not resolved should be reported. Prior to running the formal stabilization runs it was noted that some manholes had oscillations larger than 300mm. Therefore, the overall timestep was reduced from 0.5s to 0.25s. The overall timestep is when information is passed between the 1D and 2D models and therefore reducing it is likely to reduce oscillations associated with overflowing manholes/sumps. The exponential smoothing factor was also reduced to 0.2 for all manholes coupled to the MIKE 21 model.

2.3 MIKE 11 oscillations

In round one three MIKE 11 branches show oscillations greater than 150mm. These were Hals.MinsonsDrain, Hals.KnightstreamDrain, and Hals.GreenDrain. In at least one simulation in the batch, each of these also showed oscillations greater than 300mm.

File Note

2.4 Actions taken to resolve oscillations

- For Hals.MinsonsDrain at confluence with Hals.HalswellRiver.1 we:
 - Changed Hals.MinsonsDrain left and right bank to use M21 as their structure source parameter. The true left bank of Hals.HalswellRiver1 here uses MIKE 21 as its structure source parameter. This means there is no difference in the coupling between the two rivers at the confluence.
 - Changed the exponential smoothing factor for the lateral links on Hals.HalswellRiver.1 to 0.2 from 0.8.
- At the true left bank of Hals.PaynesDrain near Creamery Ponds we:
 - Reduced the exponential smoothing factor for the lateral links at Hals.PaynesDrain to 0.2 from 1.
 - Reduced the exponential smoothing factor for the lateral links at Hals.CreameryPonds.1 to 0.2 from 1.
- For the Halswell Springs Reserve internal dike we:
 - Increased the critical level difference parameter on the dike from 10mm to 50mm.
- For the Dawson Creek at Ellesmere Road MIKE 21 culvert we:
 - Increased the 'alpha zero' parameter from 10mm to 100mm.
 - Corrected the culvert location.
- For the downstream end of Hals.KnightstreamDrain we:
 - Added dummy pipe with a large diameter at the bottom of Hals.LonghurstDrain to absorb some of the oscillations.
 - Added a dummy/transitional cross section to the bottom of Hals.LonghurstDrain to smooth the transition into the pipe that goes to Ella Park.
- At the start of Hals.GreenDrain we:
 - Reduced the exponential smoothing factor from 1 to 0.2.

File Note

3 Stabilization Round Two

3.1 MIKE 21 oscillations

At the bottom of Hals.LonghurstDrain oscillations in the MIKE 21 were significantly reduced. They are now smaller than 100mm (Figure 3-1) across all runs in the batch (listed in section 1.1).



Figure 3-1: MIKE 21 oscillations at downstream end of Hals.LonghurstDrain

Oscillations larger than 150mm were observed in the second round near the confluence of Hals.MinsonsDrain and Hals.HalswellRiver.1 (Figure 3-2).

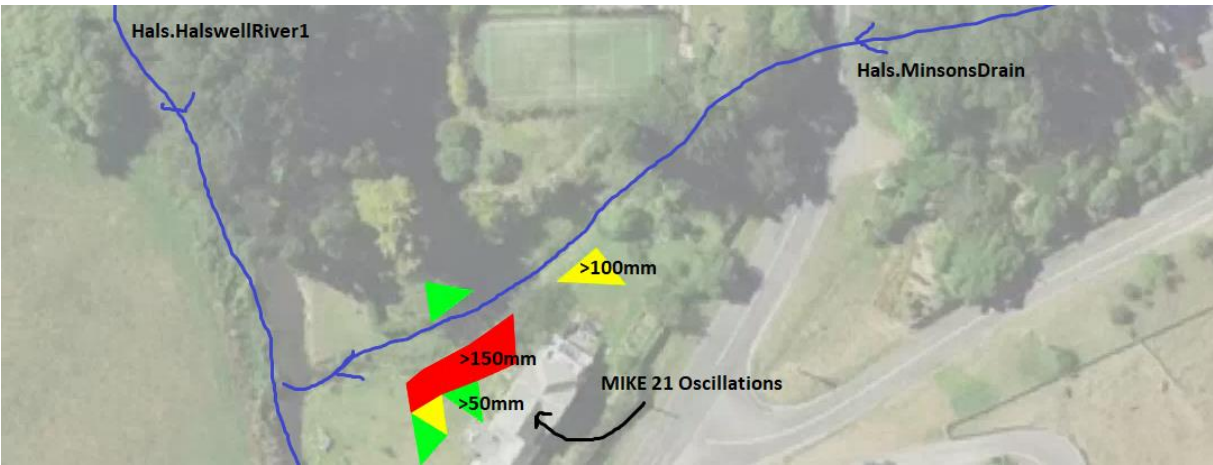


Figure 3-2: MIKE 21 oscillations at the confluence of Hals.MinsonsDrain and Hals.HalswellRiver.1

File Note

There were no oscillations at Paynes Drain at Creamery Ponds in the second round (but there were in round one - Figure 2-3). Oscillations larger than 150mm were observed at Dawsons Creek at Ellesmere Road in the second-round batch (Figure 3-3).



Figure 3-3: Oscillations observed in second-round batch at Dawsons Creek at Ellesmere Road

Oscillations larger than 150mm were observed at the internal dike in Halswell Springs Reserve. The oscillations are less than 250mm.

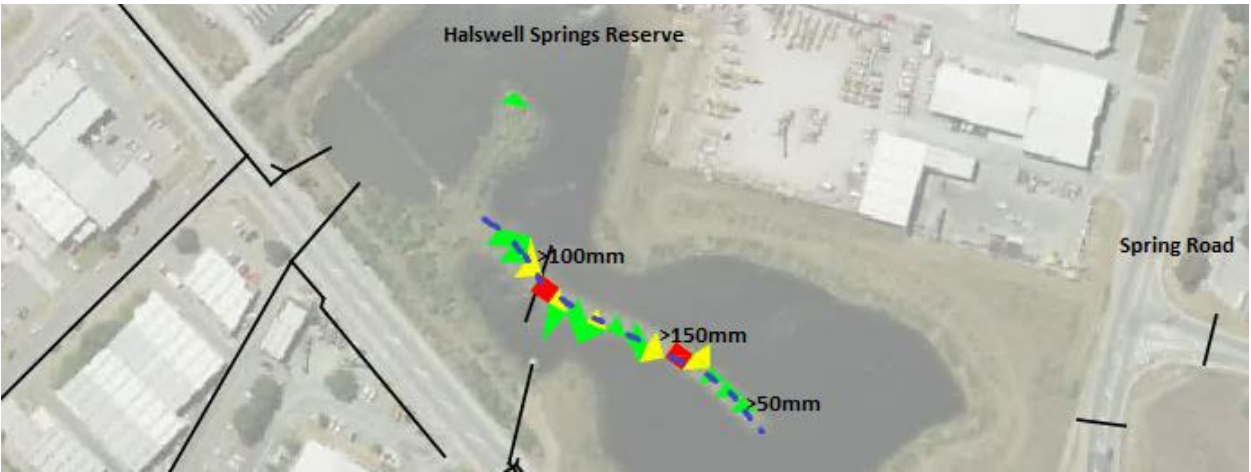


Figure 3-4: MIKE 21 oscillations at Halswell Springs Reserve internal dike in the second-round batch

3.2 MIKE Urban oscillations

In round two 231 manholes showed oscillations greater than 150mm (out of 1685 or 13.7%). These were recorded in a shapefile as per the methodology. 31 manholes showed oscillations greater than 300mm (out of 1685 or 1.8%). These were reported as per the methodology.

3.3 MIKE 11 oscillations

In round two three MIKE 11 branches show oscillations greater than 150mm. These were Hals.MinsonsDrain, Hals.KnightstreamDrain, and Hals.GreenDrain. In at least one simulation in the batch, each of these also showed oscillations greater than 300mm.

File Note

4 Stability Status

As per section 3 Stabilization Round Two, there are persistent oscillations in the MIKE 21, MIKE Urban and MIKE 11 models. The methodology trigger for a second attempt at resolving oscillations is ‘any MU [MIKE Urban] sites where the associated M21 [MIKE 21] levels show level oscillations > 100mm’ of which there are none. The methodology specifies any oscillations remaining should be reported. Shapefiles were produced showing these locations for all three model components (MIKE 21, MIKE 11, and MIKE Urban). They are included in the Existing Development 2021 peer review package under the folder “Stabilization Files” provided to Christchurch City Council on 29 November 2022.

Kind regards,

Leif Healy



File Note



Appendix A - Stabilization methodology

Natasha Webb

From: Elliot Tuck
Sent: Tuesday, 10 October 2017 1:42 PM
To: Natasha Webb
Subject: FW: Halswell Model Stability Standard

FYI some more info on the stability once we get the models up and running.

From: Pasco, Ben [mailto:Ben.Pasco@ccc.govt.nz]
Sent: Tuesday, 10 October 2017 1:06 p.m.
To: Elliot Tuck <Elliot.Tuck@beca.com>; Kate Purton <Kate.Purton@beca.com>
Cc: Parsons, Tom <Tom.Parsons@ccc.govt.nz>
Subject: Halswell Model Stability Standard

Hi Kate / Elliot

Below are some further notes on stability criteria being applied to CWM. This has been prepared by GHD in relation to CWM so application to Halswell may require tweaking for relevance (selection of stabilisation runs?)

General stability standard methodology for the Citywide stormwater models

1. Stability assessments will be done in batches to be defined in scoping at the outset. Batches may include various AEP events (eg: 10/50/200yr) but shall not include different families of model runs (ie: pre quake and post-quake)
2. Scoping at the outset will also define which runs to evaluate and/or stabilise – this will typically be a subset of runs within a family with selection based on being representative of the family, with emphasis on priority of runs in the batch and consideration of cost / effort. Typically selected runs will be evaluated in both 1D and 2D results and stability improved but this protocol could also be applied to evaluation based on only 1D or 2D results or evaluation for reporting only with no attempt at improvement.
3. Runs will be typically be evaluated from results saved with the standard results save time steps
 - a. M21 save time steps were agreed in tech meeting 28/7/2017 (minutes of which refer back to XLS from TimPreston email sent 20170701_1430)
 - b. M11 and MU save time steps are four times the frequency of M21 save time steps (these are often therefore not integer values)
 - c. also refer GHD N:\NZ\Christchurch\Projects\51\33275\00.1Job Mgmt\04.Programs_Schedules\20160118 Revisions to future stages\CFM run timesteps 20160701.xlsx
4. For 1D results
 - a. Load the 1D result (MU or M11) into Mike View starting with the 25% timestep (ie: for an 80 timestep result file load from timestep 20-80, do not load the initial 25% of results).
 - b. Evaluate level oscillations within the MU and M11 results using the Mike View oscillation tool as described below. All sites with oscillation tool amplitude >150mm are to be tabulated, locations mapped (shapefile) and the 1D level timeseries data presented in XLS format (ref 1. Below). All sites will have max amplitude (defined as the smaller of the value changes either side of a local extreme point) calculated in the XLS and tabulated. All MU sites in this set will have the associated M21 timeseries results extracted from the cell above the node if the node is not coupled or the lowest coupled cell if there is any MU-M21 couple (using “Data Extraction FM” tool with a list of named x,y coordinates) and plotted for inspection also.
 - c. Work to reduce instabilities shall proceed as follows
 - i. For oscillations [150mm-300mm], then we would typically “do nothing” and report them, except for any MU sites where the associated M21 levels show level oscillations > 100mm in which case we would make one attempt to fix them and report thereafter whatever the outcome

- ii. For oscillation >300mm, we would make an initial attempt to fix them. If not solved initially then we would typically “do nothing” and report them, except for any MU sites where the associated M21 levels show level oscillations > 100mm in which case we would make a second attempt to fix them and report thereafter whatever the outcome
- 5. For 2D results
 - a. Run the DHI tool using bin values {0, 0.05, 0.15, 0.30, 0.50, 1, 2, 5m}, producing overall oscillation frequency summary data and a DFSU of max oscillation ‘map’ for each run
 - b. For each batch of results being evaluated
 - i. Compile the frequency summary data into a single XLS table and present graphically with highlights on any outliers
 - ii. convert the DFSU oscillation data into a polygon geodatabase format, remove shapes with less than 50mm max oscillation and compile into a singular shape with an attribute field for each model run result. Add fields of ‘max across runs’ and ‘avg across runs’ and ‘product of max-avg’.
 - c. Work to reduce instabilities shall be at the discretion of the modeller. Further attention shall be directed at runs with outlier oscillation frequencies and locations in the shape with high values in the three summary fields.
- 6. The deliverables for each batch assessed are;
 - a. Transmittal note, covering email, readme file or similar defining the model runs being evaluated and tabulating both their long and abbreviated file names
 - b. 1D spreadsheets – one for each model run - that Council can play with (drop down menu for 1D timeseries graphs)
 - c. 1D shapefile, per batch of model runs being evaluated, with a separate field for each model run and a summary count of occurrences across the batch
 - d. 2D spreadsheet per batch assessed with XLS and graphical 2D statistics
 - e. 2D shapefile per batch with summary statistics on each mesh tringle
- 7. File / field naming: The abbreviated 10 char run naming convention defined below should be used throughout the reporting including; drop down XLS functions, shapefile field names and individual XLS file names. The file names for a batch of the 1D spreadsheets should share a common batch name prefix of not more than 12 char and the abbreviated run name as suffix.
 - a. Std Format: ###_##[T]e##h – where [T] means optional character
 - b. eg: 079_10e12h translates as Model version 079, 10% exceedance probability rainfall, 12 hour storm duration
 - c. eg: 083_20Te01h translates as Model version 083, 20% exceedance probability rainfall [T]idal run, 1 hour storm duration
 - d. In both AEP and storm duration the 0.5 values (0.5% AEP or 0.5 hr) will be represented as "00".

Using the Mike View Oscillation Tool

This tool evaluates and provides summary report on instabilities in the Mike Urban and Mike 11 model results.

How to Access:

1. Open Mike Urban or Mike 11 model results (limit results to load according to other specification).
2. While the ‘Horizontal Plan’ is active, Go to ‘Tools’ -> ‘Compute’ -> ‘Instability’

Tool settings

- ‘Data type’ - Node level (Mike Urban) and Water Level (Mike 11)
 - o Note the flow data is not required to be assessed due the limited practicality, high level of effort required and the lower importance of flows in relation to flood levels
- ‘Calculation period’ - All Data (control data period for analysis when loading the result)
- ‘Oscillations’ option selection
- ‘Limit for number of extremes’ – zero
- ‘Duration of time interval’ field – leave as default
- ‘Min. difference for extremes’ – ie: set to 0.15 or 0.30m or otherwise in accordance with the general specification

Instability

File: 00_20s_steady_10_362_v4a.res11

Data type: Water Level

Calculation period

☒ All Data 12:00:00 a.m. 12:00:00 a.m.

☐ User Defined 30/12/1899 12:00:00 a 30/12/1899 12:00:00 a

☐ Maximum Change in Value

$ABS(Y[i+1] - Y(i)) < coeff * Y(i) \text{ OR } ABS(Y[i+1] - Y(i)) < maxdiff$

coeff. 0.1

maxdiff. 0

☒ Oscillations

Maximum number of local extremes in every time interval is less than limit.

Limit for number of extremes 0

Duration of time interval 0 days 12:00:00

Min. difference for extremes 0.15

OK Cancel

References:

1. Tim Preston email 20170209-1315, especially notes in the attached XLS and tech meeting minutes thereafter
2. DHI M21 oscillation evaluation tool received 17/2/2017:
N:\NZ\Christchurch\Projects\51\33275\99.Automation tools\00_MikeFloodFM_DHITools\DHI M21 oscillation tool
3. Background discussion on how to use 1D oscillation tool - emails with Tim / Chamila 20170922_1215

Further Notes (Follow up Email from GHD):

1. Stability standards will be done in two batches – post quake and pre quake
2. Work on ‘stability standards’ for either batch will commence once run completion has been achieved across all the specified model runs in that family
3. In the post quake batch we will evaluate and stabilise a set of 10 runs as follows;
 - i. 10y 1hr *
 - ii. 10y 6hr
 - iii. 50y 1hr
 - iv. 50y 6hr *
 - v. 200y 2hr
 - vi. 200y 3hr *
 - vii. 200y 6hr
 - viii. 200y 24hr *
 - ix. 200y 24hr tidal pair
 - x. March 2014 calibration event (this list is as reported to CCC 20170209-1315 but with two runs removed)
4. In the pre quake batch we will evaluate and stabilise a set of 4 runs (those above marked with ‘*’)
5. We will initially evaluate and report the model results ‘as supplied to Council’ which includes some now quite old model versions. This reporting is to set a benchmark and to educate by inference the stability qualities of the set of existing deliverables. This evaluation and reporting will be limited to GIS deliverables and M21 frequency analyses but will exclude XLS 1D evaluation (timeseries inspection)

6. We will re-run this set of design results on the then current model version and evaluate those results as the basis for identifying locations stability improvement work
 - a. The Mar 2014 event will have been re-run as part of VO56 scope prior to stability standards and so will not require re-running for stability standard purposes.
7. We will follow the general method below for one attempt to fix all issues reported >150mm, and re-evaluate
8. If such problems remain we will attempt the second fix for issues that have >300mm oscillations and with M21 oscillations however our expected and budgeted effort for this is nil. If such work is required then a third cycle of evaluation will be required
9. We will replicate fixes in both directions between the post / pre quake models
10. We will supply to Council in XLS and GIS format for each batch, both the initial evaluation and final evaluation

We have a PCG in 2 weeks so I would hope that this can be interpreted by then, and ideally application started so that we will have an idea of the scale of any stability issues before the meeting. Have you had any update on delivery of the sump couple file?

Kind regards,

Ben Pasco

Project Manager

Land Drainage Recovery Programme
City Services Group - 3 Waters and Waste

DDI: 03 941 5914

Mobile: 027 278 6736

Email: ben.pasco@ccc.govt.nz

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Christchurch City Council

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PO Box 237, Christchurch, 8140

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Appendix I – Model peer review documentation

Christchurch City Council Model Review

Section 3 Review Details

Instruction Notes:
1. **About FIGURES** -- Please note figures should be clearly **labelled** and included the FIGURES tab and **referenced** in the review comments.
2. **Traffic Light Rating Scores** (0 - no issue, 3 - major issue)
0 - No issue found
1 - Minor issue or non-standard approach, but unlikely to significantly impact on objectives of the study
2 - Some concerns, likely to have an impact on model results
3 - Concerns that may have a significant impact on model results and not meeting the study objectives

A - General Information Review

A:1 - Deliverables

Item	Description	Rating Score	Modeller's Initial Notes	Reviewer's Comments - 20250114	Modellers Response	Updated Rat	Reviewer Comment 20250318	Modellers Reaponse 20250328	Reviewer comment 20250416
A:1.1	Is tab "Section 1 - Model Metadata" filled in and does it provide an accurate summary of the supplied model data.	0		yes some minor comments		0			
A:1.2	Have all agreed deliverables been provided – see "User Requirements" Tab	0		yes		0			
A:1.3	Is the model delivered in the required software version?	0		yes		0			
A:1.4	Are all associated model input files supplied in specified format, i.e. in folders with appropriate naming.	1		the MU files provided do not match with the files used in the Model, i.e. they do not match the results or the shapefiles provided. This has caused some issue with the review, as the MU could not be used as a source of truth. It is assumed that the shapefiles provided are a better representation of the model and the comments refer to the values in these files.	It is unclear what has caused this difference - though it may be that an old shapefile was provided. For the final delivery we will export the shapefiles from the MU after making any changes. While copying the files across for this peer review response we noticed there is an old .mdb in the 01Data folder. Note the Halswell model uses the .mdb in the 02Setup folder. We generate the .mex in the MAIN folder then copy it out to all the other setup folders. This may explain the difference.	0	MDB from data folder removed		
A:1.5	Are all required modelled scenarios included in the deliverable? List Scenarios checked. Does the model database include result files for the scenarios submitted?	0		yes		0			

A:2 - Previous Review Comments

Item	Description	Rating Score	Modeller's Initial Notes	Reviewer's Comments	Modeller's Response		Reviewer Comment 20250318	Modellers Reaponse 20250328	Reviewer comment 20250416
A:2.1	Confirm that all previous review comments have been incorporated or resolved, if any. List any that have not, and comment on impact to model usability.	0		Previous comments have been addressed		0			
A:2.2	Assess model against any other review recommendations produced during the model development. If there was no formal process for resolving the reviewers comments, then each item should be listed below and a comment made as to whether or not the issue has been resolved, and if it has significant impacts.	0		NA		0			
A:2.3	Identify and document any agreed divergence from spec and adopted model build process - see "Decision Register" tab.	1		Decision register tab has not been filled out	We have started to add information to the decision register in this spreadsheet regarding decisions made recently however, not all of the columns are applicable for all the decisions. The decisions will be transferred to the shared online version in the future.	0	Good start, please keep updating with additional points as they come up.		

Christchurch City Council Model Review

Section 3 Review Details

Item	Description	Rating Score	Modeller's Initial Notes	Reviewer's Comments - 20250114	Modellers Response	Updated Rat	Reviewer Comment 20250318	Modellers Reaponse 20250328	Reviewer comment 20250416
A:3 - Model Speed and Stability									
Item	Description	Rating Score	Modeller's Initial Notes	Reviewer's Comments	Modeller's Response		Reviewer Comment 20250318	Modellers Reaponse 20250328	Reviewer comment 20250416
A:3.1	Check model simulation period and time steps, including result time steps.	0		Average 2d timestep is between .06s(200yr 12hr) and .5s 1D timestep is 0.5s. M11 and MU results are saved every 1minute, 2D time varying results are saved every 20 minutes (12hr) or 1minute (1hr). The 2D results are saved at varying intervals dependant on the duration which is as it should be.		0			
A:3.2	Comment on run time expected in terms of the catchment size and complexity.	0		run time is reasonable and as expected		0			
A:3.3	Check model validation errors and warning messages.	1		No errors. Some warnings in the log files. Main ones to check are the MU log: Some node diameters are very small 100-50mm please check that these are sensible. Note the warning 719 for high velocities in the pipes, this may indicate instabilities. A number of pipes have negative slopes and may need to be reviewed. Warning 737 should be checked to ensure structures are working as intended.	1) Small diameter manholes have been resolved. Some nodes have a small diameter (~300mm) - these are normally sumps and have their values taken from CCC GIS. 2) Pipes with negative slopes have been resolved where possible - noting that there are several bubble ups in this catchment. The negative slopes have been moved away from outlets to avoid water generation. 3) Warning 737 has been resolved by lowering the manhole inverts. These manholes are connected to structures which have had their levels set based on design drawings. It is likely that the 'manhole' invert was initially set arbitrarily to put the structures into the model.	0	good		
A:3.4	Assess model stability i.e. identify time step critical locations. Any apparent issues in model results caused by model instabilities? Is peak impacted by instabilities?	1		2d instabilities are occurring largely in the steep areas of the mesh and at the mesh edges - these are of less concern. There are 2 locations in the flat area of the model that should be addressed to see if stability could be improved - around elements 300563 and 1116919. Some higher oscillations in the MU points are observed, however on closer inspection of the results these do not appear significant in terms of when they occur during the simulation and how they are propagating. M11 instabilities are minor, only location of interest is at Hals.minsonsdrain where one of the M21 instabilities is occurring.	These have not been fully resolved however the issue is minor. Based on logs, in M21 there is a step in the solver that re-orders mesh elements. So we had some trouble confirming where the elements listed are. We note that 1116919 is at the bottom of the catchment, outside the city boundary.	1	Ok, note you can switch off this reordering in the M21 interface. Add to the anomalies register.	Added to anomalies list.	
A:3.5	Review mass balance (<1%in general, if more than 1%, find out why & whether improvements should be made, discuss with CCC if mass balance error cannot be reduced)	2		Mass error has large values for inflow and outflow correction. These are similar values and may cancel each other out, however it would be useful to investigate further in case the issue is serious. We have run a test of the model setup removing all inflows and rainfall. This has indicated some areas where water is being generated, Figure4. These issues arose at locations where there are negative slopes at inlets, urban and at the Hals.KnightStreamDrain. Recommendations from this are to ensure that there are no negative slopes at inlets and outlets, and reschematise the KnightStreamDrain so it does not generate water. Possible options for re-schematisation would be to model the part currently in M11 in M21 (i.e. add some mesh here). Or convert the upper part of the stream into M11 (which is currently open channel in MU), and add the outlet culverts at the downstream end into M11, to avoid switching back to MU, and connecting the channel to the basin with a standard link.	Inflow and outflow correction The inflow and outflow correction is associated with M21 culverts. We know this because when we delete these the inflow and outflow correction goes to zero. We believe it is due to high discharge oscillations on large culverts outside the city boundary (for example, Gebbies Valley). It is unclear why these oscillate so much - carefully checking the culvert flows we see that a 10mm head difference can result in 700l/s of flow. General negative gradients: Negative slope pipes at outlets have had been resolved by updating upstream inverts. Some water generation areas are associated with M11 flow boundary conditions - these are associated with a low base flow for model stability. Some of these are associated with base flow that is realistic (groundwater springs). Some of them spill onto the surface for example the patch at Knights Waterway Reserve (which is a wetland). For pipes with negative slopes at outlets we have updated the pipe inverts so that the negative grade pipe is upstream by one link from the outlet to prevent any water generation. Knights Stream Drain: The levels in the open channel MU (upstream of Richmond Ave) were erroneously ~1m below reality. So, the pipes under Richmond Ave had an erroneous negative gradient to match invert to invert with the M11 (downstream of Richmond Ave). We raised MU open channel to it's correct level and correct the negative gradient of the pipes under Richmond Ave. This appears to be more stable now.	1	Suggest that the M21 culverts could be shifted to the river model, and linked with standard links, as this would allow for damping factors to be applied. This could be added to the anomalies register. No immediate action is necessary since the culverts are away from the area of interest. Knights stream drain stability is improved.	Added to anomalies list.	

Review Hold Point – if there is any corrective action required as a result of the above – the review is to be halted until the issue is resolved to the satisfaction of the appointed reviewer and Christchurch City Council

Christchurch City Council Model Review

Section 3 Review Details

Item	Description	Rating Score	Modeller's Initial Notes	Reviewer's Comments - 20250114	Modellers Response	Updated Rat	Reviewer Comment 20250318	Modellers Reaponse 20250328	Reviewer comment 20250416
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B - Detailed Model Review

B:1 - Model Boundary Conditions

Item	Description	Rating Score	Modeller's Initial Notes	Reviewer's Comments	Modeller's Response		Reviewer Comment 20250318	Modellers Reaponse 20250328	Reviewer comment 20250416
B:1.1	Confirm rainfall files used are correct, and that modelled values are equivalent to what is included in the associated reporting.	2		Spot check shows that rainfall files are correct, and the CWM rainfall files are being used, however it is noted that no ARF scaling is applied. Note this was applied for Avon and Heathcote, please confirm why this hasn't been applied.	ARFs make the model more confusing for design purposes. This may be why we decided not to implement one for Halswell. This has prompted a wider discussion with Council. On 12 Feb 2025 the panel agreed to not use ARF for the Halswell model. The overall catchment size triggers the need for one but because we are primarily focused on the city boundary - it is less necessary. In an email the peer reviewer commented that "It would make sense to consider only the developed area of the catchment as your catchment area for this calculation, as this is the area of interest."	0	Accepted. Note that ECAN should be made aware of this, if using the results for the lower catchment.		
B:1.2	Assess downstream water levels with reference to coastal marine boundary or other appropriate sources. Review timing of tidal boundary.	1		Downstream boundary uses the lake levels. Levels have been converted to NZVD, however the boundary timeseries still reference an adjustment to CCD in the title.	Resolved - title updated.	0	resolved		
B:1.3	Describe and review any inflow boundary conditions and/or flow transfers across catchment boundaries	2		Source point inflows are used to apply the RORB inflows. Spot checks show that the timeseries item referenced in the M21 model is not available in the timeseries file - for example item G1, this may mean that the incorrect item is being used for the model setup. Please revise the M21 source points. Intercatchment boundary conditions there are currently only 2 specified, which were pre-existing. Further to this additional boundaries are specified in the DHI boundaries memo, these new boundaries defined with Heathcote have not been included. These should be applied where data is available, this mainly affects the boundary with Awatea (HALS.Pipe.Inserted.6706), where flows could be extrapolated from previous Haswell modelling. In addition flows to HALS.Manhole.CCCGIS.1033 can now be taken from the v26 Heathcote results, and could be used instead of the dummy flows currently being used. For inlet HALS.Manhole.CCCGIS.1150 the Heathcote model should also include this so that the sump flow can be transferred into the Haswell model - this will be added into the boundary memo, and updated in the Heathcote model accordingly.	RORB timeseries item names RORB inflows have been replaced with dsf0's with the titles corrected. These are now consistent with all the CWM models. The m21fm file has also been modified with correct item names and numbers. Intercatchment boundary conditions The intercatchment boundaries have been added to the model - however the flows from the Heathcote model excluded the first 1 hour of the event. The peer reviewer has offered to re-run the Heathcote model and we can update our boundary conditions with the new data once that is ready. In the meantime, the boundary conditions have been configured but switched off (Apply = faux). We have created a script that processes the Heathcote PRFs into Halswell DFS0 boundary conditions. So that when the new PRFs are provided we can quickly add them to the Halswell model and switch them on. Beca provided a run list to DHI to re-run the Heathcote model.	0	New issue. See figure 5, some of the source points are not lining up with the mesh. And the results look like the flow is not being added. Other issues with naming have been resolved. Note the wilmers basin may also overflow into the Heathcote at high flows, this may be more relevant to the MPD modelling. However it may be helpful to include an outflow boundary here.	Relocated the source points within the boundary. No modifications have been made to Wilmers Basin at this time. Email from Victor at CCC confirmed that Wilmers not hydraulically connected to Heathcote. My checks confirmed that the water depth would need to be over 7m deep and would likely back flow up the connected swale from CSM and spill Halswell. Previous model results confirmed this is unlikely but we will check again with the new model results.	Source points corrected. Accepted explanation for leaving Wilmers basin boundary.
B:1.4	Check how model initial conditions are applied for both 1D and 2D. The use of model features such as initial condition zone for tidal areas and ponds, etc.	1		2D initial conditions use a depth representation. It would be more appropriate to use water level especially considering the initial condition depth doesn't appear to match well with the 2D boundary water levels, and the water moves at the boundaries in the first timestep. M11 initial conditions use a fixed WL based on the initial lake level and a local level at the creamery ponds - No issues with the 1D initial conditions.	Set up initial condition layer using water surface elevation and speed.	0	resolved		
B:1.5	Check time varying inputs and make sure their start and finish time aligns with simulation setting.	0		All OK		0			
B:1.6	How is climate change applied? Check rainfall and tide boundary	0		NA - no climate change in runs reviewed		0			
B:1.7	Confirm RORB inputs are at the correct location, and there is no overlap in model extent and RORB extent.	0		Spot checks show the inflow points are in the correct location. RORB catchment extent does not appear to overlap with 2D extent.		0			

B:2 - Model Catchments

Item	Description	Rating Score	Modeller's Initial Notes	Reviewer's Comments	Modeller's Response		Reviewer Comment 20250318	Modellers Reaponse 20250328	Reviewer comment 20250416
B:2.1	Review modelled catchment extent. Confirm that it matches the agreed boundaries.	0		As agreed.		0			
B:2.2	Check overlap with hillside hydrologic model is correct (if applicable)	0		As above no issues		0			

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Section 3 Review Details

Item	Description	Rating Score	Modeller's Initial Notes	Reviewer's Comments - 20250114	Modellers Response	Updated Rat	Reviewer Comment 20250318	Modellers Reaponse 20250328	Reviewer comment 20250416
B:3 - Pipe Networks									
Item	Description	Rating Score	Modeller's Initial Notes	Reviewer's Comments	Modeller's Response		Reviewer Comment 20250318	Modellers Reaponse 20250328	Reviewer comment 20250416
B:3.1	Confirm all critical network and structures are included in model (trunk network, known flooding points, key structures, etc.)	0		Yes, some smaller pipes still missing, and represented via the M21-MU links, this could be updated at a later stage so all pipes are included.		0			
B:3.2	Check if the model extent is suitable for generating floodplains, i.e. does it extend far enough upstream and include all flood prone areas.	0		Yes		0			
B:3.3	Check asset naming convention. Can model ID be linked to assets in the GIS	1		In some locations the assets have been given intermediate names i.e. inserted, or manhole instead of the actual CCC asset names, in some cases this is due to the network simplification however the original ID's should be referenced to allow for cross checking to asset data. This is likely a hangover from these assets not having a defined name in GIS when they were added to the model. However, these MUID's in the model should be updated so that they match the CCC asset data as best as possible.	This has not been done yet. We will discuss with Council the requirement/timeline. We accept that this <i>minor</i> to stand in the mean time.	1	Add to anomalies register	Added	
B:3.4	Confirm node/manhole data source flagging and if it is documented for attributes such as lid level, invert level, shaft area, flood type, etc.	1		Data source for manholes is documented in the MUID, some flagging is applied to the various attributes but this it not applied to all nodes. We suggest this could be reviewed once AWA and CCC have confirmed the requirements and any improvements applied as necessary.	We are expecting to see a draft flagging convention soon. We have not updated the flagging or data sources yet as this item is a minor issue (1).	1	Add to anomalies register	Added	
B:3.5	Confirm pipe asset data source flagging and if it is documented for attributes like shape, diameter / width/ height, material, upstream and downstream inverts, etc.	1		Data source for manholes is documented in the MUID, some flagging is applied to the various attributes but this it not applied to all nodes. We suggest this could be reviewed once AWA and CCC have confirmed the requirements and any improvements applied as necessary.	As above.	1	Add to anomalies register	Added	
B:3.6	Spot check data entry of asset inspection/survey records for 10 locations			Survey records not made available for checking.					
B:3.7	Spot check node attributes for 10 locations (diameter, shaft area, invert level and lid level) match asset data or are interpolated appropriately.	2		HALS.Manhole.Inserted.7139 - not interpolated well, discrepancy at HALS.Manhole.SCIRTGIS.20179 and HALS.Manhole.SCIRTGIS.21577 and HALS.Manhole.CCCGIS.915, note also general small differences ~2mm between asset and model likely due to NZVD conversion. Given how many issues were found in the small sample, suggest doing a model wide check against the asset data.	We have updated 7139 and 915. The other two (20179 and 21577) match with CCC GIS. Modeller has confirmed that wider checks have been made previously and data generally is consistent with Council GIS. The 2mm difference has not been corrected as this likely to have a small impact on the results.	0	accepted		
B:3.8	Spot check node lid levels for 10 locations to LIDAR	1		Review has used model dfsu as reference. Differences observed between the MU and the M21 levels, however model is using M21 levels and these appear consistent from spot checks. Suggest applying the DFSU or DEM value to the MU ground level so that all long section plots will correctly represent the levels used in the modelling.	This is a good idea. We had not done this before running the peer review runs (provided). But we will do it for the main model.	1	to check in final model	Will do in Final Model	
B:3.9	Check cover types are appropriate i.e. sealed, stored, 2D, etc.	0		All cover types are set to Normal. This is appropriate assuming that the dhiapp.ini setting is setting the flood limit to a high level.		0			

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Item	Description	Rating Score	Modeller's Initial Notes	Reviewer's Comments - 20250114	Modellers Response	Updated Rat	Reviewer Comment 20250318	Modellers Reaponse 20250328	Reviewer comment 20250416
B:3.10	Spot check pipe attributes (diameter, shape, length, material, invert levels) match asset data or are interpolated sensibly	1		Generally good match from spot checks, main issues arising are slight differences in invert levels of pipes. Recommend doing a full model check against asset data.	As per B:3.8. We would need council approval to do a full model check at this point as it would require a scope change.	1	Accepted, please add to anomalies register	Added	
B:3.11	Check pipe long section and gradient for steep, zero and negative grades	2		377 pipes with negative slope, 143 with zero slope. Where negative slope is associate with inlets and outlets these should be resolved by adjusting the pipe invert levels. This will help with water generation issues.	The catchment is very flat, so some negative slope pipes are unavoidable and are realistic due to wide-spread bubble up outlets. Pipes leading to outlets have had upstream end lifted to enforce positive slope, several pipes upstream may have been lifted as well to avoid very large differences between inverts at manholes. Inlets have also had their slope changed to be positive by changing the level at the inlet node so all coupled links should have positive slopes.	0	accepted, 118 pipes now have negative slope, so some improvement has been made		
B:3.12	Check if continuation pipe is matched using soffit levels	1		This is not generally the case. However 1) this is not specified in the schema that this needs to be done, and 2) it has less significance in flat networks like this one, as the pipe slope does not change significantly by matching the inverts or not. For steep parts of the network however it is recommended where the downstream level of the pipe is unknown that the soffit to the upstream pipe could be matched to improve the model performance.	This has not been updated in the model has not been changed. It may be better to do as part of the model data review mentioned above.	1	Accepted, please add to anomalies register	Added	
B:3.13	Ground cover. Identify pipes that have insufficient cover – less than 300mm.	0		Nothing of significant concern, some pipes appear close to the ground when inspecting the upstream and downstream levels vs the DEM however on spot check these are generally shallow subsoil drains in basins.		0			
B:3.14	Identify any network which has decreasing diameters in a down-stream direction.	0		Checked visually - no issues identified		0			
B:3.15	Check pipe lengths less than 10m, and if any actions required.	0		Yes some pipes have shorter lengths, this is noted in the log files. No actions required as model is automatically applying a length of 10m.		0			
B:3.16	Check pipe roughness assumptions appropriate for material and condition	0		Roughness appears appropriate		0			
B:3.17	Check manhole headlosses in the model match with CCC guidance	2		Previous model review advice on the manhole losses was to use a Lower loss (weighted inlet energy .25) for manholes, and keep the higher loss for inlets. Ongoing investigations are being done to confirm the most appropriate losses to use. However, in the first instance using the above proposed losses is recommended as this produced good calibration results for Heathcote. Note the suggestion here is just to change the manholes that are not inlets to type weighted inlet energy km= .25.	These have been updated.	1	Manhole headlosses adjusted correctly in some locations but not all. Figure 6 shows some examples of what is still an issue.	Updated	Note, further discussion with Elliot. We have considered this futher and the high 0.5km losses should only be applied at end points that are inlets, and not for standard manholes that have inlets connected. I.e. where many inlets for pipes <300mm have been connected. This would be mainly applicable in the older parts of the model which do not include all pipes.
B:3.18	Check entry and exit losses of pipes and any minor losses caused by bends, side connections or joint defects, etc.	0		Loss types of manholes and the pipe roughness is the main definition of the losses. These have been discussed elsewhere.		0			
B:3.19	Check natural depression areas or dry pond are modelled with proper outlet configuration i.e. it drains properly after flooding.	0		Spot check on basins. It appears that they are generally draining but slowly. The simulation does not extend far enough to get a good handle on this, however this model is designed for assessing peak flood levels, and it not currently looking into basin drainage so this is ok for now.		0			
B:3.20	Check pipe model computational parameters are within reasonable limits, such as those in dhiapp file.	1		No specific dhiapp is applied, please ensure this is used with the recommended values.	This file was in our install folder. We have moved it to the setup folders and it will be included in the delivery.	0	correct dhiapp file being used		

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Item	Description	Rating Score	Modeller's Initial Notes	Reviewer's Comments - 20250114	Modellers Response	Updated Rat	Reviewer Comment 20250318	Modellers Reaponse 20250328	Reviewer comment 20250416
B:4 - Channel/Stream Networks									
Item	Description	Rating Score	Modeller's Initial Notes	Reviewer's Comments	Modellers Response		Reviewer Comment 20250318	Modellers Reaponse 20250328	Reviewer comment 20250416
B:4.1	Are channels modelled appropriately? (in 2D or as 1D river reaches)	1		Yes however, recommend that the HALS.KNIGHTSTREAMDRAIN branch be switched to 2D or all M11 to improve model stability at the complex structures here.	See discussion in row A:3.5.	0	accepted		
B:4.2	In case of burning surveyed cross-sections in 2D, spot check cross-sections from 2D bathymetry compared to the surveyed cross-sections.	0		NA		0			
B:4.3	Spot check modelled cross-sections and banklines with LiDAR	0		Spot checks on mflateral show the MIKE11 bank level and linked 2D elements match reasonably well with no issues observed.		0			
B:4.4	Is location and spacing between cross sections appropriate? (e.g. maximum dx in MIKE11)	0		Yes		0			
B:4.5	Spot check of modelled cross-sections whether it includes low flow channel.	0		Generally the low flow channel is being modelled in 1D, while the highflow/overflows are in 2d. The model appears to be setup correctly in this regard.		0			
B:4.6	Spot check data entry of survey records for 5 locations			No survey data available for cross check					
B:4.7	Identify any topography which may cause instabilities – such as flat sections.	0		No indication of flat sections or those that would cause instability. XNS could be improved by using survey where the model is currently relying on lidar sections, which are generally less accurate.		0			
B:4.8	Review the use of “channel markers” or “new panels”.	0		NA		0			
B:4.9	Identify if cross sections are drawn properly: - check length and extents sufficient to cover flood flows - any sections which are not perpendicular to the direction of flow. - are sections straight lines? Comment on the impact to the conveyance, and to the model results.	0		Yes these are appropriate		0			
B:4.10	Check locations where flooding extends from the channel to the 2D mesh – comment on merging of 1D/2D representation.	0		Selection of 1D/2D areas appropriate - as previously reviewed. However due to stability issues consider re-schematising HALS.KNIGHTSTREAMDRAIN as mentioned.		0			
B:4.11	Comment on application of roughness values.	0		1D bed resistance set in xns11 file, spot checks show these have not changed since previous review and are generally set to n = 0.035 which is reasonable		0			
B:4.12	Identify any double counting of volumes, in overland flow paths basins other cross sections	0		Cross sections line up well with the block-out area and double counting is expected to be minor.		0			
B:4.13	Check gradient for steep, zero and negative grades.	0		No issues found		0			
B:4.14	Confirm no double counting of flood storage volumes, at locations such as basins or connection nodes at the ends of channels, , etc.	0		Basins all modelled in 2D, and only smaller channels and main river in 1D. No issues encountered.		0			
B:4.15	Check river model computational parameters are within acceptable limits (m11.ini and HD11 default parameters)	1		HD values are acceptable. M11 ini file does not have the file_flush_freq = 1 set, this allows the modeller to open res11 results while the sim is running and if the model has crashed which is very useful. WL exceedance is set to 8x the cross section height, which is reasonable.	Update made. This should be visible in the delivery.	0	resolved		

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Item	Description	Rating Score	Modeller's Initial Notes	Reviewer's Comments - 20250114	Modellers Response	Updated Rat	Reviewer Comment 20250318	Modellers Reaponse 20250328	Reviewer comment 20250416
B:5 - Hydraulic Structures and Control Elements									
Item	Description	Rating Score	Modeller's Initial Notes	Reviewer's Comments	Modellers Response		Reviewer Comment 20250318	Modellers Reaponse 20250328	Reviewer comment 20250416
B:5.1	Are inlets represented correctly? Do they align with surrounding terrain?	0		Yes, from spot checks these appear to have been applied correctly.		0			
B:5.2	Check outlet and/or outfall representations. Do they align with surrounding terrain or connect appropriately with downstream features?	0		Yes, spot checks show the outlets are generally matching with downstream levels, including pipes discharging into rivers.		0			
B:5.3	Check representation of culverts. Shape, number of barrels, inlet/outlet losses, roughness, gradient, etc.	2		MarshsRd culvert, Hals.KnightsStream 2272, does not match the diameter of the asset data (.9 vs 1.1m). Hals.CreameryDrain 10 also does not match asset, pipe in model is a half circle with 1m radius, while in the asset data this has a 1.5x2m box culvert. From google street view this looks like a box culvert too. Hals.NottinghamStream 3497 diameter is 0.9 in model and 1.1 in asset data. All structures that have CCCGIS references i.e. pipe ID's need to have their references added to the Culvert ID. Inlet and outlet losses all standard, no comments there.	Checked Asset data on CCCGIS, renamed culverts (and corresponding weirs) that have data on CCCGIS to align with MU naming conventions. Resized the specified culverts to align with CCCGIS geometry data.	0	Accepted. Note missing asset names may be covered in the CCC Watercourse layers, however these appear limited in the Halswell area.		
B:5.4	Review bridges representation: - cross sections - contraction and expansion losses - bridge deck, profile and coefficients - bridge skew - bridge opening, gradient, inlet and outlet losses	0		No bridges		0			
B:5.5	Check representation of storages, depressions, dams or constructed ponds: - stage storage relationship - any controls - inlets and outlets - initial or permanent water levels - overtopping arrangements (single level or irregular shape; weir coefficients; 2D mesh / breaklines);	1		Storages all modelled in the 2D model. No smaller storages are modelled in the 1D models. Suggestion that the model reporting should include details on complex basin structures that can't easily be defined in the GIS files. This would make it easier to check if these are operating as intended. MU model could be flagged with details such as "scruffy dome" to help clarify inlet types etc.	Model report is not being updated as part of this scope as per CCC's suggestion. But this is a very good idea. The basins are complex and having reporting explaining how they are modelled would be useful for us as well.	1	accepted, suggest to add Adonal reporting to future scope		
B:5.6	Check pump configurations. On/off levels, pump type, pump curve, pump controls, etc.	0		No pumps	There is a pump that moves water into Knights Waterway Reserve (from Ella Park Basin).	0			
B:5.7	Check hydraulic control structures real time regulations. E.g. Gate controls that rely on a model water level for activation	0		No control gates		0			
B:6 - Other Asset Features									
Item	Description	Rating Score	Modeller's Initial Notes	Reviewer's Comments	Modellers Response		Reviewer Comment 20250318	Modellers Reaponse 20250328	Reviewer comment 20250416
B:6.1	Soakage modelling methods and representation in the model.	0		Soakage is represented in the evaporation file, where a couple of high soakage basins have been modelled using ground tested infiltration rates. The remaining soakage is standard based on soil drainage type and landuse.		0			
B:6.2	How is the soakage outlet capacity modelled. The assumptions, e.g. ARIs, etc.	0		As above		0			
B:6.3	Review the use of weir units in the model. Comment on the weir representation and coefficients used	0		MU weirs, all use standard configuration. Note that naming is not consistent with schema for all weirs and should be revised. 49 weirs in the MIKE 11 model, using standard configuration, level width relationships appear sensible based on spot checks.		0			
B:6.4	Review the use of orifice units in the model, comment on the associated coefficients applied.	0		One orifice applied. Standard setup parameters used.		0			
B:6.5	Check representation of tunnels/underpasses	0		No known underpasses represented		0			
B:6.6	Check representation of stopbanks	0		Pond banks defined in the 2D dikes, no specific stopbanks on the rivers		0			

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Item	Description	Rating Score	Modeller's Initial Notes	Reviewer's Comments - 20250114	Modellers Response	Updated Rat	Reviewer Comment 20250318	Modellers Reaponse 20250328	Reviewer comment 20250416
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B:8 - 2D Model Components

Item	Description	Rating Score	Modeller's Initial Notes	Reviewer's Comments	Modellers Response		Reviewer Comment 20250318	Modellers Reaponse 20250328	Reviewer comment 20250416
B:8.1	Review 2D extent and mesh sizes (any terrain sensitive meshing, and no extremely large or small meshes) Are mesh sizes appropriate at inlets and outlets.	2		Figure 2 shows an example of where one of the ponds is not filling in the flood result, i.e. it is 0.5m lower than the adjacent basin. This could be due to incorrect representation of the inlets, as the mesh appears to be blocking the flowpath. The mesh could be made smaller or the low levels burned in to allow water to reach the inlet structure unrestricted by the mesh.	Lowered the level of the element that impeded the flow of water, added to the shapefile of manually adjusted levels.	0	Filling is occurring as expected however, it is clear now that the basin is also not emptying. Please check that the outlet is correctly setup, and the outlet is linked to a mesh element that is sufficiently within the basin, so that water can enter it.	Scruffy Dome outlet control structure has been updated based on the Design Report (COX'S QUAIFES STORMWATER) and contruction drawings. Some water may remain in thre FF basin at the end of model run. This relies on infiltration and the model has not been run long enough to capture the full drain down.	Basin appears to start draining. This appears to be resolved.
B:8.2	How have building footprints been represented	1		Buildings are modelled as high roughness, note that in areas where a composite roughness has been used (where building outlines are unknown in new developments) these should be flagged for update once building outlines are available. Please add into anomalies	Added to the anomalies register.	0	accepted		
B:8.3	Review DEM and identify if any errors in DEM, e.g. around buildings	0		DEM appears sensible based on a visual check of the model dfsu		0			
B:8.4	Check representation of any key obstructions such as stopbanks. These may be represented as dikes or within the mesh levels.	1		Dikes generally used to define pond banks these appear to be applied correctly. Note inter basin weirs are also using dikes but in some cases this is creating instability when the water levels are high, these may be better represented directly in the mesh instead.	No change made here.	1	Ok, please add to anomalies register	Added	
B:8.5	Check roughness zones and values	2		In some areas where there are new developments there are high roughness values used for the buildings as well as a composite roughness value used for the surrounding residential area. To be consistent with the rest of the model, where buildings are represented the roughness value of 20 should be used in the area surrounding buildings (not 8). See Figure 1.	We have updated the roughness layer to correct this issue.	0	This has been corrected		
B:8.6	Review and check double counting between 1D and 2D model components. For example 2D cells not blocked out where flow is represented in 1D.	0		Model cross sections match the blackout width well. No issues encountered.		0			
B:8.7	Check 1D/2D interface and coupling method and parameters are appropriate. Check appropriate 1D/2D connections are applied at 2D nodes, inline banks, river reach banks, etc.	1		Non standard depth tolerance and weir coefficients have been used in a large portion of the links, where depth tolerance is set to 0 and the weir coefficient to 2. Please explain reasoning and decision here. Lowering the depth tolerance can reduce link stability. Reverting this setting where M21 instability is occurring at the lateral link may help. The Lateral links either M21 and HGH however it is unclear why one has been used over the other, as some river branches change between the two methods often - please provide some explanation on the method for choosing which. Urban links appear to have sensible parameters.	The linking method was originally set up to use HGH where possible due to a historical assumption that this would better capture the banks of the streams. During previous stabilisation the method was changed to M21 to try to improve the stability. We have moved to M21 throughout except in areas where the topography calls for HGH where there are banks that are captured by the survey but not the mesh (for example, stopbanks on lower section of Halswell river). The depth tolerance has also been reset to the standard.	0	accepted		

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Item	Description	Rating Score	Modeller's Initial Notes	Reviewer's Comments - 20250114	Modellers Response	Updated Rat	Reviewer Comment 20250318	Modellers Reaponse 20250328	Reviewer comment 20250416
B:8.8	Check impervious zones and values	1		Generally appear correct. Note figure 3 where there are some checkered areas, it is not clear what these are representing. Please explain.	This layer was created from a Lynker land cover classification layer. This classification layer includes a lot of detail - however our layer was sampled with a relatively low resolution (10m). The checkered areas are areas where the land classification is flipping frequently between one type and another. Increasing our sample resolution may have improved the clarity here, but we have update the methodology for infiltration to use the CWM - which uses a DFSU for infiltration rates. So this is no longer relevant.	0	accepted		
B:8.9	Check infiltration values applied	2		Soil type zones appear to be different for those being used for Heathcote and Avon models. Recommend that this is checked to ensure appropriate values are being used. The reporting states that the older Heathcote rates are being used - because good data for the Haswell model calibration is not available, however the Heathcote model has been recalibrated and is now using higher rates than the Haswell model. This will lead to more conservative flood levels especially with the extension of the mesh to the north west. Rates being used in the model are also not matching with the reporting. Recommend that the Haswell model switch to using the infiltration and leakage method instead of evaporation and revising the rates used as part of this.	We (including help from DHI) have updated the infiltration methodology to be consistent with the other models. We have checked that the correct infiltration rates are been used - consistent with the Heathcote model (for a given soil type) based on the geodatabase file provided by DHI.	0	accepted, new infiltration layer has been correctly added to the model. Note that 2D results do differ from the previous version, however the difference is as expected.		
B:8.10	Check 2D computational parameters, including equations used (high/low order), critical CFL number and flooding and drying limits are within expected ranges	0		Low order equations, flood and dry 3 and 1mm respectively, CFL .8. All within expected ranges.		0			
B:8.11	Check 2D eddy viscosity representation	0		Standard value of 0.1 constant eddy viscosity used.		0			

C - Model Results Review

C:1 - Model Results Check

Item	Description	Rating Score	Modeller's Initial Notes	Reviewer's Comments	Modellers Response		Reviewer Comment 20250318	Modellers Reaponse 20250328	Reviewer comment 20250416
C:1.1	Have all events been simulated and results provided?	0		Yes		0			
C:1.2	All correct input data assigned to the run file for each simulation? and check simulation start and stop times.	2		No, timeseries do not match items correctly for M21 sources as mentioned. The remaining inputs appear correct.	RORB inflows have been replaced with dsf0's with the titles corrected. These are now consistent with all the CWM models. The m21fm file has also been modified with correct item names and numbers.	0	accepted		
C:1.3	Check if flow, level and velocity are within reasonable range for pipes. - Identify Pipes with velocities >6m/s;	0		Yes maximum is 4.3m/s in the 12hr 200yr event.		0			
C:1.4	Check if flow, level and velocities are within reasonable range for overland flow paths, open channels and floodplain	1		High velocity in the 2D is generally in steeper areas but the highest is at a dike in the west corner of Murphys basin, we suggest adjusting the alignment of the dike to match better with the mesh elements, and this may resolve the issue.	The dike placement has been adjusted near here. The levels were left as is - which will not impact the flow behaviour significantly.	0	high velocities around the dike at Murphys basin have been improved.		
C:1.5	Is there any depression area or ponding not drained at the end of simulation? Check outlet configuration for depression.	1		Within the city area the main pond that is not draining has been mentioned in B8.1, i.e. Figure 2. Aside from this the lower catchment floodplain is not past the peak in the 12hr 200yr event. This is not overly concerning considering that this area is of less importance to CCC, however if this lower catchment is being looked at in detail it needs to be clear that the model simulations need to be run longer.	We made checks that the CSDNC reporting point is past the peak - by checking that the hydrograph has a significant receding limb. The CSDNC reporting point is just downstream of the Minson's Drain confluence with the Halswell River. We could run the 60hr longer as this could add value for ECan.	1	Agree that it would make sense to run the 60hr longer for Ecan.		

Christchurch City Council Model Review

Section 3 Review Details

Item	Description	Rating Score	Modeller's Initial Notes	Reviewer's Comments - 20250114	Modellers Response	Updated Rat	Reviewer Comment 20250318	Modellers Reaponse 20250328	Reviewer comment 20250416
C:1.6	Are predicted losses at manhole and pipe connections within reasonable range and as expected?	1		Losses are as expected based on the loss type used and the observation of long sections. However, note suggestions to use a lower km loss type for standard manholes.	This has been updated.	1	See comment in B:3.17	Updated	
C:1.7	Are predicted losses at inlet and outlet within reasonable range and as expected?	0		Yes		0			
C:1.8	Culvert Performance: - Is culvert operating as expected? Headlosses within reasonable range. - Is flow limiting observed for 1D/2D connection at inlet/outlet? - Spot Check with HY8 and manuals calcs at least 2 locations, more maybe required if model includes large number of culverts.	1		HY8 was tested for two culverts, see Hy8cals tab for QH graphs. The HALS.NOTTINGHAMSTREAM 2035 culvert matches within a reasonable range with the model calculation lower than HY8 at low flows and higher at high flows. For the HALS.KNIGHTSSTREAM 3392 culvert the model is significantly higher than the HY8 calculation. On observation the headlosses through this culvert do appear higher than expected, so it is recommended this culvert be assessed, and the inlet losses lowered as needed. Suggest undertaking structure Headloss exercise that was done for Avon, to assess if any other culverts are overestimating losses, or have incorrect data. Note model not specifically setup to model flow limiting and inlets (this is not in schema)	This was not done due to time constraints. It is a good idea to check these and document the checks. If this is needed we will agree it with Council and accept that this item will stand for now.	1	Accepted, please add to anomalies register.	Added	
C:1.9	Bridge Performance: - Is bridge operating as expected? - Are contraction and expansion losses within reasonable range.	0		No bridges		0			
C:1.10	Check if 1D / 2D flow transfers as expected. Any location with significant instabilities, unexpected headloss or flow limiting.	1		Spot checks on M11-M21 links show no obvious issues. MU-M21 links show some oscillations, although most have very low discharge. One of the highest inlets that has significant oscillations is the HALS.Manhole.Inserted.0002 inlet, which is entering from a pond. This inlet may be improved by giving it a positive slope, the main issue here may be to prevent possible blow up in the link as the oscillations appear to be fairly well contained.	There is a pump here that may cause some of the apparent oscillations by the switching of it's control. No changes have been made.	0	Accepted, there is a pump at this location.		
C:1.11	Check if pump operation as expected	0		No pumps	There is a pump that moves water into Knights Waterway Reserve (from Ella Park Basin)	0			

C:2 - Model Validation

Item	Description	Rating Score	Modeller's Initial Notes	Reviewer's Comments	Modellers Response		Reviewer Comment 20250910	Modellers Reaponse 20250328	Reviewer comment 20250416
C:2.1	Check if overall flood extent sensible. Compare new flood extent with any previous floodplains.	0		Flood extents appear as expected		0	Flood extents checked against phtography provided in reporting. Appears reasonably consistent.		
C:2.2	Check calibration and validation events	0		Not provided. Previously reviewed however.		0	One validation event assessed. This was chosen due to new gauges being available to assess levels.		
C:2.3	Validation against gauged data or flood surveys? Check validation statistics, rating curves, etc.	0		Validation not part of this review. Has been previously reviewed.		1	See Calibration tab for more details.		

Christchurch City Council Model Review

Section 3 Review Details

Item	Description	Rating Score	Modeller's Initial Notes	Reviewer's Comments - 20250114	Modellers Response	Updated Rat	Reviewer Comment 20250318	Modellers Reaponse 20250328	Reviewer comment 20250416
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D - Additional Checks

D:1 - Additional Check Items

Item	Description	Rating Score	Modeller's Initial Notes	Reviewer's Comments	Modellers Response		Reviewer Comment 20250318	Modellers Reaponse 20250328	Reviewer comment 20250416
D:1.1	Does the model report provides adequate documentation on: - project objectives and purpose; - data analysis and model schematisation; - modelling methodology for key model components - assumptions and limitations.	1		Modelling report requires an update to cover the most recent model build. Including updating figures to cover the new model extent. Updating table 4-5 to remove references to CCD. To include detail on the NZVD datum used. In 3.1 the text indicates that the soils are poor draining, however this is not true for the upper catchment and may confuse some readers. Runtime performance table does not match notes in this spreadsheet. Add references to using lynker landuse data where appropriate. Updating infiltration rates used.	We have agreed with council not to update report for now. Possible discussion at the panel meeting - what is required for reporting, especially during this period of frequent changes.	1	As stated by CCC the model results cannot be used until all reporting and review is complete. Thus the report will need to be completed at the final delivery.	Will upadate in Final Delivery	
D:1.2	If applicable, are options represented adequately with appropriate levels of details? Comment on confidence level based on both model setup and model results.	0		NA		0			
D:1.3	Should any aspects of the model be refined or redone in order to further investigate flooding effects?	0		No aside from improvements described in the other comments		0			
D:1.4	Which scenarios are modelled? Comment on the adequacy of scenarios modelled for achieving the project objectives	0		Scenarios align with the CCC requirements		0			
D:1.5	Any other assumptions used in the model that may have an impact on the overall model performance and meeting project objectives?	0		No		0			
D:1.6	Describe any additional checks or issues to raise	1		Note the User requirements tab, some data was not provided in the correct format. Notably some of the supporting shapefiles were not produced.	These will be corrected for the final model delivery. We are happy for this minor (1) to stand in the mean time. For this peer review response we have not updated all the User Requirements. We hope what we have provided is sufficient evidence to resolve the remaining twos (2s).	1	To review at final delivery	Will update in Final Delivery	Note the save timestep of the 1hr results is 1 minute, it could be set to 5minute to save space. We used a 5 minute minimum for the 2D results for Heathcote.

Placeholder for modeller to insert images that may help the review

Figure 1 Roughness
red is 8, yellow is 20 and the blue is 5

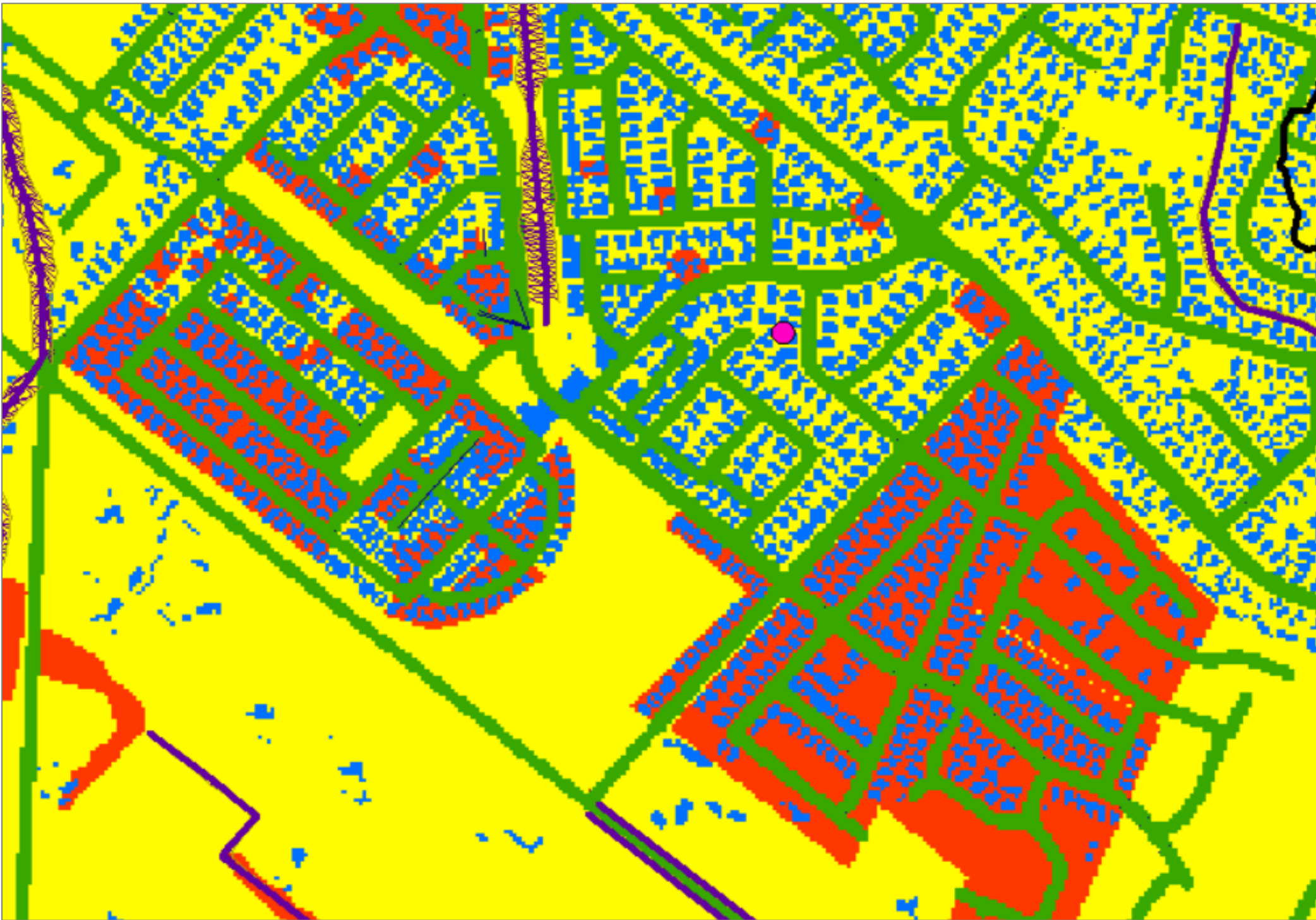


Figure 2 Pond not filling well. May be due to inlets not being represented properly. Note that the north connection to the pond is blocked by the mesh levels - even though the connection cell is low. This indicates that the water may not be able to flow correctly at the inlets.

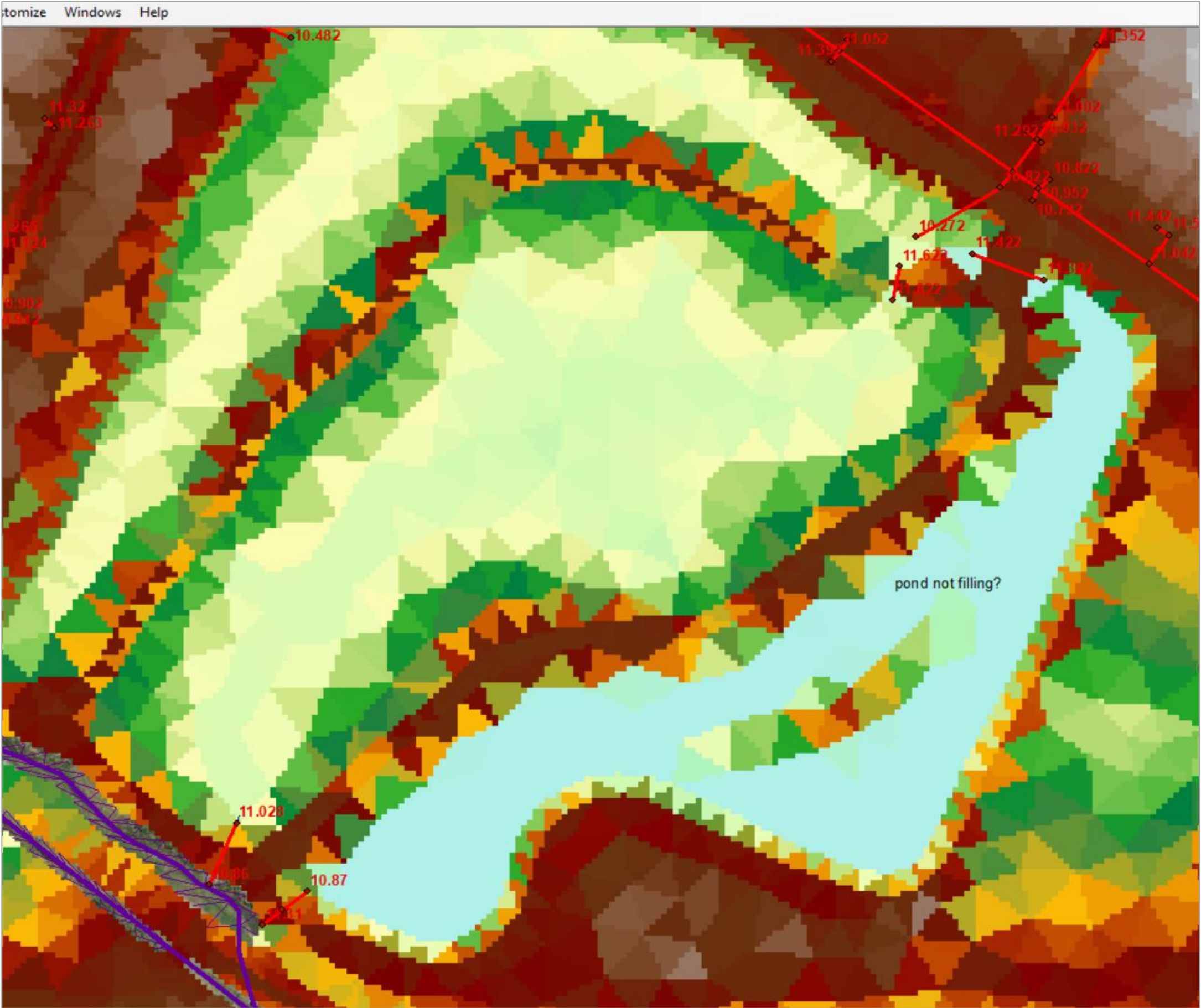


Figure 3 Infiltration

Pervious vs partially impervious infiltration areas appear to be defined correctly for the most part. However some areas appear to have a combination of rates applied, see checkered areas. Please explain what these are representing.



Figure 4 Areas generating water in the 2D. The red areas show where elements have become wet, despite there being no inflows. The water is being generated in 1D or through the 1D/2D links, so what we are seeing here is the generated water exiting the 1D network into the 2D domain. For this reason in some cases the red areas indicate the area downstream of the water generation, not the exact location.

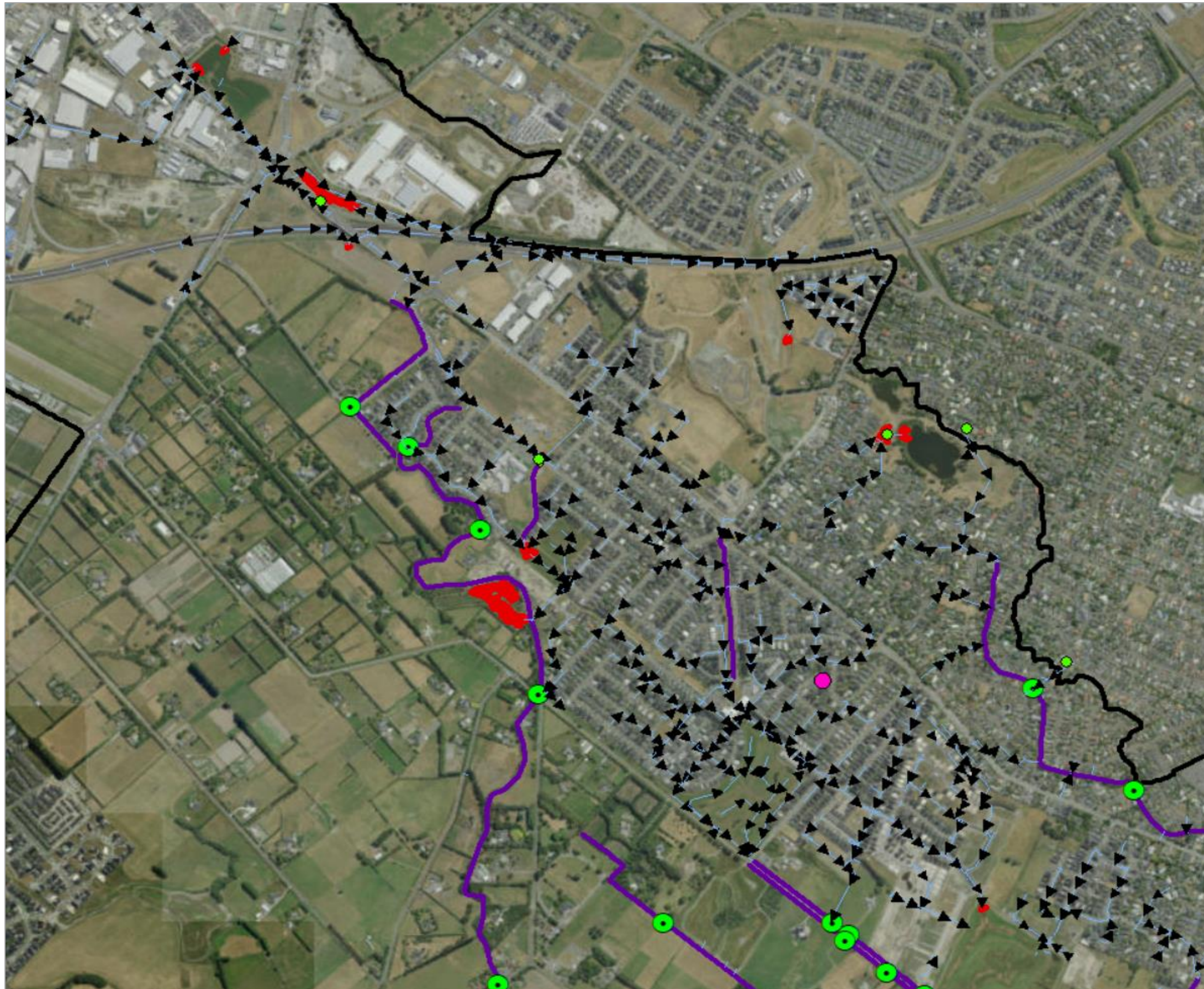


Figure 5 Some of the source points are sitting outside the mesh, and don't appear to be adding flow to the model. Please shift these so they are all within the mesh. Below is an example.

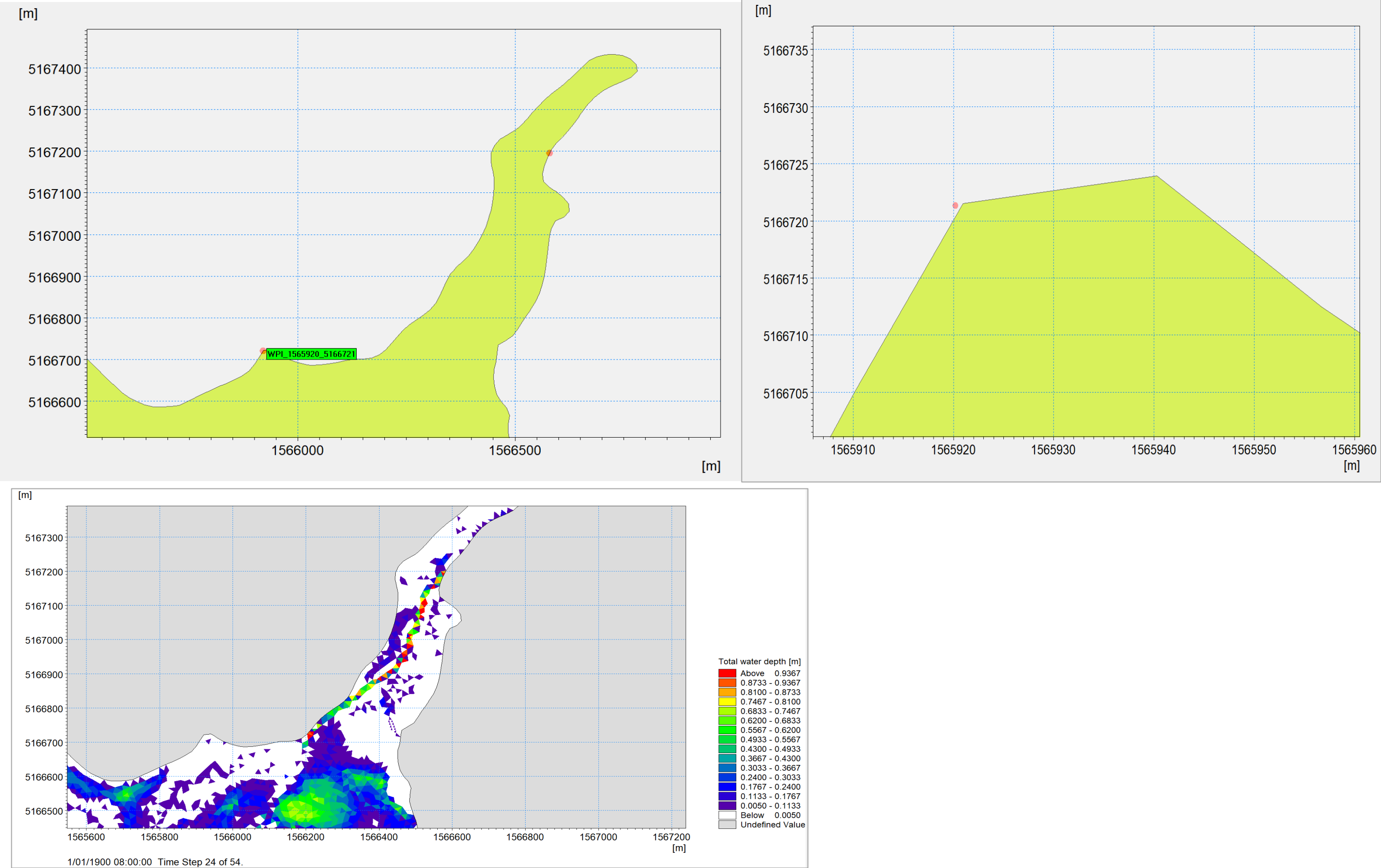
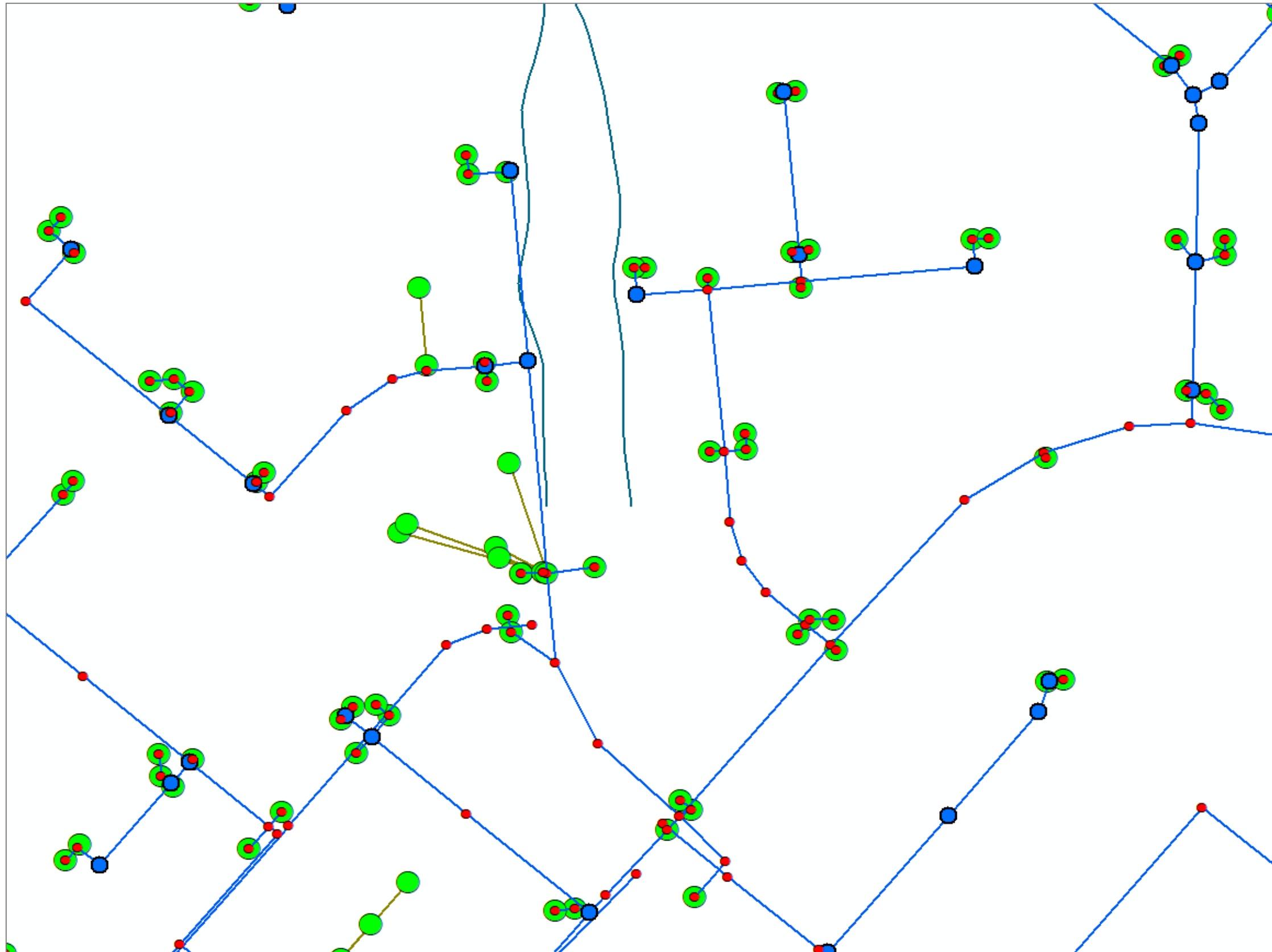


Figure 6 - manhole losses. Red = km50 mouse classic, blue = km25 weighted inlet energy. Green shows where inlets are located. Based on the methodology suggested if the node is not linked and not a flow through node it should be set to km25 weighted inlet energy.

for example where you see red points with no green, this is incorrect and they should be blue instead



Calibration Review			
Initial review of the calibration was provided via email on the 6th August 2025. The text of the email is as follows.			Modeller's Response
	As discussed in our meeting the other day. I think the validation is looking better than expected. The only concern I had was that the pervious area infiltration rates are potentially too low, as you've mentioned as well. This is highlighted by the mismatch at Selby's drain. This follows also from my discussion with Peter that the anecdotal evidence in the upper catchments is that most frequent runoff will go to ground. My suggestion would be to run a sensitivity test at least, to ascertain if adjusting the infiltration rates would help the calibration in this area. The other side to this would be to ensure that changing these pervious rates will have minimal impact on the calibration at the other locations. Which I think is your assumption. If you can prove that the pervious rates are minor for the Christchurch City areas, then I believe it would be reasonable to proceed with the design simulations. For infiltration rates, if you are overestimating the volume by 58% at Sabys can we use that to identify how much more additional water would need to be lost in that catchment? Then you could derive a rate from that. Other comments I had were: • The radar data, it looks like the time is out by 12hrs, you should double check the time zone the data was provided in, it may be GMT or something • For the Halswell Junction basin are you missing a low flow inlet by any chance? This might account for this discrepancy • Are you addressing any of the cross section issues identified?		I've had a look at the infiltration rates in the rural areas for Halswell. The Sabys Rd recorder catchment is mostly gravel and has a 5mm/hr infiltration rate. This is low considering the underlying gravel so happy that we should increase that. We were thinking a 50% increase in the fixed rates (the lower catchment is ~3mm/hr currently). I wanted to check that the GW level was low enough to enable the infiltration increase to take effect. I realized we have a large area (see image below) where GW is at ground level (we spoke about this in the past) therefore the runoff generated will be high. Looking at the GW level during the event and the model at the same location (image below numbers are in the following format, Recorded depth to GW _Model depth to GW) shows that the model is higher, in most cases by a lot but one is close, 0.162 Recorded verse 0.2 model. Therefore changing just the infiltration rate might not be enough and a increase in the depth to GW surface might also be required.

As referenced in main review spreadsheet. Review of the Halswell Hydraulic Model-Calibration Report_2025.pdf dated 8/09/2025

Model Validation

Item	Reviewer's Comments 10/09/2025	Rating Score	Modeller's Response 16/09/2025
C:2.1	On page 9 and 10 there are missing references to figures	1	Thank you for pointing this out. It appears that the references were altered during the PDF conversion. We will update it to include the appropriate figure references as part of the main report.
C:2.2	In the discussion of the Saby's road water level. It seems likely that the main reason that the water level it not correct here is because the flow is also out. The discussion could be adjusted to indicate this.	1	The site records water level and it is converted to flow using a rating curve. We are assuming that the water level measurement is accurate, but the rating curve may need to be extended. We'll clarify this in the text if this isn't clear.
C:2.3	For the match to the flow at Ryan's bridge, it would be good to see the volume comparison. The shape appears off but the volume looks more reasonable. Given the slow drawdown time of the floodplain the shape of the hydrograph may be less of an issue.	1	We have calculated and compared the volumes (over the same time period). The volumes are: gauge=3.50 million m3, baseline model=3.25 million m3, calibrated model= 2.89 million m3. In other words compared to the gauged data: -the baseline model has a similar but slightly less volume (approx. 7% less) -the calibrated model has less volume (approx. 17% less than the gauged data).

C:2.4	How have you determined the magnitude of the differences when comparing against aerial photography? The report states that the differences are in the order of 100-150mm.	1	In the aerial photos of Ella Park and Murphy Drains Reserve, you can see flooding in the lower areas, but not on the higher ground. To work out the exact flood extent at those spots, we adjusted the minimum elevation cutoff in the depth raster and compared it to the photos. We found that when the minimum elevation was set to 100 -150 mm, the model's inundation matched much more closely with what was shown in the photos.
C:2.5	It is not quite clear in the report what the recommendation is for going forward with the Design runs. I.e. will you change the models to use the lowered groundwater and increased rates or just to keep as is? Does the text indicate the intention is to keep with the conservative estimates for now?	1	At this stage, we are not recommending any changes to the model setup for the design runs. We suggest keeping the infiltration rates and groundwater settings as they are. The current base model is conservative. Sensitivity testing also indicates that the city area is less sensitive to the parameters tested. Further refinement of the calibration would require more targeted work - specifically, varying groundwater levels and adjusting infiltration based on soil type rather than applying a blanket change.
C:2.6	The large difference at Ella park seems concerning especially given that the rest of the model area doesn't seem that sensitive to the rates. How much have the rates and groundwater changed in this particular area, compared to Murphys drain for example? Have you checked to see if there might be some other issues like a model instability or something? Aside from this area the overall calibration did appear to produce an improved result with these increased infiltration rates, so it would be good to understand the differences at Ella Park better.	2	We have reviewed the changes and checked for potential model instabilities or other issues, but did not find any obvious problems with the model setup. Additionally, we conducted a sensitivity test by increasing the infiltration rate by 50% without changing the groundwater level its closely matching with the aerial photo - see Figure 1. Figure 2 shows the results when the groundwater level is also lowered by 0.3 m. We also compared the pipe flow, which indicates that there is less overland flow reaching the basin and this is because of an increase in unsaturated zone storage. Lowering the groundwater level has a significant impact on the water level in the Ella park basin. This gives futher weight to not carrying out a blanket lowering of groundwater level.
Figure/Refrence			

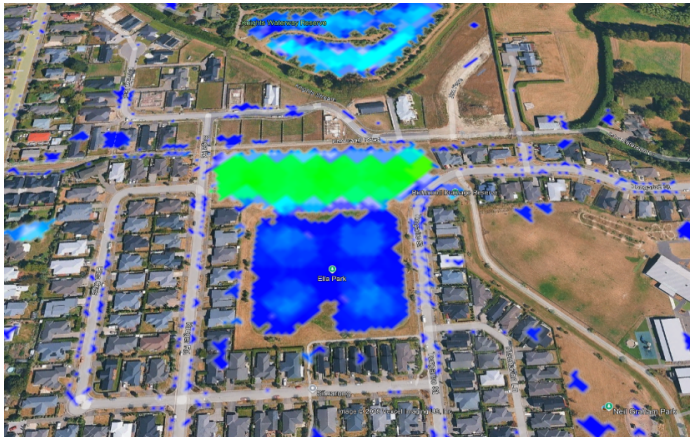


Figure-1

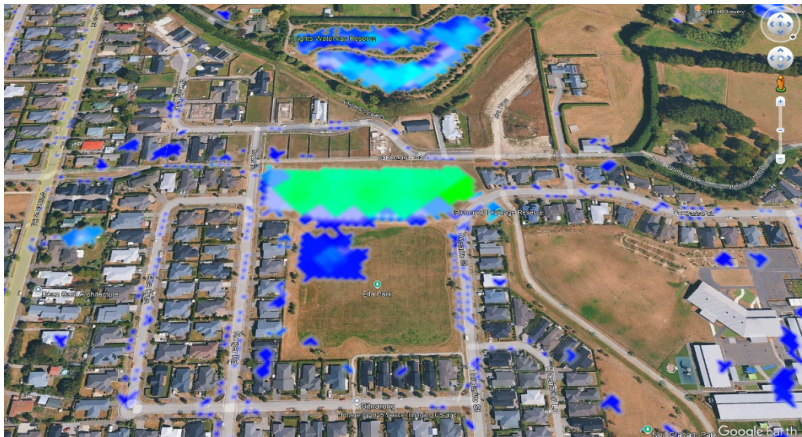


Figure-2

