REPORT

Tonkin+Taylor

Selwyn DISTRICT COUNCIL

Selwyn District Flood Model

Hydraulic Model Build Report

Prepared for
Selwyn District Council
Prepared by
Tonkin & Taylor Ltd
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Executive summary

Selwyn District Council (SDC) have engaged Tonkin & Talyor Ltd (T+T) to build a 2-dimensional hydraulic flood model of selected areas within the Waikirikiri Selwyn District.

The hydraulic model has been built to perform two functions, including assisting SDC's planning and infrastructure teams for the design of infrastructure within eleven of the district's townships, and to inform Flood Hazard Certificates within rural areas of district.

The model was built in TUFLOW HPC software and covers an area of approximately 2,300 km^2 including the plains area between the Waimakiriri River, Rakaia River, the Alps foothills and the sea and Te Waihora, Lake Ellesmere. The model includes a district-wide domain that allows simulations to be run at a coarser resolution, and 11 township models which enable finer resolution simulations.

The model incorporates terrain elevation DEM from the 2023 Selwyn LiDAR survey, supplemented by additional datasets to complete spatial coverage. The model includes input data for soils, land use, building footprints, drainage networks, stopbanks, and boundary conditions including rainfall, inflows, tides, lake levels.

Hydrological scenarios were modelled for a range of AEP events (10%, 1%, 0.5%, and 0.2%) under both historical and future climate conditions (RCP8.5 2081 - 2100), with storm durations including 1, 6, 12, 24, 48 and 72 hours. Calibration was undertaken using the July 2017 event, with validation against the June 2013 and May 2021 events.

The model outputs include maximum water depth, level, velocity, depth x velocity and hazard, along with time-series data compatible with GIS platforms.

Several model limitations and future improvement opportunities have been identified in this report.

1 Introduction

The Waikirikiri Selwyn District is located within the Waitaha Canterbury region on the east coast of Te Waipounamu the South Island. The district extends from the mountains, Kā Tiriti o Te Moana the Southern Alps to the west, Ngā Kōhatu Whakarakaraka o Tamatea Pokai Whenua Port Hills and the sea, to the east. The district covers an area of approximately 6,500 square kilometres.

The district is bounded by two large, braided rivers, the Waimakariri River to the north and Rakaia River to the south. A network of foothill fed rivers, lowland streams, ephemeral waterways, wetlands, springs and other waterways flow into Te Waihora, Lake Ellesmere.

Selwyn District Council (SDC) have engaged Tonkin & Talyor Ltd (T+T) to build a 2-dimensional hydraulic flood model of selected areas within Selwyn District, as shown on Figure 1-1. The purpose of the model is outlined in Section 2.

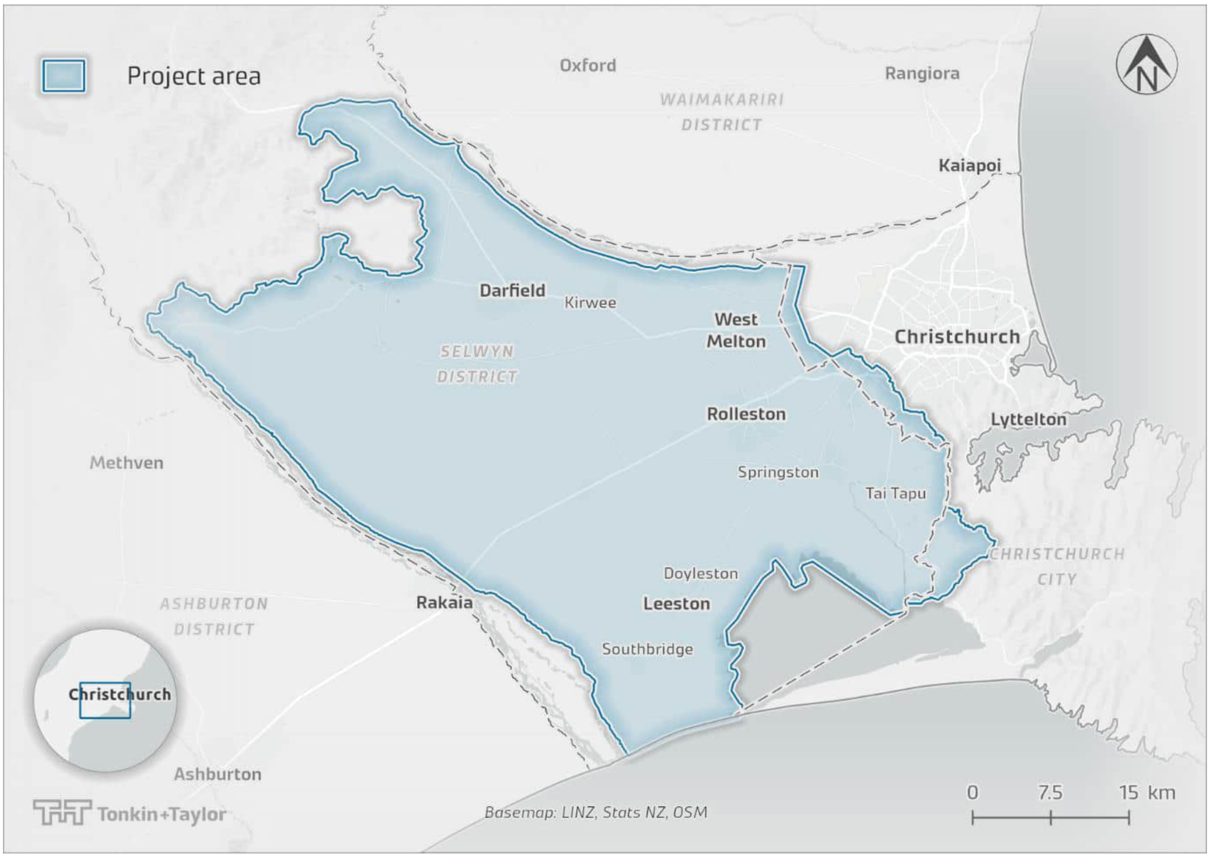


Figure 1-1: Project area.

This draft report summarises the model schematisation and hydrology methodology for the purposes of review and discussion prior to further advancement of the model build.

This project has been undertaken under conditions of contract "*Hydraulic flood model of the Waikirikiri Selwyn District*". The contract was varied on 17th January and 2nd May 2025 to include additional townships (Kirwee, West Melton) and additional culvert data.

The model has been peer reviewed by Pattle Delamore Partners Ltd (PDP). PDP's peer review report is provided in Appendix F.

2 Model purpose

SDC have requested that a hydraulic model of the Waikirikiri Selwyn District is built which will perform two functions, including:

i Assisting SDC's planning and infrastructure teams for the design of infrastructure within the townships of Darfield, Lincoln, Springston, Rolleston, Leeston, Doyleston, Southbridge, Tai Tapu, Prebbleton, Kirwee and West Melton.

ii Assisting SDC to inform Flood Hazard Certificates within rural areas of the district.

A hydraulic model which can fulfil these two functions, requires different approaches. More detail and finer resolution are required in the townships to better represent local drainage, terrain and infrastructure. Less detail and coarser resolution are required in the spatiality larger rural areas to maintain practical model simulation times. To achieve function (i), "township" models were built for the eleven townships listed. To achieve function (ii), a "district" model was built for the rural areas of the district included in the project area.

The district model estimates flooding within the project area where more detailed modelling is not available. The district model is general in nature, and a more detailed site-specific assessment may be required for some purposes (e.g. for subdivision, change in land use, infrastructure design or building works).

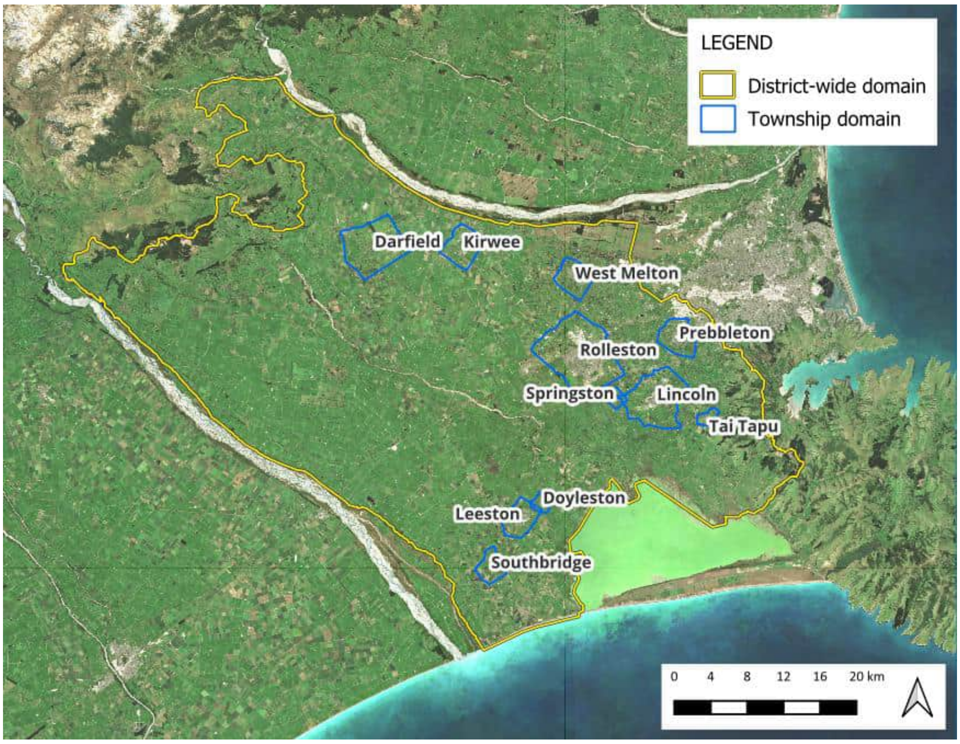
The accuracy of the models relies on the completeness and accuracy of the model inputs, most notably for the township models, the performance of the as-built drainage infrastructure (e.g. pipes, sumps etc). In areas where significant gaps in the data exist, or the accuracy of the data is inadequate, additional model refinements may be required, which could include undertaking additional infrastructure as-built survey.

SDC have requested that the simulation time of the model remain reasonable. The approach adopted is to target a less than 12-hour simulation time provided cell size convergence is reasonable. This approach also allows for a more sensitivity simulations to be run to address model uncertainty.

3 Model schematisation

Table 3-1 provides the schematisation of the hydraulic model. The purpose of schematisation is to outline the model build approach at a high-level for each key model component.

Table 3-1: Schematisation summary

<table>
<tr><th>Model Element</th><th>Description</th></tr>
<tr><td>Software</td><td>TUFLOW Heavily Parallelised Compute (HPC) Software.
The model uses the HPC solver adaptive timestep.
Further information is provided in Sections 4.1 and 4.2.</td></tr>
<tr><td>Model structure</td><td>The model uses TUFLOW's GeoPackage spatial format.
The district and township models share the same overall folder structure, managed through TUFLOW's Scenario control.</td></tr>
<tr><td>Domain</td><td>The district domain includes the plains area of Waikirikiri Selwyn between the Waimakiriri River, Rakaia River, the Alps foothills and the sea and Te Waihora, Lake Ellesmere. The domain area is approximately 2,300 km^2.
The township domains include eleven separable township areas nominated by SDC comprising Darfield, Lincoln, Springston, Rolleston, Leeston, Doyleston, Southbridge, Tai Tapu and Prebbleton, Kirwee and West Melton. The combined township domain area is approximately 190 km^2.


Further information is provided in Section 4.5.</td></tr>
<tr><td>Hydrological scenarios</td><td>Design scenarios comprise: 10%, 1%, 0.5% and 0.2% Annual Exceedance Probability (AEP) events for both 'historical' and 'future' climate conditions Representative Concentration Pathway 8.5 (RCP8.5) 2081 – 2100.
Storm durations include 1-hour, 6-hour, 12-hour, 24-hour, 48-hour and 72-hour as per HIRD's temporal profiles for 'East of SI'.</td></tr>
</table>

	Model calibrated to the July 2017 event and validated to the June 2013 and May 2021 events. Further information is provided in Section 4.6.1.
Infiltration	Soil infiltration was applied within the model domain using TUFLOW's 'tsoilf' feature which applies infiltration rates to different soil permeability types. Soil infiltration is represented by Hortons method. Soil permeability types were based on the Landcare Research Fundamental Soils Layer (FSL) Permeability Profile. Further information is provided in Section 4.6.6. Infiltration rates were adjusted based on the July 2017 event. Impervious overlays were applied to the model, including: • Building footprints outside district soakage areas at 100% impervious. • Building footprints within district soakage areas at a constant loss rate of 12 mm/hr (approximately equivalent to the 10% AEP 1-hour rainfall event intensity). • Road footprints at 100% impervious. • Residential urban areas based (excluding roads and buildings) at 25% imperviousness. • Business urban areas based (excluding roads and buildings) at 80% imperviousness. Further information is provided in Section 4.6.6. **Township model** Discharge of road stormwater at soakholes has been allowed for by applying an outflow boundary at the soakhole. Further information is provided in Section 4.10.6.
Boundary conditions	**Rainfall** Design rainfall scenarios: Time and spatially varying direct rainfall was applied within the model domain as grids using TUFLOW's 'Read RF grid' feature. Rainfall grids are generated on a 2 km x 2 km grid from HIRDSv4. Calibration & validation events (July 2017, June 2013, May 2021): recorded rainfall from available NIWA and ECan recorders within and the near to the model domain will be applied within the model domain using TUFLOW's 'Read RF points' feature. Further information is provided in Section 4.6.3.
	Lumped catchment inflows Lumped catchment inflows from the Southern Alps foothills were provided by ECan. These data are relied on and have been applied to the upstream extent of the model domain. Township models include upstream inflows extracted from the district model result outputs. No allowance for inflows to the model from the Rakaia and/or Waimakariri rivers as instructed by ECan. Further information is provided in Section 4.6.5.
	Downstream boundary Te Waihora, Lake Ellesmere levels represented by a time varying level provided by ECan. Further information is provided in Section 4.6.9.

	Tide water levels were applied at the coastal boundary of the model domain based on joint-probability storm tide and wave setup estimates. Further information is provided in Section 4.6.8. Head vs. flow (HQ) boundary along the remaining edge of the model domain.
Elevation data	Model elevation data is based on the 2023 Selwyn Light Detection and Ranging (LiDAR) 1 m Digital Elevation Model (DEM), from Land Information New Zealand (LINZ). Gaps in the 2023 LiDAR were filled with 2020-2023 Canterbury, Christchurch 2020-2021 and Banks Peninsula 2023 1 m LiDAR DEM. The model uses the New Zealand Vertical Datum (NZVD) 2016. DEM from some recent developments within the district have been included. Further information is provided in Section 4.7.
Geometry modifications	Geometry modifications were applied to the model using TUFLOW's '2d_zsh' feature, including: **District model:** • Stopbanks • Rail embankment • Roads • Coastal dune • Road – river channel "burning" • Central Plains Water bund. **Township model:** • For existing development scenarios, the elevation of the DEM was raised within existing LINZ building outlines to "block" out buildings. • Other minor modifications as required to resolve terrain errors e.g. at culvert outlets. Further information is provided in Section 4.8.
Computational cell size	The model incorporates computational cell size adjustment through TUFLOW's quadtree nesting. The district model has a base cell size of 20 m with quadtree nesting of 10 m and 5 m. The township models computational cell size is 5 m with quadtree nesting along drains of 1.25 m. TUFLOW's sub-grid sampling was applied to the to the model computational grid. Further information is provided in Section 4.10.2.
Hydraulic roughness	Hydraulic roughness is represented in the model using the Mannings 'n' approach. Depth-varying Mannings 'n' roughness values are applied to different land cover classifications within the model domain using TUFLOW's 'Log Law' feature. Land Cover Database (LCDB)[1] version 5, supplied by Landcare Research New Zealand is used to define land cover classes. The database, released in January 2020, considers land cover classification up until the end of 2018. Additional roughness overlays applied, including: • Selwyn River channel and berm. • Residential and Business area overlays from SDC operative plan.

[1] https://lris.scinfo.org.nz/layer/104400-lcdb-v50-land-cover-database-version-50-mainland-new-zealand/, downloaded 30 May 2023.

	• Roads. • Drainage channels within townships. Further information is provided in Section 4.13
Culverts and bridges	The district model includes culverts larger than 0.5 m diameter supplied by SDC, KiwiRail, ECan and NZTA as 1-dimensional elements. Township models include all culverts as supplied by SDC, KiwiRail, ECan and NZTA as 1-dimensional elements. Bridges have not been included in the model. Further information is provided in Section 4.9.
Stormwater infrastructure	Township models include the pipe network as 1-dimensional elements (sumps, manholes and pipes) supplied by SDC. Further information is provided in Section 4.10.
Calibration & Validation	The model was calibrated to the July 2017 event and validated to the June 2013 and May 2021 events. Further information is provided in Section 5.
Outputs	For all scenarios: Maximum model output grids (.tiff) format comprising estimates of the following: • Maximum water depth (m above ground level). • Maximum water level (m above vertical datum). • Maximum water velocity (m/s). • Maximum depth x velocity (m^2/s). • Maximum flood hazard. TUFLOWS timeseries output (.xmdf), compatible with GIS plugin viewer. Separate output files will be created for each township. Further information is provided in Section 6.1.

4 Model methodology

4.1 Model solver

The model has been built and run using 2D TUFLOW HPC 2025-03 release version.

TUFLOW HPC is an explicit solver for the full 2D Shallow Water Equations (SWE), including a sub-grid scale eddy viscosity model. The scheme is both volume and momentum conserving, is 2nd order in space and 4th order in time. Single precision (iSP) will be adopted for the model.

4.2 Timestep

The model uses the HPC solver adaptive timestep to maintain stability. The timestep is adjusted so that it complies with the mathematical stability criteria of a 2D SWE explicit solution. There are three primary processes that determine the maximum timestep that an explicit solution to the SWE uses, including the Courant Number (Nu), Wave Celerity Number (Nc) and Diffusion Number (Nd). The model uses the highest timestep possible without exceeding Courant number <1.0, Celerity Control < 1.0 and Diffusion control: < 0.3.

4.3 Coordinate system and datum

The model uses New Zealand Transverse Mercator (NZTM) horizontal coordinate system and the New Zealand Vertical Datum (NZVD) 2016 vertical datum.

4.4 Model structure

The model uses TUFLOW's GeoPackage spatial format.

The district and township models share the same overall folder structure (managed through TUFLOW's Scenario control) to minimise duplication of input data and provide better adaptability for future use.

4.5 Domain

District model

The district model encompasses the area as shown in Figure 4-1. The domain includes the plains area of Waikirikiri Selwyn between the Waimakiriri River, Rakaia River, the Alps foothills and the sea and Te Waihora, Lake Ellesmere. The domain area is approximately 2,300 km^2.

The domain was delineated from the following information:

- SDC Local Authority Boundary.
- Natural topographical features (river terraces of the Rakaia and Waimakriri Rivers, and the Port Hill ridgelines defined from LiDAR DEM).
- Catchment boundary map for the Halswell River from Christchurch City Council.
- ECan's lumped inflow catchment extents for the Alps foothills (Section 4.6.5).
- Coast and Te Waihora, Lake Ellesmere.

TUFLOW's Location definition ('2d_loc') has been rotated in a northwest to southeast direction to generally align with direction from flow across the plains.

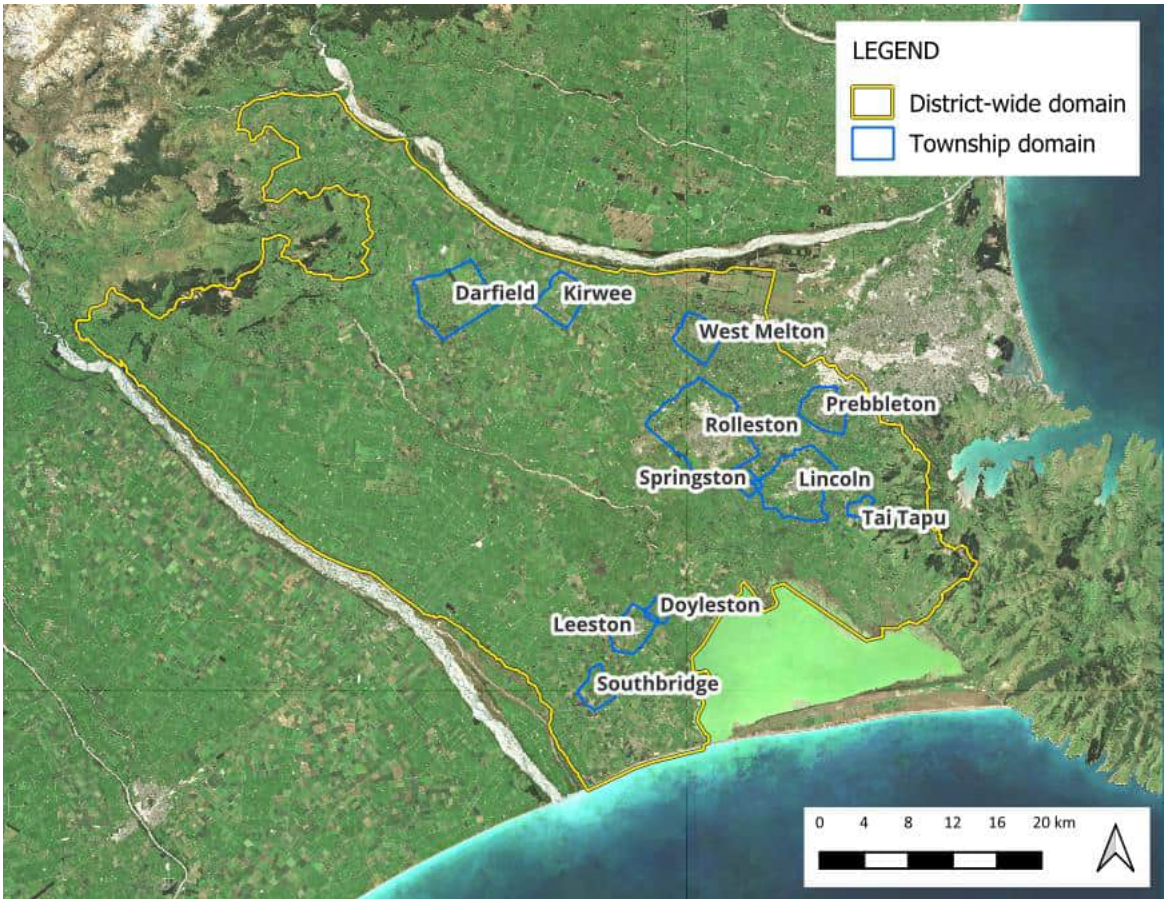


Figure 4-1: District and township domains.

For the model calibration simulations, the domain was extended to include the Kaituna River and Hoon Hay Stream which are located in the Port Hills. These catchments were included so that modelled discharge could be compared to recorded discharge.

Township model

Township spatial boundaries were supplied by SDC and encompass the townships of Darfield, Lincoln, Springston, Rolleston, Leeston, Doyleston, Southbridge, Tai Tapu, Prebbleton, Kirwee and West Melton as shown in Figure 4-1. Spatial modifications were made to the provided boundaries to simplify the domain shapes and merge separate domain areas within the same township. The model domain area of each township is provided in Table 4-1.

Table 4-1: Township domain area

Township	Domain area (km^2)
Rolleston	53
Darfield	33
Lincoln	32
West Melton	14
Kirwee	13
Prebbleton	13

Township	Domain area (km^2)
Leeston	12
Southbridge	8
Tai Tapu	3
Doyleston	4
Springston	4

4.6 Hydrology

4.6.1 Hydrological scenarios

A summary of the hydrological scenarios modelled as requested by SDC are provided in Table 4-2.

Table 4-2: Hydrological scenarios summary

Model	AEP	Climate Scenarios	Rainfall durations
District Township	• 10% • 1% • 0.5% • 0.2%	• 'Historical' • 'Future' (RCP8.5 2081 – 2100)	• 1-hour • 6-hour • 12-hour • 24-hour • 48-hour • 72-hour

The model was calibrated to the July 2017 event and validated to the June 2013 and May 2021 rainfall events.

4.6.2 Hydrological boundaries

District model:

The district model has five hydrological boundaries, including:

- Direct-rainfall within the model domain.
- Inflow hydrographs from the Southern Alps foothill catchments.
- Tide water level at the coast.
- Water level at Te Waihora, Lake Ellesmere.
- Head vs. flow (HQ) boundary along the remaining edge of the model domain.

Township model:

The township models have three hydrological boundary conditions, including:

- Direct-rainfall within the township model domain.
- Flow vs. time (QT) boundary along the upstream edge of the model domain.
- Head vs. flow (HQ) boundary along the downstream edges of the model domain.

4.6.3 Direct rainfall

Direct rainfall was applied to the model to represent rainfall falling on the ground within the model domain. Rainfall was applied in the form of spatially and time varying rainfall over the duration of the model simulation.

Rainfall depths were sourced from NIWA's High Intensity Rainfall Design System V4 (HIRDS)[2]. Rainfall depths were sourced from HIRDS for historical climate and the future climate conditions as requested by SDC. Total rainfall depths range within the model domain as shown in Table 4-3.

[2] https://niwa.co.nz/sites/default/files/2018022CH_HIRDSv4_Final.pdf, https://hirds.niwa.co.nz/, downloaded September 2024

Table 4-3: Direct rainfall depths

Duration	10% AEP		1% AEP		0.5% AEP		0.2% AEP	
	Historical	RCP8.5	Historical	RCP8.5	Historical	RCP8.5	Historical	RCP8.5
1-hour	16-20	21-27	28-36	38-48	33-41	45-56	40-50	54-67
6-hour	38-53	48-68	65-91	84-118	75-104	97-135	88-122	114-158
12-hour	52-80	64-99	86-134	109-169	98-152	124-192	114-177	144-223
24-hour	67-115	81-138	110-190	135-232	124-215	152-263	144-249	175-304
48-hour	85-158	100-186	136-258	162-308	153-291	182-347	175-335	209-399
72-hour	95-185	111-216	151-300	178-354	169-338	199-398	193-387	227-456

Rainfall was temporally distributed using the HIRDS temporal patterns as per Chapter 6 of '*High Intensity Rainfall Design System'* (NIWA, 2018). The "East of South Island" temporal profile was used. Figure 4-2 shows an example set of hyetographs for the 0.5% AEP future climate conditions event at one example location within the model domain.

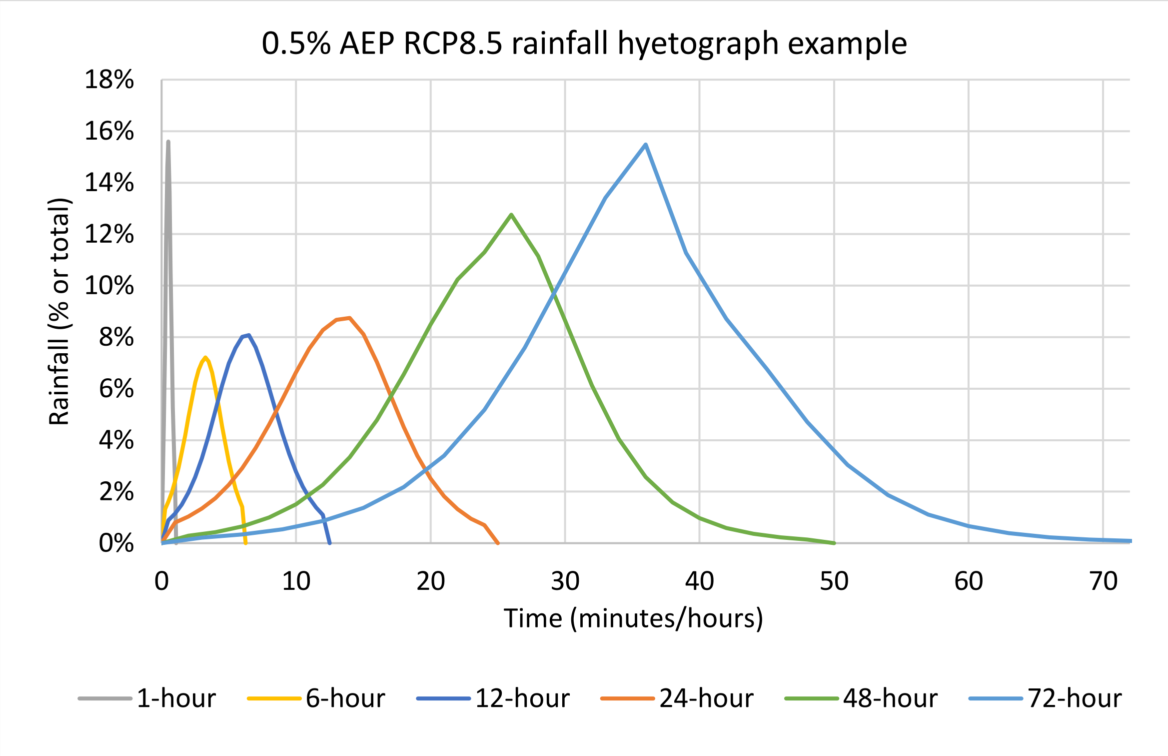


Figure 4-2: HIRDS temporal profiles – example location for 0.5% AEP RCP8.5 scenario.

The HIRDS rainfall was spatially distributed over the model domain using TUFLOW's 'Read RF grid' feature on a 2 km x 2 km grid. Figure 4-3 shows the gridded rainfall total for the 0.5% AEP RCP8.5 climate 24-hour event. Rainfall is applied to the entire model domain during the simulation.

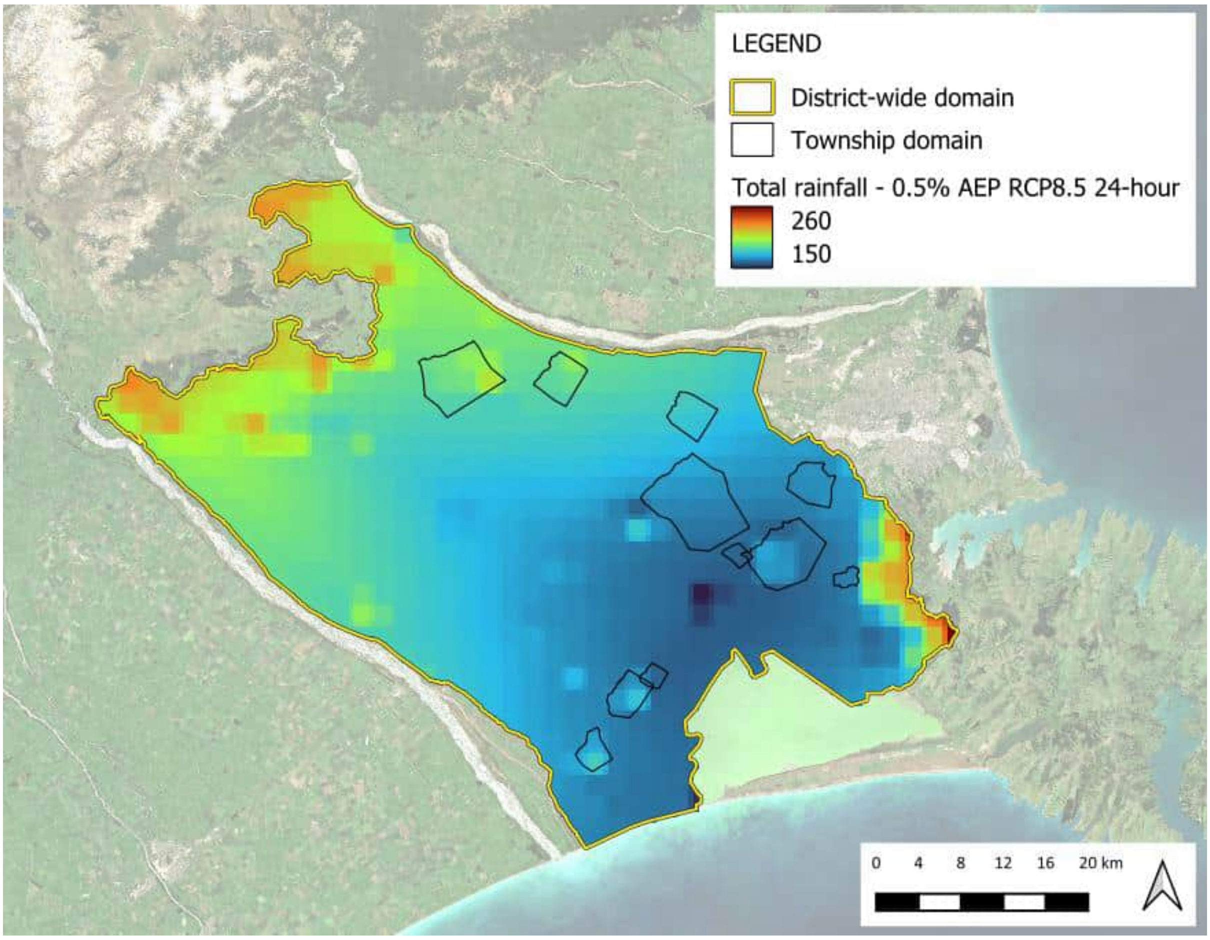


Figure 4-3: HIRDS gridded rainfall – total rainfall 0.5% AEP RCP8.5 climate 24-hour event.

For the model calibration events, rainfall depths from rainfall recorders within the district were applied to the model using TUFLOW's 'Read RF Points' feature. TUFLOW spatially distributes the recorded rainfall at each timestep using the IDW interpolation method.

Recorded rainfall data for calibration and validation events was provided by ECan and NIWA. Figure 4-4 shows the location of the recorder sites used in the model.

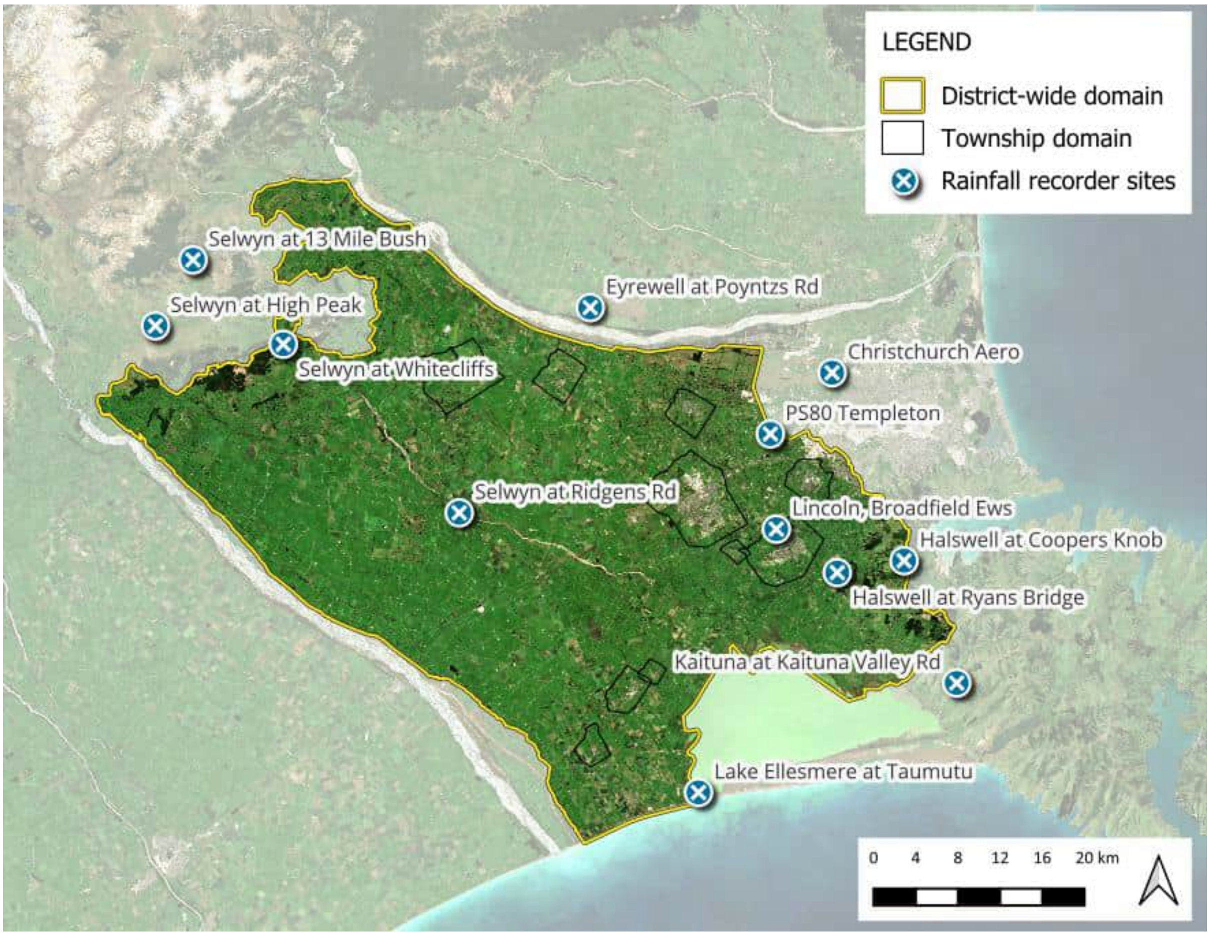


Figure 4-4: Rainfall recorder sites.

4.6.4 Areal Reduction Factors

Areal Reduction Factors (ARF) can be used to account for the variation of rainfall intensity across large catchments during a design storm event. There are several methods to estimate ARF, most of which are based on the catchment area upstream of a specific point of interest.

No ARF was applied to the district or township models because there is no specific point of interest within the district in which the upstream catchment area can be defined. Applying an ARF across the entire district may cause an underestimation of flooding in smaller catchments (e.g. Port Hills) and an over estimation of flooding in larger catchment areas (e.g. lower Selwyn River). For this model, the precautionary approach was adopted, i.e. no ARF was applied.

A future improvement opportunity regarding ARF is provided in Section 9.

4.6.5 Inflow hydrographs

District model:

Inflow hydrograph boundaries were applied into the district model domain at the foothills of the Southern Alps as shown on Figure 4-5.

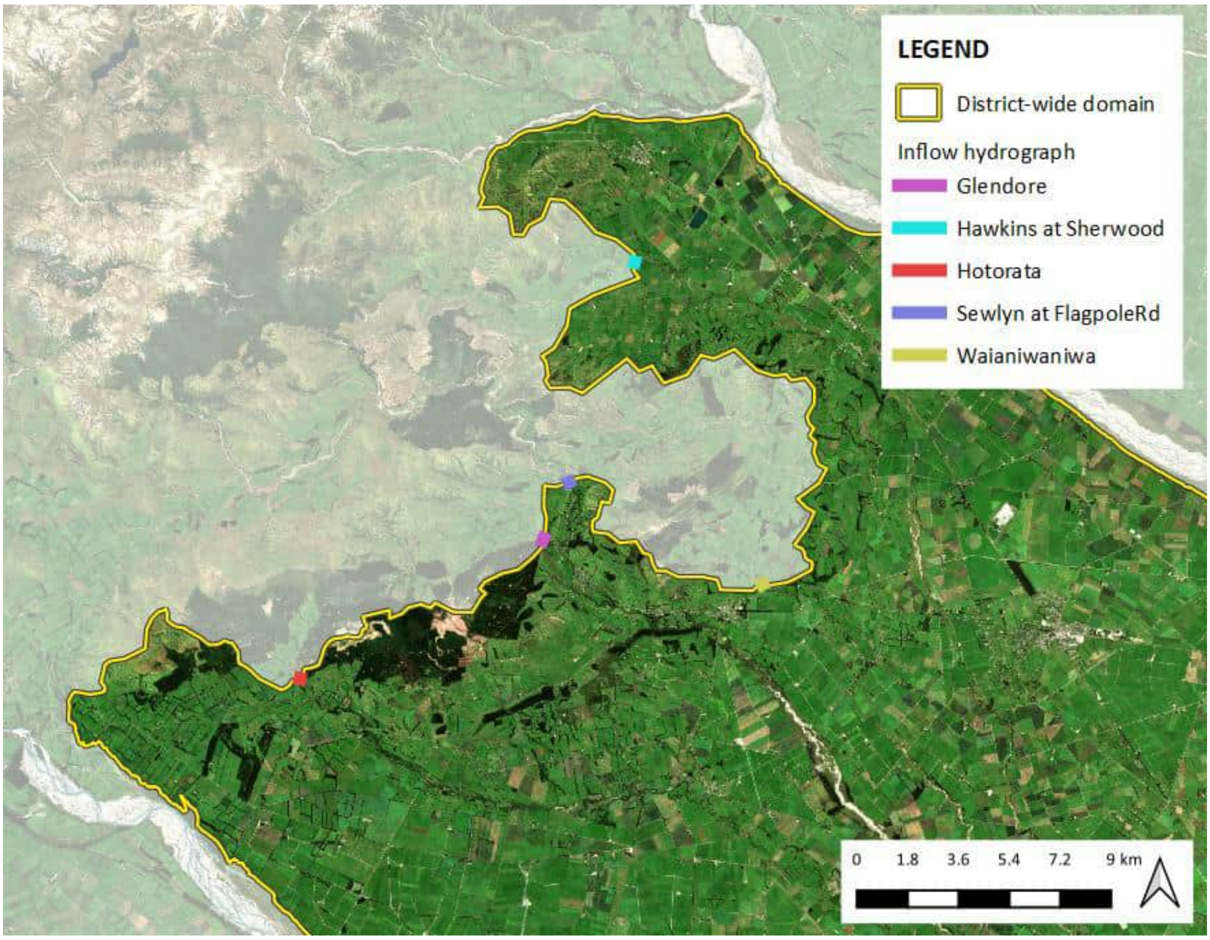


Figure 4-5: Inflow hydrograph locations.

There is no allowance for inflows to the model from the Rakaia and/or Waimakariri rivers as instructed by ECan.

Inflow hydrographs for the boundary locations were estimated by ECan using a RDI hydrological rainfall runoff model (DHI MIKE+ software). Details regarding how the hydrographs were estimated are provided in the ECan report '*Waikirikiri/Selwyn River foothill hydrological modelling and design flows'* (ECan, 2025).

An example inflow hydrograph for the 1% AEP present day climate event provided by ECan is shown in Figure 4-6.

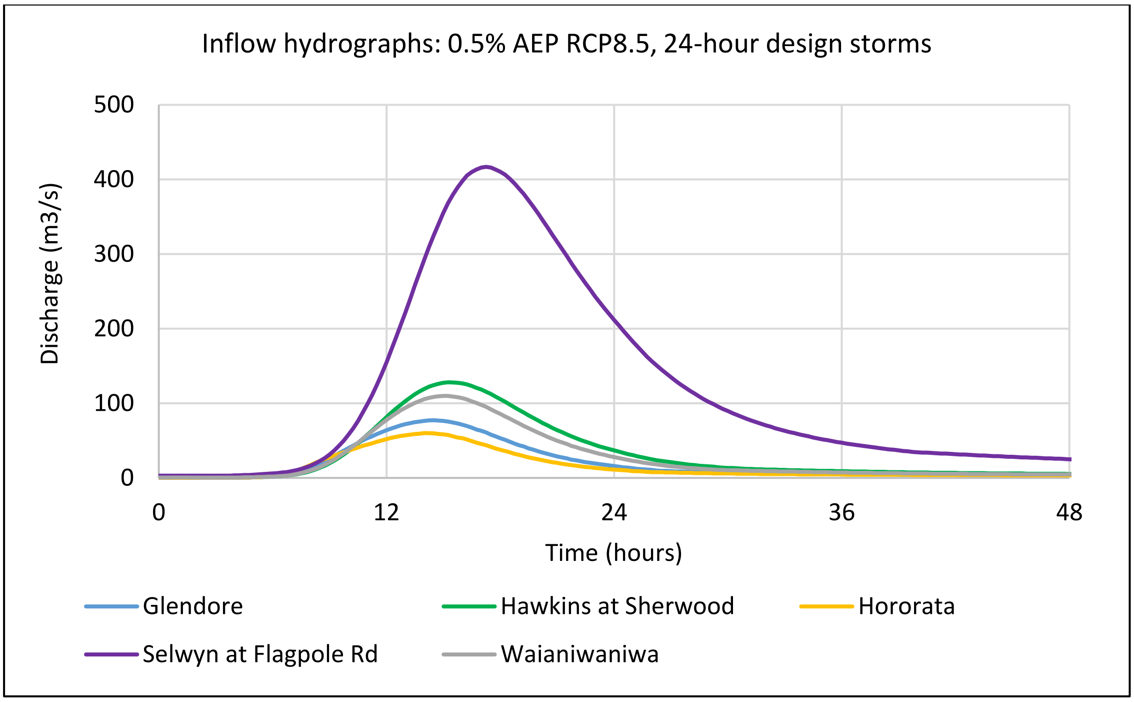


Figure 4-6: 0.5% AEP RCP8.5 24-hour climate inflow hydrographs.

For the calibration events, inflow hydrographs provided by ECan were applied to the model at the boundary locations, as shown in Figure 4-7, Figure 4-8 and Figure 4-9. For the Selwyn River, the recorded flow at Whitecliffs was used.

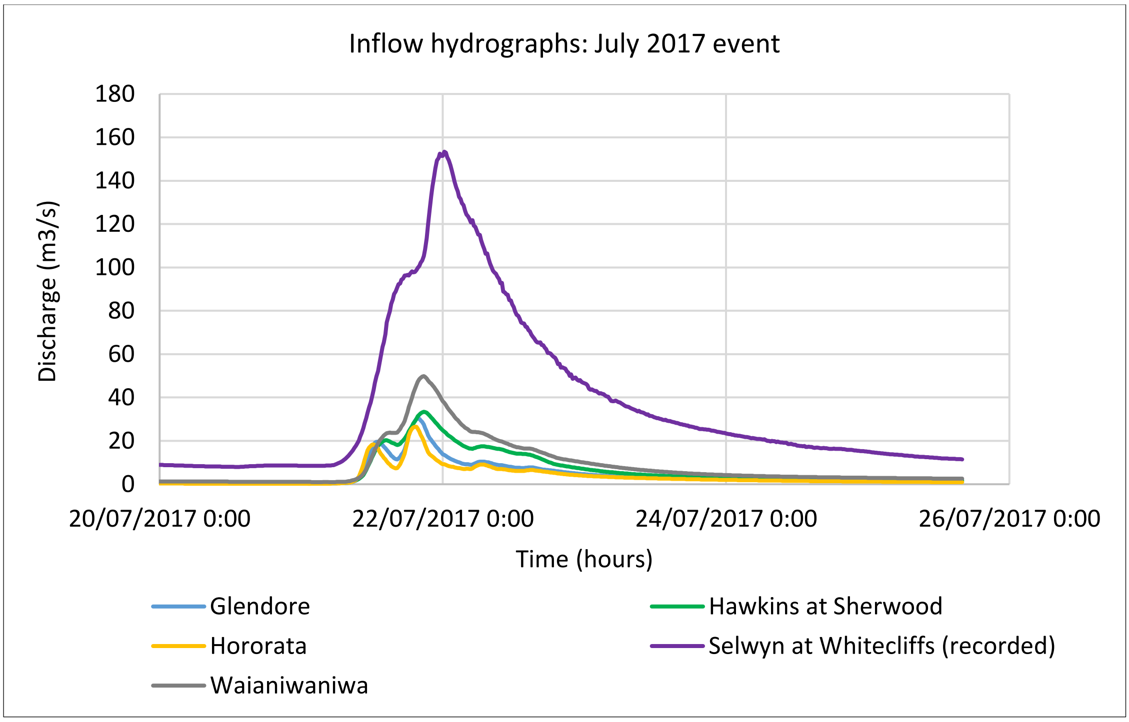


Figure 4-7: Inflow hydrographs – July 2017 event.

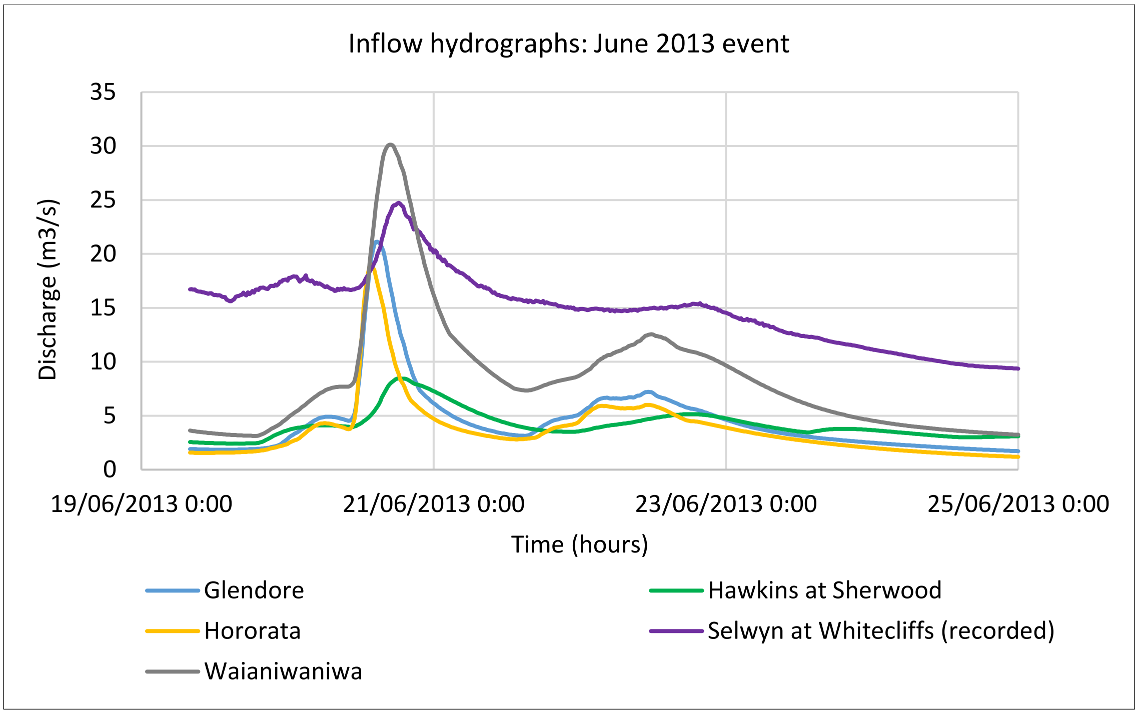


Figure 4-8: Inflow hydrographs - June 2013 event.

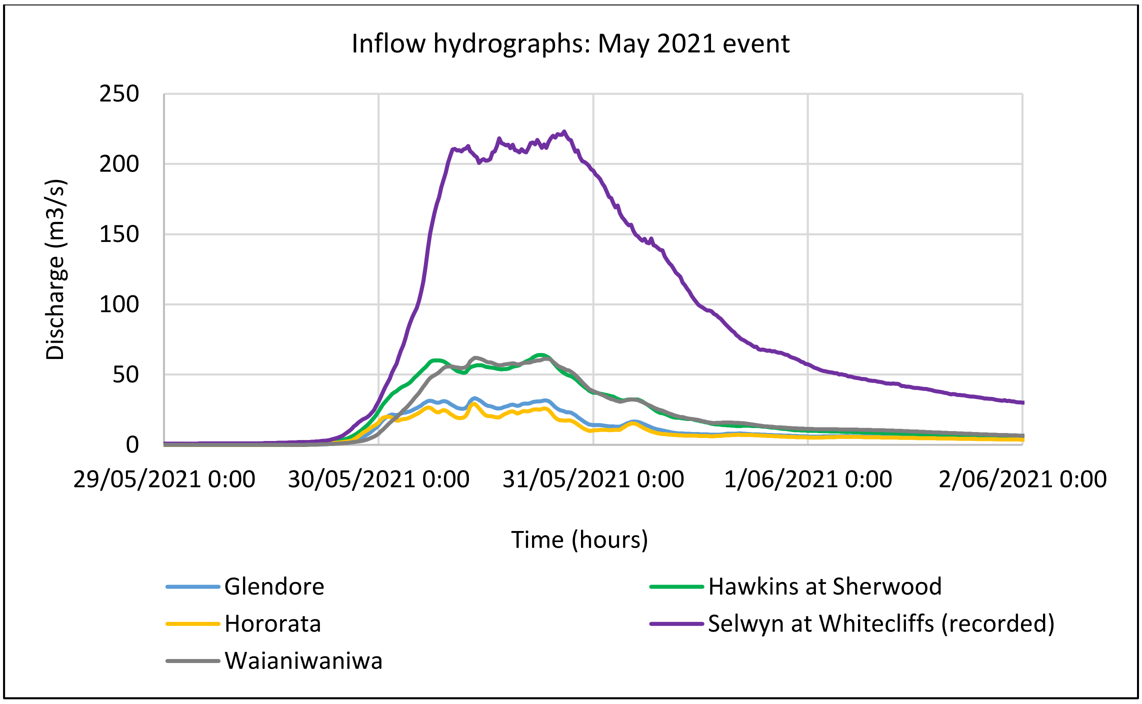


Figure 4-9: Inflow hydrographs – May 2021 event.

Inflow hydrographs will vary from event to event and no two events will be the same, with each event having a different peak discharge and volume. Different hydrograph temporal profiles with the same peak discharge may result in different flood levels due to storage volume within the floodplain and other timing effects. The timing of hydrographs will particularly effect flood levels.

Township model:

The township models include a QT boundary along the upstream edge of the model domain. The QT boundary is the flow from the district model extracted using TUFLOW's "PO" output feature at 50 m intervals. The QT boundary is applied to the township model along a constant water level elevation to minimise hydraulic inaccuracies along the upstream edge of the model domain. Figure 4-10 shows an example of how the QT boundary is applied for Leeston and Doyleston townships.

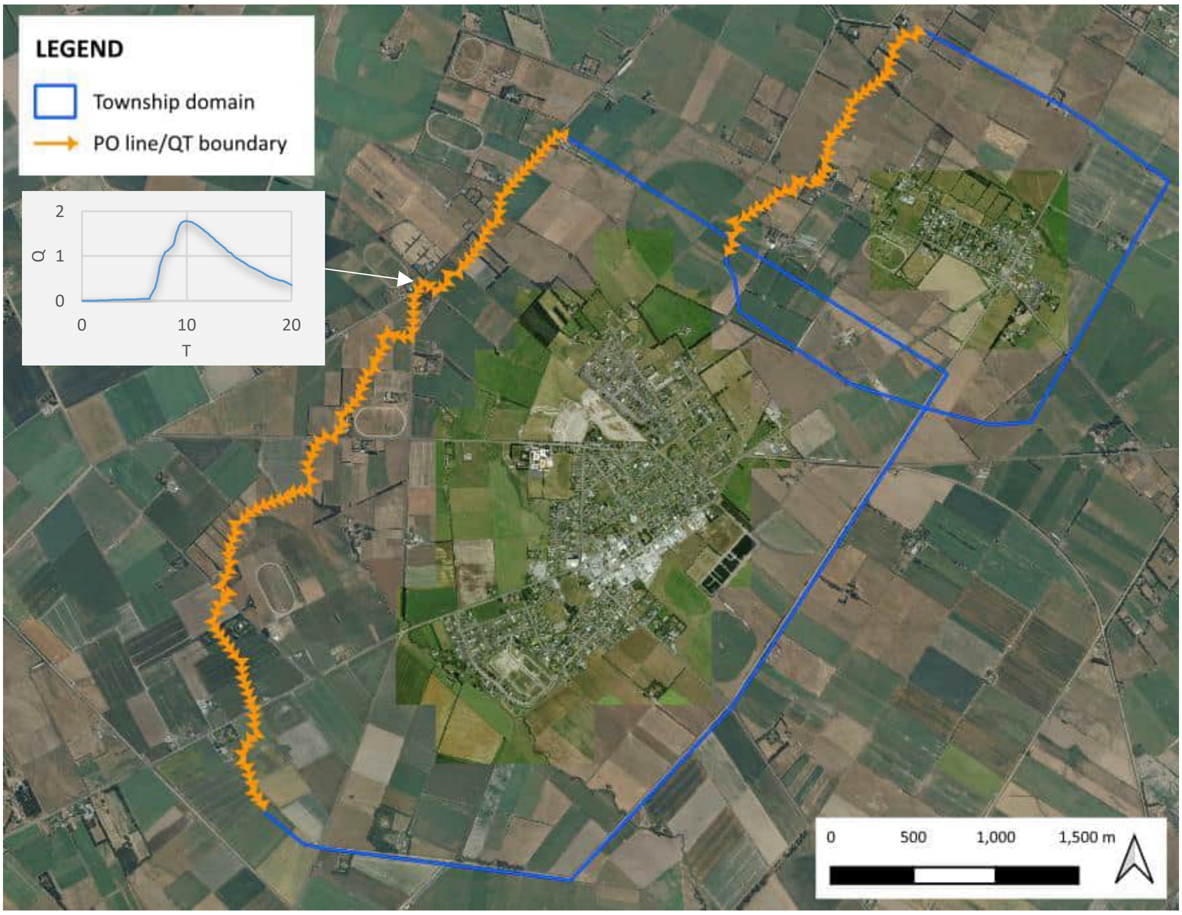


Figure 4-10: Inflow QT boundaries

A downstream HT boundary was applied to the Lincoln township model where tailwater effects may cause flooding within the model domain. The HT boundary is the water level from the district model extracted using TUFLOW's "PO" output feature.

The above QT boundary approach assumes that rainfall occurs within the entire catchment area upstream of the township during the simulation which in some cases, results in large inflows into the township model domains. In some instances, the flooding caused by these inflows far exceeds the flooding caused by localised rainfall within the township itself. For example, during some AEP events, the flooding caused by a breakout of the Selwyn River causes much more flooding than that caused by rainfall within the township. A future improvement opportunity regarding the township domains and application of rainfall using alternative approaches is provided in Section 9.

4.6.6 Infiltration

Soil infiltration was applied within the model domain using TUFLOW's 'tsoilf' feature which applies infiltration rates to different soil types.

Soil types for the district were sourced from the Landcare Research Fundamental Soils Layer (FSL) Permeability Profile[3] which spatially defines soil permeability classes for different soil types. Figure 4-11 shows the soil permeability classes within the model domain.

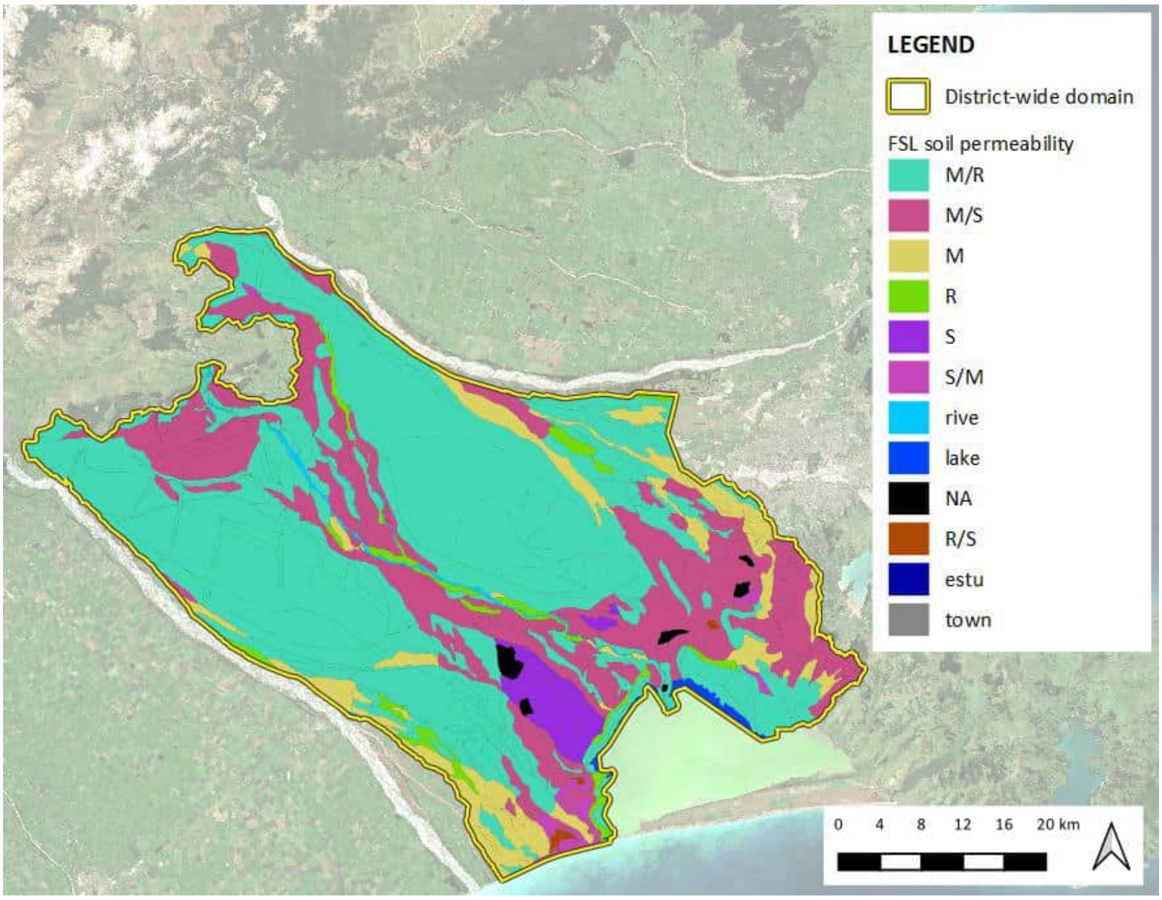


Figure 4-11: FSL soil permeability.

[3] https://lris.scinfo.org.nz/layer/48105-fsl-permeability-profile/, downloaded October 2024

Table 4-4 provides the soil permeability types used in the model.

Table 4-4: FSL Soil permeability coverage

Soil permeability	Model domain coverage (km^2)	Model domain coverage % model
Moderate over rapid (M/R)	1308	58%
Moderate over slow (M/S)	569	25%
Moderate (M)	199	8.8%
Rapid (R)	57	2.5%
Slow (S)	57	2.5%
Slow over moderate (S/M)	20	0.9%
River	17	0.7%
Lake	16	0.7%
Not classification (NA)	12	0.6%
Rapid over slow (R/S)	4.0	0.2%
Estuary	0.1	0.004%

The Horton Loss approach for estimate infiltration was applied to the model. The Horton Loss parameters used in the model are provided in Table 4-5 and were based on literature review (Appendix A) and the outcome model of calibration (Section 5). Sensitivity testing of the Horton Loss parameters was undertaken (Section 7).

Table 4-5: Hortons loss parameters (after calibration)

Soil permeability	Initial infiltration rate (mm/hr)	Ultimate infiltration rate (mm/hr)	Horton decay (hrs^{-1})
Slow[1]	2	0.5	5.4
Moderate over slow	3	0.5	5.4
Moderate	6	1	0.36
Moderate over rapid	10	2	0.108
Rapid	15	4	0.108

Notes:

1. River, lake and estuary assumed to be impervious.
2. Includes R/S soil (4.0 km^2).

The model includes the following impervious overlays which applies a level of imperviousness to buildings, roads and urban areas:

- LINZ building outlines[4] at 100% impervious.
- Road footprints at 100% impervious. Road footprints are spatially based on the LINZ Primary Road Parcels[5] with a 5 m negative buffer applied to the parcel to approximate the road surface. The buffered parcels were clipped with the LINZ NZ Roads Addressing[6] layer to remove un-built road parcels.
- Township urban areas (excluding roads and buildings) at 25% impervious and business areas at 80% impervious. Township urban areas are spatially based on "built-up areas" from the Landcare Research New Zealand Land Cover Database Version 5 (LCDB)[7] and updated based on 2022-2023 aerial imagery[8] and SDC District Plan zone layers (operative 'Residential" and "Business" zones).

An example of the impervious area overlays for Leeston is shown on Figure 4-12.

Figure 4-12: Impervious area overlays example (Leeston).

[4] https://data.linz.govt.nz/layer/101290-nz-building-outlines/, downloaded October 2024
[5] https://data.linz.govt.nz/layer/50796-nz-primary-road-parcels/, downloaded October 2024
[6] https://data.linz.govt.nz/layer/53382-nz-roads-addressing/, downloaded October 2024
[7] https://lris.scinfo.org.nz/layer/104400-lcdb-v50-land-cover-database-version-50-mainland-new-zealand/, downloaded October 2024.
[8] https://data.linz.govt.nz/layer/115058-selwyn-0075m-urban-aerial-photos-2022-2023/, downloaded October 2024.

Discharge of runoff from building roofs into ground via soakage within the soakage area shown on Figure 4-13 was represented in the model using TUFLOW's Initial and Constant Loss approach. Soakage areas were defined based on SDC's LIM and PIM spatial layer[9]. A constant loss rate of 12 mm/hr was applied to LINZ building roof outlines within the soakage area which is approximately equivalent to the 10% AEP 1-hour rainfall event intensity from HIRDS with future climate conditions (RCP8.5 2081 – 2100 as per SDC's Engineering Code of Practice Chapter 8.5.2). Soakage has not been applied to buildings less than 15 m^2 within the soakage area as these are likely to be small, shed type structures with no soakage. Building roofs outside of the soakage areas assume no discharge into ground, i.e. 0 mm/hr constant loss.

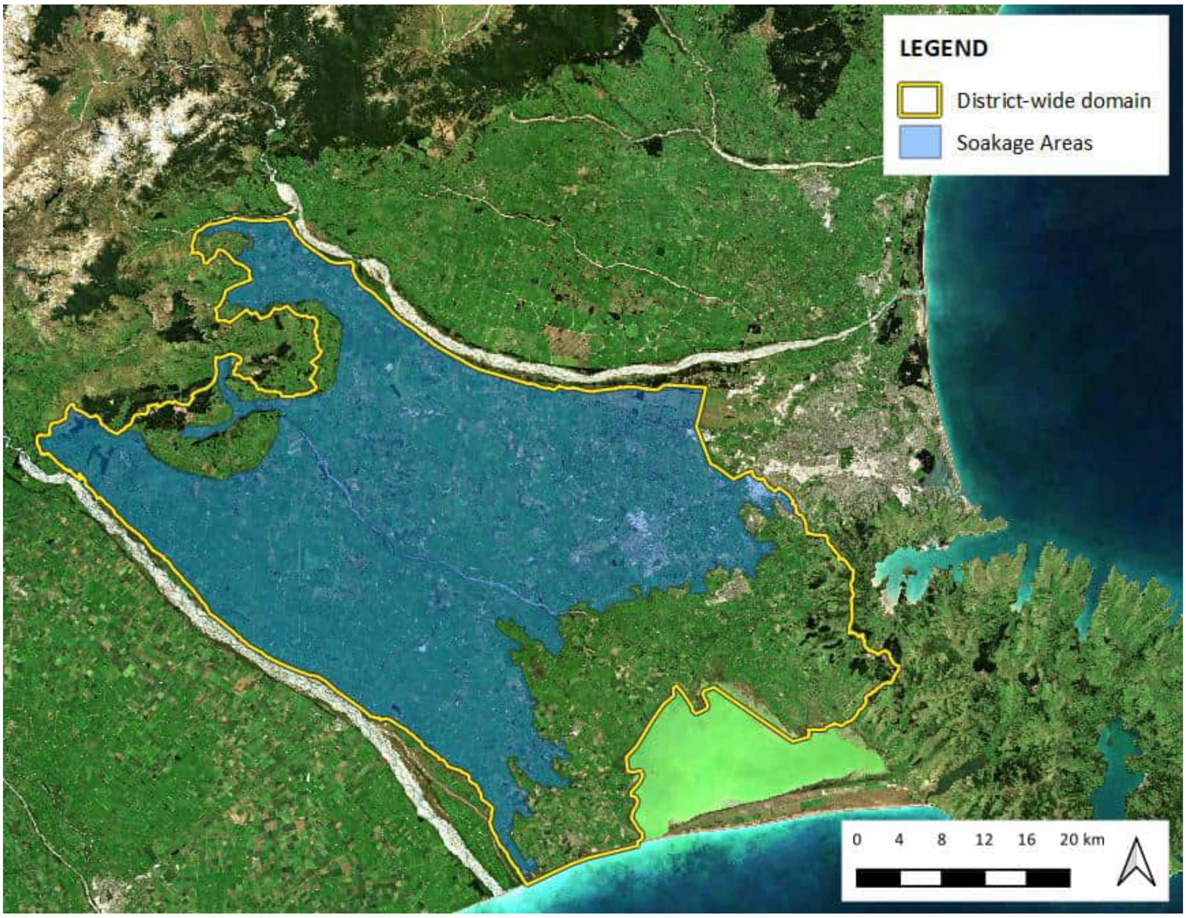


Figure 4-13: Soakage areas.

Soakage to ground via infiltration basins was included in the model. SDC asset data identifies the location of the basins and in some cases, the design function. An infiltration rate of 50mm/hr was applied within the footprint of identified basins. 50 mm/hr is a common design infiltration rate for infiltration basins. A future improvement opportunity regarding modelling of stormwater basins is provided in Section 9.

[9] #SR-28598 Data request Stormwater_Lims_Pims featureclass for modeling, provided November 2024.

4.6.7 Selwyn River

The Selwyn River is the primary river system flowing through the district. Within the foothills, it flows in a south-easterly direction along a depression formed between the merged Waimakariri and Rakaia river outwash fans (CRC, 1996). As the Canterbury plains gravels are mainly free-draining, the mid-plains reach of the Selwyn River is ephemeral. Surface flow often only passes along the full length of the river for a few months of the year (Vincent, 2005). For large periods of the year, the main tributaries of the Selwyn River (i.e. the Hororata, Waianiwaniwa, and Hawkins Rivers) also tend to have dry riverbeds in their upper plains reaches (Vincent, 2005).

It is hypothesised that a significant volume of the rivers surface flow can be lost to a 'shallow braid plain aquifer' beneath the river. When the river is dry, a large amount of flow is lost into the braid plain aquifer at the start of a flood event, resulting a longer lag between flows in the upper and lower catchment. If the river is flowing at the start of an event, then much of the braid plain aquifer is already saturated and therefore flow is lost at a slower rate, resulting in a shorter lag time. The existence of a shallow braid plain aquifer in the Selwyn River was confirmed by recent research by Lincoln Agritech and NIWA.

The properties of the river described above results in different hydrological responses during flood events. Figure 4-14 shows the recorded discharge at Whitecliffs and Coes Ford for two historical events, July 2017 and May 2021. In July 2017, the flow peak lag time between Whitecliffs and Coes Ford peak was around 12 hours. However, in May 2021 the lag time was almost around 24 hours (noting the flat peak at Whitecliffs is not typical). In the July 2017 event, the flow at Whitecliffs and Coes Ford was similar (8.5 m^3/s) prior to the event. In the May 2021 event, the flow was 1.3 m^3/s and 0.2 m^3/s respectively.

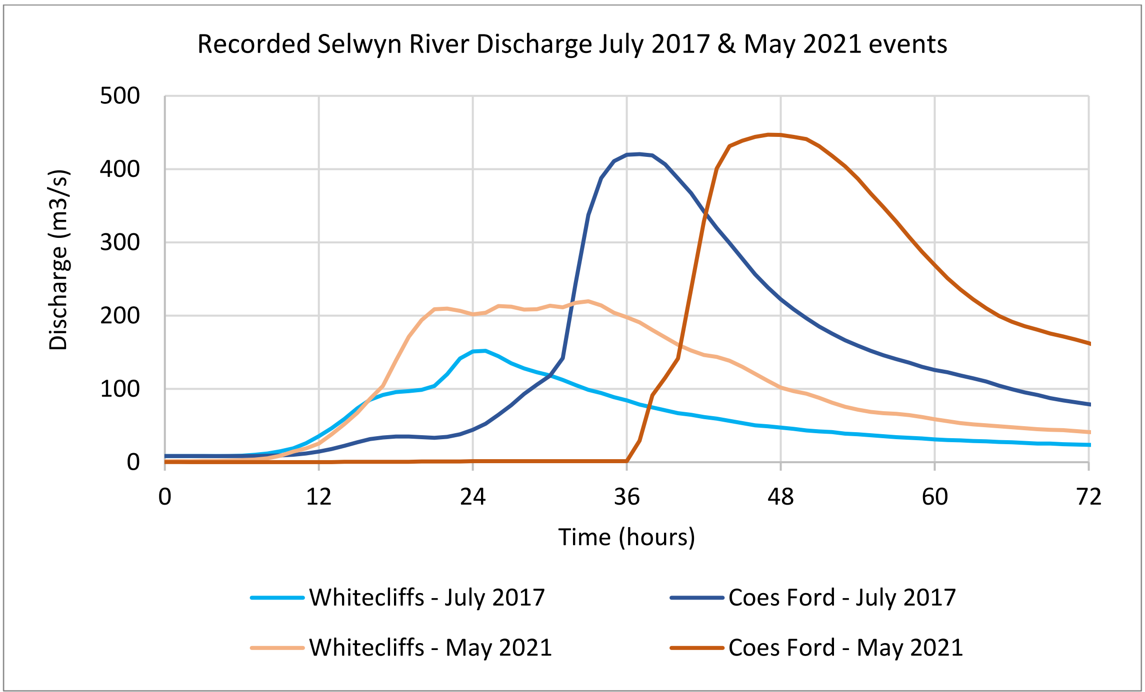


Figure 4-14: Recorded discharge for Selwyn River.

In the months prior to the May 2021 event, river flows were relatively low and no notable flood events occurred, which means the braid plain aquifer had the potential to absorb a significant volume of water at the start of the event. Prior to the July 2017 event, river flows were higher and several small flood events had occurred, which means the braid plain aquifer was essentially full. The May 2021 event had much more rainfall in the headwaters compared to July 2017 (around twice as much) but produced similar flows at Coes Ford. These observations support the hypothesis described above.

Anecdotal observations during flood events and aerial imagery suggests that tributaries Hororata, Hawkins and Waianiwaniwa may also experience loss to the shallow aquifer similar to the Selwyn River.

Calibration of the model will consider how the above hypothesis may affect the modelled flows within the Selwyn River.

Surface-groundwater interactions are not explicitly represented in the model currently due to the limitations of data (geology and groundwater) and software capability. A future improvement opportunity regarding modelling of surface-groundwater interaction is provided in Section 9.

4.6.8 Coast water level

A water level boundary including storm tide + wave setup at the coast was applied to the model at the location shown in Figure 4-15.

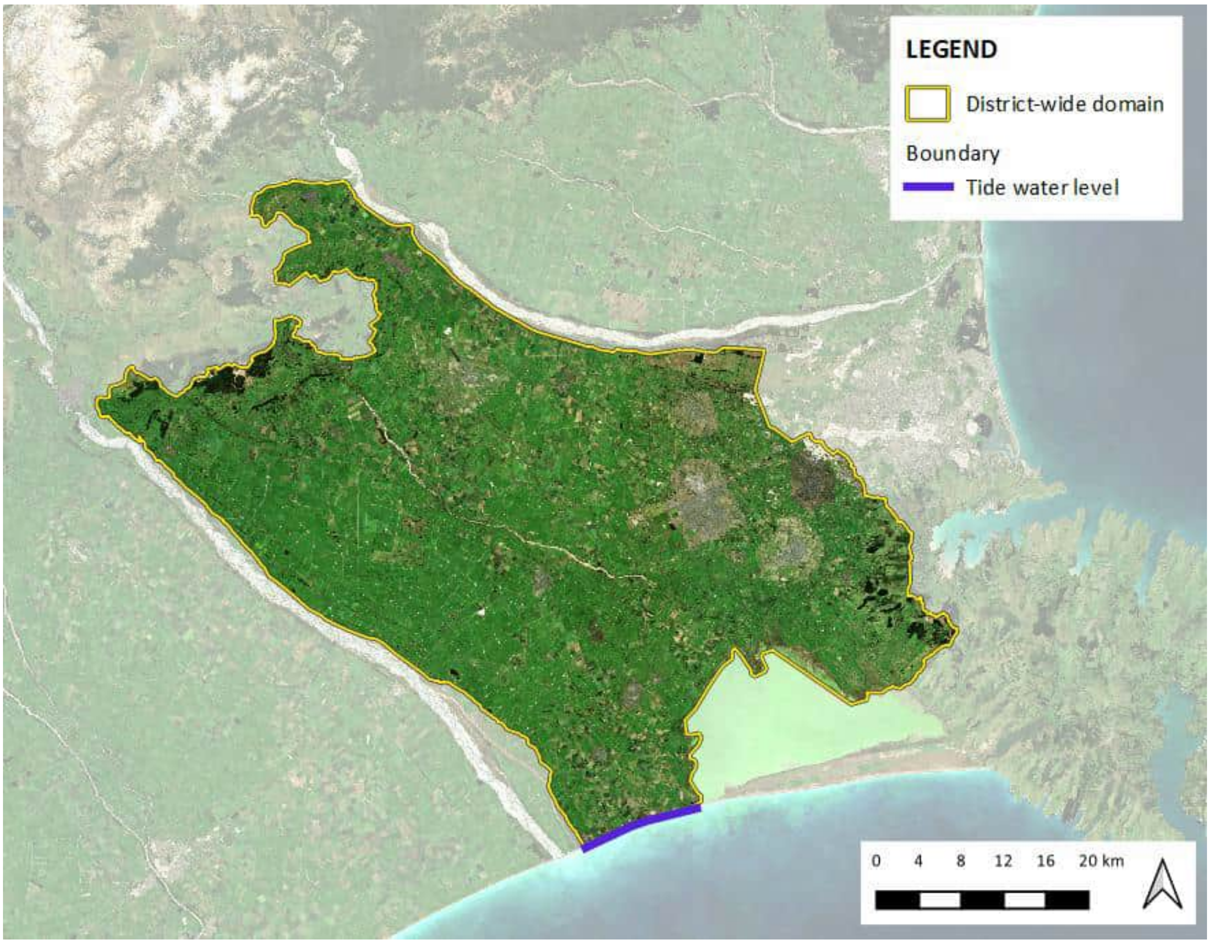


Figure 4-15: Coast water level boundary.

Return period water levels were based on the joint-probability storm tide and wave setup values provided within the Coastal Calculator for Taumutu, (NIWA, 2015). Water levels include the combination of storm tide, wave setup and for future climate condition events, sea level rise. Sea level rise was based on values provided by (MfE, 2017) for the future climate conditions (RCP8.5 2081 - 2100) scenario. Sea level rise (SLR) to the year 2100 was adopted to align with the upper end of the HIRDS rainfall inputs into the model.

The 0.2% AEP water level was extrapolated from the calculators joint-probability curve (which only extends to 0.5% AEP) using a logarithmic trend, and therefore, is approximate.

Conversion from Lyttelton 1937 to NZVD2016 vertical datum was calculated by subtracting 0.34[10] from the Lyttelton 1937 levels.

Table 4-6 provides the applied peak water levels in NZVD2016 vertical datum.

Table 4-6: Peak coast water levels

Climate scenario	AEP			
	10%	1%	0.5%	0.2%
Historical	2.04	2.31	2.41	2.56
Future (RCP8.5[1])	2.83	3.10	3.20	3.35

Notes:

3. RCP8.5 SLR to the year 2100: 0.79 m

The water levels in Table 4-6 were applied to the model using TUFLOW's '2d_bc' HT boundary. A time-varying water level was used with the highest tide (with storm surge + wave setup) level coinciding with the approximate time that the peak overland flow from the Plains reaches the coast.

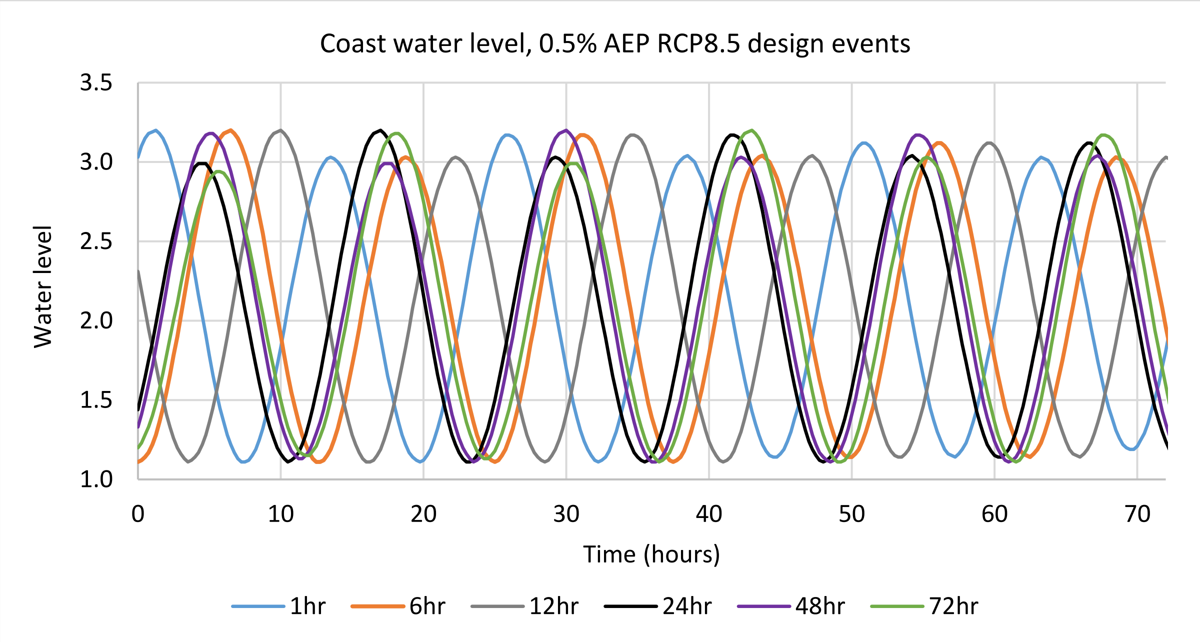


Figure 4-16: Coast water level boundary – 1% AEP 'historical' climate 24-hour event.

Approximate water levels for the calibration events were sourced from the Sumner Head sea level recorder, noting tide conditions at the coast may have differed from that at Sumner. The modelling shows that water levels at the coast likely had minimal effect on flooding.

[10] https://data.linz.govt.nz/layer/53432-lyttelton-1937-to-nzvd2016-conversion/, downloaded October 2024.

4.6.9 Te Waihora/Lake Ellesmere water level

A water level boundary for Te Waihora/Lake Ellesmere was applied to the model at the location shown in Figure 4-17.

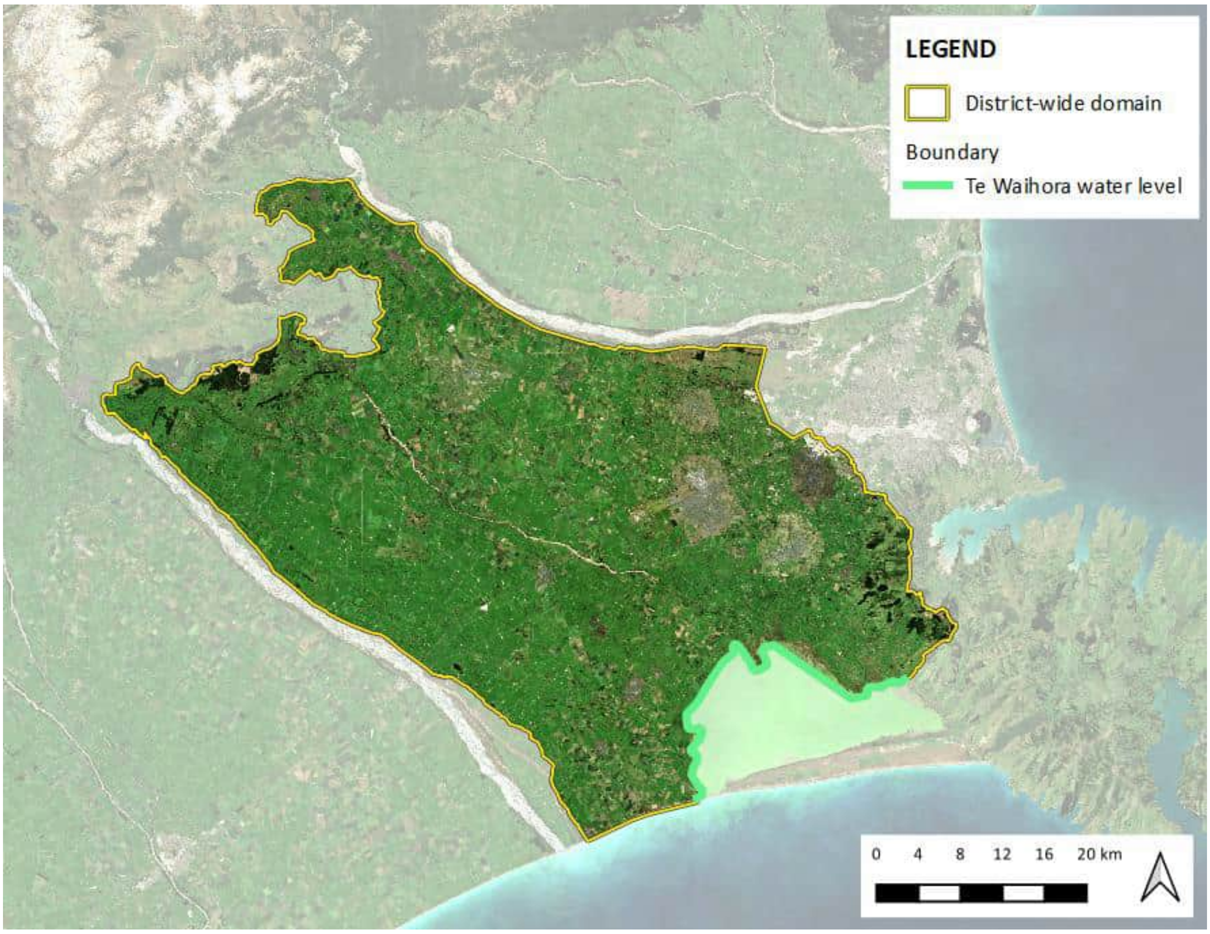


Figure 4-17: Te Waihora water level boundary.

Water levels were provided by ECan in Lyttelton 1937 vertical datum starting at 1.1 m rising to 1.8 m over a 36-hour period. Conversion from Lyttelton 1937 to NZVD2016 vertical datum was calculated by subtracting 0.32 from the Lyttelton 1937 levels giving 0.78 m rising to 1.48 m. The levels provided by ECan were used in previous modelling which considered a single 72-hour nested storm rather than the temporal storms used for this model. The model adopts a constant water level of 1.48 m for the 1-hour storm. For longer duration storms, the water level rises linearly from 0.78 m to 1.48 m at the midpoint of the storm to approximate the rise in water level as the lake fills. These levels were applied to all return period events as instructed by ECan.

The lake levels were applied to the model using TUFLOW's '2d_bc' HT boundary.

Lake levels for the calibration and validation events were sourced from ECan's water level recorder sites at Kaituna (site 68304) for June 2013 and Seabridge (site 68307) for July 2017 and May 2021 as shown in Figure 4-18. These levels were applied to the model using TUFLOW's '2d_bc' HT boundary.

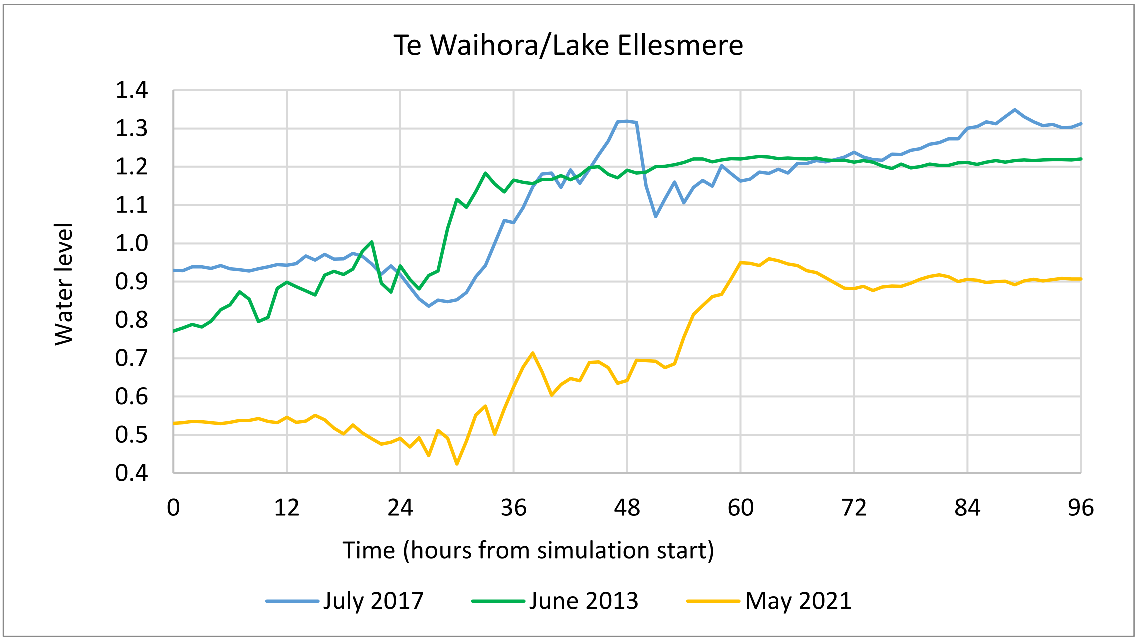


Figure 4-18: Te Waihora/Lake Ellesmere July 2017, June 2013 and May 2021 water levels

Water levels in Te Waihora/Lake Ellesmere are affected by several factors, primarily wind setup and the condition of the lake opening to the coast. Different conditions within the lake may result in different water levels within the area of influence around the lake margins. A future improvement opportunity regarding lake levels is provided in Section 9.

4.7 Elevation data

Ground elevation data for the model was primarily based on the Light Detection and Ranging (LiDAR) 1 m DEM for Canterbury - Selwyn captured between 24 March and 4 May 2023. The LiDAR covers approximately 93% of the model domain. The LiDAR has stated specification accuracies of Vertical +/- 0.2 m (95%) and Horizontal +/- 1.0m (95%). Density for the LiDAR capture is 4 pulses/square metre. The source link to the data is at: https://data.linz.govt.nz/layer/115805-canterbury-selwyn-lidar-1m-dem-2023/

The LiDAR is available from Land Information New Zealand (LINZ) as a Digital Elevation Model (DEM), which is used in the model as supplied. The DEM is a gridded bare earth dataset which is supposed to exclude trees, buildings and other above ground surface objects. Verification of the DEM accuracy was not part of this study.

The remaining 7% of the model domain was not covered by the 2023 Canterbury - Selwyn LiDAR DEM. Additional LiDAR DEMs were included in the model to cover this remaining area.

Table 4.7 provides a summary of all LiDAR DEM data included to cover the full model domain. Where LiDAR DEM overlap, the model uses the most recent as priority.

Table 4.7: Model LiDAR DEM

<table>
<tr><th>LiDAR DEM name</th><th>Capture date</th><th>Model domain coverage</th><th>Accuracy</th></tr>
<tr><td>Canterbury – Selwyn</td><td>24 Mar 2023 – 4 May 2023</td><td>93%</td><td rowspan="5">Vertical +/- 0.2 m (95%)
Horizontal +/- 1.0 m (95%)</td></tr>
<tr><td>Canterbury – Banks Peninsula</td><td>18 Feb 2023 – 15 Aug 2023</td><td>1.3%</td></tr>
<tr><td>Canterbury</td><td>1 May 2020 – 28 Apr 2023</td><td>3.7%</td></tr>
<tr><td>Canterbury – Christchurch</td><td>18 Dec 2020 – 17 Feb 2021</td><td>1.6%</td></tr>
<tr><td>Canterbury – Christchurch – Ashley</td><td>20 Jul 2018 – 1 Mar 2019</td><td>0.4%</td></tr>
<tr><td>Canterbury</td><td>Mar 2018 – May 2019</td><td>0.02%</td><td>Unknown</td></tr>
</table>

Note:
LiDAR DEM data source:
https://data.linz.govt.nz/layer/115805-canterbury-selwyn-lidar-1m-dem-2023/
https://data.linz.govt.nz/layer/115802-canterbury-banks-peninsula-lidar-1m-dem-2023/
https://data.linz.govt.nz/layer/111133-canterbury-lidar-1m-dem-2020-2023/
https://data.linz.govt.nz/layer/109641-canterbury-christchurch-1m-dem-2020-2021/
https://data.linz.govt.nz/layer/104497-canterbury-christchurch-and-ashley-river-lidar-1m-dem-2018-2019/
https://data.linz.govt.nz/layer/104931-canterbury-lidar-1m-dem-2018-2019/

The model DEM was updated where SDC provided DEM's for developments, including:

- TIN DESIGN ARBOR STG 20 DEM 0.1m
- TIN DESIGN BROADFIELD 1-3 DEM 0.1m
- TIN DESIGN KARUMATA STGS 1 2 AND 4 DEM 0.1m
- TIN DESIGN MADDISONS QUARTER DEM 0.1m
- TIN DESIGN ROSEMERRYN STGS 17 AND 21 DEM 0.1m

The coverage of the DEM's is shown in Figure 4-19.

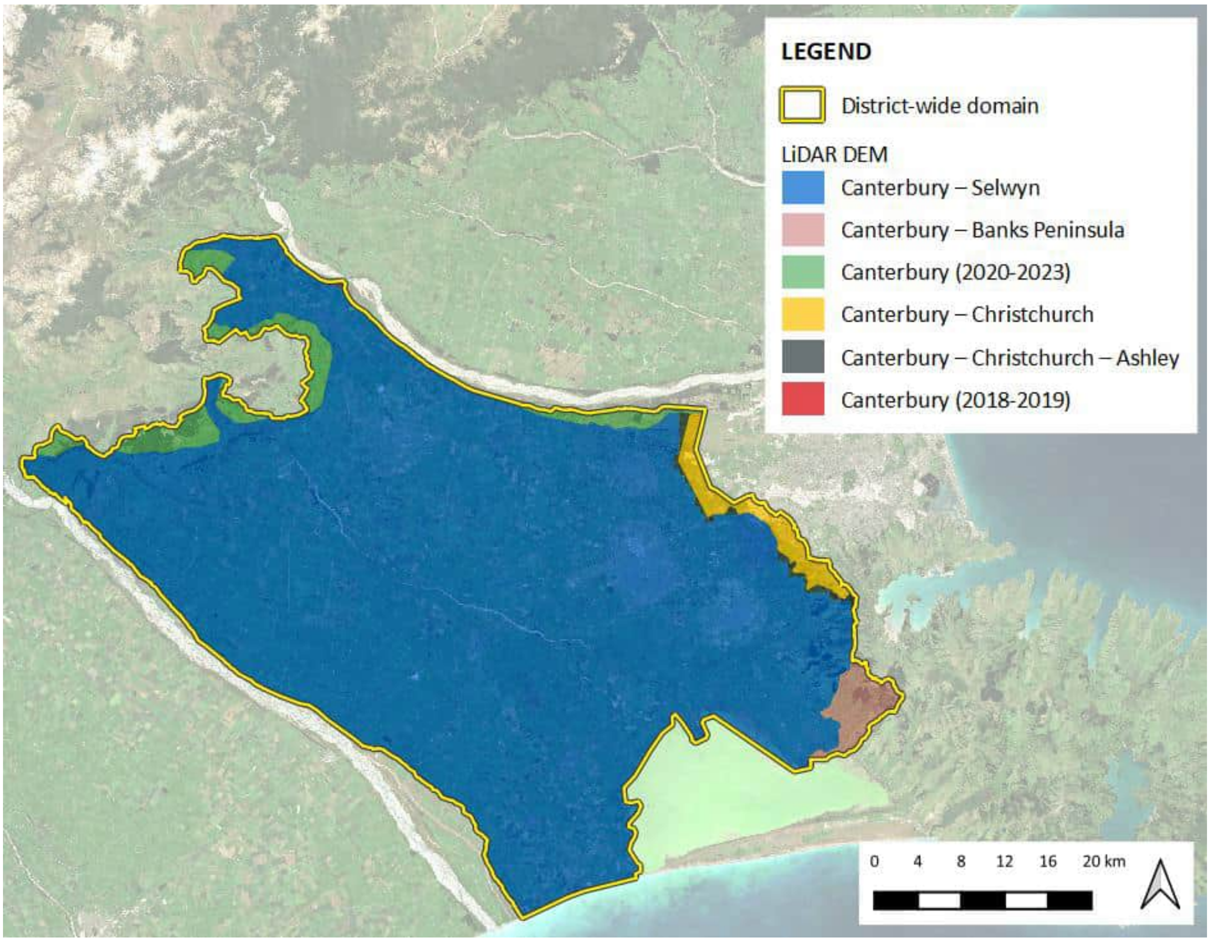


Figure 4-19: LiDAR DEM coverage.

4.8 Geometry modifications

4.8.1 Feature crest alignments

District model:

The crest elevations of several features including stopbanks, roads, rail and the coastal dune were represented in the model using TUFLOW's '2d_zsh' feature which enforces the estimated crest elevation along the feature centreline into the model using the following approach:

1. Feature alignment lines were supplied as follows:
   a. Stopbanks – ECan (sourced from the ECan GIS web viewer[11])
   b. Railway – KiwiRail (sourced from the LINZ Data Service[12])
   c. Roads – LINZ (sourced from the LINZ Data Service[13])
   d. Coastal dune – ECan (digitised from Canterbury – Selwyn LiDAR DEM)
   e. Central Plains Water bund.
2. Intermediate points created at 10 m intervals along the alignment lines.

[11] *Stopbanks_(Flood_Protection_and_Drainage_Bylaw_2013_-_amended_2019).shp,* downloaded October 2024
[12] *https://data.linz.govt.nz/layer/50319-nz-railway-centrelines-topo-150k/*, downloaded October 2024,
[13] *https://data.linz.govt.nz/layer/50329-nz-road-centrelines-topo-150k/,* downloaded October 2024,

3 5 to 10 m long transect lines created at intermediate points perpendicular to the alignment lines.

4 Maximum elevation of the DEM sampled along each transect (at 0.2 m spacing) and joined to the intermediate points along the alignment lines to create the 2d_zsh Point feature. This step is required because the sourced alignment lines do not always follow the exact crest alignment of the feature.

Figure 4-21 shows a visual example of how the approach detailed above is applied.

Because the maximum crest elevation along the transect line is joined to the intermediate point on the alignment line, the 2d_zsh Point feature may not always follow the exact alignment of the features crest. Manual adjustment to the feature alignments were made where the source data alignment was a significant distance from the true crest as indicated by the DEM.

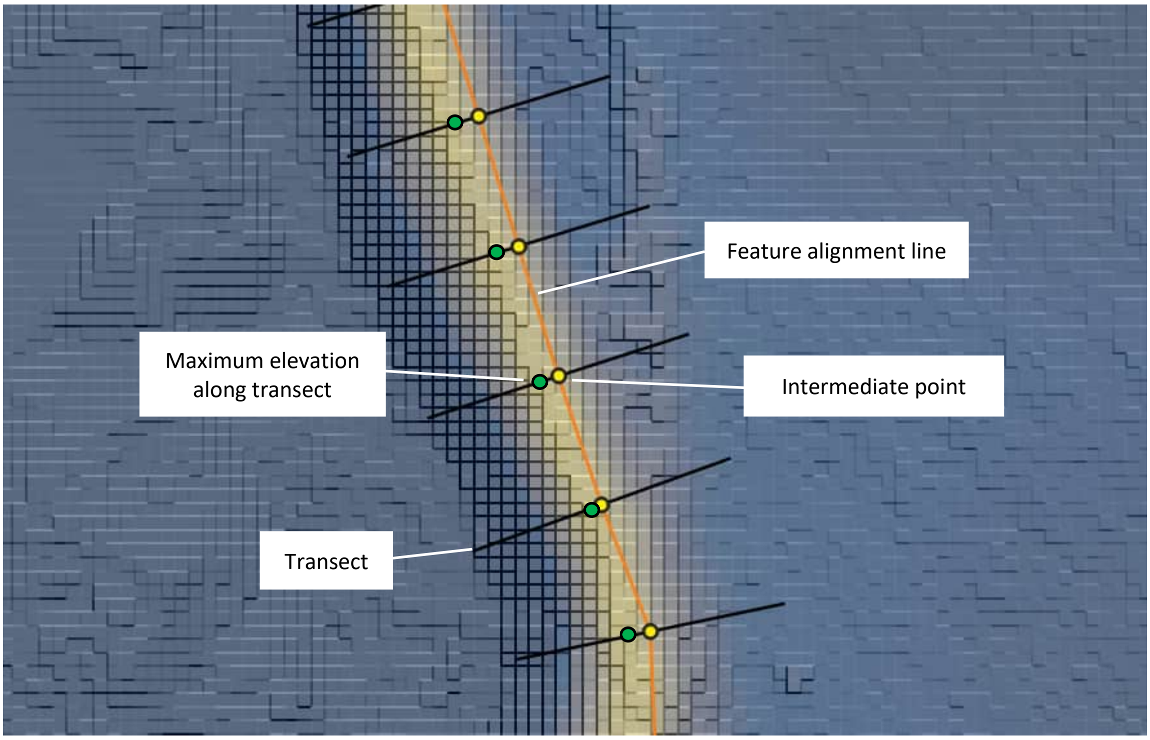


Figure 4-20: Feature alignment crest elevation approach.

Roads within the Port Hills and Southern Alps foothills were not included as they have minimal hydraulic effect and the LINZ alignment lines were found to deviate a significant distance from the true road alignment.

The CPW bund on the upstream side of the canal has been modelled using the '2d_zsh' feature. Inflows into the canal from the Rakaia River are not included in the model.

Where a road alignment crossed a river centreline[14] and a '1d_nwk' feature was not available, the road '2d_zsh' feature was either removed (to retain the DEM's definition if already hydrologically corrected), or a new '2d_zsh' feature was added to "burn" a channel into the DEM through the road embankment. This encourages the transfer of water through the embankment where it is likely that a culvert or bridge exists which minimises the area of false ponding upstream of the embankment.

[14] *https://data.linz.govt.nz/layer/50327-nz-river-centrelines-topo-150k/,* sourced November 2024

Where road alignments were near and parallel to significant channels, the road 2d_zsh feature was not implemented so that it did not block the channel geometry. This occurred mostly along the L2 and Halswell channels.

The feature alignments applied to the model are shown on Figure 4-20.

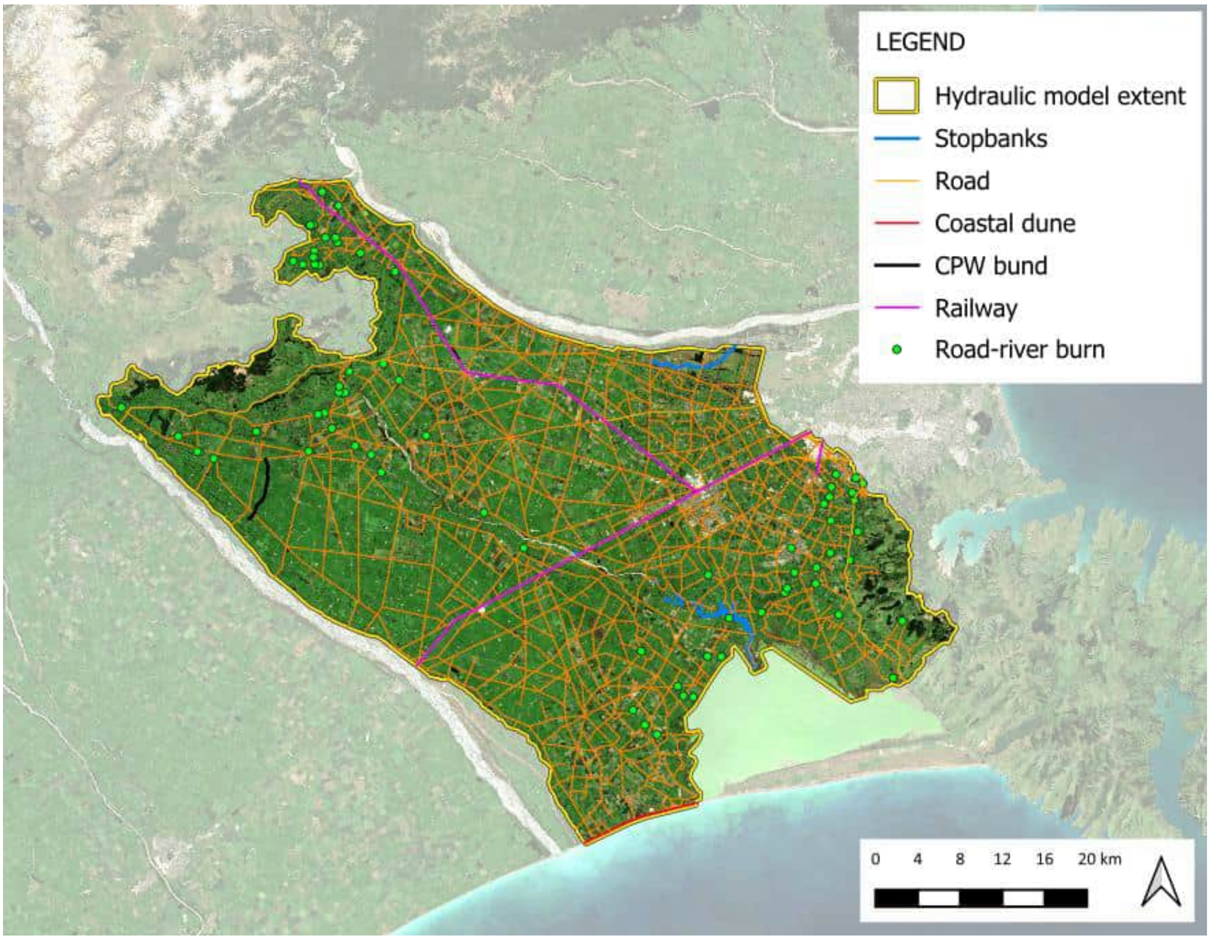


Figure 4-21: Feature alignments.

The DEM along the coast was lowered to an elevation of -2 m (NZVD) using the '2d_zsh' feature to accommodate coastal boundary water levels which fall below the supplied DEM elevation.

Township model:

Due to the smaller computational cell resolution of the township models, the above crest alignments were not required to be represented in the model using the '2d_zsh' feature.

The DEM, along several small drains, was modified to remove blockages caused by drain crossings (where no culvert data was available) or where vegetation had resulted in inconsistent DEM levels. The DEM was modified using TUFLOW's '2d_zsh' feature which enforces the drain invert elevation (sampled upstream and downstream of the blockage) along the drain into the model.

4.8.2 Buildings

District model:

Building outlines as delineated by LINZ[15] were represented as high Mannings 'n' roughness (Section 4.13). A "block out" approach (as described below) was not considered appropriate because the computational grid cell size of the district model of the model is too large to suitably represent the building outlines.

Township model:

Building outlines as delineated by LINZ[15] were raised within the model DEM, as shown in Figure 4-22. This "blocks out" the building and prevents any water from entering or flowing through the building. "*Blocking out buildings may provide a more visually "correct" impression of the water flowing around the building, but does not simulate the effects of storage and produces no flood level within the building"* (Syme, 2008). At water depths of less than 150 to 200 mm, the implications on storage are minimal as most buildings would be expected to be constructed on a concrete slab of this height which removes storage in any case.

The building outlines were raised using TUFLOW's '2d_zsh' feature. The outside boundary of the building outlines was raised by 2 m. An additional '2d_zsh' point was added to the building centroid at an additional 1 m to approximate a sloped roof. This facilitates rainfall to run off the building onto the ground, rather than ponding.

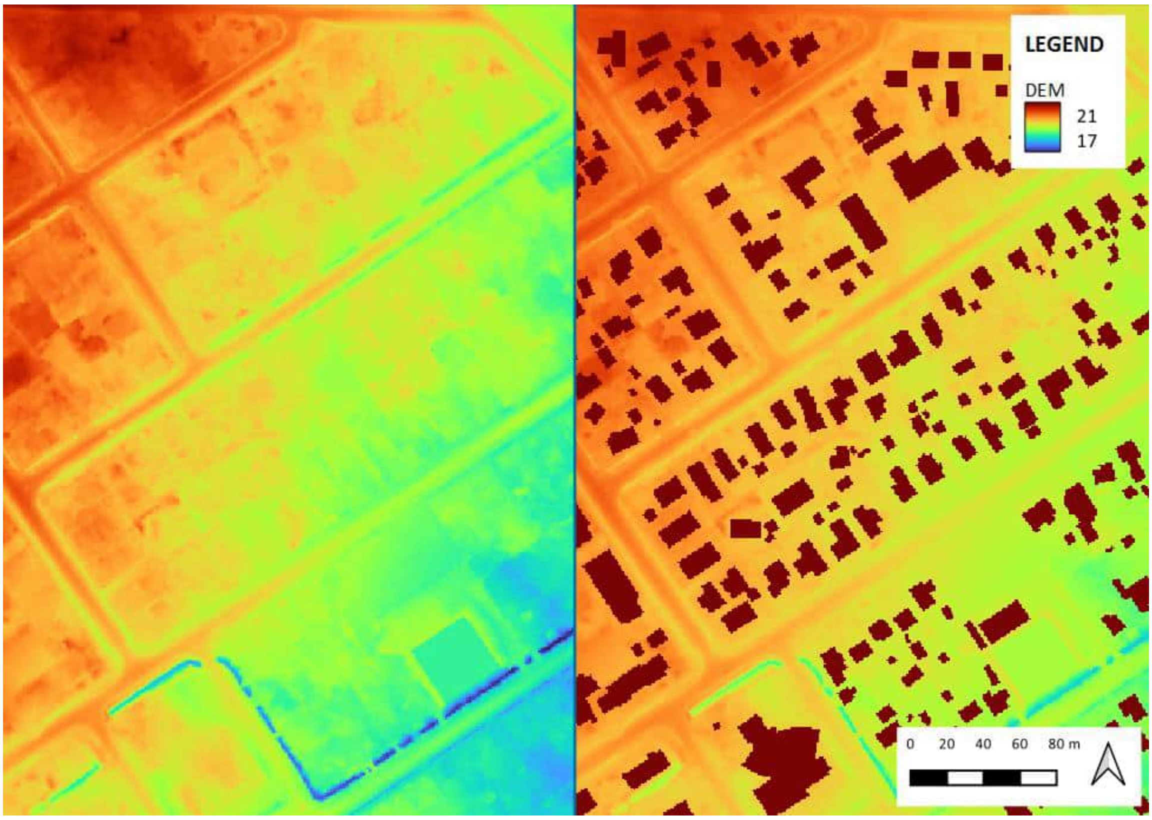


Figure 4-22: Building "block out" example (left: DEM, right: DEM with "block out")

[15] *https://data.linz.govt.nz/layer/101290-nz-building-outlines/*, downloaded October 2024.

4.9 Culverts and bridges

District model

The district model of the model includes bridge and culvert structures using TUFLOW's '1d_nwk' feature. Structures were included where sufficient data was provided and where those structures were expected to affect hydraulic conveyance. The structures included in the model are shown in Figure 4-23.

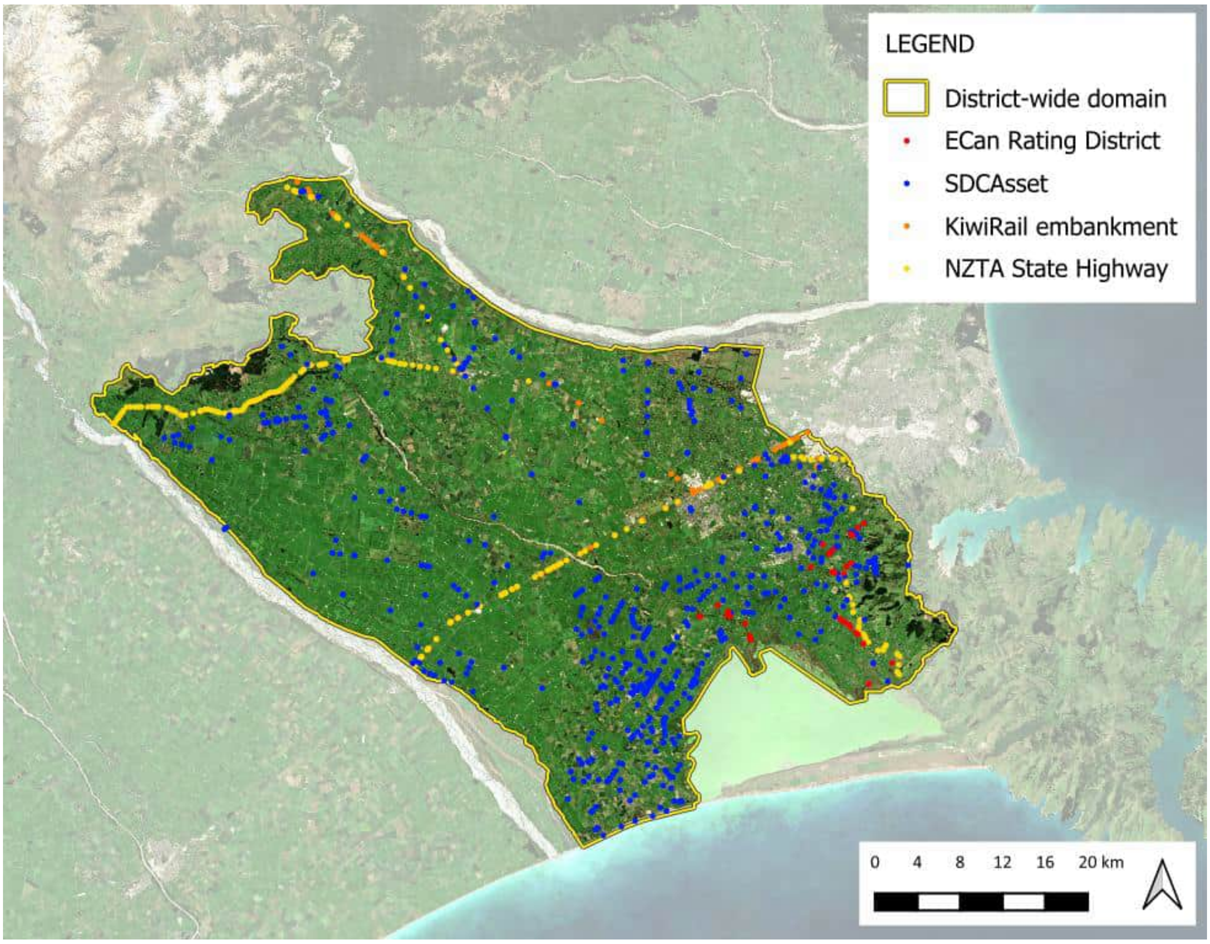


Figure 4-23: District culverts.

Structure data was supplied by SDC, KiwiRail, NZTA and ECan and is summarised in Table 4-8. The model relies on the information supplied and these data have not been checked. In some instances, assumptions were required to address data gaps as outlined below.

Table 4-8: Supplied structure data

Type	Source data and reference
SDC asset data	SDC asset data: • WaterAssetExport_04_09_2024.gdb, supplied September 2024. • Drainage_Point.shp, supplied April 2025.
KiwiRail	KiwiRail Open Data: • Culverts_KiwiRail_3605529429111973827.shp, supplied Oct 2024. • KiwiRailBridges_5671926860241123762.shp, supplied Oct 2024.
NZTA State Highway	HSIMS Structures: • 20241022_HSIMS Extract_Selwyn Project.xlsx, supplied Oct 2024
	• Road assessment and maintenance management (RAMM_GridExport_Pipe (AMDS) (1).xlsx, supplied Oct 2024
ECan Rating District (Selwyn and Halswell)	Rating District structures: • Culverts and Floodgate Points.shp, supplied Oct 2024
ECan - other	Dimensions for culverts along SH1 and the KiwiRail embankment, south of the Selwyn River: • Selwyn_structural inventory.doc, supplied Oct 2024.

Larger bridge structures, such as the Selwyn River SH1 road and rail bridges have not been included in the model. These structures may cause some localised effects on flooding but are not expected to significantly affect flooding outside of this. A future improvement opportunity regarding larger bridges is provided in Section 9.

Most of the SDC asset culvert alignments required manual readjustment so that the upstream and downstream culvert ends aligned with the drainage channel DEM. To limit the amount of manual adjustment required, only SDC culverts larger 0.5 m in diameter were included in the model as these culverts will have the most effect on flooding. A future improvement opportunity regarding culverts is provided in Section 9.

Applied structure parameters are provided in Table 4-9.

Table 4-9: Structure parameters

Parameter	Method
Type	Circular, unless provided data states otherwise
n_nF_Cd[1] (Manning's n value)	• Pipe material: As per provided data, where missing: Concrete >= 225mm diameter, PVC < 225 mm • Mannings 'n': Circular concrete: 0.015, rectangular concrete (natural bottom): 0.025, HDPE/uPVC = 0.011
US_Invert (Upstream invert)	0.1 m above lowest DEM ground level within a 2 m radius of the inlet/outlet
DS_Invert (Downstream invert)	
Form_Loss (additional dynamic head loss coefficient)	0
pBlockage (blockage)	0%
Width_or_Dia (diameter)	As per provided data
HConF_or_WC (height contraction coefficient)	Square edge: 0.6
WConF_or_Wex (width contraction coefficient)	Default: • Circular: 1.0 • Rectangular: 0.9
EntryC_or_WSa (entry loss coefficient)	0.5 as recommended by TUFLOW (TUFLOW, 2024)
ExitC_or_WSb (exit loss coefficient)	1 as recommended by TUFLOW (TUFLOW, 2024)

Note:

1. Manning's 'n' coefficients as per the New Zealand Building Code E1 Surface Water (NZBC, 2023).

Township model:

Structures applied to the township models are discussed in Section 4.10.

4.10 Stormwater network (townships only)

4.10.1 Data

SDC has provided spatial stormwater network asset data which includes line and point data for stormwater infrastructure. Table 4-10 provides a summary of the provided data. A list of specific data file references is provided in the Data Register, Appendix C.

Table 4-10: Provided stormwater network asset data

Type	Description	Provided by and date
SDC asset	Stormwater network and water race line and point spatial data. Includes pipes, sumps, manholes, inlets/outlets, soakholes etc.	SDC, September 2024
SDC sumps	Point spatial data of stormwater network sumps with sump type specified (single or double).	SDC, February 2025
Leeston bypass	As-built and design drawings for the Leeston Bypass.	SDC, January 2025
Southern Motorway Stage 2	Design drawings for the Southern Motorway Stage 2 drainage.	CCC, March 2025
Stormwater pond drawings	As-builts and design drawings for several stormwater ponds within townships.	SDC, May 2025

Table 4-11 and Table 4-12 provides the total number of each asset type provided within each township model domain. The percent indicates completeness of the data for key parameters including diameter and material for pipes, culverts and invert level for manhole, sumps.

Culvert and bridge data supplied by SDC, KiwiRail, NZTA and ECan as summarised in Table 4-8 was also included into the township models.

The accuracy of the stormwater network inputted into the model relies on the accuracy of the provided network data and these data have not been field verified. In some instances, assumptions were required to address data gaps as outlined below. Based on a review of the data, the following issues have been identified:

- Stormwater pipe invert levels are set by provided manhole invert levels because pipe invert levels are not currently available. Where manhole levels were missing, they were interpolated using an automated process based on upstream and downstream levels. This process may result in some inaccuracies in the levels.
- Provided stormwater “inlet/outlets” and “nodes” include both free outlet (i.e. pipe discharging to drain) or bubble up chambers. In some cases, bubble up chambers were misrepresented as free outlets which can result in a reverse grade on the connecting pipe.
- Where a pipe discharges to an open drain via a “inlet/outlets”, the pipe invert level was set based on the lowest nearby DEM level. In some cases, this causes the pipe to have a reverse grade because of limitations in the DEM.
- Culvert invert levels were set from DEM because culvert invert levels are not currently available.
- There is some spatial misalignment in the data (e.g. sumps located a short distance away from the actual location).

These issues may cause some inaccuracies in the model. Manual adjustment of the network was completed where practicable to resolve key issues identified, however some gaps remain. These gaps are unlikely to significantly affect the model accuracy at a catchment scale, however, may affect accuracy at a property scale. Future improvement opportunities regarding stormwater network are provided in Section 9.

When using the model to assess flooding at property scale, it is recommended that the modelled stormwater network is checked for inconsistencies or gaps. If the network has a significant effect on flooding, the model should be updated which could require additional network level survey to be captured.

Table 4-11: Stormwater infrastructure data summary - points

SDC asset type	Darfield	Doyleston	Leeston	Lincoln	Prebbleton	Rolleston	Southbridge	Springston	Tai Tapu	Kirwee	West Melton
CHAMBER	2	-	24	62	15	23	1	1	1	-	-
EQUIPMENT	1	1	2	10	-	2	-	-	1	-	-
FACILITY	-	-	1	-	-	-	-	-	-	-	-
GATE	15	-	1	3	1	16	-	-	-	3	8
GRILL	18	-	-	-	-	3	1	-	-	2	2
HEADWALL	48	-	-	6	48	129	2	-	-	17	22
INLET/OUTLET	119	30	113	134	54	18	12	3	18	-	25
MANAGEMENT	3	-	10	52	23	135	3	1	6	2	10
MANHOLE	25 (0%)	20 (5%)	149 (75%)	1057 (84%)	287 (88%)	417 (46%)	36 (53%)	11 (82%)	50 (54%)	-	96 (70%)
NODE	167	47	52	141	90	262	60	63	50	30	63
POND	7	-	-	-	1	6	-	-	-	-	13
SOAKHOLE	251	-	-	67	133	1481	1	-	3	111	72
SUMP	329 (44%)	29 (7%)	390 (29%)	1809 (54%)	689 (48%)	4055 (60%)	119 (21%)	48 (4.2%)	138 (21%)	87 (72%)	437 (58%)
VALVE	-	-	5	14	2	2	-	-	5	-	-
WEIR	1	-	-	-	-	1	-	-	-	-	-

Table 4-12: Stormwater infrastructure data summary - lines

SDC asset type	Darfield	Doyleston	Leeston	Lincoln	Prebbleton	Rolleston	Southbridge	Springston	Tai Tapu	Kirwee	West Melton
AQUEDUCT	1	-	-	-	-	-	-	-	-	-	-
CHANNEL	174	21	69	216	100	260	45	30	83	33	138
CULVERT	107 (dia.29%) (mat.31%)	-	-	19 (dia.68%) (mat.68%)	44 (dia.52%) (mat.52%)	311 (dia.79%) (mat.77%)	6 (dia.0%) (mat.0%)	1 (dia.100%) (mat.100%)	-	21 (dia.29%) (mat.0%)	61 (dia.54%) (mat.0%)
DRAIN	-	22	48	17	-	-	-	2	-	-	-
LATERAL	14	-	-	5	5	36	6	-	-	-	15
LOCAL	80	-	-	7	28	103	-	-	-	17	40
MAIN	62	-	-	8	16	43	-	-	-	24	40
PIPE	332 (dia.100%) (mat.100%)	118 (dia.99.2%) (mat.99.2%)	1286 (dia.99.5%) (mat.99.7%)	6210 (dia.99.5%) (mat.99.3%)	1363 (dia.99.8%) (mat.99.7%)	4183 (dia.98.4%) (mat.98.1%)	180 (dia.98.9%) (mat.99.4%)	162 (dia.98.8%) (mat.100%)	332 (dia.99.4%) (mat.99.1%)	101 (dia.100%) (mat.100%)	475 (dia.99.2%) (mat.99.2%)
SIPHON	-	-	-	-	-	1	-	-	-	-	-
Soakhole w/Hoz Soakage	48	-	-	-	10	587	-	-	-	TBC	5

4.10.2 Pipes

Pipes (including culverts) were included in the model using TUFLOW's '1d_nwk' feature. All culverts and pipes were included in the model where sufficient data was available. Applied pipe parameters are provided in Table 4-13.

Table 4-13: Pipe parameters

Parameter	Method
Type	Circular, unless provided data states otherwise
n_nF_Cd[1] (Manning's n value)	• Pipe material: As per provided data, where missing: Concrete >= 225mm diameter, PVC < 225 mm • Culvert Mannings 'n': Circular concrete: 0.015, rectangular concrete (natural bottom): 0.025 • Pipe Mannings 'n': PVC, PE: 0.011, concrete: 0.013
US_Invert (Upstream invert)	Culverts or pipe outlets: 0.1 m above lowest DEM ground level within a 2 m radius of the inlet/outlet Pipes: Set from manhole invert
DS_Invert (Downstream invert)	
Form_Loss (dynamic head loss coefficient)	0
pBlockage (blockage)	0%
Width_or_Dia (diameter)	From provided data, where missing: Interpolated from nearest upstream and downstream pipe where available, otherwise: 0.3 m
HConF_or_WC (height contraction coefficient)	Sharp edge: 0.6
WConF_or_Wex (width contraction coefficient)	Default: • Circular: 1.0 • Rectangular: 0.9
EntryC_or_WSa (entry loss coefficient)	0.5 as recommended by TUFLOW (TUFLOW, 2024)
ExitC_or_WSb (exit loss coefficient)	1 as recommended by TUFLOW (TUFLOW, 2024)

Note:

1. Manning's 'n' coefficients as per the New Zealand Building Code E1 Surface Water (NZBC, 2023).

Pipe connection to the 2D domain was applied using TUFLOW's '2d_bc' feature. 'SX lines' were used for rectangular culverts and for pipe diameters >1m which connects multiple 2D cells to the inlet/outlet to allow better transfer of water in and out of the pipe. 'SX points' were used for culvert/pipe diameters <1m. The DEM level at the pipe inlet/outlet was set at the lowest DEM level within a 2 m radius to facilitate better transfer of water into the pipe.

In some areas, roof downpipes may be directly connected to the stormwater network via a lateral pipe without a manhole or chamber at the connection. Roof catchment areas are not separately defined in the model, so they cannot be isolated from other areas and discharged into the network. However, ignoring the lateral connections could result in less runoff entering the stormwater network. To encourage some roof runoff to enter the stormwater network, a virtual sump was applied at each lateral connection point. This approach relies on the model DEM directing runoff onto the road, which may not be the case in all areas.

4.10.3 Manholes

Manholes were included in the model using TUFLOW's '1d_mh' feature. Applied manhole parameters are provided in Table 4-14.

Table 4-14: Manhole parameters

Parameter	Method
Type	Circular, unless provided data indicates other
Loss Method (Manhole loss method)	Engelund
Invert level (bed elevation of manhole)	From provided data, where missing: Interpolated from DEM and connected network.
Flow_Width (flow width of manhole)	• Circular: 1.05 m • Rectangular: 0.9 m • Inspection chamber: 0.6 m
Flow_Length (flow length of manhole)	• Circular: n/a, • Rectangular: 0.9 m
Km (Manhole exit coefficient)	Default: • Circular: 0.25 • Rectangular: 0.5
K_Bend_Max (upper limit of KΘ and Kdrop)	Default: maximum K energy loss coefficient of 4.0

4.10.4 Sumps

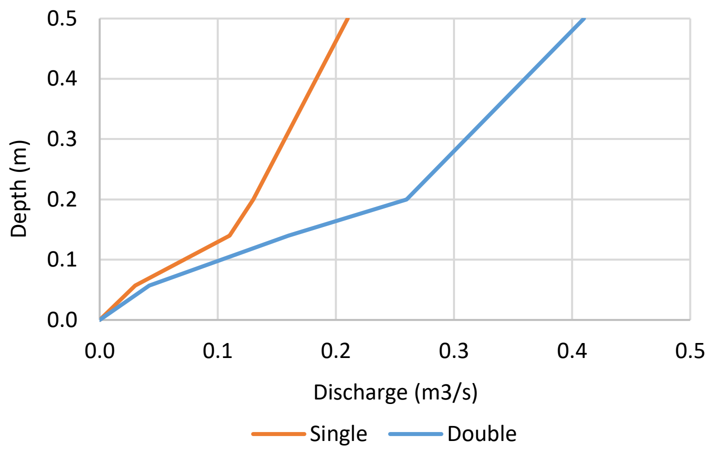
Sumps were included in the model using TUFLOW's '1d_pit' feature. Applied sump parameters are provided in Table 4-15.

Table 4-15: Sump parameters

Parameter	Method
Type	Q - pit flow defined by a depth-discharge curve
US_Invert (ground elevation of the pit)	0.1 m below DEM ground level using SXL connection
DS_Invert (Downstream invert)	From provided data, where missing: 0.6 m below DEM ground level
Form_Loss (energy loss to all outgoing culverts)	0
pBlockage (blockage)	0%
Inlet_Type (pit inlet type)	From provided data, where missing: • SumpS – single sump • SumpD – double sump
Conn_1D_2D (1D to 2D connection type)	SXL

Table 4-16 provides depth vs. discharge curves for sump types as per SDC's Engineering Code of Practice Chapter 8.5.13 (SDC, July 2022). The curves were developed from Chart 9A of HEC-22 (U.S. Department of Transportation, 2009) based on the clear opening area, length and width of the sump.

Table 4-16: Sump depth vs. discharge

Sump type	Full flow area (m^2)	Flow width (m)	Depth vs. discharge
Single 	0.122	0.43	
Double 	0.243	0.43	

TUFLOW's 'SXL' connection was applied to the sumps 1D-2D connection. This lowers the sumps connected 2D cell by 100 mm to encourage water to enter the sump inlet.

4.10.5 Outlets

Inlet/outlet structures such as "scruffy domes" were included in the model using TUFLOW's '1d_nwk' feature. Depth vs. discharge curves for different outlet geometry were applied as per drop inlet hydraulic equations (Auckland Council, 2013).

4.10.6 Soakholes

Soakholes were included in the model using TUFLOW's '1d_bc' feature. A QH discharge was applied to the '1d_bc' feature at each soakhole to represent the soakage of stormwater into the ground.

The discharge rate for each soakhole was estimated from the 2% AEP critical duration storm intensity multiplied by the impervious area of the road. 100 mm/hr has been used for the soakhole sizing which is approximately the 2% AEP 10-minute rainfall event intensity from HIRDS with future climate conditions.

The contributing impervious area of the road was estimated using an automated analysis of the DEM as shown on Figure 4-24.

Due to inaccuracies in the automated process used to estimate road catchment area, a minimum soakhole area of 100 m^2 was applied where the catchment area was estimated to be less. This accounted for approximately 80 soakholes (less than 5% of the total number).

Figure 4-24: Soakhole catchment area

Given the large number of soakholes (thousands) in the district, each soakhole was assigned to one of 15 “bins” based on road catchment area, e.g. a soakhole with a road catchment area of 160 m^2 was assigned to the 100-200m^2 soakhole bin. A single discharge rate was assigned to each bin which ranged from 4 L/s for the smallest bin (100-200m^2) to 240 L/s for the largest bin (>10,000 m^2)

The adopted approach assumes all existing soakholes are designed to the 2% AEP design rainfall event. Noting that after the release of SDC’s new Engineering Code of Practice in July 2022, new development is to be sized to a 1% AEP.

The model assumes no blockage of the soakholes.

For soakholes where the provided network asset data had no connecting pipe, a dummy sump was created and a pipe was connected from the sump to the soakhole. This approach allows overland flow to be captured and discharged into the soakhole.

4.11 Computational cell size

The model incorporates computational cell size adjustment through TUFLOW’s quadtree nesting. Quadtree nesting enables smaller cell sizes to be used in areas requiring detailed resolution, and larger cell sizes in areas where coarser resolution will not significantly affect conveyance. By varying the cell sizes, the model runtime can be optimized whilst maintaining detailed resolution where required. Cell size is adjusted in the model by specifying quadtree nest levels.

District model:

The adopted quadtree nest level and corresponding computational cell size for the district model are provided in Table 4-17. Figure 4-25 shows an example of the quadtree nesting.

Table 4-17: District computational cell size

Quadtree nest	Computational cell size	Quadtree description
Level 3	5 m	Culvert inlets/outlets
Level 2	10 m	State Highway, Rail corridors
Level 1	20 m	All remaining areas

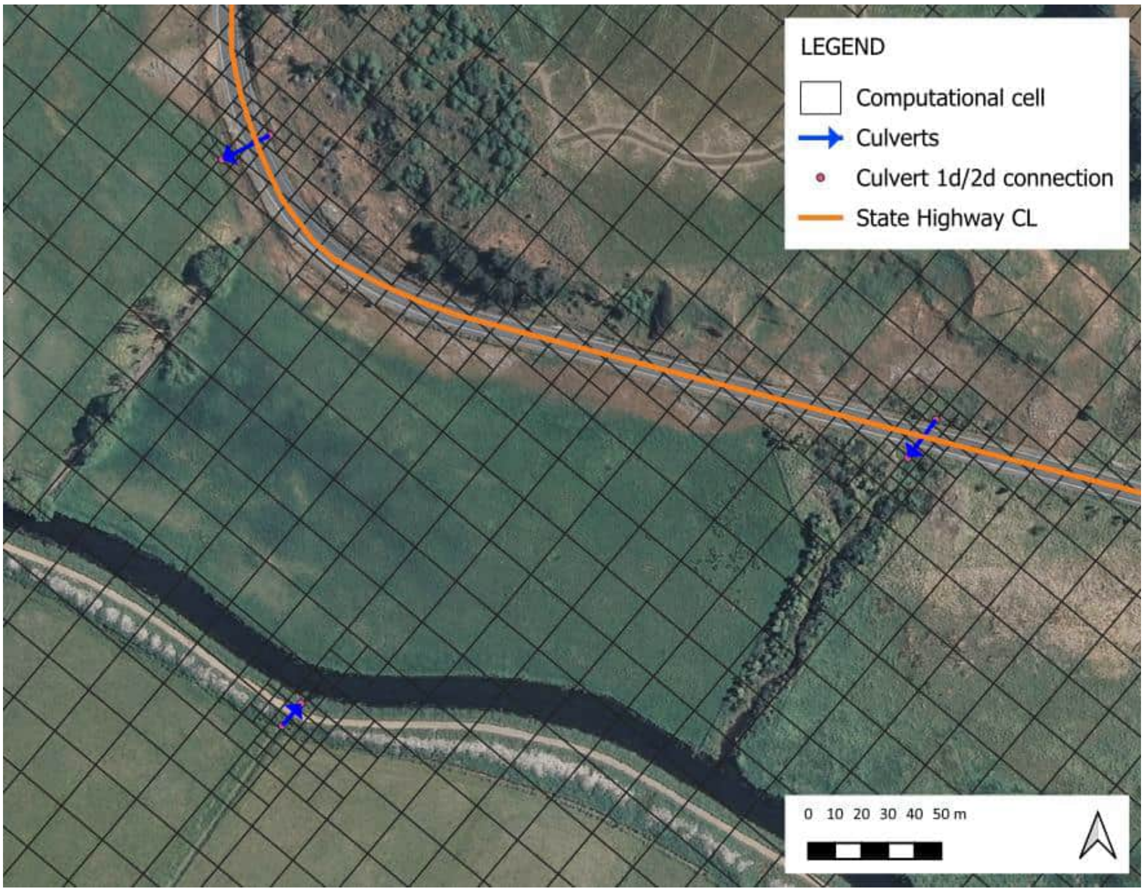


Figure 4-25: Quadtree nesting: District model example

The computational cell sizes and SGS parameters used for the township model are provided in Table 4-18.

Table 4-18: Township computational cell size

Quadtree nest	Computational cell size	Quadtree description
Level 3	1.25 m	Along drains/channels
Level 1	5 m	All remaining areas

Convergence testing was undertaken for the district model to assess the sensitivity of the model simulation time to the base computational cell size. The model was run with 7 different base cell sizes and the simulation time for each was recorded as shown in Table 4-19. The convergence test was undertaken for a 24-hour storm (30-hour simulation time), 1% AEP event and on a single GeForce RTX 3080Ti GPU.

Table 4-19: Convergence testing cell size

Base cell size (m)	Model simulation time (hours)
10	N/A – GPU memory exceeded
12	43
15	23
20	6
30	4
40	3
50	2

Figure 4-26 shows the cumulative maximum absolute water level difference for each simulation compared to the smallest modelled base cell size (12 m), e.g. for the 20 m base cell size model (blue line), the absolute water level difference compared to the 12 m model was less than 100 mm for 94% of the model wet cells.

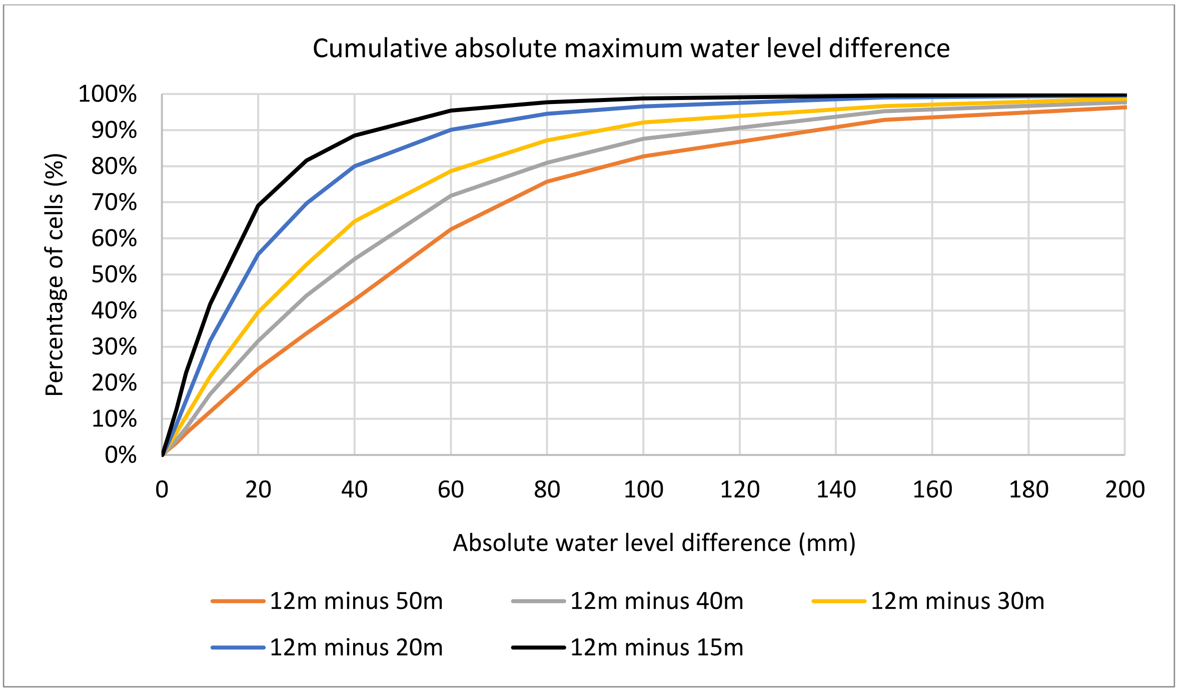


Figure 4-26: Convergence test results – Cumulative absolute maximum water level difference

Figure 4-27 shows the same data as Figure 4-26 but with signed values, i.e. with negative and positive water level differences. The figure indicates that the proportion of positive and negative differences are similar.

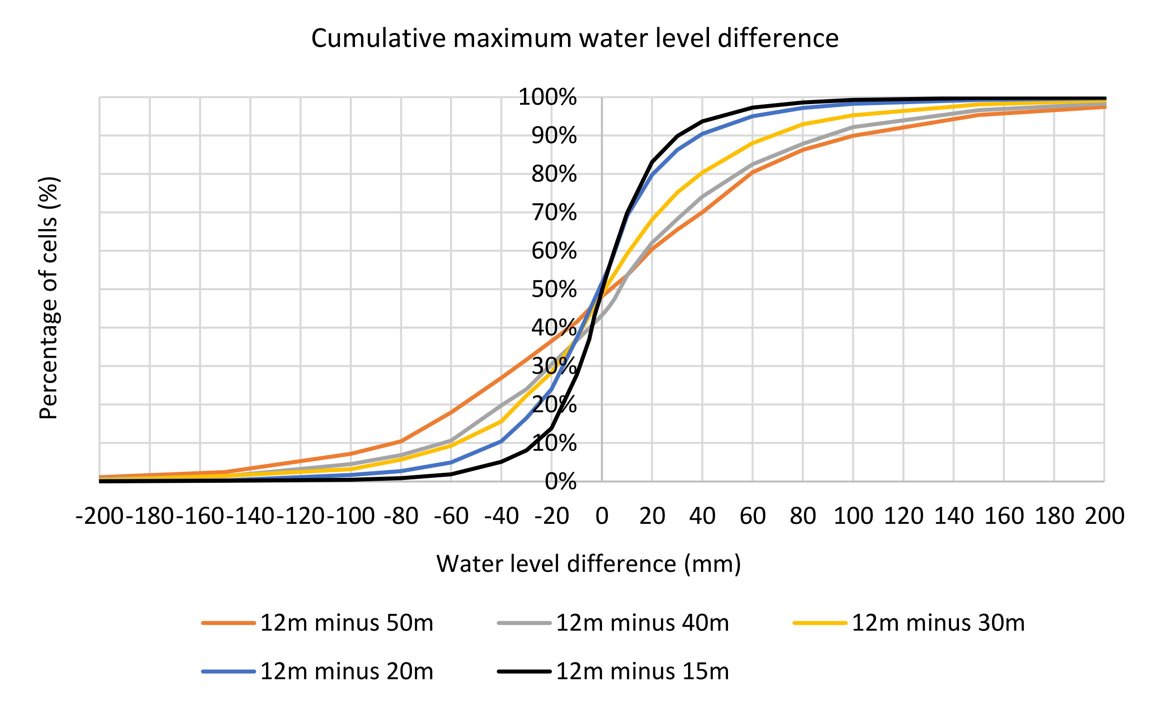


Figure 4-27: Convergence test results – Cumulative maximum water level difference

A 20 m base cell size simulation was adopted for the model as this provided a reasonable balance between simulation time (6-hours) and depth difference compared to the 12 m model. The simulation time may vary for different AEP and climate events. However, similar results are expected. This simulation time aligns with the model purpose statement. A future improvement opportunity regarding computational cell size is provided in Section 9.

Because the township models already use a relatively small cell sizes, convergence testing was not considered necessary.

4.12 Sub-grid sampling

The model incorporates sub-grid sampling (SGS). Rather than using a single elevation value for the grid cell elevation, SGS uses the underlying DEM cell elevations to calculate a water surface elevation vs volume relationship for each grid cell. Similar is performed along the cell faces, using the topography across the cell face to generate water surface elevation vs width relationships to represent fluxes between adjacent cells. The SGS parameters adopted for the model are shown in Table 4-20.

Table 4-20: SGS parameters

Quadtree nest	SGS parameters
SGS Approach	Method C
SGS Sample Target Distance	District = 2 m Township = 1 m
SGS Depth Output	Cell average

For the district model, a 2 m target distance was adopted due to limitations of the GPU memory. A future improvement opportunity regarding sub-grid sampling is provided in Section 9.

4.13 Roughness

Hydraulic roughness is used to describe the resistance to surface water flow across the ground, within a channel, or through a pipe. Hydraulic roughness is represented in the model using a Manning's 'n' coefficient.

The model base land use is from Landcare Research New Zealand Land Cover Database (LCDB)[16] version 5 which spatially defines different types of land cover as shown in Figure 4-28. The database, released in January 2020, considers land cover classification up until the end of 2018. The model applies a 'n' coefficient to each of the LCDB land cover types.

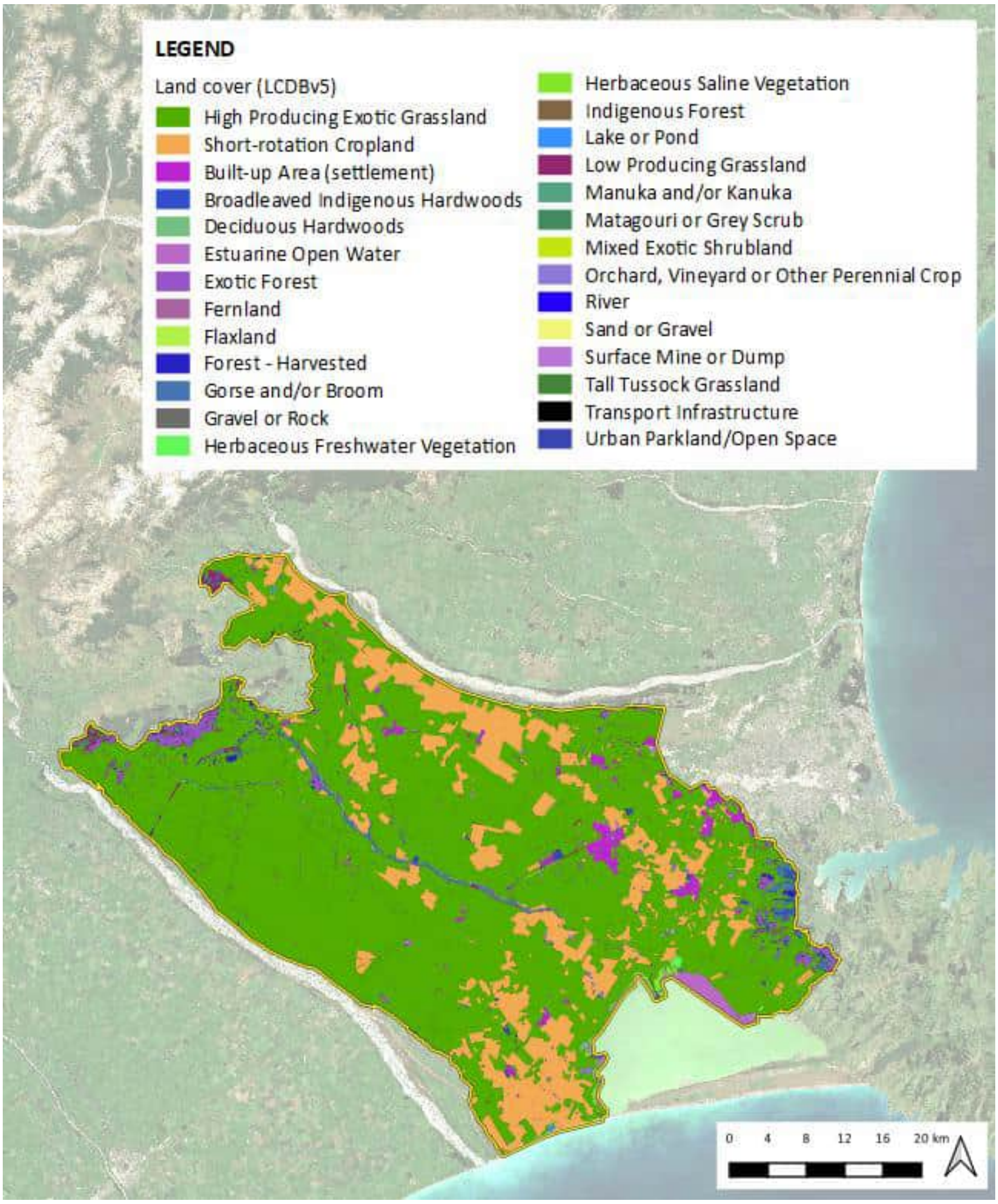


Figure 4-28: Land cover.

16 https://lris.scinfo.org.nz/layer/104400-lcdb-v50-land-cover-database-version-50-mainland-new-zealand/, downloaded October 2024.

Mannings 'n' coefficients for each land cover were based on several documents including '*Open-Channel Hydraulics*', (Chow, 1959), *Australian Rainfall & Runoff Book 6*, (Ball J, 2019) and the outcome model of calibration (Section 5).

At very shallow depths the Manning's 'n' coefficient and/or equation may not be a reliable estimate of bed resistance. The Log Law or "Law of the Wall" approach offers a theoretically based derivation of resistance based on a bed shear analysis. This relationship along with benchmarking against flume test results was used by (Boyte, 2014) to derive the following equation that varies 'n' coefficients with depth based on the roughness height of the surface.

$$n = \max\left[\frac{\kappa y^{\frac{1}{6}}}{\sqrt{g}\ln\left(\frac{y}{z_0 e}\right)}, n_{limit}\right]$$

$$z_0 = \frac{k_s}{30} + \frac{0.11\nu}{U_f}$$

k_s: roughness height in m
κ: 0.4
y: depth
v: kinematic viscosity (10^{-6} m^2/s)
U_f: friction velocity defined as √*Sgy,* y approximates *A/P* and *S* is water surface slope
N_{limit}: limiting 'n' coefficient, i.e. the 'n' applicable to greater depths

TUFLOW's 'Log Law' feature was used to apply depth varying 'n' coefficients as per the method described above based on a defined roughness height and limiting 'n' coefficient. An example for High Producing Exotic Grassland is provided in Figure 4-29.

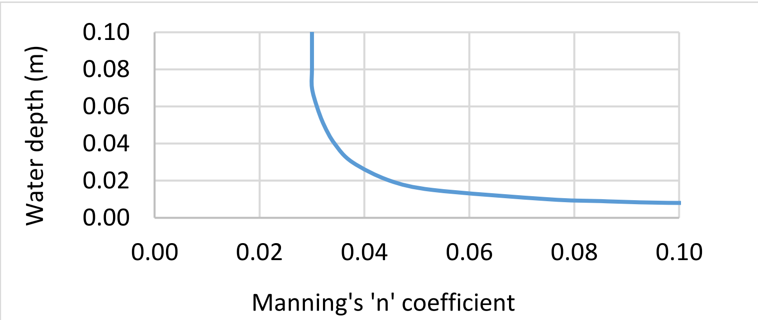


Figure 4-29: Depth varying 'n' coefficient example for high producing exotic grassland.

The model applies a separate 'n' coefficient for buildings[17] within the model domain. The model applies a depth varying roughness within the building outline (0.01 at depths < 50 mm and 0.3 at depths > 50 mm) to simulate rapid runoff from building roofs at shallow water depth and high roughness at deeper water depth where the building is intercepted by overland flow. The higher roughness at deeper depths is not applicable in the township models because buildings are "blocked out" of the DEM, as described in Section 4.8.2.

The model applies a separate 'n' coefficient for roads within the model domain based on applying a 5 m negative buffer to the LINZ Primary Road Parcels, as described in Section 4.6.6.

The model applies a separate 'n' coefficient for drainage channels within the township domain areas. Drainage channel extents were estimated based on applying a buffer to channel lines supplied by SDC[18]. Because significant manual adjustment of the supplied lines was required to align the channels to the DEM, only channels within townships were applied to the model. A future improvement opportunity regarding channel roughness definition is provided in Section 9.

The land cover types, and 'n' coefficients used in the model are provided in Table 4-21. Sensitivity testing of the 'n' coefficient was undertaken (Section 7).

[17] https://data.linz.govt.nz/layer/101290-nz-building-outlines/, downloaded October 2024.
[18] SDC supplied channel lines, supplied September 2024.

Table 4-21: Land cover and 'n' coefficients (after calibration)

Land cover type (Material ID)	Model domain coverage (km^2)	Model domain coverage %	Roughness height, Limiting 'n' coefficient
High Producing Exotic Grassland (40)	1595	71%	0.05, 0.028
Short-rotation Cropland (30)	387	17%	0.15, 0.04
Exotic Forest (71)	64	2.9%	0.05, 0.08
Residential (108)[1]	34	1.5%	0.05, 0.04
Road (101)	32	1.4%	0.001, 0.016
Gorse and/or Broom (51)	21	0.9%	0.1, 0.1
Estuarine Open Water (22)	21	0.9%	0.03
Selwyn River berm (105, 106, 107)	16	0.7%	0.055
Building (100)[2]	13	0.6%	0.01 to 0.3[2]
Low Producing Grassland (41)	10	0.4%	0.05, 0.035
Deciduous Hardwoods (68)	6.9	0.3%	0.05, 0.15
Orchard, Vineyard or Other Perennial Crop (33)	7.3	0.3%	0.05, 0.1
Forest – Harvested (64)	6.8	0.3%	0.05, 0.04
Herbaceous Saline Vegetation (46)	6.3	0.3%	0.1, 0.065
Business (109)[1]	6.0	0.3%	0.05, 0.04
Broadleaved Indigenous Hardwoods (54)	4.6	0.2%	0.05, 0.08
Urban Parkland/Open Space (2)	3.9	0.2%	0.05, 0.03
Selwyn River channel (102, 103, 104)	3.7	0.2%	0.03
Built-up Area (1)	3.2	0.1%	0.05, 0.040
Township drainage channels (110)	2.2	0.1%	0.05, 0.04
Indigenous Forest (69)	2.0	0.09%	0.05, 0.12
Lake or Pond (20)	1.9	0.08%	0.025
Herbaceous Freshwater Vegetation (45)	1.6	0.07%	0.1, 0.065
Manuka and/or Kanuka (52)	1.5	0.07%	0.05, 0.08
Surface Mine or Dump (6)	1.1	0.05%	0.02, 0.027
Matagouri or Grey Scrub (58)	1.0	0.04%	0.1, 0.1
Sand or Gravel (10)	1.0	0.04%	0.01, 0.025
Tall Tussock Grassland (43)	0.8	0.04%	0.2, 0.05
Mixed Exotic Shrubland (56)	0.5	0.02%	0.1, 0.1
Gravel or Rock (16)	0.4	0.02%	0.01, 0.04
River (21)	0.2	0.01%	0.03
Flaxland (47)	0.03	0.001%	0.1, 0.1
Transport Infrastructure (5)	0.03	0.001%	0.001, 0.02
Fernland (50)	0.01	0.0004%	0.1, 0.1

Notes:

1. Residential and Business areas based on SDC plan layers.
2. Assumes a depth varying 'n' coefficient of 0.01 at depth < 50 mm, 0.3 at depth > 50 mm.

The roughness applied to the model reflects the specific land cover conditions at a given time. Changes in land cover, such as vegetation clearance or growth, are anticipated to lead to varying roughness values. While the roughness of the active channel may remain relatively consistent, significant changes could occur in overbank and floodplain areas due to human activities or natural processes. A sensitivity analysis provided in Section 7 was completed to test the variability in the model results using a lower and higher range of potential ‘n’ coefficients.

5 Model calibration and validation

Notable flooding events within the district occurred in the years 1945, 1951, 2000, 2013, 2017, 2021 and 2022.

The approach taken to select the calibration and validation events is based on the following criteria:

- The event represents the different likely flooding dynamics within the district, i.e. fluvial flooding from the Selwyn River and pluvial flooding away from the Selwyn River.
- There is visual flood observation data available for the event, which could include aerial imagery, surveyed water/debris marks and ground observations.
- There is flow recorder observation data available for the event.
- The magnitude of the event is close to the magnitude of the design event.

Ideally, the selected events would meet all the above criteria, however in reality, there are several factors to be considered. Recorded flood event history is very short on a hydrological scale and therefore few flood events may have occurred for which observational data is available. The quality of the observational data including flow recorders, aerial imagery and survey will vary and will have their own inherent uncertainty. Uncertainty in flow recorder data for the district is documented in the ECan report '*Flood Frequency analysis updates – May 2021 flood event'* (ECan, 2023).

Based on a review of the available data, and in agreement with SDC and ECan, the following three events were selected:

- **Calibration event:** July 2017: A significant fluvial flood event in the Selwyn River.
- **Validation events:** May 2021 and June 2013: May 2021 significant fluvial and pluvial flood event, June 2013 significant pluvial flood event reported by SDC staff.

These three events were selected because on balance and relative to other events, they best meet the selection criteria set out above. Notwithstanding this, it is important to note key limitations of the data available for these two events:

- High resolution aerial imagery is spatially limited within the district and was taken after the peak of the flood.
- Flow recorders have uncertainty and limitations, in particular most of the recorders within the Plains have poor rating at higher discharge. Some of these recorders are also significantly influenced by other factors such as weed growth and groundwater. Some of these limitations are documented (ECan, 2023).

If a flood event occurs which better matches the selection criteria, it is recommended to undertake further calibration and/or validation of the model. A future improvement opportunity regarding modelling other historical flood events is provided in Section 9.

For the calibration event, input parameters were adjusted and the model was run iteratively to achieve the best agreement between model outputs and observed data. The primary parameters adjusted were the Manning's roughness 'n' coefficients and infiltration rates. Initial values for these parameters were based on typical "textbook" values, as outlined in the relevant parameter sections. The final calibrated values generally fell within the range between these initial values and the adopted values. Other parameters were also tested, including disabling enforcement of road crest elevations, applying uniform roughness values, and using alternative loss models (such as initial and constant loss, and the SCS method). However, these parameters were found to either produce unrealistic results or have an insignificant impact on model outputs.

5.1 July 2017 event

On 20th July 2013 a large and complex low-pressure system moved over New Zealand producing a strong and moist south-easterly flow across the South Island. During Saturday 22 July, the system moved slowly off to the east.

The event occurred after the Canterbury Plains had received relatively high rainfall in the weeks and months preceding it compared to the other modelled events (2013 and 2021). The soil moisture deficit[19] (SMD) taken on 20th July (prior to the event) is shown in Figure 5-1. This indicates that soil moisture was at or near field capacity within the Canterbury Plains on the day prior to the event, suggesting wet antecedent soil conditions.

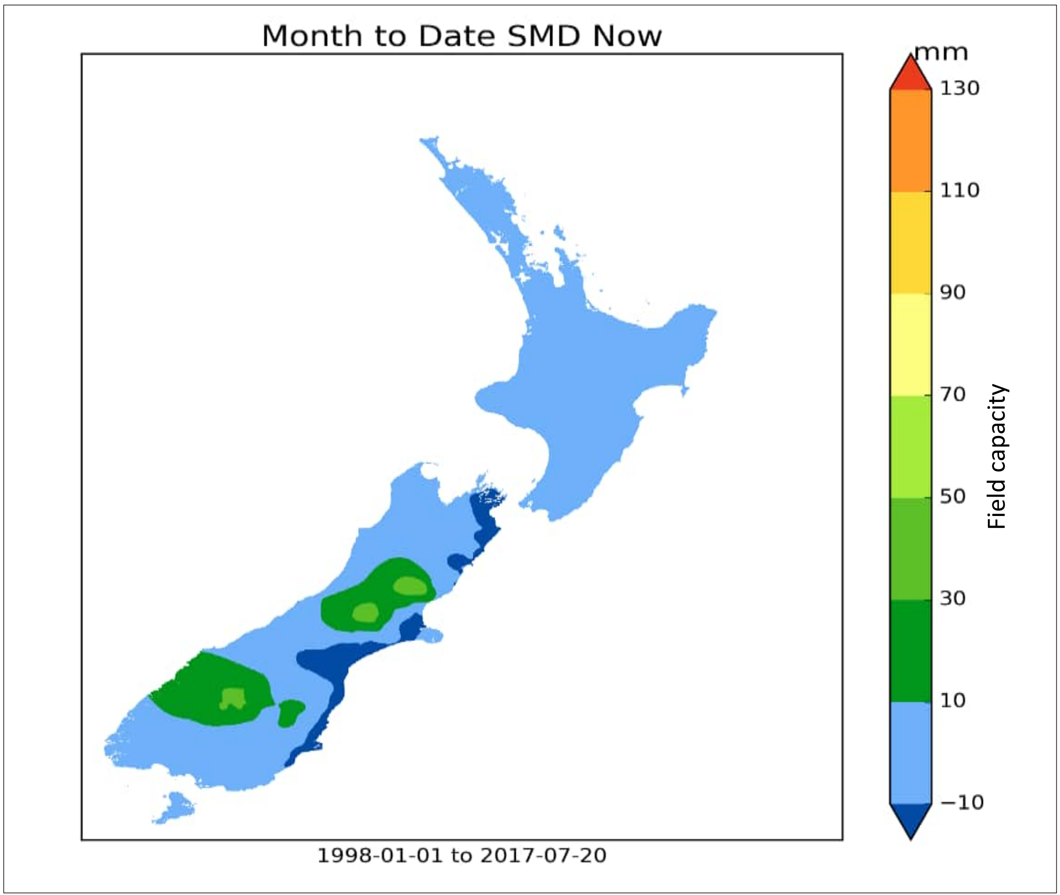


Figure 5-1: Soil moisture deficit map of NZ 20th July 2017 (figure supplied by ECan)

The Selwyn River at Coes Ford had a baseflow (approx. 8 m^3/s) prior to the event, however it is unknown if the river was flowing upstream of SH1. Other waterbodies within the district had relatively low baseflow prior to the event due to the minimal rainfall in the days immediately preceding it.

[19] SMD indicates the amount of rainfall needed to bring the soil moisture back to field capacity

Figure 5-2 shows the recorded rainfall over the entire duration of the event and the estimated AEP for the 24-hour period based on the HIRDSv4 frequency values. Note, generally the 24-hour period resulted in the highest AEP rainfall across the different durations considered by HIRDS.

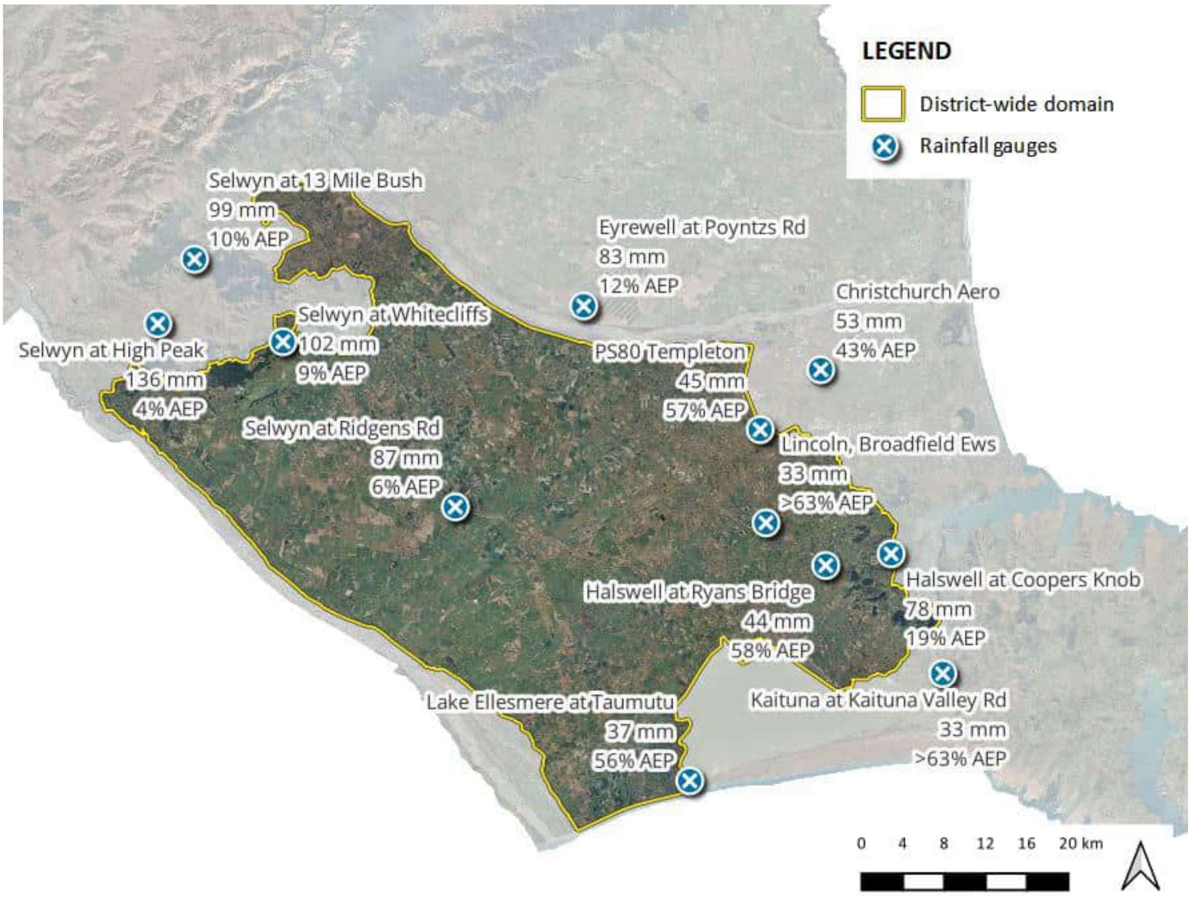


Figure 5-2: July 2017 estimated 24-hour rainfall AEP.

The preceding rainfall data and SMD map indicate that the plains area of the district had relatively wet antecedent soil conditions prior to the event. However, the lack of rainfall immediately prior to the event likely resulted in the relatively low baseflows recorded.

Several iterations of the model were run varying the input parameters, with the key parameters being infiltration and roughness. The results presented below represent the selected model iteration which best fit the observational data.

Aerial and ground imagery was captured by ECan across the district during the event. Appendix D provides a comparison of the images to the modelled flood extents at locations shown in Figure 5-3. The timing of the modelled extents has been aligned to the approximate time that the images were captured. Flood depths less than 50mm have been removed from the modelled extents.

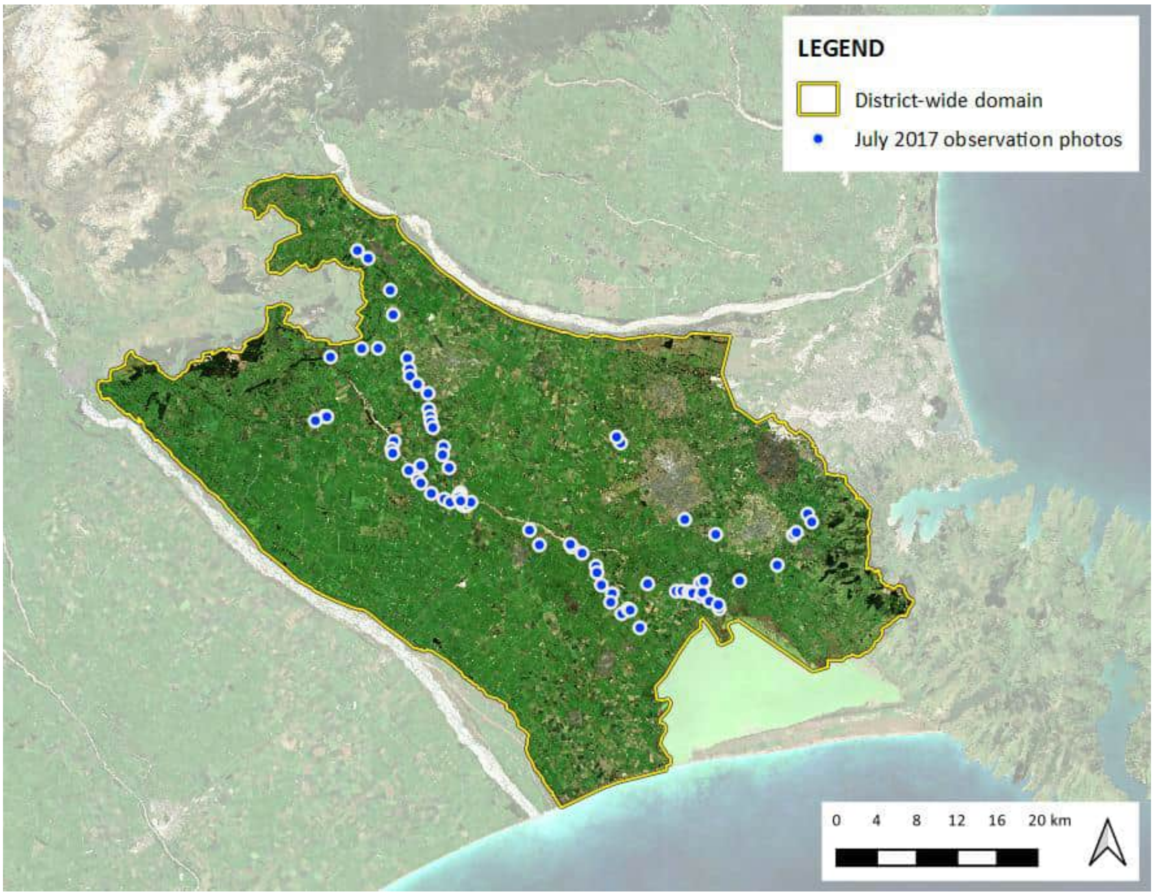


Figure 5-3: July 2017 observation imagery locations

ECan and NIWA operate several flow recorder sites within the district. The accuracy of the recorders will vary, and some recorders may not be accurate, particularly at higher flows. As a result, recorded flows should be treated with some caution. A detailed review of recorder accuracy is not part of this study.

Table 5-1 shows a comparison of the recorded peak discharge to the modelled peak discharge.

Table 5-1: July 2017: recorded and model peak discharge

Recorder site	Discharge (m^3/s)		
	Recorded (estimated AEP)	Recorded baseflow prior to event	Modelled
Selwyn at Whitecliffs	153 (8%)[1]	9	153
Selwyn at Coes Ford	420[2] (5%)[1]	9	382
Hororata at Mitchells Rd	37 (10%)[1]	4	96
Hoon Hay Stream	10 (<0.1%)[2]	0	6
Kaituna River at Kaituna Valley Rd	40 (>20%)[2]	1	40
Halswell at Ryans Bridge	12 (5%)[2]	1	9
L-2 at Pannetts Rd	8	3	6
Doyleston Drain ds The lake Rd	4 (20%)[2]	0	5
Harts Ck at TY	8	1	11
Lee River at Brooklands	4	1	5

Notes:

1. "Flood frequency analysis updates – May 2021 flood event", ECan Report.
2. New Zealand River Flood Statistics (NIWA).

Figure 5-4 shows a comparison of the recorded and modelled discharge at Coes Ford for the event.

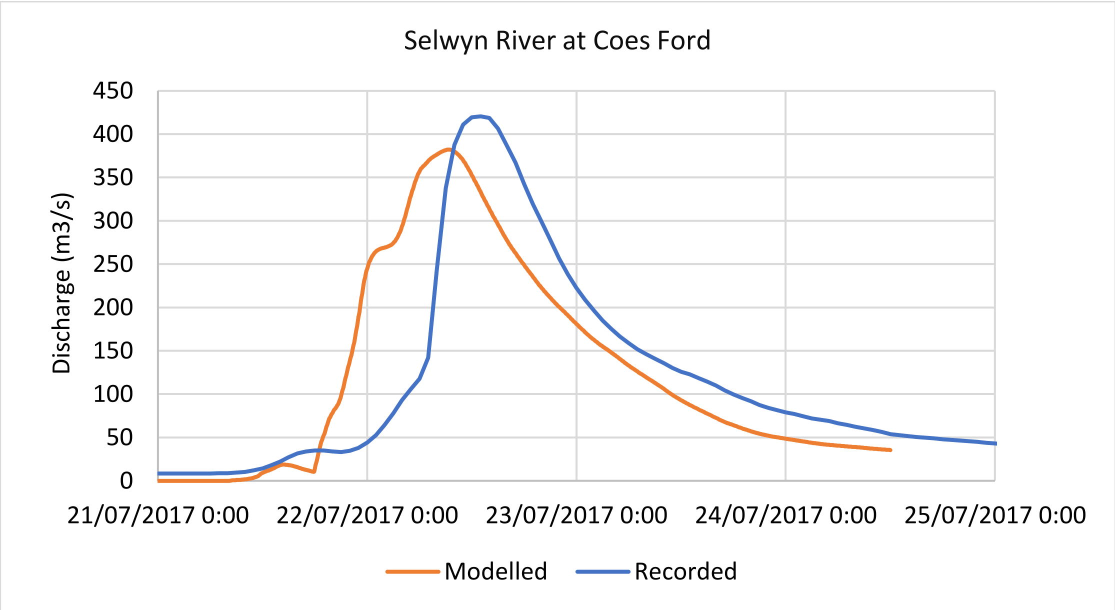


Figure 5-4: Recorded and modelled discharge Selwyn River at Coes Ford July 2017

5.2 June 2013 event

In June 2013, a long duration rainfall event occurred within the Plains area of the district. The event was situated over the Plains area of the district, with only minor rainfall within the hill catchments of the Selwyn River.

The event occurred after the Canterbury Plains had received a moderate rainfall in the weeks and months preceding it compared to the other modelled events (2017 and 2021).

The Selwyn River at Coes Ford had a relatively high flow (approx. 80 m^3/s) prior to the event due to preceding rainfall events in the upper catchment. It is unknown if the river was flowing upstream of SH1 prior to the event. Other waterbodies within the district had relatively moderate to above average baseflow prior to the event due to preceding rainfall events within the Canterbury Plains.

Figure 5-5 shows the recorded rainfall over the entire duration of the event and the estimated AEP for the 24-hour period based on the HIRDSv4 frequency values.

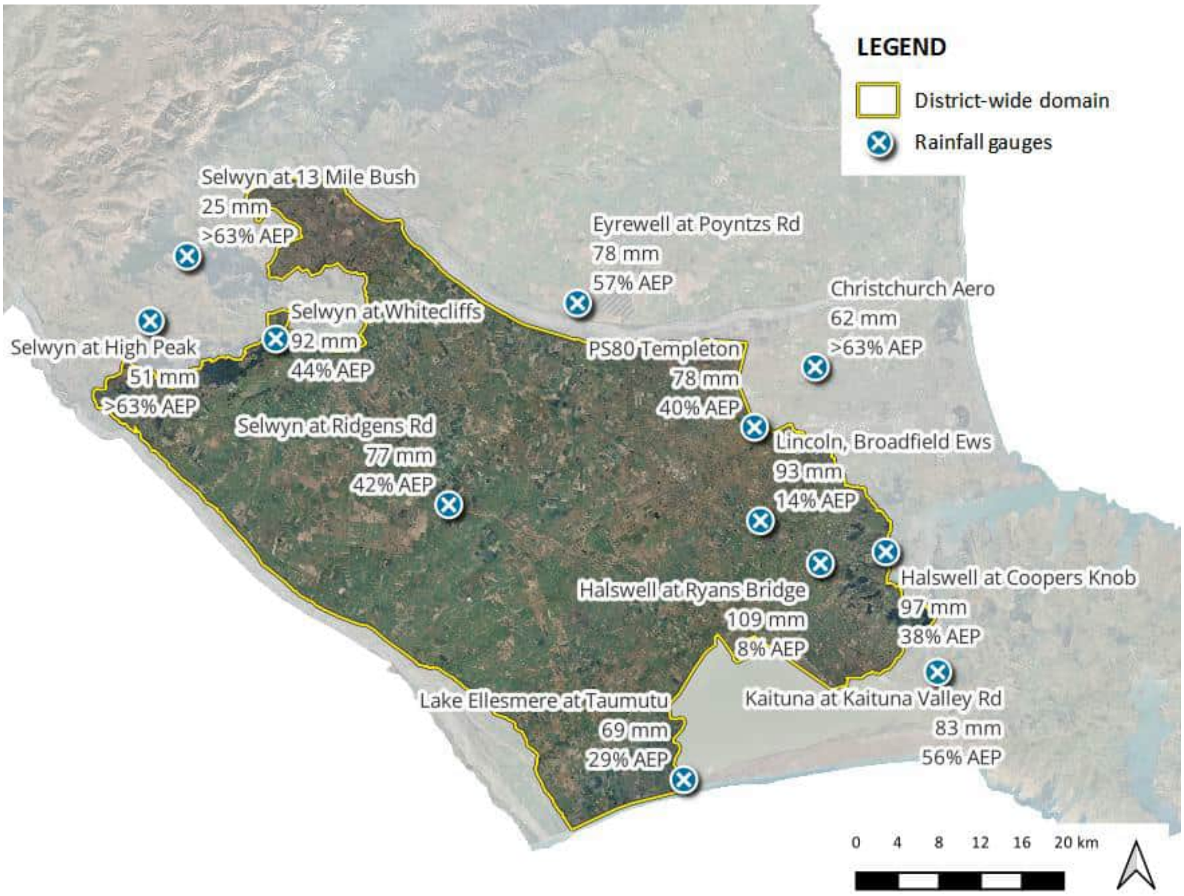


Figure 5-5: June 2013 estimated 72-hour rainfall AEP.

The model parameters for this event are the same as the selected model iteration which best fit the observational data for the July 2017 event.

Aerial and ground imagery was captured by ECan across the district during the event. Appendix D provides a comparison of the images to the modelled flood extents at locations shown in Figure 5-6.

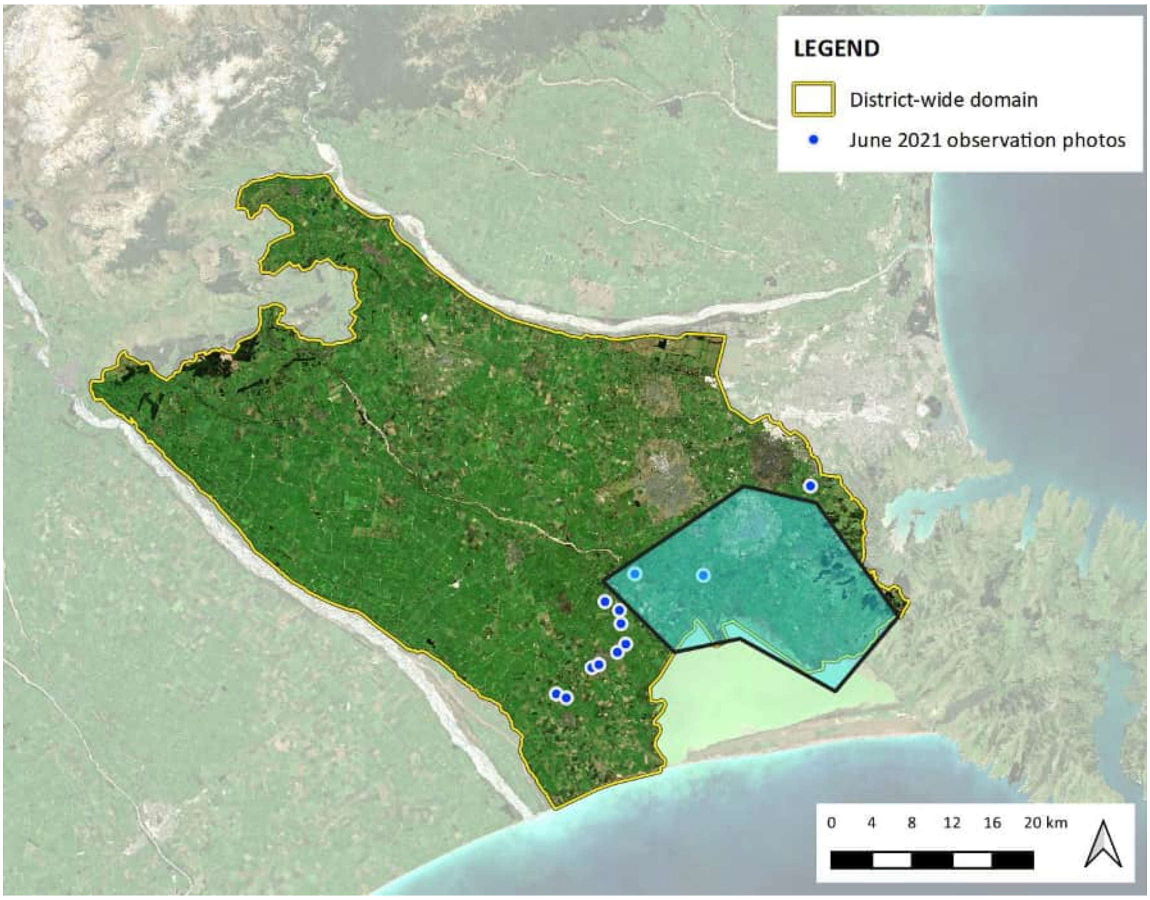


Figure 5-6: June 2013 observation photo locations (blue shading indicates a general area of photos capture)

Table 5-2 shows a comparison of the recorded peak discharge to the modelled peak discharge.

Table 5-2: June 2013: recorded and model peak discharge

Recorder site	Discharge (m^3/s)		
	Recorded (estimated AEP)	Recorded baseflow prior to event	Modelled
Selwyn at Whitecliffs	23 (>20%)[1]	17	25
Selwyn at Coes Ford	144 (>20%)[1]	79	135
Hororata at Mitchells Rd	22 (>20%)[1]	10	34
Hoon Hay Stream	3 (10%)[2]	0	4
Kaituna River at Kaituna Valley Rd	26 (>20%)[2]	4	31
Halswell at Ryans Bridge	13 (5%)[2]	4	9
L-2 at Pannetts Rd	11	5	6
Doyleston Drain ds The lake Rd	5 (10%)[2]	1	3
Harts Ck at TY	12	2	5
Lee River at Brooklands	7	2	2

Notes:

1. “Flood frequency analysis updates – May 2021 flood event”, ECan Report.
2. New Zealand River Flood Statistics (NIWA).

5.3 May 2021 event

In May 2021, a severe and widespread low-pressure system caused prolonged and intense rainfall over Canterbury. Southeasterly winds and orographic effects intensified rainfall over the Canterbury Plains and surrounding foothills.

The event occurred after the Canterbury Plains had received significantly less rainfall in the weeks and months preceding it compared to the other modelled events (2013 and 2017). The 3-month Standardised Precipitation Index[20] (SPI) up until the 28th May 2021, based on 29 rainfall recorders is shown in Figure 5-7. This indicates dry to extremely dry areas within the district.

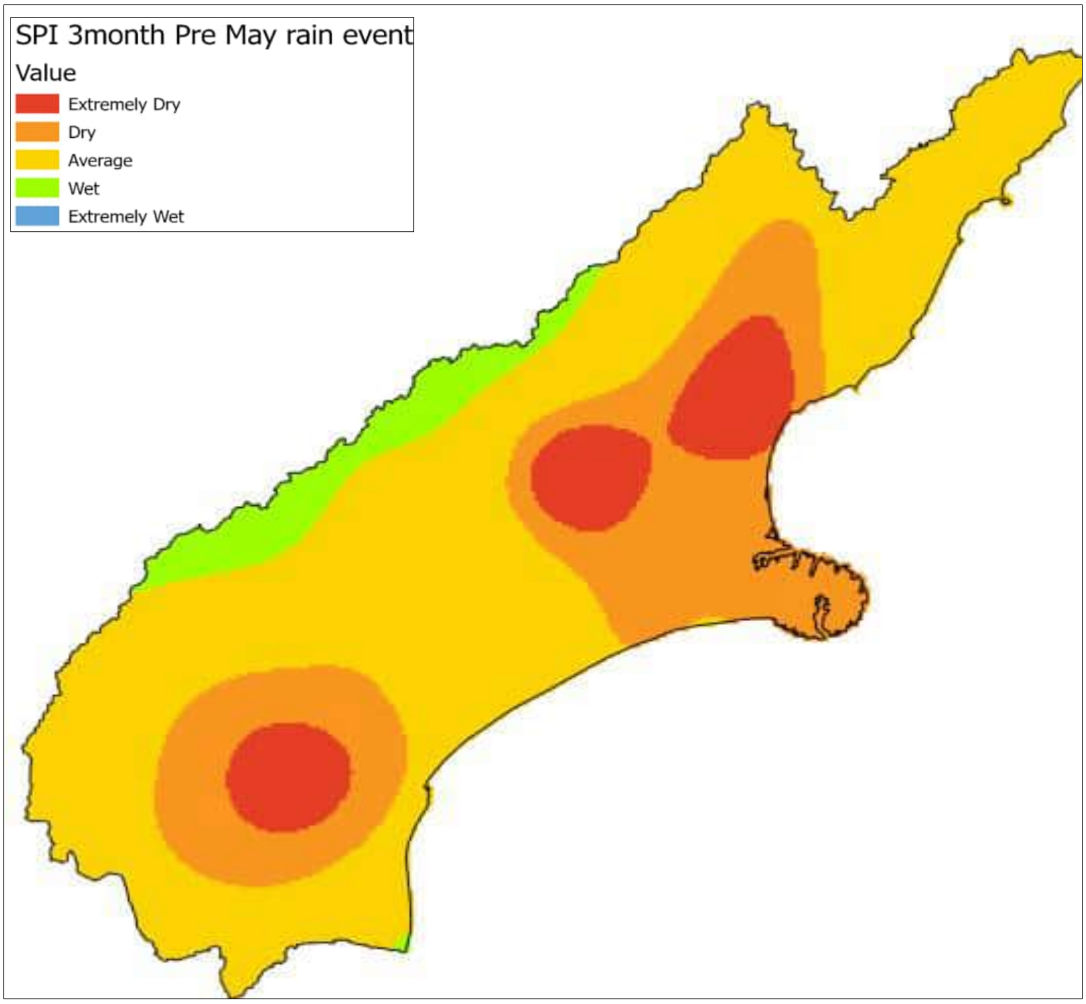


Figure 5-7: Standardised Precipitation Index prior to May 2021 event (figure supplied by ECan)

The Selwyn River at Coes Ford was almost dry prior to the event, reflecting the dry antecedent conditions. It is likely that the river was also dry within the plains above SH1 prior to the event. Other waterbodies within the district had low to very low baseflow prior to the event due to the lack of rainfall in the days, weeks and months preceding it.

Figure 5-8 shows the recorded rainfall over the entire duration of the event and the estimated AEP for the 24-hour period based on the HIRDSv4 frequency values.

[20] The SPI is a measure of dryness and wetness and is based on the accumulated precipitation for a given time period.

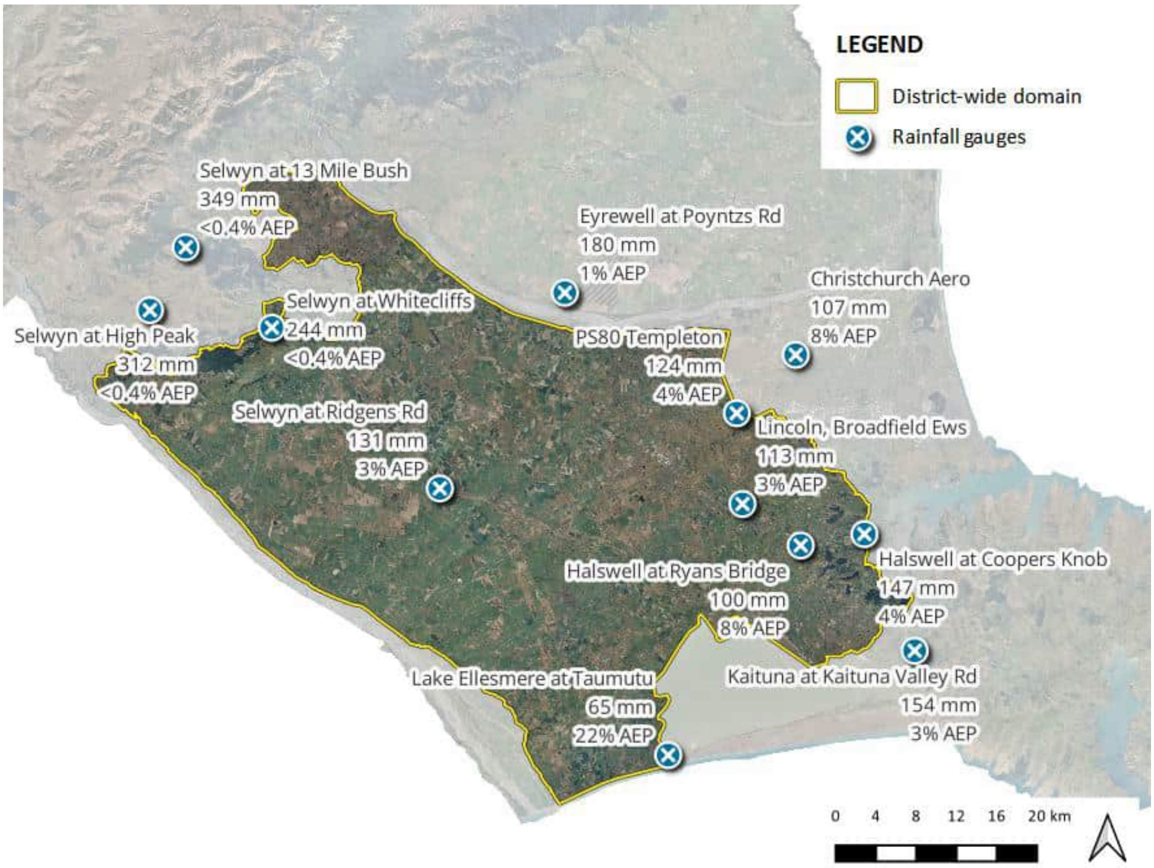


Figure 5-8: May 2021 estimated 48-hour rainfall AEP.

The model parameters for this event are the same as the selected model iteration which best fit the observational data for the July 2017 event except for including a high initial loss into the ‘shallow braid plain aquifer’ within the Selwyn River and tributaries (Hororata, Hawkins and Waianiwaniwa) channel and overbank area (see Section 4.6.7).

Debris extents were digitised by ECan within the Selwyn River catchment after the event. Appendix D provides a comparison of the debris extent to the modelled flood extents. Additional aerial imagery captured by ECan along the Selwyn River during the event is also provided in Appendix D.

SDC have previously engaged T+T to undertake additional hydrological analysis and hydraulic modelling for Springfield township following the May 2021 event. A comparison of the model results to that previous work is provided in Appendix D. The comparison shows that the modelled water depths align reasonably well with the previous Springfield area model.

Table 5-3 shows a comparison of the recorded peak discharge to the modelled peak discharge.

Table 5-3: May 2021: recorded and model peak discharge

Recorder site	Discharge (m^3/s)		
	Recorded (estimated AEP)	Recorded baseflow prior to event	Modelled
Selwyn at Whitecliffs	223 (5%)[1]	3	227
Selwyn at Coes Ford	447[2] (4%)[1]	0	471
Hororata at Mitchells Rd	50 (2%)[1]	1	224
Hoon Hay Stream	1 (>20%)[2]	0	7
Kaituna River at Kaituna Valley Rd	42 (20%)[2]	0	60
Halswell at Ryans Bridge	7 (>20%)[2]	0	14
L-2 at Pannetts Rd	6	1	11
Doyleston Drain ds The lake Rd	1 (>20%)[2]	0	7
Harts Ck at TY	1	1	29
Lee River at Brooklands	1	1	4

Notes:

1. "Flood frequency analysis updates – May 2021 flood event", ECan Report.
2. New Zealand River Flood Statistics (NIWA).

Figure 5-9 shows a comparison of the recorded and modelled discharge at Coes Ford for the event. Two model scenarios are shown, one with the high initial loss to simulate water loss to the shallow aquifer, and one without the high initial loss.

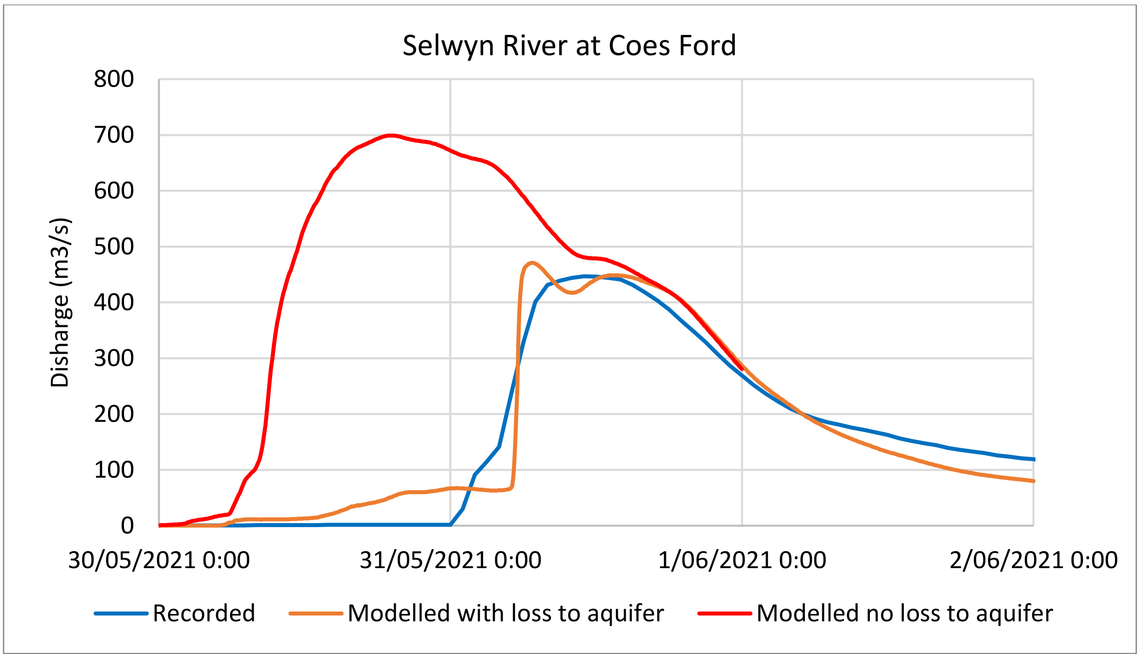


Figure 5-9: Recorded and modelled discharge Selwyn River at Coes Ford May 2021

5.4 Summary of calibration and validation events

A summary overview of the calibration and validation results is provided in Table 5-3.

Table 5-4: Summary of calibration and validation

Observation data	July 2017	June 2013	May 2021
Antecedent conditions	• Wet antecedent soil conditions. • Low baseflows in waterbodies	• Moderately wet antecedent soil conditions. • Moderate to high baseflows in waterbodies.	• Dry antecedent rainfall. • Very low baseflows in waterbodies.
Aerial imagery	Align well in most areas, except for some areas between Leeston and the Selwyn River	Align well in most areas, except for some areas within the lower Halswell River catchment.	Align well.
Flow recorders	• Model peak discharge at Coes Ford within 10% of recorded discharge. • At other flow recorder sites, model peak discharges are in the same order with some variability.	• Model peak discharge at Coes Ford within 7% of recorded discharge. • At other flow recorder sites, model peak discharges are in the same order with some variability. • Preceding higher baseflow conditions likely had some influence on recorded discharges during the June 2013 event.	• Model peak discharge at Coes Ford within 5% of recorded discharge when including a high initial loss within the Selwyn River channel and overbanks. • At other flow recorder sites, model peak discharge is higher than recorded.
Debris extents	-	-	Model peak flood extent aligns closely with debris extents.

Figure 5-10 presents a map of points where modelled flood extents are compared to the observation photos (refer to Appendix D), indicating where the modelled extents align well, or are higher or lower than the observations. The points show good alignment across the upper, mid, and most of the lower catchment. Some modelled extents in the lower catchment are higher than the observations for the July 2017 and June 2013 events, including:

- Areas between Leeston and the Selwyn River during the July 2017 event, where the model may have overestimated breakout flow from the river, potentially due to higher channel roughness at the breakout location.
- Areas within the lower Halswell River catchment, where lake influences or drainage not represented in the model may have affected observed water levels.

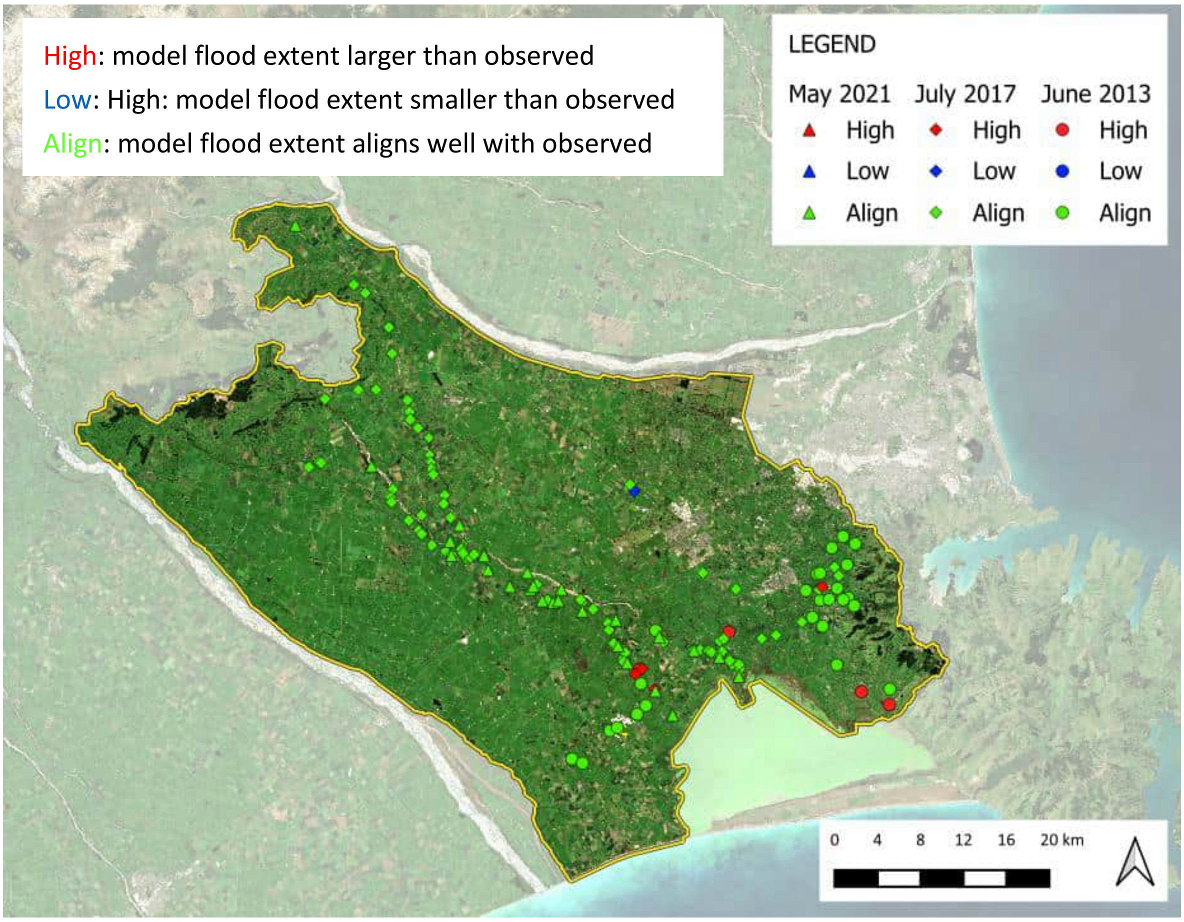


Figure 5-10: Calibration summary at observation locations

Further commentary of the calibration and validation results is provided below.

- Modelled flood extents align well with observed aerial and ground imagery for the July 2017 and June 2013 events (refer to Appendix D) within areas where observations are available. Some modelled extents in the lower catchment are higher than the observations for the July 2017 and June 2013 events.
- When including a high initial loss within the channel and overbanks of the Selwyn River during the May 2021 event, observed debris extents closely align with the modelled peak flood extent (refer to Appendix D).
- The modelled flood extent within Springfield during the May 2021 event aligns well with the extent produced by the detailed flood model previously developed for the township.
- Comparison of modelled peak discharge to recorded peak flows is variable across the recorder sites, but generally are in the same order for the July 2017 and June 2013 events.
- The Selwyn River (Coes Ford) modelled peak discharge is within 10%, 7% and 5% of the recorded discharge during the July 2017, June 2013 and May 2021[21] events respectively.
- The Selwyn River (Coes Ford) modelled peak discharge is within 10% of the recorded discharge during the July 2017 event, although the peak occurs approximately four hours earlier. The total modelled discharge volume aligns with the recorded volume.
- The flood breakout of the Selwyn River right bank aligns well with observed aerial and ground imagery in the July 2017 and May 2021[21] events.

[21] When including a high initial loss within the Selwyn River and channel and overbanks

- In the July 2017 event, the Hororata River (Mitchells Road) modelled peak discharge is significantly higher than the recorded discharge, although it is noted the recorder site has limitations at high flows (ECan, 2023). In the June 2013 event, the modelled discharge is more consistent with recorded discharge where lower discharges were generally observed.
- In the May 2021[21] event, modelled peak discharges (except for the Selwyn River) were significantly overestimated compared to recorded discharges. Although the recorded rainfall was relatively high compared to the other events, the recorded peak discharges were lower at most recorder sites. This may be due to the dry antecedent soil conditions, which likely resulted in higher infiltration losses and lower recorded peak discharges. These higher losses are not captured by the model, which has been calibrated to the July 2017 event under relatively wet antecedent conditions.
- The loss of water to the shallow plain aquifer in Selwyn River and upper tributaries is evident when comparing modelled discharge to recorded discharge at Coes Ford. When including a high initial loss within the channel and overbanks during the May 2021 event, the modelled discharge (peak and timing) is more consistent with recorded discharge. A similar loss to a lesser a degree may have also occurred in the July 2017 event, which could explain the difference in timing.
- Several areas of the district, particularly on the western side outside the Selwyn catchment, had no or minimal flood observations recorded during the events. However, where comparable land use and soil types exist, modelled flood extents generally align well.
- The model does not include baseflow which could have been significant in the June 2013 event. Within the Port Hills and Plains catchments, modelled discharge was generally lower than recorded discharge. For example, the Halswell River at Ryans Bridge recorded a peak discharge of 13 m^3/s, but the model estimated a peak of 9 m^3/s. At the start of this event the river had a baseflow of approximately 4 m^3/s, as shown in Figure 5-11. Similar baseflow behaviour was observed in several other catchments.

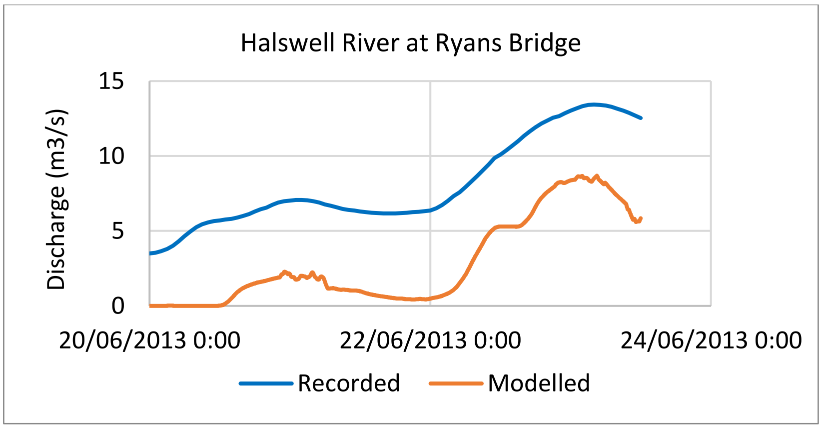


Figure 5-11: Recorded and modelled discharge Halswell River at Ryans Bridge June 2013

In the July 2017 and May 2021 events, baseflow was minimal and therefore would likely have limited impact on the model results.

- The model shows some ponding in all events within Rolleston, generally confined to roads. It is likely the district model overestimates flooding within Rolleston because it does not include roadside soakholes which would reduce flooding, partially within roads. The soakholes are included in the Rolleston township model.
- In the July 2017 event, the modelled flood extent at Leatham Swamp was significantly larger than the observed extent. This could be due to the model overestimating runoff into the swamp, or underestimating discharge out of the swamp, noting the aerial imagery was

recorded after the peak of the rainfall. In the June 2013 event, the modelled flood extent aligns well to the observed extent.

Overall, the modelled flood extents align well with observed aerial, ground imagery and debris extents across the three historical events. The comparison of modelled peak flows to recorded values shows some variability, noting that the recorders have uncertainty, particularly those within the Plains. Within the Selwyn River, modelled peak discharge and volume generally aligns with the recorded values, noting there are some differences in the timing of peak flows.

Based on observations of historical flood events, water loss to the shallow plains aquifer from the Selwyn River and its tributaries, along with antecedent rainfall conditions across other areas of the district, has a significant influence on flooding within the district. The final soil loss parameters adopted for the model assume no loss to the aquifer and relatively wet antecedent conditions, consistent with those observed during the July 2017 calibration event and the June 2013 validation event. As a result, the model is likely to estimate higher flood levels compared to a scenario with drier antecedent conditions preceding the event.

A future improvement opportunity regarding model calibration and validation is provided in Section 9.

6 Model results

6.1 Model outputs

Maximum water level, depth, velocity, depth x velocity and hazard has been outputted from the model in raster format (.tiff). The resolution of the raster is 20 m for the district model and 2 m for the township models.

Additional 'High resolution' outputs for maximum water level and depth have been outputted for the district model at a resolution of 4 m, and 1 m for the township models. The 'High resolution' water level is interpolated from the computed 2D water levels. The 'High resolution' depth is the difference between the interpolated water level and the sub-grid elevation. The 'High resolution' outputs retain the sub-grid detail of the terrain information at coarse computational cell size.

Hazard output is based on the curves as per (G.P. Smith, 2014) shown in Figure 6-1.

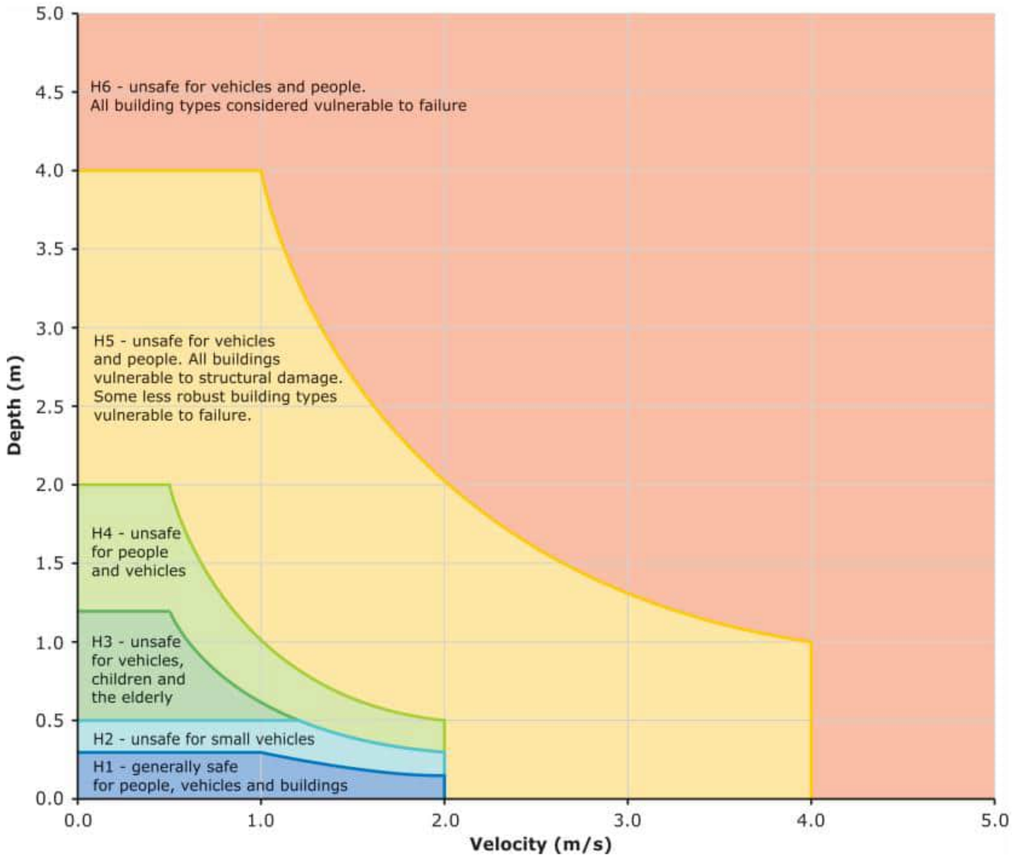


Figure 6-1: Hazard curves

Maximum water level, depth, velocity, depth x velocity and hazard "Peak of Peaks" rasters (.tiff) have been produced for each AEP and climate change event. These rasters capture the highest value at each grid cell across the six rainfall durations (1, 6, 12, 24, 48 and 72-hour).

6.2 Critical duration

Maps showing the estimated critical duration within the district for the 0.5% AEP event under future climate conditions event are shown in Figure 6-2. The maps for the remaining events are provided in Appendix E. The critical duration is the rainfall event duration (either 1, 6, 12, 24, 48 or 72-hour) which results in the maximum water level within each computational cell.

The critical duration may be different for some areas depending on the AEP and climate change scenario of the event. Generally, the lower the AEP the longer the critical duration.

Some townships have different critical durations in different areas of the township.

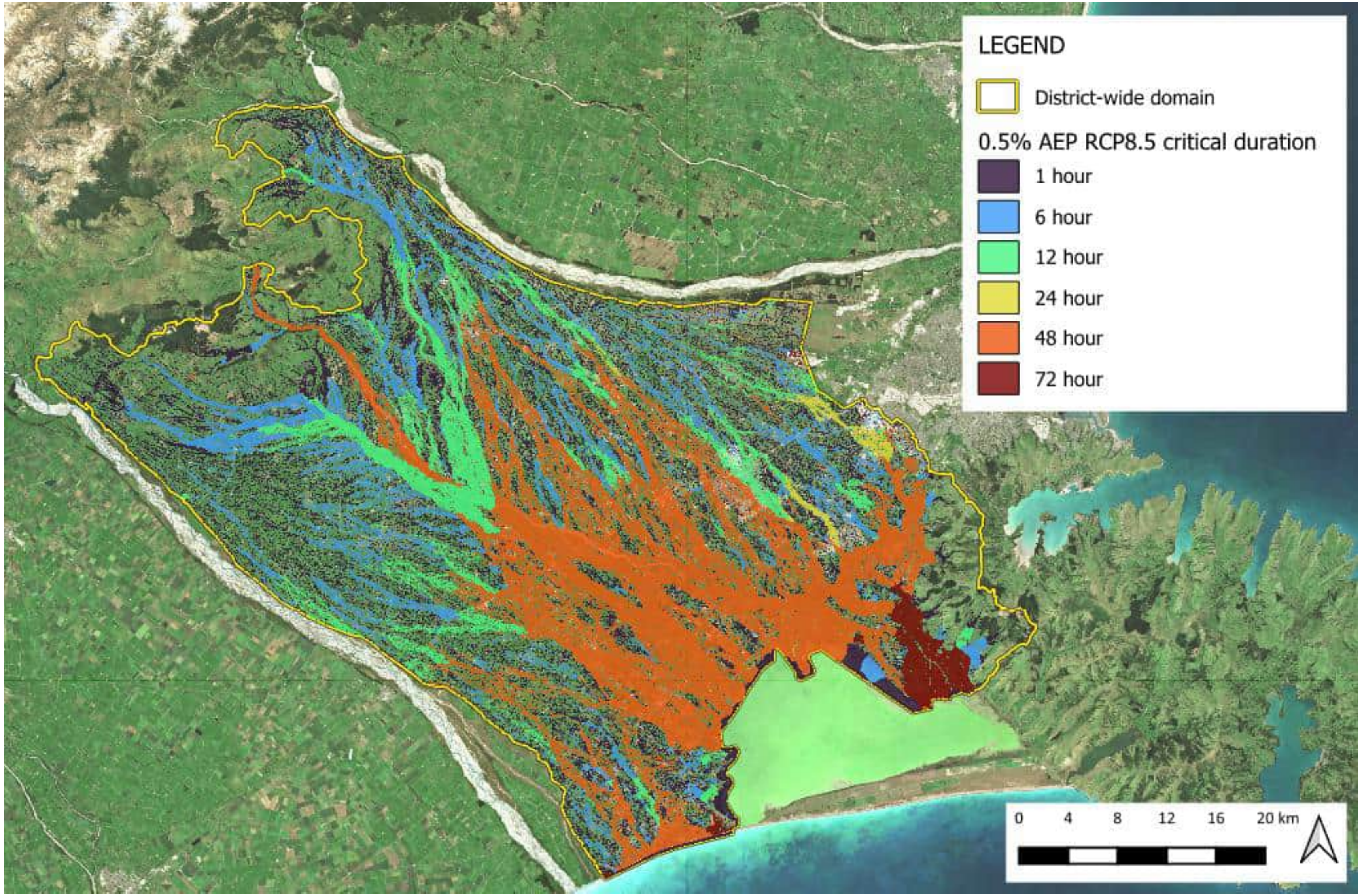


Figure 6-2: Critical duration map 0.5% AEP RCP8.5 event.

7 Model sensitivty

Several model sensitivity scenarios listed in Table 7-1 have been simulated. The purpose of these simulations is to estimate the relative differences in flooding, that may result from varying model parameters, particularly those with the greatest uncertainty.

The sensitivity scenarios were run for the 0.5% AEP event under future climate conditions, with a 24-hour duration. While the 24-hour event is not the critical duration for all areas of the district, it provides a useful basis for estimating relative differences in flooding while minimizing simulation time. The district model was used for all scenarios except for 'sensD' which uses the Leeston township model.

Table 7-1: Model sensitivty scenarios

Scenario	Description
Base case	Standard model parameters as per this report.
sensA	All culverts (1d_nwk) 100% blocked.
sensBa	Higher roughness 'n' coefficients – limiting coefficient based on upper end of recommended values from (Chow, 1959).
sensBb	Lower roughness 'n' coefficients - limiting coefficient based on lower end of recommended values from (Chow, 1959).
sensCa	Higher infiltration: x2 base case final loss rates.
sensCb	No infiltration.
sensD	Buildings not blocked out (Leeston township model). Model applies high roughness within building footprint at water depths >50 mm.
sensEa	Higher rainfall (design rainfall + one standard error)
sensEb	Lower rainfall (design rainfall – one standard error)

Figure 7-1 shows a map indicating which sensitivity scenario (SensA, Ba, Bb, Ca, Cb, Ea and Eb) results in the highest absolute water level difference compared to the base case. The scenario with the greatest difference suggests that the model is most sensitive to the parameter associated with that scenario, e.g. for much of the Selwyn River, the model was most sensitive to the higher roughness 'n' coefficient scenario (orange colour). In the Tai Tapu area, the model was most sensitive to the higher and lower rainfall scenarios (red and blue colours).

Figure 7-2 shows a maximum water level difference histogram for each sensitivity scenario compared to the base case, e.g. for the no infiltration scenario, the water level difference compared to the base case was between 0 and 100 mm for 86% of the model wet cells. The histogram indicates that water level differences for all scenarios are within 120 mm for approximately 90% of all wet cells, except for the lower rainfall scenario which has a larger difference.

Figure 7-3 shows a maximum water level difference map for the SensD scenario (buildings not blocked out of the model DEM). The figure indicates that when buildings are not blocked out, water levels are lower in most areas, with larger differences immediately upstream of building footprints. Generally, water level differences are less than +-100 mm.

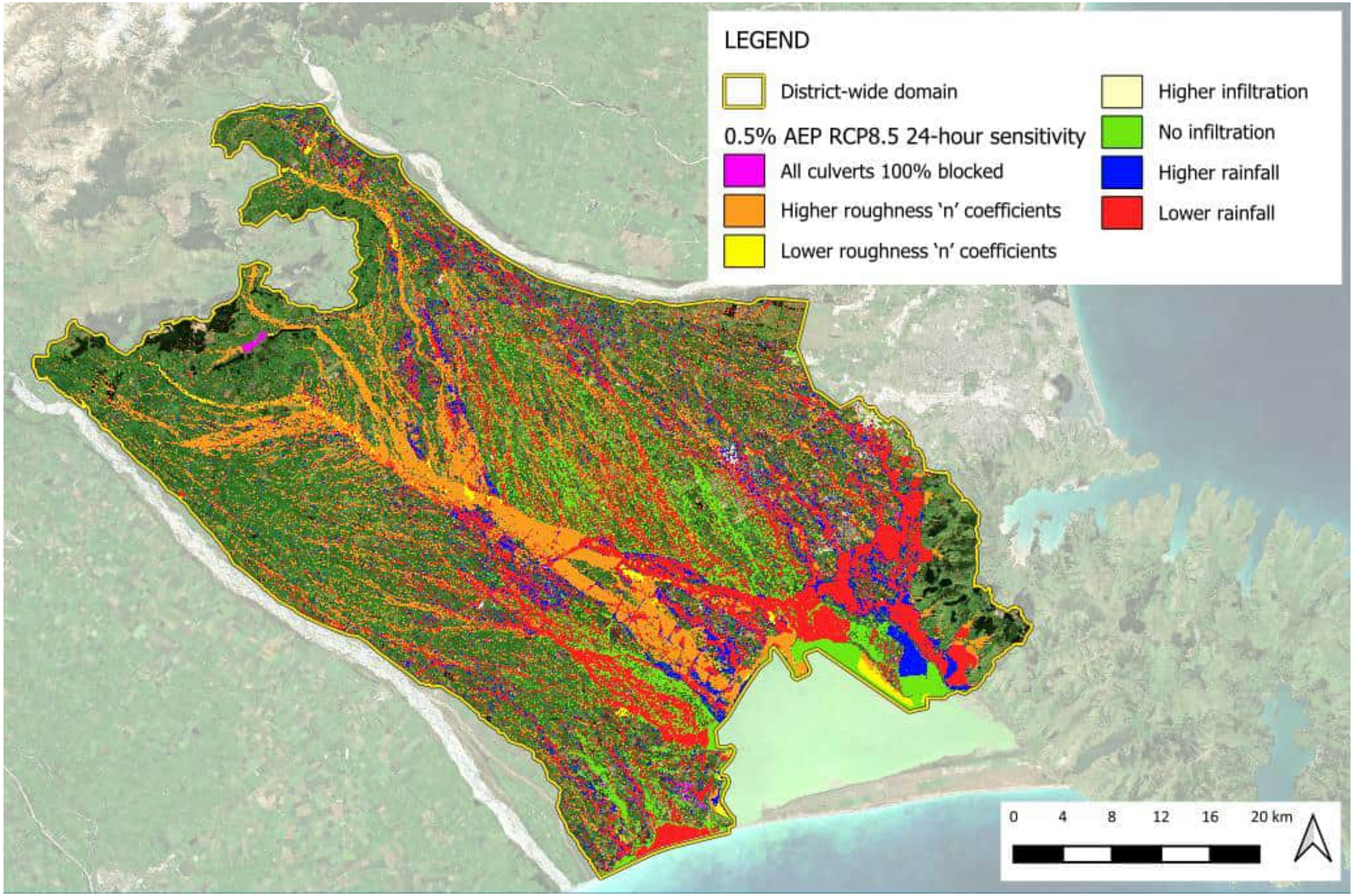


Figure 7-1: Model sensitivity result map 0.5% AEP RCP8.5 24-hour event.

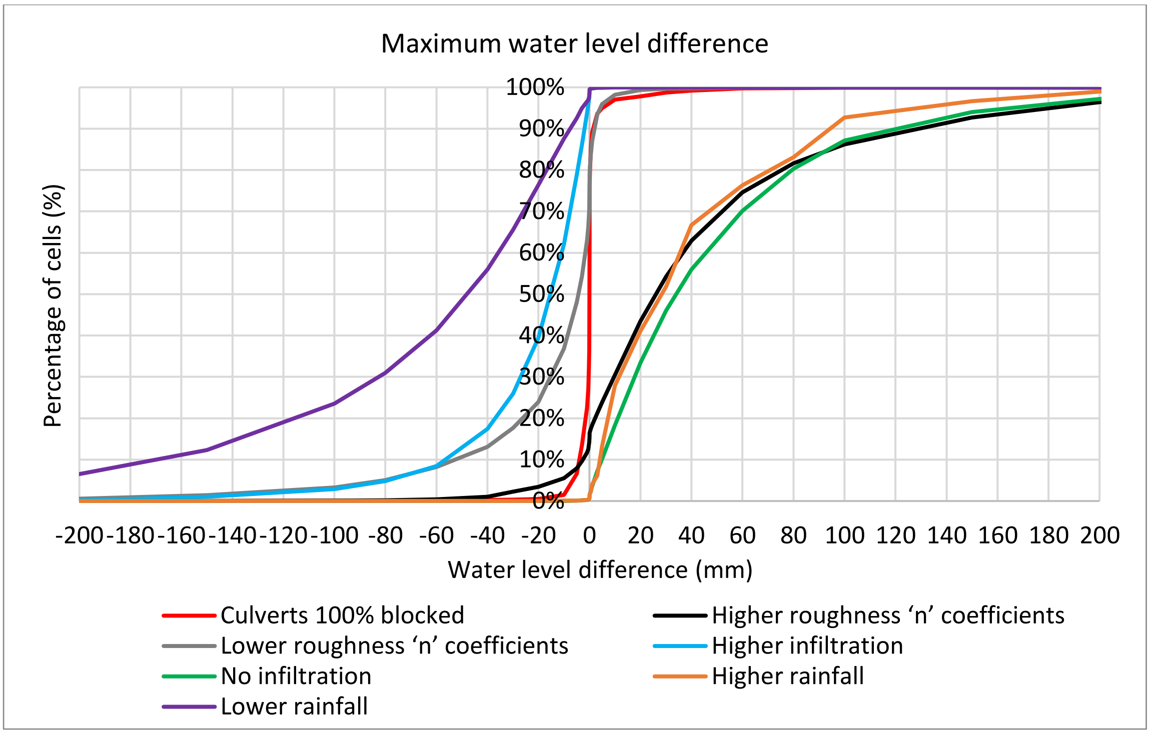


Figure 7-2: Model sensitivity – Maximum water level difference

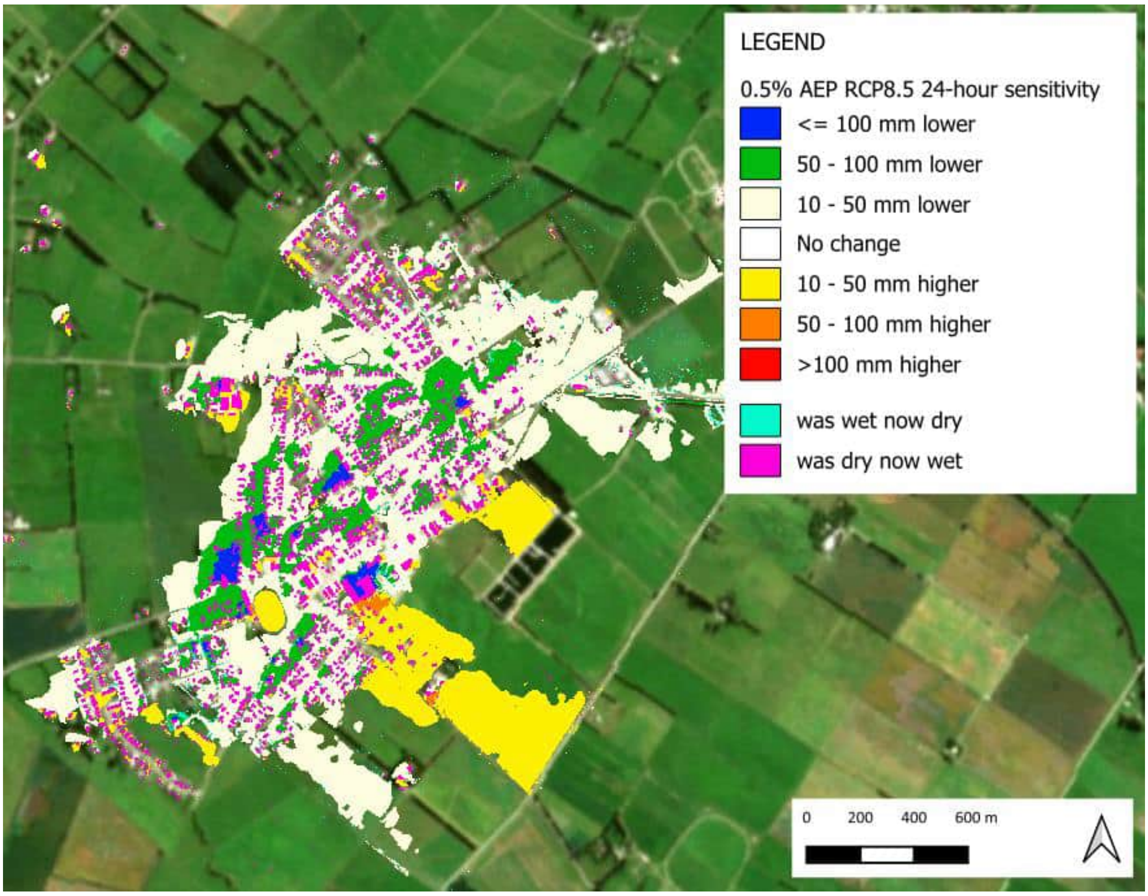


Figure 7-3: Model sensitivity result map Leeston buildings blocked out versus not blocked out

8 Model limitations

The following key model limitations are provided below:

- Model accuracy depends on the completeness and quality of input data. In areas with significant data gaps or poor-quality inputs, further refinement may be required, including additional as-built surveys.
- Model inputs such as soils, land use, building footprints, drainage networks, stopbanks, terrain, and boundary conditions (rainfall, inflows, tides, lake levels) have been sourced from data collected at different times. These inputs may change over time due to processes such as river evolution, vegetation changes, or new development.
- Comparison of model results for calibration and validation is limited to areas where historical flood observations were collected. No comparison of model results can be made in areas where observational data has not been collected.
- For property scale flooding assessments, it is recommended that model inputs, particularly as-built drainage infrastructure, are reviewed for accuracy and completeness in areas of hydraulic influence. Where discrepancies are identified, updates should be made, potentially requiring additional as-built surveys or site inspections, depending on the accuracy required for the assessment.
- The model uses Horton's method to estimate soil infiltration, calibrated to the July 2017 event (which had relatively wet antecedent soil conditions) and validated against the 2013 and 2021 events. Historical flood observations indicate that water loss to the shallow plains aquifer from the Selwyn River and its tributaries, along with antecedent rainfall conditions, significantly influence flooding within the district. The adopted Horton's parameters assume no loss to the aquifer and relatively wet antecedent soil conditions, consistent with those observed during the July 2017 calibration and June 2013 validation events. Consequently, the model may estimate higher/lower flood levels compared to events preceded by wetter/drier conditions.
- HIRDS rainfall is applied spatially across the entire model domain for selected AEP events and climate scenarios, using HIRDS temporal profiles for durations of 1, 6, 12, 24, 48, and 72 hours. Inflows from upstream overland flow (extracted from the district model) are applied at the upstream township model boundaries. As such, the model is expected to estimate higher flood levels than would be estimated under an isolated storm of the same AEP falling on only a specific area.
- No Areal Reduction Factor is applied to the model because there is no specific point of interest within the district in which the upstream catchment area can be defined. Applying an ARF across the entire district may cause an underestimation of flooding in smaller catchments (e.g. Port Hills) and an over estimation of flooding in larger catchment areas (e.g. lower Selwyn River).
- Surface - groundwater interactions are not explicitly modelled, except for surface infiltration using Horton's infiltration method.
- Lumped catchment inflows are provided by Environment Canterbury (ECan); associated limitations are documented in ECan's 2025 report.
- Te Waihora (Lake Ellesmere) water levels used in the model were provided by ECan.
- Some stormwater network data (e.g. culverts, pipes, sumps, soakholes, manholes) contain known gaps and inconsistencies.
- The model does not include baseflow.
- Erosion, sedimentation, and other dynamic geomorphic changes that may occur during floods are not represented.

- Small-scale terrain features, such as kerbs, may not be accurately captured in the model DEM.
- Inflows to the CPW canal and contributions from the Rakaia and Waimakariri Rivers are not included in the model.
- Debris blockages are not explicitly modelled, although a sensitivity assessment has been undertaken.
- Potential emergency responses (e.g. sandbagging, gate operations) are not included in the model.

9 Model future improvements

The following potential future improvement opportunities have been identified.

- As additional flood events occur within the district (e.g. the April/May 2025 event), further validation and calibration of the model could be undertaken, focusing on the townships and other areas where minimal historic flood observations are currently available.
- Include a nested storm profile into the model inputs to allow this rainfall profile to be run if required.
- The township models currently include both local rainfall and upstream catchment inflows (extracted from district model results). This assumes uniform rainfall across the entire upstream catchment. Alternative approaches, such as applying localised storm isohyetal patterns to the township and surrounding areas, could be considered.
- Run simulations with multiple Areal Reduction Factors (ARFs) to produce a range of flood outputs. When reviewing flooding at a specific location, the user can estimate the upstream catchment area and refer to the model result with the most appropriate ARF applied.
- Improve spatial definition of land use and impervious areas using automated satellite classification or manual delineation from high-resolution aerial imagery.
- Incorporate larger bridges into the model using TUFLOW's 2d_bg feature. Structure surveys or as-built data would be required for accurate representation.
- Include surface–groundwater interaction in the model by implementing TUFLOW's Interflow Module. This requires spatial input data such as soil porosity, layer thickness, water table depth, and hydraulic conductivity.
- Refine model geometry detail, including more accurate stopbank crest alignments.
- Refine model assumptions as computational capabilities improve, including:
  - Reducing the base computational cell size with advances in GPU processing.
  - Introducing additional Quadtree nesting in hydraulically sensitive areas.
  - Reducing SGS (Sub-Grid Sampling) distance to 1 m for district-scale models as GPU memory increases.
- Review and update the design function and assumed infiltration rates of all stormwater basins.
- Undertake further analysis of Te Waihora (Lake Ellesmere) levels, such as joint probability assessments and investigations of lake mouth opening dynamics.
- Include all remaining SDC culverts under 0.5 m diameter in the model. This would require improved spatial accuracy of culvert data, either through better data collection or manual adjustment.
- Channel roughness values have been applied using buffers around SDC-supplied channel alignments. These alignments often require manual adjustment to align with the DEM. Further refinement or enhanced channel extent capture (especially outside township areas) could improve model roughness representation.
- Conduct additional field surveys of stormwater network assets and update the model as needed, particularly where property-specific flood risk assessments are required and may be affected by current network data gaps.

10 Conclusions

Selwyn District Council have engaged Tonkin & Talyor Ltd to build a 2-dimensional hydraulic flood model of the Waikirikiri Selwyn District. The hydraulic model has been built to perform two functions, including assisting SDC's planning and infrastructure teams for the design of infrastructure within eleven of the district's townships, and to inform Flood Hazard Certificates within rural areas of district.

The model was built using TUFLOW HPC software and incorporates terrain elevation DEM from the 2023 Selwyn LiDAR survey, supplemented by additional datasets to complete spatial coverage. The model includes input data for soils, land use, building footprints, drainage networks, stopbanks, and boundary conditions including rainfall, inflows, tides, lake levels.

Hydrological scenarios were modelled for a range of AEP events (10%, 1%, 0.5%, and 0.2%) under both historical and future climate conditions (RCP8.5 2081 - 2100), with storm durations including 1, 6, 12, 24, 48 and 72 hours. Calibration was undertaken using the July 2017 event, with validation against the June 2013 and May 2021 events.

The model outputs include maximum water depth, level, velocity, depth-velocity product, and hazard, along with time-series data compatible with GIS platforms.

Several model limitations and future improvement opportunities have been identified in this report.

11 References

Chow, V. T. (1959). *Open-channel hydraulics.*

ECan. (2019). *Selwyn River/Waikirikiri floodplain investigation.*

ECan. (2024). *Selwyn foothill catchment design flows.*

FHA. (1978). *Hydraulics of Bridge Waterways.*

G.P. Smith, E. D. (2014). *Flood Hazard UNSW Australia Water Research Laboratory Technical Report 2014/07.*

Mason, H. a. (1991). *Roughness Characteristics of New Zealand Rivers.*

MfE. (2017). *Coastal Hazards and Climate Change. Guidance for Local Government.*

NIWA. (2015). *Storm-tides and wave runup in the Canterbury Region. Prepared for Environment Canterbury.*

NIWA. (2018). *High Intensity Rainfall Design System Version 4.*

NZBC. (2023). *NZBC E1 Surface Water.*

SDC. (July 2022). *Enigneering Code of Practice.*

Syme, W. (2008). *Flooding in urban areas - 2D modelling approaches for buildings and fences.* National Conference on Hydraulic in Water Engineering.

Tonkin & Taylor Ltd. (2023). *Coastal Inundation: Tangoio to Clifton.*

TUFLOW. (2024). *TUFLOW Classic/HPC User Manual 2023-03.*

U.S. Department of Transportation. (2009). *Urban Drainage Design Manual.*

USGS. (1989). *Guide for Selecting Manning's Roughness Coefficients for Natural Channels and Flood Plains.*

USGS. (1989). *United States Geological Survey Water-Supply Paper 2339.*

12 Applicability

This report has been prepared by Tonkin & Taylor Limited (T+T) for the exclusive use of our client Selwyn District Council, with respect to the particular brief given to us and it may not be relied upon in other contexts or for any other purpose, or by any person other than our client, without our prior written agreement. We understand and agree that this report will be used by Selwyn District Council in undertaking its regulatory functions.

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Appendix A: Selwyn River/Waikirikiri foothill hydrological modelling and design flows

CANTERBURY REGIONAL COUNCIL

Selwyn River/Waikirikiri foothill hydrological modelling and design flows

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Kaunihera Taiao ki Waitaha

Selwyn River/Waikirikiri foothill hydrological modelling and design flows

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Executive summary

Background:

A rain on grid model of the Selwyn District (Selwyn ROG model) has been developed by Tonkin and Taylor for the Selwyn District Council. As part of this work, Environment Canterbury produced a range of design inflows for the five Selwyn River/Waikirikiri foothill catchments which contribute flow to the Selwyn ROG model. The Selwyn ROG model will provide updated floodplain and township flood hazard information for Selwyn District Council and Environment Canterbury.

The problem:

Flow time series were required as inputs to the Selwyn ROG model for the five largest (and steeply sloping) Selwyn River/Waikirikiri foothill catchments, as they have been excluded from the model grid extent. Required flows for these catchments include:

- Calibration flows for storm events in June 2013, July 2017, and May 2021.
- Present-day and climate change adjusted (RCP[1]-8.5 projected to 2081-2100) design flows for 1, 6, 12, 24, 48, and 72 hour storm durations and 10, 100, 200, and 500 year average recurrence intervals (ARIs).

What we did:

We simulated flows for the five Selwyn River/Waikirikiri foothill catchments using the Rainfall Dependent Infiltration (RDI) model within the DHI MIKE+ 1D software platform. Recorded rainfall was used in the RDI model to simulate flows at locations where flow was recorded. Model parameters were then adjusted until there was a good match between simulated flow and recorded flow. Calibrated RDI models then generated design flows, from South Island East Coast design rainfall profiles provided by Tonkin and Taylor, for the required range of storm durations and ARIs.

What we found:

Our simulated flows provided a reasonable fit to recorded flows for the Selwyn River at Whitecliffs, Hawkins River at Dalethorpe Road and Hawkins River at Willows. Realistic maximum flows were also simulated for the five Selwyn River/Waikirikiri foothill catchments over the modelled 1989 to 2024 period.

The present-day simulated design flows were generally within 10 to 15% of flows derived by scaling published design flows for Selwyn River at Whitecliffs and Hawkins River at Dalethorpe Road - except for the Hororata River at downstream of Boundary Creek where our modelled flows were ~25 to 35% more than those estimated by scaling.

Climate change scenario RCP8.5 (projected to 2081-2100) increased maximum design flows for the five Selwyn River/Waikirikiri foothill catchments by 24 to 49%.

Overall, the simulated flows for recent storm events are appropriate for use in the Selwyn ROG model calibration, and the present-day and climate change adjusted design flows are appropriate for the Selwyn ROG model design runs. For the Selwyn ROG model calibration, preference should be given to using the Selwyn at Whitecliffs recorded flow over the simulated flow for Selwyn River at downstream of Flagpole Road. Care should be taken if the models are used to simulate flows for storm events that include snow to low elevations, as the snow module has not been included in these models.

[1] Representative Concentration Pathways

What does it mean?

We consider the flows produced by the Selwyn River/Waikirikiri foothill catchment models suitable for use in the Selwyn ROG model. Further development of these catchment models will be carried out in 2025/2026 so they can be utilised in live forecasting of river flows during rainfall events, to assist with flood response decision making.

How we have considered climate change:

We have modelled design flows incorporating climate change adjusted rainfall (scenario RCP8.5 to 2081-2100) to align with the rainfall inputs used in the Selwyn ROG model.

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1 Introduction

The ~770 km^2 Selwyn River/Waikirikiri catchment lies west of Christchurch, extending from the Canterbury foothills downstream to Te Waihora/ Lake Ellesmore (Figure 1-1). Across the catchment average annual rainfall varies from ~2000 mm in the foothills to ~700 mm on the plains (Topélen, 2007).

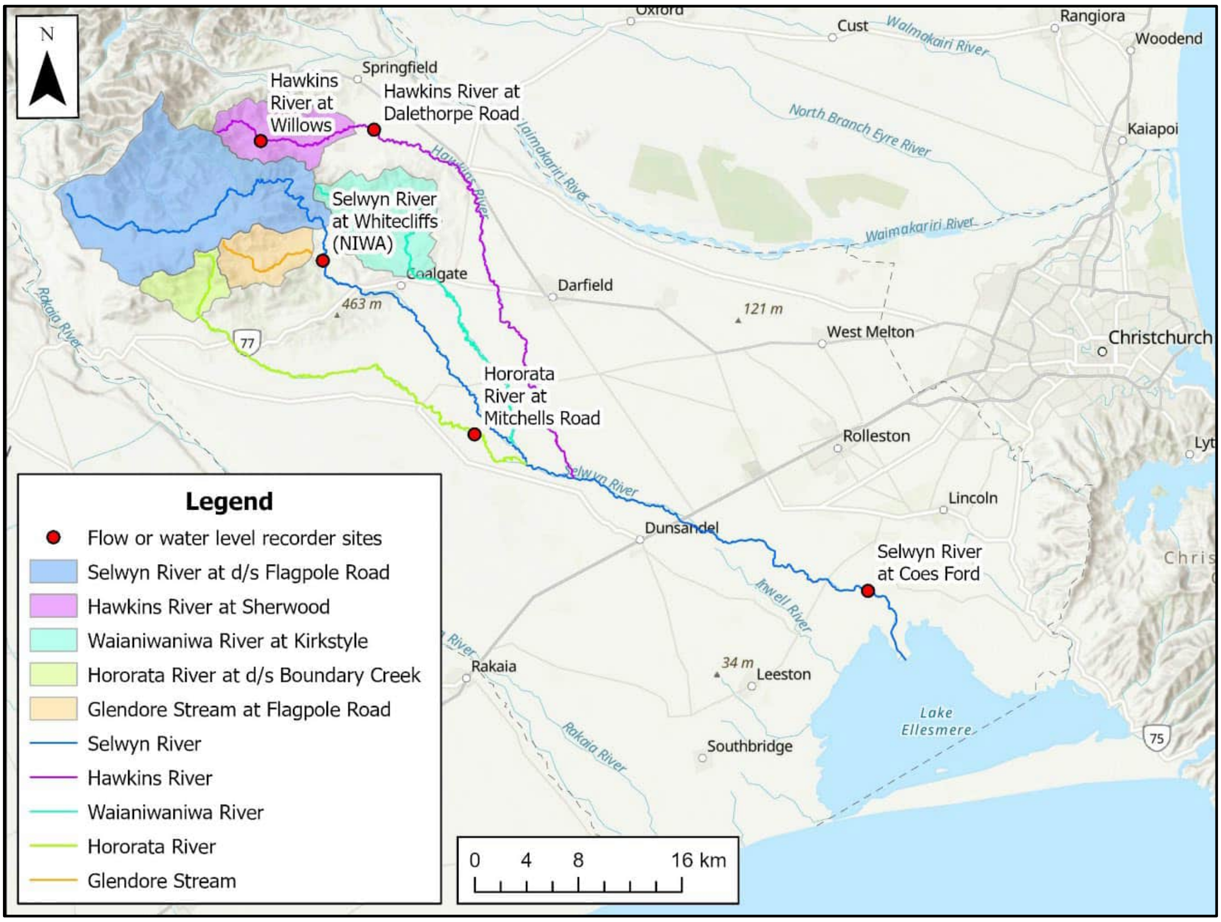


Figure 1-1: Selwyn River/Waikirikiri location map

The Selwyn River/Waikirikiri follows a depression that has formed where the Waimakariri and Rakaia River outwash fans have historically merged (CRC, 1996). The main tributaries of the Selwyn River/Waikirikiri are the Hawkins, Waiāniwaniwa and Hororata/Te Hororātā rivers. Glendore Stream also drains ~27 km^2 of the Canterbury foothills into the Selwyn River/Waikirikiri as it exits the foothills. As the upper floodplain area is largely free-draining gravels, water only flows along the full length of the Selwyn River/Waikirikiri for a few months of the year. The upper reaches of the main tributaries also tend to remain dry for long periods during the year (Vincent, 2005).

1.1 Selwyn rain on grid (ROG) model

A rain on grid model of the Selwyn District (Selwyn ROG model), which includes the Selwyn River/Waikirikiri catchment, has been developed by Tonkin and Taylor (T+T) for the Selwyn District Council (SDC). This model updates the existing flood hazard information for the Selwyn District floodplain and main townships.

As Environment Canterbury will be one of the primary end users of the Selwyn ROG model, we produced design flows for the five largest Selwyn foothill catchments contributing flow to the model, to assist with its development. Flows exiting these five catchments were introduced into the Selwyn ROG model as flow boundary conditions, which enabled the model grid extent to be reduced (to exclude the five foothill catchments areas). This reduced the Selwyn ROG model run times and lessened the likelihood of other computational issues, which may arise from the simulation of rainfall runoff on large, steeply sloping, catchment areas. The five Selwyn River/Waikirikiri foothill catchments are shown in Figure 1-1 and Figure 1-2. They are:

- Selwyn River at downstream of Flagpole Road
- Hawkins River at Sherwood
- Waiāniwaniwa River at Kirkstyle
- Hororata River at downstream of Boundary Creek
- Glendore Stream at Flagpole Road

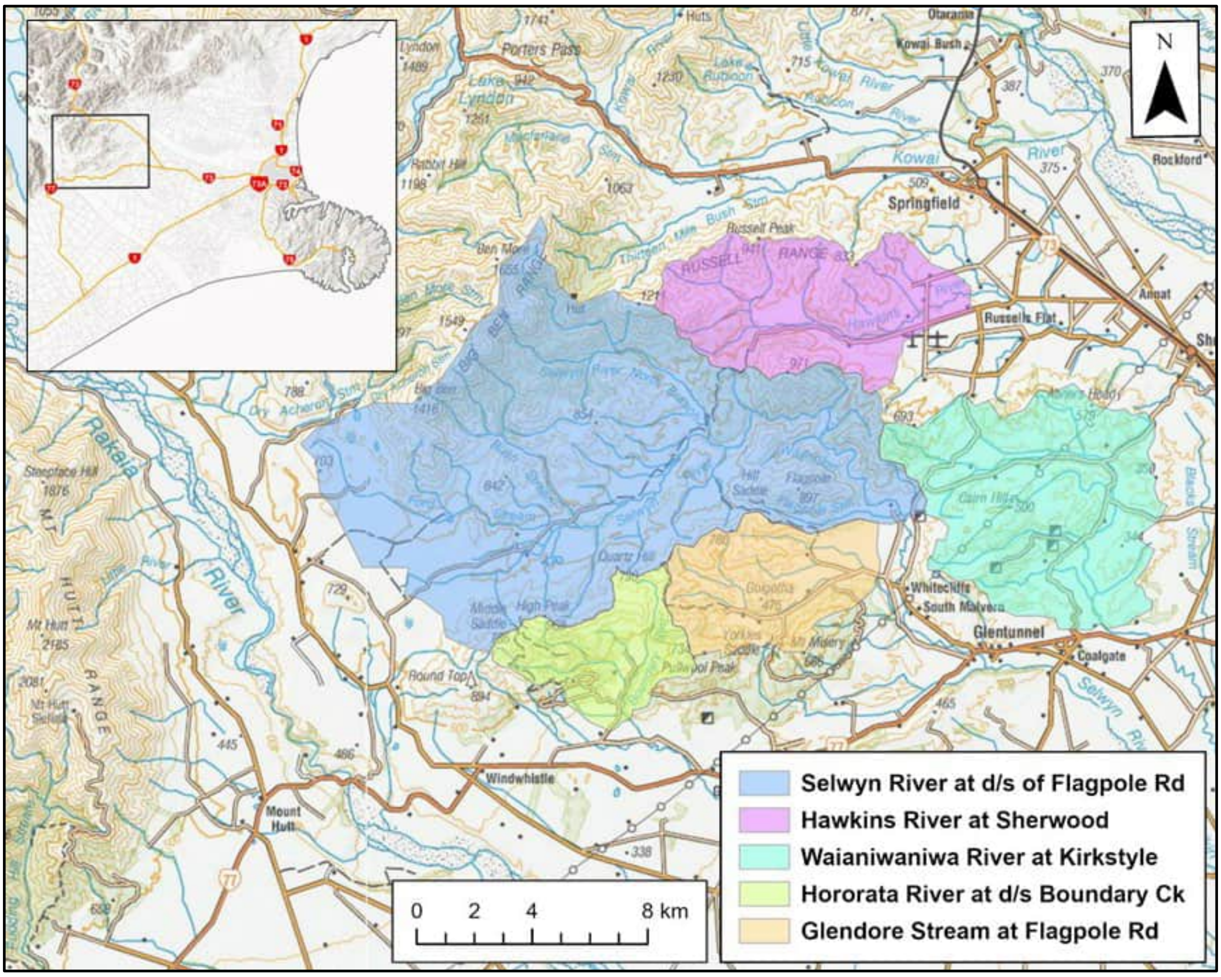


Figure 1-2: Selwyn River/Waikirikiri foothill catchments location map

1.2 RDI modelling of five Selwyn River/Waikirikiri foothill catchments

The five foothill catchments shown on Figure 1-2 were delineated using topographic maps (but could be refined in the future using the latest LiDAR data to better define the boundaries and catchment areas). Unfortunately, these five foothill catchments do not have flow recorders at the locations where flow boundaries are required for the Selwyn ROG model (Figure 1-3). To derive design flows for these locations we initially developed a hydrological Mike+ 1D Rainfall Dependent Infiltration (RDI) model for the Selwyn River. at Whitecliffs catchment (Figure 1-3). This model, which converts rainfall into flow, was calibrated using recorded local rainfall (with modelled flow compared to the recorded Selwyn River at Whitecliffs flow). To enable the model to be validated, the rainfall and flow records were divided into two time periods so the model could be validated with a period not included in the calibration.

We then used Selwyn River at Whitecliffs RDI model parameters as the basis for validating Hawkins River at Dalethorpe Road and Hawkins River at Willows RDI models, using the same local rain gauges along with characteristics specific to each Hawkins River catchment. The different scaling of evaporation and rainfall between the Selwyn and Hawkins RDI models meant two separate RDI models were developed to simulate flow from rainfall for the five required Selwyn River/Waikirikiri foothill catchments. One model simulated the Selwyn River/Waikirikiri flows and the other model simulated Hawkins River, Waiāniwaniwa River, Hororata River/Te Hororātā, and Glendore Stream flows – based on the assumption that the smaller foothill catchments were more likely to respond like the smaller Hawkins River catchments than the larger Selwyn River/Waikirikiri catchment.

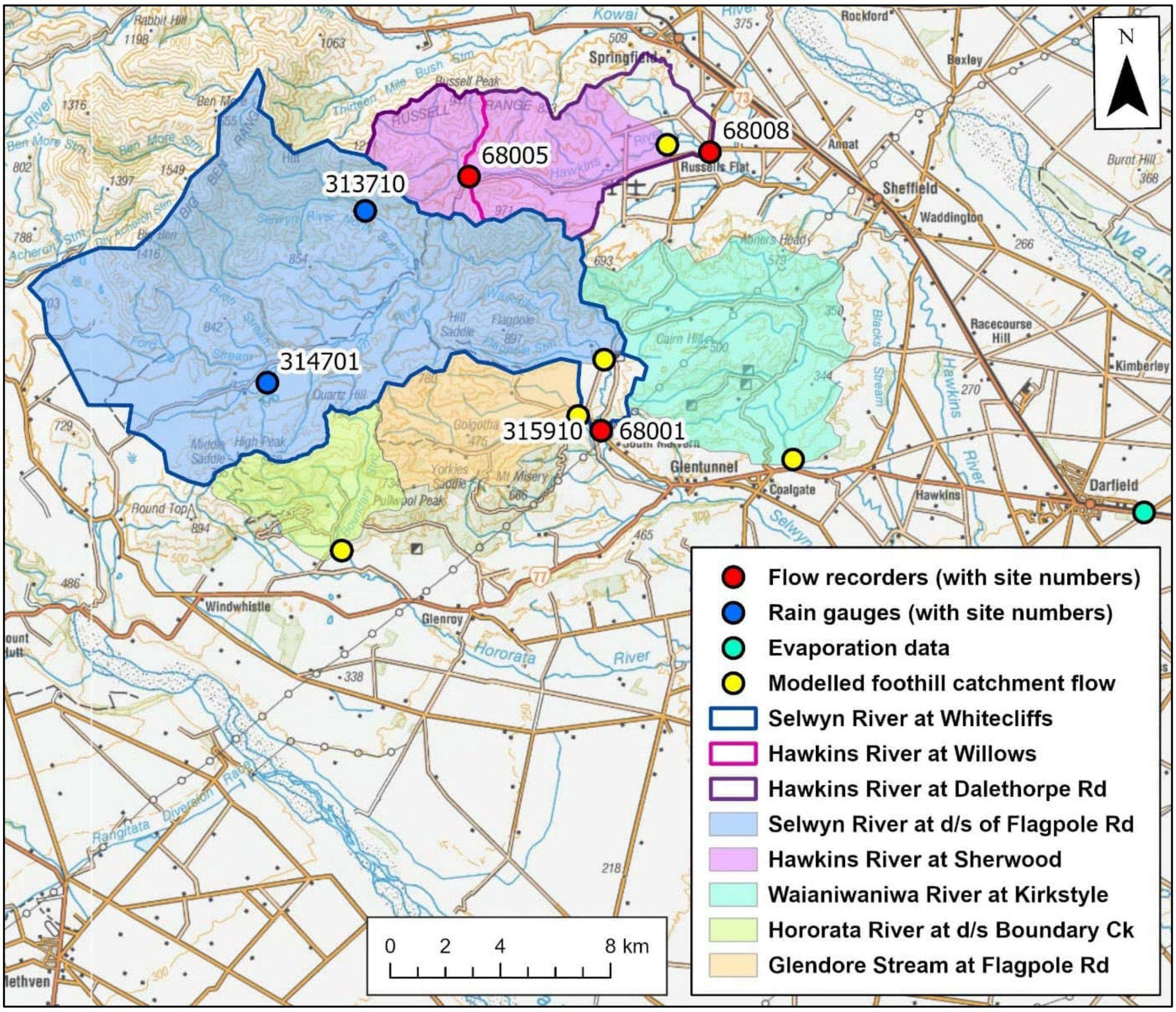


Figure 1-3: Location of recorders and modelled foothill catchment flows [see Table 3-1 and Table 3-4 for rain gauge and flow recorder details, respectively]

Simulated flow hydrographs were requested by Tonkin and Taylor for the five Selwyn River/Waikirikiri foothill catchments for the following scenarios:

- June 2013 storm event
- July 2017 storm event
- May 2021 storm event
- Present-day and climate change adjusted (RCP-8.5 projected to 2081-2100) design flows for 1, 6, 12, 24, 48, and 72 hour storm durations and 10, 100, 200, and 500 year average recurrence intervals (ARIs).

These scenarios are a combination of simulated flows for recent floods, simulated flows which could occur for a range of present-day rainfall intensities and durations, and simulated flows which could occur for projected rainfall intensities and durations for a future climate scenario. For the present-day and climate change adjusted design storm events, the rainfall time series were provided by Tonkin and Taylor for the rain gauge recorder sites shown on Figure 1-3.

2 Catchment description

2.1 Selwyn River/Waikirikiri foothill catchment characteristics

The Selwyn River/Waikirikiri foothill catchments vary in size from 20 to 155 km^2, draining the foothills area from as far west as the Big Ben Range and Russell Range. Based on the New Zealand Land Cover Database (LCDB version 5, lris.scinfo.org.nz/) and aerial photography, land within the Selwyn River/Waikirikiri foothill catchments is largely steeply sloping tussock grassland, low producing grassland and forested areas (indigenous and exotic), with higher producing exotic grassland on the more gently sloping land. Table 2-1 summarises the Selwyn River/Waikirikiri foothill catchment areas, channel lengths, channel slopes and derived time of concentration. All the Selwyn River/Waikirikiri foothill catchments have similar land cover and average channel slopes of between 7 to 38 m/km, except for the smaller and steeper Hawkins at Willows catchment.

Table 2-1: Selwyn River/Waikirikiri foothill catchment characteristics

Site name	Catchment area (km^2)	Main channel length (km)	Channel slope (equal area) (m/km)	Channel slope (average) (m/km)	Catchment time of concentration (hours)[a]
Selwyn River at Whitecliffs	159	36.5	6	7	12.0 – 14.9
Hawkins River at Willows	14.3	4.8	51	102	1.5 – 1.6
Hawkins River at Dalethorpe Road	47.7	18.0	12	34	5.1 – 7.3
Selwyn River at downstream of Flagpole Road	154.4	33.2	6	7	11.1 – 13.6
Hawkins River at Sherwood	40.2	16.0	13	38	4.6 – 6.5
Waiāniwaniwa River at Kirkstyle	57.3	17.5	5	10	6.3 – 8.3
Hororata River at downstream of Boundary Creek	20.5	7.2	29	34	2.6
Glendore Stream at Flagpole Road	26.9	10.2	11	28	3.4 – 4.4

[a] The range in catchment time of concentration is calculated by using both the Bransby Williams and Temez equations. See Appendix 1 for details.

2.2 Catchment soils and soil drainage

Table 2-2 summarises soil types and dominant drainage for each Selwyn River/Waikirikiri foothill catchment. All Selwyn River/Waikirikiri foothill catchments are generally a mixture of loams (stony, sandy, and silt) that are well, moderately, or imperfectly drained (although some have small pockets of poorly or very poorly drained soils).

Table 2-2: Selwyn River/Waikirikiri foothill catchment soil descriptions

Site name	Main soil types[a]	Dominant drainage[a]
Selwyn River at Whitecliffs	Loam, sandy loam, silty loam, silty loam over loam, and silty loam over loamy peat	Well, moderately well and imperfectly drained
Hawkins River at Willows	Stony silt loam and silt loam	Well and imperfectly drained
Hawkins River at Dalethorpe Road	Silty loam and silty loam over clay	Well, moderately well, imperfectly and poorly drained
Selwyn River at downstream of Flagpole Road	Loam, sandy loam, silty loam, silty loam over loam, and silty loam over loamy peat	Well, moderately well, imperfectly and very poorly drained
Hawkins River at Sherwood	Silty loam and silty loam over clay	Well, moderately well, imperfectly and poorly drained
Waiāniwaniwa River at Kirkstyle	Silty loam over sandy loam, silty loam/stony loam, silty loam over clay	Well, moderately well, imperfectly, and poorly drained
Hororata River at downstream of Boundary Creek	Loam and silty loam	Well, moderately well, imperfectly and poorly drained
Glendore Stream at Flagpole Road	Loam and silty loam	Well, imperfectly and very poorly drained

[a] Landcare S-map online (S-Map Online | Manaaki Whenua - Landcare Research)

2.3 Historic flood events

Historic flood event data is useful for model calibration and validation. As the purpose of this modelling exercise is to convert design rainfall data into design flows, historic data is only helpful if we have both rainfall and flow data for the events. Since no rainfall data is available for events prior to 1988, only events that occurred after this date can be used for model calibration and validation.

Table 2-3 summarises events from 1988 onwards that are used for model calibration and validation. Most events have a peak flow at Selwyn River at Whitecliffs (Site 68001) greater than a 5 year ARI (120 m^3/s, Lintott and Martin, 2023) but some smaller magnitude calibration and validation storm events, that likely caused surface flooding, are also included. For example, the July 2019 event where localised flooding around Hororata was observed to be almost as much as for the July 2017 event, despite the Selwyn River at Whitecliffs peak flow being only 21 m^3/s.

Table 2-3: Summary of recent storm events in the Selwyn River/Waikirikiri foothill catchments (1989 to present)

Event	Description of event	Selwyn River at Whitecliffs peak flow (m^3/s)
25-28 July 1994	A strong easterly flow followed by a slow-moving front (moving south over the whole country during 25 to 28 July), brought heavy easterly rainfall to the eastern districts of Canterbury. During this event Selwyn River/Waikirikiri flood levels came within 30 mm of stopbank crests in the Coes Ford area. However, Lake Ellesmere levels were low and the opening to the sea remained open (Vesey, 1994).	152
18-20 August 2000	Typical easterly heavy rain event with large low developing over the North Island and a strong southeast flow over Canterbury (overrun at slightly higher levels by a milder and moister easterly to northeasterlies). A record 1.8 m of snow at Mt Hutt. Dry conditions before the event most likely prevented flooding from being worse. (hwe.niwa.co.nz/event/August_2000_South_Island_Flooding)	343
11-13 January 2002	Heavy rain along the east coast from 11 to 13 January. Result of a large, slow-moving low moving eastwards towards the North Island. East to northeast flow covered central and southern New Zealand. Frontal rain band moved southwards onto the South Island. (hwe.niwa.co.nz/event/January_2002_South_Island_and_Waikato_Flooding)	218
30 July – 1 August 2008	On 28 July a low developed over most of the Tasman Sea, moving south-east to lie east of the South Island on 30 July. This brought heavy rain to the east coast of the South Island. (hwe.niwa.co.nz/event/July_2008_New_Zealand_Severe_Storm) On 31 July ~20cm of snow fell in Temuka and other parts of inland Canterbury. (NIWA Climate Summary, 0807sum.pdf).	130
25-27 May 2010	Wettest week in Canterbury in 36 years. A front travelled down the North Island carrying heavy rain before stalling over Canterbury due to a low pressure system over the Tasman Sea. A cold, strong, southerly flow brought snow to low levels in Canterbury. https://hwe.niwa.co.nz/event/May_2010_New_Zealand_Storm On 27 May snow closed Porters Pass. (Climate_summary_May2010_FINAL)	109
16-19 June 2013	On 17 June there was widespread flooding in Christchurch of roads and several houses as well as closing several shops, schools, and roads in the Canterbury area. On 20 June flood water entered several houses in Leeston as well as causing traffic disruptions and closing schools in the area. (climate_summary_june_2013_final.pdf)	60
17-19 April 2014	Ex-tropical cyclone Ita, located to the west of the North Island, brought heavy rain and strong winds. It moved southwards during the period 17-19 April bringing heavy rain that caused flooding. https://hwe.niwa.co.nz/event/April_2014_New_Zealand_Storm	104
6-7 April 2017	Remnants of Cyclone Debbie brought heavy rain and flooding. https://hwe.niwa.co.nz/event/April_2017_New_Zealand_Ex_Cyclone_Debbie	63

Event	Description of event	Selwyn River at Whitecliffs peak flow (m^3/s)
21-22 July 2017	A large complex low-pressure system slowly moved east over the country, directing a strong and moist south-easterly flow across the South Island. hwe.niwa.co.nz/event/July_2017_New_Zealand_Flood There was no mention of snow in the NIWA Monthly Climate Summary (Climate_Summary_July_2017.pdf)	153
30 July – 2 August 2019	On 30/31 July a southerly change brought snow together with strong, cold southerlies. Environment Canterbury Duty Flood Controller Log documented someone from Hororata saying on the morning of the 31 July that “there was quite a bit of flooding around up there”. Environment Canterbury staff visited the Hororata area around 1pm that day and assessed flooding to “not be as severe as July 2017 but getting close”. In the Selwyn District several properties were flooded. (https://niwa.co.nz/sites/default/files/Climate_Summary_July_2019_Finalweb.pdf)	21
29 May – 1 June 2021	A large complex low pressure system occurred to the west of the North Island, moving slowly south-eastwards. This directed a strong and moist south-easterly flow across the South Island and brought widespread rain to most of NZ including the Canterbury region. People were evacuated from Peel Forest. (https://hwe.niwa.co.nz/event/May_2021_Canterbury_Flooding) At high elevations there was also significant snowfall. Mt Hutt ski area observed 5cm at ~1440 m above sea level (asl), increasing to 30-40 cm (1610 m asl) and 4 metres (2080 m asl). (Climate_Summary_May_2021_Final.pdf)	223
19-20 November 2022	A low pressure system brought heavy rain to Canterbury including around the eastern foothills. Relatively short duration rainfall event on catchments with dry antecedent conditions.	45
23-24 July 2023	Slow-moving low to the east of NZ directed a moist easterly flow over the South Island. The Selwyn River/Waikirikiri had overflows into the Irwell River and across SH1. Coes Ford peaked at 284 m^3/s. A man was rescued from the roof of his vehicle in the Hawkins River floodwaters. Mt Hutt ski area reported ~70 cm of fresh snow at their base area (1610 m asl). (Climate_Summary_July_2023_Final.pdf)	91

3 Available data

The location of rainfall, flow, and evaporation data used within this modelling study are shown in Figure 1-3. These data are described in more detail below.

3.1 Rainfall

There are three rainfall sites in the Selwyn River/Waikirikiri foothill area (Table 3-1 and Figure 1-3). Mean annual rainfall for these sites varied from 940 to 1193 mm for the period of overlapping record (1989 to 2023). Table 3-2 provides a summary of maximum 3 and 12-hour rainfall depths for the events summarised in Table 2-3. This indicates that flooding is caused by a range of different rain patterns, and that the highest rainfall depths do not always occur at the same rainfall site.

Table 3-1: Summary of available rainfall data

Site	Site name	Elevation (m)	Source	Start date	Mean annual rainfall (1989 to 2023, mm)
313710	Selwyn at 13 Mile Bush	488	Environment Canterbury	1 Jan 1963	1193
314701	Selwyn at High Peak	457	Environment Canterbury	1 Jan 1958	973
315910	Selwyn at Whitecliffs	280	Environment Canterbury	26 May 1988	940

Table 3-2: Maximum 12 hour rainfall depths (mm) for recent storm events (3 hour rainfall depths in brackets)[a]

Rainfall event	13 Mile Bush (Site 313710)	High Peak (Site 314701)	Whitecliffs (Site 315910)
July 1994	66 (24)	60 (20)	55 (26)
August 2000	82 (27)	117 (36)	90 (26)
January 2002	74 (24)	56 (18)	61 (22)
July 2008	49 (18)	79 (25)	53 (16)
May 2010	54 (20)	59 (21)	52 (17)
June 2013	32 (11)	35 (20)	40 (21)
April 2014	41 (19)	56 (22)	57 (28)
April 2017	45 (17)	59 (21)	52 (16)
July 2017	64 (21)	88 (33)	73 (28)
July 2019	42 (18)	55 (19)	68 (37)
May 2021	130 (40)	110 (32)	100 (28)
November 2022	60 (23)	44 (16)	57 (21)
July 2023	61 (21)	81 (26)	73 (26)

[a] Calculated over a rolling time window over the duration of the storm event

To determine which rainfall site(s) should be used for modelling flows for each Selwyn River/Waikirikiri foothill catchment, we calculated Thiesson polygons. Thiesson polygons partition the Selwyn

River/Waikirikiri foothill catchment area up into non-overlapping polygons representing the areas that are closest to each rainfall site. Thiesson polygons are often utilised in catchment modelling for determining catchment rainfall. For example, a recent DHI flood forecasting model for the Opihi River, using an RDI model, compared catchment rainfall derived using Thiesson polygons to catchment rainfall based on an 8 kilometre grid superimposed on the Opihi sub-catchments (DHI, 2023). This study concluded that, for the Opihi sub-catchments, the Thiesson polygons produced a better calibration.

The Thiesson polygon rainfall weighting for each catchment can be adjusted to account for rain gauges that may be more representative of catchment rainfall. This will usually be a judgement (based on knowledge of the catchment) when only limited spatial rainfall data is available. For example, if one rain gauge is located within the catchment, while another is in an adjacent catchment (close by but on the other side of a mountain barrier), the rain gauge located within the catchment may be given a higher weighting to better represent rainfall in the catchment. Conversely, prevailing wind conditions may lead to a more distant rain gauge (upwind of the catchment) being more representative of catchment rainfall. For this study we adjusted rainfall weightings iteratively to reduce the difference between the recorded and modelled water balance (mean flow) and to improve the match between recorded and modelled peak flows (Table 3-3). For example, we adjusted the Hawkins River at Dalethorpe Road catchment area to 70% (0.7) 13 Mile Bush rainfall and 30% (0.3) Whitecliffs rainfall to better represent rainfall in the catchment during southerly storm events. It was also considered more appropriate to use the Whitecliffs rainfall for the Hororata River at downstream of Boundary Creek catchment (rather than the High Peak rainfall) due to the catchment and Whitecliffs rain gauge both being located adjacent to the Selwyn floodplain, where they are exposed to similar storm events approaching from the south and east. Table 3-3 summarises the proportion of each catchment that is represented by each rainfall site using the Thiesson polygon method.

Table 3-3: Thiesson polygon rainfall weighting for Selwyn River/Waikirikiri foothill catchments

Site	Site name	Catchment area (km^2)	Rainfall sites		
			13 Mile Bush (Site 313710)	High Peak (Site 314701)	Whitecliffs (Site 315910)
68001	Selwyn River at Whitecliffs	159	0.39	0.48	0.13
68005	Hawkins River at Willows	14	1.00 (0.70)	-	- (0.30)
68008	Hawkins River at Dalethorpe Road	48	0.90 (0.70)	-	0.10 (0.30)
-	Selwyn River at downstream of Flagpole Road	154	0.40	0.50	0.10
-	Hawkins River at Sherwood	40	0.95 (0.70)	-	0.05 (0.30)
-	Waiāniwaniwa River at Kirkstyle	57	-	-	1.00
-	Hororata River at downstream of Boundary Creek	21	-	1.0 (-)	- (1.00)
-	Glendore Stream at Flagpole Road	27	-	0.25 (-)	0.75 (1.00)

() = Adjusted Thiesson polygon rainfall weighting values (to better represent catchment)

The rainfall data can also be scaled to increase or decrease the amount of rainfall contributed by each rain gauge. For example, if a rain gauge is located at a lower elevation (e.g., on the windward side of a barrier), it may underestimate rain falling at higher elevations (on the same windward side of the barrier). Scaling of rainfall data is described in Section 5.

3.2 River flow

The Selwyn River at Whitecliffs (Site 68001) and Hawkins River at Dalethorpe Road (Site 68008) flow recorders are currently operating in the Selwyn River/Waikirikiri foothill catchments (Table 3-4 and Figure 1-3). The Hawkins River at Dalethorpe Road recorder was installed as a replacement for the Hawkins River at Willows recorder after it was damaged in the May 2021 storm event.

At these sites, water level is recorded and then flow is determined by applying a rating curve (i.e., a water level to flow relationship). Rating curves are produced for each site by fitting a curve to a series of gauged flows at a range of water levels. Where high flows have not been gauged, there is considerable uncertainty in the magnitude of the high flows estimated using the rating curve. Table 3-4 summarises maximum flows (generated from recorded water level using rating curves) and maximum gauged flows. All these sites are quality assured on a monthly to quarterly basis (by NIWA or Environment Canterbury) to ensure the data available for analysis has any irregularities removed (e.g., data spikes, offsets where water levels have been artificially increased, etc). However, both the Hawkins River sites have only been gauged at flows that are ~10% of the maximum flows (and the Selwyn at Whitecliffs ~50% of the maximum flows). This indicates that ratings (and therefore high flows) could be improved further by gauging at higher flows.

Table 3-4: Summary of available flow data

Site	Site name	Area (km^2)	Time step (min)	Source	Start date (End date)	Mean flow (m^3/s)	Max flow (m^3/s)	Max gauged flow (m^3/s)
68001	Selwyn River at Whitecliffs	159	5[a]	NIWA	26 May 1964	3.1[c]	343	178
68005	Hawkins River at Willows	14.3	5[b]	Environment Canterbury	15 Dec 2005 (30 May 2021)	0.3	29.4	2.4
68008	Hawkins River at Dalethorpe Road	47.7	5	Environment Canterbury	22 Sept 2022	0.5	33.4	3.8

[a] 15 minute time step until 2/7/2015
[b] 15 minute time step until 8/8/2019
[c] 1989 to 2023 (inclusive)

Based on available flow records and regional flood estimation methods, Lintott and Martin (2023) and Tonkin and Taylor (2017) derived design flows for four Selwyn River/Waikirikiri foothill catchments (Table 3-5).

Table 3-5: Design flows for Selwyn River/Waikirikiri foothill catchments

Site	Site name	Area (km^2)	Method	Design flow (m^3/s)			
				10 year	100 year	200 year	500 year
68001	Selwyn River at Whitecliffs	159[a]	L&M (2023)	170	330	380	440
68005	Hawkins River at Willows	14	L&M (2023)	17	28	31	36
68006	Hororata River at Mitchells Road	97	L&M (2023)	37	57	63	71
1680108	Waiāniwaniwa River at Coaltrack Road	117	T+T (2017)	75	130	140	165

L&M (2023) = Lintott and Martin (2023)
T+T (2017) = Tonkin and Taylor (2017)
[a] Lintott and Martin (2023) use a different catchment area to what has been calculated for this study.

These sites either had a flow record or were required for flood modelling and analysis purposes (e.g., Waiāniwaniwa River at Coaltrack Road). Lintott and Martin (2023) included the May 2021 flow data, which resulted in a significant shift in the design flow magnitudes for some sites. Lintott and Martin (2023) flows are used in preference over those produced by Tonkin and Taylor (2017) for the Selwyn River/Waikirikiri catchment.

Care should be taken when using the Hororata River at Mitchells Road design flows as the rating for this site is unreliable for higher flows. Once the main watercourse is overflowing, water disperses over a large area with very little increase in water level. This catchment also has a large proportion of floodplain area compared to the Hororata River at downstream of Boundary Creek catchment which only extends as far as the base of the foothills.

No flow record exists for the Waiāniwaniwa River. Design flows for the Waiāniwaniwa River at Coaltrack Road were determined by using nearby representative flood frequency sites to estimate a rainfall adjusted mean annual flood factor and 100 year ARI growth factor. For more details see T+T (2017, p143) where it is noted that "t*here remains notable uncertainty in the 100 year ARI growth factor selected and the resulting flood estimates*". The Waiāniwaniwa River at Coaltrack Road catchment also has a large proportion of floodplain area compared to the Waiāniwaniwa River at Kirkstyle catchment which only extends as far as the base of the foothills.

Design flows for the five Selwyn River/Waikirikiri foothill catchments were derived by scaling the design flows for both Selwyn River at Whitecliffs and Hawkins River at Willows using the following relationship:

$$Q_{foothill\ catchment} = Q_{L\&M\ catchment} x \left[\frac{A_{foothill\ catchment}}{A_{L\&M\ catchment}}\right]^{0.9}$$

where
$Q_{\text{foothill catchment}}$ = design flow for foothill catchment (m^3/s)
$Q_{\text{L\&M catchment}}$ = design flow from Lintott and Martin (2023) (m^3/s)
$A_{\text{foothill catchment}}$ = foothill catchment area (km^2)
$A_{\text{L\&M catchment}}$ = Lintott and Martin catchment area (km^2)

Table 3-6 summarises the present-day peak design flows derived for the five Selwyn River/Waikirikiri foothill catchments. The range of design peak flows in Table 3-6 represents the difference between the design flows calculated using the Hawkins at Willows flow record (lower design peak flow estimate) versus the Selwyn at Whitecliffs flow record (higher design peak flow estimate). These values are derived directly from flow records using a method that does not take storm duration into account. This means the peak design flows cannot be robustly converted into flow time-series for specific storm durations. Hence, the RDI models are being used to take the Selwyn ROG model rainfall time series (with varying storm durations and ARIs) to produce the design flow time series.

Table 3-6: Estimate of present-day design peak flows for Selwyn River/Waikirikiri foothill catchments (derived from Selwyn at Whitecliffs and Hawkins at Willows design peak flows)

Catchment	Area (km^2)	10 year	100 year	200 year	500 year
Selwyn River at downstream of Flagpole Road	155	160[a]	310[a]	360[a]	420[a]
Hawkins River at Sherwood	40	43-48	71-93	79-107	92-124
Waiāniwaniwa River at Kirkstyle	57	60-66	98-128	109-148	126-171
Hororata River at downstream of Boundary Creek	21	24-26	39-51	43-59	50-68
Glendore Stream at Flagpole Road	27	30-33	50-65	55-75	64-87

[a] Based only on Selwyn River at Whitecliffs

3.3 Potential evapotranspiration

Evapotranspiration combines evaporation (conversion of water in soil and surface waters from a liquid to a gas) and transpiration (process during photosynthesis where plant leaves release water vapour). Actual evapotranspiration is the measured amount of water released into the atmosphere based on real-world conditions (e.g., available water) while potential evapotranspiration estimates how much evapotranspiration would occur if there was no limit to water availability under standard climatic conditions. The RDI model uses potential evaporation, along with model parameters, to calculate evapotranspiration.

The Darfield weather station is located ~12 km south-east of the Waiāniwaniwa River at Kirkstyle catchment at an elevation of 195 m above mean sea level (Figure 1-3). Daily evaporation (raised pan) data were extracted from the National Climate Database (CliDB)[2] for Darfield (CliDB Agent Number 4836) for 1980 to 2014. As daily data were not available for more recent years, we generated an evaporation time series using average daily evaporation rates for each month (Table 3-7). We calculated this using the time series from 1989 to 2014 - excluding the evaporation data from 1980 to 1988 as it was prior to the Selwyn at Whitecliffs rainfall gauge becoming operational, and outside of the period simulated by the RDI model. Average evaporation data used for the daily time series equated to 751 mm of evaporation annually.

As the aim of this study was to simulate flood events (where evapotranspiration was not particularly significant), a more detailed potential evaporation time series was not generated.

Table 3-7: Mean monthly evaporation (mm/day) – Darfield (1989 to 2014)

Month	Average evaporation (mm/day)
January	3.9
February	3.4
March	2.5
April	1.4
May	0.8
June	0.4
July	0.5
August	0.8
September	1.6
October	2.4
November	3.2
December	3.8

3.4 Water balance

Calculating the various components of a catchment's water balance helps us to understand the water cycle within the catchment and provides a sense check of the rainfall and flow data. Water losses for the Selwyn River at Whitecliffs and Hawkins River at Willows catchments were estimated by converting long term rain gauge mean annual rainfall depths and catchment mean annual outflow into equivalent mean catchment water depths. The difference between rainfall entering the catchment, and flows leaving the catchment, represents catchment water losses (i.e., evapotranspiration, groundwater recharge and soil storage).

[2] https://niwa.co.nz/climate-and-weather/national-climate-database

3.4.1 Selwyn River at Whitecliffs catchment

Water losses from the Selwyn River at Whitecliffs catchment were estimated for 1989 to 2023.

Catchment mean annual rainfall depth

Based on mean annual rainfall depths for the three rain gauges in the catchment (Table 3-1), and Thiesson polygon rainfall weighting for each rain gauge (Table 3-3), the mean annual rainfall depth for the catchment has been calculated (Table 3-8). This equates to an average of 1055 mm of water depth over the entire catchment each year due to rainfall.

Table 3-8: Selwyn River at Whitecliffs catchment mean annual rainfall depth

	13 Mile Bush	High Peak	Whitecliffs	Total
Mean annual rainfall (1989-2023) (mm)	1193	973	940	
Proportion of catchment rainfall applied to	0.39	0.48	0.13	1.0
Contribution to catchment mean annual rainfall depth (mm)	465	467	122	1055

Catchment mean annual flow

From 1989 to 2023 the mean annual flow for Selwyn River at Whitecliffs (Site 68001) was 3.13 m^3/s. Assuming a catchment area of 159.1 km^2, this equates to an average of 621 mm of water depth (over the entire catchment area) exiting the catchment each year as river flow.

Summary

The mean catchment rainfall depth available for water losses is estimated to be 434 mm (i.e., 1055 mm of rainfall with 621 mm of catchment outflows subtracted).

3.4.2 Hawkins River at Willows catchment

Water losses from the Hawkins at Willows catchment were estimated for 2006 to 2020.

Catchment mean annual rainfall depth

Based on mean annual rainfall depths for the rain gauges in the catchment (Table 3-1), and Thiesson polygon rainfall weighting for each rain gauge (Table 3-3), the mean annual rainfall depth for the catchment was calculated (Table 3-9). This equated to an average of 1114 mm of water depth over the entire catchment each year due to rainfall.

Table 3-9: Hawkins River at Willows catchment mean annual rainfall depth

	13 Mile Bush	Whitecliffs	Total (mm)
Mean annual rainfall (2006-2020) (mm)	1190	936	
Proportion of catchment rainfall applied to	0.70	0.30	1.0
Contribution to catchment mean annual rainfall depth (mm)	833	281	1114

Catchment mean annual flow

From 2006 to 2020 the mean annual flow for Hawkins at Willows (Site 68005) was 0.26 m^3/s. Assuming a catchment area of 14.3 km^2, this equated to an average of 574 mm of water depth (over the entire catchment area) exiting the catchment each year as river flow.

Summary

The mean catchment rainfall depth available for water losses is 540 mm (i.e., 1114 mm of rainfall with 574 mm of catchment outflows subtracted). This indicates likely greater water losses (to evapotranspiration, groundwater and/or soil storage) for the Hawkins at Willows catchment compared to the Selwyn River at Whitecliffs catchment. This may be due to the Hawkins at Willows catchment having a larger proportion of forested area.

4 Model description

The rainfall runoff (RR) module of the DHI MIKE+ 1D river modelling software was used to generate Selwyn River/Waikirikiri foothill catchment flows for the Selwyn ROG model. Recorded rainfall was used to simulate calibration event flows, and the present-day and climate change adjusted design rainfall was used to simulate design storm event flows.

Of the hydrological models available within the RR module, we selected the Rainfall Dependent Infiltration (RDI) rainfall runoff model. This model is used internationally for a wide range of climatic conditions and catchment characteristics. It is also versatile as it can be used to model single events as well as undertake continuous hydrological modelling. At Environment Canterbury the RDI model is currently also being used for flow forecasting. It is anticipated that the five Selwyn River/Waikirikiri foothill catchments will be incorporated into a new flow forecasting model for the Selwyn River/Waikirikiri. This will be documented separately.

The RDI model is a deterministic, lumped, conceptual model that converts precipitation and potential evaporation into a flow series at the catchment outlet. Compared to a physically based model, the RDI lumped, conceptual model is more simplified (i.e., it focuses on the fundamental physical principles and semi-empirical equations and ignores some of the more complex components found in physically based model computations). As parameters within the model are averaged over an entire catchment, physical catchment data can only be used as a guide, and final parameter values are calibrated against recorded flow time series at the catchment outlet. The RDI model structure is shown in Figure 4-1.

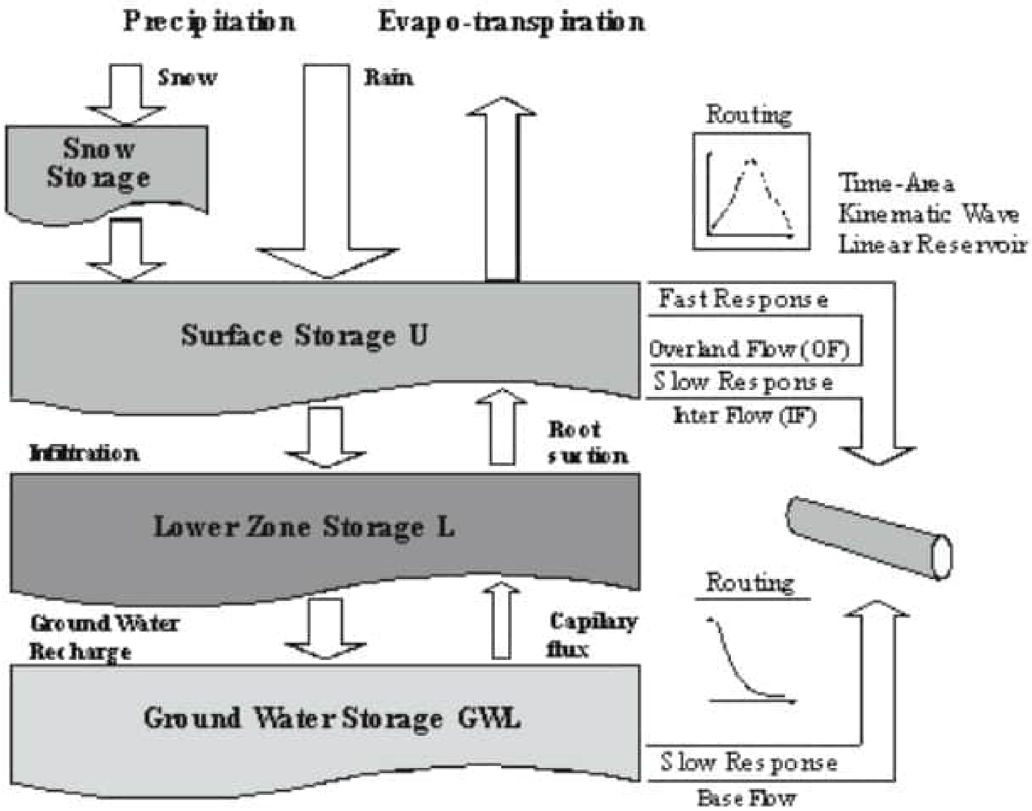


Figure 4-1: RDI model structure. Source: DHI (2025, Figure 7.1, p 168)

The main components within the RDI model are the rapidly responding overland flow, and the slower responding inter- and base-flow. These flows are modelled as a function of the interrelated moisture contents in the storages described in Table 4-1.

Table 4-1: Description of RDI model storage

Snow storage	Precipitation controlled by temperature and current amount of snow lying on the ground. Precipitation is either retained as snow or diverted to surface storage.
Surface storage, U	Includes moisture intercepted by vegetation, stored in surface depressions, and stored in the thin layer of ground immediately below the surface (usually around 10-20 mm). Water is continuously lost from the surface storage as evaporation and interflow (horizontal leakage). When excess water is available (i.e., U>Umax) overland flow and infiltration into the lower (root) zone and groundwater storage occur.
Lower (root) storage, L	Layer below the ground surface where transpiration by vegetation takes place. The moisture content determines the volume of percolation into the groundwater zone, and the amount of interflow and overland flow.
Groundwater storage, GWL	Infiltrated water that percolates down through the lower (root) storage provides recharge to the groundwater storage. Baseflow comes from the groundwater storage.

Note: The storage parameters are an average over the whole catchment so are often difficult to determine.

To match the rainfall and flow input data, we used a model time step of 15 minutes. The main model surface and lower (root) zone, and groundwater model parameters are summarised in Appendix 2. Selwyn River/Waikirikiri foothill catchment model input data and catchment characteristics are described in Section 2 and 3. A more detailed description of the model and model parameters is provided by DHI (2025), which is the main source of the information summarised above.

We calibrated the Selwyn River at Whitecliffs model by adjusting the main and threshold surface and lower (root) storage parameters. Default values were used for the ground water parameters and snowmelt was not included due to a lack of data.

4.1 Model limitations

The limited availability of recorded rainfall and flows across the five Selwyn foothill catchments provided uncertainty – particularly for extreme storm events that occurred infrequently and other events where rainfall was not evenly distributed across the catchments. For example, the Waiāniwaniwa River, Hororata River/Te Hororātā, and Glendore Stream foothill catchments do not have any rain gauges or flow recorders within the catchment areas where flows are required.

For the Selwyn ROG model, where a range of storm durations and ARIs are required, the RDI model was able to provide the required flow time series. The limitations of the RDI model were partially addressed by undertaking a model sensitivity assessment (Section 5.5) where the various model inputs and model parameters were adjusted to determine how strongly each influenced modelled catchment flows. The snow storage module was not used due to a lack of available data. However, this was not considered a problem for the simulated Selwyn ROG model flows as the calibration events were unlikely to have had significant (if any) snowfall within the five Selwyn foothill catchments for the larger July 2017 and May 2021 storm events.

5 Calibration and validation

5.1 Summary

We initially developed a RDI model for the Selwyn River at Whitecliffs catchment as this catchment had three available rain gauges and a flow time series at the catchment outlet (Selwyn River at Whitecliffs). To ensure the Selwyn River at Whitecliffs RDI model was producing accurate flow simulations, we divided the 1989 to 2024 period into a calibration period (January 2010 to May 2024) and a validation period (January 1989 to December 2009). The calibration period was used to adjust the RDI model parameters so that the simulated flows provided a good match to the recorded flows. The validation period used the RDI model parameters determined by the calibration model to assess the model performance. RDI parameters are described in Appendix 2.

As additional flow data were available for the adjacent Hawkins River at Willows and Hawkins River at Dalethorpe Road catchments, we also developed validation models for these catchments using the Selwyn River at Whitecliffs RDI model parameters – the exception being the time constants for routing (i.e., CK_{IF}, $CK_{1,2}$ and CK_{BF} parameters which are dependent on catchment size and how fast it responds to rainfall). Rainfall distribution was also adjusted for these catchments.

The model calibration and validation are outlined in more detail below.

5.2 Calibration

5.2.1 Selwyn River at Whitecliffs (2010 to 2024)

The main components of the Selwyn River at Whitecliffs calibration model are:

- Rainfall (Table 3-1) - rainfall depths were accumulated over a 15 minute time interval to match the flow data and model time step.
- Model parameters (Appendix 2) – generally empirical and conceptual (so not able to be properly determined by physical characteristics of the catchment).
- Recorded flow at downstream limit of catchment (i.e. Selwyn River at Whitecliffs)

Once the model was set up, we used the more recent part of the recorded rainfall from 1 January 2010 to 12 August 2024 to simulate flows at the Selwyn River at Whitecliffs flow site. This more recent part of the rainfall and flow data was used as it included the June 2013, July 2017 and May 2021 storm events that Tonkin and Taylor require for their Selwyn ROG model.

Evaporation and Selwyn at 13 Mile Bush rainfall were adjusted during the model calibration. This reduced the difference between the recorded and modelled water balance (mean flow) and improved the match between recorded and modelled peak flows, respectively.

Evaporation was ultimately scaled by 0.9 to account for catchment characteristics (e.g., steep south-facing slopes) in the Selwyn River/Waikirikiri foothill catchment. This adjustment helped ‘correct’ for the losses identified in the water balance described in Section 3.4 (i.e., 434 mm/year of available mean catchment rainfall depth versus the annual potential evaporation of 751 mm).

The Selwyn at 13 Mile Bush (Site 313710) rainfall was also scaled by 1.25 to account for the rain gauge potentially underestimating rainfall in the north-western portion of the catchment due to:

- the higher elevation eastern slopes of the Big Ben Range generally capturing larger volumes of rainfall in southerly or easterly events. HIRDS design 12 hour duration rainfall depths for the uppermost eastern slope of the Big Ben Range were up to 50 to 67% higher than at the Selwyn at 13 Mile Bush rain gauge location for 250 and 5 year ARI events, respectively.
- the Selwyn at 13 Mile Bush rain gauge being located, for southerly events, on the leeward side of the adjacent ‘hilly’ topography.

The proportion of the catchment attributed to each rain gauge is summarised in Table 3-3. To get the best possible match (calibration) between the modelled and recorded (Selwyn River at Whitecliffs, Site

68001) flow we optimised the model parameters using the model autocalibration feature. Table 5-1 describes the objective functions that can be optimised during the autocalibration.

Table 5-1: Selwyn River at Whitecliffs RDI calibration model objective function summary

Objective function	Description
Overall water balance	Overall volume error (good agreement between average simulated and observed catchment runoff). Assumed ~5% difference between simulated and observed runoff was acceptable (more concerned about hydrograph peak magnitude and shape being simulated well than any volume errors due to low flows being consistently over or underestimated)
Overall root mean square error (RMSE)	Good agreement of hydrograph shape. Assumed r^2 of 0.75 or greater was acceptable (Minimising RMSE maximises r^2)
Peak flow RMSE, for peak flows over a specified flow (40 m^3/s for this study)	Good agreement of timing, magnitude and volume of peak flows. A difference of 20 m^3/s was considered acceptable (i.e., ~10% of largest observed flow peaks)
Low flow RMSE, for flows less than a specified flow (10 m^3/s for this study)	Good agreement for low flow recessions and baseflows (not so important for this study)

All objective functions are given an equal weighting in the autocalibration so the objectives with less importance should not necessarily be selected for the autocalibration. DHI (2025, p 196) notes that "trade-offs often exist between the different objectives. For instance, one may find a set of parameters that provide a very good simulation of peak flows but a poor simulation of low flows, and vice versa." For this study the autocalibration stopping criterion feature runs a maximum of 2000 evaluations, testing a range of model parameters within a specified lower and upper bound as specified in Table 5-2. The RDI model parameters are described in Appendix 2.

Table 5-2: Selwyn River at Whitecliffs calibration model parameters

Parameter	Calibration value	Autocalibration		Units
		Lower bound	Upper bound	
Umax	14.4	10	30	mm
Lmax	42.7	40	200	mm
CQOF	0.55	0.3	0.9	-
Sy	0.1	-	-	-
$CK_{1,2}$	14.2	10	20	hour
CK_{IF}	151	50	1000	hour
CK_{BF}	1586	400	4000	hour
TOF	0.48	0	0.99	-
TIF	0.55	0	0.99	-
TG	0.18	0	0.99	-
Carea	1	-	-	-
Sy	0.1	-	-	-
GWLmin	0	-	-	m
GWLbf0	10	-	-	m
GWLfl1	1	-	-	m

As we are most interested in peak flows and hydrograph shape, we initially used the autocalibration to optimise the overall water balance, overall RMSE and peak flow RMSE (> 40 m^3/s) for Umax, Lmax, $CK_{1,2}$, CK_{BF}, CK_{IF}, and CQOF (while TOF, TIF and TG were set to 0). After additional manual adjustments, varying the model parameters one-by-one (to see if a better fit could be made), a second autocalibration was completed using the newly adjusted parameters as a starting point.

Umax, Lmax, and CQOF were then fixed with the values from this autocalibration (Table 5-2). CK_{IF}, $CK_{1,2}$, CK_{BF}, TOF, TIF and TG were then adjusted in a further autocalibration using the same objective functions. A final autocalibration (fixing all parameters except CK_{IF}, CK_{BF}, CQOF and TG) was then undertaken using the low flow RMSE objective function to try and improve the base flows. Sy, CQLow and CKLow were left fixed with the default values throughout the calibration process.

Visual checks of the modelled time series were completed after each calibration, along with examining the overall water balance, overall RMSE and coefficient of determination (r^2). The model parameters resulting from the calibration are shown in Table 5-2.

The calibrated model flows (mean and accumulated) were ~2.2% more than the recorded Selwyn River at Whitecliffs (Site 68001) flow for the 2010 and 2024 period. There was good agreement to the hydrograph shape (r^2=0.85) and peak flow RMSE for flows greater than 40 m^3/s (RMSE=12.8 m^3/s). We considered this acceptable for this modelling study. The recorded and modelled accumulated flows for the Selwyn River at Whitecliffs are shown in Figure 5-1.

Table 5-3 summarises the recorded and modelled Selwyn River at Whitecliffs peak flows for the flood events described in Table 2-3. Figures 5-2 and 5-3 show the recorded and modelled flood flow hydrographs for these events.

The model produced a good fit to the recorded data for a range of flood events and for the duration of the model calibration period. A key observation is that the accumulated modelled flow marginally overpredicts the recorded accumulated flow from around 2019 (Figure 5-1).

Peak modelled flows were generally within ±25% of the recorded flows, with some of the differences in both the accumulated flow and peak flows likely to be due to rainfall (or snow) in the Selwyn River at Whitecliffs catchment not being properly represented by the rainfall recorded at the rain gauges. Two of the storm events in Table 5-3 produced more significant differences between modelled and recorded peak flows:

- April 2014 - event was caused by ex-Tropical Cyclone Ita. During this event less rainfall was recorded at the High Peak and 13 Mile Bush recorders compared to at Whitecliffs. The Selwyn River at Whitecliffs flow may have been underestimated by 49% due to rainfall not being fully represented by the rain gauges (i.e., there may have been more rainfall in the catchment areas represented by the 13 Mile Bush and High Peak rain gauges than was recorded due to the location of the rain gauges and nature of the event).
- July 2019 - event occurred during a southerly storm event (with snow) that followed closely after a larger storm event that saturated the catchment. Snow may have contributed to the modelled peak Selwyn River at Whitecliffs flow being overestimated by 68%. This event was also small (peak recorded flow of 21 m^3/s), and below the peak flow threshold the model calibration focussed on.

Table 5-3: Selwyn River at Whitecliffs summary of recorded and modelled peak flows (2010 to 2023 storm events)

Rainfall event	Peak flow, m^3/s		Difference (%)
	Recorded	Modelled	
May 2010	109	107	-2
June 2013	60	60	0
April 2014	104	53	-49
April 2017	63	60	-4
July 2017	153	126	-18
July 2019[a]	21	36	+68
May 2021	223	252	+13
November 2022	45	40	-12
July 2023	91	114	+26

[a] This event is the smaller peak flow that follows a larger storm event. Saturated ground conditions meant this rainfall event produced substantial surface water runoff on the Selwyn floodplain, making it a suitable calibration event for the Selwyn ROG model.

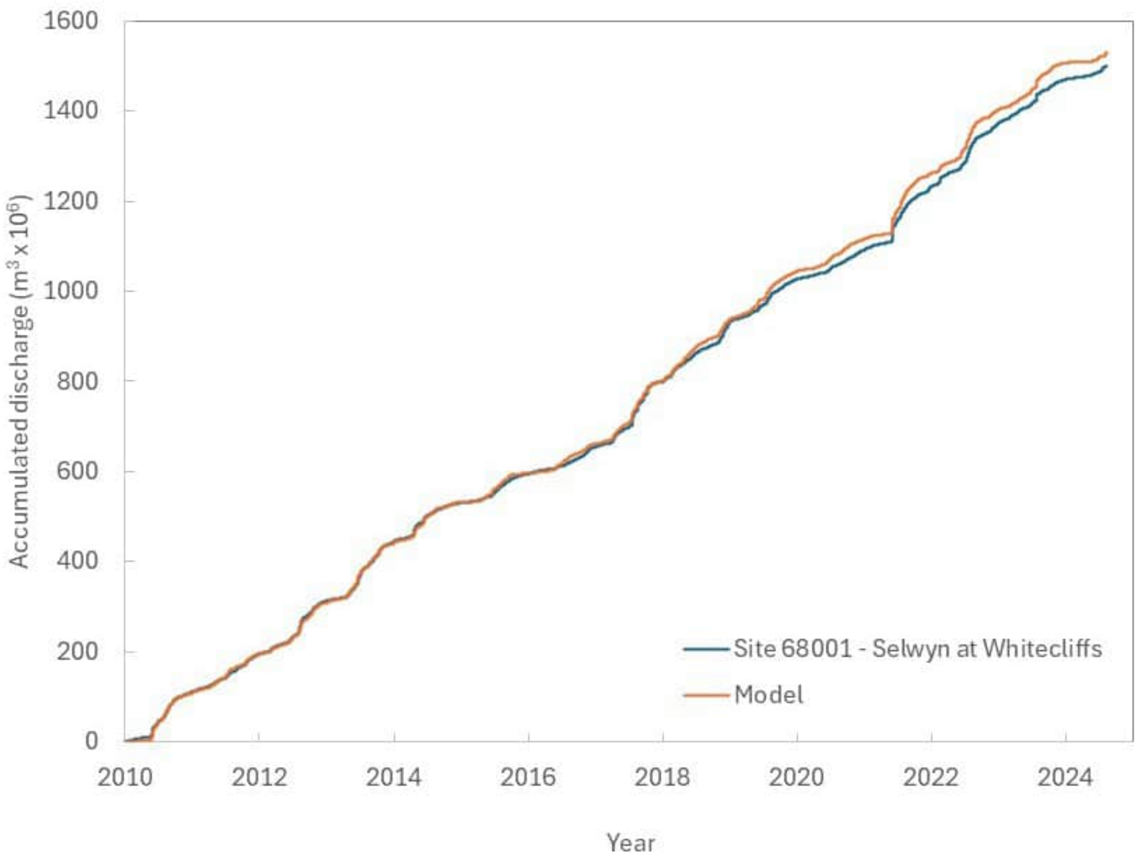
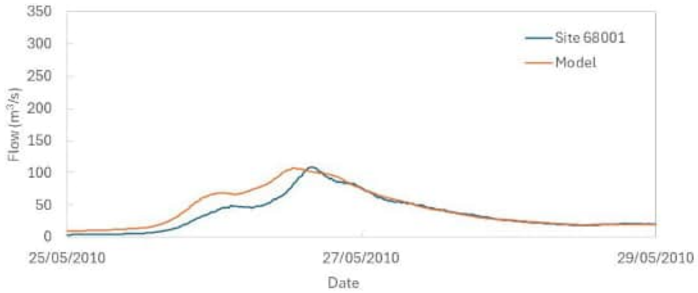
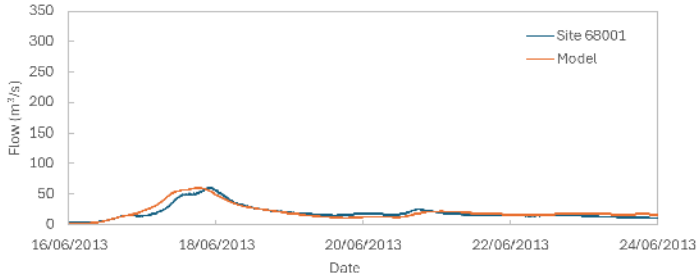


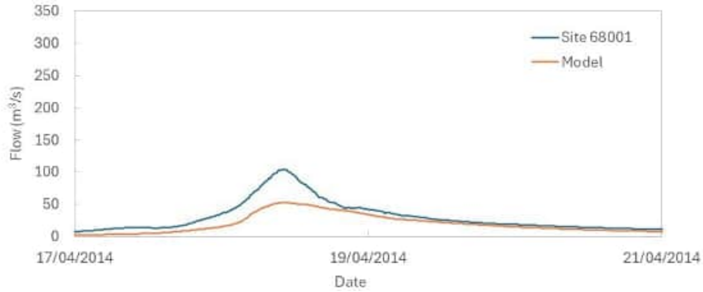
Figure 5-1: Comparison between accumulated Selwyn River at Whitecliffs recorded and modelled flows (January 2010 to August 2024)



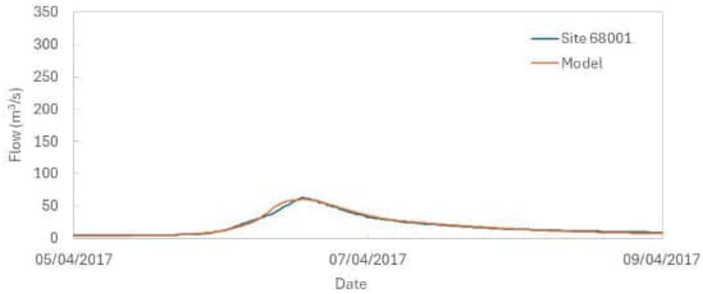
May 2010 (r^2=0.78)



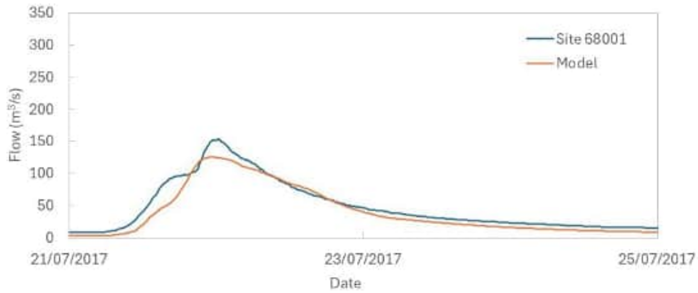
June 2013 (r^2=0.83)



April 2014 (r^2=0.56)

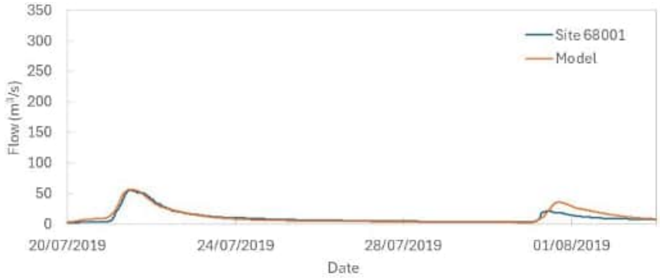


April 2017 (r^2=0.98)

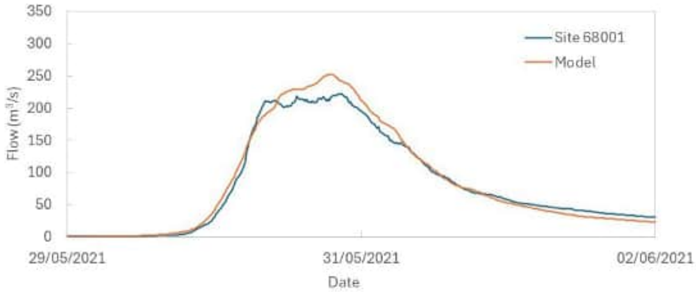


July 2017 (r^2=0.91)

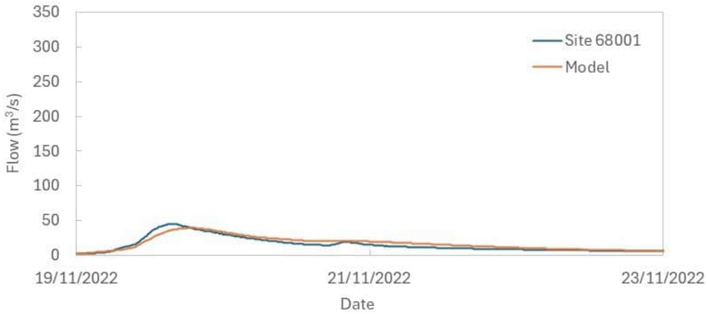
Figure 5-2: Comparison between Selwyn River at Whitecliffs recorded and modelled flood flows (2010 to 2017)



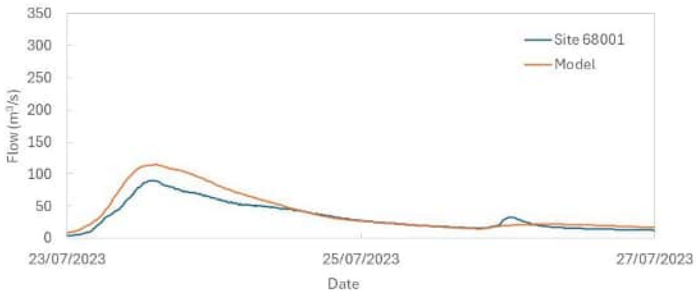
July 2019 (r^2=0.82) (*r^2=negative for 30 July to 2 August)



May 2021 (r^2=0.97)



November 2022 (r^2=0.86)



July 2023 (r^2=0.64)

Figure 5-3: Comparison between Selwyn River at Whitecliffs recorded and modelled flood flows (2019 to 2023)

5.3 Validation

To validate the Selwyn River at Whitecliffs model for use for the five Selwyn River/Waikirikiri foothill catchments, we created Selwyn River at Whitecliffs (January 1989 to December 2009), Hawkins River at Willows (December 2005 to May 2021) and Hawkins River at Dalethorpe (September 2022 to May 2024) validation models using the Selwyn River at Whitecliffs calibration model parameters.

Validation of flows for the Selwyn and Hawkins River catchments provides us with confidence that the same method for determining model parameters can be applied to the five Selwyn River/Waikirikiri foothill catchments to estimate calibration and design flow hydrographs for use in the Selwyn ROG model. The validation models are described below.

5.3.1 Selwyn River at Whitecliffs (1989 to 2009)

We validated the Selwyn River at Whitecliffs model using the remaining portion of the rainfall time series (1 January 1989 to 31 December 2009) together with the Selwyn River at Whitecliffs calibration model parameters (Table 5-2) and scaling factors (i.e., 0.9 for evaporation and 1.25 for 13 Mile Bush rainfall).

Figure 5-4 compares the recorded and modelled accumulated flows for the Selwyn River at Whitecliffs recorder. The model flow (mean and accumulated) was ~0.2% less than the recorded Selwyn River at Whitecliffs (Site 68001) flow for the 1989 and 2009 period (r^2=0.77). We considered this acceptable for this modelling study.

Table 5-4 summarises the recorded and modelled Selwyn River at Whitecliffs peak flows for the flood events between 1989 and 2009 that are described in Table 2-3. Figure 5-5 compares recorded and modelled flood flow hydrographs for these events.

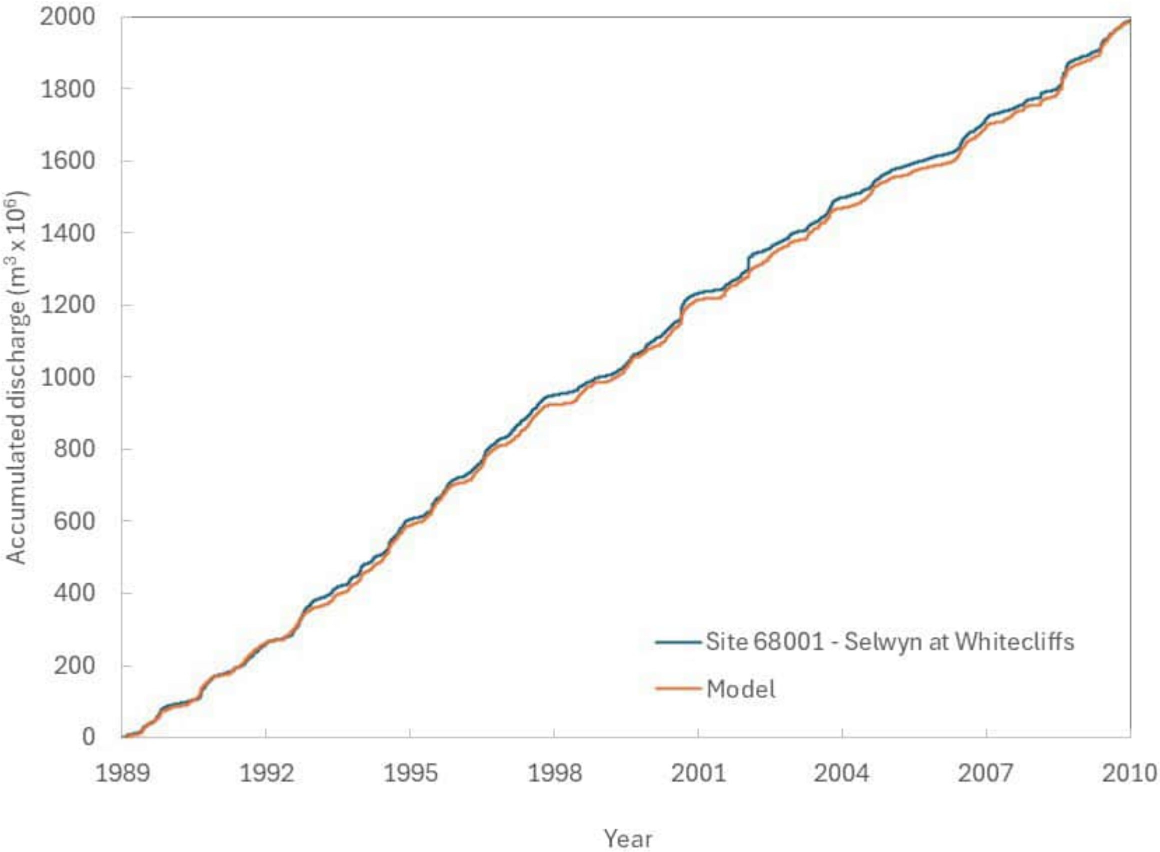
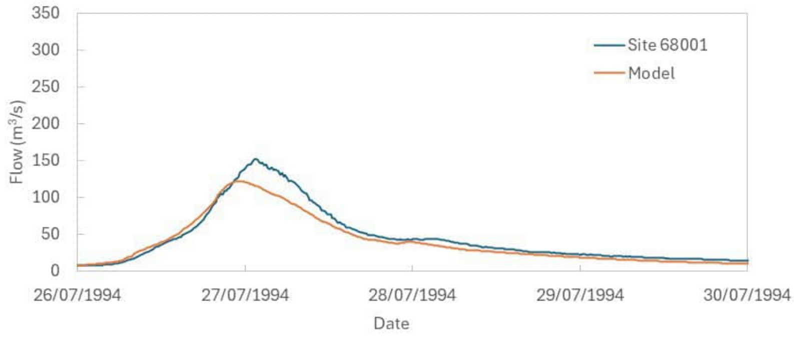


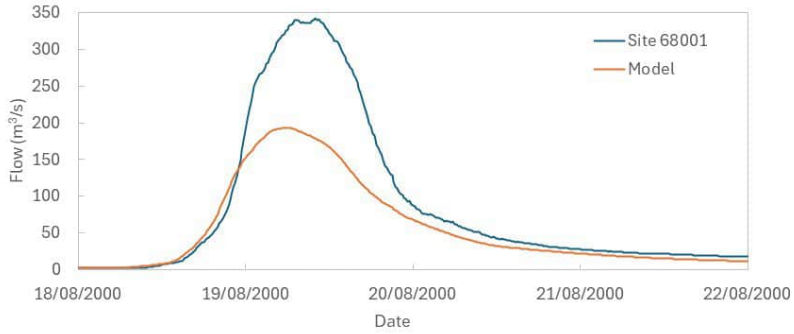
Figure 5-4: Comparison between accumulated Selwyn River at Whitecliffs recorded and modelled flows (1989 to 2009)

Table 5-4: Selwyn River at Whitecliffs summary of recorded and modelled peak flows (1994 to 2008 storm events)

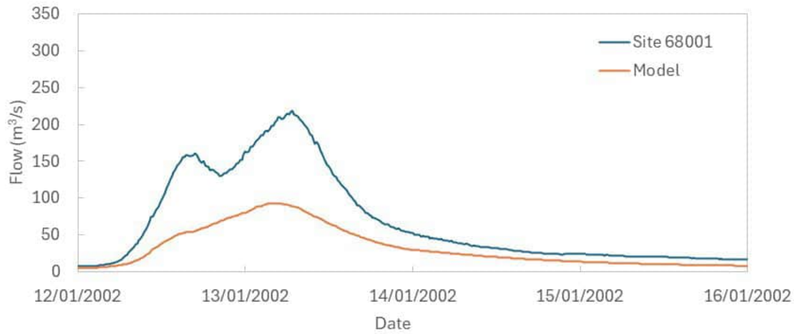
Rainfall event	Peak flow, m^3/s Recorded	Peak flow, m^3/s Modelled	Difference (%)
July 1994	152	122	-20
August 2000	343	193	-44
January 2002	218	93	-58
July 2008	130	114	-12



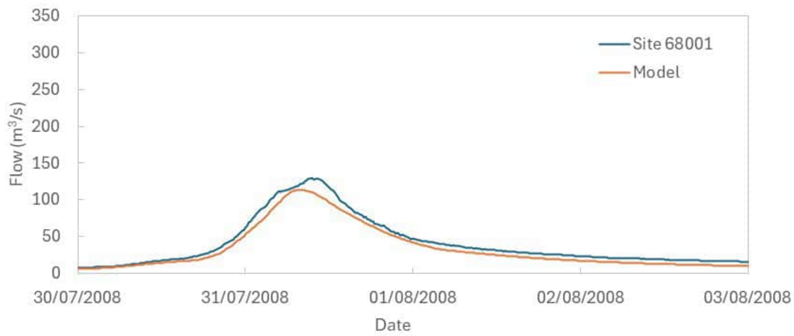
July 1994 (r^2=0.91)



August 2000 (r^2=0.70)



January 2002 (r^2=0.33)



July 2008 (r^2=0.94)

Figure 5-5: Comparison between Selwyn River at Whitecliffs recorded and modelled flood flows (1994 to 2008)

There is a reasonable fit for the July 1994 and July 2008 storm events but the peak flows for the August 2000 and January 2002 storm events are significantly underestimated by 44 to 58% and the coefficient of determination (r^2) is poor at only 0.33 for the January 2002 event, suggesting a poor fit both in magnitude and hydrograph shape.

Snowfall occurred during the August 2000 storm event so this event may be better modelled by incorporating snow into the model. For both the August 2000 and January 2002 events observed flooding on the lower Selwyn River/Waikirikiri floodplain, and recorded rainfall in the upper catchment, were not consistent with such high flows at the Selwyn River at Whitecliffs recorder. For example, based on recorded rainfall in Table 3-1, and the May 2021 recorded peak flow, it would appear unlikely that the August 2000 event would have a significantly larger peak flow, or that the January 2002 event would have a similar peak flow – even if the catchment had wet antecedent conditions for both these events. At this stage these events have not been investigated further as they are not being modelled as calibration events for the Selwyn ROG model. Given that the July 1994 and July 2008 events provide a good fit (r^2 of 0.90 and 0.94, respectively, and peak flows within 20 m^3/s of the recorded peak), we consider the model is fit for purpose for simulating Selwyn River at Whitecliffs flows for the Selwyn ROG model when recorded data is not available.

5.3.2 Hawkins River at Dalethorpe Road (2022 to 2024)

The Hawkins River at Dalethorpe Road validation model incorporated:

- Rainfall (Table 3-1) - rainfall depths accumulated over a 15 minute time interval to match the flow data and model time step.
- Selwyn River at Whitecliffs RDI model parameters - except for the CK time constant parameters (Table 5-2).
- Recorded flow at downstream limit of catchment (i.e. Hawkins River at Dalethorpe Road).

The model parameters used for the Hawkins River at Dalethorpe Road validation are shown in Table 5-5 and described in Appendix 2.

Table 5-5: Hawkins River at Dalethorpe Road model parameters

Parameter	Calibration value	Units
Umax	14.4	mm
Lmax	42.7	mm
CQOF	0.55	-
Sy	0.1	-
$CK_{1,2}$	7.0	hour
CK_{IF}	70	hour
CK_{BF}	700	hour
TOF	0.48	-
TIF	0.55	-
TG	0.18	-
Carea	1	-
Sy	0.1	-
GWLmin	0	m
GWLbf0	10	m
GWLfl1	1	m

The time constant parameter for routing interflow and overland flow, $CK_{1,2}$, depends on the catchment size and catchment response to rainfall, and determines the shape of hydrograph peaks. We have therefore based this parameter on time of concentration (Tc) for the catchment. The other time constants, CK_{IF} and CK_{BF}, are considered less important. The time constant for interflow, CK_{IF}, quantifies the surface water drainage to interflow and the time constant for baseflow, CK_{BF}, determines the hydrograph recession and hydrograph shape during dry periods. Although CK_{IF} and CK_{BF} are not considered particularly important for simulating flow hydrograph peaks, the hydrograph shape is at least partially dependent on both parameters (and catchment characteristics such as catchment size). We have therefore assumed that these two parameters will be proportional to the Selwyn River at Whitecliffs calibration model parameters (i.e., $CK_{1,2}$ was multiplied by 10 and 100 to obtain CK_{IF} and CK_{BF}, respectively).

Once the model was set up, we used the recorded rainfall from 1 January 1989 to 21 May 2024 to simulate flows at the Hawkins River at Dalethorpe Road site. The proportion of the catchment rainfall attributed to each rain gauge is summarised in Table 3-3. We did not consider it necessary to scale potential evaporation or rainfall as:

- initial modelling suggested water balance was adequate for the short record.
- the HIRDS design rainfall depths for both the Selwyn at 13 Mile Bush and Selwyn at Whitecliffs rain gauges were very similar to the average design rainfall depths across the Hawkins River at Dalethorpe Road catchment.

The recently installed recorder for Hawkins River at Dalethorpe Road (Site 68008) has only been operating since September 2022 and currently has a maximum gauged flow of ~2 m^3/s. The Darfield evaporation data, used to create the monthly average evaporation rates, also does not align with the rainfall and flow data used in this validation model. Although this may have some impact on the water balance, we consider this appropriate for this study since water losses to evaporation are likely to be low relative to rainfall inputs during flood events. We were also able to use the longer 1989 to 2024 modelled flow record to assess whether any unusual or uncharacteristic flow peaks were generated over the longer rainfall record.

Figure 5-6 compares the recorded and modelled accumulated flows for the Hawkins at Dalethorpe Road flow site for the recorded 22 September 2022 to 21 May 2024. Table 5-6 summarises the recorded and modelled Hawkins at Dalethorpe Road peak flows for the 2022 to 2024 flood events described in Table 2-3. Figure 5-7 shows the recorded and modelled flood flow hydrographs for these events.

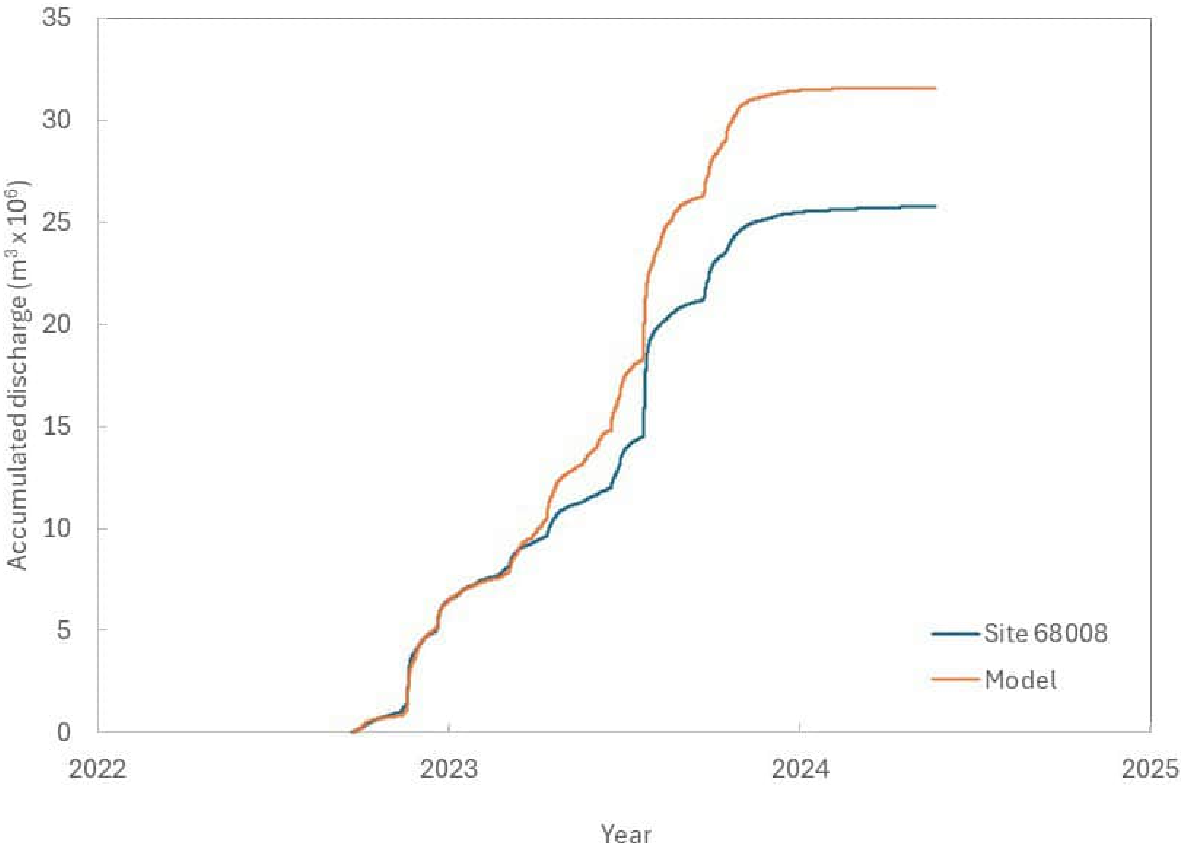


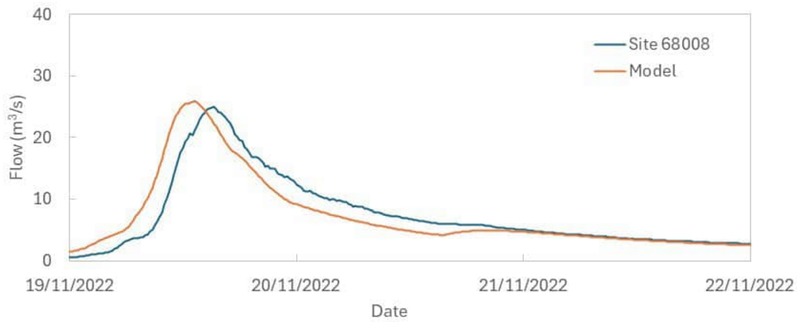
Figure 5-6: Comparison between accumulated Hawkins River at Dalethorpe Road recorded and modelled flows (September 2022 to May 2024)

Table 5-6: Hawkins River at Dalethorpe Road summary of recorded and modelled peak flows (2022 to 2023 storm events)

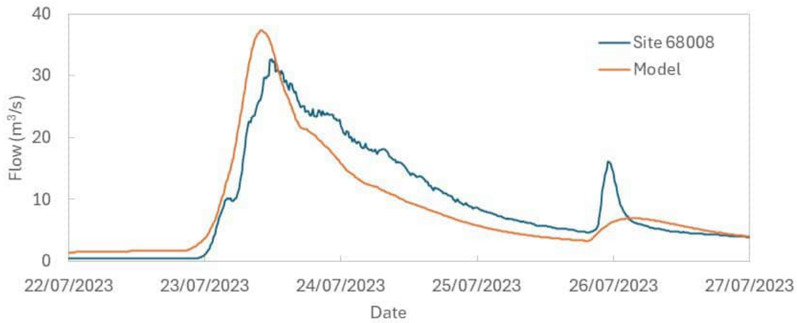
Rainfall event	Peak flow, m^3/s		Difference (%)
	Recorded	Modelled	
November 2022	25.1	25.9	+3.2
July 2023	32.6	37.3	+14.5

The model mean and accumulated flow was ~22% larger than the recorded Hawkins at Dalethorpe Road flow (Site 68008) over the September 2022 to May 2024 period. The model appears to mainly overestimate the baseflow and flows that occur due to small amounts of rainfall and we do not know how much of this difference can be attributed to the model (i.e., model parameters) versus the hydrological data (e.g., limited gauged flow data, limited spatial rainfall data coverage with no rain gauges in catchment).

Despite the difference in mean and accumulated flow, the model produced a good fit to both the November 2022 and July 2023 storm event peak flows. This demonstrated that it is valid to use the Selwyn at Whitecliffs calibrated model parameters as a proxy for the other Selwyn foothill catchments (with the exception of the CK parameters). As the events simulated were small (significantly less than a 10 year ARI), the model could be revisited once larger flood events occur.



November 2022 (r^2=0.80)



July 2023 (r^2=0.80)

Figure 5-7: Comparison between Hawkins River at Dalethorpe Road recorded and modelled flow hydrographs (2022 to 2023)

5.3.3 Hawkins River at Willows (2005 to 2021)

The Hawkins River at Willows validation model incorporates:

- Rainfall (Table 3-1) - rainfall depths accumulated over a 15 minute time interval to match the flow data and model time step.
- Selwyn River at Whitecliffs model parameters - except for the CK time constant parameters (Table 5-2).
- Recorded flow at downstream limit of catchment (i.e. Hawkins River at Willows).

The model parameters for the Hawkins River at Willows validation model are shown in Table 5-7 and described in Appendix 2. As for the Hawkins River at Dalethorpe Road validation model, we have based $CK_{1,2}$ on time of concentration (Tc) for the catchment and $CK_{1,2}$ was multiplied by 10 and 100 to obtain CK_{IF} and CK_{BF}, respectively.

Table 5-7: Hawkins River at Willows model parameters

Parameter	Calibration value	Units
Umax	14.4	mm
Lmax	42.7	mm
CQOF	0.55	-
Sy	0.1	-
$CK_{1,2}$	1.5	hour
CK_{IF}	15	hour
CK_{BF}	150	hour
TOF	0.48	-
TIF	0.55	-
TG	0.18	-
Carea	1	-
Sy	0.1	-
GWLmin	0	m
GWLbf0	10	m
GWLfl1	1	m

Once the model was set up, we used the recorded rainfall from 15 December 2005 to 30 May 2021 to simulate flows at the Hawkins River at Willows site. The proportion of the catchment attributed to each rain gauge is summarised in Table 3-3. We did not consider it necessary to scale evaporation and rainfall as:

- initial modelling suggested water balance was good (i.e., around 5% difference between simulated and observed runoff volumes before adjustments to the proportion of the catchment attributed to each rain gauge).
- High Intensity Rainfall Design System (HIRDS) design rainfall depths for the Selwyn at 13 Mile Bush and Selwyn at Whitecliffs rain gauge locations were similar to average design rainfall depths across the Hawkins River at Willows catchment.

In Figure 5-8 we compared the recorded and modelled accumulated flows for the Hawkins River at Willlows flow recorder. Table 5-8 summarises the recorded and modelled Hawkins River at Willows peak flows for the 2008 to 2017 flood events described in Table 2-3. Figures 5-9 and 5-10 show the recorded and modelled flood flow hydrographs for these events.

The model mean and accumulated modelled flow was ~1.3% more than the recorded Hawkins at Willows flow (Site 68005) over the December 2005 to May 2021 period. This may have been improved by scaling evaporation or rainfall, but we have not considered this necessary for this study since it is only a small over-estimation of the mean modelled flows, and we are more interested in the flood hydrographs. The model appears to have a relatively good fit to the peak flow magnitudes - although the modelled flows tended to produce a 'peakier' hydrograph shape and the timing of the rising limb varied for some events, reducing the coefficient of determination (r^2) to as low as 0 for the extended June 2013 storm event.

Despite the differences in the flood hydrographs, we consider the model to have produced a reasonable estimate of flood hydrographs for peak flows of ~11 m^3/s or greater, indicating this method for determining model parameters should be acceptable for the smaller Selwyn River/Waikirikiri foothill catchments (i.e., Hororata River downstream of Boundary Creek and Glendore Stream to Flagpole Road). We do however note that the events the model was validated for are all less than a present-day 10 year ARI (17 m^3/s), and the rain gauges used for the validation model are all located outside of the catchment. The catchment area is also less than 10% of the catchment area of the Selwyn River at Whitecliffs, used for the calibration model.

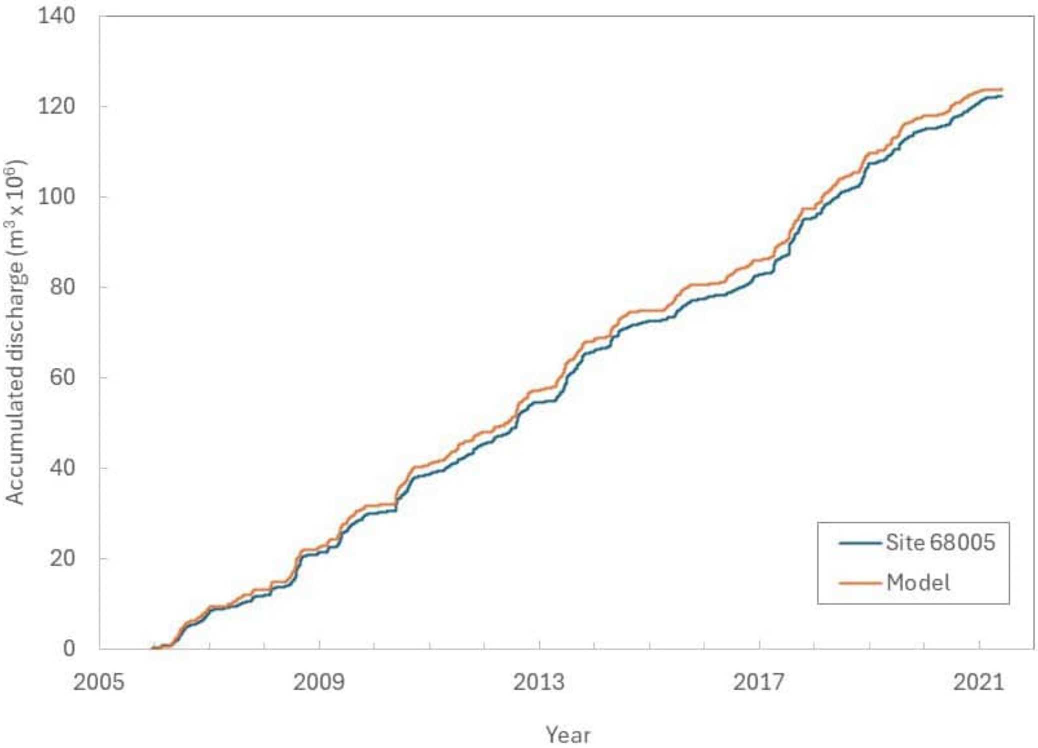
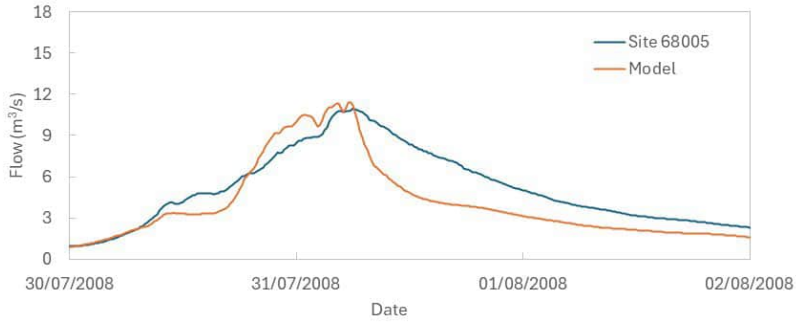


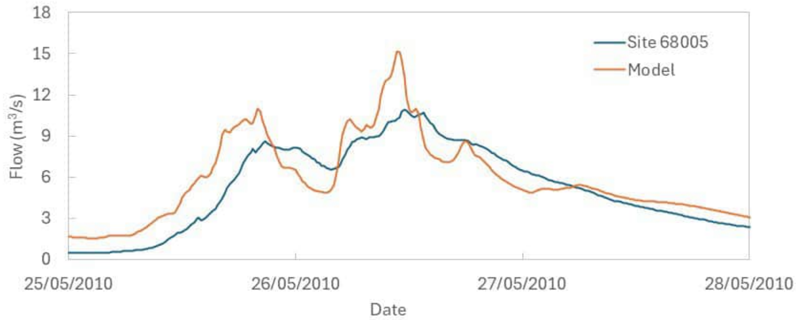
Figure 5-8: Comparison between accumulated Hawkins River at Willows recorded and modelled flows (December 2005 to May 2021)

Table 5-8: Hawkins River at Willows summary of recorded and modelled peak flows (2008 to 2017 storm events)

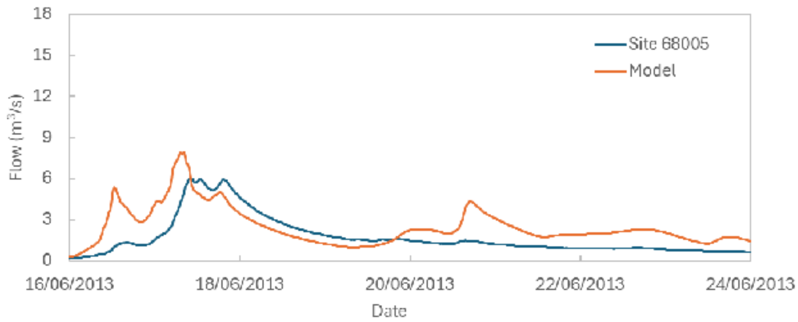
Rainfall event	Peak flow, m^3/s		Difference (%)
	Recorded	Modelled	
July 2008	11.0	11.4	+3.9
May 2010	10.9	15.2	+39.1
June 2013	6.0	7.9	+31.6
April 2014	10.1	14.0	+39.5
April 2017	12.3	10.9	-11.7
July 2017	15.6	15.4	-1.7



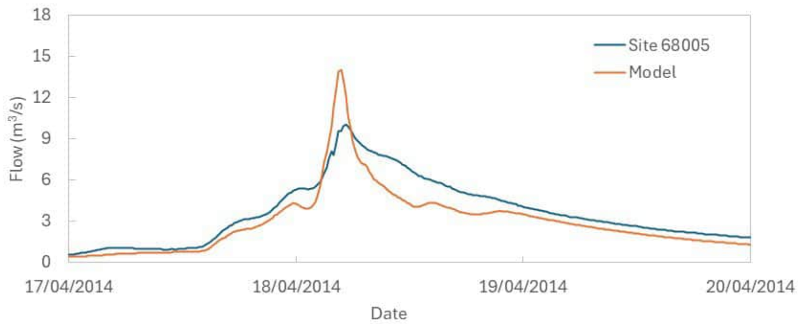
July 2008 (r^2=0.60)



May 2010 (r^2=0.68)

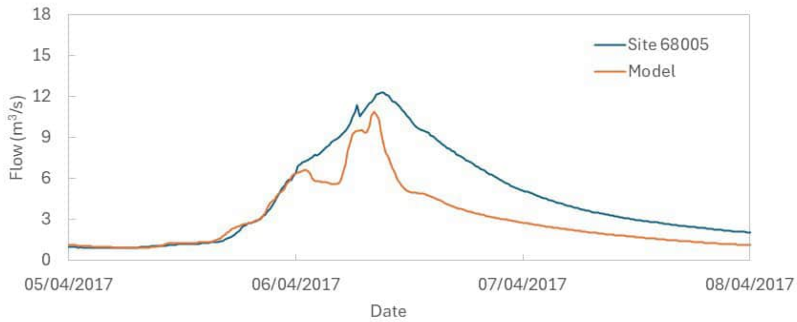


June 2013 (r^2=0)

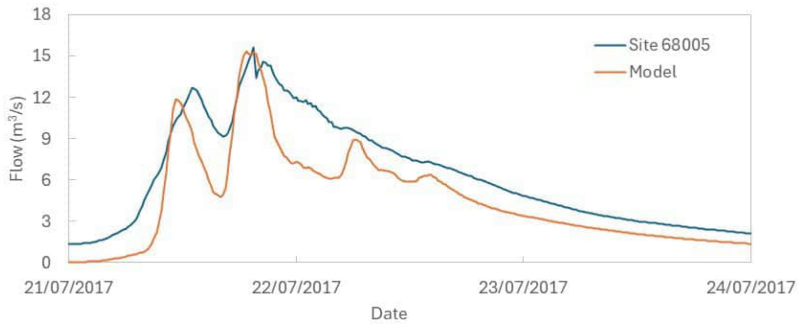


April 2014 (r^2=0.77)

Figure 5-9: Comparison between Hawkins River at Willows recorded and modelled flow hydrographs (2008 to 2014)



April 2017 (r^2=0.58)



July 2017 (r^2=0.65)

Figure 5-10: Comparison between Hawkins River at Willows recorded and modelled flow hydrographs (2017)

5.4 Modelled historic flow time series for Selwyn River/Waikirikiri foothill catchments

As all five Selwyn River/Waikirikiri foothill catchments have similar catchment characteristics, we assumed that most model parameters and hydrological inputs could be based on the Selwyn River at Whitecliffs calibration model (Table 5-9, see Appendix 2 for description of model parameters). The main exceptions being:

- the CK parameters (used for routing overland flow, interflow and baseflow) were adjusted for each catchment to reflect the varying catchment sizes. Where calibration data were not available, we based the $CK_{1,2}$ parameter on time of concentration (Tc), and CK_{IF} and CK_{BF} were assumed to be $CK_{1,2}$ multiplied by 10 and 100, respectively. The CK parameters are summarised in Table 5-10 (see Appendix 2 for description of model parameters).
- the Selwyn River to downstream of Flagpole Road catchment had evaporation scaled by 0.9 and Selwyn at 13 Mile Bush rainfall scaled by 1.25 (as described in Section 5.2.1 for the Selwyn River at Whitecliffs catchment model). The four other catchment models had no scaling for evaporation or Selwyn at 13 Mile Bush rainfall.

We then simulated a continuous historic flow time series for each of the five Selwyn River/Waikirikiri foothill catchments for the 1989 to 2024 period. Figure 5-11 to Figure 5-13 compare the Selwyn River at Whitecliffs recorded flow to the modelled flows (Selwyn River at Whitecliffs and the five Selwyn River/Waikirikiri foothill catchments) for the storm events used in the calibration of the Selwyn ROG model.

Table 5-9: Selwyn River/Waikirikiri foothill catchment model parameters

Parameter	Calibration value	Units
Umax	14.4	mm
Lmax	42.7	mm
CQOF	0.55	-
Sy	0.1	-
TOF	0.48	-
TIF	0.55	-
TG	0.18	-
Carea	1	-
Sy	0.1	-
GWLmin	0	m
GWLbf0	10	m
GWLfl1	1	m

Table 5-10: CK parameters for models of Selwyn River/Waikirikiri foothill catchments

Catchment	$CK_{1,2}$	CK_{IF}	CK_{BF}
Selwyn River at Whitecliffs	14.2	151	1586
Hawkins River at Willows	1.5	15	150
Hawkins River at Dalethorpe Road	7.0	70	700
Selwyn River at downstream of Flagpole Road	13.0	130	1300
Hawkins River at Sherwood	6.0	60	600
Waiāniwaniwa River at Kirkstyle	8.0	80	800
Hororata River at downstream of Boundary Creek	2.6	26	260
Glendore Stream at Flagpole Rd	4.0	40	400

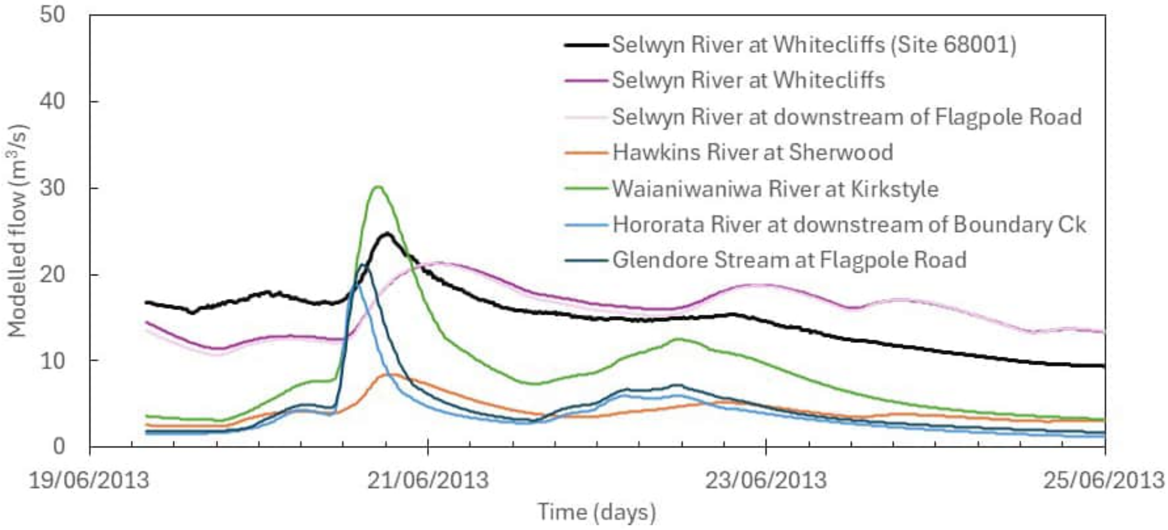


Figure 5-11: June 2013 – modelled Selwyn River/Waikirikiri foothill catchment flows

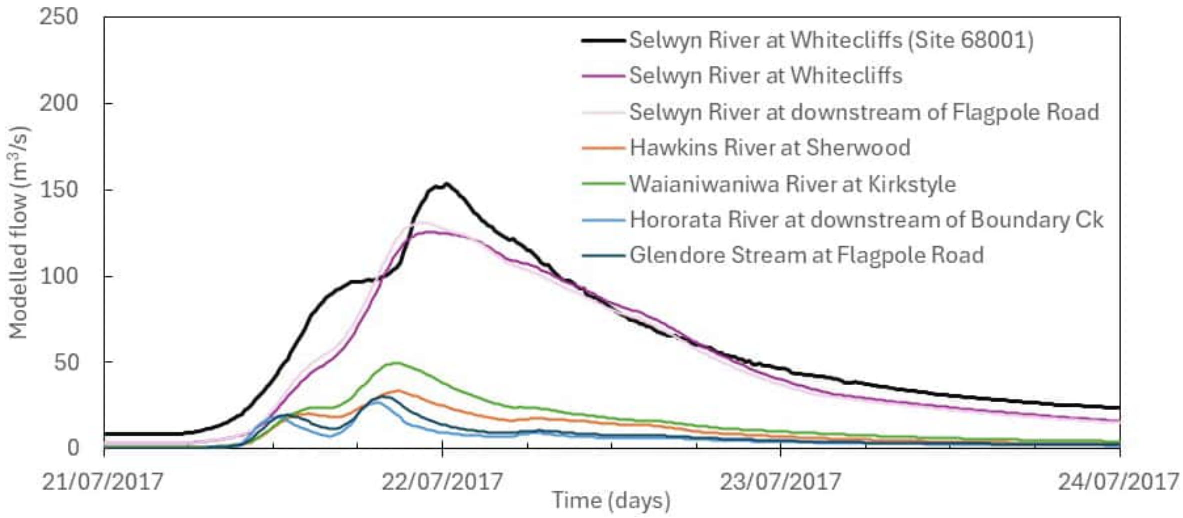


Figure 5-12: July 2017 – modelled Selwyn River/Waikirikiri foothill catchment flows

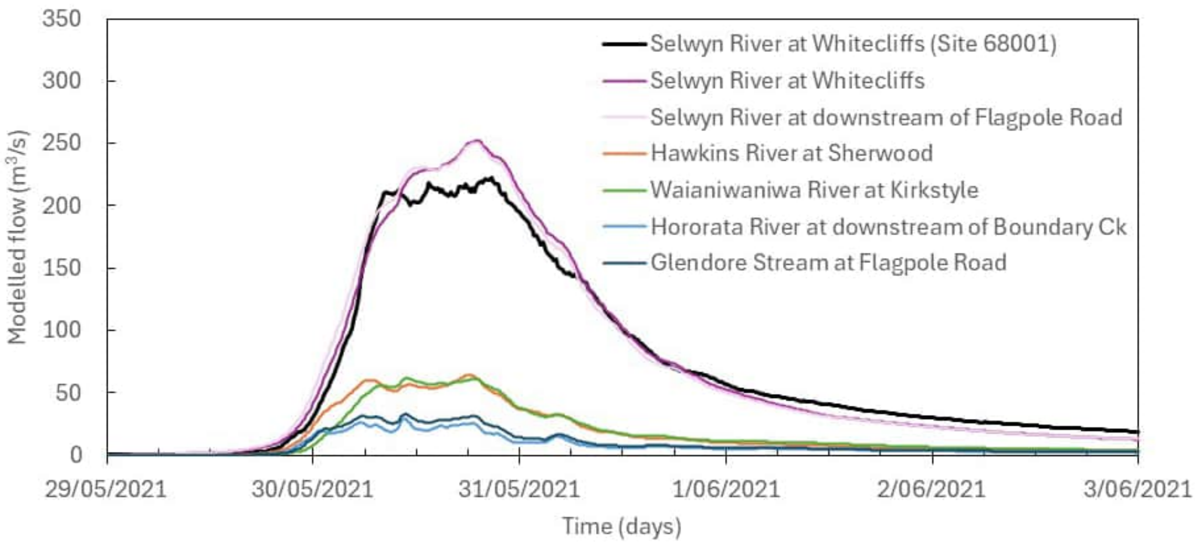


Figure 5-13: May 2021 – modelled Selwyn River/Waikirikiri foothill catchment flows

As there are no recorded flow time series for each of the five Selwyn River/Waikirikiri foothill catchments (at the locations modelled), we compared peak flows for the January 1989 to May 2024 modelled flow series for each foothill catchment to the calculated present-day 10 and 100 year ARIs to get an indication as to whether the peak flows seem realistic. Table 5-11 shows the maximum modelled flows for the January 1989 to May 2024 period are within the range of a present-day 10 to 100 year ARI peak flow for all five Selwyn River/Waikirikiri foothill catchments. These peak flows and associated present-day ARIs are consistent with other observations for these events. The modelled Selwyn River at downstream of Flagpole Road flows also closely matched the modelled flows for the Selwyn River at Whitecliffs. This suggests that the recorded Selwyn River at Whitecliffs flows (Site 68001) are likely to best represent the flows at the Selwyn River at downstream of Flagpole Road location, if the recorded flow data are available (e.g. for model calibration).

Table 5-11 also shows that the May 2021 storm event produced the largest modelled peak flows for the larger Selwyn River/Waikirikiri foothill catchments (i.e. Selwyn, Hawkins and Waiāniwaniwa River catchments). The smaller Hororata River/Te Hororātā and Glendore Stream catchments had larger modelled peak flows during a storm event in July 2019 (35.4 and 34.5 m^3/s, respectively) with the May 2021 event producing the second largest peak flows (29.3 and 33.3 m^3/s, respectively). Table 3-2 shows 37 mm of rainfall in 3 hours at the Selwyn River at Whitecliffs rain gauge – the highest 3 hour rainfall total for all storm events included in this study. Flooding in the Hororata area was also observed during this event, confirming it was a significant event (see Section 2.3).

Table 5-11: Comparison of modelled peak flow to the estimated 10 and 100 year flow average recurrence intervals (January 1989 to May 2024)

Catchment	Modelled peak flow (m^3/s)	Present-day 10 year ARI[a]	Present-day 100 year ARI[a]	Date
Selwyn River at downstream of Flagpole Road	250	160	310	30/5/2021
Hawkins River at Sherwood	64	43-48	71-93	30/5/2021
Waiāniwaniwa River at Kirkstyle	62	60-66	98-128	30/5/2021
Hororata River at downstream of Boundary Creek	35	24-26	39-51	31/7/2019
Glendore Stream at Flagpole Road	34	30-33	50-65	31/7/2019

[a] See Table 3-6

5.5 Model sensitivity assessment

To test the sensitivity of the modelled catchment flows to the various model parameters and inputs, we completed sensitivity model runs. Sensitivity model runs are quick to set up and run for hydrological models and provide valuable insight into how sensitive the modelled flows are to the various model parameters. It is anticipated that these sensitivity model runs will be used as a reference for calibrating future flow forecasting models for other Canterbury foothill and alpine catchments.

The sensitivity model runs adjusted individual model parameters and inputs based on an approximate range we might expect each parameter or input to potentially change by (should all the other parameters and inputs remain fixed). An attempt was made to ensure the range would be substantial enough to produce a noticeable change in the flow. For the model parameters and inputs that had more significant impacts on the flood flows, we completed an additional sensitivity model run to examine how much modelled flows would change if the model parameter or input was increased or decreased in the opposite direction.

We completed the following sensitivity model runs:

1. Evaporation decreased by 10%.
2. Rainfall increased and decreased by 25%.
3. Umax increased from 14.4 to 20 mm.

4. Lmax increased from 42.7 to 80 mm.
5. CQOF increased from 0.55 to 0.80, and decreased from 0.55 to 0.30.
6. TOF decreased from 0.48 to 0.25.
7. TIF decreased from 0.55 to 0.25.
8. TG decreased from 0.18 to 0.
9. CK parameters ($CK_{1,2}$, CK_{IF}, CK_{BF}) increased and decreased by 25%

The June 2013, July 2017, and May 2021 storm event hydrographs illustrate the effect of these model adjustments (see Appendix 3) and identify the main model parameters and inputs that the model is sensitive to. For example, the modelling indicates that peak flows are most sensitive to changes in rainfall, CQOF, and the CK parameters while the rising limb of the hydrographs are most sensitive to Umax, Lmax, CQOF and the CK parameters.

Increasing Umax and Lmax (and to a much lesser degree TIF and TG) has more of an impact on the rising limb when the antecedent conditions are dry. For example, June 2013 and May 2021 had ~3 mm and ~10 mm of rainfall on the catchments, respectively, in the 8 days prior to the storm events occurring. By comparison, the July 2017 storm event had ~31 to 47 mm of rainfall on the catchments in the 8 days prior to the storm event. The more saturated catchment pre-July 2017 storm event resulted in changes to Umax and Lmax having a much lesser impact on modelled flows.

Evaporation was also shown to have a very small to negligible impact on flood hydrographs, although it does impact the long-term water balance. Not only do the storm events coincide with low evaporation rates during the winter months, but the evaporation is small relative to the rainfall depths occurring during storm events.

5.6 Discussion

The modelled historic flows (Section 5.4, Figure 5-11 to Figure 5-13) show that the Selwyn River at Whitecliffs and Selwyn River at downstream of Flagpole Road flows are very similar in terms of peak flow and timing. These Selwyn River/Waikirikiri catchments are the most significant source of flow from the five Selwyn River/Waikirikiri foothill catchments (due to them having the largest, and almost identical, catchment extent).

At the beginning of the July 2017 event, the modelled Selwyn River at Whitecliffs base flow is underestimated, suggesting the model may not fully represent the antecedent conditions. However, none of the model sensitivity runs managed to reproduce the base flow either. The minimal impact of sensitivity run adjustments to Umax and Lmax for this event suggest that the model is correctly simulating the catchment as being saturated at the start of this storm event so we do not know whether this lower base flow is due to rainfall not being captured by the rain gauges, or the model not properly representing the antecedent conditions at the beginning of the event. We also do not know whether the other foothill catchment base flows and peak flows are underestimated for this event. Overall, the largest magnitude May 2021 storm event achieved the best fit between the model and recorded flow for the Selwyn River at Whitecliffs.

The modelled July 2017 peak flows are underestimated, while the June 2013 and May 2021 peak flows are over-estimated. Sensitivity runs show that, to get a good match to the July 2017 peak flow, it is likely to result in June 2013 and May 2021 being over-estimated further. Part of this variation is likely to be due to natural spatial variability of rainfall within the catchment, and partly due to other model limitations (e.g., entire catchment being simplified so it can be represented by one set of parameters).

Despite model limitations, the simulated peak flows provided a reasonable fit to the Selwyn River at Whitecliffs (Table 5-3 and 5-4), Hawkins River at Dalethorpe (Table 5-6), and Hawkins River at Willows (Table 5-8) flow records. Most modelled peak flows were within 20 to 25% of the observed peaks with the main outliers being the smaller Hawkins River at Willows catchment (with modelled flow peaks up to 40% higher than observed peak flows) and a small number of Selwyn River at Whitecliffs catchment flood events (August 2000, January 2002 and April 2014) where modelled flows were 44 to 58% lower than the observed peak flow. The 1989 to 2024 modelled flows also produced realistic maximum flows that are comparable to estimated flood frequency design flows (i.e., the maximum modelled flow between 1989 and 2024 was within the range of a 10 to 100 year ARI present-day design flow for the five Selwyn River/Waikirikiri foothill catchments).

6 Modelled design flow time series

We generated present-day and RCP8.5 (to 2081-2100) climate change scenario design flows using the High Intensity Rainfall Design System (HIRDS) South Island east coast storm rainfall profiles (Carey-Smith, et al., 2018). These rainfall data were provided by Tonkin and Taylor for the three Selwyn River/Waikirikiri foothilll rainfall sites.

6.1 Design rainfall

For each design storm duration, all three design rainfall time series have rainfall starting at the same time, and maximum rainfall intensity occurring simultaneously. This is likely to provide a good representation of peak design flows for smaller catchments (where rainfall varies less spatially) and/or for longer duration regionwide storm events (e.g., May 2021, Figure 6-1).

Conversely, short duration storm events (e.g., localised thunderstorms) are likely to be over-estimated for large catchments, such as the Selwyn River at Whitecliffs, as peak rainfall intensities are not likely to impact the entire catchment area simultaneously. Fortunately, shorter duration storm events do not produce the highest design peak flows in larger catchments such as the Selwyn River at Whitecliffs. Therefore, even if the peak flows are over-estimated for shorter duration storm events, they are unlikely to result in any out of channel flows (i.e., the Selwyn ROG model simulations are unlikely to be affected by any over-estimations of peak Selwyn River at Whitecliffs design flows for the shorter duration storm events).

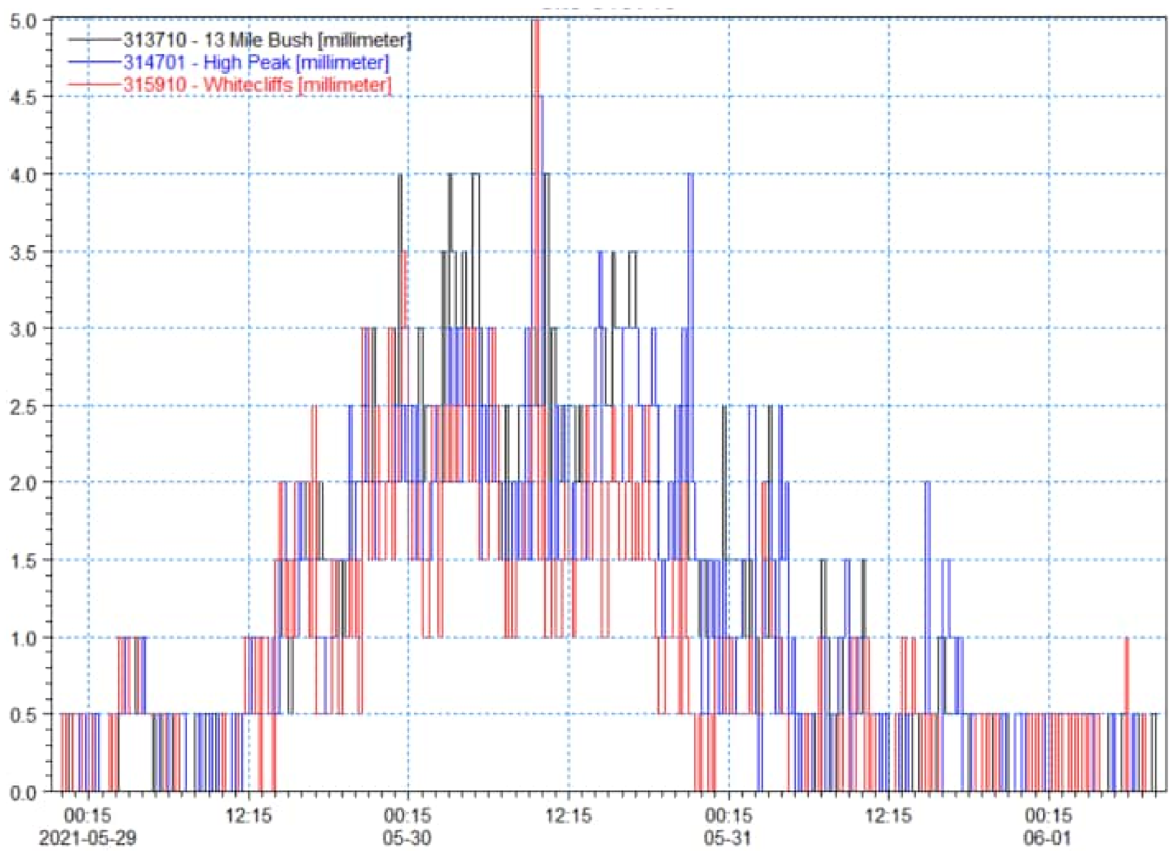


Figure 6-1: Recorded rainfall for May 2021 storm event (rainfall is in mm/15 minutes)

The four smaller Selwyn River/Waikirikiri foothill catchments have catchment areas varying from 27 to 57 km^2 and are likely to produce their largest design peak flows in storm events that lie somewhere between a localised thunderstorm and a long duration, regionwide storm event. If one of these storm events approached from the southeast, it would be possible for rainfall to be arriving at several of the Selwyn River/Waikirikiri foothill catchments simultaneously, but there would likely be some delay between it reaching all catchments. We have not made any adjustments to the timing of design rainfall time series for any of the catchments for this study.

6.2 Antecedent conditions

The July 2017 storm event is considered 'typical' of events that may occur in the Selwyn River/Waikirikiri foothill catchments when there are relatively wet, but not extreme, antecedent conditions. For the design storm models we used the recorded rainfall time series for the time period preceding this July 2017 event (i.e., from 1 January 2017 until 1am on 21 July 2017). From this time onwards, the design rainfall time series replaced the recorded rainfall for the three rainfall sites.

All other model parameters are the same as used for the historic flow time series described in Section 5.4.

6.3 Areal reduction factors

Areal reduction factors (ARFs) are used to convert rain gauge (point source) rainfall, with a specified frequency and duration, into an average rainfall occurring over a specified larger catchment area.

Carey-Smith et al. (2018) recommends the following equation for storm events with a maximum duration of 24 hours and catchment areas greater than 20 km^2.

$$ARF = 1 - 0.023A^{0.43}D^{-0.52}(lnT)^{0.23}$$

Where:	ARF	=	Areal reduction factor (-)
	A	=	Catchment area (km^2)
	D	=	Storm duration (hours)
	T	=	Average recurrence interval (years)

The ARF for each catchment are summarised in Appendix 4. For the storm durations and ARIs specified for each catchment peak flow (see Table 6-1 and Table 6-3), a maximum ARF of up to 0.94 (6% reduction) could be applied to the storm rainfall for the Selwyn River/Waikirikiri foothill catchments.

Given the uncertainty in various factors including catchment rainfall distribution, HIRDS design rainfall data, ARF equation and the model parameters, we have not applied ARFs to rainfall for the Selwyn River/Waikirikiri foothill catchments used in the Selwyn ROG model. We considered this an appropriate level of accuracy for inflows for the Selwyn ROG model given any over-prediction of rainfall (and therefore river flow) for short duration storms is unlikely to result in river flows that will overflow onto the floodplain and, for the longer duration storm events (where overflows are more likely), a decrease in rainfall of the order of ~5% is unlikely to produce a significant decrease in maximum flood water levels on the Selwyn River/Waikirikiri floodplain. Section 5.5 and Appendix A3.3 show the more significant impact on catchment flows if design rainfall is reduced by 25%. A future improvement to the Selwyn ROG model could be to include areal reduction factors in the five Selwyn foothill catchments. This would be a more important consideration if ARFs were being considered for the Selwyn ROG model.

6.4 Present-day design flows

The modelled present-day design hydrographs for the five foothill catchments are provided in Appendix 5 for the simulated 1, 6, 12, 24, 48, and 72 hour duration storms with 10, 100, 200 and 500 year ARI. These hydrographs are all required for the Selwyn ROG model.

Table 6-1 summarises the present-day design peak flows (and storm duration producing the peak flow). A summary of peak flows for all storm durations is provided in Appendix 6 and Table 6-2 compares 10, 100 and 200 year ARI present-day modelled design peak flows to present-day design flows derived from flow frequency analyses (Table 3-6).

Table 6-1: Present-day modelled design peak flows (and storm duration producing the peak flow) for the five Selwyn River/Waikirikiri foothill catchments

Catchment	Modelled design peak flow, m³/s (duration, hrs)			
	10 year	100 year	200 year	500 year
Selwyn River at downstream of Flagpole Road	156 (48)	293 (48)	341 (48)	408 (48)
Hawkins River at Sherwood	41 (48)	81 (12)	98 (12)	122 (12)
Waiāniwaniwa River at Kirkstyle	54 (48)	103 (12)	126 (12)	160 (12)
Hororata River at downstream of Boundary Creek	28 (12)	64 (6)	78 (6)	98 (6)
Glendore Stream at Flagpole Road	32 (12)	68 (6)	86 (6)	111 (6)

Table 6-2: Comparison of 10, 100 and 200 year ARI present-day modelled design peak flows to design flows derived by areal scaling of current flow frequency derived design flows (Table 3-5)

Catchment	Modelled 10 year ARI peak flow (m^3/s)	Present-day 10 year ARI[a]	Modelled 100 year ARI peak flow (m^3/s)	Present-day 100 year ARI[a]	Modelled 200 year ARI peak flow (m^3/s)	Present-day 200 year ARI[a]
Selwyn River at downstream of Flagpole Road	156	160	293	310	341	360
Hawkins River at Sherwood	41	43-48	81	71-93	98	79-107
Waiāniwaniwa River at Kirkstyle	54	60-66	103	98-128	126	109-148
Hororata River at downstream of Boundary Creek	28	24-26	64	39-51	78	43-58
Glendore Stream at Flagpole Road	32	30-33	68	50-65	86	55-75

[a] See Table 3-6

6.5 RCP8.5 (to 2081-2100) climate change design flows

The modelled RCP8.5 (to 2081-2100) climate change design hydrographs for the five foothill catchments are provided in Appendix 5 for the simulated 1, 6, 12, 24, 48 and 72 hour duration storms with 10, 100, 200 and 500 year ARI. Table 6-3 summarises the RCP8.5 (to 2081–2100) climate change design peak flows (and storm duration producing the peak flow) and a summary of peak flows for all storm durations is provided in Appendix 6. It is interesting to note that several simulated design peak flows under the RCP8.5 climate change scenario are attained as a result of shorter design storm durations (compared to those in Table 6-1).

Table 6-3: RCP8.5 (to 2081-2100) climate change design peak flows (and storm duration producing the peak flow) for the five Selwyn River/Waikirikiri foothill catchments

Catchment	Modelled design peak flow, m^3/s (design storm duration, hrs)			
	10 year	100 year	200 year	500 year
Selwyn River at downstream of Flagpole Road	195 (48)	362 (48)	421 (48)	508 (24)
Hawkins River at Sherwood	53 (12)	113 (12)	135 (12)	174 (6)
Waiāniwaniwa River at Kirkstyle	68 (24)	146 (12)	177 (12)	222 (12)
Hororata River at downstream of Boundary Creek	41 (6)	92 (6)	109 (6)	134 (6)
Glendore Stream at Flagpole Road	45 (12)	103 (6)	126 (6)	159 (6)

Table 6-4 summarises the percentage increase in peak flow due to climate change for each ARI for the storm duration(s) that produced the maximum peak flows. The storm durations that produce the maximum peak flows are shown in brackets. For example, the larger Selwyn River downstream of Flagpole Road catchment is likely to have peak flows increase by 24 to 25% due to climate change, while the smaller catchments may experience higher increases in maximum peak flow of 25 to 49%. *Climate change produces a 24% increase in peak flow for the simulated 500 year ARI design storm for the Selwyn River downstream of Flagpole Road location. This increase is based on a present-day maximum peak flow of 408 m^3/s (48 hour storm) increasing with climate change to a maximum peak flow of 508 m^3/s (24 hour storm). The design storm duration is represented in* Table 6-4 *by (48/24) to represent the change in design storm duration from 48 to 24 hours (due to climate change).*

Table 6-4: Increase in peak flow due to climate change (RCP8.5 to 2081-2100) for the five Selwyn River/Waikirikiri foothill catchments

Catchment	Percentage increase (%) (design storm duration, hrs)			
	10 year	100 year	200 year	500 year
Selwyn River at downstream of Flagpole Road	25 (48)	24 (48)	24 (48)	24 (48/24)
Hawkins River at Sherwood	27 (48/12)	39 (12)	38 (12)	42 (12/6)
Waiāniwaniwa River at Kirkstyle	25 (48/24)	41 (12)	40 (12)	38 (12)
Hororata River at downstream of Boundary Creek	47 (12/6)	43 (6)	41 (6)	38 (6)
Glendore Stream at Flagpole Road	39 (12)	49 (6)	47 (6)	44 (6)

6.6 Discussion

6.6.1 Design flows

The present-day modelled design flows are generally within 10 to 15% of the design flows (derived by areal scaling of the current flow frequency design flows for Selwyn River at Whitecliffs and Hawkins River at Dalethorpe Road; Table 6-2). The exception being the Hororata River at downstream of

Boundary Creek modelled design flows (greater than a 10 year ARI) which are ~25 to 35% more than those estimated by scaling. As the model produced comparable results to the published method for present-day peak design flows, we consider the modelled design flows fit for purpose and appropriate to use for simulating the impact of climate change on design flows.

Originally, we completed all model runs with a 15 minute time step. As the 1 hour design rainfall time series was provided by Tonkin and Taylor with a 5 minute time step (due to the shorter storm duration), we completed additional model runs using a 5 minute time step for the four design ARIs (10, 100, 200 and 500 year). This showed that the smaller Glendore Stream at Flagpole Road and Hororata River at downstream of Boundary Creek catchments were most sensitive to the smaller 5 minute time step, with peak flows reducing by up to ~6% for the model runs with the 5 minute time step. This reduction in peak flows may be partly due to the specified '0.08333' hour time step not producing an 'exact' 5 minute time interval – instead it was slightly offset from the 15 minute time step results produced for all the other model runs (especially since the model run starts on 1 January 2017 but design rainfall is not inserted into the rainfall time series until July 2017). Regardless, the modelled 1 hour design peak flows are significantly less than the 6 hour peak flows and are not likely to be out of channel and causing floodplain flooding. We did not consider it necessary to change any of the model runs from a 15 minute to a 5 minute time step.

6.6.2 Climate change

Climate change scenario RCP8.5 (to 2081-2100) increases 100 year ARI peak flows by up to 120% for the 1 hour duration storms (Appendix 6). For the five Selwyn River/Waikirikiri foothill catchments this reduces to a 31 to 44% increase in peak flows for 12 hour storms, and a 22 to 24% increase for 48 hour duration storms.

The largest increase with climate change was simulated for the Hororata River at downstream of Boundary Creek catchment (160%) for a 1 hour storm duration with a 10 year ARI (peak flow increases from 3 to 8 m^3/s). For the 6 hour storm duration with a 10 year ARI, climate change only increases peak flows by 52%, but flow increases from 27 to 41 m^3/s. There is a much higher likelihood of flooding for this climate change scenario even though the increase in peak flow is 52% compared to 160%.

Climate change not only increases the design peak flow but can also reduce the storm duration that generates the peak flow. This is largely because the higher flows travel more rapidly along the river system. For example, for the 500 year ARI design storm, the Selwyn River at downstream of Flagpole Road storm duration that produces the maximum peak flow decreases from 48 to 24 hours when climate change is included.

7 Conclusions

The calibration and validation models provided a reasonable fit to the Selwyn River at Whitecliffs, Hawkins River at Dalethorpe Road and Hawkins River at Willows flow records, and the 1989 to 2024 simulated flow records for all catchments provided realistic maximum flows for known flood events.

The modelled Selwyn River at downstream of Flagpole Road flows were also very similar to the modelled Selwyn River at Whitecliffs flows. We suggest that the Selwyn River at Whitecliffs flow record (Site 68001) be used instead of the modelled Selwyn River at downstream of Flagpole Road flows to provide more accurate calibration flows for the Selwyn River at downstream of Flagpole Road inflow location for the Selwyn ROG model.

The present-day modelled design flows are generally within 10 to 15% of the design flows derived by scaling published design flows for Selwyn River at Whitecliffs and Hawkins River at Dalethorpe Road - the exception being the Hororata River at downstream of Boundary Creek design flows for greater than a 10 year ARI which are ~25 to 35% more than those estimated by scaling. We therefore consider the Selwyn foothill catchment models fit for purpose and appropriate to use for simulating present-day design flows and the impact of climate change on design flows.

Climate change scenario RCP8.5 (to 2081-2100) increased maximum peak flows for the Selwyn River/Waikirikiri foothill catchments by 24 to 49%. As ARIs increased, climate change also led to peak flows occurring during shorter duration design storms for some catchments.

8 Recommendations

We recommend that the Hawkins River at Dalethorpe Road site be gauged at higher flows to improve the rating curve. The Hawkins River at Dalethorpe Road model could be reassessed once there is a longer flow record with more accurate high flow data at the Hawkins River at Dalethorpe Road recorder.

Both the Selwyn River at Whitecliffs and Hawkins River at Dalethorpe Road models could also be reassessed after another large flood event such as in May 2021.

9 Acknowledgements

Technical input and feedback were much appreciated from Dan Clark (Canterbury Regional Council), Adam Martin (Canterbury Regional Council), Ben Throssell (PDP) and Richard Brunton (Tonkin and Taylor).

10 References

Carey-Smith, T.; Henderson R.; Singh S. (2018). High Intensity Rainfall Design System Version 4. Prepared for Envirolink by NIWA*. NIWA Client Report 2018022CH*. 73 p.

CRC. (1996). The natural resources of Lake Ellesmere (Te Waihora) and its catchment, with editor KJW Taylor. *Canterbury Regional Council Technical Report 96/7*.322 p.

DHI. (2023). Opihi flood forecasting upgrade, *Prepared for Environment Canterbury by DHI. Project No 44801831.* 28 July 2023. 23 p.

DHI. (2025). MIKE 1D, DHI Simulation Engine for 1D river and urban modelling, Reference Manual. https://manuals.mikepoweredbydhi.help/latest/Water_Resources/MIKE_1D_reference.pdf. 346 p.

Institution of Engineers, Australia (1987) *Australian Rainfall and Runoff: A Guide to Flood Estimation,* Vol. 1, Editor-in-chief D.H. Pilgrim, Revised Edition 1987 (Reprinted edition 1998), Barton, ACT.

IPCC. (2013). *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 1535 p.

IPCC (2021). Summary for Policymakers. In: *Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change* [Masson-Delmotte, V., P. Zhai, A. Pirani, S.L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M.I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J.B.R. Matthews, T.K. Maycock, T. Waterfield, O. Yelekçi, R. Yu, and B. Zhou (eds.)]. In Press. 31 p.

Lintott, C. and Martin, A. (2023). Flood frequency analysis updates – May 2021 flood event. *Environment Canterbury Technical Report No. R23/08*. 104 p.

MfE. (2018). *Climate Change Projections for New Zealand: Atmosphere Projections Based on Simulations from the IPCC Fifth Assessment, 2nd Edition*. Wellington: Ministry for the Environment. 131 p.

Salimi, E.T.; Nohegar, A.; Malekian, A.; Hoseini, M.; Holisaz, A. (2017). Estimating time of concentration in large watersheds. *Paddy and Water Environment*, **15**:123-132.

Tonkin and Taylor. (2017). Flood frequency analysis for Canterbury Rivers. *Prepared for Environment Canterbury by Tonkin & Taylor Ltd. Environment Canterbury Content Manager Reference No. C17C/109083*. 394 p.

Topélen, J. (2007). Mean annual low flow (Seven Day) and mean flow mapping for the Upper Selwyn River Catchment. *Environment Canterbury Technical Report U07/68*. 17 p.

Vesey, R. (1994). Flood Damage – July 1994. Prepared 28 July 1994. *Environment Canterbury Content Manager Reference C16C/52635*. 2 p.

Vincent, C.N. (2005). Hydrogeology of the Upper Selwyn Catchment. M.Sc. Thesis, University of Canterbury, Christchurch, New Zealand. 183 p.

Webb, T.H.; Lilburne, L.R. (2011). Criteria for defining the soil family and soil sibling: the fourth and fifth categories of the New Zealand Soil Classification. *Landcare Research science series; no 3 (2nd ed.).* Manaaki Whenua Press. 39 p.

Appendix 1 Time of concentration

To determine the time of concentration (Tc, minutes) for the five Selwyn River/Waikirikiri foothill catchments, we used the Bransby Williams and Temez equations. The longest drainage path, equal-area channel slope and average slope were derived using the latest available LiDAR data captured between 1 May 2020 and 4 February 2023. The main catchment characteristics used in the equations are summarised in Table 2-1.

Bransby Williams equation

This equation was developed in India in 1922 and is considered better suited to rural catchments with an area less than 130 km^2. Mean annual rainfall was also greater than 762 mm in the Indian study area.

$$T_c(minutes) = 58.5\ L\ A^{-0.1}\ S^{-0.2}$$

where L = Length of longest drainage path (km), A = Catchment area (km^2), S = Equal Area Slope (m/km).

* Bransby Williams used the average slope but the 1987 Australian Rainfall and Runoff Guidelines (Institution of Engineers, Australia,1987, p 97) preferred the equal area slope "*especially when there are large variations of slope within the catchment*". We have chosen to also use the equal area slope.

Temez equation

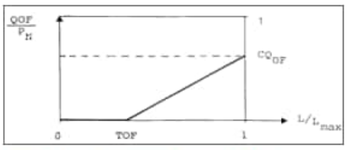
This equation was developed in 1978 for natural basins in Spain. It is suitable for catchment areas from 1 to 3000 km^2 and time of concentrations between 15 minutes and 24 hours.

$$T_c(hours) = 0.3\ L^{0.76}\ S^{-0.19}$$

where L = Length of longest drainage path (km), S = Average slope of the catchment (m/m).

Appendix 2 RDI model parameters

A2.1 Surface-rootzone model parameters (extracted from DHI (2025))

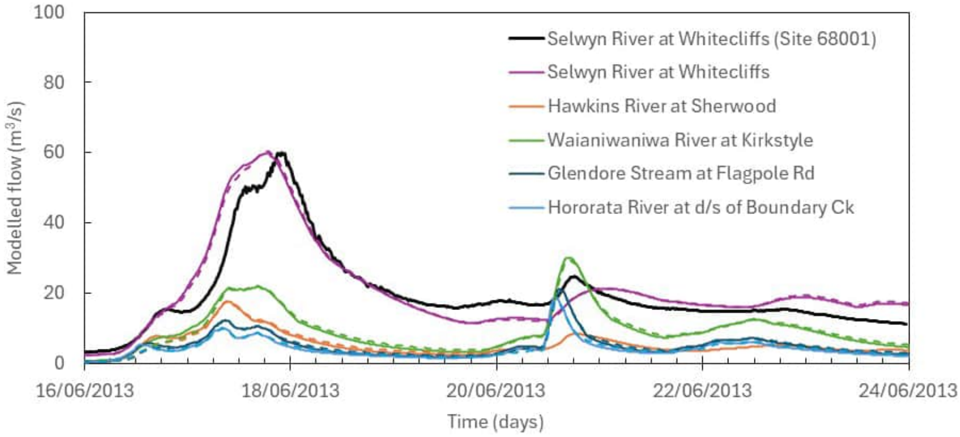
Parameter	Description	Units
Umax	Maximum water content in surface storage. In dry periods, amount of net rainfall before overland flow occurs can be used to estimate Umax.	mm
Lmax	Maximum water content in the lower or root zone storage. As a rule, a fixed relationship of Umax = 0.1 Lmax can be used unless special catchment characteristics or hydrograph behaviour indicate otherwise.	mm
CQOF	Overland flow runoff coefficient. Determines the extent to which excess rainfall runs off as overland flow and the magnitude of infiltration. Small values = flat catchments with coarse, sandy soils and a large unsaturated zone, large values = low permeable soils such as clay or bare rocks. Known to vary between 0.01 to 0.9.	-
CK_{IF}	Time constant for routing interflow. Is the dominant routing parameter of the interflow because CK_{IF}>>$CK_{1,2}$. Since interflow is seldom the dominant streamflow component, CK_{IF} is not, in general, a very important parameter. Usually in range 500-1000 hours.	hour
CK_{12}	Time constant for routing interflow and overland flow. Determines the shape of the hydrograph peaks. Value depends on the size of the catchment and how fast it responds to rainfall. If modelled peak discharges are too low or arriving too late, decreasing CK_{12} may correct.	hour
TOF	Root zone threshold value for overland flow (i.e., no overland flow generated if the relative moisture content of lower zone L/Lmax<TOF).  Figure 7.5 Generation of overland flow.	-
TIF	Root zone threshold for interflow. Comparable to TOF for overland flow.	-

A2.2 Groundwater model parameters (extracted from DHI (2025))

Parameter	Description	Units
TG	Root zone threshold value for GW recharge. Same effect on recharge as TOF has on overland flow. (Important for simulating rise of groundwater at beginning of wet season)	-
CK_{BF}	Time constant for routing baseflow. Determines the shape of the modelled hydrograph in dry periods.	hour
C_{area}	Ratio of GW-area to catchment area.	-
S_y	Specific yield of groundwater reservoir. Assessed from hydrological data (e.g., pump tests) or estimated from literature for different soil types (e.g., clay = 0.01 to 0.1, sand = 0.1 to 0.3)	-
GWL_{BF0}	Maximum GW-depth causing baseflow. Represents the outflow level of the groundwater reservoir given as a distance between the average ground level of the catchment and the minimum level of the river to which it drains.	m
GWL_{BF1}	Groundwater depth for unit capillary flux. Depends on soil type (see Table 7.3 in Mike1D reference manual)	m

Appendix 3 Modelled sensitivity run flow hydrographs

A3.1 Evaporation decreased by 10%



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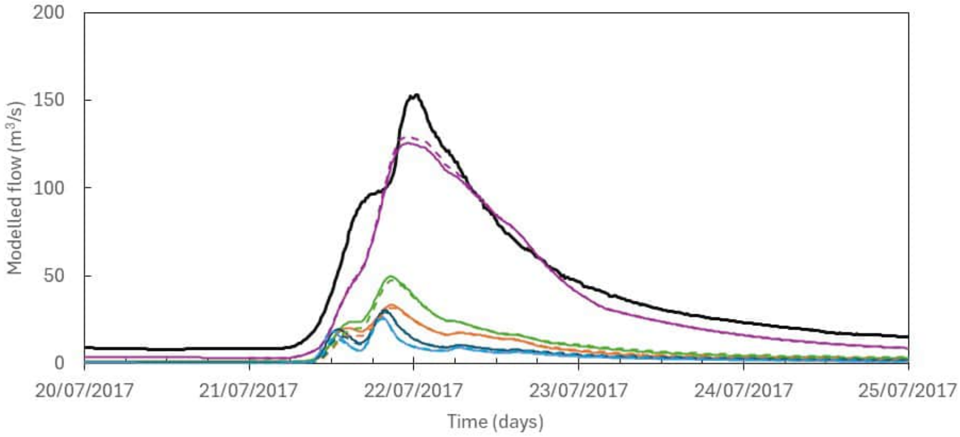
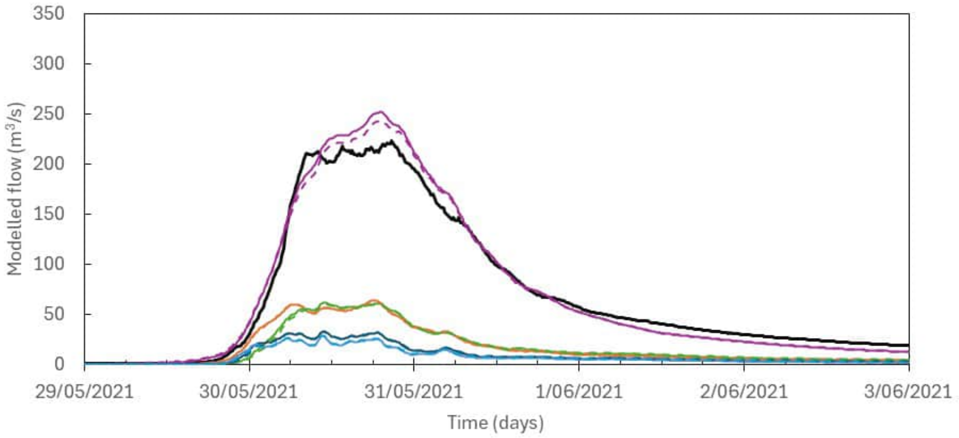


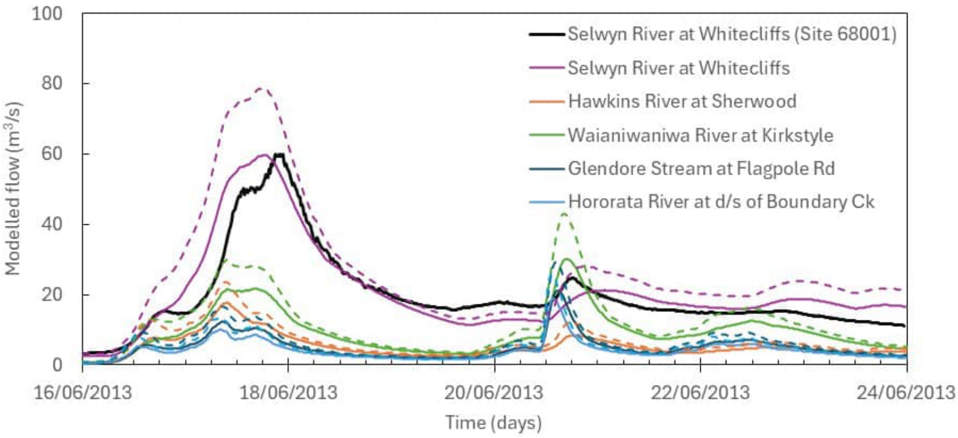
July 2017



May 2021

Figure A3-1: Model results for three storm events with evaporation decreased by 10% (dashed lines)

A3.2 Rainfall increased by 25%



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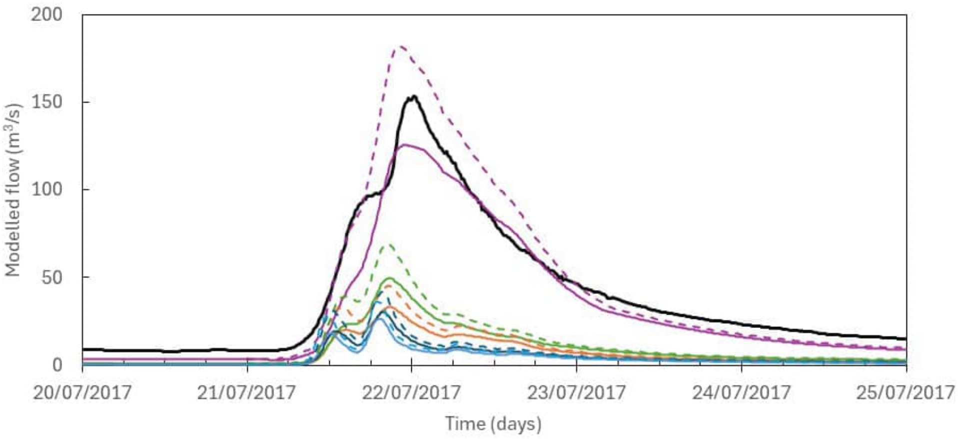

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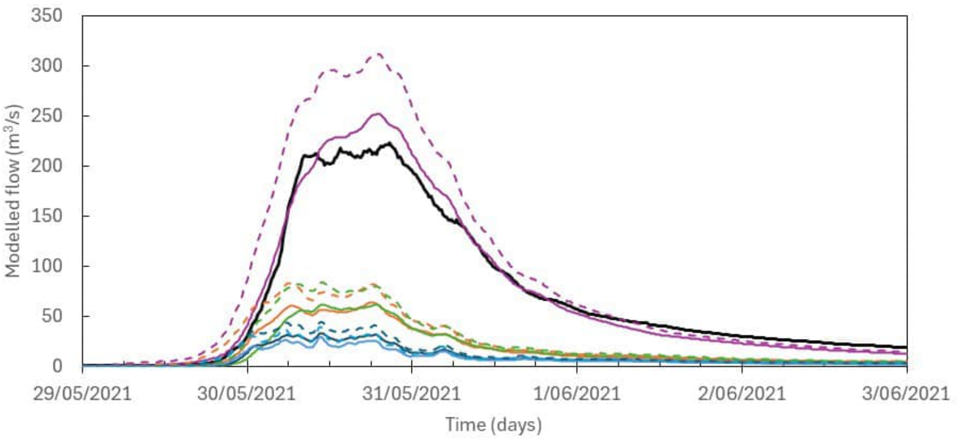
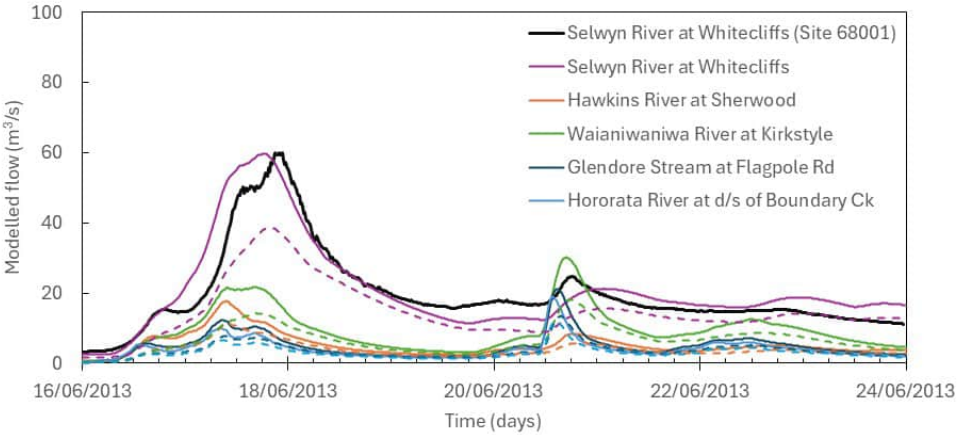


May 2021

Figure A3-2: Model results for three storm events with rainfall increased by 25% (dashed lines)

A3.3 Rainfall decreased by 25%



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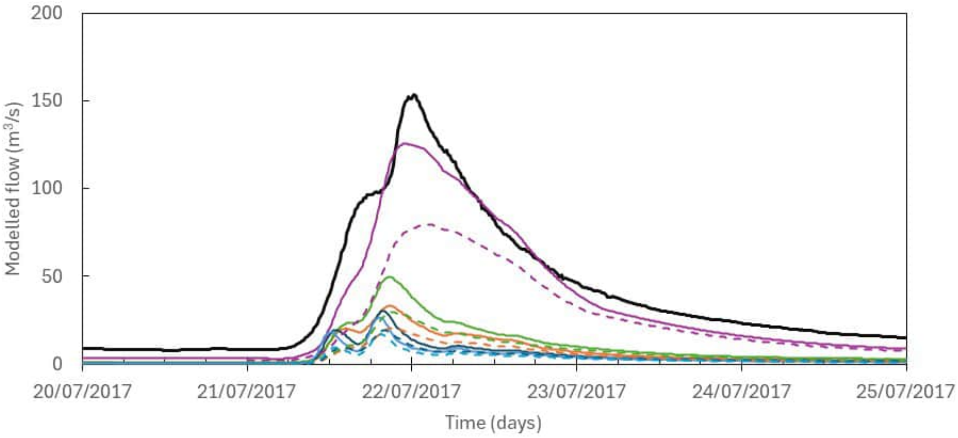

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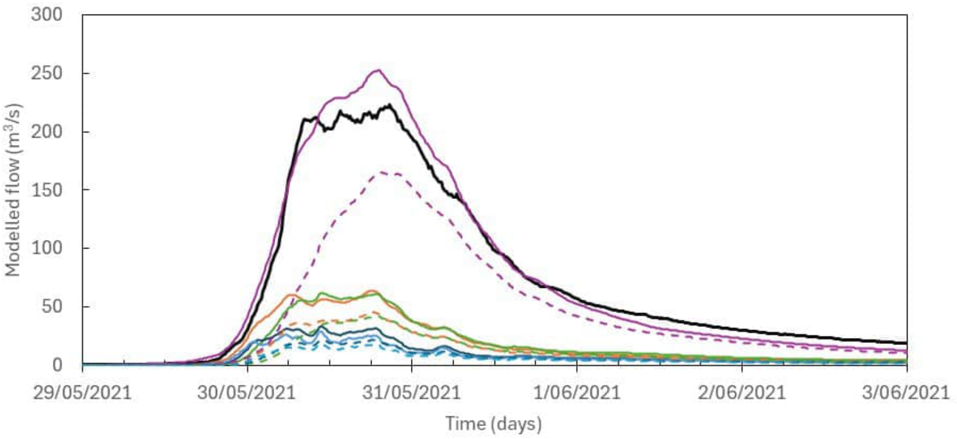
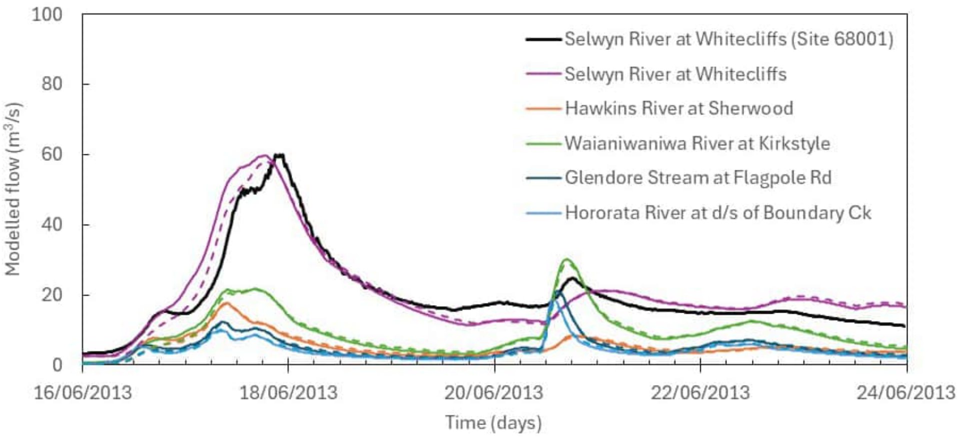


May 2021

Figure A3-3: Model results for three storm events with rainfall decreased by 25% (dashed lines)

A3.4 Umax increased from 14.4 to 20 mm



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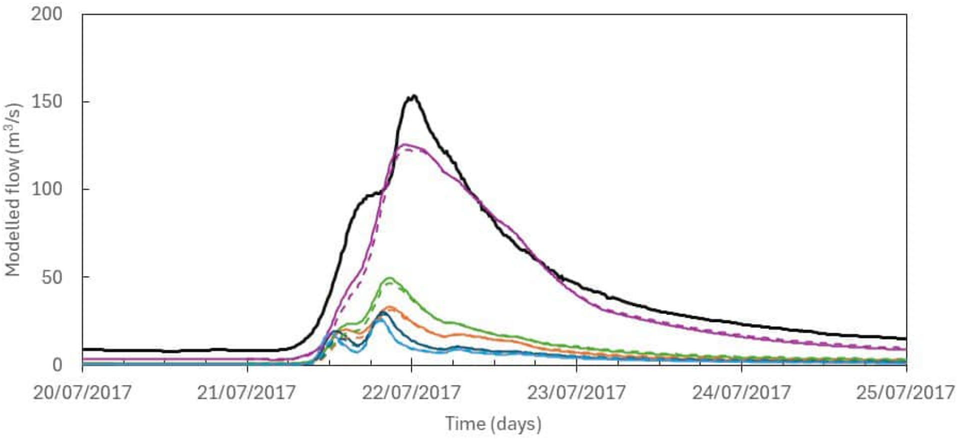

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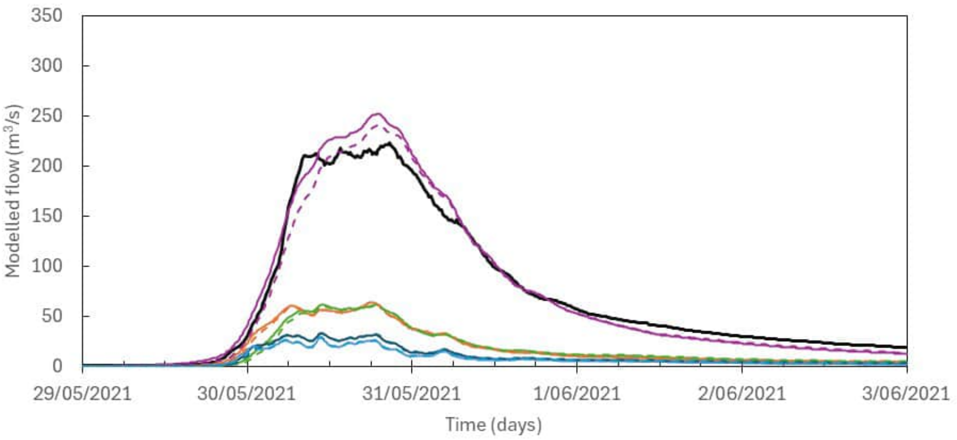
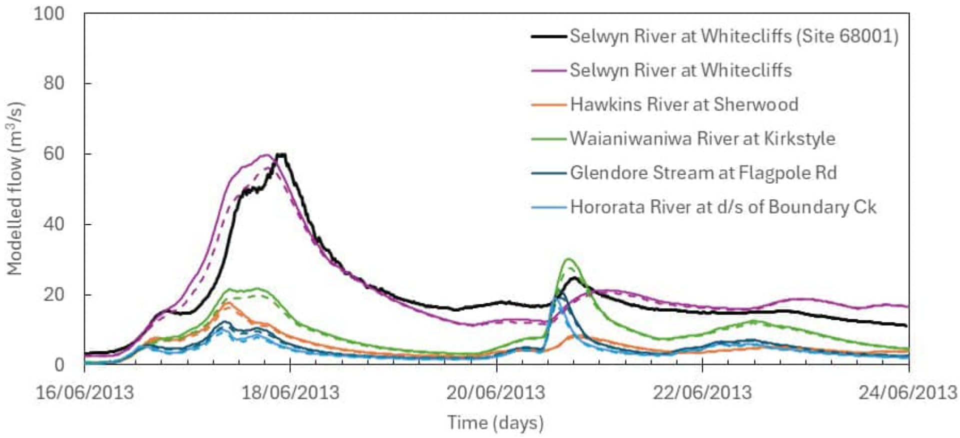


May 2021

Figure A3-4: Model results for three storm events with Umax increased from 14.4 to 20 mm (dashed lines)

A3.5 Lmax increased from 42.7 to 80 mm



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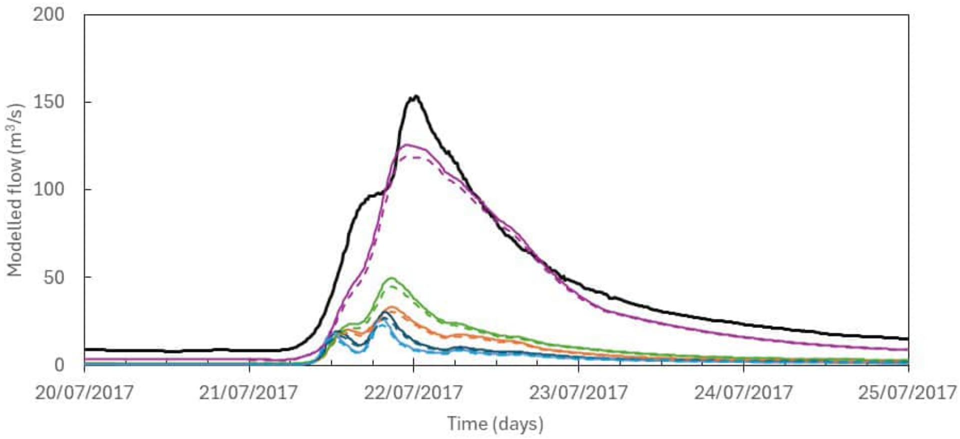
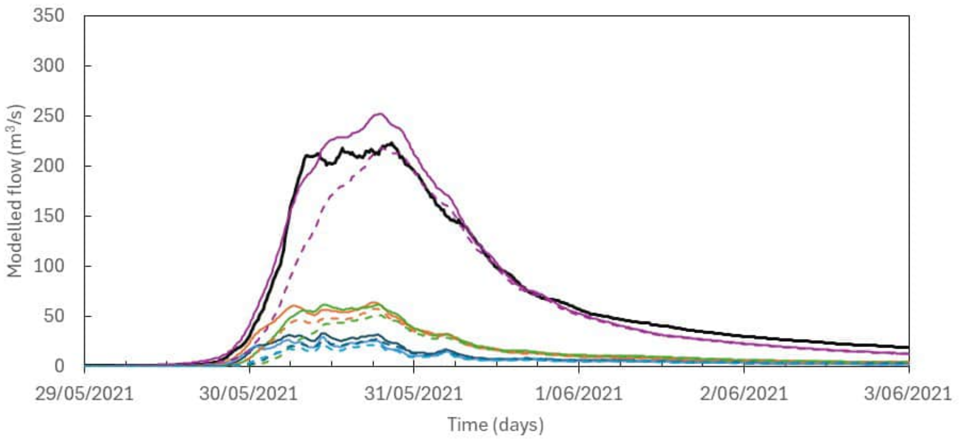


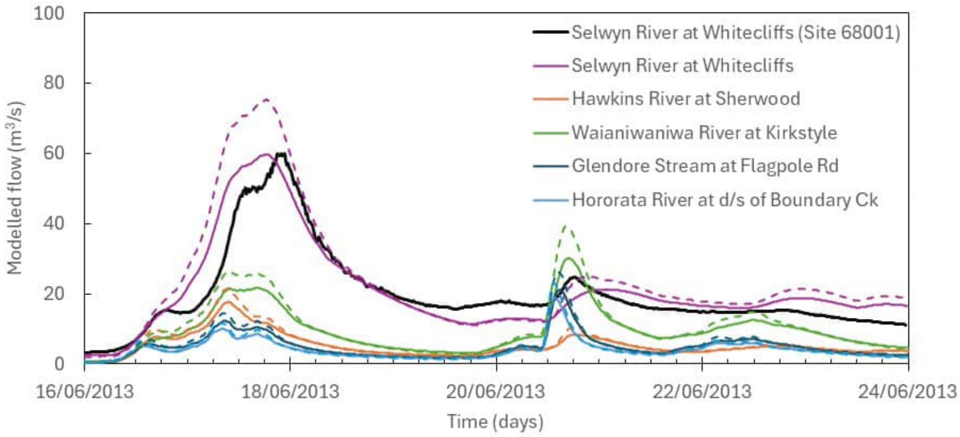
July 2017



May 2021

Figure A3-5: Model results for three storm events with Lmax increased from 42.7 to 80 mm (dashed lines)

A3.6 CQOF increased from 0.55 to 0.70



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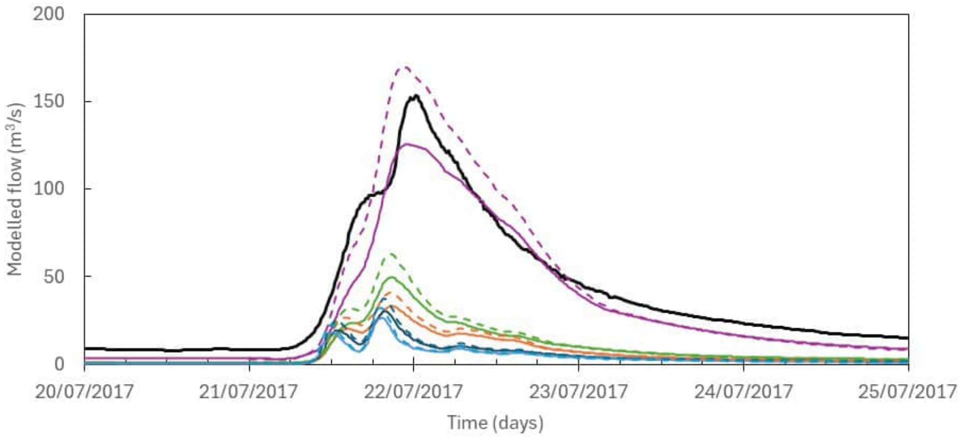
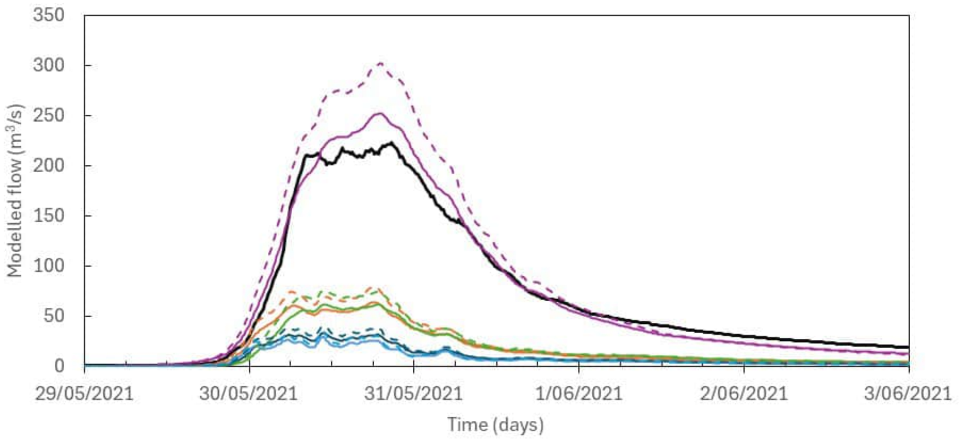


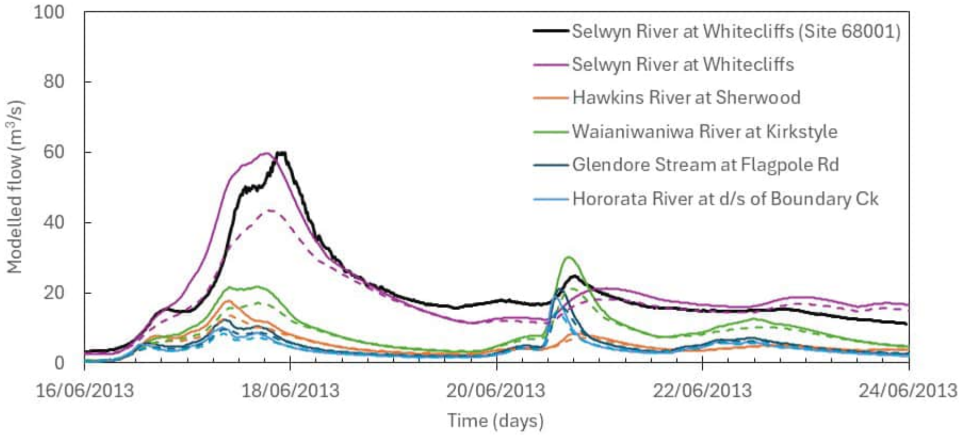
July 2017



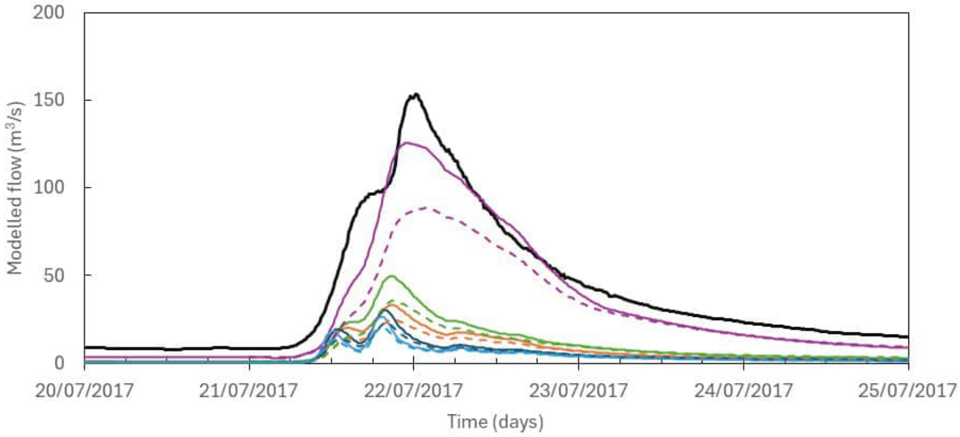
May 2021

Figure A3-6: Model results for three storm events with CQOF increased from 0.55 to 0.70 (dashed lines)

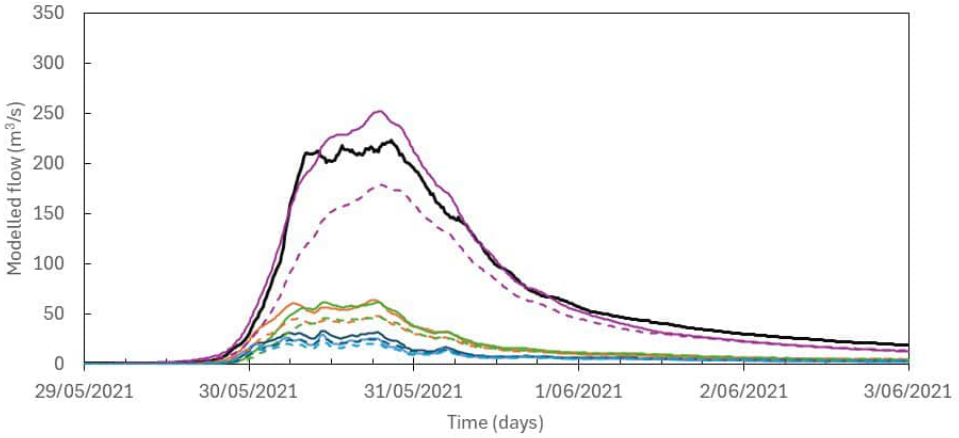
A3.7 CQOF decreased from 0.55 to 0.40



June 2013



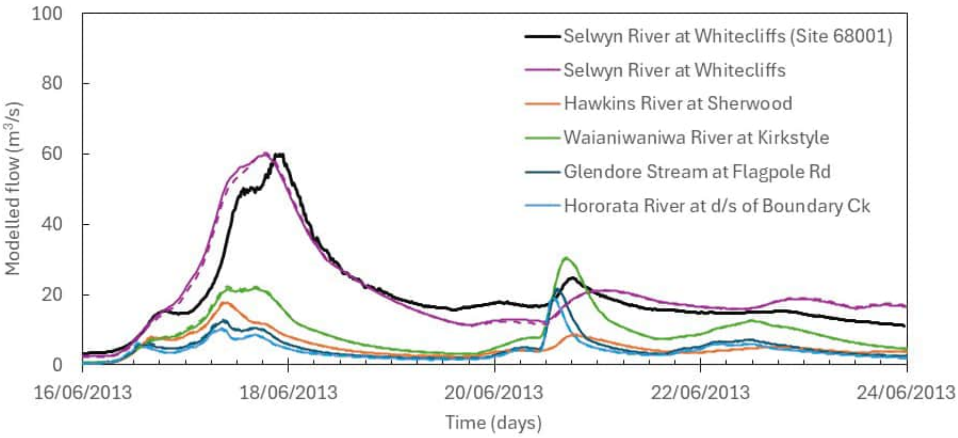
July 2017



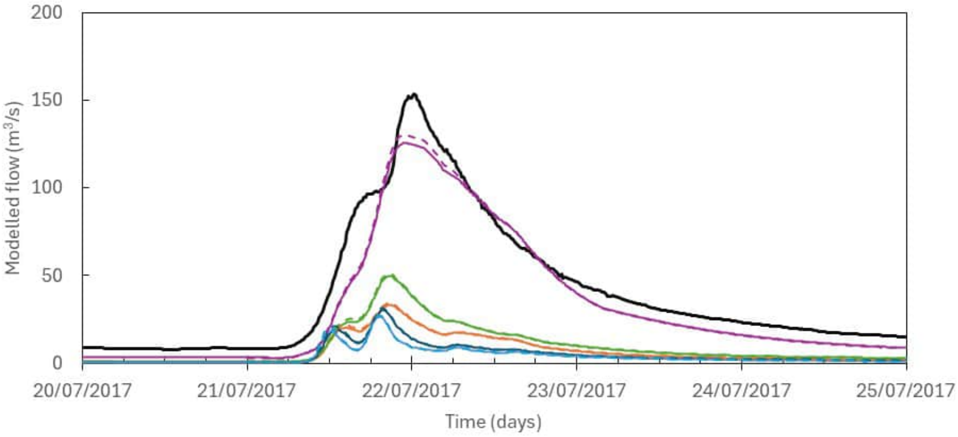
May 2021

Figure A3-7: Model results for three storm events with CQOF decreased from 0.55 to 0.40 (dashed lines)

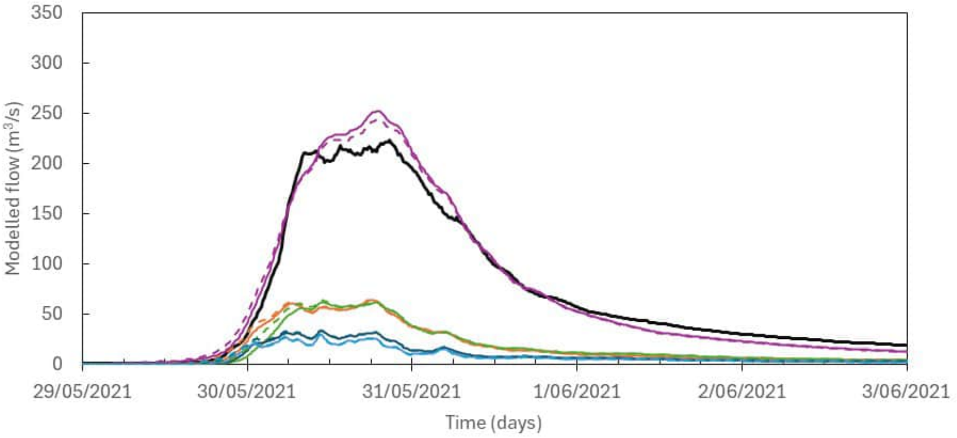
A3.8 TOF decreased from 0.48 to 0.25



June 2013



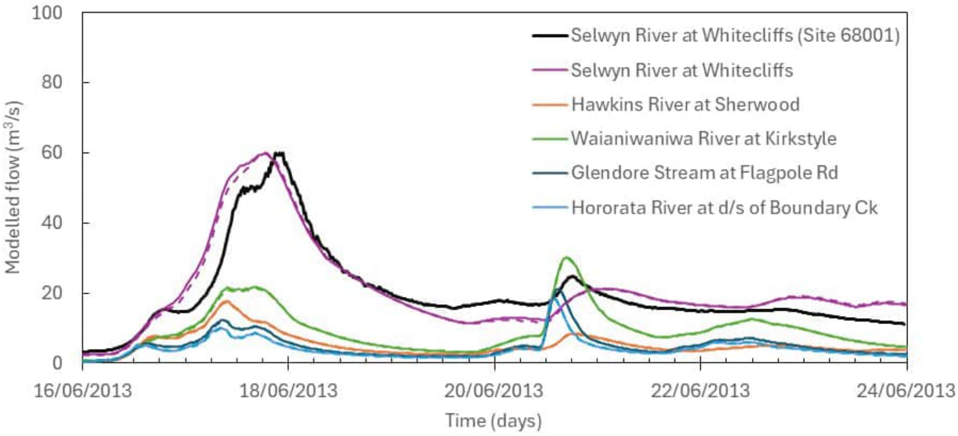
July 2017



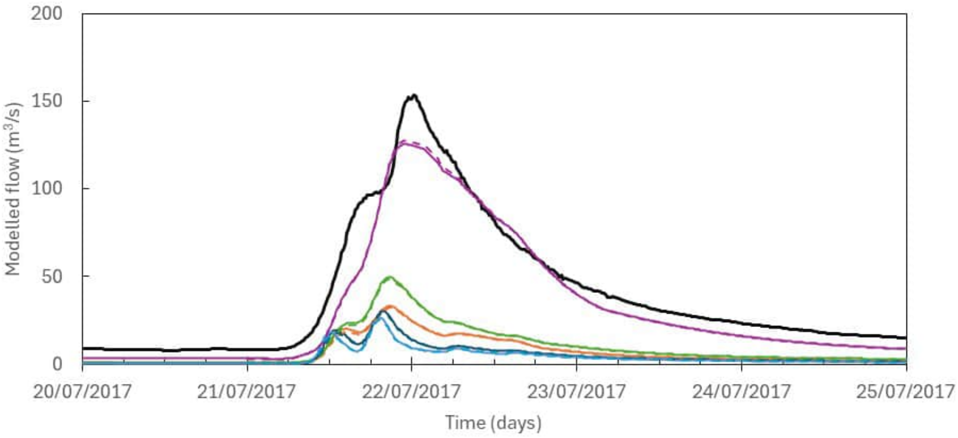
May 2021

Figure A3-8: Model results for three storm events with TOF decreased from 0.48 to 0.25 (dashed lines)

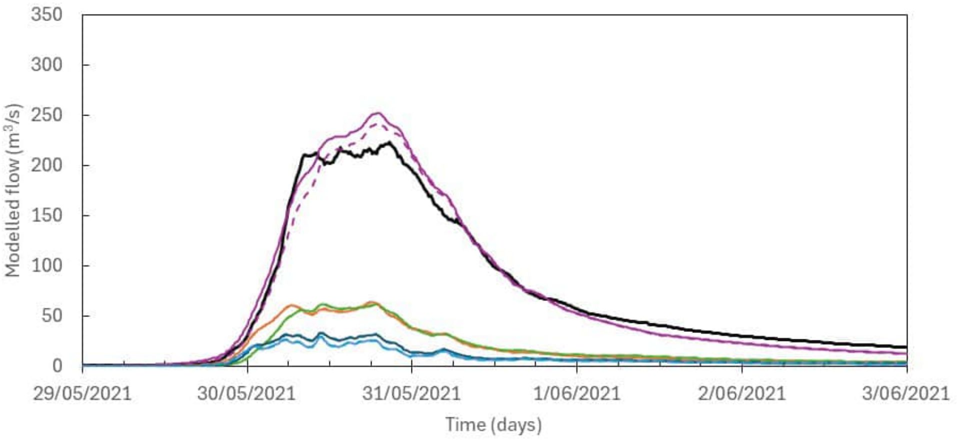
A3.9 TIF decreased from 0.55 to 0.20



June 2013



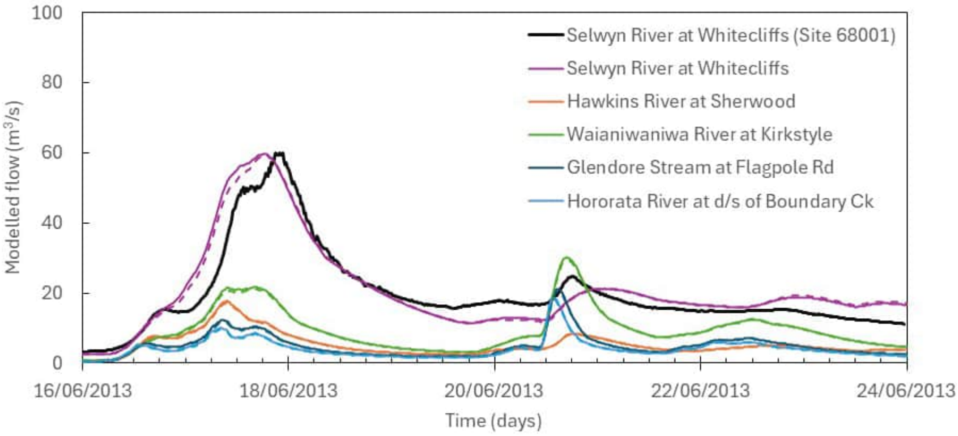
July 2017



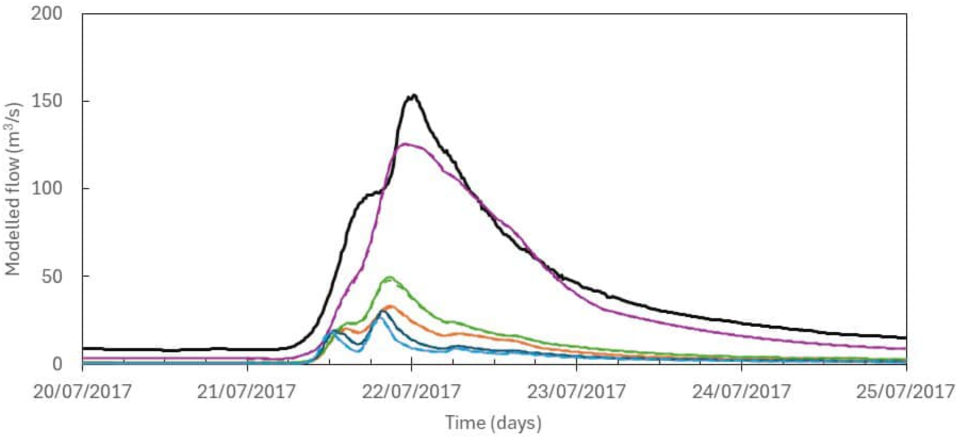
May 2021

Figure A3-9: Model results for three storm events with TIF decreased from 0.55 to 0.20 (dashed lines)

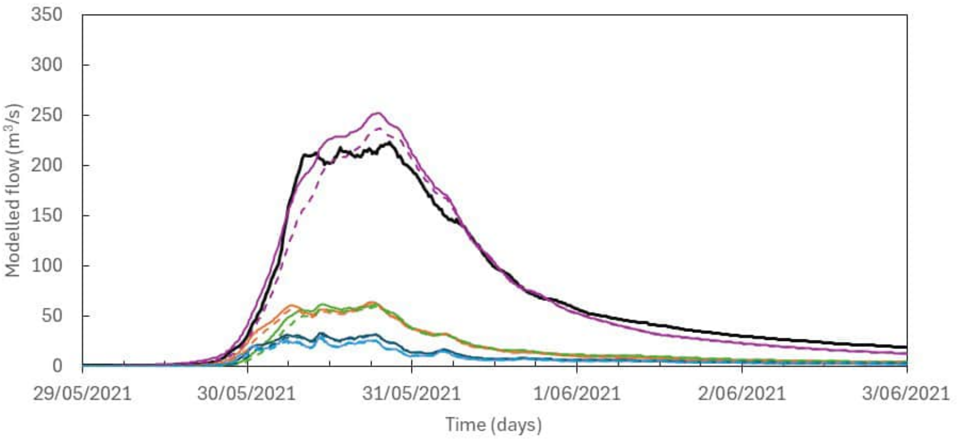
A3.10 TG decreased from 0.18 to 0



June 2013



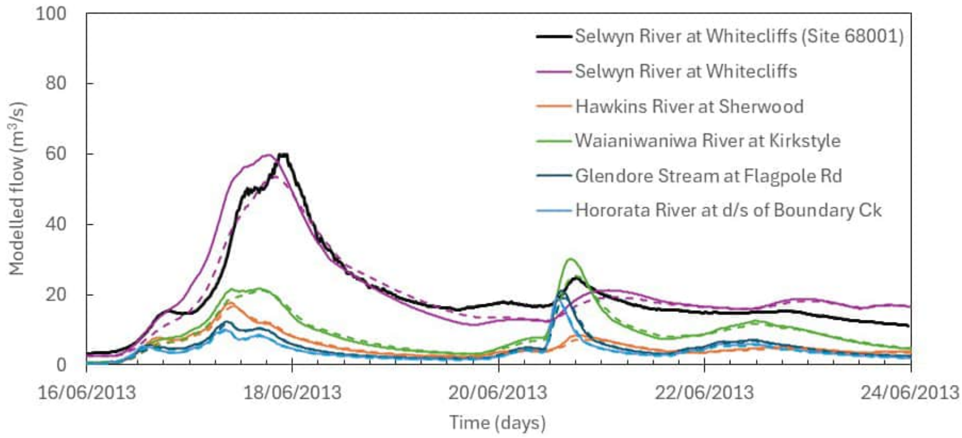
July 2017



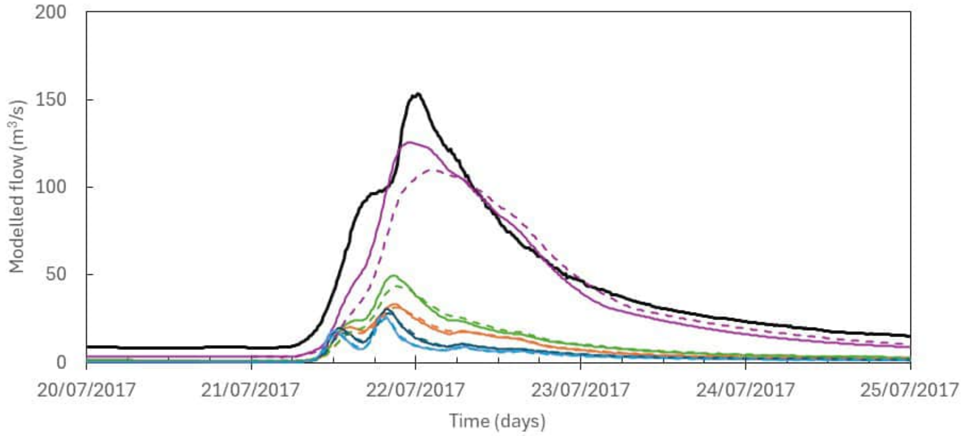
May 2021

Figure A3-10: Model results for three storm events with TG decreased from 0.18 to 0 (dashed lines)

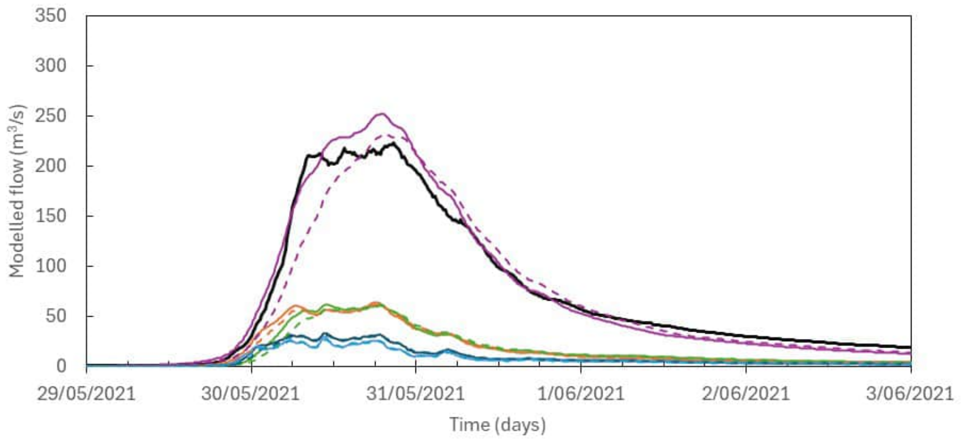
A3.11 CK parameters increased by 25%



June 2013



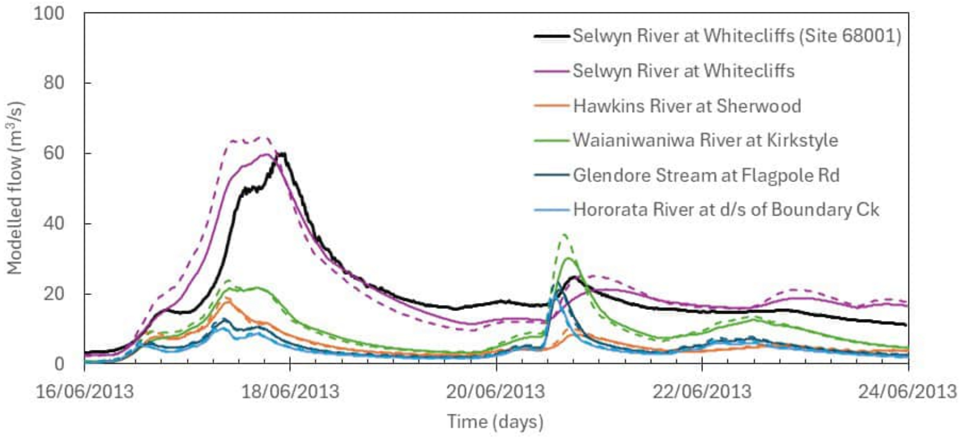
July 2017



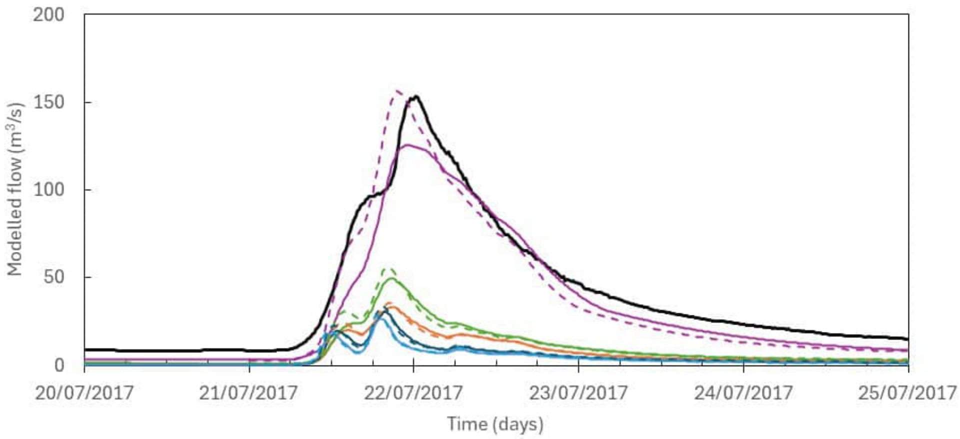
May 2021

Figure A3-11: Model results for three storm events with CK parameters increased by 25% (dashed lines)

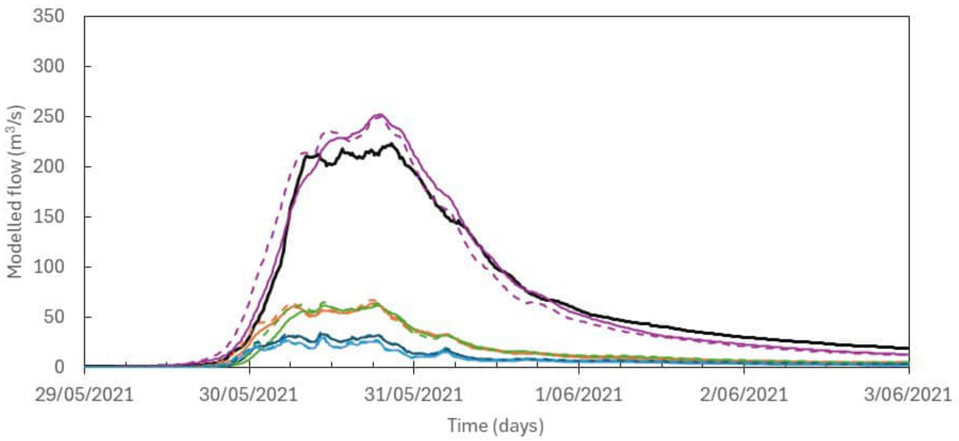
A3.12 CK parameters decreased by 25%



June 2013



July 2017



May 2021

Figure A3-12: Model results for three storm events with CK parameters decreased by 25% (dashed lines)

Appendix 4 Areal reduction factors

Selwyn River to Whitecliffs Catchment area, A = 159.1 km^2

Storm duration (hrs)	Average recurrence interval (years) 10	100	200	500
1	0.75	0.71	0.70	0.69
6	0.90	0.89	0.88	0.88
12	0.93	0.92	0.92	0.91
24	0.95	0.94	0.94	0.94

Hawkins River to Dalethorpe Rd Catchment area, A = 55.4 km^2

Storm duration (hrs)	Average recurrence interval (years) 10	100	200	500
1	0.84	0.82	0.81	0.80
6	0.94	0.93	0.93	0.92
12	0.96	0.95	0.95	0.95
24	0.97	0.96	0.96	0.96

Selwyn River to downstream of Flagpole Rd Catchment area, A = 154.6 km^2

Storm duration (hrs)	Average recurrence interval (years) 10	100	200	500
1	0.76	0.71	0.71	0.69
6	0.90	0.89	0.88	0.88
12	0.93	0.92	0.92	0.92
24	0.95	0.95	0.94	0.94

Hawkins River to Sherwood Catchment area, A = 40.2 km^2

Storm duration (hrs)	Average recurrence interval (years) 10	100	200	500
1	0.86	0.84	0.83	0.83
6	0.95	0.94	0.93	0.93
12	0.96	0.96	0.95	0.95
24	0.97	0.97	0.97	0.97

Waianiwaniwa River to Kirkstyle Catchment area, A = 57.3 km^2

Storm duration (hrs)	Average recurrence interval (years) 10	100	200	500
1	0.84	0.81	0.81	0.80
6	0.94	0.93	0.92	0.92
12	0.96	0.95	0.95	0.95
24	0.97	0.96	0.96	0.96

Hororata River to downstream of Boundary Creek Catchment area, A = 20.5 km^2

Storm duration (hrs)	Average recurrence interval (years) 10	100	200	500
1	0.90	0.88	0.88	0.87
6	0.96	0.95	0.95	0.95
12	0.97	0.97	0.97	0.96
24	0.98	0.98	0.98	0.98

Glendore Stream to Flagpole Road Catchment area, A = 26.9 km^2

Storm duration (hrs)	Average recurrence interval (years) 10	100	200	500
1	0.89	0.87	0.86	0.86
6	0.95	0.95	0.95	0.94
12	0.97	0.96	0.96	0.96
24	0.98	0.97	0.97	0.97

Appendix 5 Modelled design flow hydrographs

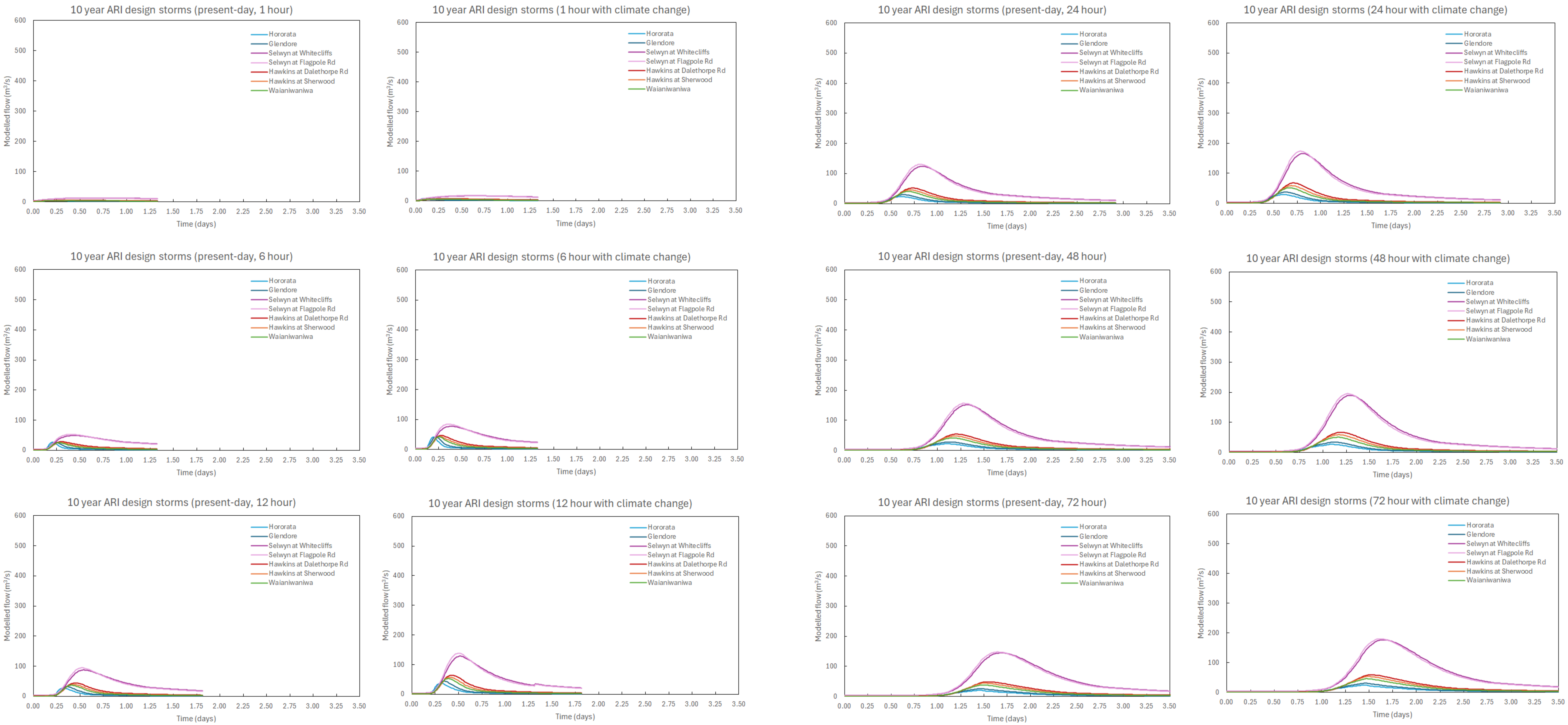


Figure A5-1: 10 year ARI design flow hydrographs

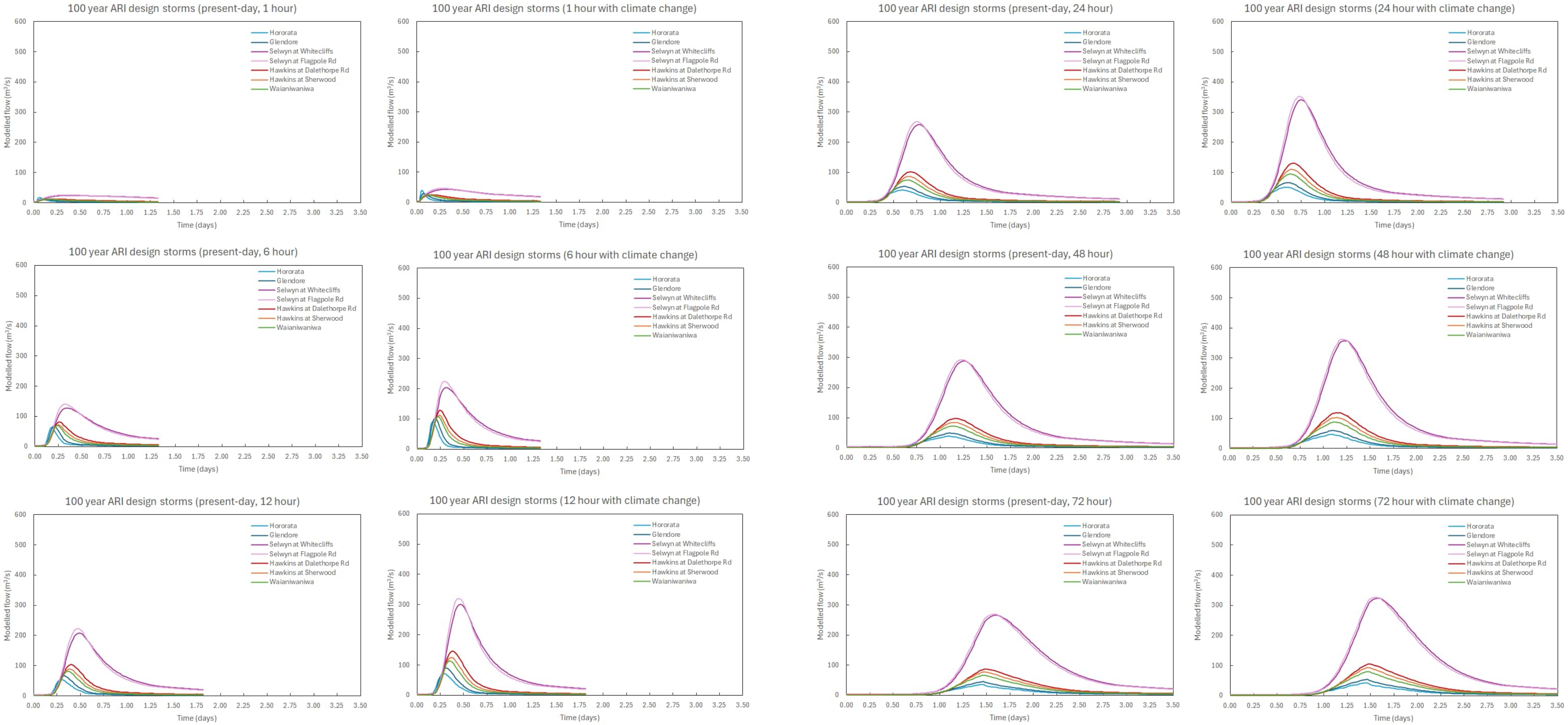


Figure A5-2: 100 year ARI design flow hydrographs

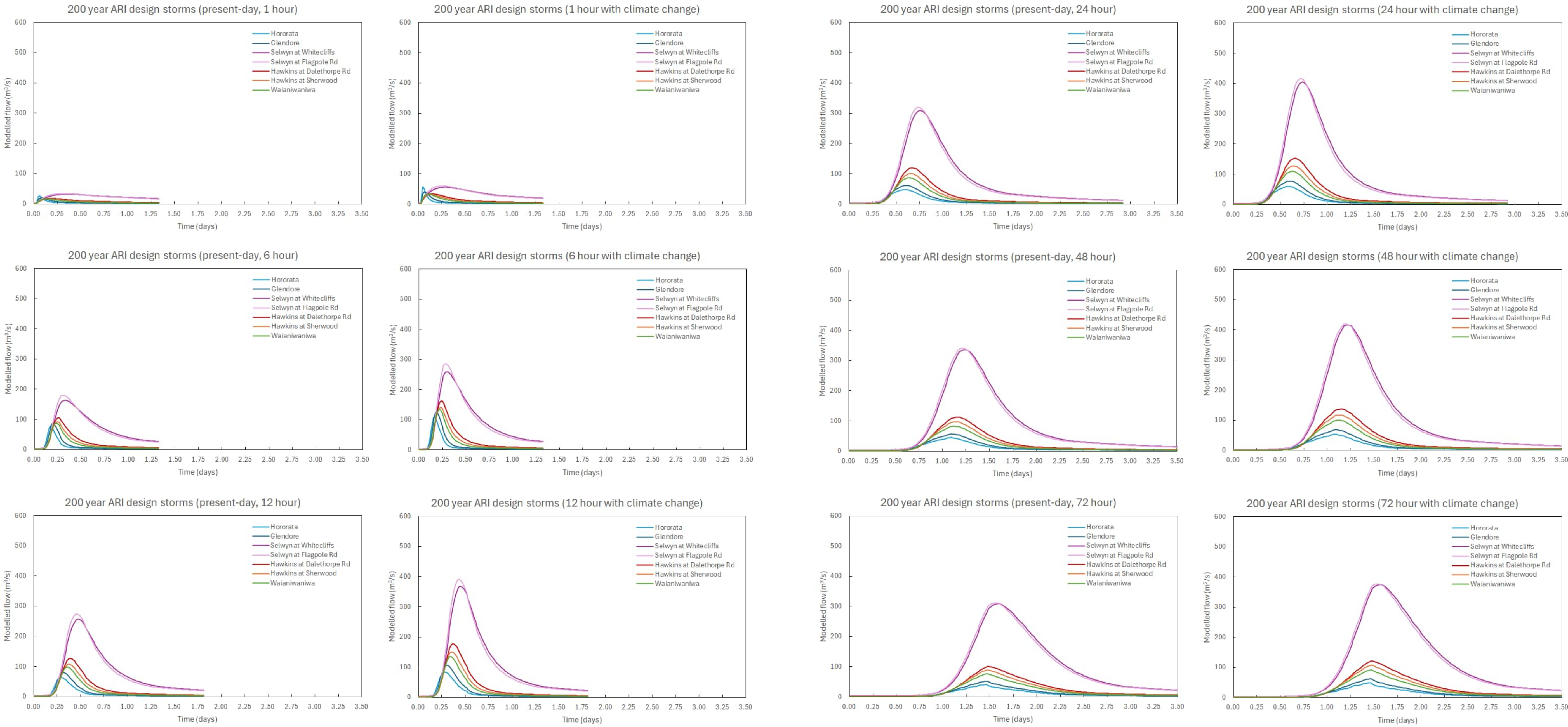


Figure A5-3: 200 year ARI design flow hydrographs

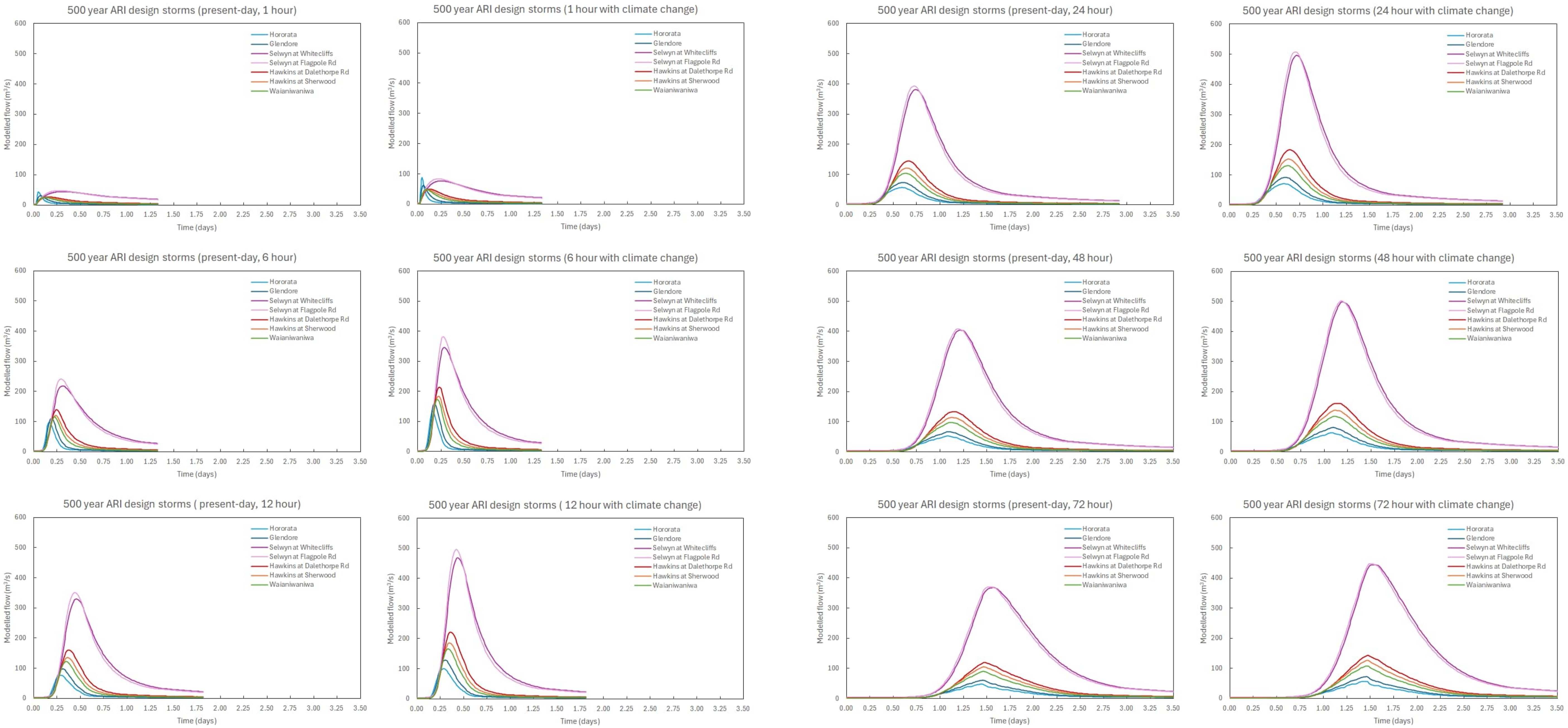


Figure A5-4: 500 year ARI design flow hydrographs

Appendix 6 Summary of modelled design peak flows

Note: Maximum "Flow increase due to climate change (%)" for each ARI represents the percentage increase in flow between the maximum present-day peak flow (for all durations) and the maximum peak flow with climate change (for all durations). For example, for the Selwyn River at Whitecliffs the maximum present-day 10 year ARI peak flow is 151 m^3/s and the maximum 10 year ARI peak flow with climate change is 190 m^3/s. This equates to a 25% increase in the 10 year ARI peak flow due to climate change.

Selwyn River at Whitecliffs

Storm duration (hrs)	Present-day Peak flow (m^3/s) Average recurrence interval (years)				Peak flow with climate change (m^3/s) Average recurrence interval (years)				Flow increase due to climate change (%) ARI (years)			
	10	100	200	500	10	100	200	500	10	100	200	500
1	13	25	32	45	17	43	56	78	38	73	74	74
6	49	128	163	218	77	204	259	346	57	60	59	58
12	88	208	256	329	129	300	368	468	47	44	43	42
24	124	259	309	382	165	341	405	497	33	32	31	30
48	151	289	336	403	190	358	416	498	25	24	24	23
72	145	267	309	368	177	324	374	444	22	22	21	21
MAX	**151**	**289**	**336**	**403**	**190**	**358**	**416**	**498**	25	24	24	23

Selwyn River at downstream of Flagpole Road

Storm duration (hrs)	Present-day Peak flow (m^3/s) Average recurrence interval (years)				Peak flow with climate change (m^3/s) Average recurrence interval (years)				Flow increase due to climate change (%) ARI (years)			
	10	100	200	500	10	100	200	500	10	100	200	500
1	13	27	35	48	18	47	61	85	40	77	77	76
6	53	140	179	241	84	225	286	382	59	61	60	58
12	95	222	274	350	138	320	391	496	46	44	43	41
24	131	269	320	393	173	352	417	508	33	31	30	29
48	156	293	341	408	195	362	421	502	25	24	24	23
72	148	270	311	370	180	326	377	448	22	21	21	21
MAX	**156**	**293**	**341**	**408**	**195**	**362**	**421**	**508**	25	24	24	24

Hawkins River at Sherwood

Storm duration (hrs)	Present-day Peak flow (m^3/s) ARI (years)				Peak flow with climate change (m^3/s) ARI (years)				Flow increase due to climate change (%) ARI (years)			
	10	100	200	500	10	100	200	500	10	100	200	500
1	4	12	17	26	6	25	35	51	66	103	100	96
6	26	70	88	115	42	108	135	174	64	55	53	51
12	37	81	98	122	53	113	135	166	43	39	38	36
24	40	75	87	104	52	95	110	131	28	27	26	25
48	41	72	82	97	50	87	100	118	21	22	22	22
72	38	67	77	90	46	81	92	108	21	20	20	20
MAX	**41**	**81**	**98**	**122**	**53**	**113**	**135**	**174**	27	39	38	42

Waianiwaniwa River at Kirkstyle

Storm duration (hrs)	Present-day Peak flow (m^3/s) Average recurrence interval (years)				Peak flow with climate change (m^3/s) Average recurrence interval (years)				Flow increase due to climate change (%) ARI (years)			
	10	100	200	500	10	100	200	500	10	100	200	500
1	5	13	18	27	7	25	35	52	50	93	91	89
6	28	82	105	140	47	129	163	214	65	58	56	53
12	45	103	126	160	64	146	177	222	45	41	40	38
24	52	102	120	145	68	131	153	184	31	28	27	27
48	54	98	112	133	67	119	137	161	23	22	21	21
72	48	87	101	119	59	105	121	143	21	21	21	20
MAX	**54**	**103**	**126**	**160**	**68**	**146**	**177**	**222**	25	41	40	38

Hororata River at downstream of Boundary Creek

Storm duration (hrs)	Present-day Peak flow (m^3/s) Average recurrence interval (years)				Peak flow with climate change (m^3/s) Average recurrence interval (years)				Flow increase due to climate change (%) ARI (years)			
	10	100	200	500	10	100	200	500	10	100	200	500
1	3	18	27	44	8	40	57	84	160	120	110	92
6	27	64	78	98	41	92	109	134	52	43	41	38
12	28	54	63	77	38	71	83	100	33	31	30	30
24	23	41	48	57	29	52	60	71	24	25	25	25
48	22	39	45	53	27	47	54	64	21	22	21	21
72	21	35	41	48	25	42	48	57	19	20	19	19
MAX	**28**	**64**	**78**	**98**	**41**	**92**	**109**	**134**	47	43	41	38

Glendore Stream at Flagpole Road

Storm duration (hrs)	Present-day Peak flow (m^3/s) ARI (years)				Peak flow with climate change (m^3/s) ARI (years)				Flow increase due to climate change (%) ARI (years)			
	10	100	200	500	10	100	200	500	10	100	200	500
1	3	14	21	33	6	30	43	66	103	116	109	101
6	27	69	86	111	43	103	126	159	58	49	47	44
12	32	67	80	98	45	90	106	129	39	34	33	32
24	30	53	62	74	37	67	77	92	25	25	25	25
48	28	49	57	67	34	60	69	81	21	22	22	21
72	26	45	52	61	31	54	62	72	19	20	20	19
MAX	**32**	**69**	**86**	**111**	**45**	**103**	**126**	**159**	39	49	47	44

Appendix 7 Model log

Mike+ 1D RDI Model Log - Selwyn foothill catchments

Software	**Mike+ 1D 2025**
Coordinate system	**NZGD2000/NZTM 2000**
Time step	**15 minutes (unless stated)**
Directory	**...\Selwyn_River_2024\Model_Final\...**

Sel = Selwyn River
Haw = Hawkins River
Cal = Calibration
Val = Validation
Des = Design

ET = Evapotranspiration
Sens = Sensitivity run
tstep = Time step
min = Minutes
hr = hour
CC = Climate change

Model description	*.mupp/*.sqlite	Start time	Finish time	Catchment(s)	Rainfall file (*.dfs0)	Evaporation (PET) site	PET File (*.dfs0)	Flow site	Flow file (*.dfs0)
Model calibration	**...\Cal_Sel_Whitecliffs**								
Calibration model for Selwyn at Whitecliffs catchment	Sel_cal_2010_2024	1/01/2010	12/08/2024	Selwyn River at Whitecliffs	Rainfall_Selwyn_1989_to_2024_15min	Darfield	Darfield_PET_Jan_1989_to_present	Selwyn River at Whitecliffs	Q_Site_68001_15min_1989_2024
Model validation									
	...\Val_Sel_Whitecliffs								
Validation model for Selwyn at Whitecliffs catchment	Sel_val_1989_2009	1/01/1989	31/12/2009	Selwyn River at Whitecliffs	Rainfall_Selwyn_1989_to_2024_15min	Darfield	Darfield_PET_Jan_1989_to_present	Selwyn River at Whitecliffs	Q_Site_68001_15min_1989_2024
	...\Val_Hawkins_Dalethorpe								
Validation model for Hawkins at Dalethorpe Road catchment	Haw_val_15min_2022_2024_rev1	1/01/1989	12/08/2024	Hawkins River at Dalethorpe Road	Rainfall_Selwyn_1989_to_2024_15min	Darfield	Darfield_PET_Jan_1989_to_present	Hawkins River at Dalethorpe Road (from 22/9/2022)	Q_Site_68008_15min
	...\Val_Hawkins_Willows								
Validation model for Hawkins at Willows catchment	Haw_val_15min_2005_2021	1/01/2005	5/06/2021	Hawkins River at Willows	Rainfall_Selwyn_1989_to_2024_15min	Darfield	Darfield_PET_Jan_1989_to_present	Hawkins River at Willows (from 15/12/2005)	Q_Site_68005_15min
Historic time series	**...\Historic_1989_2024**								
Simulated historic time series - Selwyn River at Whitecliffs and Selwyn River d/s of Flagpole Rd	Sel_catchments_1989_2024_ET_0_9_13_Mile_x_1_25	1/01/1989	12/08/2024	Selwyn River at Whitecliffs and Selwyn River d/s of Flagpole Rd	Rainfall_Selwyn_1989_to_2024_15min	Darfield	Darfield_PET_Jan_1989_to_present	Selwyn River at Whitecliffs	Q_Site_68001_15min_1989_2024
Simulated historic time series - Hawkins River at Dalethorpe Rd, Sherwood & Willows, Waianiwaniwa River at Kirkstyle, Hororata River at d/s of Boundary Ck & Glendore Stream at Flagpole Rd	Sel_catchments_1989_2024	1/01/1989	12/08/2024	Hawkins River at Dalethorpe Rd, Sherwood & Willows, Waianiwaniwa River at Kirkstyle, Hororata River at d/s of Boundary Ck & Glendore Stream at Flagpole Rd	Rainfall_Selwyn_1989_to_2024_15min	Darfield	Darfield_PET_Jan_1989_to_present	Hawkins River at Dalethorpe Road (from 22/9/2022)	Q_Site_68008_15min

Model description	*.mupp/*.sqlite	Start time	Finish time	Catchment(s)	Rainfall file (*.dfs0)	Evaporation (PET) site	PET File (*.dfs0)	Flow site	Flow file (*.dfs0)
Present-day design model runs	**...\Design**								
1 hour storm duration runs (** = 10, 100, 200 & 500)	Sel_des_1hr_**yr_ET_0_9_13Mile_1_25_final	1/01/2017	1/08/2017	As above - Selwyn River	Rainfall_Selwyn_July_2017_1hr_design_final	Darfield	Darfield_PET_Jan_1989_to_present	-	-
	Sel_des_1hr_**yr_final_rev1	1/01/2017	1/08/2017	As above - Hawkins, Waianiwaniwa, Hororata & Glendore	Rainfall_Selwyn_July_2017_1hr_design_final	Darfield	Darfield_PET_Jan_1989_to_present	-	-
6 hour storm duration runs (** = 10, 100, 200 & 500)	Sel_des_6hr_**yr_ET_0_9_13Mile_1_25_final	1/01/2017	1/08/2017	As above - Selwyn River	Rainfall_Selwyn_July_2017_6hr_design_final	Darfield	Darfield_PET_Jan_1989_to_present	-	-
	Sel_des_6hr_**yr_final_rev1	1/01/2017	1/08/2017	As above - Hawkins, Waianiwaniwa, Hororata & Glendore	Rainfall_Selwyn_July_2017_6hr_design_final	Darfield	Darfield_PET_Jan_1989_to_present	-	-
12 hour storm duration runs (** = 10, 100, 200 & 500)	Sel_des_12hr_**yr_ET_0_9_13Mile_1_25_final	1/01/2017	1/08/2017	As above - Selwyn River	Rainfall_Selwyn_July_2017_12hr_design_final	Darfield	Darfield_PET_Jan_1989_to_present	-	-
	Sel_des_12hr_**yr_final_rev1	1/01/2017	1/08/2017	As above - Hawkins, Waianiwaniwa, Hororata & Glendore	Rainfall_Selwyn_July_2017_12hr_design_final	Darfield	Darfield_PET_Jan_1989_to_present	-	-
24 hour storm duration runs (** = 10, 100, 200 & 500)	Sel_des_24hr_**yr_ET_0_9_13Mile_1_25_final	1/01/2017	1/08/2017	As above - Selwyn River	Rainfall_Selwyn_July_2017_24hr_design_final	Darfield	Darfield_PET_Jan_1989_to_present	-	-
	Sel_des_24hr_**yr_final_rev1	1/01/2017	1/08/2017	As above - Hawkins, Waianiwaniwa, Hororata & Glendore	Rainfall_Selwyn_July_2017_24hr_design_final	Darfield	Darfield_PET_Jan_1989_to_present	-	-
48 hour storm duration runs (** = 10, 100, 200 & 500)	Sel_des_48hr_**yr_ET_0_9_13Mile_1_25_final_rev2	1/01/2017	1/08/2017	As above - Selwyn River	Rainfall_Selwyn_July_2017_48hr_design_final	Darfield	Darfield_PET_Jan_1989_to_present	-	-
	Sel_des_48hr_**yr_final_rev1	1/01/2017	1/08/2017	As above - Hawkins, Waianiwaniwa, Hororata & Glendore	Rainfall_Selwyn_July_2017_48hr_design_final	Darfield	Darfield_PET_Jan_1989_to_present	-	-
72 hour storm duration runs (** = 10, 100, 200 & 500)	Sel_des_72hr_**yr_ET_0_9_13Mile_1_25_final	1/01/2017	1/08/2017	As above - Selwyn River	Rainfall_Selwyn_July_2017_72hr_design_final	Darfield	Darfield_PET_Jan_1989_to_present	-	-
	Sel_des_72hr_**yr_final_rev1	1/01/2017	1/08/2017	As above - Hawkins, Waianiwaniwa, Hororata & Glendore	Rainfall_Selwyn_July_2017_72hr_design_final	Darfield	Darfield_PET_Jan_1989_to_present	-	-
1 hour storm duration runs (** = 10, 100, 200 & 500) with time step reduced to 5 minutes	Sel_des_1hr_**yr_ET_0_9_13Mile_1_25_tstep_5min_final	1/01/2017	1/08/2017	As above - Selwyn River	Rainfall_Selwyn_July_2017_1hr_design_final	Darfield	Darfield_PET_Jan_1989_to_present	-	-
	Sel_des_1hr_**yr_tstep_5min_final_rev1	1/01/2017	1/08/2017	As above - Hawkins, Waianiwaniwa, Hororata & Glendore	Rainfall_Selwyn_July_2017_1hr_design_final	Darfield	Darfield_PET_Jan_1989_to_present	-	-

Model description	*.mupp/*.sqlite	Start time	Finish time	Catchment(s)	Rainfall file (*.dfs0)	Evaporation (PET) site	PET File (*.dfs0)	Flow site	Flow file (*.dfs0)
Design model runs with climate change (RCP8.5 to 2100)	**...\Design**								
1 hour storm duration runs (** = 10, 100, 200 & 500)	Sel_des_CC_1hr_**yr_ET_0_9_13Mile_1_25_final	1/01/2017	1/08/2017	As above - Selwyn River	Rainfall_Selwyn_July_2017_1hr_CC_design_final	Darfield	Darfield_PET_Jan_1989_to_present	-	-
	Sel_des_CC_1hr_**yr_final_rev1	1/01/2017	1/08/2017	As above - Hawkins, Waianiwaniwa, Hororata & Glendore	Rainfall_Selwyn_July_2017_1hr_CC_design_final	Darfield	Darfield_PET_Jan_1989_to_present	-	-
6 hour storm duration runs (** = 10, 100, 200 & 500)	Sel_des_CC_6hr_**yr_ET_0_9_13Mile_1_25_final	1/01/2017	1/08/2017	As above - Selwyn River	Rainfall_Selwyn_July_2017_6hr_CC_design_final	Darfield	Darfield_PET_Jan_1989_to_present	-	-
	Sel_des_CC_6hr_**yr_final_rev1	1/01/2017	1/08/2017	As above - Hawkins, Waianiwaniwa, Hororata & Glendore	Rainfall_Selwyn_July_2017_6hr_CC_design_final	Darfield	Darfield_PET_Jan_1989_to_present	-	-
12 hour storm duration runs (** = 10, 100, 200 & 500)	Sel_des_CC_12hr_**yr_ET_0_9_13Mile_1_25_final	1/01/2017	1/08/2017	As above - Selwyn River	Rainfall_Selwyn_July_2017_12hr_CC_design_final	Darfield	Darfield_PET_Jan_1989_to_present	-	-
	Sel_des_CC_12hr_**yr_final_rev1	1/01/2017	1/08/2017	As above - Hawkins, Waianiwaniwa, Hororata & Glendore	Rainfall_Selwyn_July_2017_12hr_CC_design_final	Darfield	Darfield_PET_Jan_1989_to_present	-	-
24 hour storm duration runs (** = 10, 100, 200 & 500)	Sel_des_CC_24hr_**yr_ET_0_9_13Mile_1_25_final	1/01/2017	1/08/2017	As above - Selwyn River	Rainfall_Selwyn_July_2017_24hr_CC_design_final	Darfield	Darfield_PET_Jan_1989_to_present	-	-
	Sel_des_CC_24hr_**yr_final_rev1	1/01/2017	1/08/2017	As above - Hawkins, Waianiwaniwa, Hororata & Glendore	Rainfall_Selwyn_July_2017_24hr_CC_design_final	Darfield	Darfield_PET_Jan_1989_to_present	-	-
48 hour storm duration runs (** = 10, 100, 200 & 500)	Sel_des_CC_48hr_**yr_ET_0_9_13Mile_1_25_final	1/01/2017	1/08/2017	As above - Selwyn River	Rainfall_Selwyn_July_2017_48hr_CC_design_final	Darfield	Darfield_PET_Jan_1989_to_present	-	-
	Sel_des_CC_48hr_**yr_final_rev1	1/01/2017	1/08/2017	As above - Hawkins, Waianiwaniwa, Hororata & Glendore	Rainfall_Selwyn_July_2017_48hr_CC_design_final	Darfield	Darfield_PET_Jan_1989_to_present	-	-
72 hour storm duration runs (** = 10, 100, 200 & 500)	Sel_des_CC_72hr_**yr_ET_0_9_13Mile_1_25_final	1/01/2017	1/08/2017	As above - Selwyn River	Rainfall_Selwyn_July_2017_72hr_CC_design_final	Darfield	Darfield_PET_Jan_1989_to_present	-	-
	Sel_des_CC_72hr_**yr_final_rev1	1/01/2017	1/08/2017	As above - Hawkins, Waianiwaniwa, Hororata & Glendore	Rainfall_Selwyn_July_2017_72hr_CC_design_final	Darfield	Darfield_PET_Jan_1989_to_present	-	-
1 hour storm duration runs (** = 10, 100, 200 & 500) with time step reduced to 5 minutes	Sel_des_CC_1hr_**yr_ET_0_9_13Mile_1_25_tstep_5min_final	1/01/2017	1/08/2017	As above - Selwyn River	Rainfall_Selwyn_July_2017_1hr_CC_design_final	Darfield	Darfield_PET_Jan_1989_to_present	-	-
	Sel_des_CC_1hr_**yr_tstep_5min_final_rev1	1/01/2017	1/08/2017	As above - Hawkins, Waianiwaniwa, Hororata & Glendore	Rainfall_Selwyn_July_2017_1hr_CC_design_final	Darfield	Darfield_PET_Jan_1989_to_present	-	-

Model description	*.mupp/*.sqlite	Start time	Finish time	Catchment(s)	Rainfall file (*.dfs0)	Evaporation (PET) site	PET File (*.dfs0)	Flow site	Flow file (*.dfs0)
Sensitivity model runs	**...\Sens_runs**								
1 - Evaporation decreased by 10%	Sel_catchments_1989_2024_ET_0_9_13_Mile_x_1_25_Sens_1_ET	1/01/1989	12/08/2024	Selwyn River at Whitecliffs and Selwyn River d/s of Flagpole Rd	Rainfall_Selwyn_1989_to_2024_15min	Darfield	Darfield_PET_Jan_1989_to_present	-	-
	Sel_catchments_1989_2024_sens_1_ET_rev1	1/01/1989	12/08/2024	Hawkins River at Dalethorpe Rd, Sherwood & Willows, Waianiwaniwa River at Kirkstyle, Hororata River at d/s of Boundary Ck & Glendore Stream at Flagpole Rd	Rainfall_Selwyn_1989_to_2024_15min	Darfield	Darfield_PET_Jan_1989_to_present	-	-
2a - Rainfall increased by 25%	Sel_catchments_1989_2024_ET_0_9_13_Mile_x_1_25_Sens_2_rain	1/01/1989	12/08/2024	As above - Selwyn River	Rainfall_Selwyn_1989_to_2024_15min	Darfield	Darfield_PET_Jan_1989_to_present	-	-
	Sel_catchments_1989_2024_sens_2_rain_rev1	1/01/1989	12/08/2024	As above - Hawkins, Waianiwaniwa, Hororata & Glendore	Rainfall_Selwyn_1989_to_2024_15min	Darfield	Darfield_PET_Jan_1989_to_present	-	-
2b - Rainfall decreased by 25%	Sel_catchments_1989_2024_ET_0_9_13_Mile_x_1_25_Sens_2b_rain_decrease	1/01/1989	12/08/2024	As above - Selwyn River	Rainfall_Selwyn_1989_to_2024_15min	Darfield	Darfield_PET_Jan_1989_to_present	-	-
	Sel_catchments_1989_2024_sens_2b_rain_decrease_rev1	1/01/1989	12/08/2024	As above - Hawkins, Waianiwaniwa, Hororata & Glendore	Rainfall_Selwyn_1989_to_2024_15min	Darfield	Darfield_PET_Jan_1989_to_present	-	-
3 - U_{max} increased from 14.4 to 20 mm	Sel_catchments_1989_2024_ET_0_9_13_Mile_x_1_25_Sens_3_Umax	1/01/1989	12/08/2024	As above - Selwyn River	Rainfall_Selwyn_1989_to_2024_15min	Darfield	Darfield_PET_Jan_1989_to_present	-	-
	Sel_catchments_1989_2024_sens_3_Umax_rev1	1/01/1989	12/08/2024	As above - Hawkins, Waianiwaniwa, Hororata & Glendore	Rainfall_Selwyn_1989_to_2024_15min	Darfield	Darfield_PET_Jan_1989_to_present	-	-
4 - L_{max} increased from 42.7 to 80 mm	Sel_catchments_1989_2024_ET_0_9_13_Mile_x_1_25_Sens_4_Lmax	1/01/1989	12/08/2024	As above - Selwyn River	Rainfall_Selwyn_1989_to_2024_15min	Darfield	Darfield_PET_Jan_1989_to_present	-	-
	Sel_catchments_1989_2024_sens_4_Lmax_rev1	1/01/1989	12/08/2024	As above - Hawkins, Waianiwaniwa, Hororata & Glendore	Rainfall_Selwyn_1989_to_2024_15min	Darfield	Darfield_PET_Jan_1989_to_present	-	-
5a - CQOF increased from 0.55 to 0.70	Sel_catchments_1989_2024_ET_0_9_13_Mile_x_1_25_Sens_5_CQOF	1/01/1989	12/08/2024	As above - Selwyn River	Rainfall_Selwyn_1989_to_2024_15min	Darfield	Darfield_PET_Jan_1989_to_present	-	-
	Sel_catchments_1989_2024_sens_5_CQOF_rev1	1/01/1989	12/08/2024	As above - Hawkins, Waianiwaniwa, Hororata & Glendore	Rainfall_Selwyn_1989_to_2024_15min	Darfield	Darfield_PET_Jan_1989_to_present	-	-

Model description	*.mupp/*.sqlite	Start time	Finish time	Catchment(s)	Rainfall file (*.dfs0)	Evaporation (PET) site	PET File (*.dfs0)	Flow site	Flow file (*.dfs0)
<u>Sensitivity model runs</u>	**...\Sens_runs**								
5b - CQOF decreased from 0.55 to 0.30	Sel_catchments_1989_2024_ET_0_9_13_Mile_x_1_25_Sens_5b_CQOF_dec	1/01/1989	12/08/2024	As above - Selwyn River	Rainfall_Selwyn_1989_to_2024_15min	Darfield	Darfield_PET_Jan_1989_to_present	-	-
	Sel_catchments_1989_2024_sens_5b_CQOF_dec_rev1	1/01/1989	12/08/2024	As above - Hawkins, Waianiwaniwa, Hororata & Glendore	Rainfall_Selwyn_1989_to_2024_15min	Darfield	Darfield_PET_Jan_1989_to_present	-	-
6 - TOF decreased from 0.48 to 0.25	Sel_catchments_1989_2024_ET_0_9_13_Mile_x_1_25_Sens_6_TOF	1/01/1989	12/08/2024	As above - Selwyn River	Rainfall_Selwyn_1989_to_2024_15min	Darfield	Darfield_PET_Jan_1989_to_present	-	-
	Sel_catchments_1989_2024_sens_6_TOF_rev1	1/01/1989	12/08/2024	As above - Hawkins, Waianiwaniwa, Hororata & Glendore	Rainfall_Selwyn_1989_to_2024_15min	Darfield	Darfield_PET_Jan_1989_to_present	-	-
7 - TIF decreased from 0.55 to 0.25	Sel_catchments_1989_2024_ET_0_9_13_Mile_x_1_25_Sens_7_TIF	1/01/1989	12/08/2024	As above - Selwyn River	Rainfall_Selwyn_1989_to_2024_15min	Darfield	Darfield_PET_Jan_1989_to_present	-	-
	Sel_catchments_1989_2024_sens_7_TIF_rev1	1/01/1989	12/08/2024	As above - Hawkins, Waianiwaniwa, Hororata & Glendore	Rainfall_Selwyn_1989_to_2024_15min	Darfield	Darfield_PET_Jan_1989_to_present	-	-
8 - TG decreased from 0.18 to 0	Sel_catchments_1989_2024_ET_0_9_13_Mile_x_1_25_Sens_8_TG	1/01/1989	12/08/2024	As above - Selwyn River	Rainfall_Selwyn_1989_to_2024_15min	Darfield	Darfield_PET_Jan_1989_to_present	-	-
	Sel_catchments_1989_2024_sens_8_TG_rev1	1/01/1989	12/08/2024	As above - Hawkins, Waianiwaniwa, Hororata & Glendore	Rainfall_Selwyn_1989_to_2024_15min	Darfield	Darfield_PET_Jan_1989_to_present	-	-
9a - CK parameters ($CK_{1,2}$, CK_{IF}, CK_{BF}) increased by 25%	Sel_catchments_1989_2024_ET_0_9_13_Mile_x_1_25_Sens_9_CKs_plus_25perc	1/01/1989	12/08/2024	As above - Selwyn River	Rainfall_Selwyn_1989_to_2024_15min	Darfield	Darfield_PET_Jan_1989_to_present	-	-
	Sel_catchments_1989_2024_sens_9_CKs_plus_25perc_rev1	1/01/1989	12/08/2024	As above - Hawkins, Waianiwaniwa, Hororata & Glendore	Rainfall_Selwyn_1989_to_2024_15min	Darfield	Darfield_PET_Jan_1989_to_present	-	-
9b - CK parameters ($CK_{1,2}$, CK_{IF}, CK_{BF}) decreased by 25%	Sel_catchments_1989_2024_ET_0_9_13_Mile_x_1_25_Sens_9b_CKs_minus_25perc	1/01/1989	12/08/2024	As above - Selwyn River	Rainfall_Selwyn_1989_to_2024_15min	Darfield	Darfield_PET_Jan_1989_to_present	-	-
	Sel_catchments_1989_2024_sens_9b_CKs_minus_25perc_rev1	1/01/1989	12/08/2024	As above - Hawkins, Waianiwaniwa, Hororata & Glendore	Rainfall_Selwyn_1989_to_2024_15min	Darfield	Darfield_PET_Jan_1989_to_present	-	-

Environment Canterbury Regional Council
Kaunihera Taiao ki Waitaha

Taking action together to shape a thriving and resilient Canterbury, now and for future generations.

Toitū te marae o Tāne, toitū te marae o Tangaroa, toitū te iwi.

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Appendix B: Summary of infiltration assessments

CCC Waterways & Wetlands Drainage Guide

Reference: https://ccc.govt.nz/assets/Documents/Environment/Water/waterways-guide/21.RainfallAndRunoff.pdf

Table 21-9: Christchurch standard soil infiltration types

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

Table 21-10: Christchurch typical and ultimate infiltration rates and Horton decay rates

Infiltration Type	Initial infiltration rate f_o (mm/hr)	Ultimate infiltration rate f_c (mm/hr)	Horton decay rate k	Approx time to decay to near ultimate (hrs)
Poor	0 - 5	1.0	1.5E-3	1.5
Moderate	5 - 10	2.5	1E-4	12
Free	10 - 15	5.0	3E-5	36

Flood mapping for Selwyn District

Reference: https://www.selwyn.govt.nz/__data/assets/pdf_file/0014/324131/DHI-Regional-Policy-Statement-Modelling.pdf

Table 3-2 - Infiltration Categories

Drainage type	Start Infiltration (mm/hr)	End Infiltration (mm/hr)	Horton's Exponent
Well drained	18.65	5.65	$5.8e^{-5}$
Moderately well drained	6.25	1.85	$6.5e^{-5}$
Imperfectly drained	2.5	0.75	$7.1e^{-5}$
Poorly drained	1.25	0.4	$8.2e^{-5}$
Very poorly drained	0.4	0.1	$1.2e^{-4}$
Roads	0 (impervious)		
Buildings in soakage areas	10% AEP rainfall intensity		

Flood Hazard Modelling for Waimakariri District

Reference: https://www.waimakariri.govt.nz/__data/assets/pdf_file/0008/140111/district-flooding-map-2019-update-DHI-report.pdf

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

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

Appendix C: Data Register

Data	Provided by	Status	Date provided	File reference
District flood model boundaries	ECan	Provided	23/09/2024	Sel_Hillcatch_v3.shp
Township model boundaries	SDC	Provided rec'd from SDC GIS	Confirmed by SDC May 2025	
Hill country sub-catchment boundaries	ECan	Provided	23/09/2024	Sel_Hillcatch_v3.shp
Inflow hydrographs from hill country sub-catchments: · 10-year ARI · 100-year ARI · 200-year ARI · 500-year ARI The inflow data will be accompanied by a memo describing the methodology used to generate the hydrographs, which will be peer reviewed.	ECan	Provided	9/04/2025	Selwyn_modelled_hydrographs_final.xlsx
District-wide model boundary conditions (Te Waihora Lake Ellesmere lake levels)	ECan	Provided	12/12/2024	Te Waihora average levels.csv
Stormwater asset information (including pipes, culverts, bridges) provided as shapefiles	SDC	Provided, rec'd from SDC GIS	25/02/2025	SUMP_Stormwater_Assets_25_02_2025.shp CSM2_drainage
LiDAR data for the district (flown March to May 2023). This data can be viewed at Canterbury - Selwyn LiDAR 1m DSM (2023) | LINZ Data Service LIDAR specifications are as outlined below: · LiDAR point cloud classified to full LINZ specifications in LAS and LAZ format · 1 m DEM in RASTER (GeoTiff) and ASCII formats · 1 m DSM in RASTER (GeoTiff) and ASCII formats · Hydro breaklines in SHP format The data has been reviewed and corrected by Environment Canterbury and LINZ for specific areas particularly relating to low crop.	LINZ	Provided	Downloaded Dec 2024	LINZ https://data.linz.govt.nz/layer/115805-canterbury-selwyn-lidar-1m-dem-2023/ https://data.linz.govt.nz/layer/115802-canterbury-banks-peninsula-lidar-1m-dem-2023/ https://data.linz.govt.nz/layer/111133-canterbury-lidar-1m-dem-2020-2023/ https://data.linz.govt.nz/layer/109641-canterbury-christchurch-1m-dem-2020-2021/ https://data.linz.govt.nz/layer/104497-canterbury-christchurch-and-ashley-river-lidar-1m-dem-2018-2019/ https://data.linz.govt.nz/layer/104931-canterbury-lidar-1m-dem-2018-2019/
As-built ground surfaces for any subdivisions completed after the LiDAR was flown (i.e. May 2023 onwards) subject to it being provided by developers	SDC	Provided	30/01/2025	TIN DESIGN ARBOR STG 20 DEM 0.1m.dem TIN DESIGN BROADFIELD 1-3 DEM 0.1m.dem TIN DESIGN KARUMATA STGS 1 2 AND 4 DEM 0.1m.dem TIN DESIGN MADDISONS QUARTER DEM 0.1m.dem TIN DESIGN ROSEMERRYN STGS 17 AND 21 DEM 0.1m.dem
Aerial imagery showing extent of flooding for several storm events – for calibration/validation purposes	SDC+ECan	2017 imagery used for initial calibration		ECan FIR, https://apps.canterburymaps.govt.nz/FIR selwynfiletransfers_labelled-aerial-photos-pptx_2024-12-03_2330 SDC_Flood_images
Road soakpit design standards/sizing method and/or drawings	SDC	Provided	12/12/2024	Confirmed via email dataed 12/12/2024 #SR-28598 Data request Stormwater_Lims_Pims featureclass for modeling
Confirm Manhole invert level vertical datum	SDC	Provided	24/01/2025	Confirmed via email data 24/1/2025
Define sump type S or D- SUMP_StrmwaterAssets_25_02_2025.zip', provided 25/2/2025	SDC	Provided	25/02/2025	SUMP_Stormwater_Assets_25_02_2025
Pond inlet/outlet design drawings for Leeston (see tab)	SDC	Provided	3/06/2025	SDC_SWPond_Details_OneDrive_2_28-05-2025

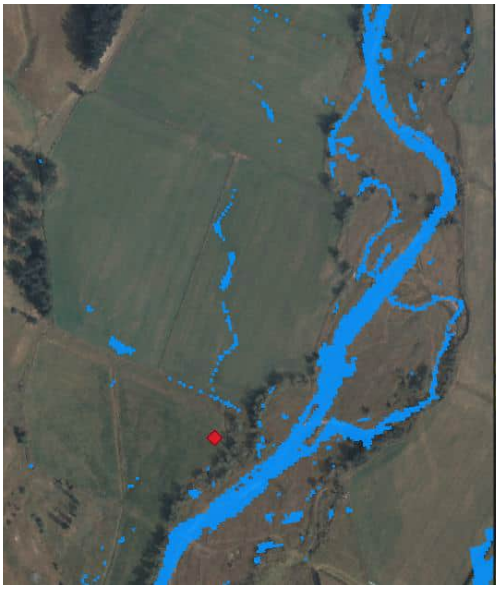
				LEESTON - 1 Palladio Avenue - Wetland.pdf LEESTON - 3-9 Pound Road - Basin (as-builts).pdf LEESTON - 3-9 Pound Road - Stormwater Basin.pdf LEESTON - 16 Country Lane - Wetland.pdf LEESTON - 78 Clausen Avenue - Both Basins (as-builts).pdf LEESTON - 78 Clausen Avenue - Both Basins.pdf LINCOLN - 1 Kaitorete Drive - All Basins.pdf LINCOLN - 1 Kaitorete Drive - Basins (design plans).pdf LINCOLN - 13 Inaka Street - All Basins.pdf LINCOLN - 13 Inaka Street - Some As-built Data page 40.pdf LINCOLN - 19 Ballinger Street - Basins As-builts.pdf LINCOLN - 30 Crowder Street - Basins (TO BE VERIFIED).pdf LINCOLN - 42 Carnaveron Drive - Basin As-built.pdf LINCOLN - 42 Carnaveron Drive - Basin.pdf LINCOLN - 45 Te Raki Drive - All Basins.pdf LINCOLN - 51 Kaitorete Drive - Western FFB As-builts.pdf LINCOLN - 58 Sunline Avenue - Basin As-built.pdf LINCOLN - 58 Sunline Avenue - Basin.pdf LINCOLN - 66 Vernon Drive and 19 Ballinger Street - All Basins.pdf LINCOLN - 74 Carnaveron Drive - Basin.pdf LINCOLN - 84 Oaks Drive - All Basins.pdf LINCOLN - 84 Oaks Drive - First Flush Basin 1 and Attenuation Basin Outfall As built.pdf LINCOLN - 84 Oaks Drive - First Flush Pond 2 As built.pdf LINCOLN - 89 Jimmy Adams Terrace - Both Basins.pdf LINCOLN - 520 Birches Road - Basin.pdf LINCOLN - 775 Ellesmere Road - Wetland.pdf LINCOLN - 1486 Springs Road - Both Basins.pdf Pond As-built Data.docx PREBBLETON - 14 James Prebble Drive - Both Basins.pdf PREBBLETON - 19-20 Mersham Drive - Wetlands.pdf PREBBLETON 30-31 William Deans Drive - Basins.pdf PREBBLETON - 43 Stationmasters Way - All Basins.pdf SOUTHBRIDGE - 7 Gabbie Place - Basin Design Drawings (outlet details).pdf SOUTHBRIDGE - 7 Gabbie Place - Both Basins.pdf SOUTHBRIDGE - 17 Bridge Street.pdf TAI TAPU - 12 Ryan Place - Both Basins.pdf TAI TAPU - 19 Gibraltar Close - East basin (as-builts).pdf TAI TAPU - 19 Gibraltar Close - East basin (outlet details).pdf TAI TAPU - 19 Gibraltar Close - East Basin.pdf

Leeston bypass design drawings	SDC	Provided	29/01/2025	[2019 model] Leeston Stormwater Bypass - Flood Modelling Report.pdf [Oct 2023] RC - Appendix 8 - Flooding technical summary Collated.pdf 201216 Leeston North SW Bypass Stage 3 As built.pdf 215689 - As-built Services & Roading part of Stage 4 and 6.pdf 215689 - Plans Full Set R12 (1).pdf 230511_5198 Karumata Oaks - Leeston Dunsandel Rd_Stage 1-2 - for EA - rd.pdf Bypass Stage 2-DW-COMBINED-SET_2016-11-03 FOR CONST(227110).pdf Construction Issue Drawings - Leeston North Stormwater Bypass Stage 3 Rev 2.pdf Drawings For Construction - Leeston North Stormwater Bypass Stage 3 Rev 2.pdf Leeston Stage 4+5 Design Report 505193-0008-REP-CC-0001[A].pdf Leeston Stage 5 Final Design Drawings.pdf Stage -1 - CONSTRUCTION SET_[26-05-15].pdf
SDC RAMM data (culvert data for roading assets) - 'ExportDrainage.zip' provided 23/4/2025	SDC	Provided	23/04/2025	Export_Drainage

Appendix D: Flooding observations vs model results

JULY 2017 EVENT

Time of photos: 4pm to 5pm 22nd July (aerials) and 9am to 11am 22nd July (ground).



N2_20170722_161202 - Looking west from the Hawkins River toward Bluff Road and Barrs Road

N2_20170722_161234 - Hawkins River at Malvern Hills Road looking east

N2_20170722_161403 - Hawkins River north of Auchenflower Road looking south-east

N2_20170722_161503 - Looking south-east along Hawkins River towards Homebush Road

N2_20170722_161700 - Looking south-east across Hawkins River south of SH 77

N2_20170722_161728 - Hawkins River north of McLaughlins Road (south-east)

N2_20170722_161813 - Hawkins River. Looking downstream toward Greendale Road

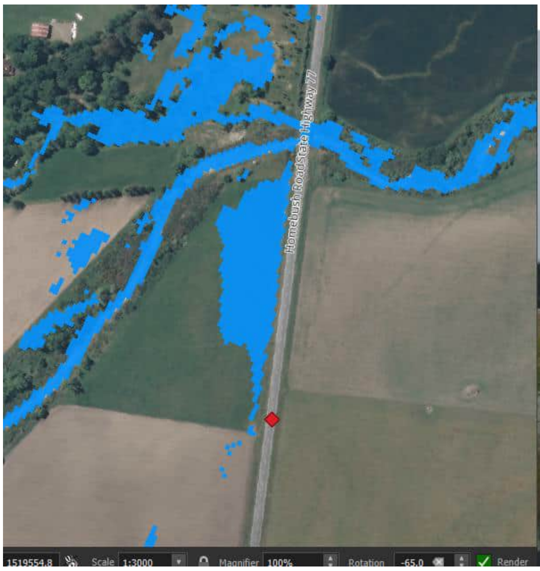
N2_20170722_162005 - Hawkins River and Bealey Road (south-east)

N2_20170722_162020 - Hawkins River at Bealey Road and Lambs Road (south-east)

N2_20170722_162138 - Hawkins River and Storeys Road (south-east)

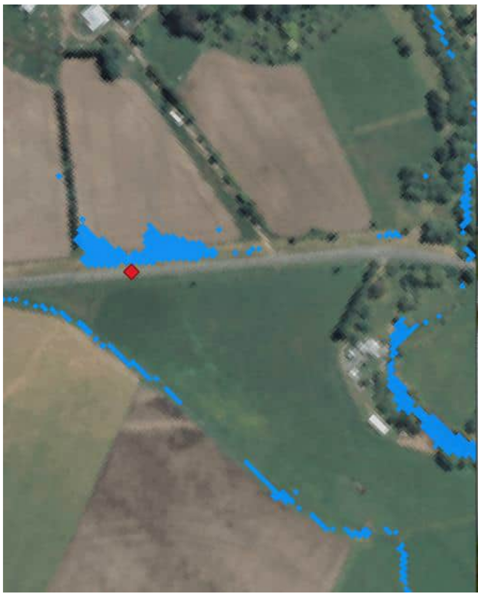
N2_20170722_162213 - Hawkins River and Ridgens Road (south-east)

N1_20170814_101752 - Looking east along Bangor Road toward Blacks Stream



N1_20170722_122511 - Looking north-east along Homebush Road toward the Waianiwaniwa River

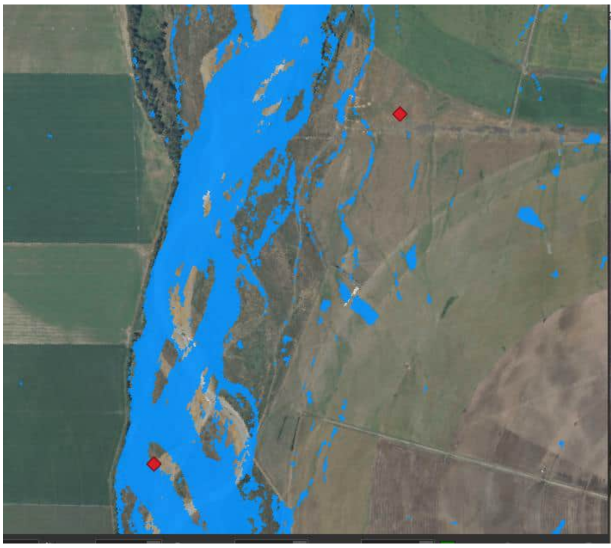
N1_20170722_122025 - Looking north from Bridge Street north of the Selwyn River



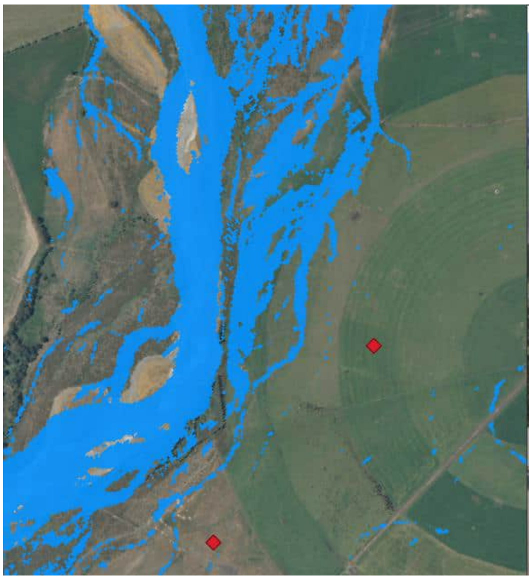
N1_20170722_112216 - Looking north from Cordys Road near the Morgans Road intersection

N1_20170722_113510 - Cordys Stream looking downstream from Cordys Road bridge

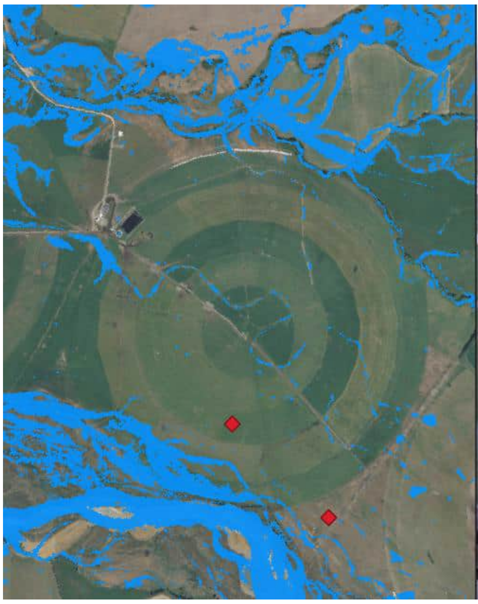
N1_20170722_113732 - Hororata township looking north from Bealey Road



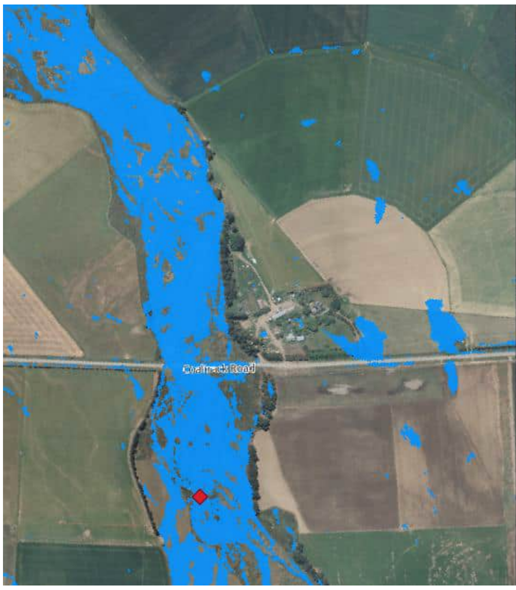
2_162527 - Selwyn River downstream of Bealey Road looking south



N2_20170722_162548 - Selwyn River looking downstream towards Waterford Road

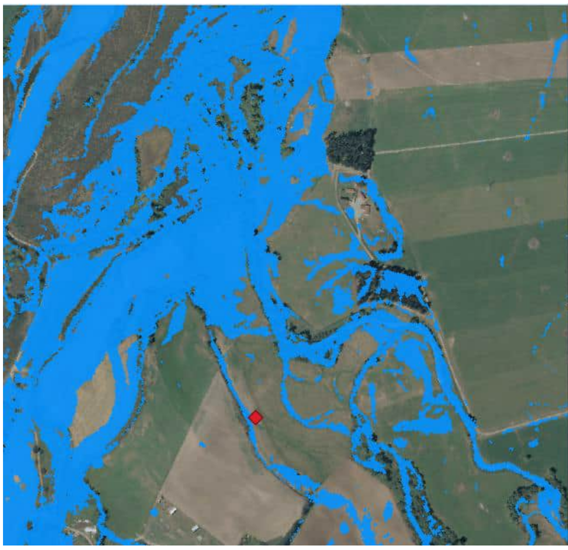


N2_20170722_162556 - Looking south-west to Hororata River upstream of Mitchells Road

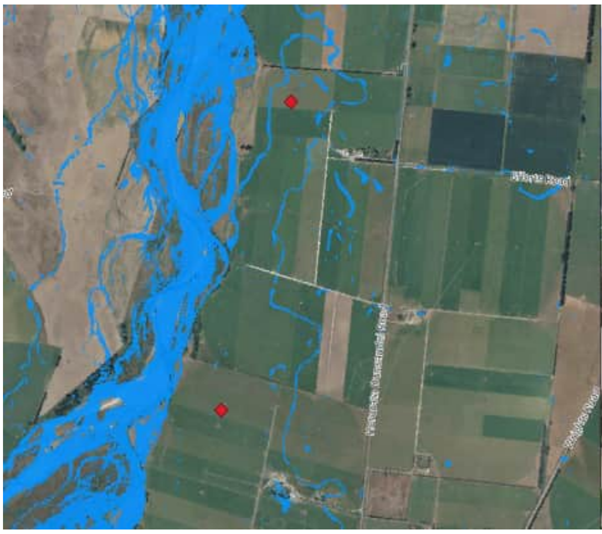


N2_20170722_162357 - Waianiwaniwa River at Coaltrack Road looking upstream

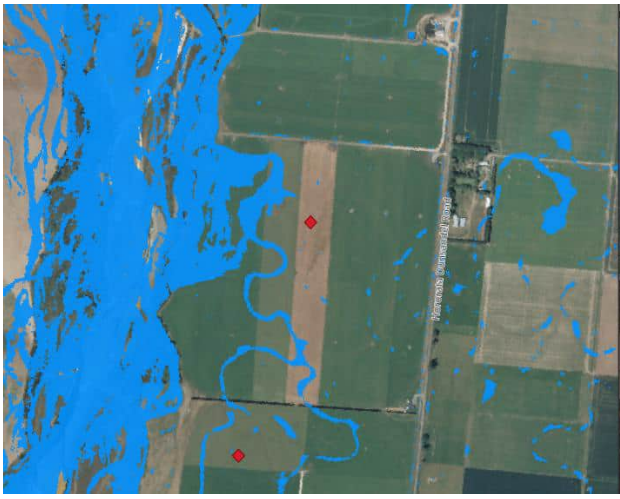
N2_20170722_162648 - Hororata River (distance) downstream of Gillanders Road looking south



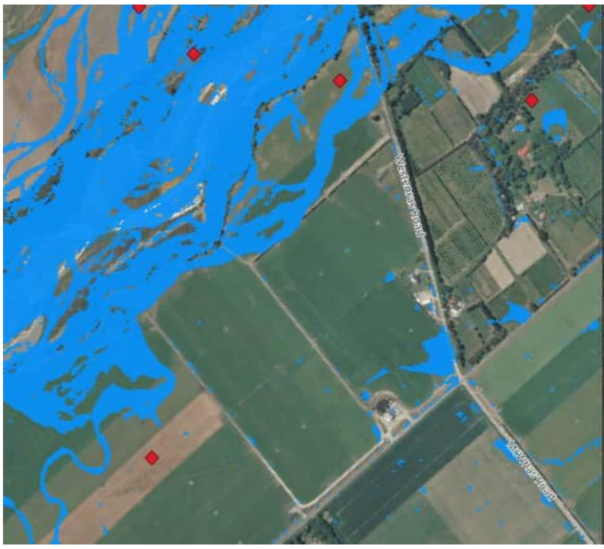
N2_20170722_162723 - Confluence of Selwyn (distance) and Hororata Rivers (south-east)



N2_20170722_162755 - Selwyn River downstream of Gillanders Road (east)

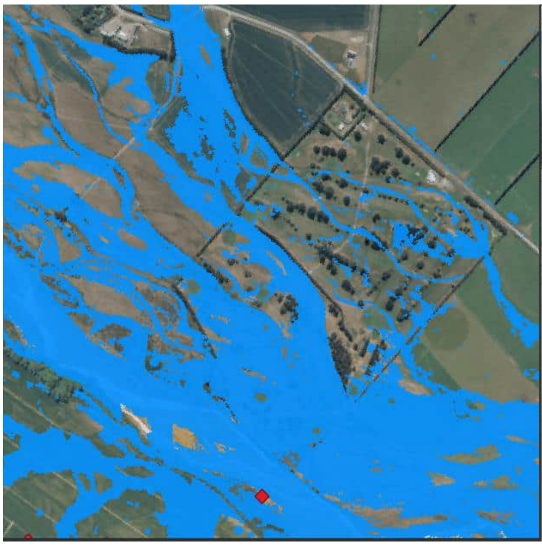


2_20170722_162823 - Selwyn River upstream of Westenras Road (east)

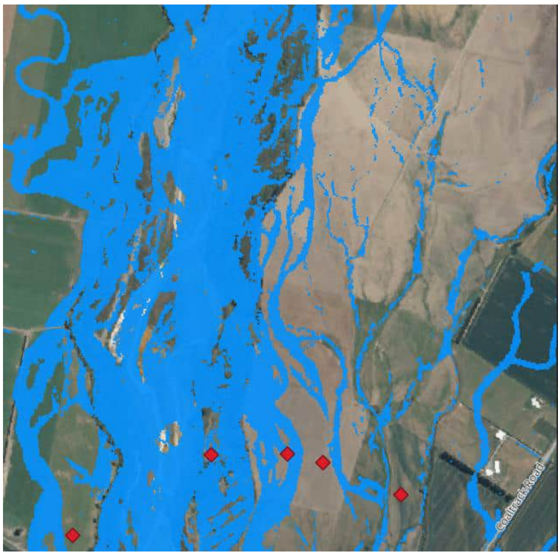


N2_20170722_162838 - Selwyn River upstream of Westenras Road (east)

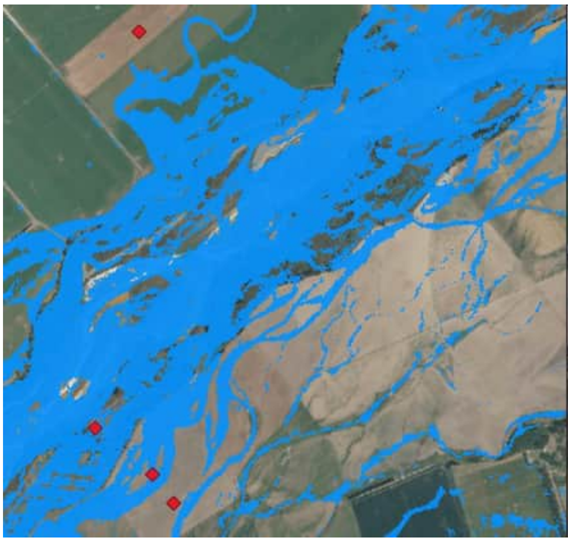
N2_20170722_162917 - Looking south-east toward Hunters Road and Hororata Dunsandel Road



N2_20170722_162926 - Selwyn River at Greendale Golf Club (north-west)



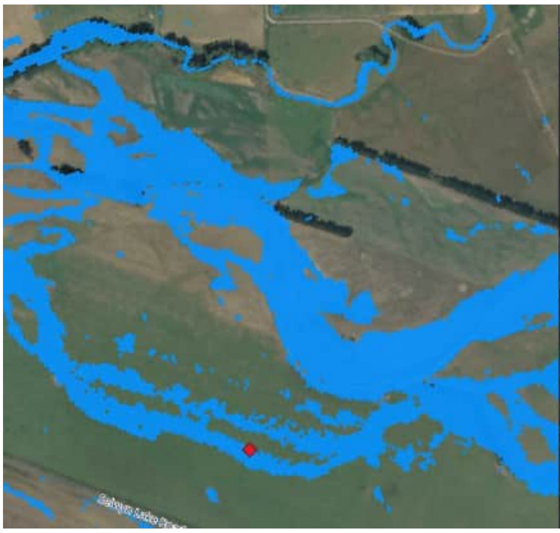
N2_20170722_163048 - Selwyn River upstream of Greendale Golf Club (west)



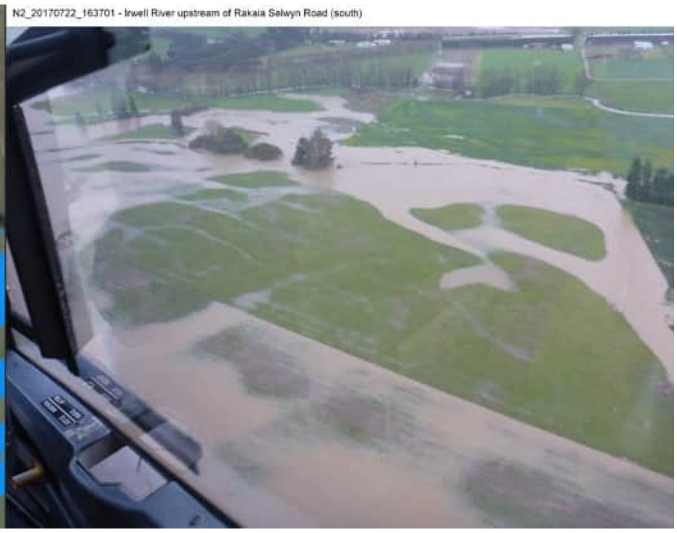
N2_20170722_163054 - Selwyn River upstream of Westenras Road (west)

N2_20170722_163404 - Selwyn River and Selwyn Lake Road upstream of SH 1 (east)

N2_20170722_163507 - Irwell River at SH 1 looking upstream



N2_20170722_163701 - Irwell River upstream of Rakaia Selwyn Road (south)



N1_20170722_102149 - Selwyn River overflows across Selwyn Lake Road (north-west)

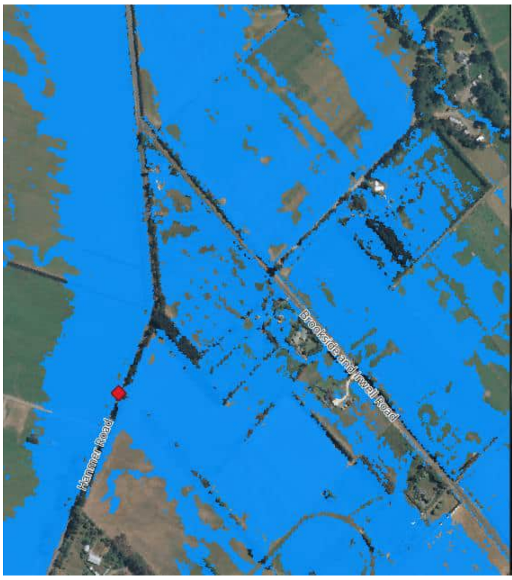
N2_20170722_163729 - Irwell River downstream of Rakaia Selwyn Road (south)

N2_20170722_163827 - Irwell River near Watsons Road (west)

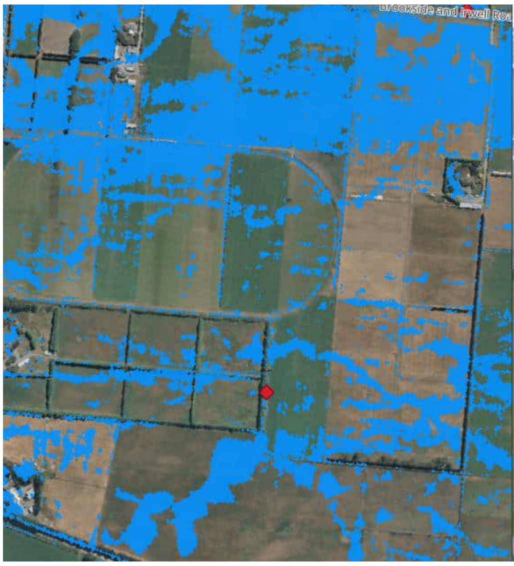
N2_20170722_163844 - Boundary Creek Road near Stewarts Road (south-west)

N2_20170722_163919 - Irwell River and Boundary Creek Road looking toward Brookside and Burnham Road (north-east)

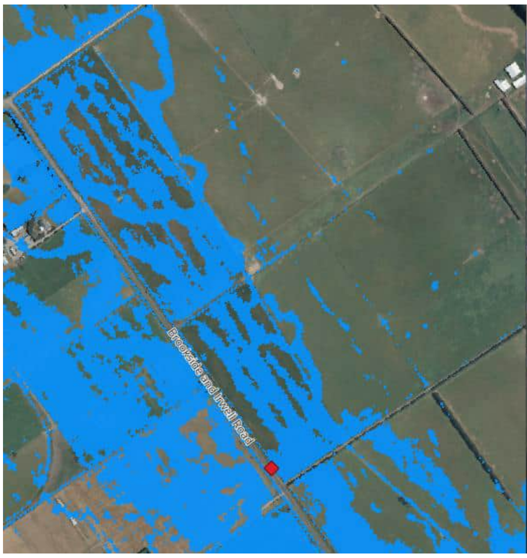
N2_20170722_163954_2 - Irwell River downstream of Brookside and Burnham Road (east)



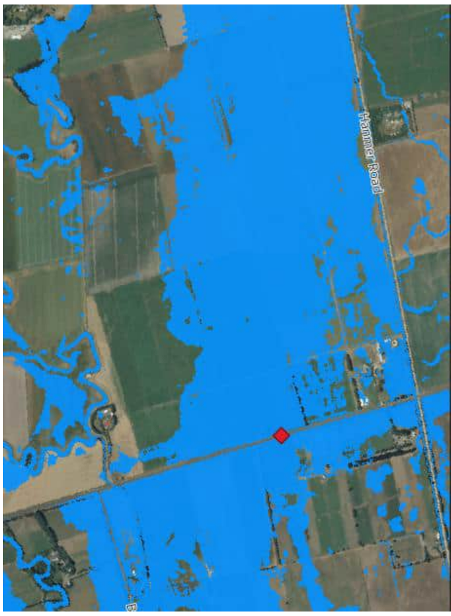
N1_20170722_100851 - Looking north along Hanmer Road south of Brookside and Irwell Road



N2_20170722_164108 - Between Stephens Road Hanmer Road and Brookside and Irwell Road (north-east)

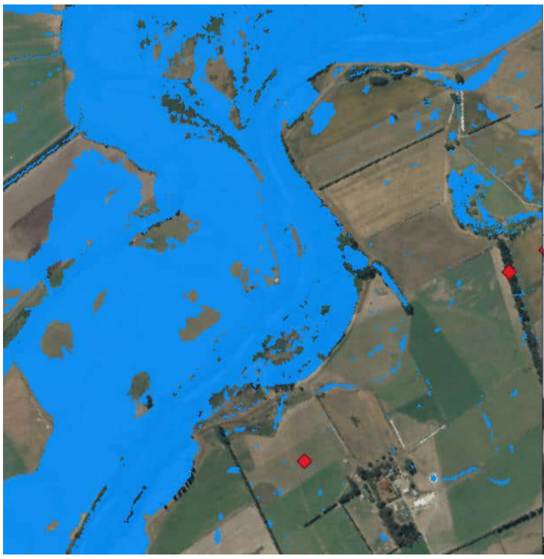


N2_20170722_164123 - Looking north across Brookside and Irwell Road toward Stephens Road



N1_20170722_095618 - Looking south-east from Leeston Road north of Hanmer Road

N2_20170722_164350 - Selwyn River downstream of Leeston Road (north-east)

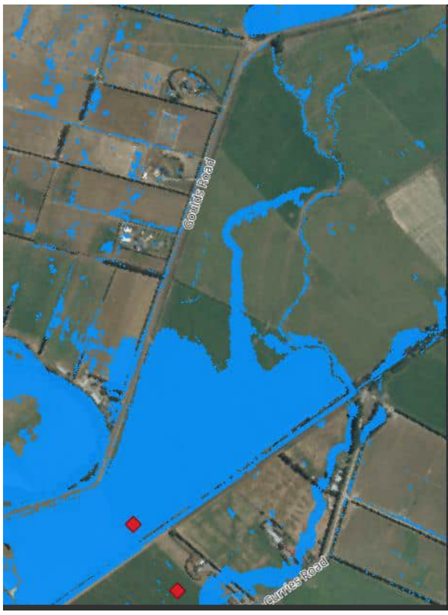


N2_20170722_164401 - Selwyn River looking downstream toward Coes Ford (north-east)

N2_20170722_164414_2 - Selwyn River at Coes Ford (north-east)

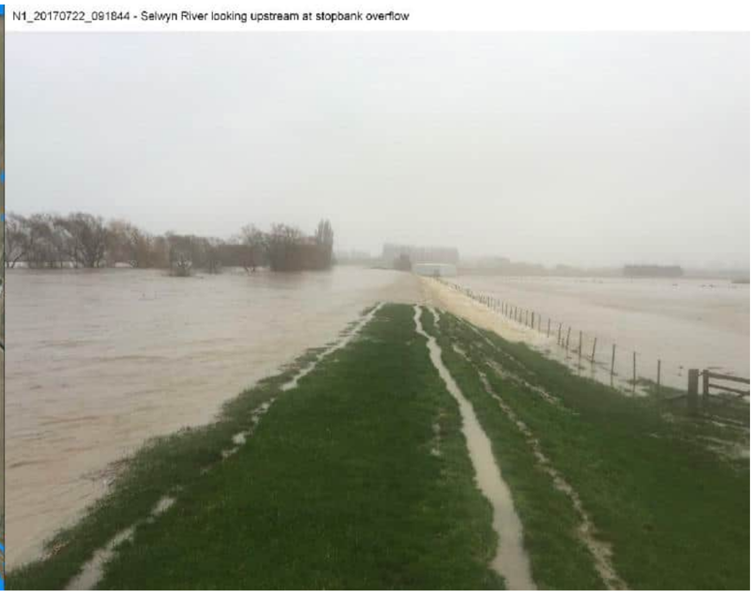
N2_20170722_164416 - The Lake Road and Coes Ford (east)

N2_20170722_164524 - Selwyn River at Coes Ford (south-west)



N2_20170722_164518 - Looking north-west between Curries Road and Goulds Road

N1_20170722_091844 - Selwyn River looking upstream at stopbank overflow



Model overtopping depth at time of photo: approx. 100 – 150 mm

N1_20170722_091222 - Looking downstream along Selwyn River stopbank at Upper Selwyn Huts

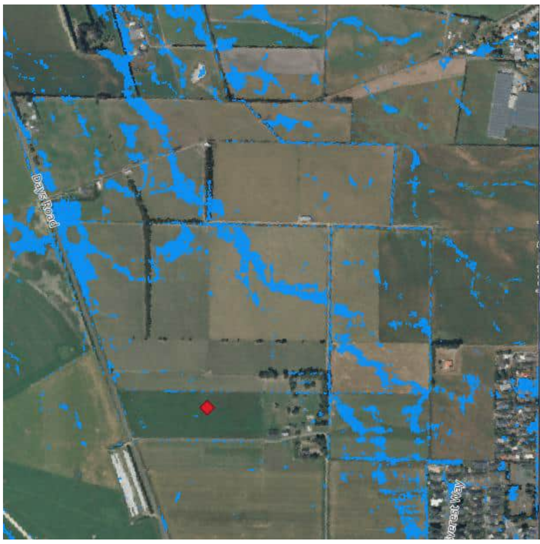
Model water level at time of photo approx. 3.8 mRL, top of stopbank: 4.5 mRL

N2_20170722_164510 - Looking north between Curries and Powells Roads

N2_20170722_165106 - Looking north across Durey Andrews and Carters Roads

N2_20170722_165129 - Looking south-east along Englishs Road toward the intersection with Andrews Road

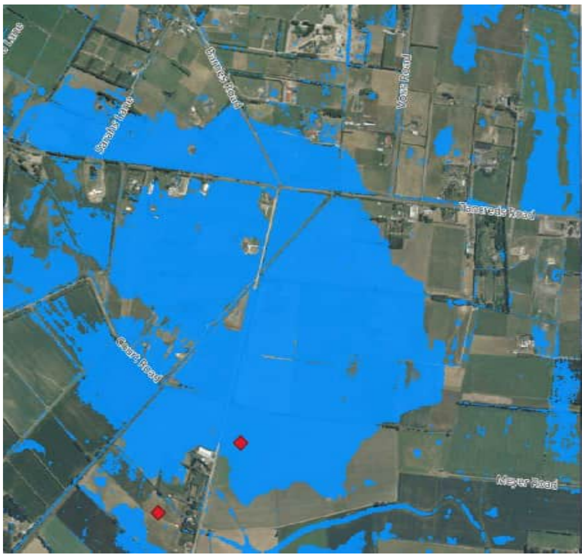
N2_20170722_170004 - Looking north-east toward the intersection of Springston Rolleston Road and Selwyn Road



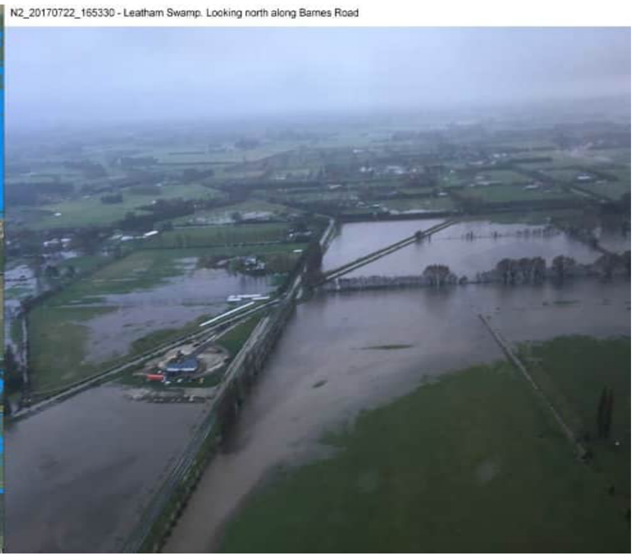
N2_20170722_165845 - Looking south between Days Road and Leeston Road

N2_20170722_165215_2 - Halswell River. Looking north along River Road from the intersection with Carters Road

N2_20170722_165322 - Looking east from Barnes Road between Perymans and Court Roads



N2_20170722_165330 - Leatham Swamp. Looking north along Barnes Road



N2_20170722_165430 - Looking south at properties between Tai Tapu Road and Voss Road (south of Osborn Road)

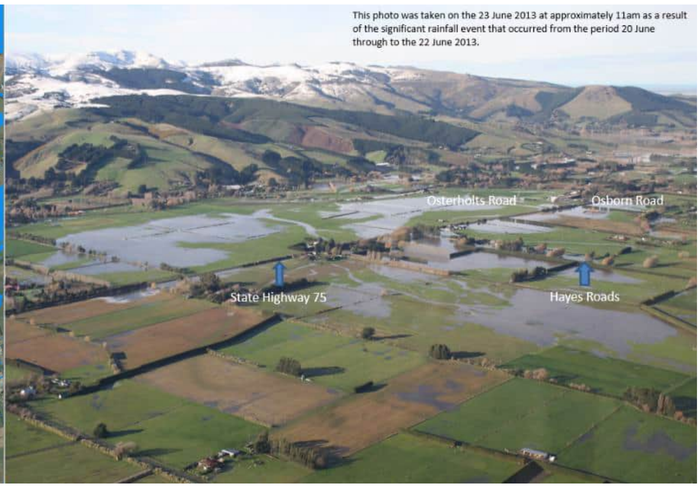
N2_20170722_165402 - Looking east across Tai Tapu Road toward the Halswell River from north of Tancreds Road

N2_20170722_170341 - Looking west between Railway Road Wards Road and Sandy Knolls Road

N2_20170722_170356 - Looking west between Railway Road Wards Road and Sandy Knolls Road

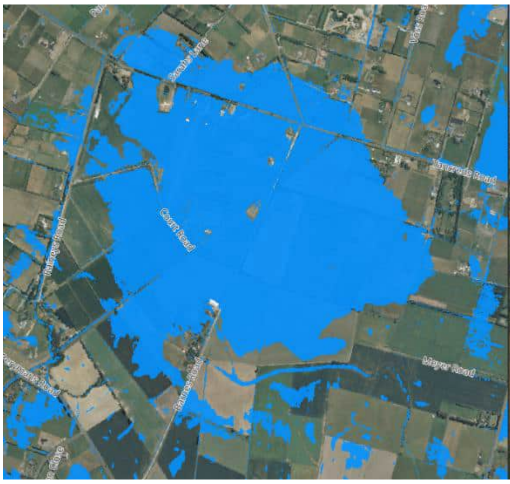
JUNE 2013 EVENT

Time of photos: 11am 23 June (aerials) and 11am to 2pm 22 June (ground)




Leavington Close
Barnes Road


This photo was taken on the 23 June 2013 at approximately 11am as a result of the significant rainfall event that occurred from the period 20 June through to the 22 June 2013.
LINCOLN
Lincoln Tai Tapu Road
Leavington Road
Perrymaans Road
Barnes Road


Tancreds Road
Meyer Road

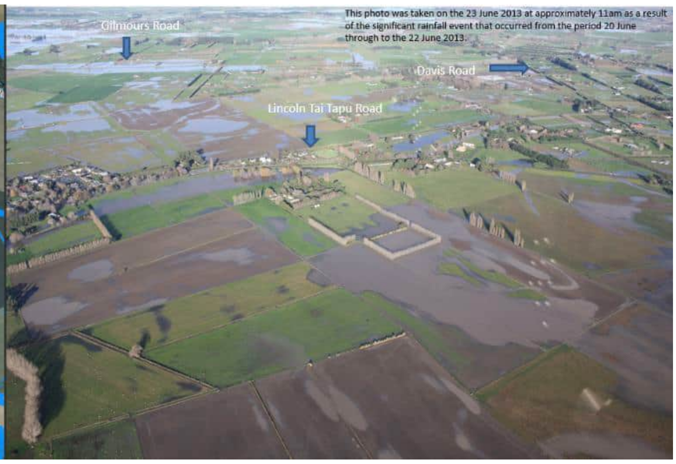

This photo was taken on the 23 June 2013 at approximately 11am as a result of the significant rainfall event that occurred from the period 20 June through to the 22 June 2013.
Lincoln
Tancreds Road
Barnes Road


Osterholts Road
Holmes Road

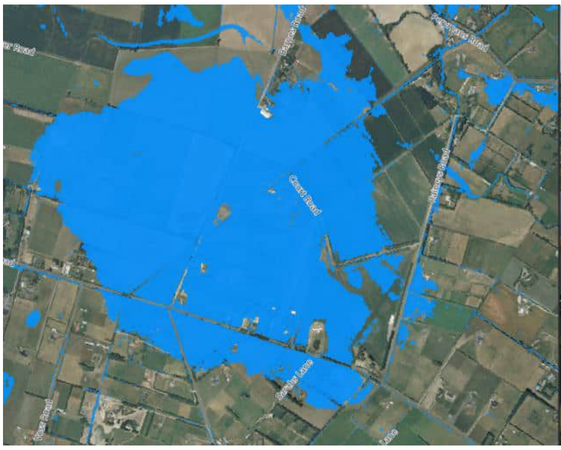

This photo was taken on the 23 June 2013 at approximately 11am as a result of the significant rainfall event that occurred from the period 20 June through to the 22 June 2013.
Old Tai Tapu Road
Osterholts Road


This photo was taken on the 23 June 2013 at approximately 11am as a result of the significant rainfall event that occurred from the period 20 June through to the 22 June 2013.
Rhodes Road
Otahuna Road

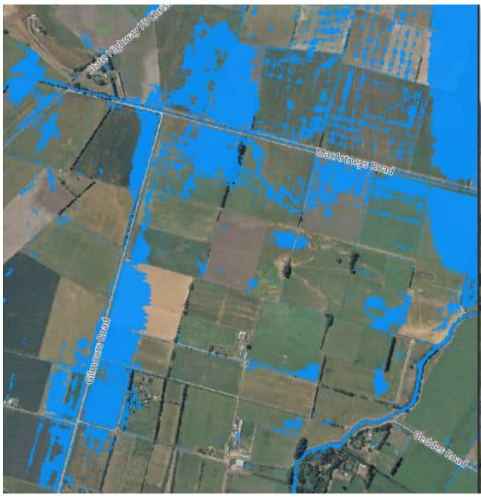

This photo was taken on the 23 June 2013 at approximately 11am as a result of the significant rainfall event that occurred from the period 20 June through to the 22 June 2013.
State Highway 75
Old Tai Tapu Road
State Highway 75

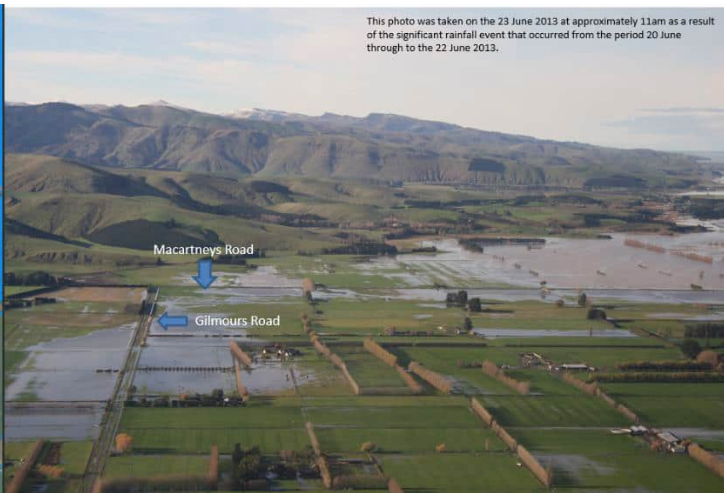

This photo was taken on the 23 June 2013 at approximately 11am as a result of the significant rainfall event that occurred from the period 20 June through to the 22 June 2013.
Gilmours Road
Davis Road
Lincoln Tai Tapu Road

This photo was taken on the 23 June 2013 at approximately 11am as a result of the significant rainfall event that occurred from the period 20 June through to the 22 June 2013.
Tancreds Road
Sarahs Lane



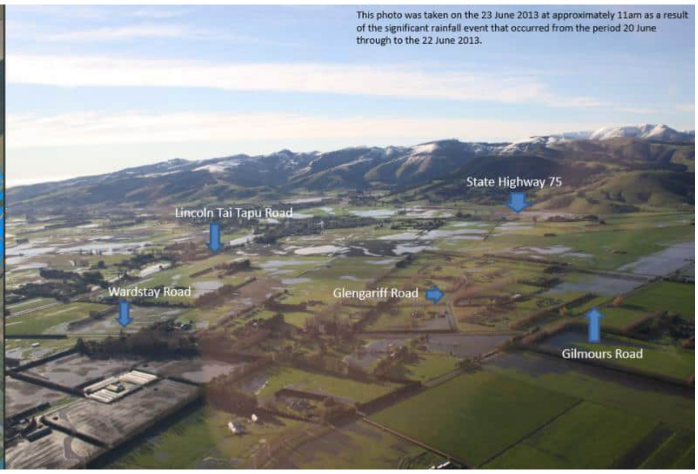
This photo was taken on the 23 June 2013 at approximately 11am as a result of the significant rainfall event that occurred from the period 20 June through to the 22 June 2013.
Barnes Road
Tancreds Road
Sarahs Lane

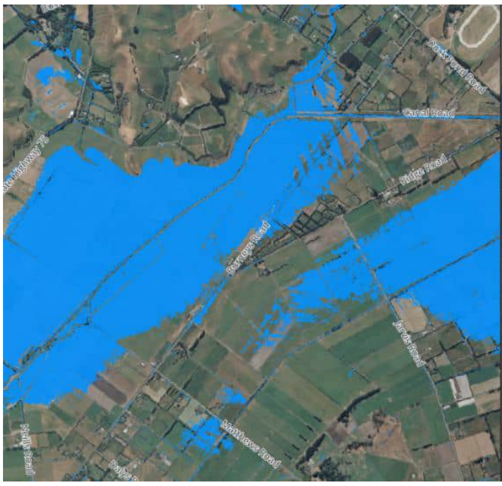




This photo was taken on the 23 June 2013 at approximately 11am as a result of the significant rainfall event that occurred from the period 20 June through to the 22 June 2013.
Macartneys Road
Gilmours Road


This photo was taken on the 23 June 2013 at approximately 11am as a result of the significant rainfall event that occurred from the period 20 June through to the 22 June 2013.
Glengarriff Road
Gilmours Road
Wardstay Road


This photo was taken on the 23 June 2013 at approximately 11am as a result of the significant rainfall event that occurred from the period 20 June through to the 22 June 2013.
State Highway 75
Lincoln Tai Tapu Road
Wardstay Road
Glengariff Road
Gilmours Road




This photo was taken on the 23 June 2013 at approximately 11am as a result of the significant rainfall event that occurred from the period 20 June through to the 22 June 2013.
Fiddlers
Duckpond
Halswell Canal
State Highway 75
Ridge Road


Streeters Road
State Highway 75 Christchurch Akaroa Road
Park Road
Miller Road
Fiddlers Road
Seabridge Road


This photo was taken on the 23 June 2013 at approximately 11am as a result of the significant rainfall event that occurred from the period 20 June through to the 22 June 2013.
Rail Trail
Seabridge Road
Fiddlers Road


Park Road

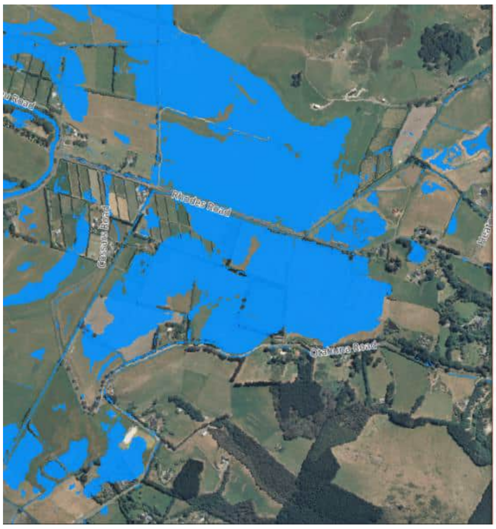

This photo was taken on the 23 June 2013 at approximately 11am as a result of the significant rainfall event that occurred from the period 20 June through to the 22 June 2013.
Seabridge Road
State Highway 75

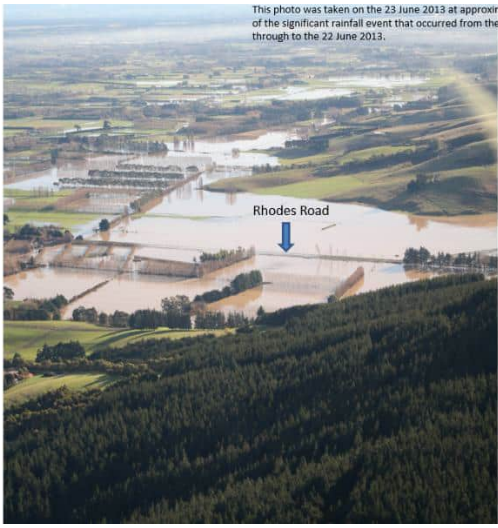

Days Road

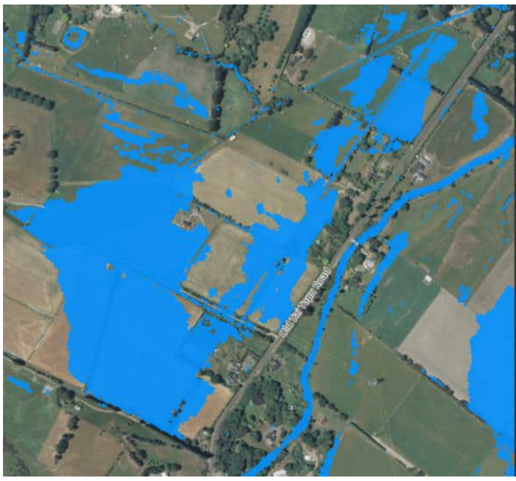

This photo was taken on the 23 June 2013 at approximately 11am as a result of the significant rainfall event that occurred from the period 20 June through to the 22 June 2013.
Lower Selwyn Huts
Upper Selwyn Huts
Days Road
Selwyn Lake


Seabridge Road
Park Road
Christchurch Akaroa Road State Highway


This photo was taken on the 23 June 2013 at approximately 11am as a result of the significant rainfall event that occurred from the period 20 June through to the 22 June 2013.
Halswell Canal
Seabridge Road


Rhodes Road
Otahuna Road


This photo was taken on the 23 June 2013 at approximately 11am as a result of the significant rainfall event that occurred from the period 20 June through to the 22 June 2013.
Rhodes Road


Old Tai Tapu Road


This photo was taken on the 23 June 2013 at approximately 11am as a result of the significant rainfall event that occurred from the period 20 June through to the 22 June 2013.
Old Tai Tapu Road
Old Tai Tapu Road

0074 - Looking south along Tai Tapu Road toward the Leadleys Road intersection - 22-06-2013

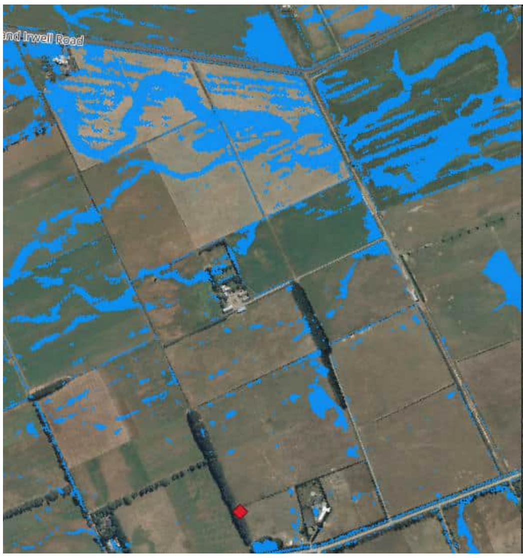
0737 - Looking south-west toward Coes Ford - 23-06-2013


0843 - Selwyn River. Looking east toward the intersection of Bethels Road and Swamp Road - 23-06-2013


20/06/2013
087 - Looking south along Hanmer Road, south of the intersection with Brookside and Irwell Road


Brookside and Irwell Road


0836 - Looking north across Brookside and Irwell Road toward Stephens Road - 23-06-2013



0835 - Looking north-east toward Brookside and Irwell Road from near the intersection of Hanmer Road and Tobins Road - 23-06-2013

006 - Looking north-west from Leeston Road on the northern outskirts of Doyleston

069 - Looking north-east along Leeston Road toward Doyleston

High Street

051 - Leeston. Looking north-east from High Street
20/06/2013

High Street

040 - Looking east along High Street toward Leeston
20/06/2013

Willis Road
Cowans Road

0808 - Looking north along Cowans Road toward the intersection with Willis, Wabys, Feredays, Tramway and Southbridge Dunsandel Roads - 23-06-2013

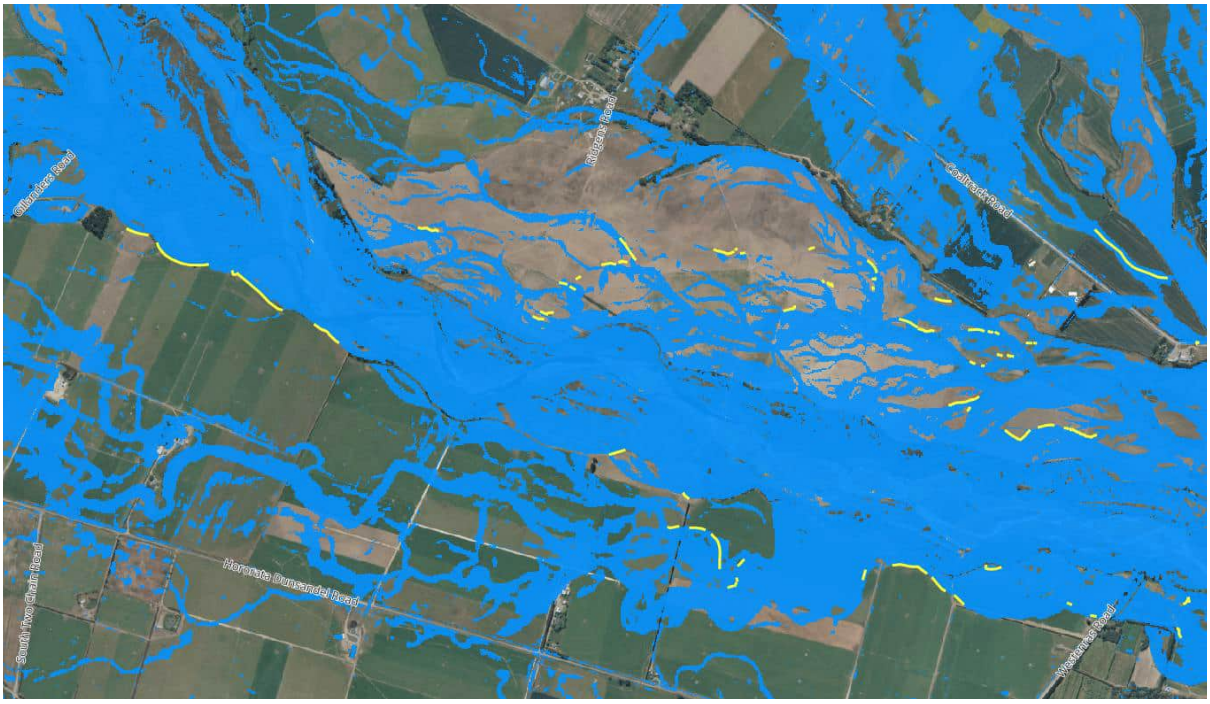

High Street
Alexanders Road
Southbridge Leeston Road
Willis Road

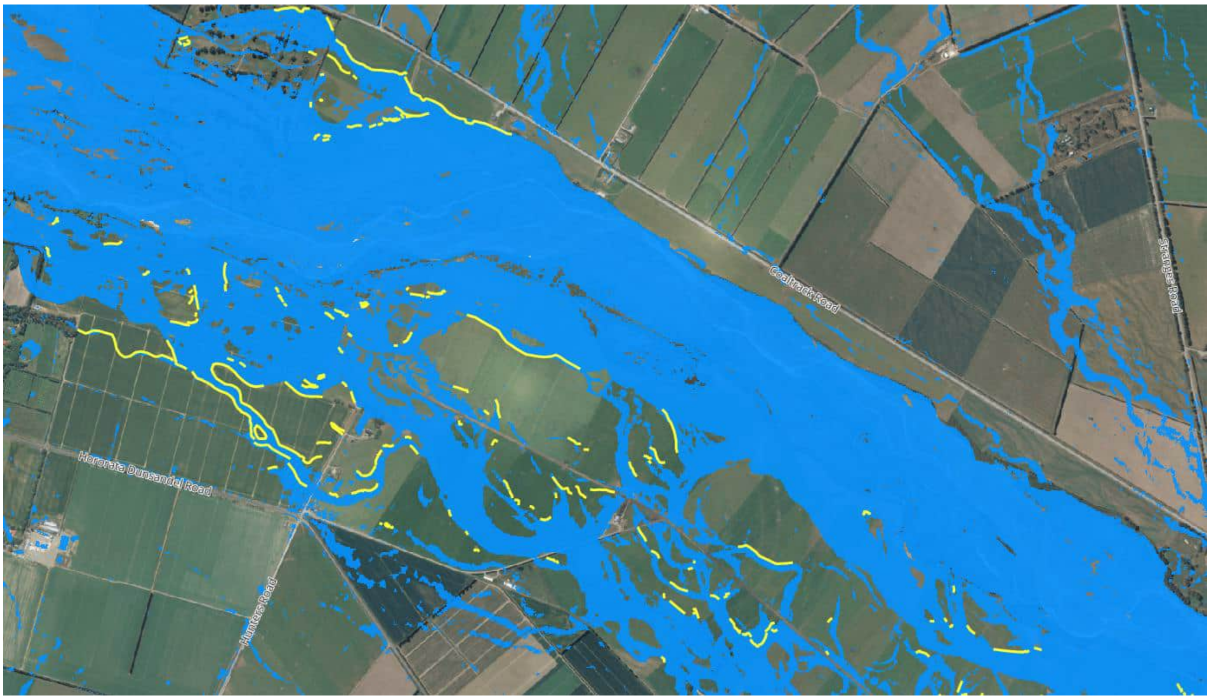

Southbridge from the intersection of Cowans Road and Southbridge Leeston Road - 23-06-2013

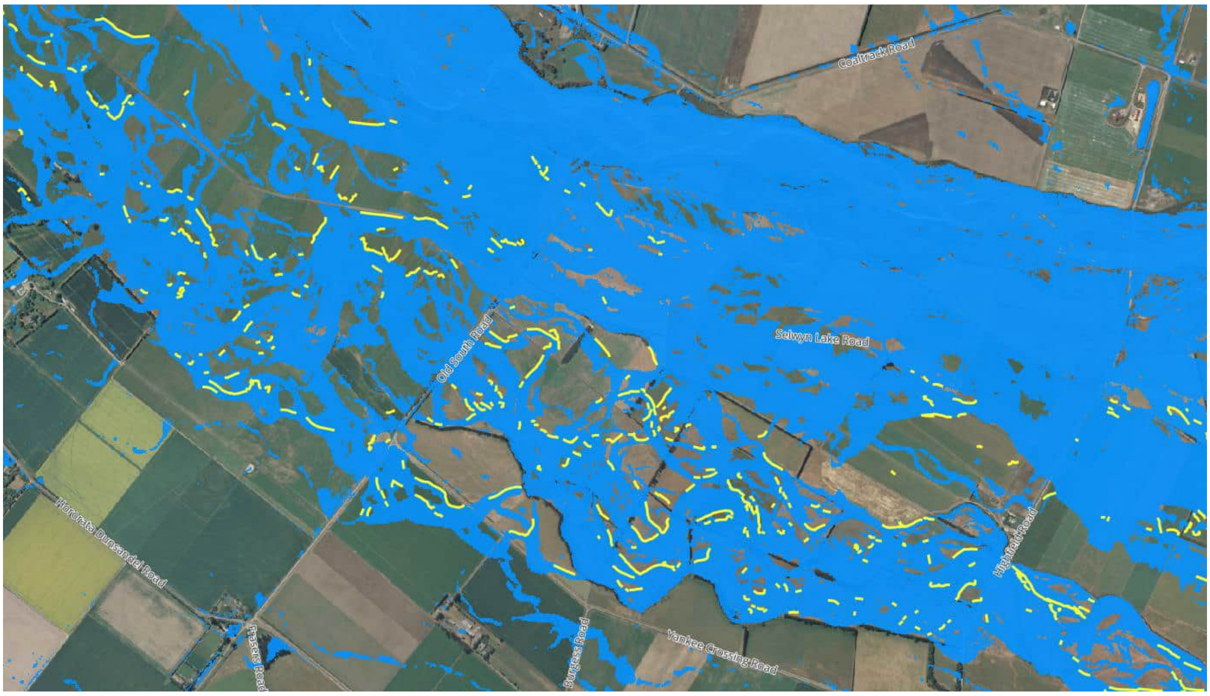
erbury

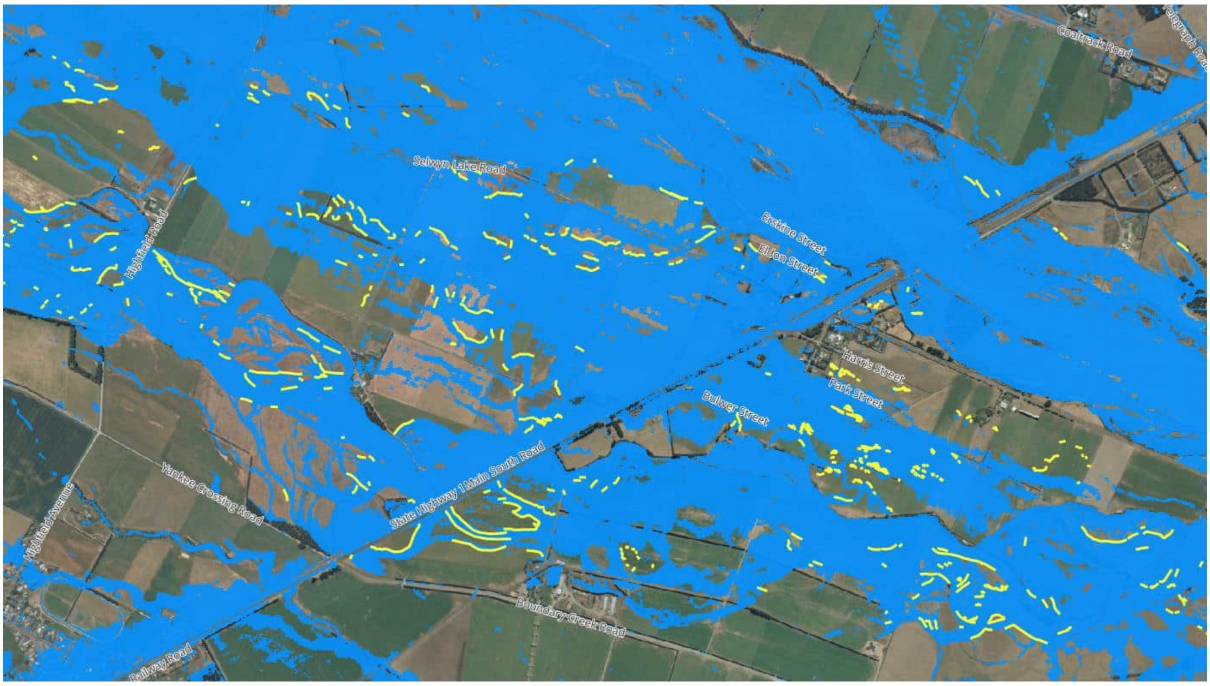
MAY 2021 EVENT

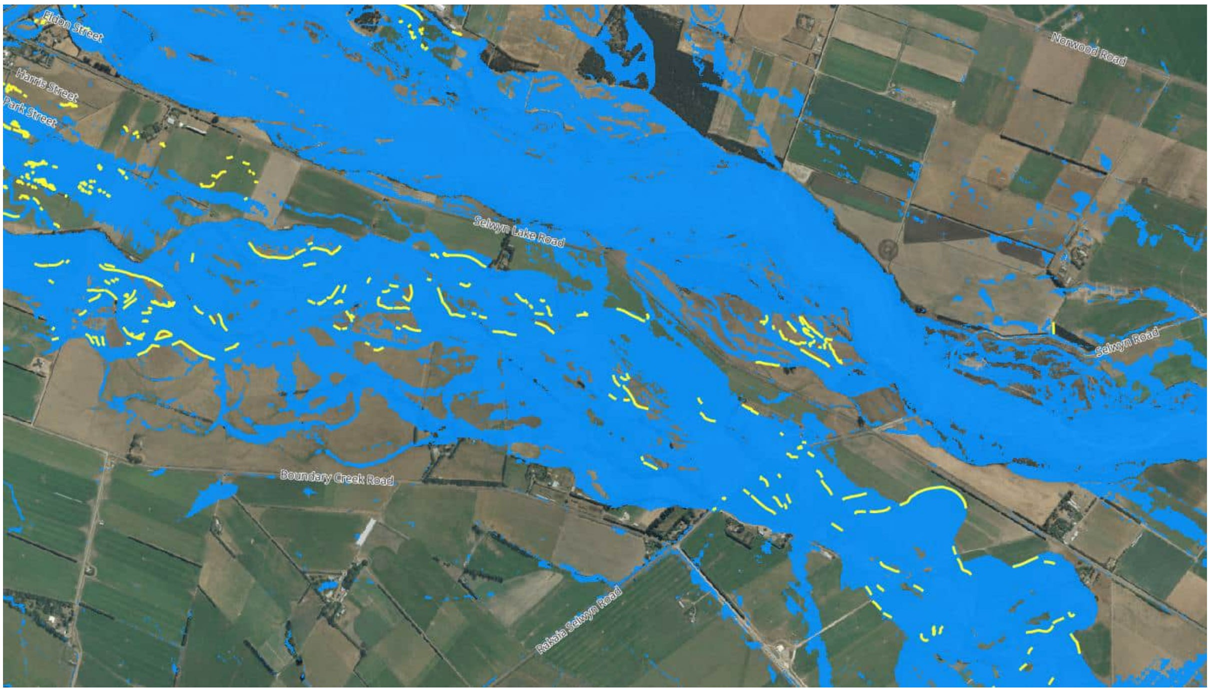
Debris extents

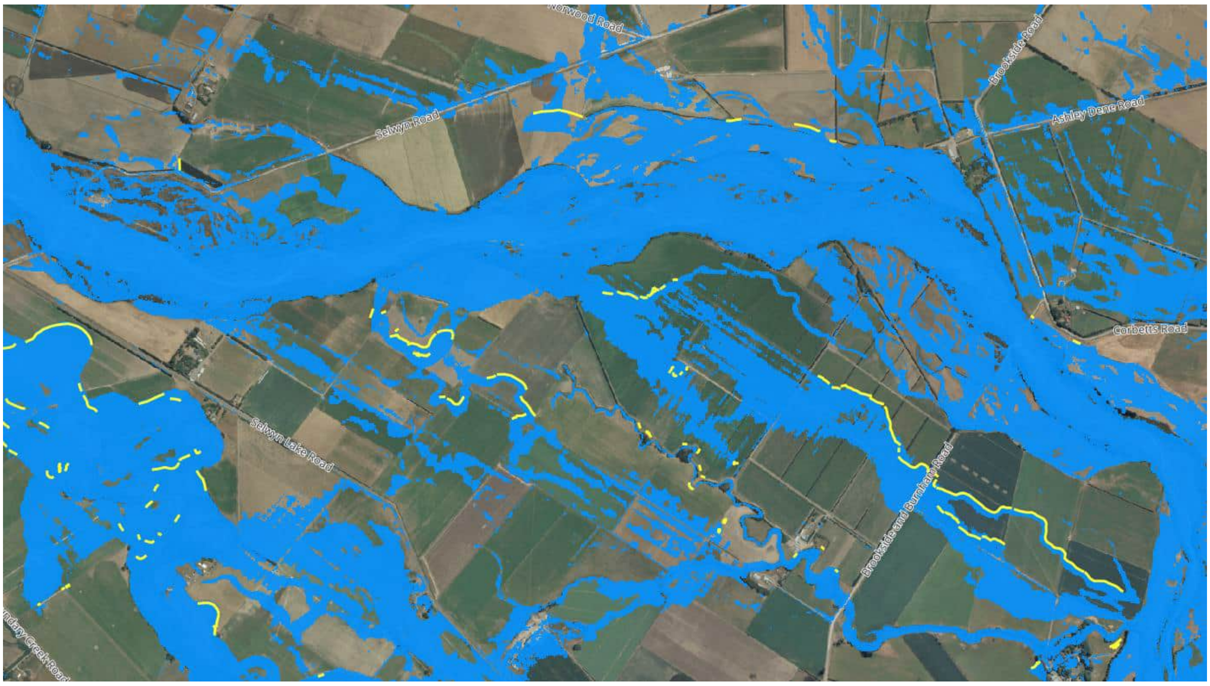


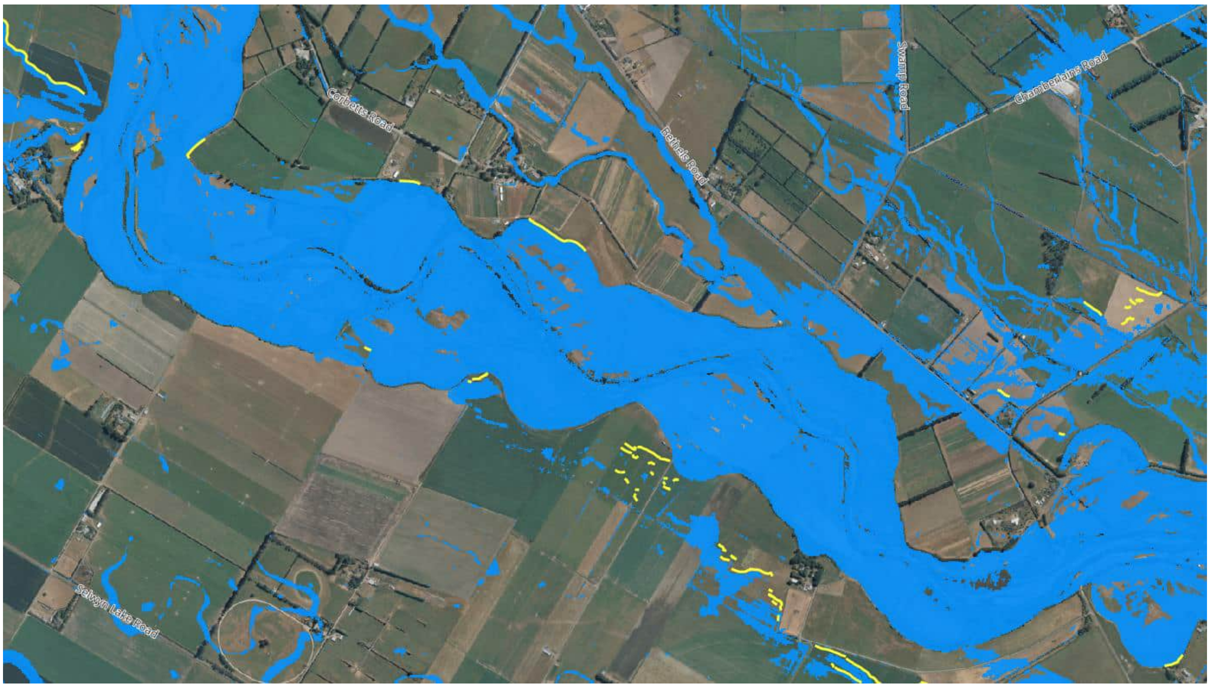


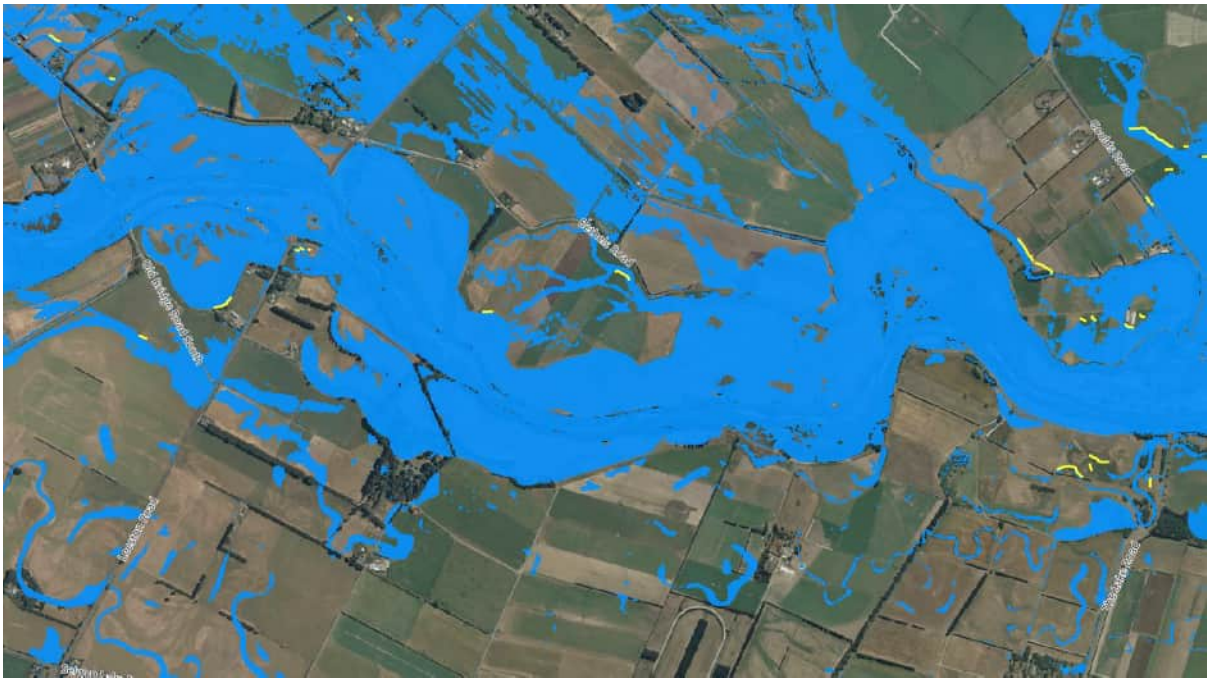

Coaltrack Road
Selwyn Lake Road
Old South Road
Highfield Road
Hororata Dunsandel Road
Burgess Road
Yankee Crossing Road


Coaltrack Road
Selwyn Lake Road
Highfield Road
Erskine Street
Eldon Street
Harris Street
Park Street
Bulwer Street
State Highway 1 Main South Road
Yankee Crossing Road
Boundary Creek Road
Railway Road

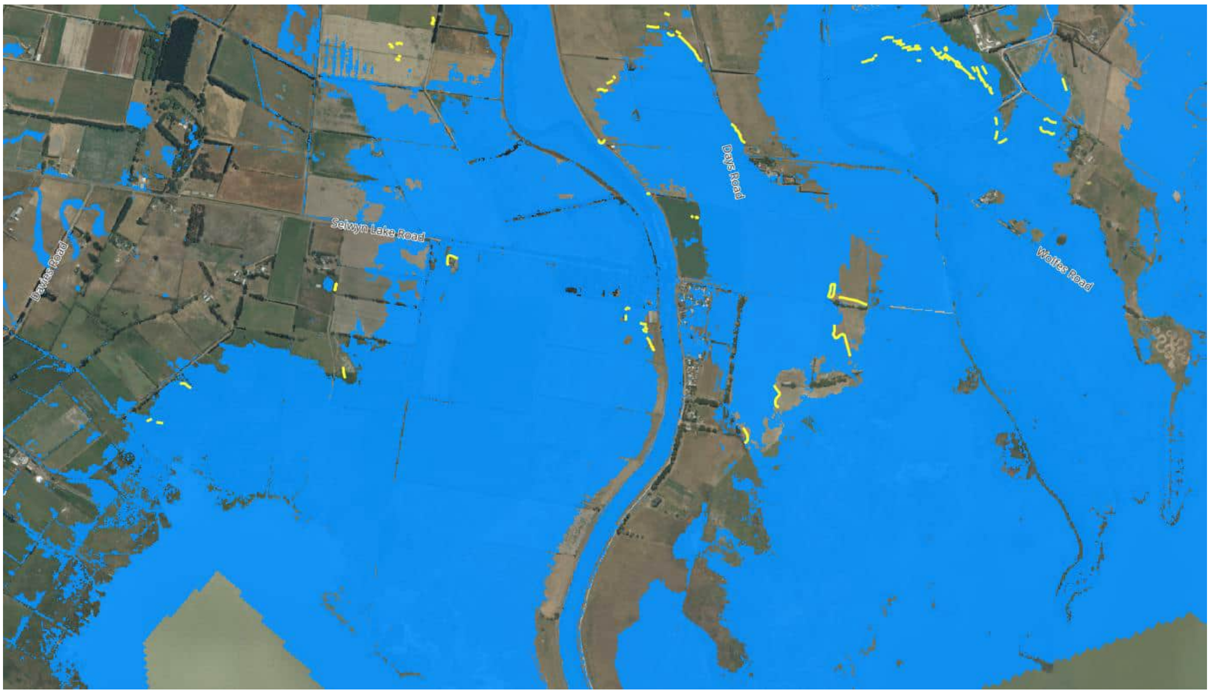

Eldon Street
Harris Street
Park Street
Norwood Road
Selwyn Lake Road
Selwyn Road
Boundary Creek Road
Rakaia Selwyn Road

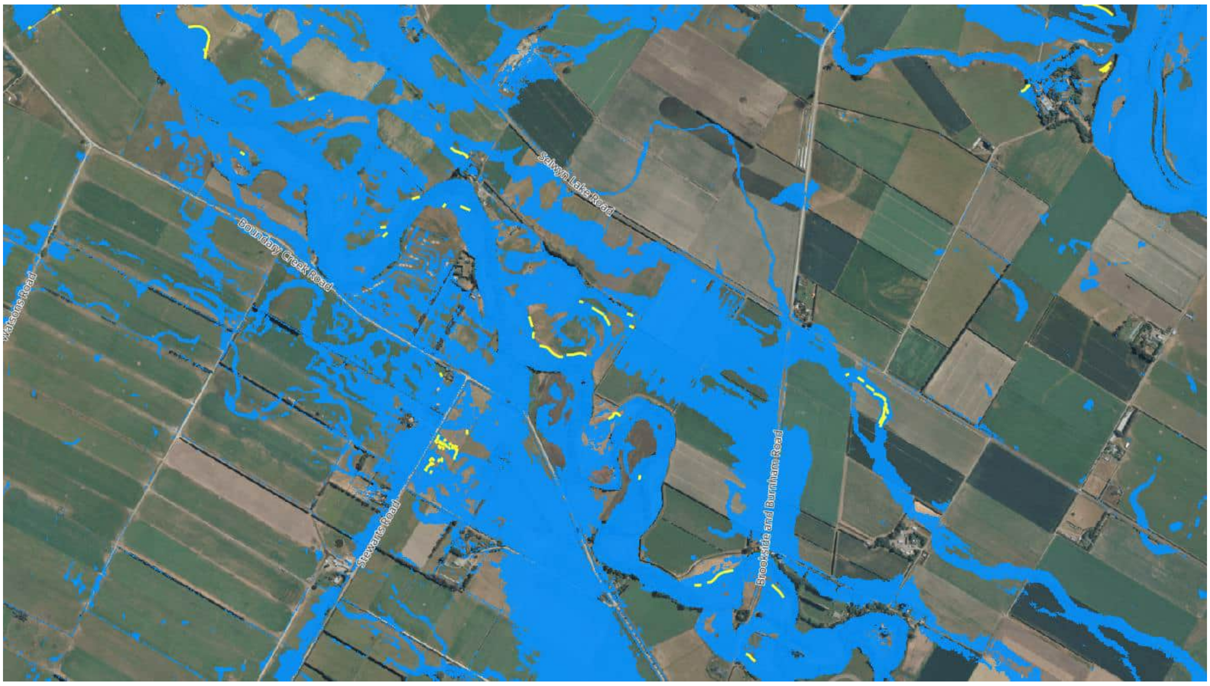

Norwood Road
Brookside Road
Ashley Dene Road
Selwyn Road
Corbetts Road
Selwyn Lake Road
Brookside and Burnham Road

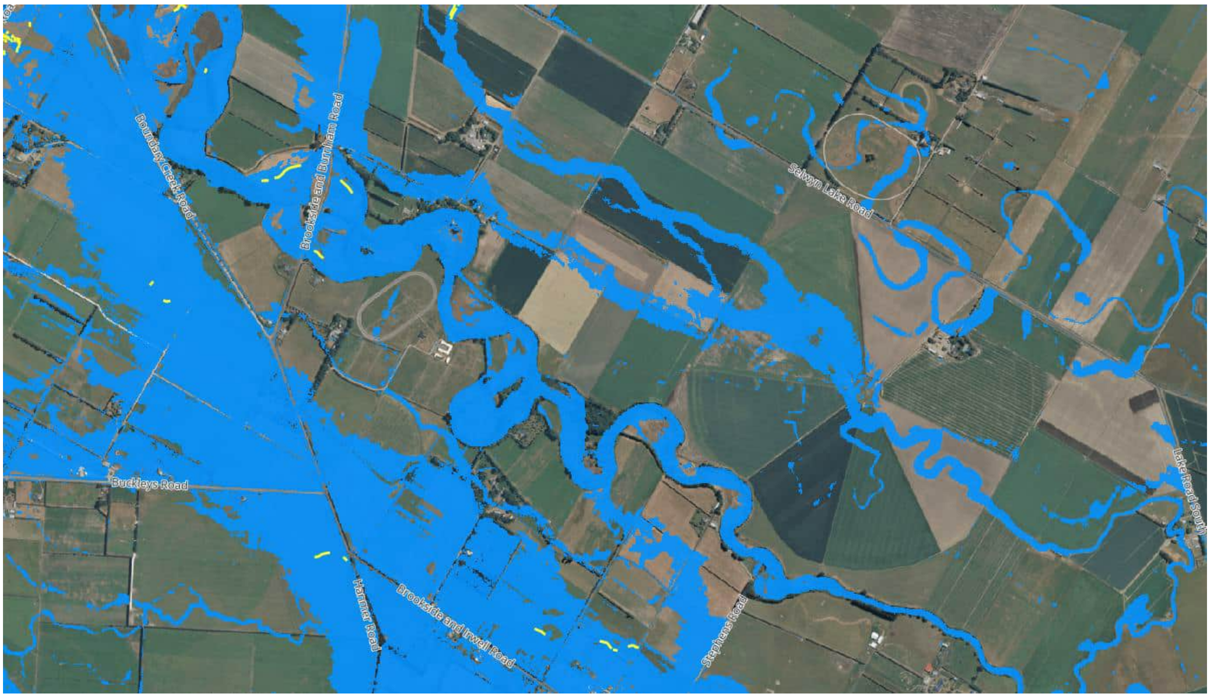

Corbetts Road
Bethels Road
Swamp Road
Chamberlains Road
Selwyn Lake Road

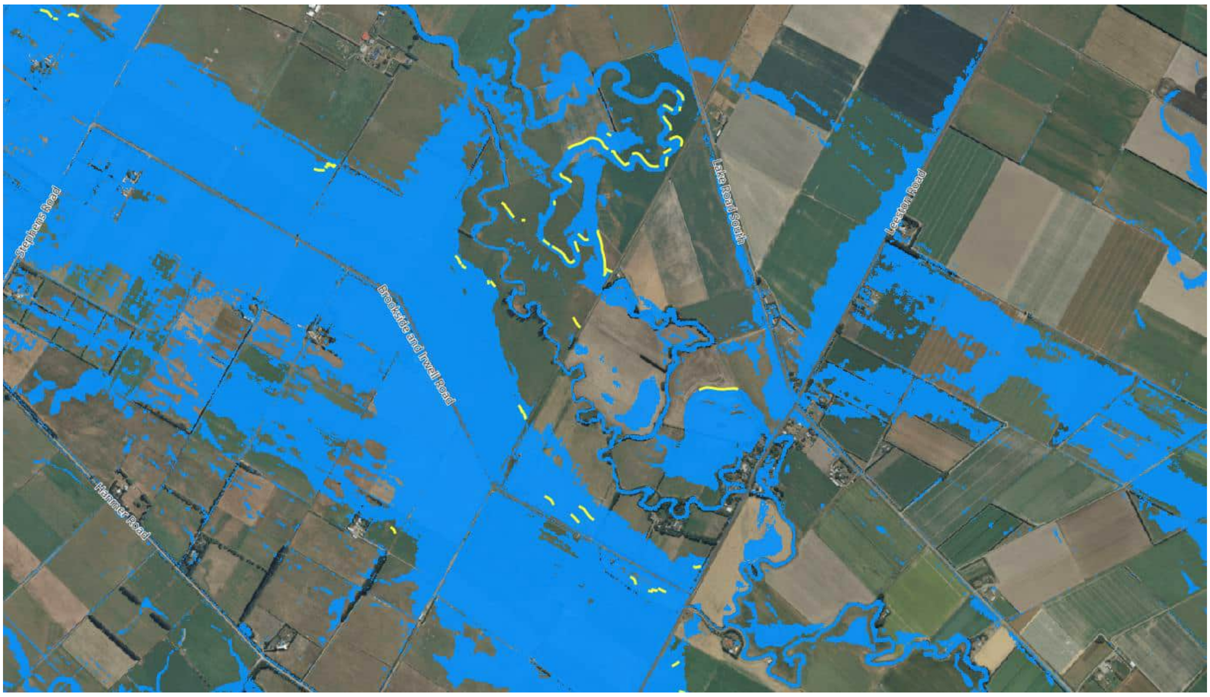


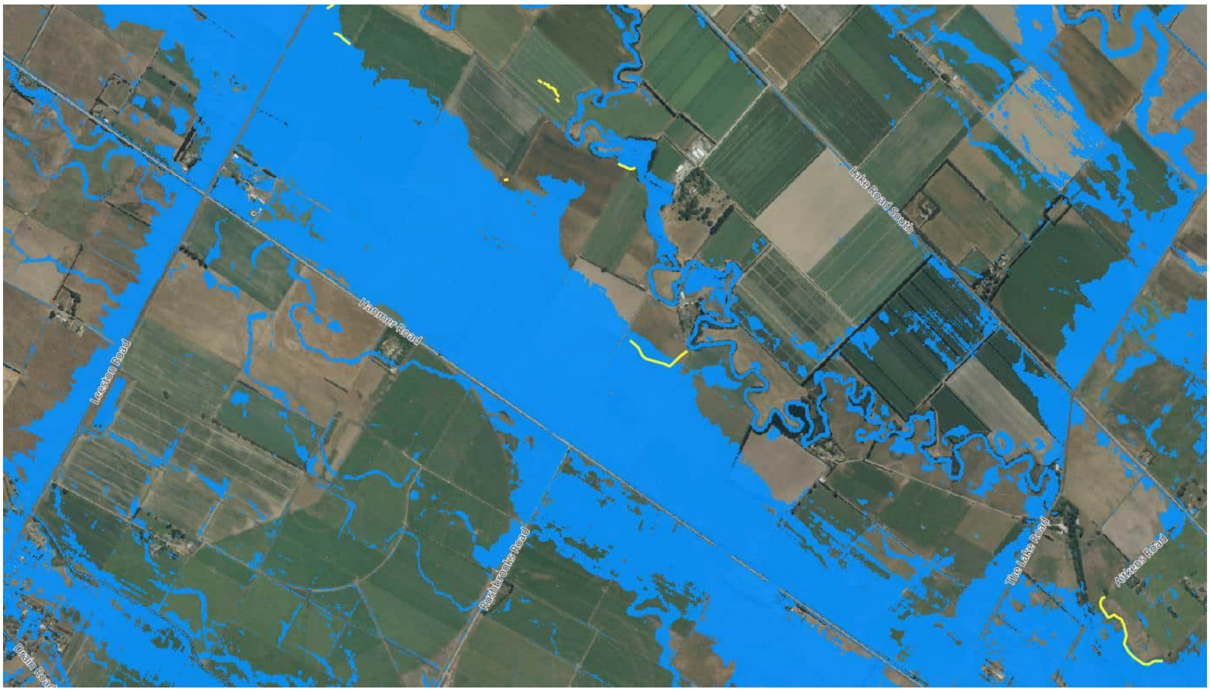

Goulds Road
Curries Road
Powells Road
Yarris Road
Pannetts Road
The Lake Road
Days Road


Days Road
Selwyn Lake Road
Davies Road
Wolfes Road


Selwyn Lake Road
Boundary Creek Road
Stewarts Road
Brookside and Burnham Road

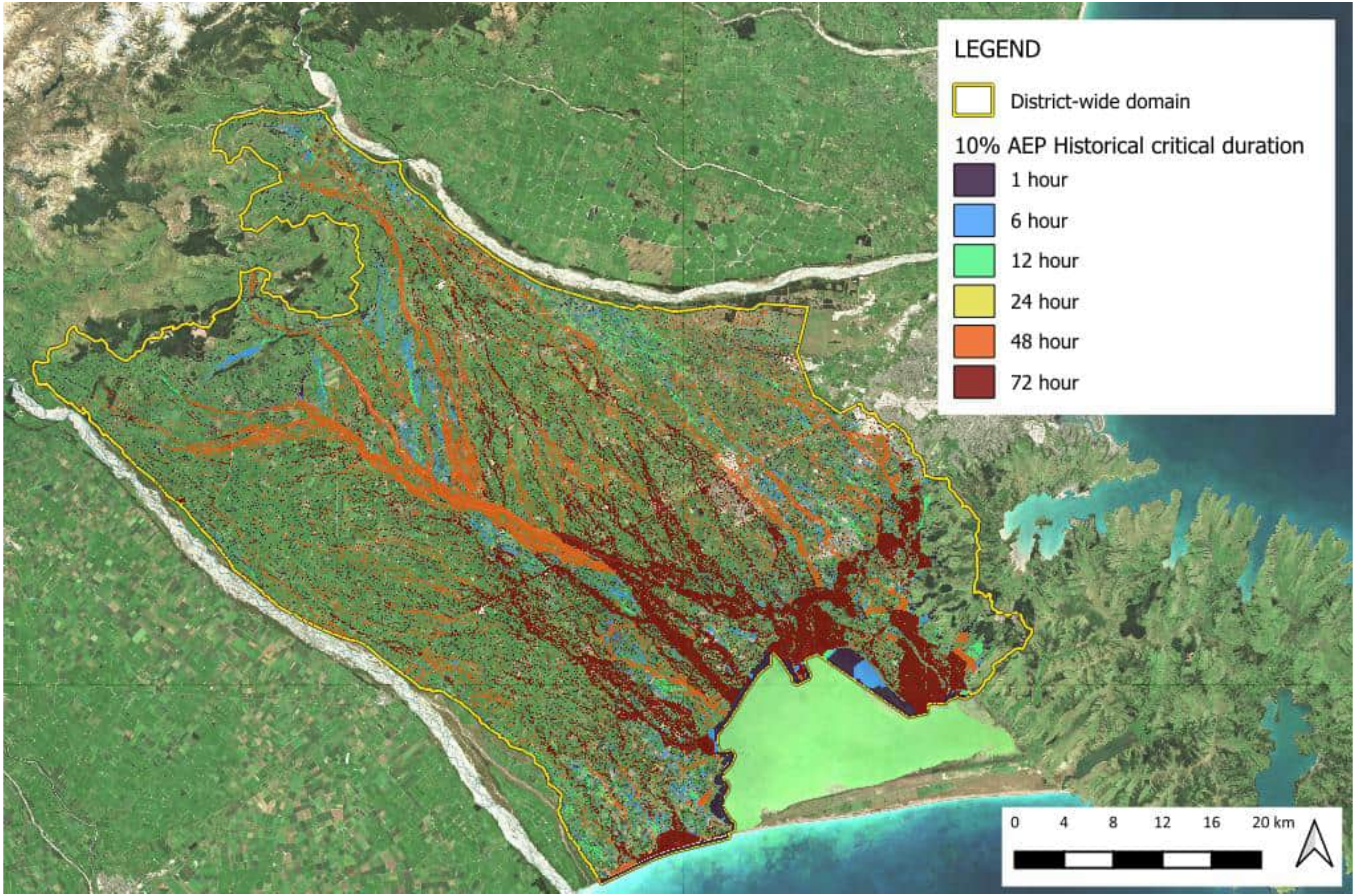

Boundary Creek Road
Brookside and Burnham Road
Selwyn Lake Road
Buckleys Road
Brookside and Irwell Road
Stephens Road

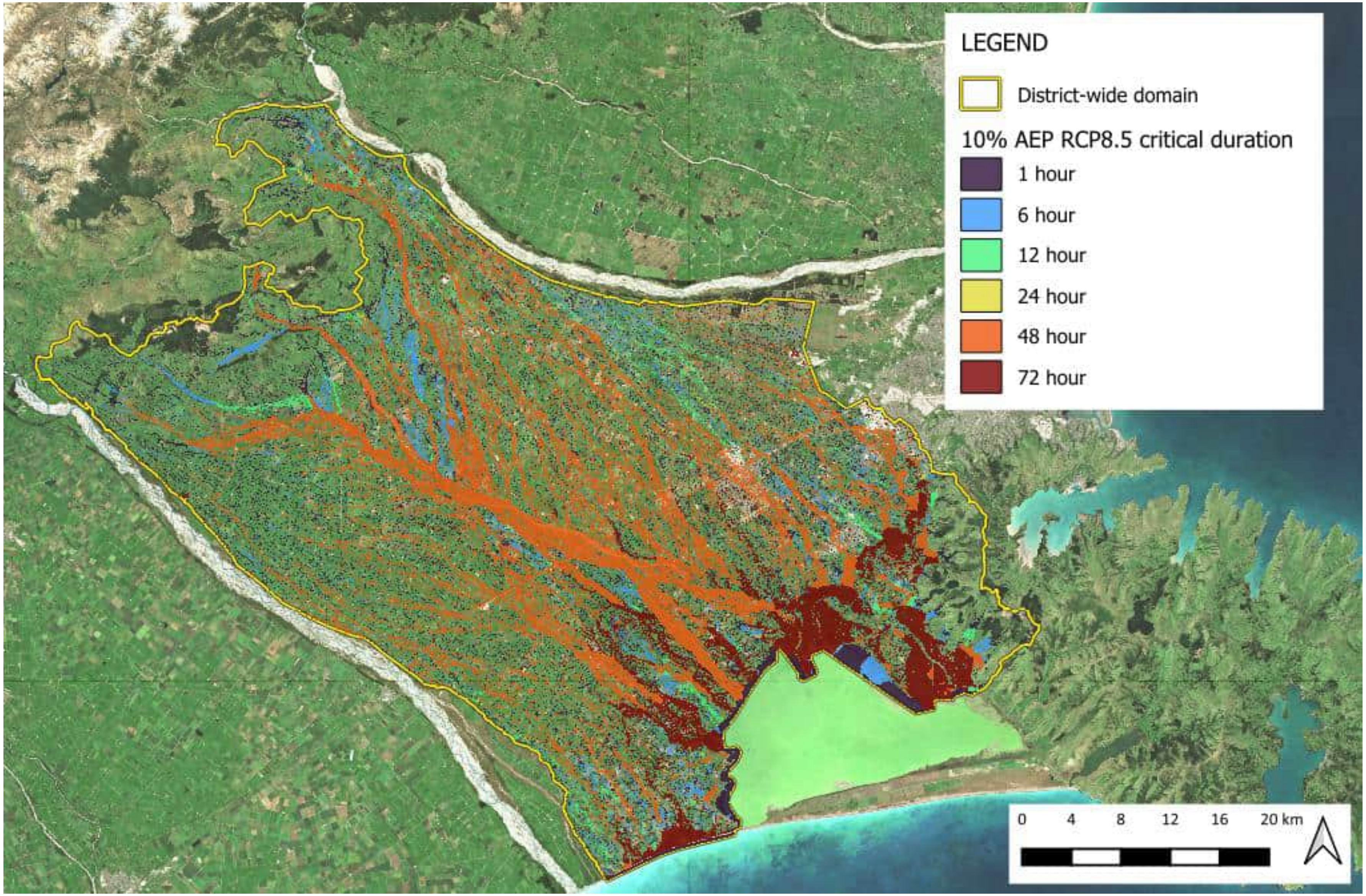

Brookside and Irwell Road
Lake Road South
Leeston Road
Hanmer Road

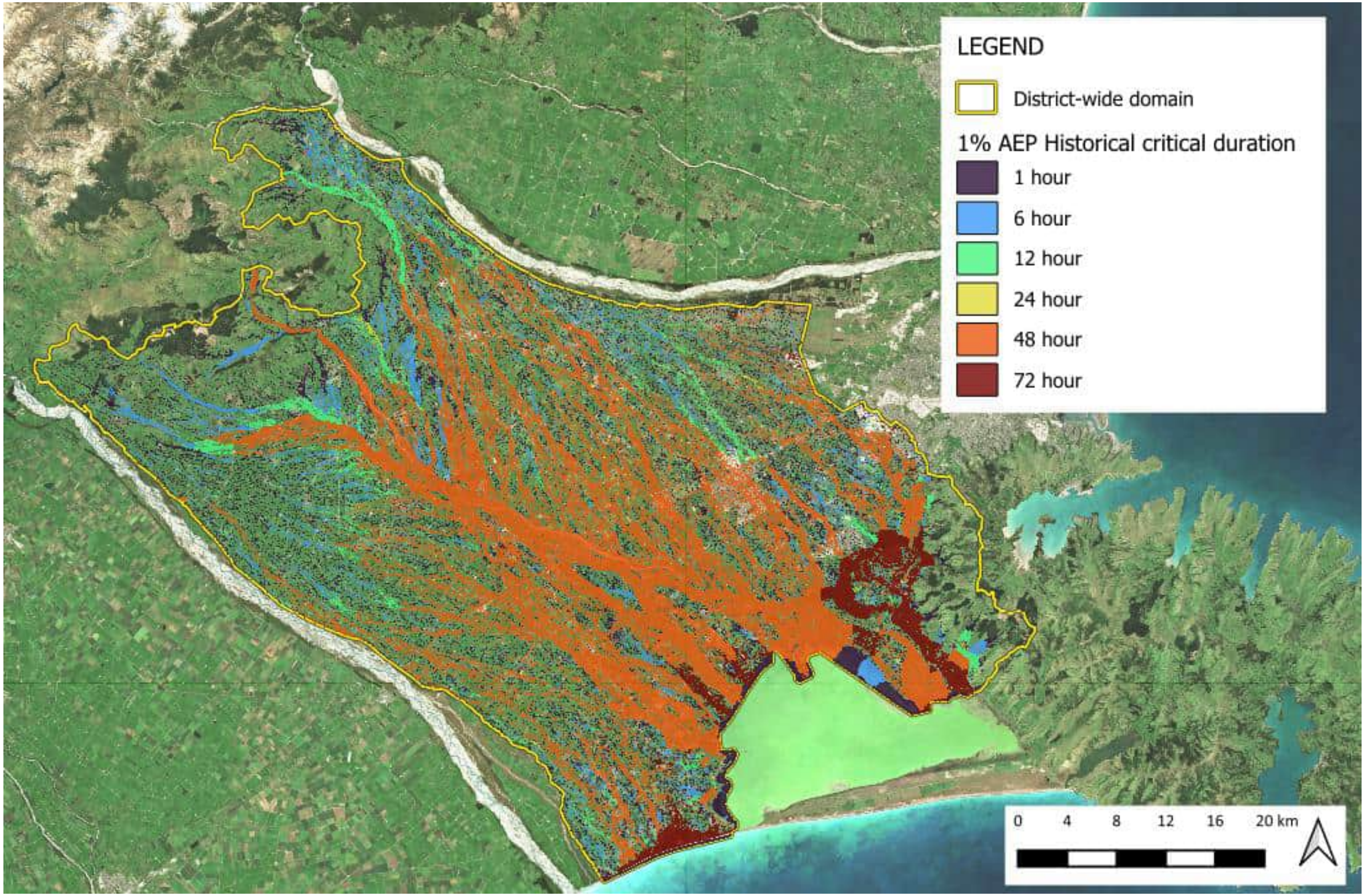

Hanmer Road
Leeston Road
Lake Road South
The Lake Road
Aitkens Road

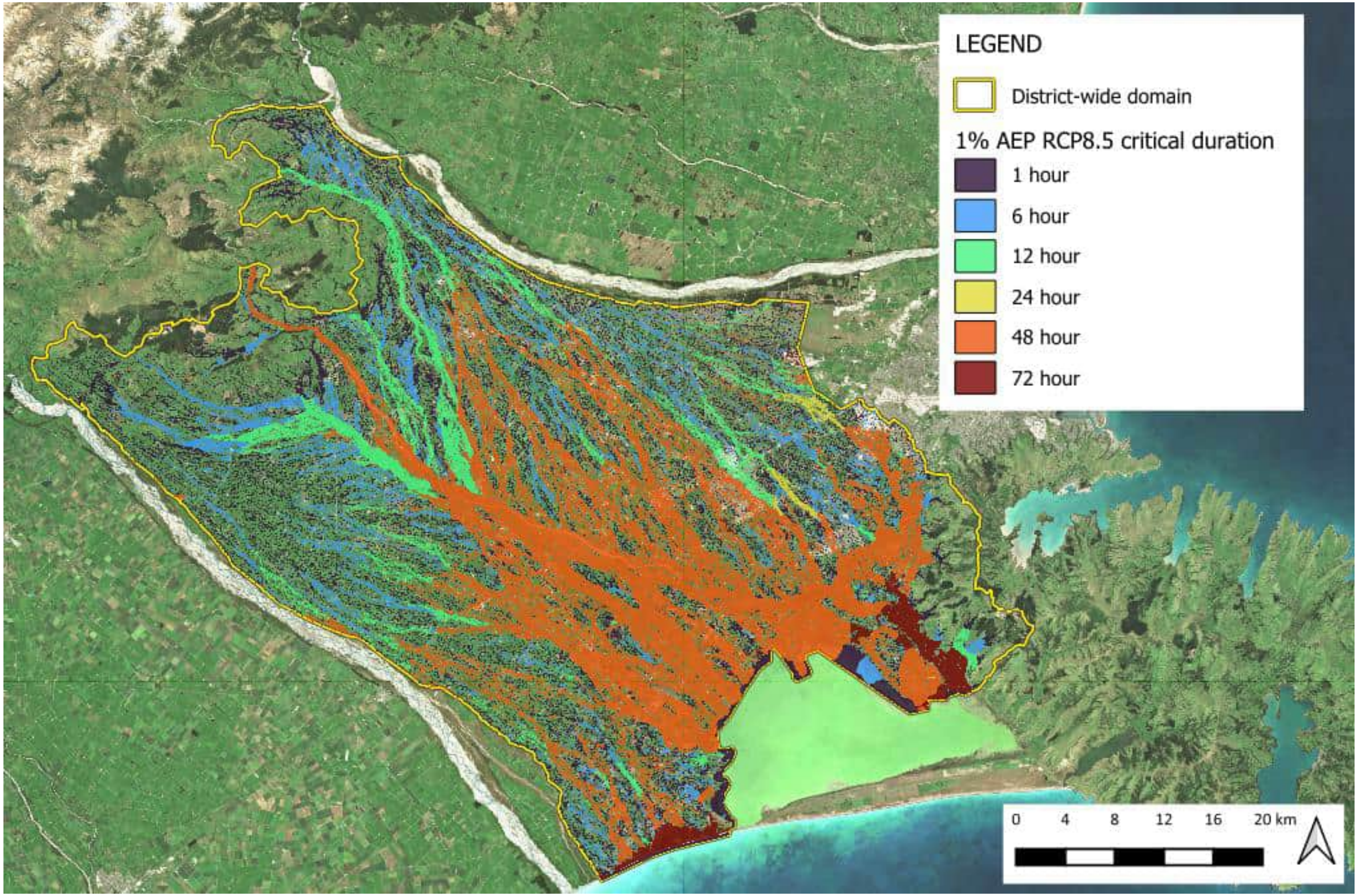
Model maximum water depth (bottom) compared to previous detailed model (top) for Springfield Township:

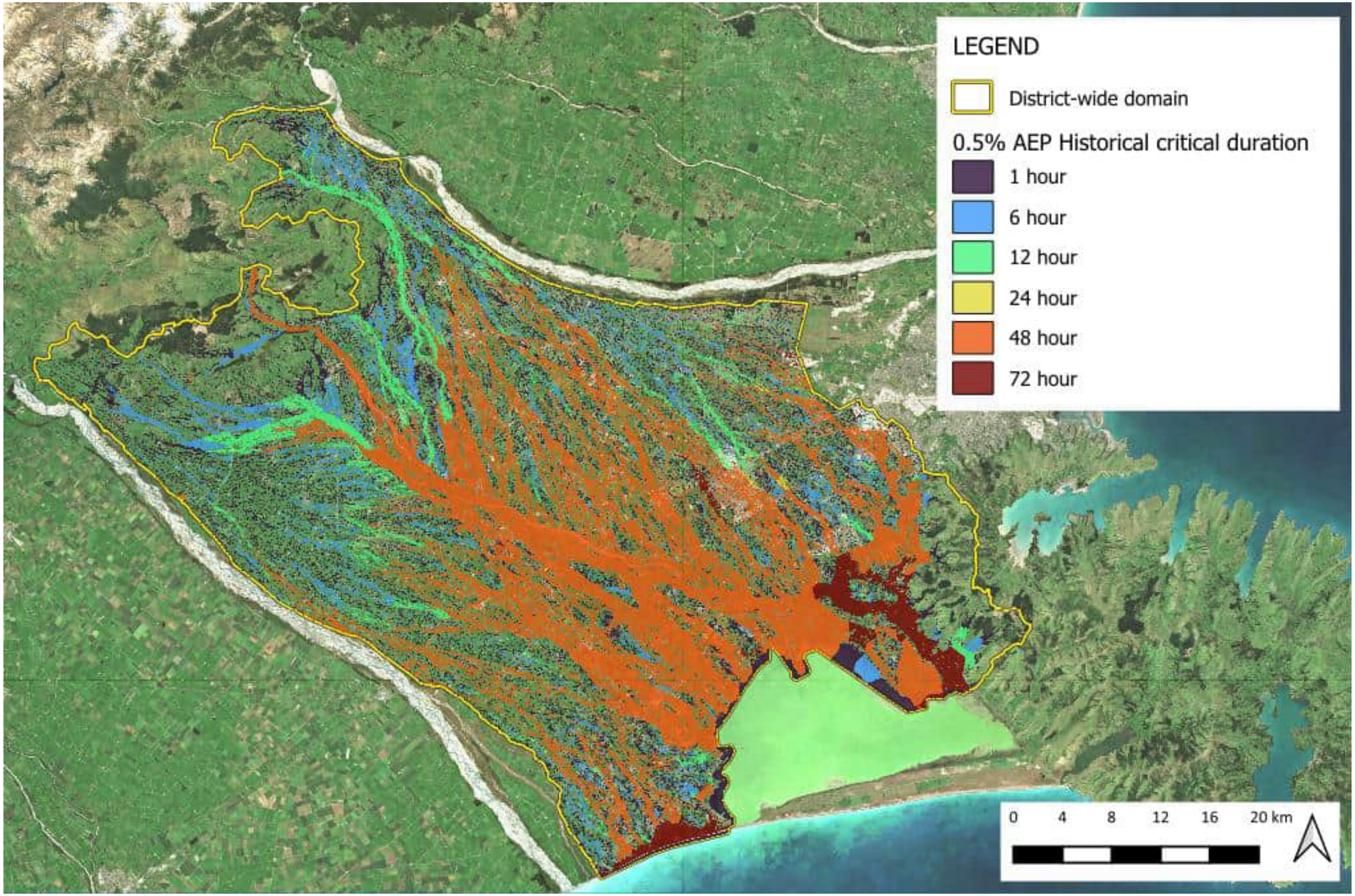
Appendix E: Critical duration maps

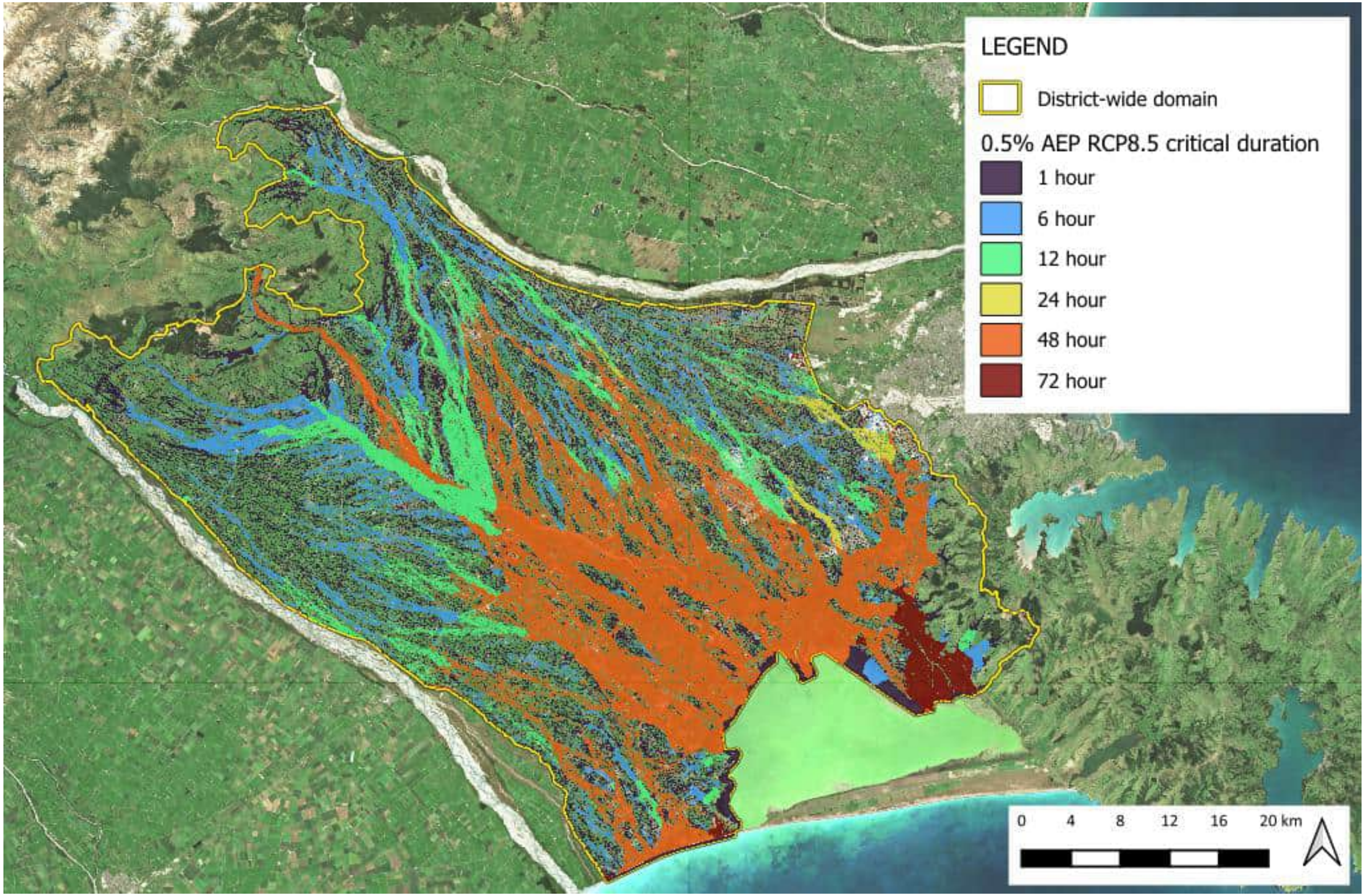

LEGEND
District-wide domain
10% AEP Historical critical duration
1 hour
6 hour
12 hour
24 hour
48 hour
72 hour
0
4
8
12
16
20 km

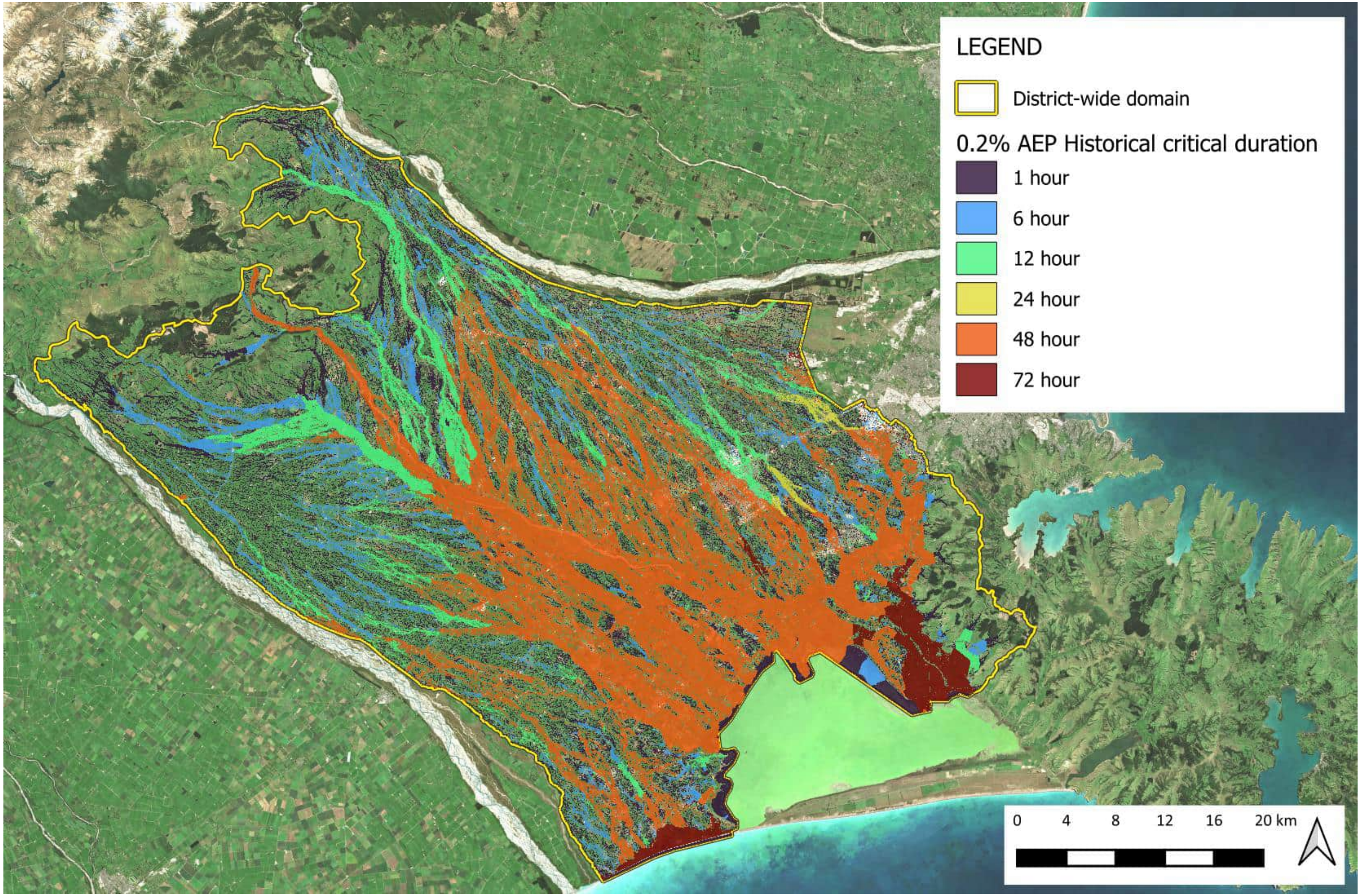

LEGEND
District-wide domain
10% AEP RCP8.5 critical duration
1 hour
6 hour
12 hour
24 hour
48 hour
72 hour
0
4
8
12
16
20 km

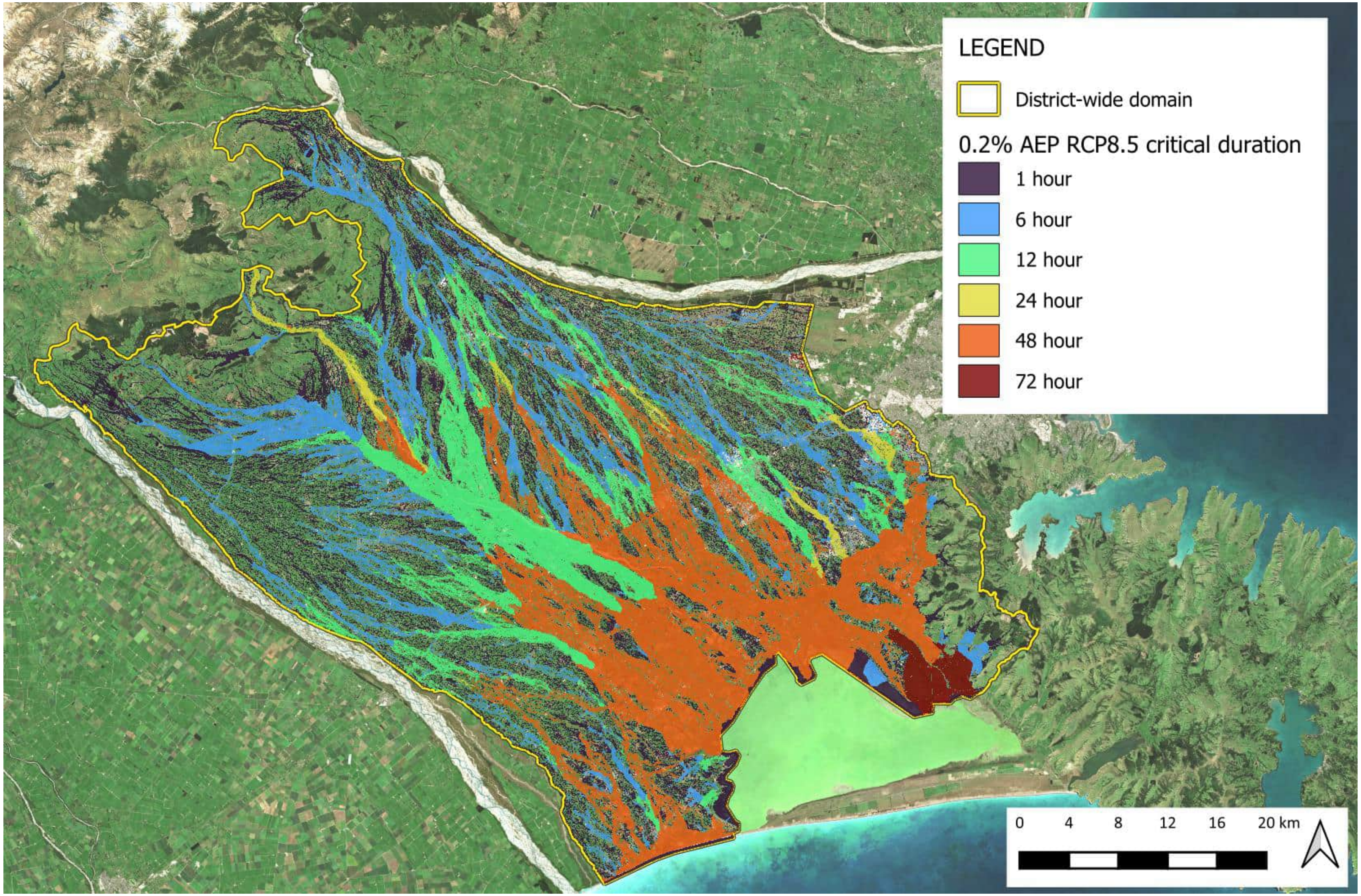

LEGEND
District-wide domain
1% AEP Historical critical duration
1 hour
6 hour
12 hour
24 hour
48 hour
72 hour
0
4
8
12
16
20 km


LEGEND
District-wide domain
1% AEP RCP8.5 critical duration
1 hour
6 hour
12 hour
24 hour
48 hour
72 hour
0
4
8
12
16
20 km


LEGEND
District-wide domain
0.5% AEP Historical critical duration
1 hour
6 hour
12 hour
24 hour
48 hour
72 hour
0
4
8
12
16
20 km


LEGEND
District-wide domain
0.5% AEP RCP8.5 critical duration
1 hour
6 hour
12 hour
24 hour
48 hour
72 hour
0
4
8
12
16
20 km


LEGEND
District-wide domain
0.2% AEP Historical critical duration
1 hour
6 hour
12 hour
24 hour
48 hour
72 hour
0
4
8
12
16
20 km


LEGEND
District-wide domain
0.2% AEP RCP8.5 critical duration
1 hour
6 hour
12 hour
24 hour
48 hour
72 hour
0
4
8
12
16
20 km

Appendix F: PDP peer review report

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1 August 2025

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SELWYN DISTRICT WIDE HYDROLOGICAL AND HYDRAULIC MODEL PEER REVIEW

Pattle Delamore Partners Ltd (PDP) has completed a technical peer review of the Selwyn District-Wide Flood Model, as requested by Selwyn District Council (SDC).

The purpose of this flood model is to help provide flood certificates for rural areas within SDC and assist the planning and design of infrastructure for the townships.

This review encompassed both the hydrological and hydraulic components of the model and was conducted in accordance with the Greater Wellington Regional Council's Flood Hazard Modelling Specification (FHMS), adapted where appropriate to reflect the modelling approach taken by the project team.

This letter summarises the methodology adopted for the review, outlines the key issues identified and how they were resolved, and provides commentary on model limitations and opportunities for improvement. Full details of the review process are provided in the two accompanying spreadsheets:

Hydrology Peer Review Spreadsheet (PDP_V2)

Hydraulics Peer Review Spreadsheet (PDP_V3)

This letter should be read in conjunction with:

Environment Canterbury (August 2025): Selwyn River/Waikirikiri foothill hydrological modelling and design flows

Tonkin and Taylor (August 2025): Selwyn District Flood Model, Hydraulic Model Build Report

1.0 Review methodology

The review was conducted in accordance with the procedures specified in the GWRC FHMS. In summary, our methodology included:

- **Initial review of model setup and calibration:** Examination of all input data, model files, configuration, and supporting reports.
- **Documentation and log review:** Verification that change logs, model versions, and underlying assumptions were transparent and traceable.
- **Multi-stage feedback loop:** Iterative communication of comments and required actions to the modelling team, followed by review of responses and model updates.

- **Resolution tracking:** Each identified issue was assigned a rating to facilitate tracking and closeout as part of the quality assurance process. The ratings were:
  - Ok - The element or parameter being used is modelled correctly;
  - Minor - Issue is unlikely to significantly affect model results;
  - Major - Issue compromises the model and should be rectified, but may be resolved by explanation or acceptance of the model limitations;
  - Critical - Issue severely compromises the model and should be rectified before moving to the next step; and,
  - Future Data Collection - Identifies where additional future data collection could result in model improvements in the future.

The full traceability of all comments, actions, and subsequent responses is provided in the accompanying review spreadsheets (Hydraulics Peer Review Spreadsheet PDP_V3 and Hydrology Peer Review Spreadsheet PDP_V2). In total, the hydraulic models (calibration and design) went through three review iterations (V1 to V3) whilst the hydrological model went through two review iterations (V1 and V2).

1.1 Hydrology

The hydrology review was split into two components:

- **Pluvial inputs** developed by T+T using nested storm profiles
- **Fluvial inputs** developed by ECan using MIKE NAMS, representing contributions from hill catchments

For the T+T hydrology, the modelling approach differs from GWRC FHMS (using direct rainfall application on the grid rather than a hydrological model), a simplified peer review method was adopted. The review included checking rainfall profiles, durations and spatial application.

1.2 Hydraulics

The hydraulic review covered two main stages:

- **Calibrated Model Review**, including stability, schematisation, boundary conditions, calibration, and model QA
- **Final Model Review**, including sensitivity testing, design runs, and optioneering

The TUFLOW model files (.tcf, .tgc, .tbc, .tef, etc.) were reviewed alongside supporting inputs. Our review was undertaken in iterative stages.

2.0 Hydrological model

The hydrological component of the Selwyn District-Wide Flood Model for the hill catchments consists of a rainfall-runoff model developed by Environment Canterbury (ECan).

2.1 Purpose

The primary purpose of the Environment Canterbury (ECan) hydrological model is to provide inflow hydrographs for the five main ungauged foothill catchments of the Selwyn River/Waikirikiri. These hydrographs serve as essential upstream boundary conditions for the Tonkin + Taylor (T+T) Selwyn District-Wide hydraulic flood model.

2.1 Description

The hydrological model was developed using the DHI MIKE+ software platform, specifically employing the Rainfall Dependent Infiltration (RDI) module. It is a lumped, conceptual model designed to convert rainfall into river flow for the Selwyn, Hawkins, Waianiwaniwa, Hororata, and Glendore catchments. The model was calibrated against the long-term flow record at the Selwyn River at Whitecliffs gauge, using a split-sample methodology; the period from 2010-2024 was used for calibration, and the period from 1989-2009 for validation.

The model was used to generate two key sets of outputs: firstly, simulated hydrographs for the historical storm events of June 2013, July 2017, and May 2021 to assist in the calibration of the T+T hydraulic model. Secondly, it produced a suite of design flow hydrographs for several storm durations (1 to 72 hours) and ARIs (10 to 500 years) under both present-day and future climate change (RCP8.5) scenarios. Our peer review confirmed that the model development, calibration, and application were undertaken using well-accepted methodologies and the model is considered suitable for it intended use.

2.2 Meetings

In addition to the monthly team wide catch ups, the hydrological peer review, included:

- Meeting with ECan (Michelle Wild) on Mon 11 November 2024 to discuss the preliminary hydrological model; and,
- Meeting with ECan (Michelle Wild) on Fri 16 May 2025 to discuss the V1 review.

2.3 Peer review

Key issues identified and the methods of resolution are outlined below:

- **Approach to Antecedent Conditions:**
  The method of directly incorporating rainfall prior to the July 2017 event into model simulations—rather than adjusting model parameters—was deemed fit for purpose and more representative of true catchment wetness at the onset of design events.
- **Rainfall Data and Areal Patterns:**
  The spatial and temporal representation of rainfall (using Thiessen polygons and HIRDS v4 design storms) was found to be suitable. Inclusion of orographically corrected polygons was noted, and the need for application of areal reduction factors was raised as a potential future improvement for larger catchments.
- **Calibration and Validation:**
  The calibration process was robust, using well-accepted methodologies with a systematic and iterative approach that included split-sample testing and multiple events. Reviewer feedback led to minor corrections regarding input parameter consistency and quality assurance of data sources to confirm the reliability of outcomes. Additional commentary regarding the reliability of streamflow rating curves at higher flows was incorporated, highlighting areas for further gauging as an ongoing improvement.
- **Sensitivity Analysis:**
  ECan conducted an extensive suite of sensitivity analyses to several parameters such as evaporation, rainfall depth, surface storage, and runoff coefficients. Some sensitivity suggestions led to re-running and clarifying of selected sensitivity scenarios, ensuring the model's responsiveness to critical assumptions is clearly understood.

Several minor issues were identified through the review process, including:

- Model Documentation and Clarity;
- Referencing sources for catchment delineation;

All recommendations and concerns regarding hydrology were either fully addressed or transparently documented as limitations or opportunities for future refinement.

2.4 Limitations

While the hydrological model is considered fit for its intended purpose, the following limitations should be understood by end-users:

- **Rating Curve Uncertainty:** As with many river systems, high flows are not directly gauged. The rating curves used to convert recorded water level to flow have considerable uncertainty at their upper ends, which directly impacts the accuracy of the calibration data for large flood events.
- **Snowmelt Processes:** The model does not explicitly simulate snow accumulation and melt. This is a known limitation for storm events where a significant portion of precipitation falls as snow, potentially affecting the timing and volume of runoff.
- **Parameter Lumping:** As a lumped model, its parameters (e.g., infiltration, time constants) represent an average over the entire catchment. It does not capture fine-scale spatial variations in soil type, land use, or rainfall intensity that may exist within a single catchment.

2.5 Future improvements

The peer review recommends the following opportunities for future refinement of the hydrological model:

- **Improved Flow Monitoring:** Install permanent flow gauges at or near the downstream hydrological model boundaries of the key ungauged catchments (e.g., Hororata, Waianiwaniwa) to allow for direct model calibration and reduce uncertainty.
- **Additional High-Flow Gauging:** Prioritise direct gauging of high-flow events at key sites (including Whitecliffs and Dalethorpe Road) to improve the reliability of rating curves.
- **Snowmelt Module Integration:** With climate change, future applications of this model may require more accurate simulation of winter/spring events. The model could be improved by adding a snowmelt module, although this would be subject to the availability of sufficient data for calibration.

3.0 Hydraulic model review

The hydraulic model peer review focused on the calibrated model and the final design model, following the structure outlined in the GWRC FHMS. All TUFLOW-based model components, including all input files (.tcf, .tgc, .tbc, .tef, etc.), were reviewed in detail. The review process was completed over three iterations for the calibrated model and two for the final design model. Issues were tracked using the review spreadsheet.

3.1 Purpose

The purpose of the Tonkin + Taylor (T+T) Selwyn District Flood Model is to provide Selwyn District Council (SDC) with a tool to quantify flood hazards resulting from a range of rainfall events across the plains. The model has been designed to perform two key functions, requiring different levels of detail and resolution:

1. **Township Infrastructure Planning:** To provide detailed flood information (including depth, velocity, and extent) within the district's main townships. This is intended to assist SDC's Planning

and Infrastructure teams with the design of future infrastructure, land use planning, and stormwater management.

2. **Rural Flood Hazard Assessment:** To provide, district-wide flood hazard information for rural areas. This is intended to support SDC in informing Flood Hazard Certificates and assessing flood risk for land use and consent applications outside of the main townships.

3.2 Description

The model is a 2-dimensional direct rainfall ("rain-on-grid") hydraulic model developed using TUFLOW HPC software. It covers approximately 2,300 km² of the plains area, from the foothills to the coast. The model uses a Digital Elevation Model (DEM) derived primarily from 2023 LiDAR as its topographic input. It simulates the movement of water across the landscape by applying rainfall directly to the model grid and routing the resulting runoff. The fluvial inflows generated by the ECan hydrological model were applied as upstream boundary conditions for the Selwyn foothills.

Key physical processes are represented through various input layers, including spatially varying infiltration based on soil types (Horton's method) and land cover-based hydraulic roughness (Manning's 'n'). The model includes critical infrastructure, representing stopbanks, roads, and railways as topographic features, and includes a 1D network of major culverts. The model was calibrated against the July 2017 flood event and validated against the June 2013 and May 2021 events, with calibration performance assessed by comparing modelled flood extents and depths against aerial imagery, ground observations, and recorded river flows.

3.3 Meetings

In addition to the monthly team wide catch ups, the hydraulic peer review, included:

- Meeting with T+T (Richard Brunton) on Thurs 17 October 2024 to discuss the preliminary hydraulic model; and,
- Meeting with T+T (Richard Brunton) on Wed 16 July 2025 to discuss the V3 review and close out the model review process.

3.4 Peer review

3.4.1 Model Schematisation and Input Data

Grid Cell Size and Refinement

The model's grid resolution was reviewed in the context of balancing computational efficiency with the need for accurate hydraulic representation. Areas of high hydraulic complexity—such as culverts, small urban channels, and township infrastructure—were assessed for appropriate use of refinement layers and nested grids.

Reviewer feedback led to localised increases in grid resolution in selected areas. Trade-offs between run times and hydraulic accuracy were discussed. These decisions and their implications are documented in the review spreadsheet, with recommendations made for updates in future versions.

Representation of Buildings

Urban buildings were incorporated into the model using block-outs to simulate obstruction to overland flow. Sensitivity testing was conducted by temporarily removing building block-outs to assess changes in flow patterns and ponding.

The review confirmed that the inclusion of building block-outs improves floodplain realism, particularly in township settings. However, it was also noted that such block-outs should be updated regularly to reflect future urban development or cadastral changes.

Infiltration and Impervious Area Treatment

Infiltration parameters were evaluated, with specific attention given to how impervious surfaces and soakage-prone areas were represented. Reviewer feedback led to improved mapping of impervious fractions based on current aerial imagery and the application of updated soakage rates derived from design rainfall intensity estimates, local soil data and engineering design standards in the SDC Engineering Code of Practice. In summary, soakage rates are expected to exceed 12 mm/hr, equivalent to the 10% APE 1-hour rainfall intensity.

Limitations in the underlying Tuflow engine's ability to simulate subsurface flow and groundwater recharge were acknowledged. These were documented in the review comments, with recommendations for integrating more detailed modelling of this hydrological process in future projects.

Topography and Digital Elevation Model (DEM)

Model terrain inputs were checked for completeness and accuracy. This included the handling of critical elevations (like stopbank and road crest heights) and the method of including supplementary data (e.g., LiDAR, surveyed structures, local breaklines).

Changes to the DEM include:

- the burning in of township drains,
- the application of breaklines along roads and stopbanks,
- smoothing and minor adjustments to known overland flow paths,

These were all reviewed for technical justification. Our review identified areas where bridge deck elevations and sub-grid features may have been under-represented. While the current DEM was found to be generally fit-for-purpose, future enhancements were recommended, particularly in areas of known hydraulic sensitivity.

3.4.2 Boundary Conditions and Structural Elements

Boundary Conditions

It was noted that some simplifications had been applied, particularly at the lake margin and coastal outfalls, where tidal dynamics and intermittent closures of lake mouths can affect backwater effects. While the applied simplifications are considered appropriate for this project scope, these limitations have been transparently acknowledged in the documentation and flagged for future refinement if outputs are to be used in more detailed coastal or lake margin assessments.

Culverts and Bridges

Structural components were assessed. The review identified instances where bridges and culverts were approximated using DEM-derived elevations due to incomplete or unavailable asset data.

Where detailed structure geometry was available (e.g., culvert diameter, invert level, blockage risk), it was included appropriately. In other areas, metadata was added to clarify where assumptions had been made. Reviewer comments encouraged this transparent documentation approach, allowing future users to easily identify areas requiring data improvement.

3.4.3 Roughness, Calibration, and Model Stability

Roughness Values

Floodplain and channel roughness values were compared against benchmark ranges and local knowledge of land use types. Paved areas (e.g., roads, parks, industrial areas) were assessed using a log-law approach to derive equivalent roughness values.

Reviewer feedback prompted the introduction of additional roughness zones to better reflect spatial variation. Sensitivity testing on these parameters was undertaken and documented, helping to confirm the robustness of flood extents to changes in surface roughness.

Calibration and Validation

Model calibration was performed using historic flood observations, including aerial imagery, known flood depths, and community-reported extents. PDP reviewers assessed:

- the quality of calibration data,
- parameter ranges tested,
- the spatial distribution of calibration points,
- residual flood depth patterns.

Feedback from reviewers led to enhanced calibration summary maps and tabulated performance statistics, as well as clearer documentation of outliers and model limitations.

The model demonstrated good alignment with observed flood extents for major events, and reviewer confidence in the calibration was high.

Model Stability and Performance

Each model iteration was evaluated for numerical stability, convergence behaviour, and mass balance performance. Reviewers tracked error logs and noted several early issues, particularly in urban catchments with steep topography and high imperviousness.

These issues were resolved through:

- timestep adjustments,
- refinements to boundary condition smoothing, and
- alterations to inertial settings in specific domains.

Reviewer comments were addressed efficiently by the modelling team, and the final version of the model met standard stability criteria.

3.5 Limitations

The final model is considered technically sound and appropriate for its purpose. Limitations of the model are set out in the T+T hydraulic model report. The main limitations are:

Simplified Groundwater Interaction: The model does not simulate the groundwater system. While surface infiltration and losses to a shallow aquifer in the Selwyn riverbed have been tested and included, the model does not represent the groundwater table, which is known to have significant effect on flood dynamics, particularly in the lower part of the Selwyn River and the Hawkins River to flooding in parts of the district. This impacts the lag time of the peaks meaning that some parts of the model will not accurately simulate when the flood waters arrive and therefore care should be taken if relying on the model for results where the timing of flooding is important, for example, evacuation planning.

Incomplete Datasets for Structures: The accuracy of the modelled stormwater network and culverts is limited by the completeness of the available asset data. As noted in the T+T report, some assumptions were required where data was missing or inconsistent, particularly for smaller culverts. These are unlikely to have a significant impact on results, particularly for the more extreme events like the 200-year (with climate change) event.

Calibration: The calibration of the model was limited by data availability. While the model showed a good overall calibration, particularly for the Selwyn River, elsewhere in the region, due to limited data, the model is essentially uncalibrated. In these areas where the model is uncalibrated, additional care should be applied when interpreting the results.

Antecedent Condition Bias: The model's infiltration parameters were calibrated to the July 2017 event, which occurred under relatively wet antecedent conditions. Therefore, the model may overestimate flood extents and depths for events that follow prolonged dry periods, as higher initial losses would not be fully captured.

Scope Exclusions: By design, the model does not include inflows from the major braided rivers (Waimakariri and Rakaia). Therefore, it cannot be used to assess flooding that originates from these sources.

Downstream Boundary: The downstream boundary (Te Waihora) has been modelled as a linearly increasing water level. The model does not simulate the state of the lake mouth. An open mouth will help to lower lake levels whereas a closed one will exacerbate flood levels. The timing of an artificial opening during a flood event will also influence flood levels in and around Te Waihora. Whilst this assumption is acceptable for a region wide model, flood results may not be suitable for detailed analysis of coastal inundation or specific lake-edge flooding issues which would need to be addressed with a more comprehensive study of lake levels and coastal hydraulics.

3.6 Future improvements

Future improvements are detailed in the T+T report. The main improvements to consider are:

Integrated Surface/Groundwater Modelling: For future model updates, or if the model is to be used for evacuation planning, we recommend implementing TUFLOW’s Interflow Module or a similar feature to dynamically simulate the interaction between surface water and the shallow groundwater system.

Additional Calibration and Validation: As and when new flood events occur, further calibration data should continue to be obtained and used to improve model accuracy, especially in locations where the model is currently uncalibrated. We note that it also useful for model calibration to identify areas that do not flood. This additional data will help test the model's performance under a range of conditions and build confidence in the outputs.

4.0 Conclusion

Pattle Delamore Partners Ltd (PDP) has completed a technical peer review of the Selwyn District-Wide Model, which was developed through a two-stage process involving:

- a hydrological rainfall-runoff model by Environment Canterbury; and,
- a hydraulic "rain-on-grid" flood model by Tonkin + Taylor.

The review was conducted in accordance with the GWRC Flood Hazard Modelling Specification and involved an iterative feedback process with both modelling teams.

The review ensured that the overall modelling approach, development, and calibration was technically sound, and in accordance with accepted industry best practice. The calibration of both models used several historical flood events to test performance under a range of hydrological conditions. The hydraulic model was calibrated to the 2017 event which experienced wet antecedent conditions and therefore the model may be slightly conservative. This is considered appropriate given the other limitations inherent in any modelling process.

While the models are considered fit for their intended purpose, it is critical that end-users understand the limitations of a district -wide model including the limitations identified during this review. The most significant of these is that the hydraulic model's calibration is biased towards wet antecedent conditions; it will therefore likely provide slightly conservative (i.e., overestimated) flood extents for events that follow prolonged dry periods. Further details on the sensitivity of the model to this parameter are discussed in the T+T report. Other key limitations include the simplified representation of groundwater interactions which influence the timing and magnitude of flood peak.

In conclusion, PDP consider both ECan hydrological model and the Selwyn District-Wide Flood Model as suitable and reliable tools for their stated purposes, primarily identifying 200-year flood levels which can be used to help prepare flood certificates and inform the planning and design of infrastructure for the Selwyn Townships. The limitations outlined in this review must be considered during the application and interpretation of the model outputs to ensure they are used appropriately and within the scope for which they were developed.

5.0 Limitations

This report has been prepared by Pattle Delamore Partners Limited (PDP) on the basis of information provided by Selwyn District Council and others (not directly contracted by PDP for the work), including Tonkin and Taylor Limited and Environment Canterbury. PDP has not independently verified the provided information and has relied upon it being accurate and sufficient for use by PDP in preparing the report. PDP accepts no responsibility for errors or omissions in, or the currency or sufficiency of, the provided information.

This report has been prepared by PDP on the specific instructions of Selwyn District Council for the limited purposes described in the report. PDP accepts no liability if the report is used for a different purpose or if it is used or relied on by any other person. Any such use or reliance will be solely at their own risk.

Yours faithfully

PATTLE DELAMORE PARTNERS LIMITED

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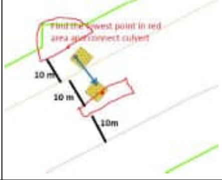
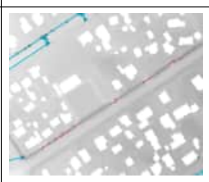
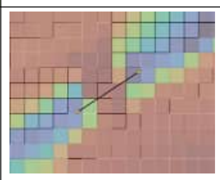
Service Leader – Water Resources

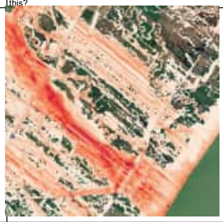
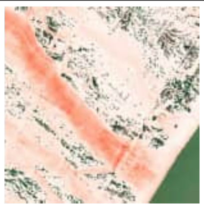
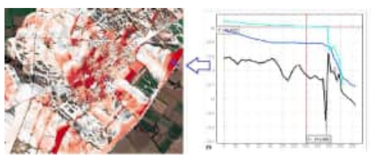
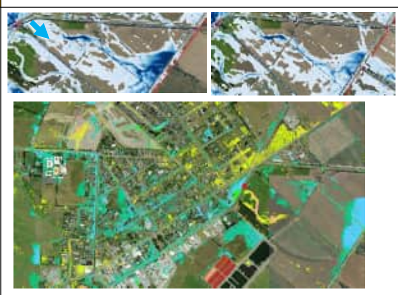
Reviewed and approved by

Bas Veendrick

Technical Director – Water Resources

Hydraulic Model Peer Review - Calibration

Element	Review - V1 21/5/2025 Reviewers Comments	Review - V1 Review rating	Modellers comments - V1 28/5/2025 Modellers Comments	Review - V2 2/7/2025 Reviewers Comments	Review - V2 Review rating	Modellers comments - V2 8/7/2025 Modellers Comments	Review - V3 7/2025 Reviewers Comments	Review - V3 Review rating
Documentation								
Model log is complete and up to date	Model log is mostly empty. The report gives a good description of the modelling process and choices, so a brief overview of the model files in the log would suffice.	Major	Log updated with additional detail, more to be added after prior to final design runs	Overview of model files is added to the log. Together with the modelling report this suffices.	Ok			Ok
All run descriptions are complete	The 0.5% AEP event is called 05pAEP, which can be confused with 5% AEP. Could be called 0pt5pAEP (or just 200yARI)	Minor	Changing this would require re-generating the rainfall grids which is a reasonable amount of work, would prefer to leave as is, SDC to comment.	Model log contains short description of events	Ok			Ok
Limitations and assumptions are clearly stated	Section is present in report, but still mostly empty (in the draft version)	Major	See updated report	Model limitations are listed and described in the model build report Ch. 8. Leaving as major pending outcome of calibration but likely to be dropped to minor.	Major	Sensitivity and calibration report sections have been updated		Ok
Sufficient information has been provided regarding modelling decisions	Yes, in the report	Ok			Ok			Ok
Schematisation								
The software used is appropriate	Yes	Ok			Ok			Ok
Model schematisation reflects known flood extents and flow routes	Yes, the model captures the plains between the Rakaia and Waimakariri River. No substantial flowpaths 'escape' the model elsewhere than Te Waihora	Ok			Ok			Ok
The modelling approach is appropriate e.g. 1D, 1D/2D, 2D etc.	2D model with 1D infrastructure elements. These are culverts in the district model and the stormwater network in the Township models. This is appropiate.	Ok			Ok			Ok
Grid cell size is appropriate	District-wide model. 20-m base, 3 step refinement (5 m) where needed. Township models: 4m (Rolleston / Lincoln) or 2m. Both use SGS sampling. These choices are an appropriate trade-off between accuracy and computation speed. Grid refinement (5m) is placed around culverts, which is required to have the inlet and outlet end up at different sides of line elements. Using a more refined approach of placing inlets and outlets (see sketch below) could perhaps achieve the same result without requiring a 5m grid. If culvert flow would be similar without refinement, using 10 m as smallest size could maybe half the computation times. Another option is to use the 5m only around culverts, and 10m on the line elements SH/railway, see comment about computation time step	Minor	2d_qnl has been updated with following approach *"Another option is to use the 5m only around culverts, and 10m on the line elements SH/railway, see comment about computation time step"*	Nest level along major roads has been reduced from 3 to 2, balancing detail and computation time. Note that the computation time itself cannot be compared to the previous iteration as tidal boundary and roughness method have changed.	Ok			Ok
			Currently, a 2d_zsh polygon (called 2d_zsh_CPIO_SDC_V001_R") is applied at culvert inlet/outlets which applies a level equal to the lowest DEM level within a 2m radius of the culvert inlet/outlet. The culvert invert (where invert data is not available) is then set 0.1m above this level. Acknowledge there are some very short culverts which may require <5m cell size but currently beyond the limits of simulation run times, added to future improvements					
Infiltration	Infiltration has been applied using a Horton's decay infiltration rate based on soil type, which is appropriate given the information available. However, given the importance of infiltration for the Selwyn district, should be revalidated/calibrated as new information comes available. In the township built-up areas, a 20% impervious fraction is assumed outside the building footprints for residential areas, and 50% for commercial areas. These seem relatively low (also considering that it's only outside the buildings). Fine to leave with future improvements (if better data available). Soakage is assumed for the upstream 2/3 of the district with larger depth to groundwater? The (draft) report is still a bit unclear on this, is it only for Rolleston and Darfield or is it for the full blue area in 4-12? Is there a validation for the 12 mm/hour for building footprint soakage?	Minor	Residential areas have been updated to 25% impervious. Commercial areas have been updated to 80% impervious Confirming approach in example below. Future improvement has been added to the report to collect better impervious cover (e.g. Satellite) For building roofs, 12mm/hr constant loss is applied within the building footprint for the "soakage areas" (blue area in report map). 0 mm/hr is assumed for the remaining buildings as they are outside the soakage area. Rates are applied using the 2d_soils layers. Report has been updated removing reference to Rolleston and Darfield. 12mm/hr rate is approximately equivalent to the 10% AEP 1-hour rainfall event intensity from HIRDS (RCP8.5 for the period 2081 – 2100 future climate as per SDC's Engineering Code of Practice Chapter 8.5.2), which is what soakpits could be expected to be sized for. T+T is not aware of any event validation specifically for roof soakpits	The limitations of TUFLOW for simulating surface water groundwater interactions are described in the limitations. OK. Inside soakage area (large depth to GW), a 12 mm/hour infiltration rate is applied within building footprint (assuming larger soakage for larger buildings). For infiltration basins 50 mm/hour (per square meter) is assumed. Both seem on the lower side which is appropriate for the model purpose (long and extreme events). OK. Including SW / GW interaction is added to future model improvements (Ch. 9) OK.	Ok			Ok
								
Model inputs								
Is the model referencing the correct input files? e.g. DEM	Yes	Ok			Ok			Ok
Does the topography/bathymetry accurately represent floodplain features e.g. stopbanks etc.	Yes. Breaklines are used along roads to make sure SGS doesn't 'shortcuts' the flow. Breaklines for stopbanks were added along the lower parts of the Selwyn River as well. **Township:** Buildings are lifted in the township model, effectively blocking out overland flow. Consider linking this to onlyt the small events. For larger events where overland flow is important, blocking out flow might lead to unexpected results (worth a sensitivity analysis, see also comment on depth-varying roughness).	Minor	Most houses will have perimeter ring or slab about 400mm high which is best represent by blocking out the DEM. Depths are generally quite shallow (i.e. less than 400mm) within urban areas even in larger events. Blocking out buildings will not simulate water volume within buildings or provide a flood level within the building but we believe it is visually more "correct". (Refer to *https://tuflow.com/media/4997/2008-flooding-in-urban-areas-2d-modelling-approaches-for-buildings-and-fences-syme-hwe-aus.pdf*). Note we only block out buildings in the township models, as grid size is too large to do so in the District model. We recommend blocking out for all events in the design runs but will conduct a sensitivity test where buildings are removed	Choices around buildings are substantiated in the report. Sensitivity analysis for this not done yet, so still "Minor"	Minor	Sensitivity scenario has been run, see sensitivity section in report.		Ok
Have changes made to the DEM been documented, and are these changes reasonable and appropriate?	Yes, changes to the DEM have been reported. The changes that were made are appropriate. Some suggestions for additional changes (township drains) are discussed in the "channel modelling" section.	Ok			Ok			Ok
The hydrology outputs match the hydraulic inputs	Yes, they seem the same Hororata is called Hotorata in the bc_dbase, Selwyn is called Sewlyn.	Minor	Naming has been updated	Naming has mostly been corrected. The quadtree layer still turns up without the 2d_qnl* in the QGIS projects. The gpkg file itself is called 2d_qnl*, but the layers in the file are not. Could be improved but very minor so "OK"	Minor	Quadtree layer has been updated as recommended.		Ok
Climate change has been applied to the model correctly	Yes, rainfall depths are in accordance with HIRDS v4 current climate and climate change scenarios	Ok			Ok			Ok
Metadata or data flags appropriately assigned to input data	Mostly. The stopbanks for example do have a datasource mentioned, but the roads do not (it's likely the DEM, but couldn't hurt to add to datasource)	Ok			Ok			Ok
Channel modelling								
Nodes are labelled and numbered correctly	N/A	Ok			Ok			Ok
Cross section data has been entered correctly, and is sufficiently detailed	The township model drains are not burned in. See for example the drains through Leeston, which have bridges/culverts on them. Especially for low return period runs this may affect flood patterns. See item "All structures in the channel have been included" below.	Minor	See below.	Drains are now burned using zsh file	Ok			Ok
Model chainage is correct	N/A	Ok			Ok			Ok
Branch lengths are correct, and branches occur in the correct locations	N/A	Ok			Ok			Ok
Roughness values used in the channel are appropriate	2D drain and channel roughness was added around the townships only. The represents the detail in which drains are modelled: Around townships, where they are part of the stormwater infrastructure during less extreme events. Not for the full district, which means that road-side drain flow is not accurately modelled (mainly due to the grid size, not roughness). That is however in line with the purpose of the district wide model, modelling flooding during more extreme events.	Ok			Ok			Ok
All structures in the channel have been included	**District**: As far as possible with the available data. Main culverts around the township / SH are modelled. Roadside culverts are not, but this is in line with the model's purpose (see previous point) **Township**: Some of the township drain culverts are missing (for an example in Leeston, see below), In absence of data it could be worth burning these out, or assuming a small culvert. Mainly for the smaller (10-year) event where they could make a difference and are likely not blocked.	Minor	Additional 2d_zsh has been added to drains in locations where A. drain crossings are blocking the DEM, and B. Vegetation appears to have blocked the DEM, see example below. 2d_zsh width has been set to 1m in most cases, 2m for wider drain through Leeston. US and DS 2d_zsh point Z levels set from the lowest DEM level within a 2m radius.	See comment about drains (row 25)	Ok			Ok
								
All bridge data (e.g. soffit level, deck height) has been entered correctly	No bridges (lfcsh) in the model, which is a modelling choice. Localized flood levels around bridges could be wrongly estimated. Recommend adding to the future improvement register.	Future Data Collection	Agree, added to Future improvements		Future Data Collection			Future Data Collection
Bridge piers been modelled appropriately e.g. shape, size, location.	As above	Ok			Ok			Ok
All culvert data has been entered and modelled correctly e.g. invert levels of inlet and outlet, dimensions, inlet losses, culvert shape, length, outlet losses and spill mechanism.	Some of the culvert data seems derived from DEM levels. For example, the starting culvert of the Leeston bypass (crossing the township model upstream boundary) slopes upward.	Minor	Where inverts are missing, the culvert invert is set as the lowest DEM level within 2m radius plus 0.1m. Recommend future improvement to update inverts as data is collected.	Leeston bypass values are feasible now. Where culvert data is unavailable values were derived from DEM. Nice to have would be to add "inverts derived from DEM" if applicable in datasource (similar to assumed Dia below). Similar to missing SW data, users could survey them if it becomes an important element in their model.	Minor	Have updated attributes as recommended		Ok
Roughness values used in culverts are appropriate	n=0.015, which is appopriate.	Ok			Ok			Ok
Losses through structures verified through external approaches	Default parameters were used for constriction factors and entry/exit losses. Constriction parameters are lower than the TUFLOW range. HConF = 0.6 (TUFLOW manual range: 0.6 to 0.8) WConF = 0.0 (TUFLOW manual range: 0.9 to 1.0) EntryC = 0.5 (TUFLOW recommends 0.5) ExitC = 1.0 (TUFLOW recommends 1.0)	Minor	The model applies 0 for WConF which according to TUFLOW manual states *"If value exceeds 1.0 or is less than or equal to zero, it is set to 1.0 for C and 0.9 for R culverts"*. However, so future users of the model are clear, the model has been updated with the same default values (0.9 and 1.0) inserted into the WConF column.	Wconf is corrected to TUFLOW's manual's default range	Ok			Ok
Appropriate length of reach upstream of inlets developed	N/A	Ok			Ok			Ok
Inputs are released upstream of inlets	N/A	Ok			Ok			Ok
Spill/weir profiles are represented correctly	Some weir/overflow levels are set in the 2D domain	Ok			Ok			Ok
Appropriate spill/weir coefficients have been used	N/A (no 1D weirs modelled)	Ok			Ok			Ok
Structure overtopping routes are represented	Yes, structure overtopping is possible through 2D.	Ok			Ok			Ok
Floodplain modelling								
All structures and embankments are included	Yes sufficiently. 2D breaklines on major line elements for the districtwide model. Stormwater infrastructure for township models.	Ok	Additional pond levels inlets and outlets will be added to next model iteration.		Ok			Ok
Roughness values used in the floodplain are appropriate	**Rural**: 'Mostly. The rural land roughness varies based on LCDB land use, meaning some areas are classified as Short-rotation cropland, grassland, orchard/vineyard with corresponding roughness values. These land use categories often seem outdated/misclassified. You could consider using a default representative value for all rural farmland. Detail: for "high producing exotic grassland" the roughness of 0.026 for > 200 mm is fairly low. **Depth varying roughness:** depth varying roughness is applied for many surfaces. This is a good feature to model lower flow velocities at small water depths when vegetation constrictions the flow (or vice versa). In the SDC model it is widely applied to most surfaces, which makes it hard to oversee the effects of this. It would be good to demonstrate the effect of using depth-varying roughness through a sensitivity analysis. **Urban/Township:** In the urban areas, the 'build-up' area has a high initial roughness (0.4) decreasing to a low roughness (0.04) for > 100 mm water depths. Buildings on the other hand have a low initial roughness (representing roof runoff I assume) which increases for higher depths (representing flow through the buildings themselves). It would be worth a sensitivity run to see how this choice compares to the usual "high roughness on buildings". Major as some sensitivity analysis is required.	Major	The land use information is based on LCDBv5 (created in 2018) which has limitations. Its worth noting that 88% of the model domain is either grassland (40) or cropland (30). **Roughness approach has been updated to the LogLaw approach in TUFLOW. See updated report for details grassland limiting n= 0.028, roughness height 50mm., cropland n = 0.05, height 150mm.** Urban/township blocks out buildings so the higher roughness for higher depths will not be triggered in the model. The higher roughness for higher depths is only relevant for the district model when buildings are not blocked out (because grid size is too large to do so). The low roughness at shallow depths within buildings is to account for rapid runoff from roofs. Sensitivity runs will be tested in calibration.	Adopted log-law approach for surface roughness seems approprite. The sensitivity analyses for these are not yet in the report, so Major awaiting their outcome.	Major	Sensitivity scenario has been run, see sensitivity section in report.		Ok
Floodplain features have been enforced appropriately	Breaklines have been used and shifted towards the highest point in the lines proximity. While this doesn't necessarily follow the 'ridge', it's a good approximation. However, some more breaklines could be added. Considering the difference between the district and Leeston models, the differences are very large where the breaklines are missing, but still significant where they are present.	Minor	Where township models exist, township results should take precedence. Therefore, in areas where models overlap but District model is missing breaklines, the township model will provide the more accurate level and the district result becomes irrelevant. See further detail below, we will continue to investigate this further.	Breaklines are unchanged. To reduce differences between District and Township, breaklines that are added to district could also be added to township, and additional breaklines could be added to both where they're currently missing. See Row 75 below for context. Note that both choices (to add or not to add) are defendable: The geometric representation is sufficient without adding more breaklines, but if the differences between district/township are considered important adding them could help.	Minor	We recommended no changes to the district or township models as the better resolution of the township models should pick up the road geometry better than the district model (even with breaklines). Breaklines enforce the crest to ensure water overtops at the correct level, however as the district model cell is is 20m the geomtry of the road is not well repsetned comarped to the township model. See further detail in comment below		Ok
Stream channel to floodplain links are modelled appropriately	N/A (No lateral 1D/2D was used)	Ok			Ok			Ok
Boundaries								
Location of downstream boundary is appropriate (does not affect results in study area)	**District:** No. The downstream boundary is placed at Lake Ellesmere / Te Waihora, or the coastline. The coastal dynamics around these areas are not properly modelled, i.e., no tide and lake mouth dynamics. This means the model results should be used with caution in these downstream areas. Note that this is in line with the model's purpose (pluvial / fluvial flooding). **Township**: For Lincoln, the downstream boundary just crosses the Halswell River. Maybe shift it slightly upstream.	Future Data Collection	Agree, added to future improvements re Lake Ellesmere. Lincoln boundaries have been updated: Added a new 2d_bc HT (levels extracted from district model PO), and added additional 2d_bc QT for Halswell River. See below.	Coastal boundary was changed into a tidal pattern. Storm surge is continuously applied (i.e., no temperal variation in the elevation of the tide), which is conservative but suits the model's purpose (similar to applying the hyetograph spatially uniform). Ok Lincoln boundary was adjusted as well. Ok	Ok			Ok
								
Downstream boundary is in agreement with the model event	**District:** No, see last comment. **Township**: current choice of BC is insensitive to event size (so yes).	Ok			Ok			Ok
Downstream boundary type is appropriate	**District**: No, see above. **Township**: Constant slope rating curves have been applied all round the D/S township boundaries. Boundaries should be placed perpendicular to the flowpath (as recommended by TUFLOW), at locations where the flow is uniform (such that the constant slope rating curve applies). Whilst this is not the case, the effect is probably small, and most boundaries are placed D/S of line elements, making the line element serve as a 'weir' boundary. This approach also makes it easy to shift the downstream boundary if someone would want to.	Ok			Ok			Ok
Application of inflows is appropriate	**District**: See hydrology review. **Township**: Yes, flows are extracted from district model. Regarding location: For Leeston, the upstream boundary could include the culvert that starts the Leeston Bypass (under Harman's Road), as this would be an important feature determining how much flow is diverted into it.	Minor	Boundary for Leeston has been moved US of Harmans Rd and the existing. culvert added, 2d_qnl & 2d_mat extended, Note, SDC have requested that the current state of the bypass is modelled, with future stages to be added into the model when they are constructed	Leeston model boundary adjusted (around Harman's Road).	Ok			Ok
Inflows are correct for stated return period and storm duration	**District**: See hydrology review. **Township**: Yes, as flows are extracted from district model.	Ok			Ok			Ok
Rain on grid boundaries	Rainfall hyetographs are provided per duration (for HIRDS profiles). It would be good to add a hyetograph with nested durations (nested storm) to this. Whilst this is more conservative, it does not require simulating all durations. I can imagine would be preferable in some cases, where the additional modelling costs to not outweight the reduced conservatism. An option would be to provide the boundary conditions (hyetograpsh, hydrographs) for the nested storm, so other users have the possibility of running this without having to derive the rainfall patterns themselves.	Minor	Agree this could be useful, T+T to discuss with SDC	Unchanged. Whilst the different HIRDS duration hyetographs provide a more nuanced answer than using a nested storm, providing the hyetograph for the nested storm could be a good addition. If users would want to use it, they will likely struggle deriving it in a similar spatially varying manner as T+T has currently done. However, if SDC/ECan agrees that demonstrating (a lack of) effects for just the critical duration (as will be presented in the final report) is sufficient, then it is not needed to provide a nested storm.	Minor	Added to future improvements	Left as minor - could be changed to OK subject to Ecan/SDC input	Minor

Run parameters								
Initial conditions are appropriate	No initial water levels have been applied. For shorter durations this might affect results, as existing drains and ponds could store part of a rainfall 'burst'. For long durations this shouldn't matter, as everything should be flooded before the peak arrives. Given that longer durations are most relevant for this district-wide model, the initial conditions are appropriate.	Ok			Ok			Ok
Run parameters are appropriate	Yes, runtimes are slightly lonfer than event durations, with the difference between runtimes and event duration being largest for the shorter event, as it should be. @ Check if max levels are not at simulation end	Ok			Ok			Ok
Run times are reasonable and the simulation period is correct	Yes, given the model scope, run times are good (12 hr for the largest longest event on T+T's PC).	Ok			Ok			Ok
The model timestep is appropriate	Model timestep is adjusted automatically by TUFLOW based on constraints, see discussion of time delta below	Ok			Ok			Ok
Error, warning and check messages have been addressed where appropriate	Some checks and warnings regarding the township stormwater models could be addressed based on assumptions. See for example below (central Leeston). Major, unless SDC has agreed to use township SW data as is. If so, should be added to future improvements	Major	All SDC network data available was added to the model, noting there are some assets which are not connected or have other issues which generate check and warnings. SDC have agreed to leave these assets in the model, a future improvement opp to collect further data has been added to the report.	As discussed: Incomplete data are left in such that users of the model are aware of it, and can improve(e.g., through survey) if necessary.	Ok			Ok
								
Results								
Is there any glass-walling on the floodplain?	The model boundaries allow for free outflow. Model extent is appropriate	Ok			Ok			Ok
Is there any glass-walling in the model?	Model boundaries don't allow for glasswalling	Ok			Ok			Ok
1D		Ok			Ok			Ok
2D		Ok			Ok			Ok
Does the long-section show any unusual head losses at structures?	No, most structures are culverts, and the culverts have a minor effect on the total flows.	Ok			Ok			Ok
Are velocities within the expected ranges in the channel and floodplain?	Velocities are within expected range. However, there are some funky patterns in the V_max, see figure below. I cannot explain this by looking at the DEM, perhaps the depth-dependent roughness plays a role in this?	Minor	This issue has been resolved. The cause was the 2d_mat_roads_SDC_V001_R layer which was being processed unexpectedly by TUFLOW.	Resolved. (error in TUFLOW handling large holed material polygons).	Ok			Ok
								
Are volumes within the expected range?	Yes, 200,000,000 m3 on 2,000,000,0000 m2 during 200-yr CC run. Avg. 10 cm water depth	Ok			Ok			Ok
Are structures operating in accordance with expected behaviour?	N/A (no operated structures)	Ok			Ok			Ok
Culverts	Many culverts do not convey much flow during the largest events, but this is mainly due to inaccurate terrain levels (preventing flow to reach the culverts). Culvert inlet could be connected to the lowest point within X radius, but this would likely only partly solve the issue. Culvert flow is unlikely to cause much effects in the largest events, perhaps a 'blocked culvert' sensitivity analysis could demonstrate this. A few of the coastal/Ellesmere culverts flow backwards during the initial phase of the event. A unidirectional culvert could be considered, unless coastal flooding is meant to be modelled.	Minor	A 2d_zsh polygon (called 2d_zsh_CPIO_SDC_V001_R") has been applied at culvert inlet/outlets which applies a level equal to the lowest DEM level within a 2m radius of the culvert inlet/outlet. The culvert invert (where invert data is not available - which is most of the culverts in the model) is then set 0.1m above this level. In the 200yr 24 hour event 89% of the culverts have some flow through them. As culverts are surveyed the model should be updated with the correct invert levels and the ground terrain modified to suite - this has been added to future improvments. Sensitivity run will be done with blocked culverts. ECan have provided requirements for coastal culverts which will be updated in the next model update, that being: + Forsyth's culvert = open (no flap valve) with a tide profile + Coopers Lagoon culvert = closed + Fish Farm culvert = open (no flap valve) with a tide profile + Cryers Ck/Jollies Brook culvert = closed Time varying tide will also be added at the next model update	Coastal boundary condition has been reconsidered and discussed with SDC/Ecan.	Ok			Ok
Soak pits	Some of the soak pits are not connected to the stormwater network. See "errors and warnings" above	Major	See comment above. SDC agree to keep assets in model and accept checks/warnings with aim to fill in missing data in the future. Future improvement added.	Ok, keep incomplete data so users notice, see above.	Ok			Ok
SW Network	See above	Major	See above	Ok, keep incomplete data so users notice, see above.	Ok			Ok
Bridges	N/A	Ok			Ok			Ok
Sensibility check of locations of flow paths and ponding areas	Flood patterns look as expected. Flow converges towards major flowpaths, ponding occurs behind roads. Notice that township model Leeston gives substantially different flood levels (see below, 200-yr event). Red mean township higher (250 mm), grey means district higher (250 mm). The locations of the ponding in the township model suggest that even though breaklines are used in the district model, the road overflow is interpreted differently. This could be due to a geometry difference (however, the crest seems fairly similar) or a depth-dependent roughness (e.g., the road cell is much larger in the 20 m district model, so there will be higher water depths on the cell. This might give a lower roughness than in the smaller water depth township model road cell). The higher levels in central Leeston could be due to blocked out buildings or cell size. Major because differences ~250 mm are similar to freeboard allowance, so should come with an explanation.	Major	The difference in this specific location is because the breakout flow from the upstream drain is higher in the township model vs the district model (see screenshots below at blue arrow, top map is township model, bottom is district). The township model has more breakout flow which then causes more water to pond behind the road downstream. Note, the DEM_Z check file shows the crest of the road is within 100mm for both models (as the review points out). Updated model results show township water depths are within 100mm in most areas (see difference map below), noting there are several blue areas which is Township model being 100-200mm higher than the district model). We will continue to investigate the differences further but it is likely that it is due to flows being directed in different directions and displacement from buildings. Where township and district models overlap, township models should take precedence because they have finer resolution and more detail.	Image below right is the update from the image below left. Differences have significantly reduced between model versions. The main differences still seem to be behind roads, likely due to breaklines, or the interpretation of roughness (through water depth) over the breakline. It could be worth adding the breakline to the township models as well. Even though it might not necessarily be needed when using a 2m or 4m grid, it could still reduce the differences between regionwide and township model. For the regionwide model, breaklines could be added along minor roads as well if ponding differences between models are considered an issue.	Minor	We have checked a few locations in the circled areas below. It appears that the district model water level is higher here not because of the road geometry, but the difference in flow breaking out from the upstream drainage channels. The district model has more flow breaking out which then results in more water ponding behind the road embankment. We recommend no changes to the model, as we believe these differences are due to the difference in resolution between the district and township models, which is to be expected. Where township and district models overlap, township models should take precedence because they have finer resolution and more detail.	Accept this clarification and have changed it to ok	Ok
								
Calibration								
Is the approach to calibration appropriate?	Approach as described in report is fine.	Ok			Ok			Ok
Aerials				Yes	Ok			Ok
Survey data				Limited, but this is the best available data	Ok			Ok
Has the approach to calibration been applied to the model correctly?				Yes	Ok			Ok
Is the calibration source data appropriate for use?				Yes, it is the best available data	Ok			Ok
Does the data used for calibration match the source data?				Yes	Ok			Ok
Has the model been satisfactorily calibrated?				Calibration and presentation of calibration is fine but further information would be useful to present: 1. Present the range of roughness/infiltration parameters that were tested (not all the associated results) 2. A high lvl summary of the three events would be useful. 2017, wettest antecedent conditions, recorder flows - good, within 20%, aerials acceptable 3. Further information on the calibration performance for the aerials would also be useful. These are probably are best source of info and it would be good to spatially identify where calibration performance was good/not so good and non-existant	Major	1. Additional text added to the report outlining which parameters were adjusted. Generally the tested parameters fell within the "textbook" values and the final adopted values. Unless where otherwise stated, e.g. High initial loss in the Selwyn River channel (which is described in the relevant report section) 2. A high level summary table has been added to the model report. 3. A map and some brief commentary has been added to the report showing which obs photos are high or low compared to the modelled extent. There is some judgement required as to what is "high" or "low" but there are a couple of patterns identified as explained in the report.	Updates look good	Ok
Model Performance								
Overall mass balance is acceptable	0.00%, which is good.	Ok			Ok			Ok
Check of any instability in model results	1 instability timestep in the calibration run (fine). Some instable time steps observed in township models as well, but nothing substantial	Ok			Ok			Ok
time delta	0.7s minimum for the largest event. Time step is constrained by TUFLOW's Nc (wave celerity) constraint. The location of the cell that gives the constraining timestep (0.7) is the underpass of the SH between Rolleston and Christchurch (see figure below, red is smallest timestep). Perhaps some easy gains in computation time could be achieved by constricting the grid refinements to the culverts inlets/outlets only, instead of the full SH/ railway line. Or using one step less refinement (10 m) on those roads, outside the inlet/outlets.	Minor	2d_qnl has been updated on these roads. See previous comment.	The potential constraint on the time step was resolved by reducing the grid refinement along the major roads.	Ok			Ok
								
control numbers (Nu, Nc and Nd)	Fine (Nc is the limiting constraint, which is to be expected in model type)	Ok		Fine	Ok			Ok
Model convergence is acceptable	Not yet reported on.		See updated report.	Yes acceptable, reporting could be improved, see my report comment: "I like the figure. Could you also make it for water level difference? I find it difficult to interpret the "depth" because of different grid sizes will lead to different base depths in cells (and I'm not sure how SGS interprets this as a single value depth). Similarly it would be interesting to take the non-absolute difference, so you can how much of it is an increase and a decrease."	Minor	Report figure changed to water level instead of depth (very similar results seen) and extra plot provided showing non-absolute differences.		Ok

Hydraulic Model Peer Review - Final

Element	Review - V1 (time/date of issue)		Modellers comments - V1 (time/date of issue)	Review - V2 (time/date of issue)	
	Reviewers Comments	Review rating	Modellers Comments	Reviewers Comments	Review rating
Documentation					
Model log is complete and up to date	Model log is mostly empty	Major		See "Hydraulic Model Calibration"	Ok
All run descriptions are complete	Events are described in model log. Event names are mostly self-explaining.	Minor		See "Hydraulic Model Calibration"	Ok
Limitations and assumptions are clearly stated	They have a dedicated report chapter, but it is still mostly empty.	Major		See "Hydraulic Model Calibration"	Ok
Model files					
tcf (control)	Well organized and clear.	Ok			Ok
tef (event)	Well organized and clear. Order of events could be changed to the order of e1, e2, e3	Minor			Minor
tgc (geometry)	Well organized and clear. Some of the layers are not named following TUFLOW convention. For example, the model code for Leeston is called "Leeston" instead of 2d_code_Leeston, which affects QGIS styling. The TSUS observation Q lines for Kirwee are added twice. This causes an error while initializing the District model.	Major		See "Hydraulic Model Calibration"	Ok
tbc (boundary)	Well organized and clear.	Ok			Ok
Model Runs					
Have the full suite of design runs been run?	*Will update after final report*				Ok
Have the correct inputs (e.g. inflow, climate change, tidal boundaries etc.) been applied to the various runs?	Boundary conditions have been checked. Set-up (naming) of events and scenarios is robust.	Ok			Ok
Are the results of the various runs in line with expectations?	*Will update after final report*				Ok
Sensitivity Test					
Has sensitivity testing been undertaken?	*Will update after final report*			Yes	Ok
Are the parameters selected for sensitivity testing (e.g. blockage, roughness, inflows, bed level changes, downstream boundary) appropriate?	*Will update after final report*			blockages have all been tested. No test to the downstream boundary which whilst interesting, will have only a localised effect	Minor
Have the changes to the sensitivity parameters been applied to the model correctly?	*Will update after final report*			Yes	Ok
Are the results of the sensitivity test results in line with expected behaviour?	*Will update after final report*			Yes	Ok
Has an assessment of likely blockage been undertaken, and applied to the model appropriately?	*Will update after final report*			Yes- culverts fully blocked	Ok
Outputs					
Are mapped extents reasonable?	Yes, mapped extents map the model extent which is appropriate. SDC could consider not presenting results in the downstream area where the waterlevels are determined by the downstream boundary (ocean level / Te Waihora)	Ok			Ok
Do flows propagate in a sensible way?	Yes, mostly overland flow with concentration in creeks/rivers/drains.	Ok			Ok
Do the maps match the model results?	*Will update after final report*				Ok