Appendix 5: Hydraulic modelling advice

Science Advice

Date	July 2025
To	Chris Fauth (ECan)
CC	Laddie Kuta (kastorworks Ltd.)
From	Daniel Ward

Washdyke Coastal Bank Hydraulic Modelling

Key Messages

- This report details the 2D hydraulic model for the Washdyke and Seadown coastal stopbank that focusses on flood impacts of surrounding infrastructure and the proposed retreat of the existing Washdyke and Seadown drain to a new location further inland.
- Model results show ponding behind the coastal stopbank with flows along Seadown Drain and into Washdyke Lagoon. In large magnitude events, like an Ōpihi River breakout, maximum water levels are controlled by the coastal stopbank with overtopping occurring.
- The Rifle Range is shown to have limited impact on flooding.
- Modelling indicates that:
    - o during an Ōpihi River breakout, the proposed stopbank and drain configuration is shown to have less than minor effects on exacerbating flood conditions across the floodplain, and the proposed flood wall protection restricts inundation from occurring in the Washdyke Industrial area.
    - during a 20 year average recurrence interval (ARI) rainfall event, the proposed stopbank and drain configuration shows lessened inundation extent and duration north of the wastewater ponds when compared to modelling of present-day conditions.
    - during a mean annual rainfall event, the proposed stopbank and drain configuration convey flows via the drain without overtopping.

Introduction and Purpose

The existing coastal stopbank between Washdyke and the Ōpihi River provides protection from high swells and tides. Increasing threat of overtopping and inundation from coastal storms has prompted the need for retreat of this stopbank to maintain protection of landside properties.

Several key features of the model study area are identified in Figure 1. The *current coastal bank* presents a barrier to overland flows, resulting in freshwater ponding on the landward side of the bank. The *wastewater treatment and retention ponds* near Aorangi Road create a choke point for flows draining into *Washdyke Lagoon* when *Seadown Drain* exceeds capacity. Similarly, the banks at the *Rifle Range* on Aorangi Road may reduce capacity through this choke point.

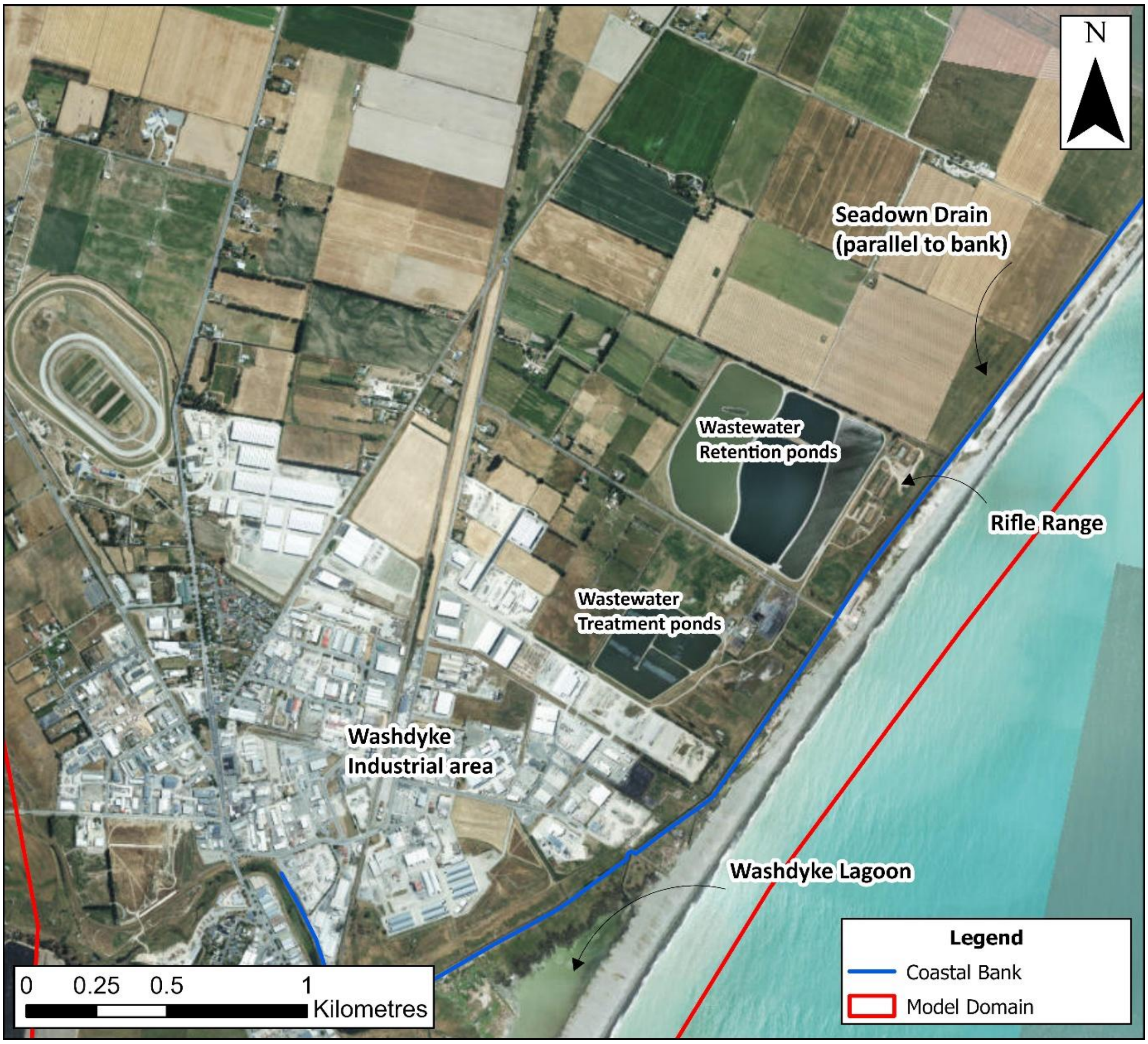

Figure 1: Key features of consideration around Washdyke and Levels area

This study details hydraulic modelling to investigate the current effect of the coastal bank and Seadown Drain on flooding. This modelling is compared to a new configuration for the coastal stopbank and Seadown drain to quantify the impacts of this new configuration on flood hazard. Additionally, this study will examine the effect of the Rifle Range on flooding.

Hydraulic Modelling

This modelling study investigated a range of scenarios to help inform design of a new coastal stopbank including:

1) Present day stopbank configuration with Rifle Range:
- 200 year ARI breakout scenario from Ōpihi River (including climate change)
- Run for an additional 24 hours post-breakout
- 20 year ARI rainfall event (including climate change)
- Run for an additional 72 hours post-rainfall

2) Present day stopbank configuration without Rifle Range:
- 200 year ARI breakout scenario from Ōpihi River (including climate change)

3) Proposed stopbank configuration with Rifle Range:
- 200 year ARI breakout scenario from Ōpihi River (including climate change)
- Run for an additional 24 hours post-breakout
- 20 year ARI rainfall event (including climate change)
- Run for an additional 72 hours post-rainfall

   a. Low flow drainage scenario (mean annual rainfall event)

Note: Ōpihi River breakout models do not include rainfall, and rainfall event models do not include Ōpihi River breakouts.

Data and analysis

Hydrology Data

Environment Canterbury has a water level/flow recorder on the Ōpihi River at Saleyards Bridge (Site 69650) (Figure 2). Flood frequency data derived from flow data at Saleyards bridge was used to estimate reasonable breakout flows (Table 1).

Table 1: Ōpihi River at Saleyards Bridge present-day flood frequency information (T+T, 2017)

Peak flow (m^3/s)								
Mean Annual Flood (m^3/s)	5 year	10 year	20 year	50 year	100 yr	200 yr	500 yr	1000 yr
416	730	1160	1700	2550	3210	3620	4350	4900

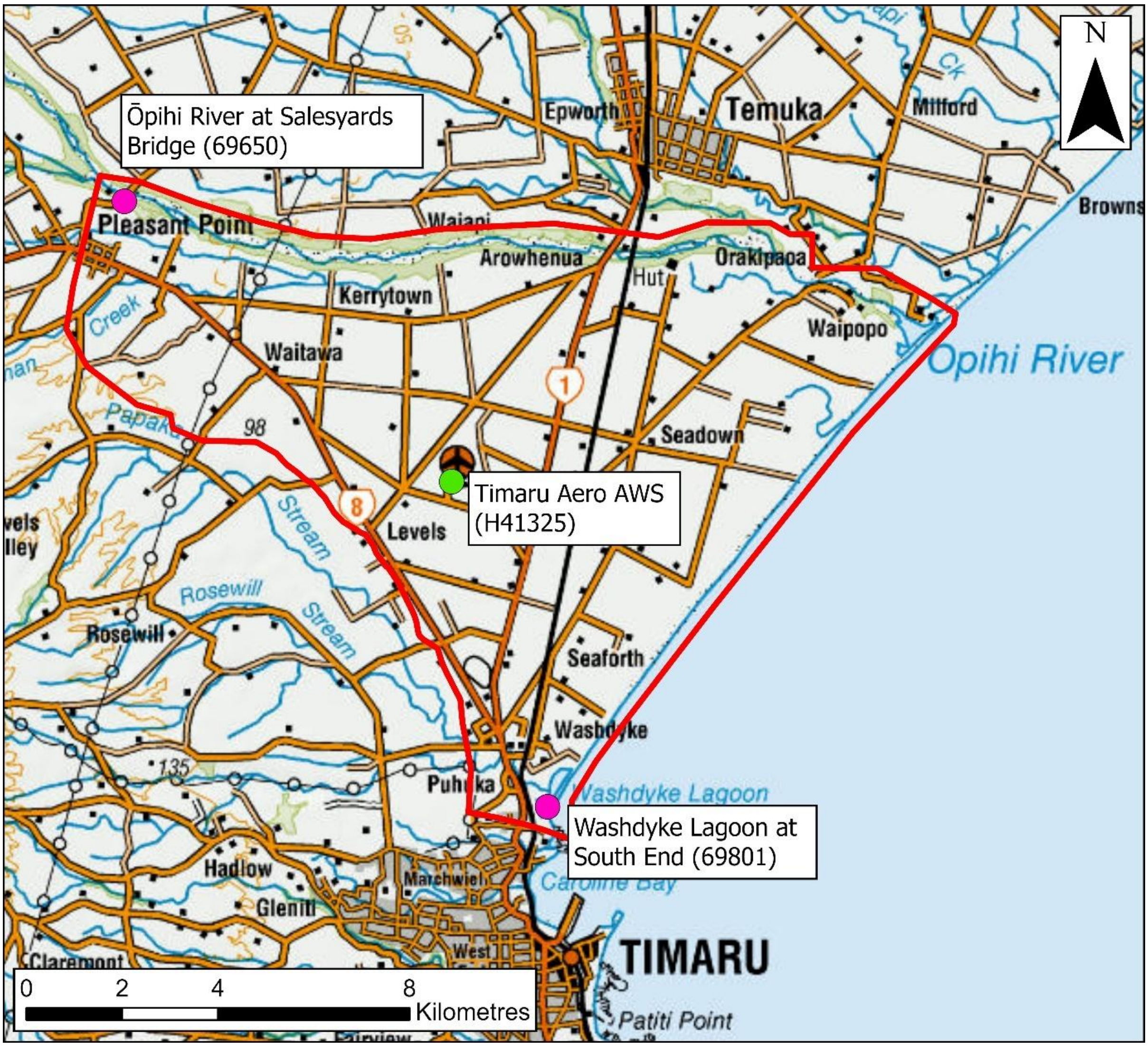

Figure 2: Model study area (red outline) and location of water level and flow gauges (pink) and rainfall recorders (green) used for modelling

Environment Canterbury have a water level recorder at Washdyke Lagoon (Site 69801). Water level data from Washdyke Lagoon (Figure 3) was used to inform initial conditions of the model.

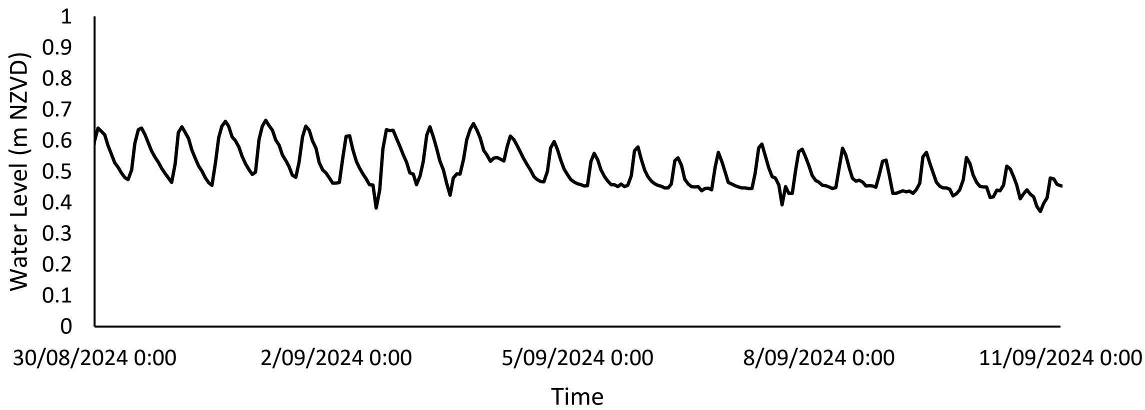

Figure 3: Example of Washdyke Lagoon water level data

Rainfall Data

To produce rainfall profiles, High Intensity Rainfall Design System (HIRDS) version 4 data for Timaru Aero AWS (H41325) was used (Figure 1). This site has a 26 year daily record (1991-2016) and 22 year sub-daily record (1995-2016) used in HIRDS analysis.

Climate change

The impacts of climate change on the Ōpihi River catchment are complex and only partially understood.

A previous modelling study by Gardner and Henderson (2019) in the Wairarapa showed that a 17% increase in peak rainfall (estimated with a 2.1°C increase in temperature from 1990 to 2090; MfE, 2008) increased peak flows by 17 to 27% (depending on catchment characteristics). Steel and Martin (2019) also estimated a 22% increase in rainfall intensity would translate to a 32% increase in peak flow for high recurrence interval (extreme) floods in the Ashley River.

Hydrologic modelling of the Ōpihi River by DHI (2023) included climate change scenarios using RCP8.5 (to 2100) rainfall inputs. This showed peak flow increases between 43% and 82%, dependent on storm duration and magnitude. Both 100 and 200 year ARI 24 hour storms were shown to increase peak flows by 45% and produce the highest absolute flows (critical duration of the catchment), while 12 hour storm events with smaller peak flows resulted in peak flow increases of 62%.

Based on the work described above (and the often non-linear river flow response to increased rainfall), present-day Ōpihi River design flows were increased by 45% for the 200 year ARI to account for the impacts of climate change scenario SSP3-7.0 to 2081-2100, with an estimated 3.6 ºC of warming (Table 2).

Climate change was also applied to direct rainfall scenarios using the RCP8.5 (to 2100) adjustments provided by HIRDS v4 (Carey-Smith *et al*., 2018).

Hydraulic model

Computational hydraulic modelling was undertaken using the DHI Mike21 flexible mesh (FM) 2 dimensional model. This model uses a triangulated irregular network (TIN) mesh to represent the ground surface, point source inflows to model breakout flows, and direct rainfall inputs across the mesh to represent model precipitation. The model produces flood inundation (with detailed water depth and flow speed information) for the area covered by the mesh grid. Input data and parameters used in the model are described below.

<u>Ground level (LiDAR) data</u>
To realistically simulate floodplain inundation with any degree of accuracy, good topographic data (including features such as banks, terraces, overland flow channels, and roads) are essential. High-resolution topographic data were obtained for the study area from LiDAR surveys from 2010, 2018, 2021, 2020, and 2025 (Figure 4). The surveyed ground levels are in metres relative to New Zealand Vertical Datum 2016 (NZVD2016).

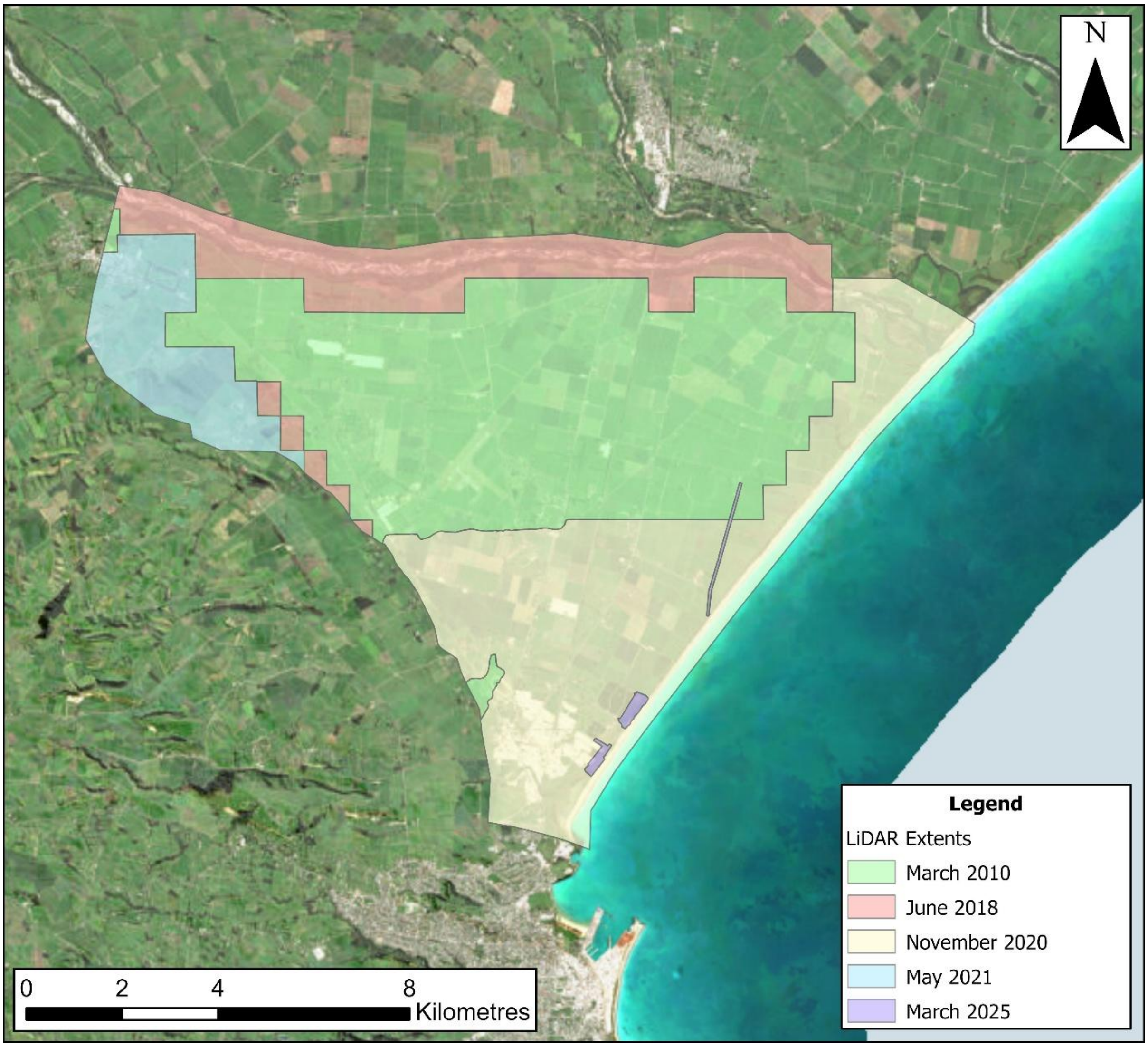

Figure 4: Model surface LiDAR extents

LiDAR data was interpolated onto a flexible TIN mesh using the maximum element sizes as in Figure 5. Breaklines were defined along the top of stopbanks, roads, and the railway line to maintain the maximum height of ‘barriers’ to flow in the mesh generation. For the low flow scenario, the Kereta Road and Seadown drains were represented with a maximum element size of 1 m².

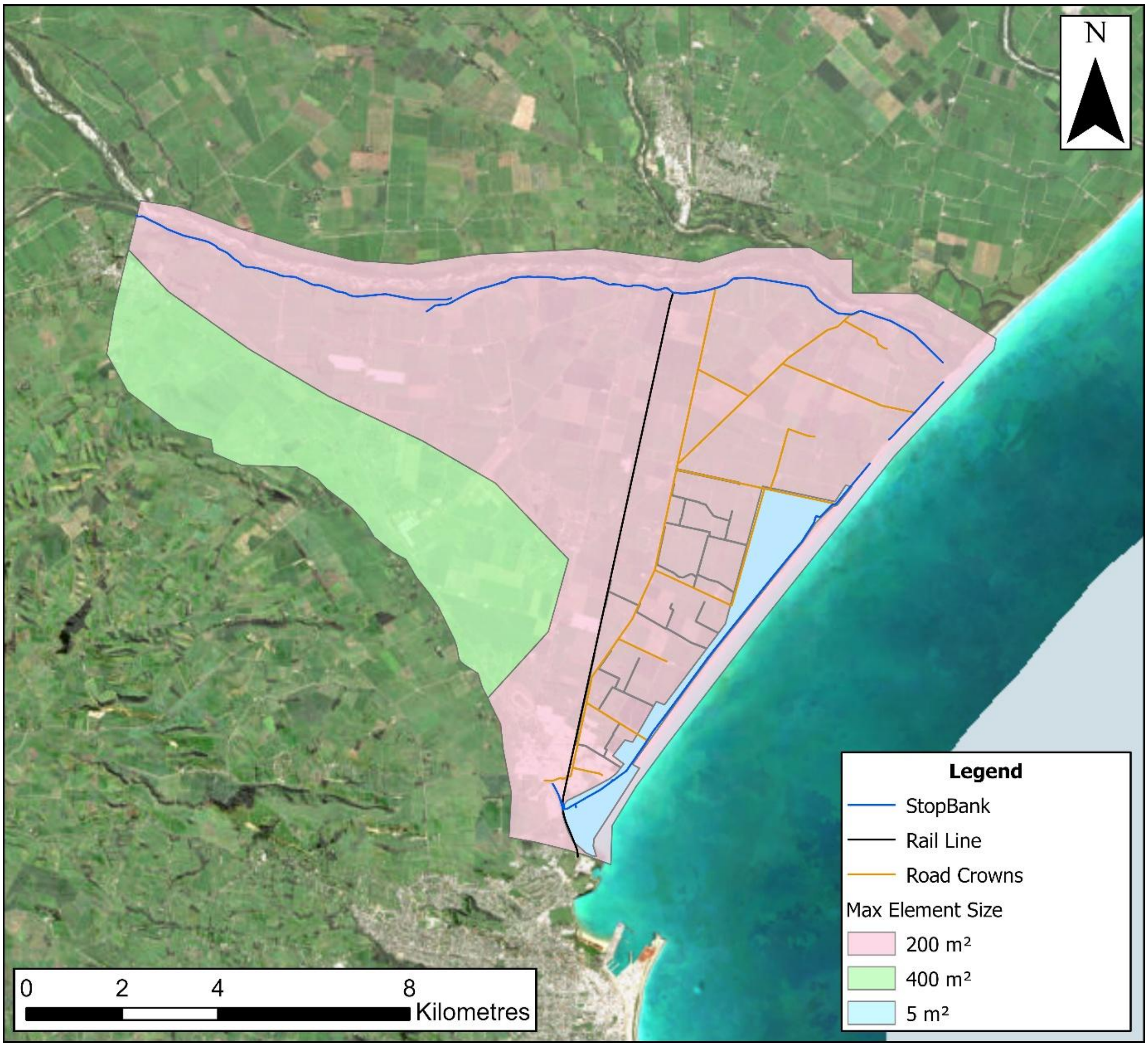

Figure 5: Model mesh delineation

<u>Ōpihi River breakout flows</u>

The location and timing of breakout flows is difficult to predict, and except for time varying surfaces (i.e., altering a stopbank profile over time) and dam breach analysis, there is no widely accepted method to estimate breakout hydrographs. To best estimate potential breakout flows, the 10 largest flow events from Ōpihi River at Saleyards Bridge were isolated, and the duration where flow was greater than 90% of the peak flow was determined. This was averaged for the 10 events, producing an average ‘peak period’ of 6 hours.

A 24 hour breakout hydrograph was constructed based on flood frequency data (+45% to account for climate change) and estimated peak flow period (Figure 6). For this exercise, it was assumed that 20% of the 200 year ARI flow was spilling to the floodplain. For this breakout hydrograph, the maximum water depth and inundation area is comfortably reached along the coast, with water overtopping the coastal bank. This is because the breakout hydrograph is long enough (and high enough peak flows) that the coastal ponding area is effectively ‘filled’. Therefore, being any more conservative (e.g., 30% of flow breaching the bank) would have negligible effect on model results in the area of interest. Additionally, this scenario produces greater inundation than a 200 year ARI rainfall event (including climate change), and so assessing the effects of a moderate magnitude, 20 year ARI rainfall event (including climate change) provides greater value than modelling a 200 year ARI rainfall event.

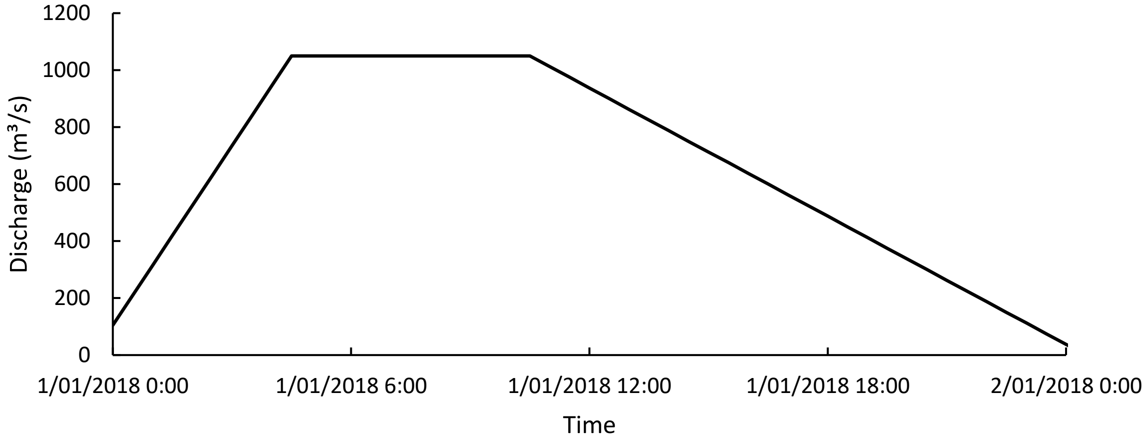

Figure 6: 200 year ARI breakout hydrograph

<u>Design rainfall</u>

Based on preliminary modelling, a 12 hour storm duration was determined to be the approximate critical duration for the catchment. Design rainfall hyetographs for 20 year ARI (RCP 8.5 to 2100) and mean annual rainfall (present day) events were constructed based on the East of SI regional design typical storm profile (HIRDS reference) (Figure 7).

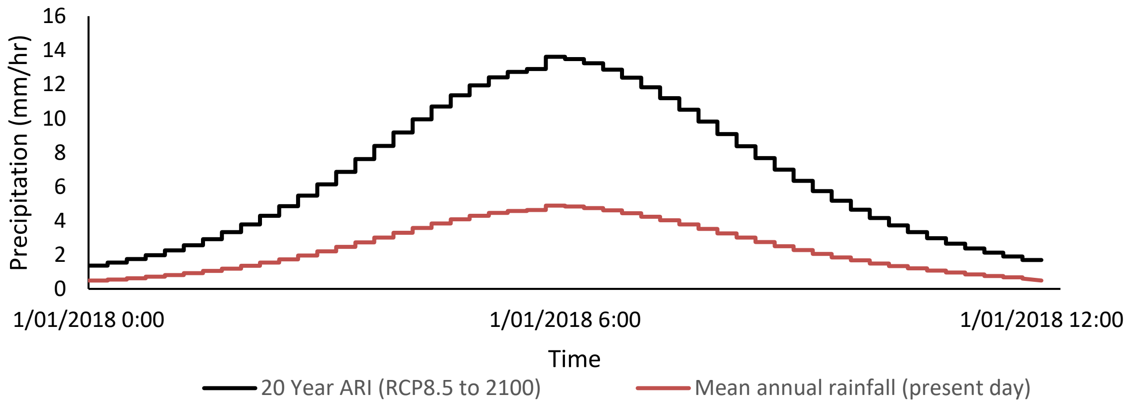

Figure 7: Design rainfall hyetographs

Roughness (Manning's n)

A roughness surface was based on the Land Cover Database (LCDB v5) and aerial imagery (Figure 9). Rural drains were given an increased roughness value based on field observations. All other roughness values were based on DHI (2020) and Ward (2024) (Table 2).

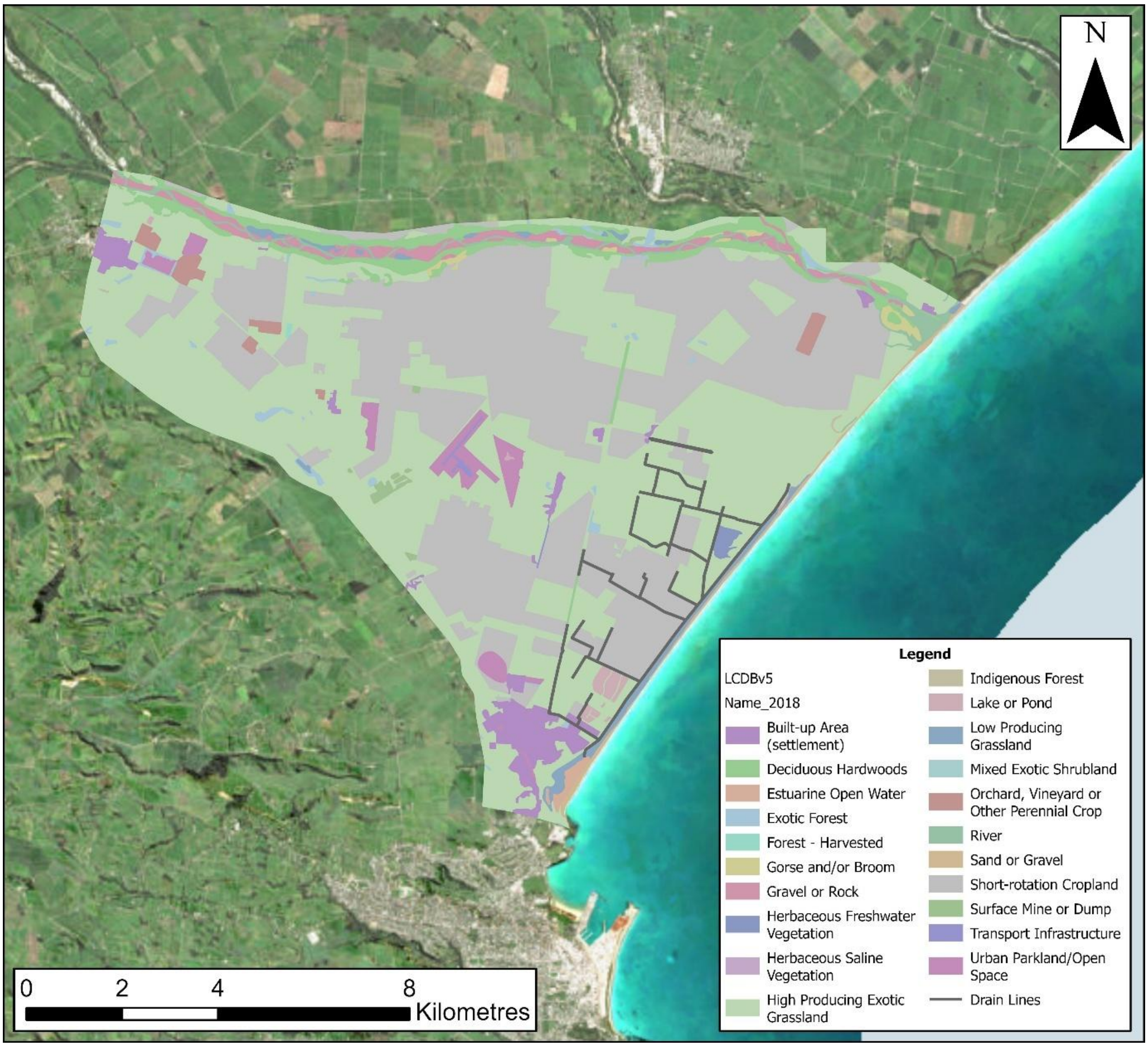

Figure 9: Model surface roughness classification

Table 2: Manning's n roughness values

Land Use (Name_2018)	Manning's n
Built-up Area	0.1
Deciduous Hardwoods	0.125
Estuarine Open Water	0.02
Exotic Forest	0.125
Forest – Harvested	0.125
Gorse and/or Broom	0.125
Gravel or Rock	0.02
Herbaceous Freshwater Vegetation	0.1
Herbaceous Saline Vegetation	0.1
High Producing Exotic Grassland	0.05
Indigenous Forest	0.125
Lake or Pond	0.02
Low Producing Grassland	0.1
Mixed Exotic Shrubland	0.05
Orchard, Vineyard, or Other Crop	0.05
River	0.02
Sand or Gravel	0.02
Short Rotation Cropland	0.05
Surface Mine or Dump	0.02
Transport Infrastructure	0.1
Drain Lines	0.07

Infiltration

A constant infiltration rate of 1.5 mm/hr has been included in the model by directly reducing precipitation (this simplified method minimises the impact on model run time). This is typical of a saturated, imperfectly – moderately well drained soil (DHI, 2019).

Structures

24 culverts were included in the model (Figure 8, Table 3). The remaining drains where specific conveyance was not deemed critical, had culverts (i.e., the ground surface above culverts in the LiDAR) and any barriers to flow (e.g., vegetation picked up in LiDAR) burned into the surface to ensure continuous flow.

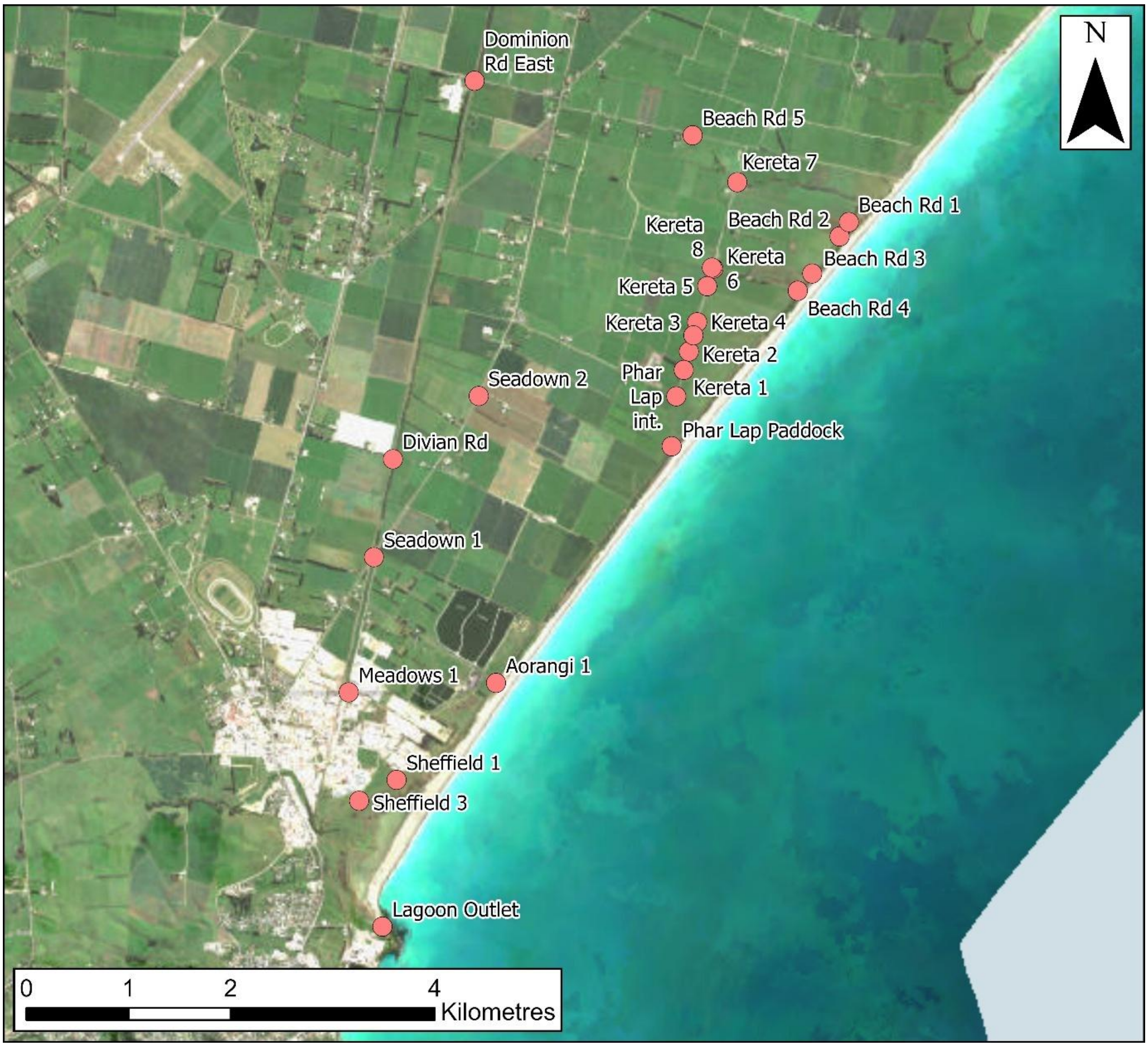

Figure 8: Model culvert locations

Table 3: Model culvert information

Culvert Name	Shape	Diameter (m)	No. of culverts	Upstream invert (NZVD2016)	Downstream invert (NZVD2016)
Lagoon Outlet	Circular	1.2	2	0.4	0.0
Sheffield 1	Circular	1.0	2	1.29	1.15
Sheffield 3	Circular	0.75	1	1.73	1.68
Meadows 1	Box	1.0 x 1.0	1	4.34	3.9
Aorangi 1	Circular	1.2	2	1.05	1.05
Seadown 1	Circular	0.54	1	8.0	8.0
Seadown 2	Circular	0.3	1	7.21	7.1
Divian Rd	Circular	0.6	1	10.15	9.95
Dominion Rd East	Circular	0.54	1	13.5	13.2
Phar Lap Paddock	Circular	1.0	1	0.9	0.9
Phar Lap Intersection	Circular	1.3	2	1.2	1.2
Kereta 1	Circular	0.6	2	1.53	1.5
Kereta 2	Circular	0.6	2	1.7	1.7
Kereta 3	Circular	0.6	1	1.9	1.8
Kereta 4	Circular	0.6	1	1.8	1.8
Kereta 5	Circular	0.6	1	2.3	2.3
Kereta 6	Box	1.0 x 1.0	1	1.85	1.85
Kereta 7	Circular	1.0	1	3.0	3.0
Kereta 8	Circular	0.6	1	2.54	2.44
Beach Rd 1	Circular	0.3	1	1.5	1.49
Beach Rd 2	Circular	0.3	1	1.75	1.73
Beach Rd 3	Circular	0.75	1	1.68	1.67
Beach Rd 4	Circular	0.75	1	1.27	1.23
Beach Rd 5	Circular	0.64	1	6.0	6.0

Model boundary conditions

The coastal boundary of the model was set at a constant water level of 0.7 m NZVD2016 (a high tide scenario). The initial water level of the model was set at 0.6 m NZVD2016 (a high tide scenario within Washdyke Lagoon).

Model parameters

The main model parameters include:

Eddy viscosity	=	1 m^2/s (constant)
Wetting/drying depths	=	0.003/0.006 m
Maximum time step	=	0.5 seconds
Solution technique	=	high order algorithm

Scenario Specific Modifications

To assess changes between different scenarios, modifications were made to the input surface. LiDAR data from 2010 (pre-Rifle Range) was used for Scenario 1 (Present day stopbank configuration with Rifle Range), while LiDAR data from 2025 was used for Scenario 2 (Present day stopbank configuration without Rifle Range) (Figure 9).

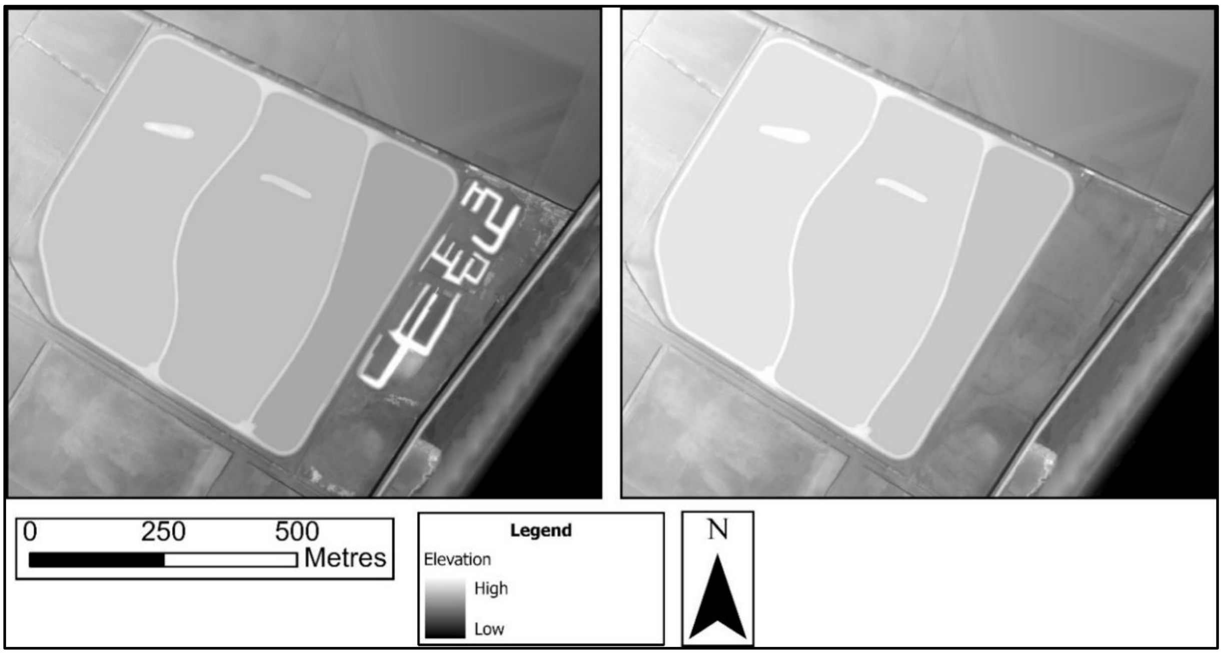

Figure 9: Elevation surface from 2025 with Rifle Range (left) and 2010 without Rifle Range (right)

Modifications made for Scenario 3 (Proposed stopbank configuration with Rifle Range) include a new stopbank (approx. 50 m inland from the existing coastal bank) and drain (Figure 10a). The new stopbank crest is 6.0 m NZVD2016, north of Aorangi Road, and 4.0 m NZVD2016, south of Aorangi Road (to allow freshwater overtopping). The stopbank has a batter slope of 2:1. In this configuration the current coastal stopbank is also lowered to 4.0 m NZVD2016 south of Aorangi Road. The new drain has an invert level of 0.5 m NZVD2016.

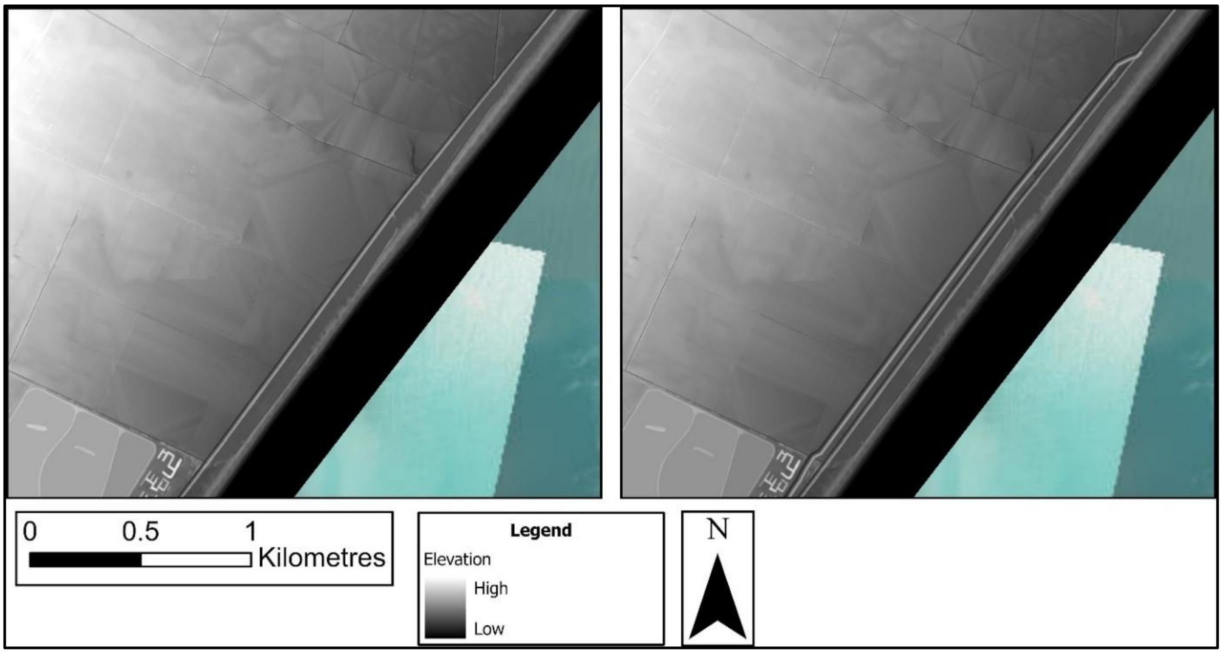

Figure 10a: Present day topography (left) and proposed stopbank and drain configuration (right) north of Rifle Range

Additionally, a dike structure (Figure 10b) was added along the margins of the Washdyke industrial area and wastewater ponds. This dike was set to an elevation of 10 m NZVD2016 (effectively glass-wall) to represent a flood wall. Water elevations between the dike and new stopbank will inform the actual height that this flood wall will need to be constructed to – it is expected maximum water levels will be just over 4.0 m NZVD2016 (at which point water should freely overtop the coastal stopbank).

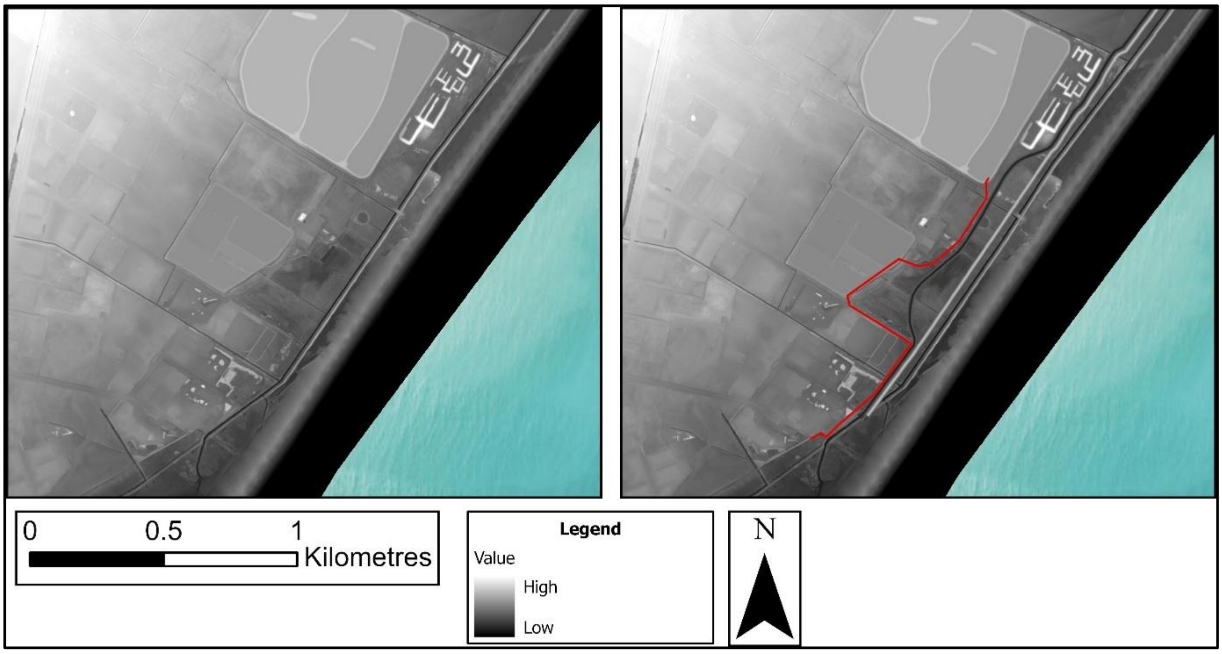

Figure 10b: Present day topography (left) and proposed stopbank and drain configuration (right) with dike location (red line) south of Rifle Range

For all Ōpihi breakout scenarios, a 50 m breach was created in the Washdyke Lagoon beach crest (Figure 11). For 20 year ARI rainfall and low flow (mean annual rainfall) scenarios, the lagoon remained closed.

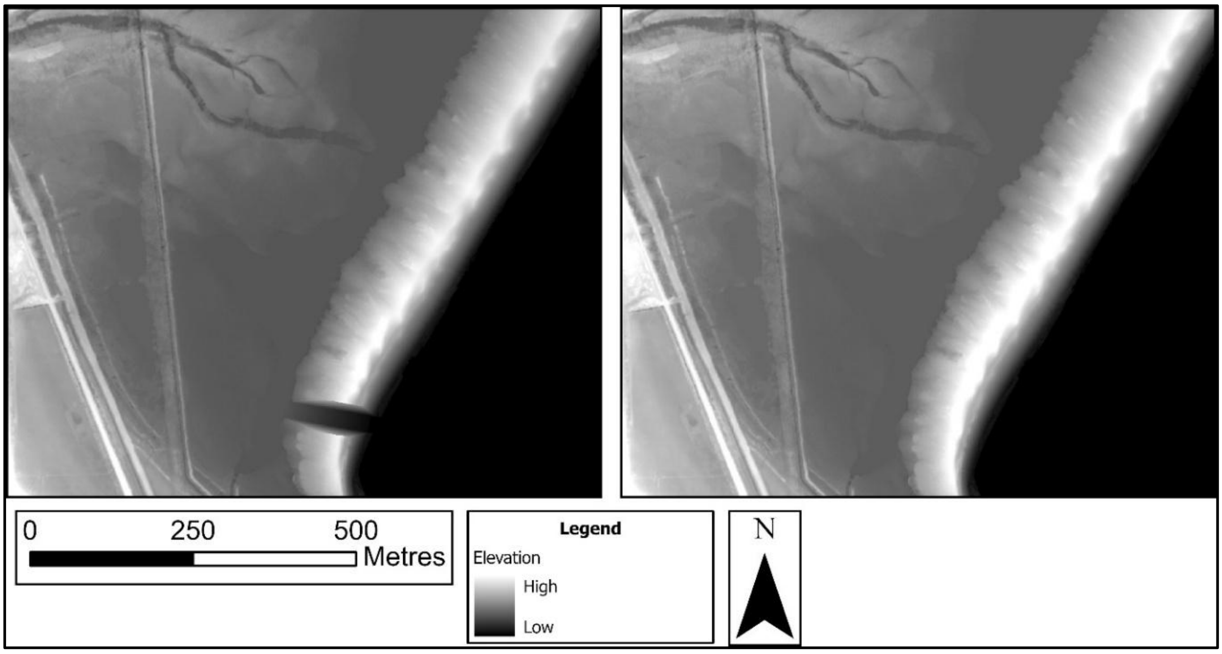

Figure 11: Washdyke Lagoon with a 50 m breach (left) and without a breach (right)

Model results

Scenario 1.a. Present day stopbank configuration with Rifle Range - 200 year ARI breakout scenario from Ōpihi River (including climate change)

Model results from scenario 1 provide a baseline for comparison with further scenarios with modified stopbank and drainage configurations.

Model results from an Ōpihi River breakout scenario show a maximum water level reached behind the coastal stopbank after approximately 13 hours (with the initial flood front taking 6.5 hours to reach the coast) before overtopping of the stopbank occurs (Figures 12a and 13a). Of the peak 1050 m³/s breakout flow, 870 m³/s crossed the floodplain towards the coastal bank, and 180 m³/s flowed back into the Ōpihi River.

The results show that a more conservative flow (a larger breakout) would not increase flooding in the area of interest (as the primary control, the coastal stopbank, is being overtopped). A greater inundation extent would be expected across the upstream floodplain with a larger breakout, but that is beyond the scope of this work.

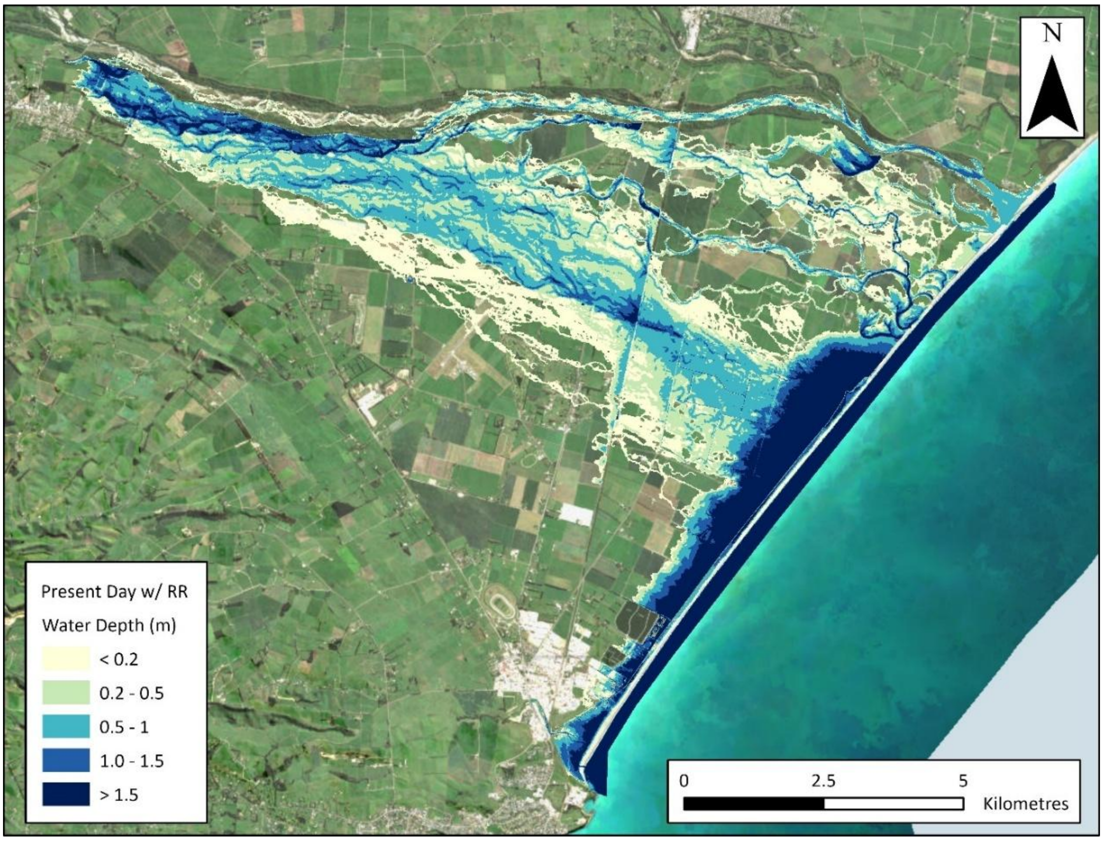

Figure 12a: Maximum modelled water depth – present day stopbank configuration with Rifle Range – 200 year ARI Ōpihi River breakout

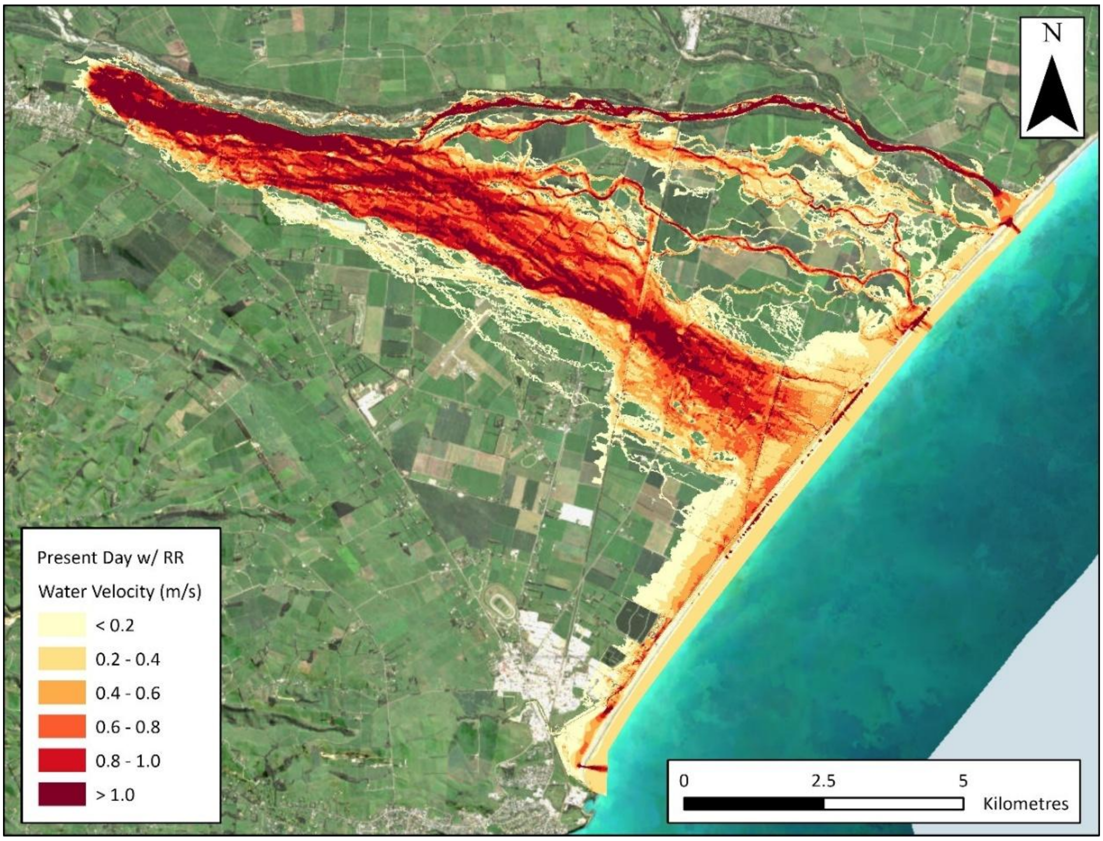

Figure 12b: Maximum modelled water velocity – present day stopbank configuration with Rifle Range – 200 year ARI Ōpihi River breakout

Model results in the area of interest near Washdyke industrial area show water channelling from the ponding area through the Rifle Range and into the lagoon (Figure 13). The topography of the area is flat, and so flows are largely driven by hydraulic head, and velocities are relatively low through this choke point (mostly less than 1 m/s).

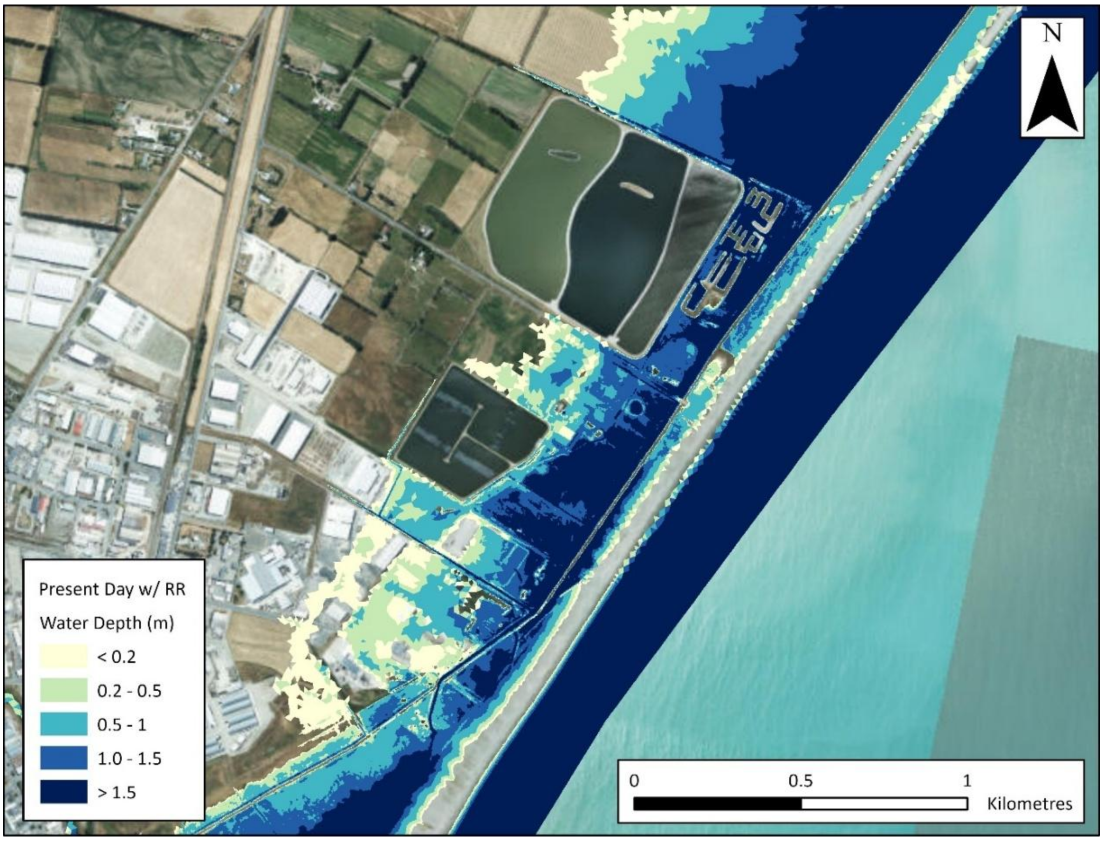

Figure 13a: Maximum modelled water depth – present day stopbank configuration with Rifle Range – 200 year ARI Ōpihi River breakout – Zoomed to Washdyke area

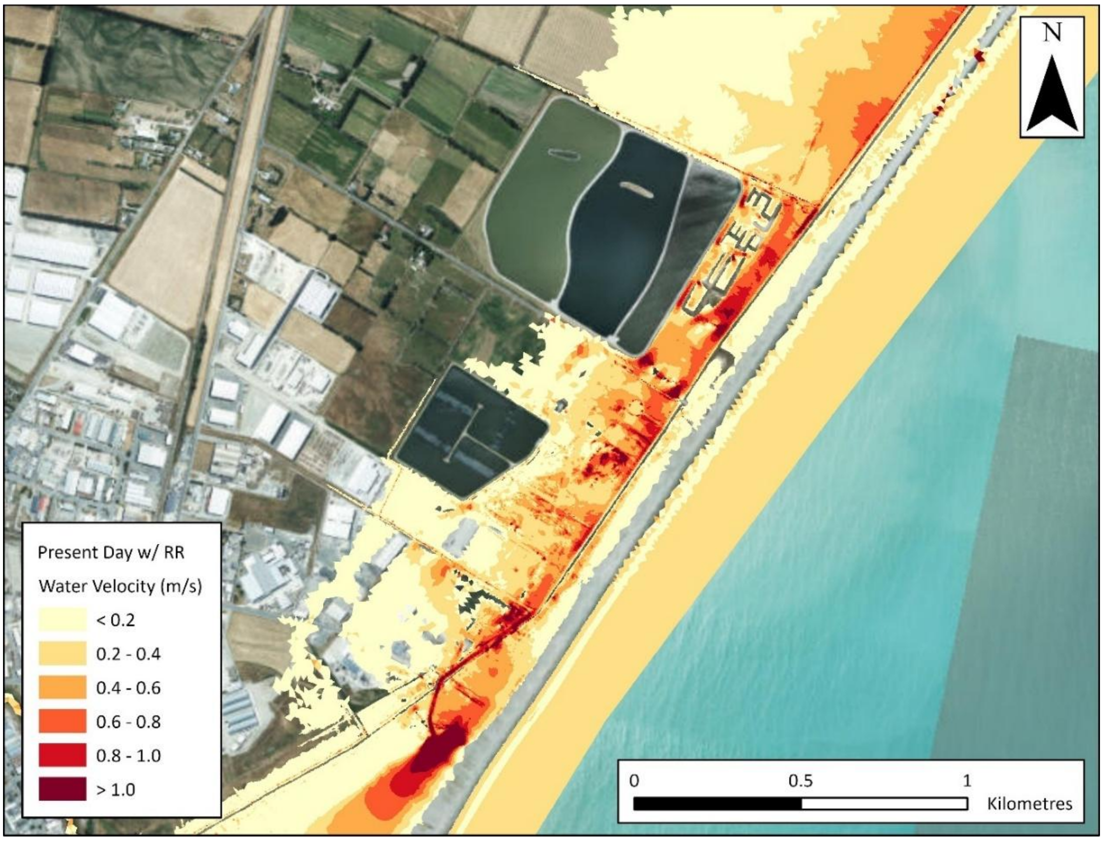

Figure 13b: Maximum modelled water velocity – present day stopbank configuration with Rifle Range – 200 year ARI Ōpihi River breakout – Zoomed to Washdyke area

Scenario 1.b. - Present day stopbank configuration with Rifle Range - 20 year ARI rainfall event (including climate change)

Model results from direct rainfall modelling do not show any unexpected areas of flooding when compared to the Ōpihi River breakout scenario (Figure 14). Significant ponding occurs behind the coastal stopbank, however not to the extent of an Ōpihi River breakout and does not overtop the coastal bank.

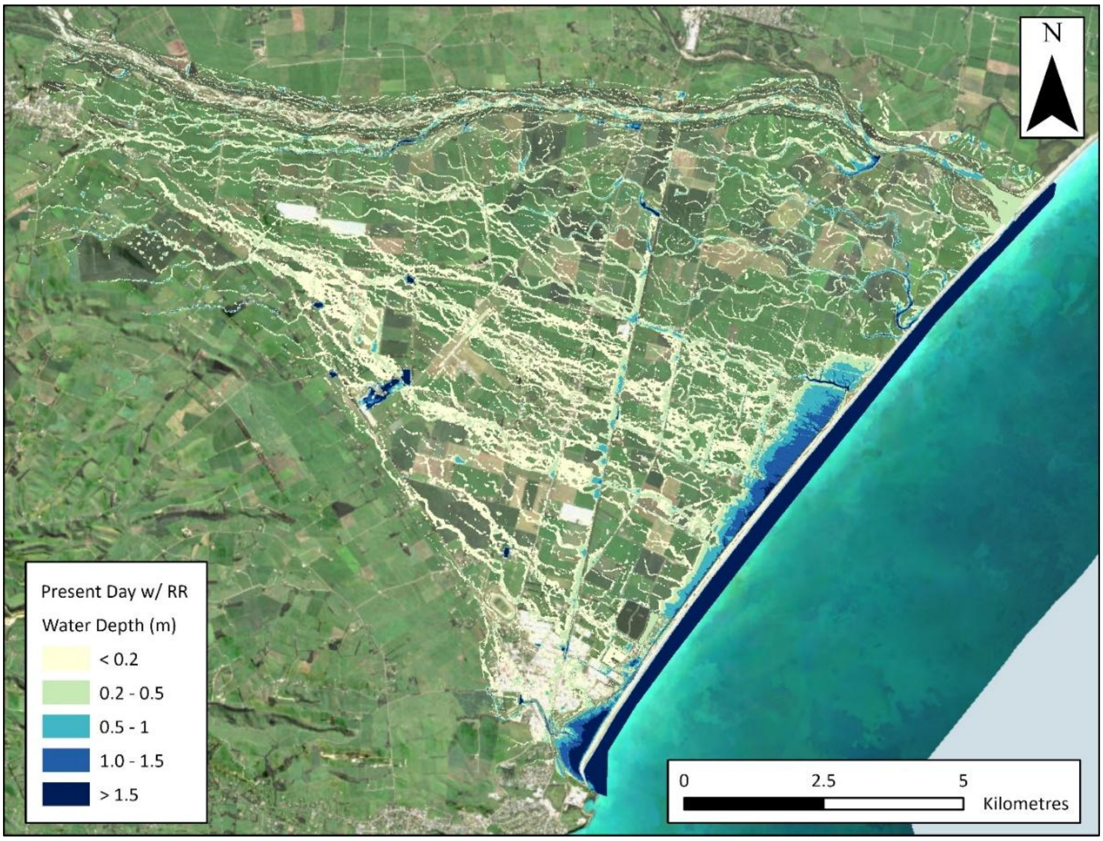

Figure 14: Maximum modelled water depth – present day stopbank configuration with Rifle Range – 20 year ARI rainfall (+CC)

The model results show that during moderate sized events (like this 20 year ARI scenario) drainage from the floodplain towards Washdyke Lagoon is largely confined to Seadown Drain (Figure 15). There is limited flow directly into the Rifle Range, due to high ground levels and vegetation cover, reducing the potential drainage from the floodplain.

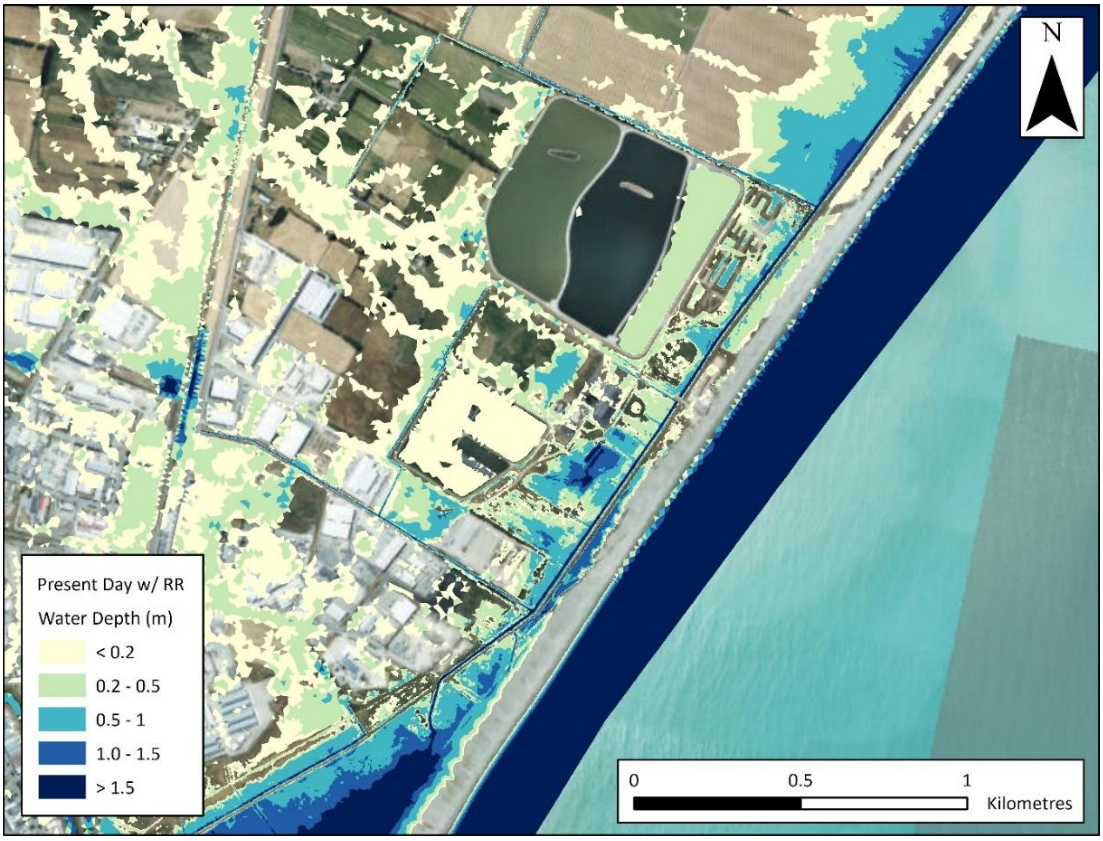

Figure 15: Maximum modelled water depth – present day stopbank configuration with Rifle Range – 20 year ARI rainfall (+CC) – Zoomed to Washdyke area

Model results from 72 hours post-rainfall have also been extracted, to assess the ability to the drainage scheme to remove standing water from the floodplain (Figure 16). This result largely acts as a baseline condition for comparison, as the model does not have a detailed representation of infiltration, evaporation, and lateral transport through the ground and beach. A separate, detailed study would be required to effectively model losses in this area.

The model results show that after 72 hours standing water is primarily across the floodplain north of the wastewater ponds (up to 1 m deep), and in the area between the Rifle Range and Washdyke Industrial area.

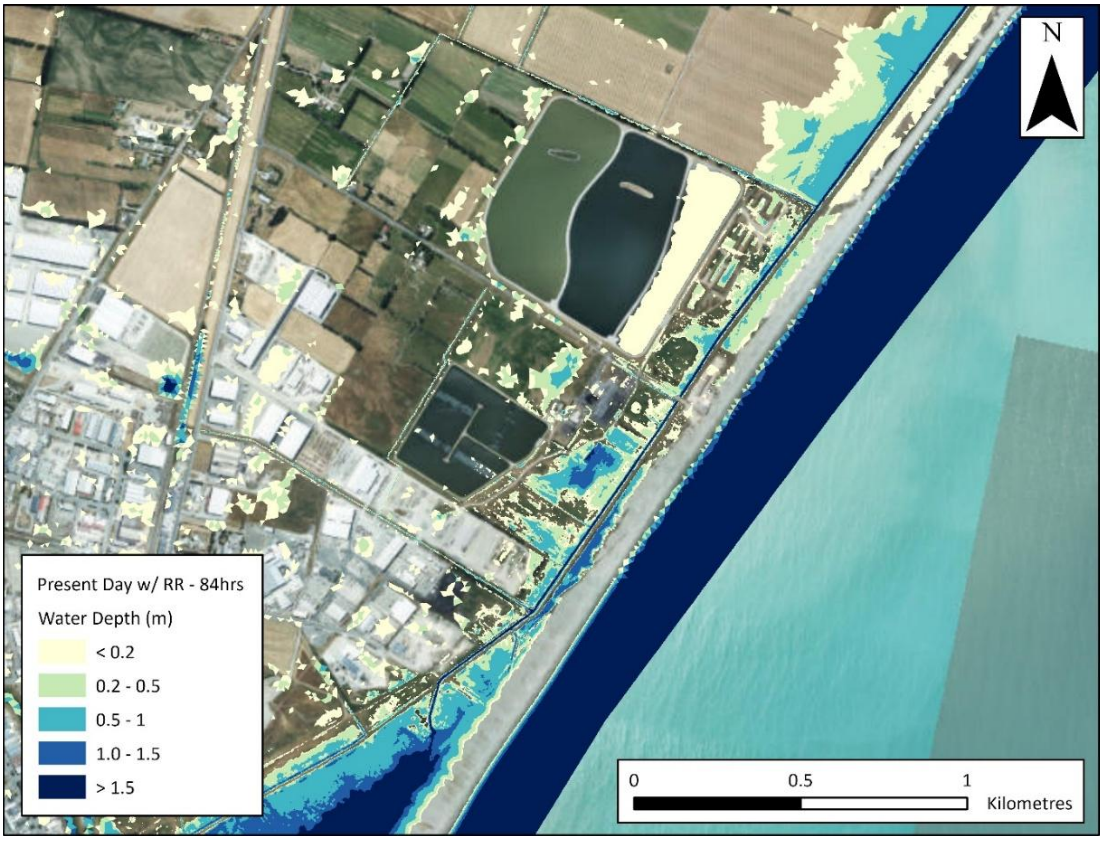

Figure 16: Maximum modelled water depth – present day stopbank configuration with Rifle Range – 20 year ARI rainfall (+CC) – 72 hours post rainfall – Zoomed to Washdyke area

Scenario 2.a. - Present day stopbank configuration without Rifle Range - 200 year ARI breakout scenario from Ōpihi River (including climate change)

In a scenario without the Rifle Range, modelled maximum water levels are slightly lower across the floodplain north of the Rifle Range and wastewater retention ponds (Figure 17); however, given the conservative nature of this breakout scenario these differences can be considered negligible. Increased flow through the Rifle Range site causes greater maximum water levels around the Washdyke industrial area, and results in overtopping into the southern wastewater treatment ponds.

There is no significant difference in velocities with or without the Rifle Range.

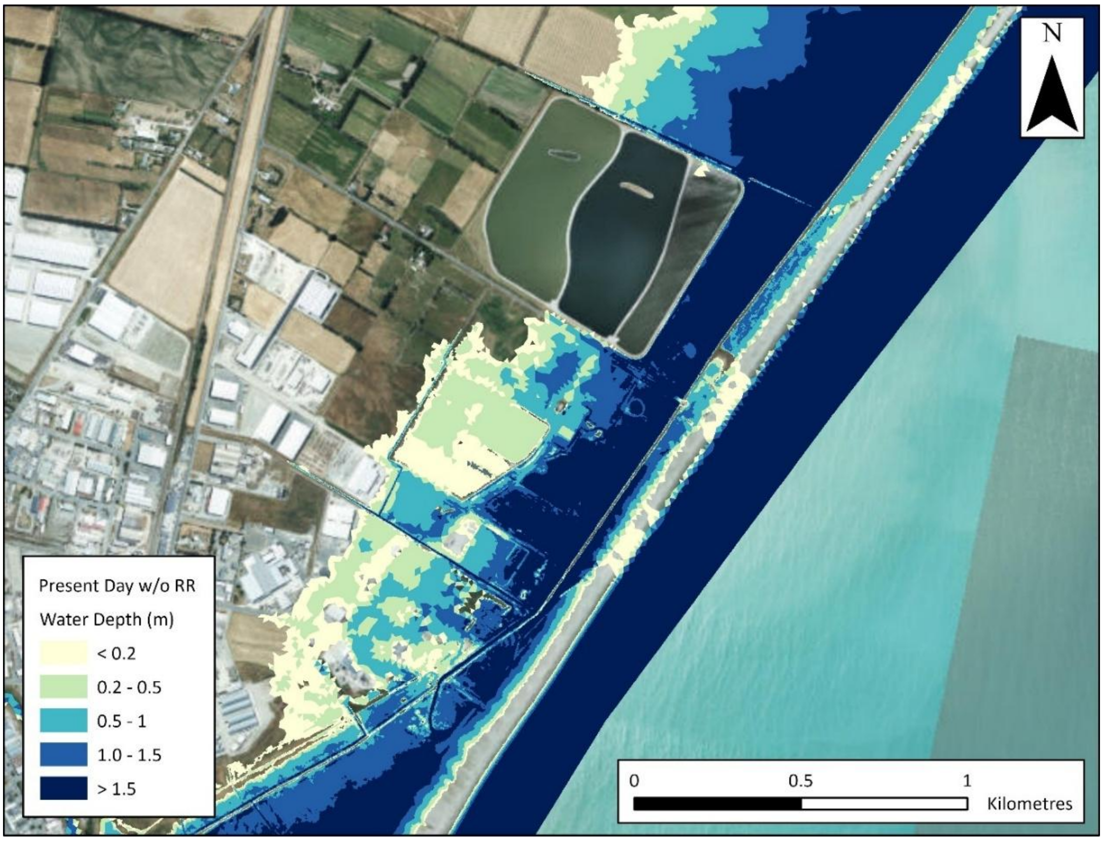

Figure 17a: Maximum modelled water depth – present day stopbank configuration without Rifle Range – 200 year ARI Ōpihi River breakout – Zoomed to Washdyke area

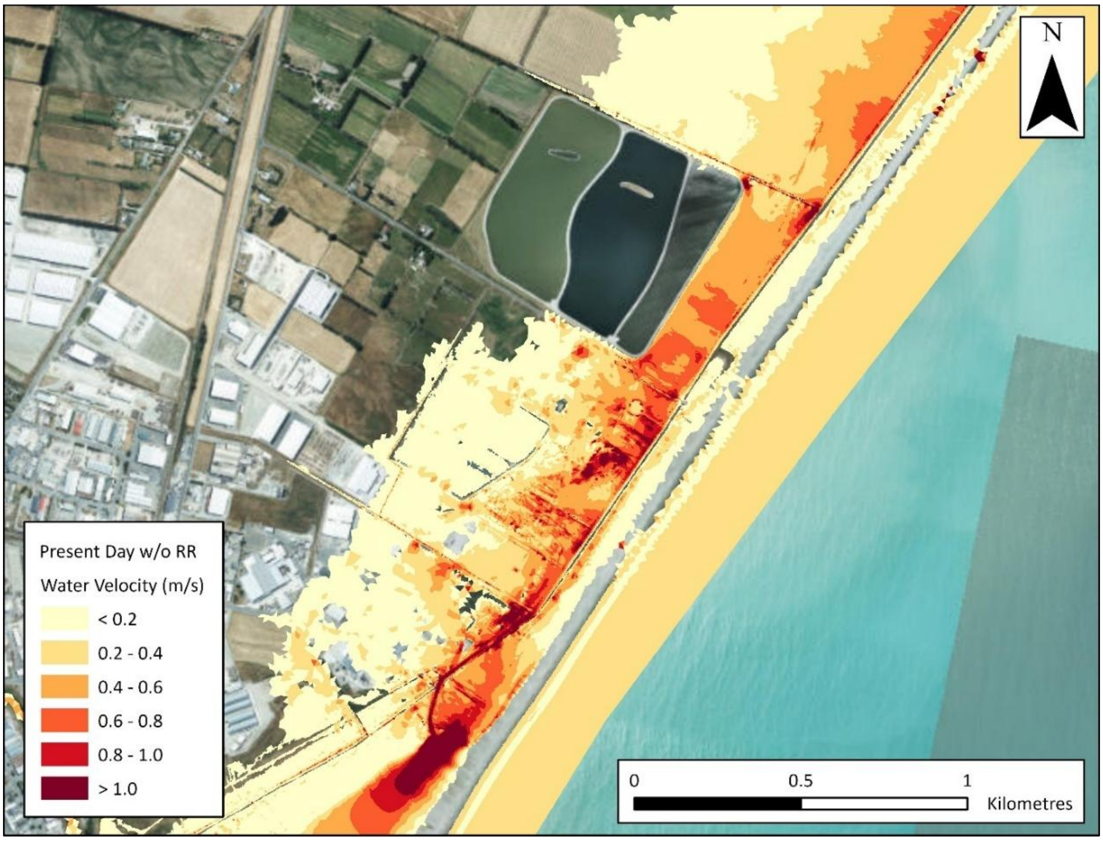

Figure 17b: Maximum modelled water velocity – present day stopbank configuration without Rifle Range – 200 year ARI Ōpihi River breakout – Zoomed to Washdyke area

Scenario 3.a - Proposed stopbank configuration with Rifle Range - 200 year ARI breakout scenario from Ōpihi River (including climate change)

The proposed stopbank and drain configuration show no significant change to the broad drainage patterns of the area (Figure 18). Ōpihi River breakout flows still pond behind the coastal stopbank, and primarily hydraulic head driven flows drain towards Washdyke Lagoon. Water velocity results show the new drain design provides greater carrying capacity than the existing drain, while water velocities outside of the drain remain primarily below 1 m/s.

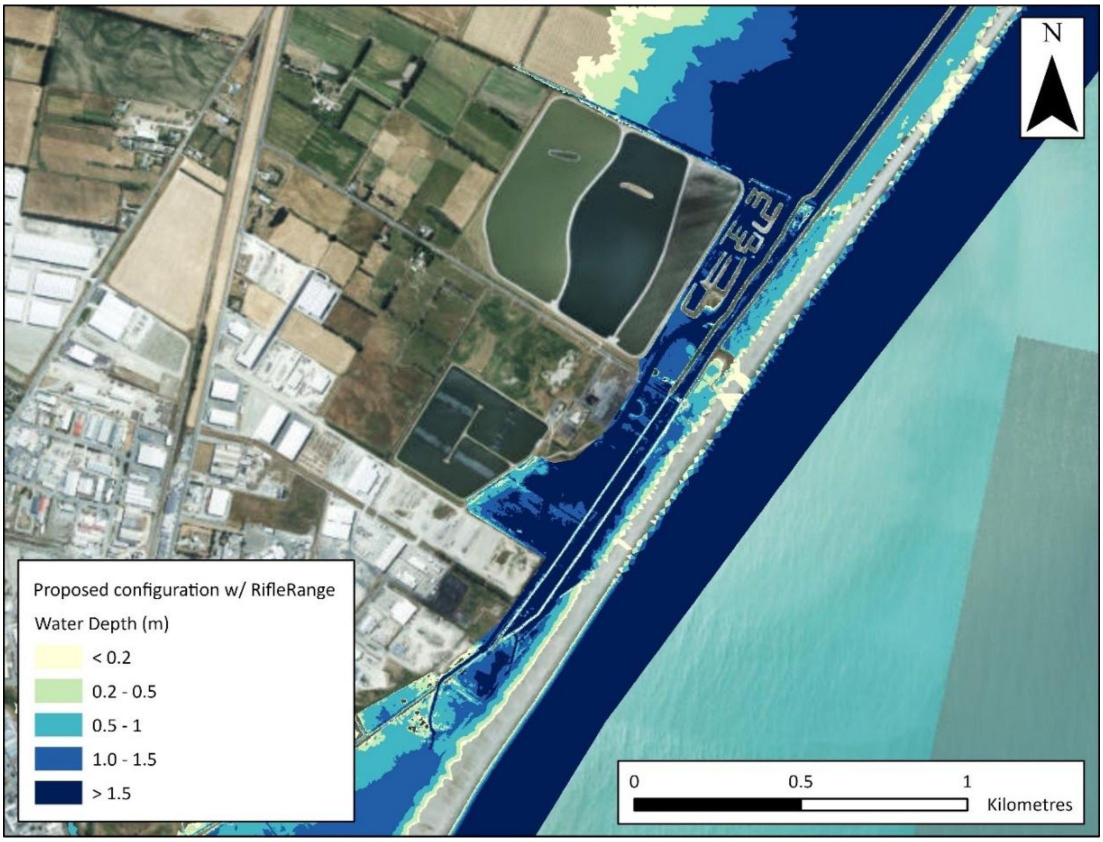

Figure 18a: Maximum modelled water depth – proposed stopbank configuration with Rifle Range – 200 year ARI Ōpihi River breakout – Zoomed to Washdyke area

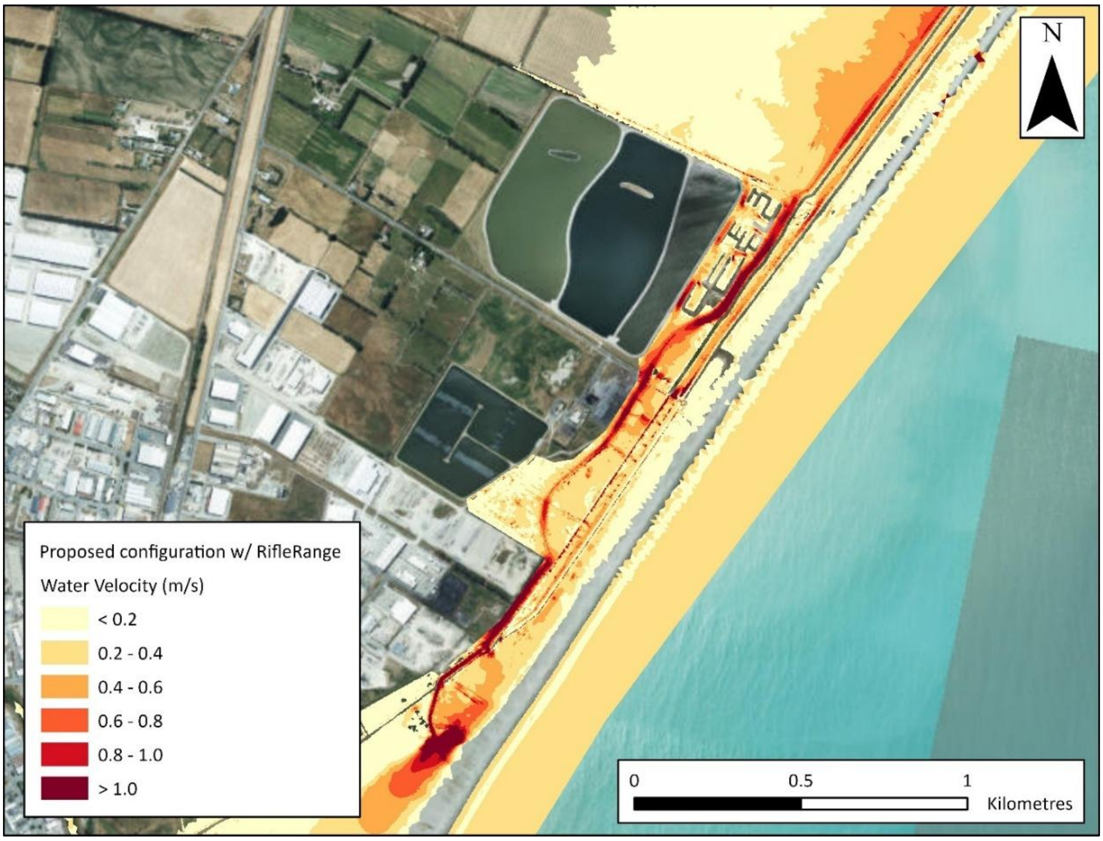

Figure 18b: Maximum modelled water velocity – proposed stopbank configuration with Rifle Range – 200 year ARI Ōpihi River breakout – Zoomed to Washdyke area

Comparisons of maximum inundation extent with present day conditions show a minor increase across the floodplain north of the wastewater retention ponds (an increased maximum water level of ~100 mm). The proposed floodwall between Aorangi Road and the Washdyke industrial area noticeably decreases maximum inundation extent, and there is effectively no difference in maximum water elevation through this area.

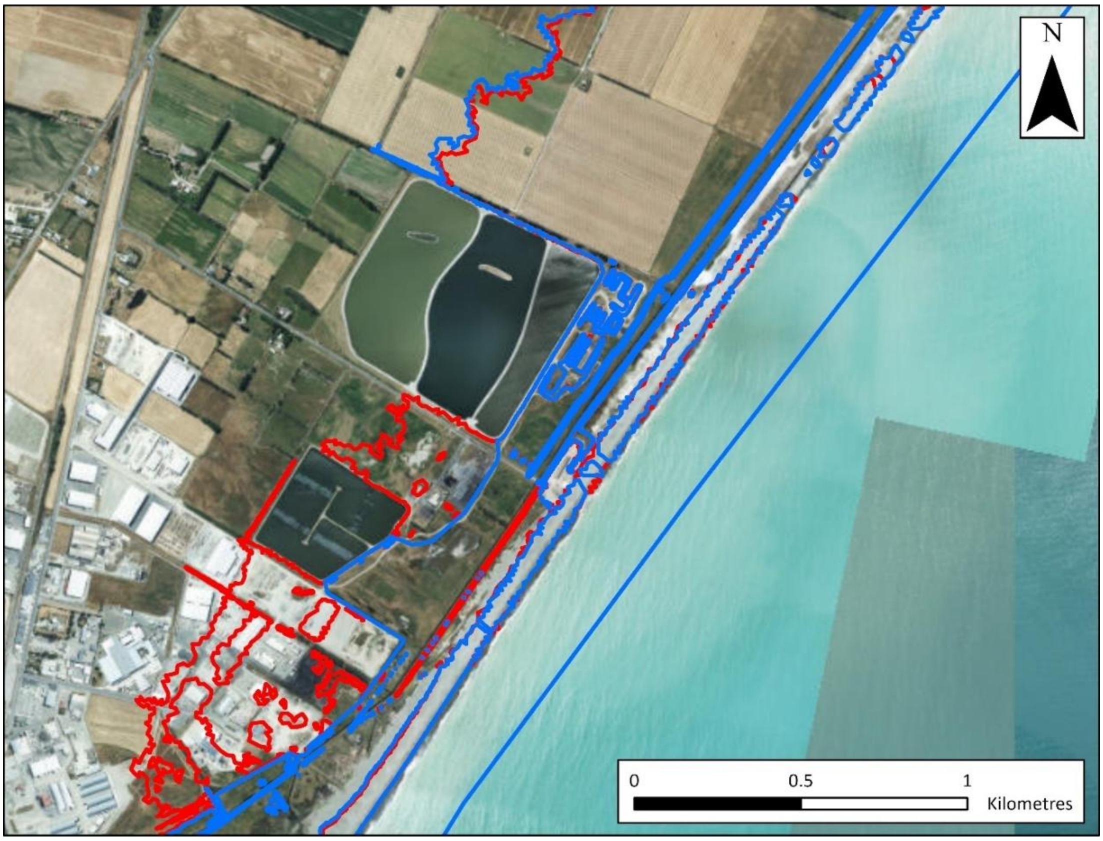

Figure 19: Maximum modelled inundation extent of Ōpihi breakout under present day configuration (red line) and proposed stopbank configuration (blue line)

Scenario 2.b. - Proposed stopbank configuration with Rifle Range - 20 year ARI rainfall event (including climate change)

Despite including the proposed coastal stopbank 50 metres further inland, model results show lower maximum water levels (~100 mm) on the floodplain north of the wastewater ponds, compared to the present-day configuration (Figure 20). This translates to a lesser extent of inundation and can be attributed to the greater conveyance through the proposed drain. Through the Rifle Range and adjacent to the Washdyke industrial area, overflows from the drain occur, however remain within the undeveloped area. These results also show, when compared to Ōpihi breakout modelling, that the proposed configuration provides greater drainage of the flood plain for small to moderate sized events, when the scheme is not overwhelmed by excess flows.

Model results from 72 hours post-rainfall show a reduction in inundation, when compared to the equivalent present-day results (Figure 21). Across the floodplain, this difference in standing water after 72 hours is 200 – 300 mm. In this model scenario, peak discharge past the Rifle Range (through the proposed drain) is 8.9 m^3/s. In present day modelling, peak discharge past the Rifle Range (through the existing drain) is 6.0 m^3/s. Again, the model does not represent losses effectively enough to draw conclusions based on absolute values but does provide a suitable comparison between scenarios.

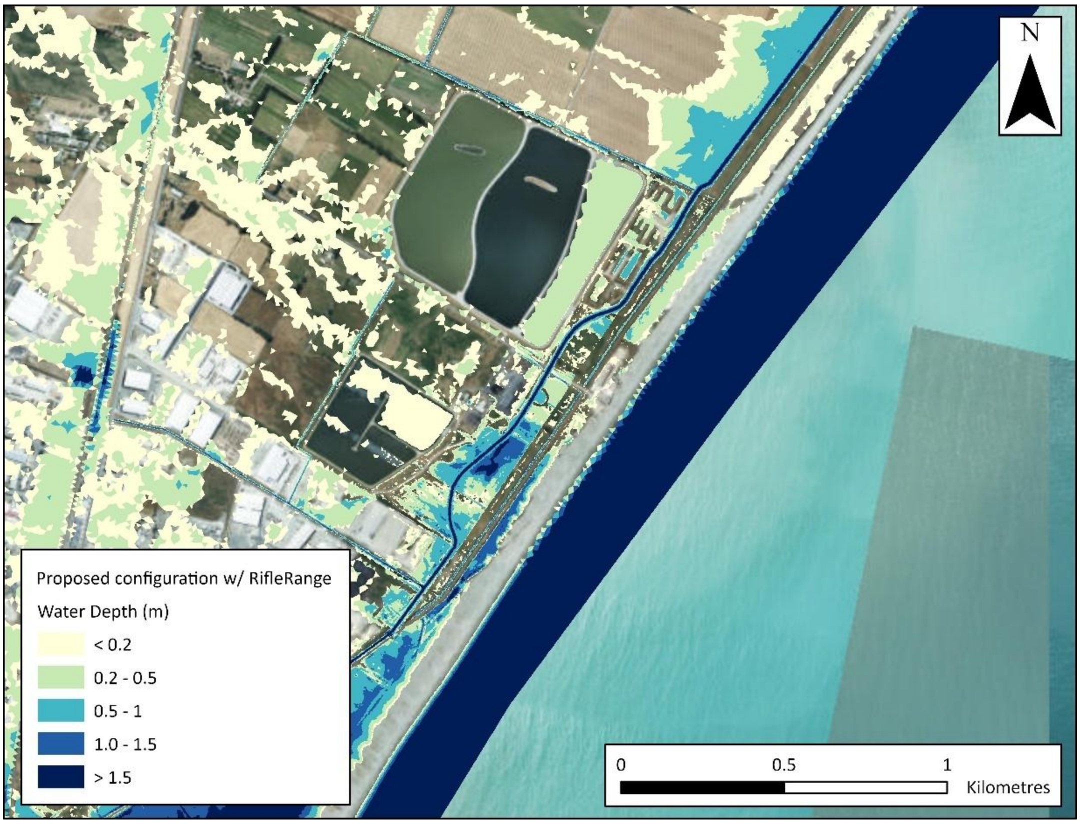

Figure 20: Maximum modelled water depth – Proposed stopbank configuration with Rifle Range – 20 year ARI rainfall (+CC) – Zoomed to Washdyke area

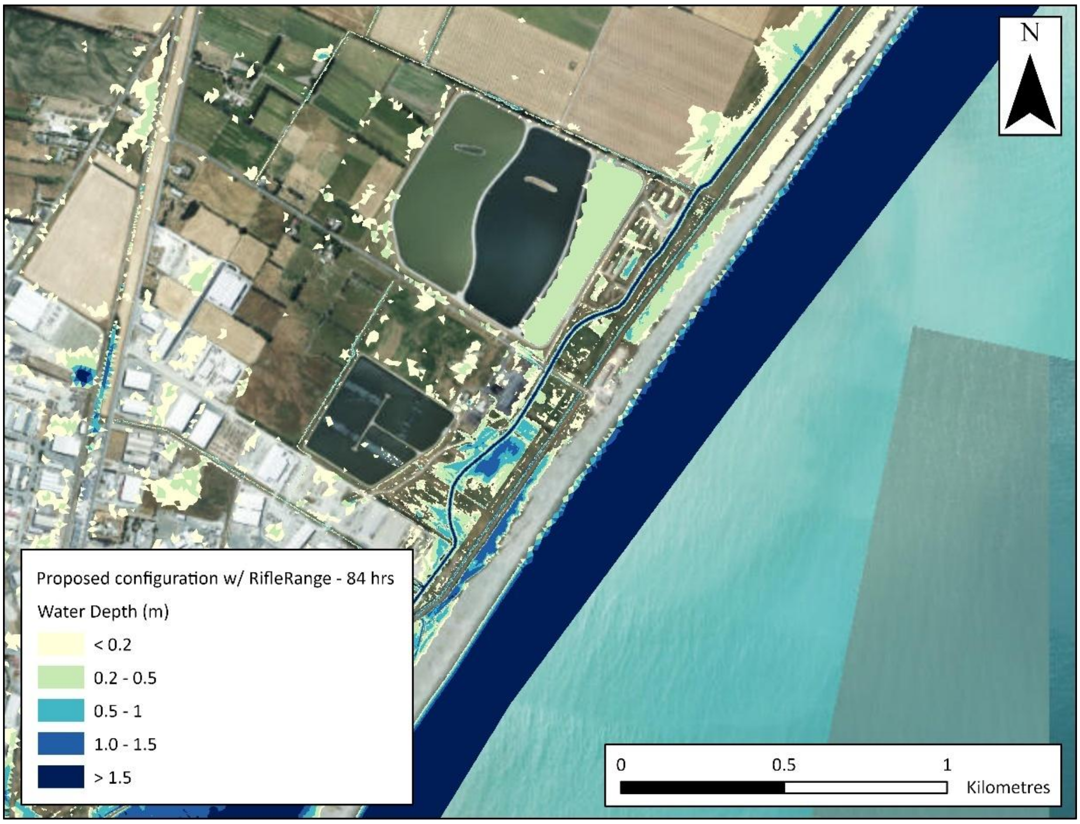

Figure 21: Maximum modelled water depth – Proposed stopbank configuration with Rifle Range – 20 year ARI rainfall (+CC) – 72 hours post rainfall – Zoomed to Washdyke area

Scenario 3.c. - Proposed stopbank configuration with Rifle Range – low flow (mean annual rainfall) scenario

Results of low flow modelling show the proposed Seadown Drain has adequate capacity to contain and convey a mean annual rainfall event (Figure 21).

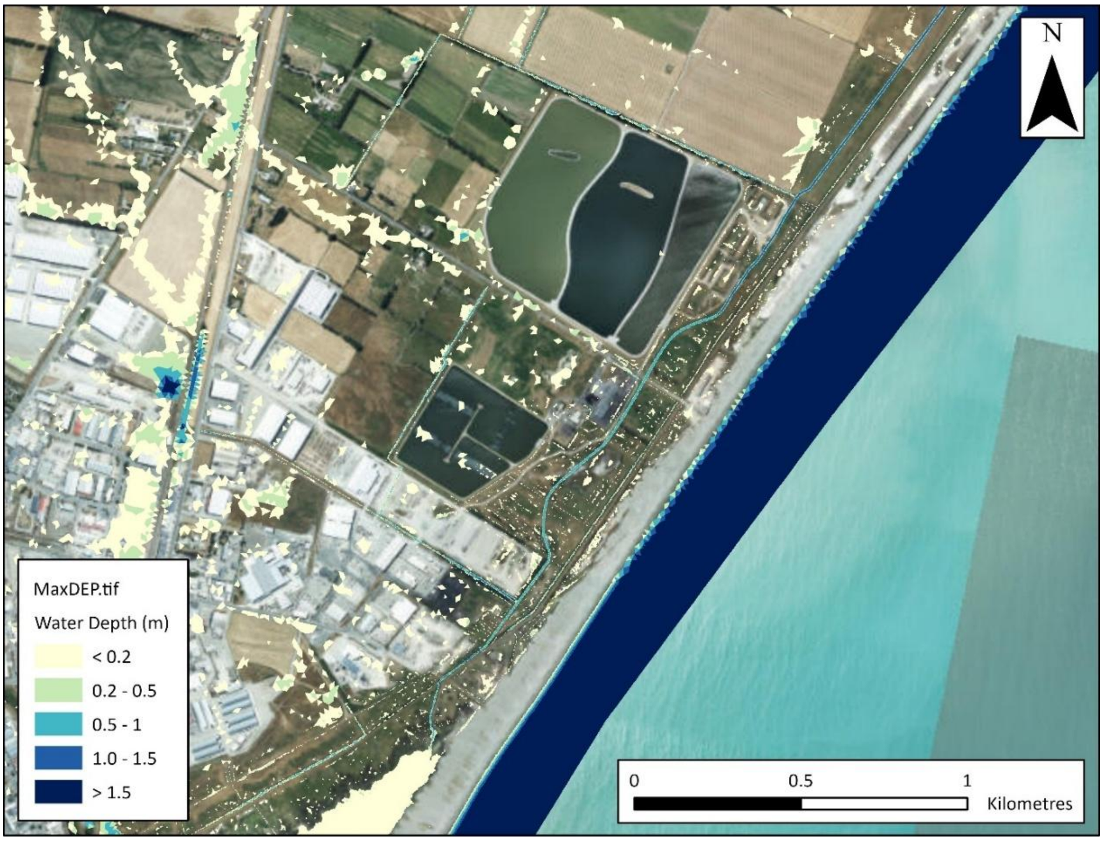

Figure 22: Maximum modelled water depth – proposed stopbank configuration with Rifle Range – mean annual rainfall – Zoomed to Washdyke area

Summary and Recommendations

This report has presented the modelling of three scenarios of the Washdyke coastal bank to assess its current impact (and the impact of the Rifle Range) on flooding from rainfall and Ōpihi River breakouts. Model results show that the Rifle Range has less than minor impact on flood inundation and acts to attenuate flows and reduce maximum water levels around the wastewater ponds and Washdyke Industrial area. Model results with the proposed stopbank and drain configuration also show negligible increase in flooding, with the addition of a floodwall around the wastewater ponds and Washdyke industrial area reducing inundation extent in this area. The proposed drain configuration also shows improved capacity to remove standing water from the floodplain after a flooding event, compared to present day conditions.

Some concessions, like a simplified representation of infiltration, were made in model construction to minimise run-time while maximising spatial resolution. These concessions were not deemed to be critical issues that would significantly impact model results but could be improved in a revisit to the model. Other similar potential improvements include:

- Representing infiltration as a spatial and temporally varying parameter.
- Considering the effect of groundwater in the model, particularly for Seadown Drain. An initial water level condition provides some representation of standing water in the drain, but further improved groundwater information could be reflected in future modelling, if available.
- Representing drains at a finer resolution for all scenarios, not just low flow.
- Understanding and representing the subsurface transport of water along the coastal zone.
- Defining the downstream boundary as a detailed tidal condition. With the relatively minor fluctuations of Washdyke Lagoon water levels it is expected this would have minimal impact on model results. However, if a model with subsurface transport along the coastal zone were developed, the coastal boundary would become crucial.

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

DHI Water and Environment (DHI). (2019). Regional Policy Statement Modelling for Selwyn District council – District Plan. November 2019.

DHI Water and Environment (DHI). (2020). Flood Hazard Models Update District and Urban and MIKE FLOOD models. *Waimakariri District Council*. May 2020.

DHI Water and Environment (DHI). (2023). Ōpihi flood forecasting upgrade, *Prepared for Environment Canterbury by DHI*. Project No 44801831. July 2023.

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

Steel, K., Martin, A., and Lintott, C. (2020). Flood frequency analysis for Canterbury rivers Part 2. *Environment Canterbury Report No. R20/54*

Ward, D. (2024). Science Advice Lower Hurunui 2D Hydraulic Modelling and model roughness, grid size, and hydrograph shape analysis. *[Environment Canterbury Internal] Content Manager Reference C24C/199867.*