Hurunui District Multi Hazards

Coastal Inundation Modelling

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Hurunui District Council

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Contents

Summary

Flooding from multiple sources at Leithfield Beach and Amberley Beach has been assessed to provide a better understanding of the coastal flood hazard in these two communities and how this will change with future sea level rise.

The combined effects of the following sources of flooding have been assessed using a flood model:

- Storm tides in the sea and river mouths
- High flow in the rivers and streams
- Heavy rainfall over the coastal floodplain
- High groundwater levels

The assessment confirms the susceptibility of both communities to flooding from multiple sources. The likelihood of flooding is currently relatively high, with widespread flooding occurring in events of an Annual Exceedance Probability of 2% or greater.

The principal sources of flooding are storm tide and high flows in the Kowai River and Waipara River. Runoff from the smaller local drainage catchments and direct rainfall also contribute to flooding, particularly in more frequent events. The extent and depth of flooding for a given likelihood of flooding will increase in the future due to the rise in mean sea level rise and increase in rainfall intensity resulting from climate change.

The main flood pathways for Leithfield Beach are overflow from the Kowai River and tidal inundation through the Kowai River mouth, Leithfield Beach Lagoon, Leithfield Drain, Ashworths Ponds and Ashley River mouth. For sea level rise below 0.5 m, fluvially dominated events result in more severe flooding at Leithfield Beach than tidally dominated events of the same likelihood of occurrence. For greater values of sea level rise tidally dominated events become more severe.

Key flood pathways to Amberley Beach are overflow of the Kowai and Waipara River and tidal inundation through the Mimimoto Lagoon and Amberley Beach Lagoon. For sea level rise values of up to 0.5 m, flood levels in Amberley Beach are higher in fluvial events and are relatively insensitive to tide level or sea level rise. Tidally dominated flood levels, which increase directly with sea level rise, starts to become worse than fluvial flooding for sea level rise above approximately 0.5 m.

Assessment of groundwater levels suggest that there is less risk of flooding within the settlements from groundwater breakout although areas inland of them are susceptible to surface ponding from high groundwater levels. High groundwater levels in the settlements could however reduce infiltration and increase runoff from direct rainfall.

Wave runup along the frontage of the settlements and at the openings to the lagoons can result in additional temporary flooding. This has not been quantified in this assessment but although potentially significant locally, the overall volumes of inundation are small compared to the tidal or fluvial flows which result in wholesale inundation of the settlements.

Important note about your report

This report has been prepared by Jacobs New Zealand Limited (Jacobs) for Hurunui District Council (the Client) for the purposes of reporting as assessment of inundation hazards at Amberley Beach and Leithfield Beach. Jacobs accepts no liability or responsibility whatsoever for, or in respect of, any use of, or reliance upon, this report (or any part of it) for any other purpose.

In preparing this report, Jacobs has relied upon, and presumed accurate, any information (or confirmation of the absence thereof) provided by the Client and/or from other sources. If the information is subsequently determined to be false, inaccurate, or incomplete then it is possible that our observations and conclusions as expressed in this report may change. Jacobs derived the data in this report from information sourced from the Client (if any) and/or available in the public domain at the time or times outlined in this report. The passage of time, manifestation of latent conditions or impacts of future events may require further examination of the project and subsequent data analysis, and re-evaluation of the data, findings, observations, and conclusions expressed in this report.

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1. Introduction

1.1 Need for study

The Hurunui Coastal Hazards assessment undertaken by Jacobs in 2020 addressed coastal inundation and erosion hazards in six coastal communities in the Hurunui District. Following the release of the assessment report and presentation of the findings to the communities, it was identified that further investigations into the relationships between multiple flood hazards at Leithfield Beach and Amberley Beach was needed in order to help make informed decisions about adaptation options.

This study undertakes a multi-hazard assessment for Leithfield Beach and Amberley Beach to better understand the coastal flood hazard in the two communities, and how this is likely to change with future sea level rise.

The combined effects of the following sources of flooding have been assessed:

- Storm tides in the sea and river mouths
- High flow in the rivers and streams
- Heavy rainfall over the coastal floodplain
- High groundwater levels

The study uses recognized flood modelling techniques to assess the flood hazards. As well as addressing the multi-hazard component, the modelling also provides more certainty on the magnitude and extent of the coastal inundation from extreme storm tides than provided by the previous ‘bathtub’ inundation assessment.

1.2 Study area

Although the flood hazard assessment is required specifically for each of the Leithfield Beach and Amberley Beach communities, the study area extends beyond the settlements in order to capture the potential sources of flooding and flood flow paths. Figure 1 shows the extent of the flood model which has been developed to assess flooding. A single model has been used to simulate flooding in both communities since some of the sources of flooding are common to both locations. The following sources of flooding and flow paths are represented in the model:

- Storm tides overtopping the shoreline along the coast between the Ashley River mouth and the Waipara River mouth
- Storm tides entering the Leithfield Beach Lagoon, Mimimoto Lagoon and Amberley Beach Lagoon
- Overland flow from the Ashley River mouth and Saltwater Creek estuary
- Overtopping from the Kowai River and Waipara River
- Runoff from the stream catchments to the west of Hursley Terrace
- Direct rainfall over the coastal floodplain
- Ponding from high groundwater levels in the floodplain

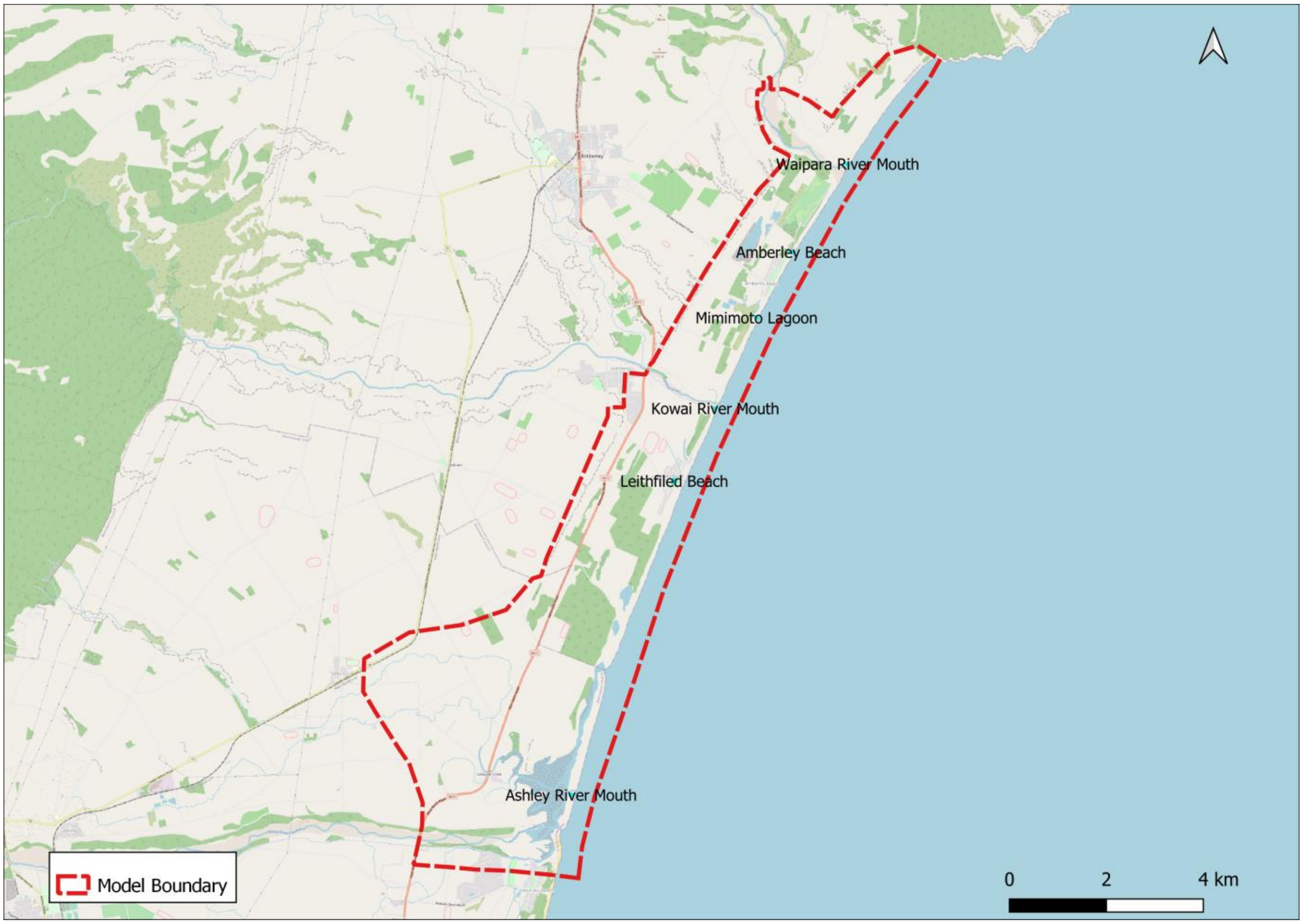

Figure 1 Model extent

1.3 Scenarios considered

Ten scenarios comprising different combinations of the likelihood of flooding and values of sea level rise have been considered as presented in Table 1. These scenarios investigate current hazard from different sources, the effect of rising sea level on the hazards, higher probability hazards which may be more appropriate for consideration in shorter term planning pathways and an upper bound hazard scenario.

The likelihood of flooding is expressed as the “Annual Exceedance Probability” (AEP), which is the percentage probability, or chance, of the flood event occurring in any one year.

The two probabilities of flooding considered are:

0.5% AEP:	a more extreme event – often considered when planning development and land use
2% AEP:	a less extreme, more frequent event – often considered when planning operation and maintenance of infrastructure

Although the chance that one of these flood events will occur in any year is relatively small, the chance of the flood occurring within a longer period of time is higher. For example, there is a 14% chance of an extreme flood (0.5% AEP) occurring at least once during a 30 year time period and a 45% chance of a less extreme flood (2%

AEP) occurring during the same period. Over a 100 year time period there is a 39% chance of an extreme event occurring and an 87% chance of a less extreme event occurring.

As presented in Table 1, 10 scenarios are considered in the assessment, to recognise that a weather system that causes a storm tide is likely to also cause some rainfall and higher river flows. However, it is also recognised that it is less likely that equally extreme tides and rainfall will be caused by the same event. For a given probability of flooding – e.g. 0.5% AEP – there are multiple possible combinations of storm tide and river flow events with the same combined probability of occurrence.

In this study a "2-point" strategy[1] is used to define two potential combinations of storm tide and river flow or rainfall which have the same overall probability of occurrence for assessment of flooding. In the absence of a detailed joint probability analysis of how the storm tide and rainfall are related to each other at the project sites, the "1/10th rule" has been used to select the probabilities of each pair of combinations. In this method the probability of one source of flooding (storm tide or rainfall) is set to the required probability and the probability of the other source of flooding is set to 10 times the required probability – i.e. the required probability is 1/10th of the other.

For example, as shown in Table 1, for the 0.5% AEP probability of flooding two separate flood events have been considered: a 0.5% AEP storm tide occurring in combination with a 5% river flow (a "tidally dominated event"); and a 0.5% AEP river flow occurring in combination with a 5% storm tide ("a fluvially dominated event").

Table 1: Flood scenarios considered in the assessment

Description	Scenario No.	Likelihood of flooding (AEP)	Mean Sea Level Rise (m)	Storm Tide AEP	Fluvial and Pluvial Flow AEP
Current hazard – relative effects of different sources of hazard	1	0.5%	0	0.5%	5%
	2		0	5%	0.5%
Effect of rising sea level on hazard	3	0.5%	0.3	0.5%	5%
	4		0.3	5%	0.5%
	5		0.5	0.5%	5.0%
	6		0.5	5%	0.5%
	7		1.0	0.5%	5.0%
	8		1.0	5%	0.5%
Higher probability hazard for shorter term planning	9	2%	0.5	2%	20%
	10		0.5	20%	2%

As also shown in Table 1, sea level rise values of 0.3 m, 0.5 m and 1.0 m have been considered in the scenarios. The storm tide levels adopted in the study are referenced to mean sea level in 2003. Under current guidelines[2] these values therefore correspond, respectively, to the projected sea level in approximately 2055, 2080 and 2120 under RCP[3]8.5 emissions scenario, or 2045, 2065 and 2100 under RCP8.5H+ emissions scenario.

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[1] A "2-point" strategy is a method for defining the number of combinations of two parameters to test for a given probability – see, for example, the report "LDRP097 Multi-Hazard Baseline Modelling - Joint Risks of Pluvial and Tidal Flooding" Rev 0 (Christchurch City Council, February 2021) for a more detailed description of this approach

[2] Coastal Hazards and Climate Change. Guidance for Local Government land. Ministry for Environment 2017

[3] Representative Concentration Pathway, which refers to the concentration of carbon in the atmosphere from emissions. RCP8.5H+ scenario is the 83rd percentile of the RCP8.5 distribution representing a more extreme scenario associated with dynamic ice sheet processes and instability thresholds that were not fully qualified in in the IPCC AR5 (2013) projections.

2. Methodology

2.1 Overview

To assess the combined hazard from storm tide, fluvial and pluvial flooding and high groundwater at Leithfield Beach and Amberley Beach, a two-dimensional hydrodynamic model of the rivers and floodplain has been used, developed using the industry standard DHI MIKE FLOOD software.

The principal tasks undertaken in the study to develop the model and perform the simulations are as follows:

i. Project kick-off meeting to confirm the scope and methodology
ii. Request and collate necessary data
iii. Develop model schematization and build model
iv. Prepare boundary conditions for model simulations
v. Perform simulations and process results
vi. Prepare report

2.2 Data

The following information and data were obtained through requests to HDC and Environment Canterbury (ECan):

i. LINZ Canterbury-Amberley 2012 LiDAR[4] 1m Digital Elevation Model (DEM)

ii. LINZ Canterbury-Rangiora 2014 LiDAR 1m Digital Elevation Model (DEM)

iii. Reports:

    a. Kowai River, Leithfield Beach and Amberley Beach flood investigation Report No. R14/99 ISBN 978-1-927314-87-6 (print) ISBN 978-1-927314-88-3 (web) Michelle Wild September 2014

2.3 Model build

The main river channels, floodplain and river mouths are represented in a two-dimensional (“2D”) MIKE21 FM model of the floodplain. The culvert outfall at the mouth of the Leithfield Drain has been modeled in a one-dimensional (“1D”) MIKE11 model which is coupled to the 2D model by developing standard links.

The 2D MIKE21 model covers the area indicated by the overall boundary in Figure 2. The model has been developed using the Flexible Mesh (FM) module of MIKE21. In this type of model, the ground surface is represented by a mesh of irregular triangular elements. The elevation of the mesh elements has been interpolated from the LiDAR data for the project area. For the offshore part of the model, where bathymetry data is not available, a nominal low seabed level has been applied.

The mouths of the Kowai River and Waipara River are usually closed to the sea by unstable gravel bars which forms lagoons behind the beach. However higher fluvial flows breach the gravel bar to form an opening of a certain width and depth depending on the flow rate and bar material consolidation. A similar situation occurs in

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[4] Light Detection and Ranging (LiDAR): a surveying method used to measure ground levels by directing laser light at the ground surface from an aircraft and measuring the reflected light with a sensor. The ground level relative to the aircraft is calculated from the time of travel and differences in emitted and return wavelengths of the reflected light.

the tidal lagoons close to Amberley Beach and Leithfield Beach settlements, for which the flood risk occurs from tides overtopping the bar into the lagoons, and fluvial-pluvial flooding building up behind the bar.

The LiDAR data captures the shape of the river mouths and lagoon entrances at the time of the survey. The data for the lagoons and the mouth of the Kowai River, which includes an opening in the bar, are considered representative of the typical condition of these features during a flood event. However, the bar at the mouth of the Waipara river is continuous in the survey whereas a breach would normally form in any sizeable flood event. For the model simulations, an opening in the gravel bar of 50 m – 60 m width, a typical size estimated from aerial photographs, is provided in the model mesh at the mouth of the river to allow the water to move more freely between the lagoon and the sea.

Key linear features, which control the flow of water out of the river channels and across the floodplain, are included in more detail in the 2D model using the MIKE21 Dike Structure module. The crest levels of the features are defined as a series of points along the line of the “dike” structure. Figure 2 shows the location of the dike structures in the model, representing features such as the dune crest along the coastline, stop banks on the Ashley River and Kowai River, State Highway 1 (SH1) and other road embankments. The entrances of the Amberley Lagoon, Mimimoto Lagoon, Leithfield Lagoon and Leithfield Drain are also defined with a “Dike” element in the 2D model, to simulate flow more accurately over the raised entrances to these pathways.

Figure 2 Model schematisation

Roughness values for the 2D model are specified according to the land cover types defined in the New Zealand Land Cover Database (LCDB) Version 4.1. Figure 3 shows the distribution of land cover types within the model boundary. The Manning's roughness coefficients assigned to each land cover type are detailed in Table 2.

Table 2: 2D Model roughness coefficients according to LCDB land cover types

LCDB Class Name	Manning's roughness coefficient "n"	LCDB Class Name	Manning's roughness coefficient "n"
Road	0.014	Lake	0.020
Sand	0.025	Gravel	0.028
Open Space	0.033	River	0.035
Orchard	0.050	Surface Mine	0.060
Mixed Exotic Shrubland	0.080	Low Producing Grassland	0.090
Built-up Area	0.100	Deciduous Hardwoods	0.125
Exotic Forest	0.150	Transport Infrastructure	0.016
Broadleaved Indigenous Hardwoods	0.10	Coastal	0.05
Estuarine Open Water	0.035	Gorse and/or Broom	0.125
Herbaceous Freshwater Vegetation	0.1	Herbaceous Saline Vegetation	0.10
High Producing Exotic Grassland	0.05	Manuka and/or Kanuka	0.10
Short Rotation Cropland	0.1	Forest - Harvested	0.16

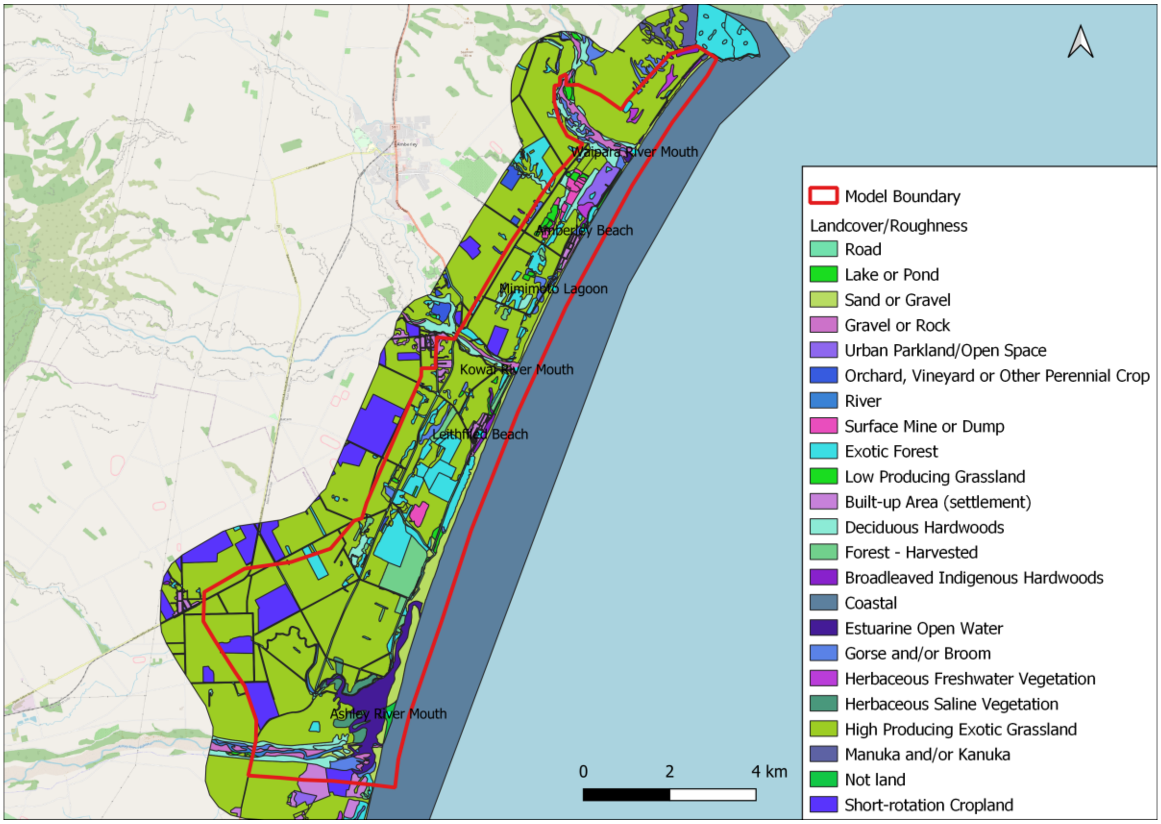

Figure 3 Land cover classes and roughness values for 2D Model

2.4 Model boundary conditions

Boundary conditions are the main inputs for the model simulations of each scenario. The boundary conditions specify

i. The tidal water level in the sea along the coastline

ii. The flow in the main rivers and the runoff from smaller catchments

iii. Rainfall over the ground surface in the model

iv. Any initial ponding on the ground surface from high groundwater level

Values of storm tide levels and extreme fluvial flows have been obtained from existing data. The duration of the model simulations corresponds to that of a representative coastal storm surge event, encompassing several tide cycles before and after the maximum design tide. In this way any potential accumulation of water in the floodplain resulting from overtopping by multiple successive high tides during a storm surge event is included in the simulations.

A time varying water level boundary is applied along the coastal boundary of the 2D MIKE21 FM model. The boundary represents the tidal water level in the sea offshore of the river mouths. A single water level time series is applied along the entire length of the model boundary such that the storm tide water levels in the sea at each of the river mouths is the same. Extreme water levels obtained from the NIWA “Canterbury Coastal Calculator” are adopted to define the maximum tidal water level in the model boundary, while the shape of model water level boundary is defined based on the astronomical tide level series.

For the main rivers (Ashley, Kowai and Waipara), flows are modelled as fixed rate inflows for each scenario coincident with the maximum tide water level. The river flows correspond to the estimated peak flow for the specified AEP and are simulated as a fixed flow over the period of the highest tide in the simulation for 12 hours (6 hours on each side of the peak tide). Outside this period, no flow is applied for the period of lower tides in the simulation. For the smaller streams, the timing of peak flows in the hydrographs derived through hydrological modelling also coincides with the maximum tide water level.

To include the pluvial source of flood hazard, rainfall is applied with a time varying intensity directly on the ground surface in the model with the peak intensity coinciding with the maximum tide water level.

Detailed groundwater modelling is excluded from scope of this study. Groundwater levels for the sea level rise values in each scenario have been interpolated from the piezometric surfaces derived under the Hurunui Coastal Hazards assessment undertaken by Jacobs in 2020. These surfaces only cover a limited portion of the model domain, in the areas around Leithfield Beach and Amberley Beach. Elsewhere groundwater contributions are not included in the model.

2.4.1 Tidal water level boundary

The storm tide boundary for the scenarios comprises a series of tides to simulate the effects of storm surge and wave setup on the astronomical tidal water level at the coast adjacent to the river mouths for a representative storm event.

The peak storm tide water levels have been derived using the NIWA Canterbury Coastal Calculator. For each of the AEPs in the scenarios in Table 1, the storm tide levels were calculated at Amberley Beach and Leithfield Beach. A storm tide beach gradient of 0.175 was adopted for both locations based on the 97th percentile gradient at Amberley Beach in the Coastal Calculator dataset. The corresponding value at Leithfield Beach

(0.231) is significantly steeper and would result in higher storm tide levels at that location compared to Amberley Beach. The beach gradient dataset for Leithfield Beach includes only one value exceeding 0.15 and the 97th percentile value may be unduly biased by the single extreme value. Since the beach profiles are expected to be similar at both locations, the value of 0.175 derived from the dataset for Amberley Beach (for which there are three surveys with beach gradient exceeding 0.15) has been adopted for both locations. The average of the storm tides calculated at each location has been adopted for the sea level boundary for the model. Table 3 summarises the extreme water levels, including wave setup, derived from the Coastal Calculator. Water levels have been transformed to NZVD 2016 vertical datum for consistency with the LiDAR ground elevation data used for the flood model.

Table 3: Extreme water levels for model coastal boundary, including wave setup, as derived from ECan Coastal Calculator

AEP	Coastal Calculator water level [a] (m LVD 1937 Datum)		Average water level (m LVD 1937 Datum)	Average water level [b] (m NZVD 2016 Datum)
	Amberley Beach	Leithfield Beach		
20%	2.38	2.32	2.35	1.99
5%	2.61	2.61	2.61	2.25
2%	2.74	2.80	2.77	2.41
0.5%	2.91	3.14	3.03	2.67

[a] based on beach slope of 0.175, referenced to MSL 1993-2012

[b] offset of -0.356 m applied for transformation to NZVD 2016 datum

The storm tide water level time series is constructed from:

i. a representative time varying astronomical tidal water level series;
ii. a representative time varying storm surge height series, scaled to achieve the required extreme sea level, including wave setup;
iii. a constant mean sea level rise allowance.

Figure 4 shows the model boundary water level series developed for Scenario 7 (0.5% AEP sea level and 1m rise in mean sea level).

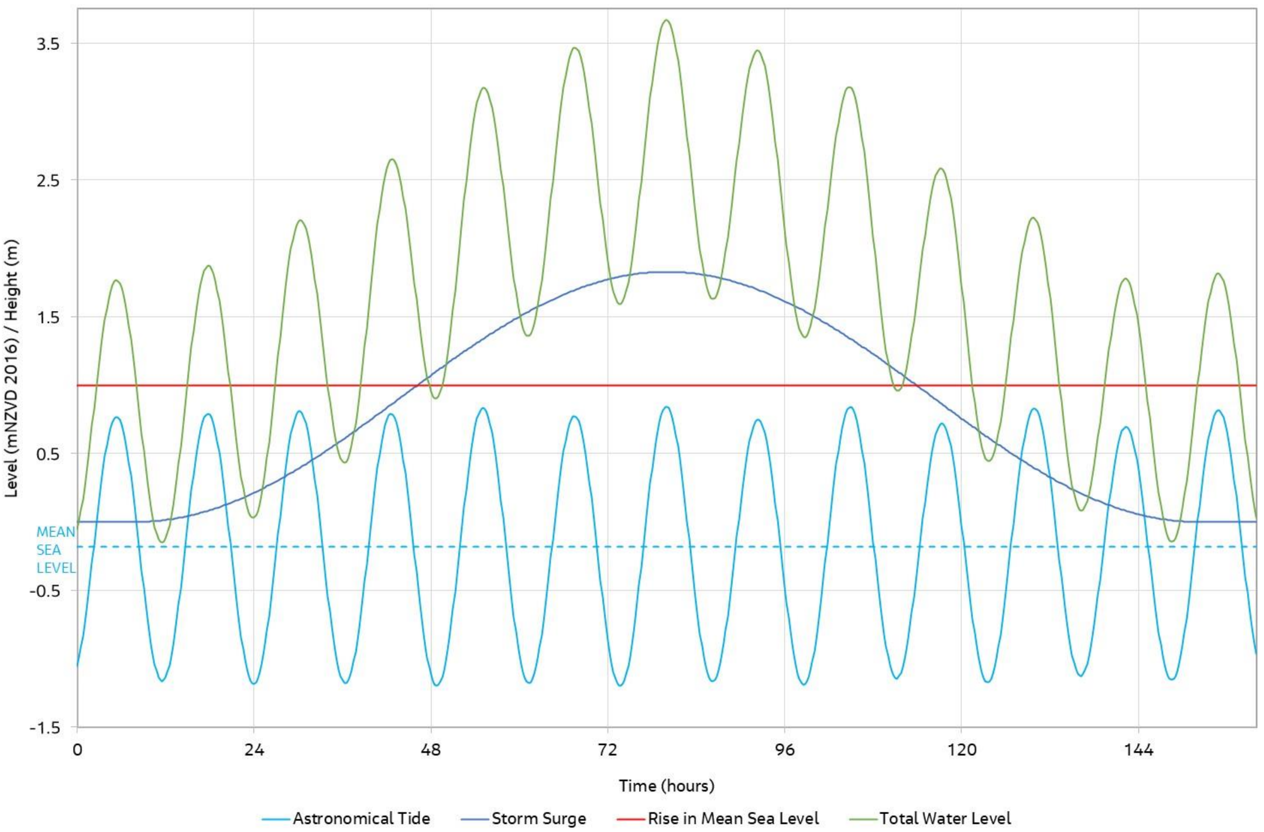

Figure 4: Development of model water level boundary for Scenario 7 (0.5% AEP sea level with 1m rise in mean sea level)

- Astronomical water level

  A representative water level series of the astronomical tide level in the study area has been derived using the DHI MIKE21FM Tide Generator software for a location close to Sumner Head (172.76E, 43.56S) at 15-minute intervals for the period 10/4/1999 to 26/4/1999. The period includes a high astronomical tide level. The calculated water level series is presented in Figure 5 together with the high and low water levels generated from the NIWA "Tide Forecaster" tool for the same period. The generated tide compares favourably with the NIWA predictions in terms of timing of the high and low waters. The generated values of high and low water levels are generally within 0.1m-0.2m of the NIWA forecast values. This is considered acceptable for the purpose of this study given that the stated accuracy of the NIWA data is +/-0.1m[5] and the water level series is adopted as a representative underlying series, to which storm surge is added to achieve the required extreme water level, rather than for simulation of an actual event.

  The highest astronomical water level in the generated time series is 1.03m above mean sea level. This is similar to the current Mean High Water Perigean Spring Tide (MHWPS) height of 1.06m above mean sea level. This tide has been selected as the central tide for the model simulation time period, to which the storm surge height is added to achieve the required extreme sea level.

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[5] https://tides.niwa.co.nz/

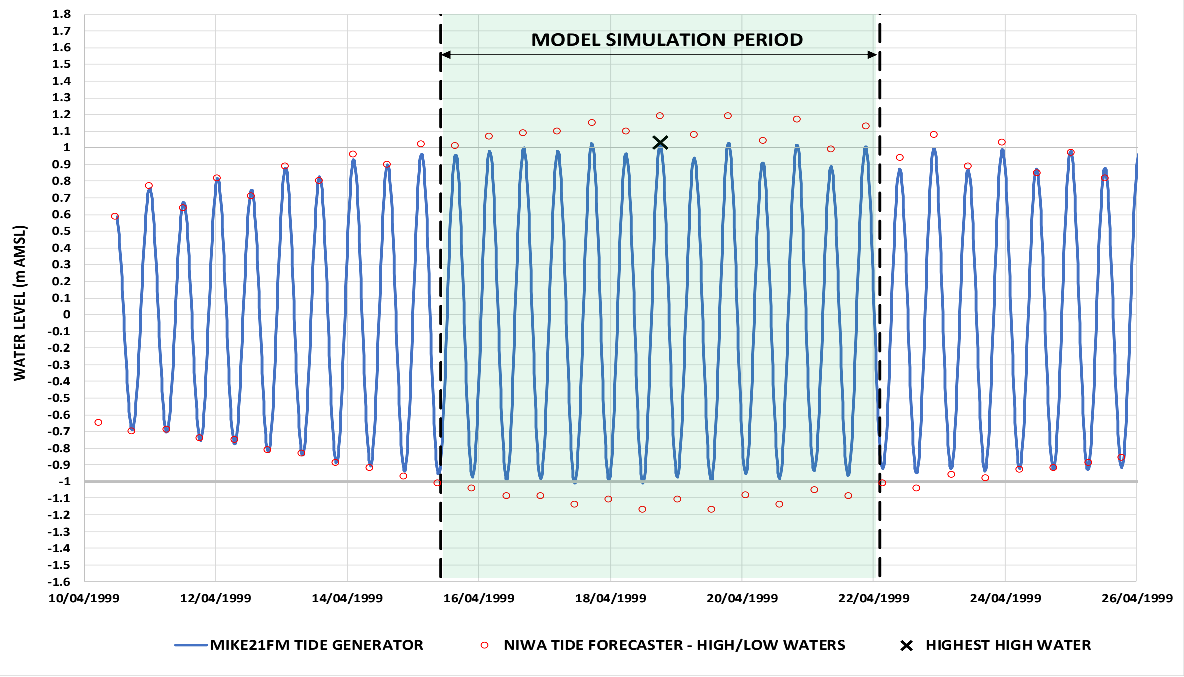

Figure 5: Astronomical water level time series generated for model water level boundary

- Storm surge height

  A representative storm surge time series has been developed by fitting a simple sinusoidal time series to the actual surge height for the event of 24 July 2017 as shown in Figure 6. The fitted surge series is scaled as required to achieve the specified extreme high-water level for each simulation scenario when added to the astronomical tide series. The surge is centered coincident with the highest astronomical high water in the series, as indicated in Figure 4.

- Mean sea level rise

  The sea level rise allowance specified for each scenario in Table 1 is added as a constant value to the entire boundary water level series for the scenario, as shown in Figure 4.

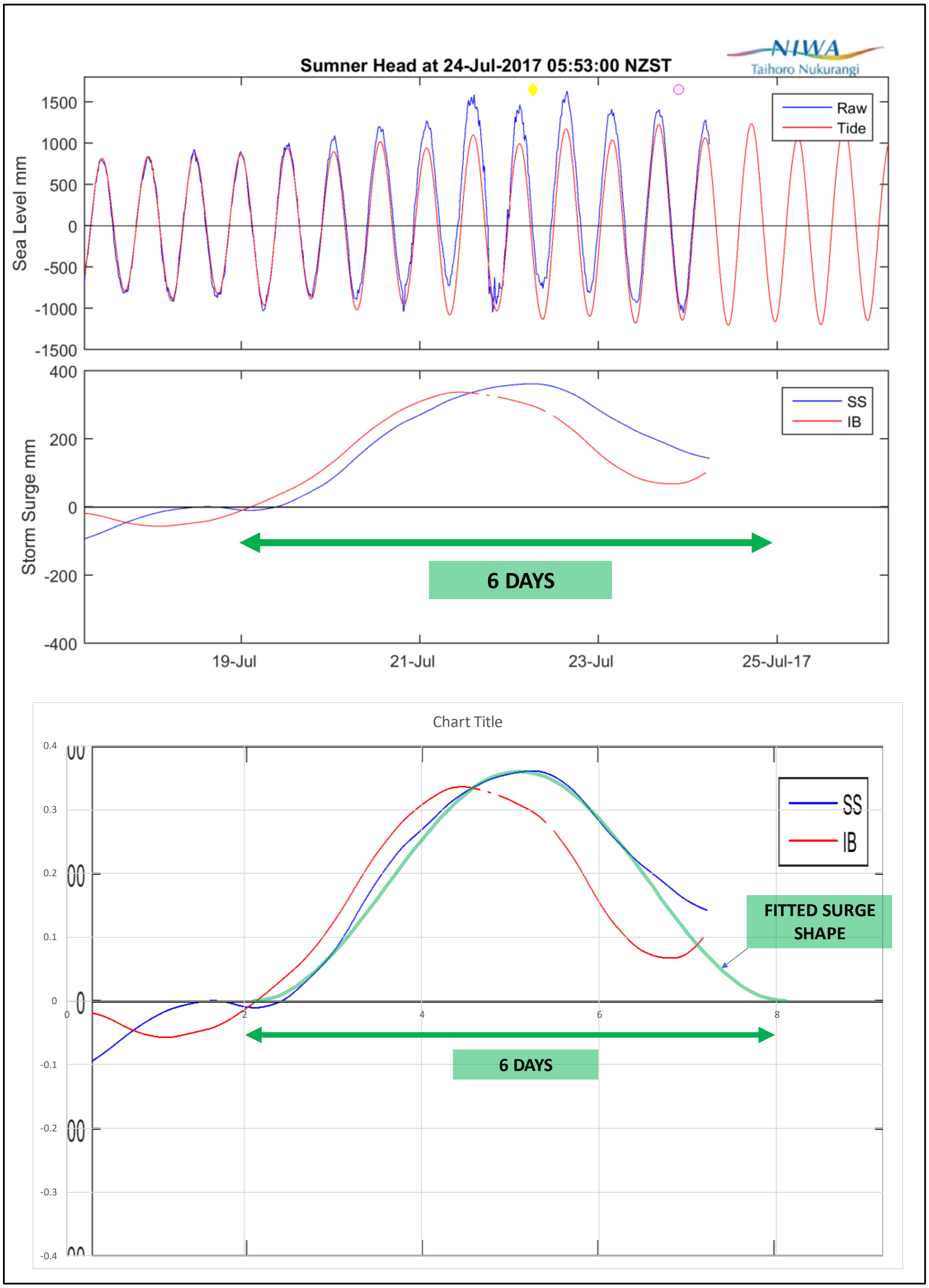

Figure 6: Development of fitted surge height time series from actual surge of 24/7/2017 (SS=Storm Surge, IB=Inverse Barometric sea level rise)

2.4.2 Inflow Boundaries

Three large rivers, the Ashley River, the Kowai River and the Waipara River, and eight smaller local catchments flow into the model area. Figure 7 shows the location of the inflow points to the model and the extents of the smaller delineated sub-catchments.

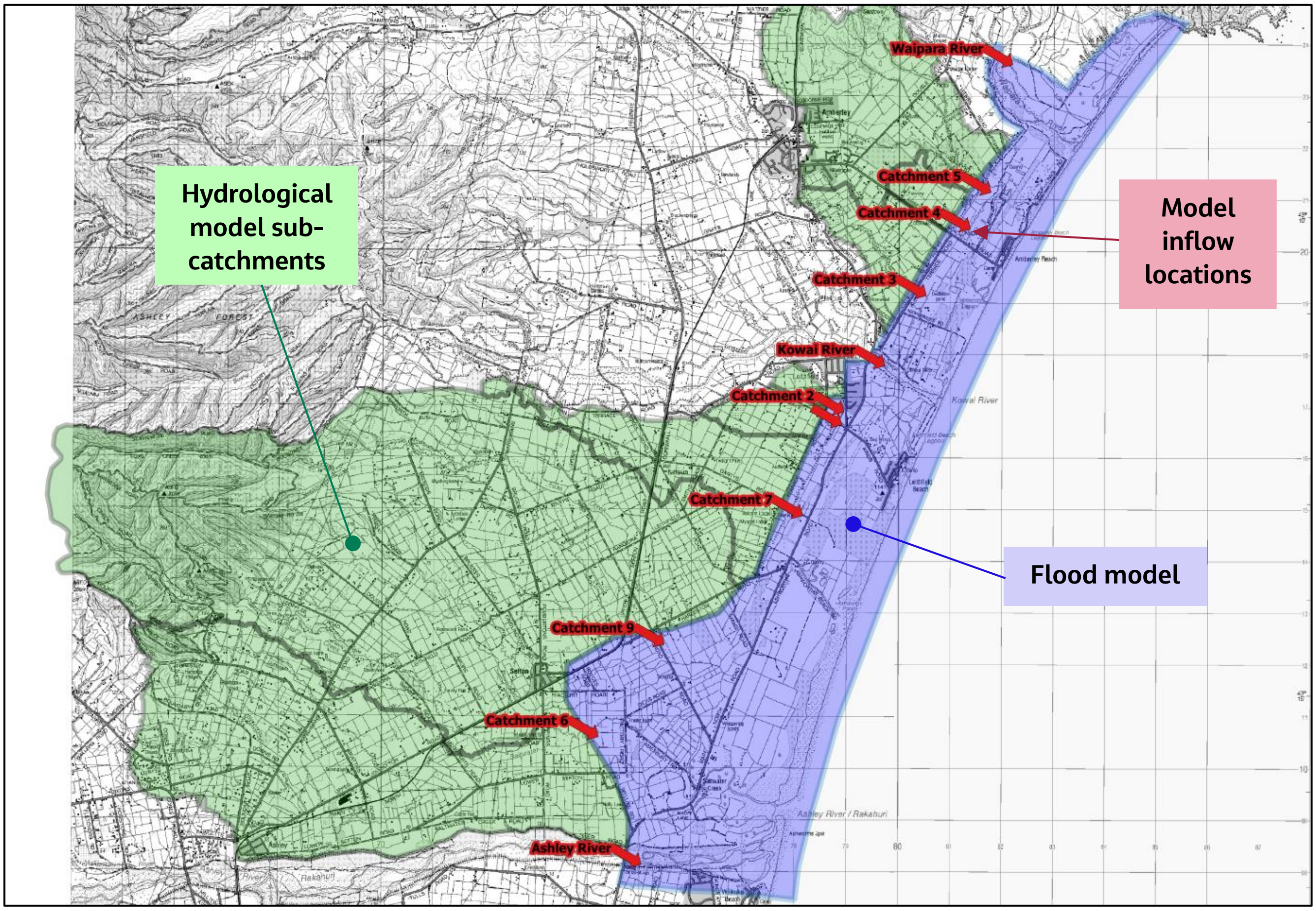

Figure 7 Model inflow locations and catchment boundaries for hydrological model

Ashley River inflow

Extreme fluvial flows derived by ECan for the Ashley[6] River at the SH1 bridges are adopted for the flows in the model boundary time series. Table 4 shows the values provided by ECan together with the AEPs for the scenarios considered in this study.

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[6] Email, A Boyle, ECan, 10 May 2019

Table 4: Extreme fluvial flows in the Ashley River at SH1 bridge (source: ECan)

River	Flow (m^3/s)			
	5 year	20 year	50 year	200 year
	20% AEP	5% AEP	2% AEP	0.5% AEP
Ashley	1070	1620	2020	2730

Kowai River inflow

To define the model flow boundary for the Kowai River, the extreme fluvial flows derived by ECan[7] for North Branch, South Branch and Stockdill Road Branch of the river are combined to apply as an inflow boundary for each specified AEP as summarised in Table 5.

Waipara River inflow

Peak flows for each AEP estimated by ECan[8] at White Gorge have been used to derive the fluvial inflow boundary for the Waipara River. The Waipara River catchment above White Gorge is approximately 370 km^2, while the total catchment area above the model boundary is around 724 km^2. The extreme fluvial flows at the model boundary have been determined using the ratio of the catchment area to the power of 0.8, as described in the NZTA Bridge Manual[9]. A power curve has been fitted to the frequency curve to extrapolate the value of peak flow for the 0.5% AEP event, which was not included in the ECan data. The peak flows adopted to define the flow boundary for the Waipara River are summarised in Table 5.

Table 5: Extreme fluvial flows in the Waipara River and Kowai River (source: ECan)

River	Flow (m^3/s)			
	5 year	20 year	50 year	200 year
	20% AEP	5% AEP	2% AEP	0.5% AEP
Kowai River	170	279	348	452
Waipara River	297	588	868	1602*

**extrapolated peak fluvial flow of the 0.5% AEP event by fitting a power curve to the frequency curve derived for White Gorge*

Local sub-catchment inflows

To derive peak flow boundaries for eight sub-catchments as shown above in Figure 7, the following two methodologies were adopted:

1. Deterministic Method: The hydrological model of each sub-catchment is developed by implementing Soil Conservation Service - Unit Hydrograph Method (SCS-UHM) in HEC-HMS software.
2. Empirical Method: Alternatively for catchments having area < 3km^2, the Modified Rational Method is applied (20131028-045953-JOHNZ_v51_2_Griffiths.pdf (hydrologynz.co.nz), and

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[7] *Kowai River, Leithfield Beach and Amberley Beach flood investigation, Environment Canterbury Regional Council, 2014.*

[8] *Waipara River Water Resource Report, Environment Canterbury Regional Council, 2002.*

[9] Bridge Manual, manual number: SP/M/022, Third Edition, NZTA, October 2018.

Whereas for catchments having area > 3km^2, the flood frequency method (McKerchar & Pearson, 1991) is applied.

For the selected events, the rainfall depths including an allowance for climate change of RCP6.0 scenario (2081-2100) are obtained from NIWA High Intensity Design System (HiRDSv4), which are given below in Table 6. A standard 24-hour temporal rainfall pattern having peak rainfall intensity at mid-duration is adopted.

Table 6: 24 hours Duration Rainfall Depths of Selected Events for each Sub-catchment

Catchment	Rainfall Depth (mm)			
	20% AEP	5% AEP	2% AEP	0.5% AEP
1	81.1	116.0	141.0	179.0
2	81.1	116.0	141.0	179.0
3	81.1	116.0	141.0	179.0
4	81.1	116.0	141.0	179.0
5	81.1	116.0	142.0	181.7
6	81.1	116.0	141.0	179.0
7	81.1	116.0	141.0	179.0
9	84.3	120.0	147.0	186.7

Tables 7 shows that the peak flows estimated for each sub-catchment using deterministic method are mostly conservative as compared to the results of empirical method. In view of this, the results of the deterministic method are suggested to simulate in the model.

Table 7: Estimated Peak Flows of Sub-Catchments for Deterministic and Empirical Methods

Catchment	Peak Flow (m^3/s)							
	Deterministic Method				Empirical Method			
	20% AEP	5% AEP	2% AEP	0.5% AEP	20% AEP	5% AEP	2% AEP	0.5% AEP
1	0.9	2.7	4.3	7.1	0.8	1.2	1.5	2.0
2	0.6	1.6	2.4	3.8	0.4	0.5	0.7	0.9
3	2.3	6.0	9.3	15.0	4.3	7.1	8.9	11.6
4	3.5	6.7	9.2	13.3	0.7	1.1	1.4	1.8
5	14.6	29.1	41.5	61.9	11.8	19.4	24.3	31.6
6	11.2	28.2	43.4	70.4	23.1	38.1	47.7	61.9
7	2.4	7.0	11.4	19.2	7.9	13.0	16.3	21.2
9	52.0	106.3	153.8	230.7	43.6	71.7	89.7	116.5

Figures 8 shows how the flow boundaries tidal water level boundary and direct rainfall are combined in the model simulations. For the Ashley, Kowai and Waipara rivers, a constant flow corresponding to the required extreme value for the scenario over the duration of the highest tide (12 hours) is applied due to the longer flow durations usually observed for these larger rivers. The flow boundaries for the eight local sub-catchments are applied such that the peak flow of each hydrograph coincides with the highest tide. Similarly the peak rainfall intensity in each rainfall event coincides with the highest tidal level.

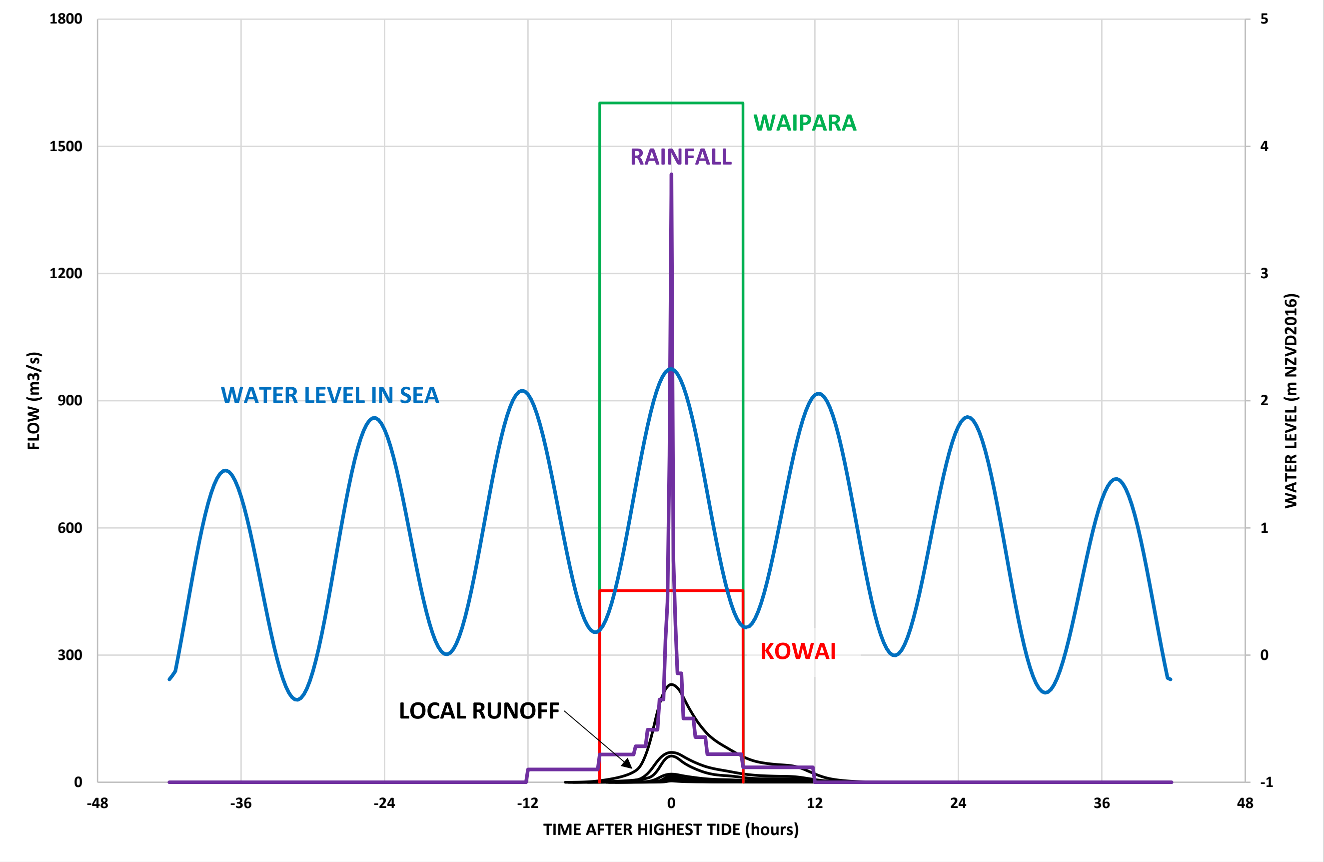

Figure 8: Example illustration of how the model water level, inflow and rainfall boundaries are combined in the model simulation.

2.4.3 Initial ponding from groundwater

The scenarios considered in this assessment include an allowance for the potential contribution to flooding through ponding from high groundwater levels. Detailed groundwater modelling is outside the scope of this study. Estimates of groundwater levels for each sea level rise value in the model scenarios have been interpolated from the piezometric surfaces derived for the Hurunui Coastal Hazards assessment undertaken by Jacobs in 2020. These surfaces were derived for sea level rise values of 0 m, 0.6 m and 1.8 m and only cover a portion of the model domain, in the areas around Leithfield Beach and Amberley Beach. Elsewhere groundwater contributions are not included in the model.

For each sea level rise scenario, the initial water levels have been determined as follows:

- For Scenarios 1 and 2 (no rise in mean sea level) the previously derived present-day groundwater levels have been adopted.

- For Scenarios 3, and 4 (0.3 m rise in mean sea level), the increase in groundwater levels due to a sea level rise of 0.3 m have been determined by linear interpolation between the groundwater levels previously derived for a rise in mean sea level of 0.6 m and present-day groundwater levels.

- For Scenarios 5, 6, 9 and 10 (0.5 m rise in mean sea level), the previously derived groundwater levels for a rise in mean sea level of 0.6 m have been adopted because the groundwater levels for a sea level rise of 0.5m are expected to be similar.

- For Scenarios 7 and 8 (1.0 m rise in mean sea level), the increase in groundwater levels due to a sea level rise of 1.0 m have been determined by linear interpolation between the groundwater levels previously derived for a rise in mean sea level of 0.6 m and 1.8 m.

Maps showing the areas of land potentially below groundwater level in the four sea level rise scenarios are provided in Appendix B. The groundwater levels in these areas have been used to define initial depths of water in the floodplain for the model simulations.

3. Limitations and assumptions

In developing the model for simulating inundation at Leithfield Beach and Amberley Beach, the representation of some aspects of the flooding mechanisms is simplified and the effects of some features of the real system are not included in the simulations. This can limit the accuracy and level of detail in the model results. The data available for developing the model has certain limitations which also limit the accuracy of the model outputs. Key limitations and assumptions that have been made are summarised below.

- Variations in sea level along the coast are not considered in defining the model boundary.
- The geometry of the river channels and mouths and the topography of the land outside the rivers are as defined in the survey data used to develop the model. The morphology of the river and lagoon mouths are dynamic, and, in the case of the Waipara River and Ashley River, the position of the main river outlet to the sea can move considerably in relatively short periods of time. Some openings are also subject to mechanical opening. Water levels in the downstream sections of the rivers, and hence flooding from the rivers, may be sensitive to the morphology of the mouths.
- The scope for this study does not include calibration or validation of the model developed in the study against actual events. However, the results have been “sense checked” against previous studies and observations.
- Ground-based surveys of stop bank crest levels and other key controls – e.g. road levels – were not available and crest levels for calculating overtopping flow in the model are generally taken from the LiDAR data available to the project. The accuracy of LiDAR data is not as high as that of ground-based survey and introduces some uncertainty in the model results.
- The crests of key features (e.g. stop banks) which control the volume of water leaving the rivers have been defined explicitly in the model. Elsewhere levels are interpolated to the model mesh from the LiDAR data. This can mean that the some smaller more local features and their effect on the spreading of the flood water are less accurately represented in the model due to the size of the model mesh elements relative to the size of the features.
- All the river and stream channels are represented in a 2D model. The resolution of the 2D mesh means that smaller drainage ditches within the floodplain are not well defined. However, their capacity is not considered significant in terms of assessing inundation from extreme events.
- Simulations of future sea level rise scenarios are based on present-day land levels and stop bank levels. Future changes to either land levels or defence levels, due to subsidence or seismic events, or through raising of stop banks or managed realignment of defences, could result in changes to the extents and depths of flooding simulated in the model.
- The simulations do not allow for the additional volume of flooding that may occur from breaching or other failures of stop banks or erosion and/or breaching of the coastal dune field under the effects of sea level rise and storm events.
- Water levels representing the estimated groundwater levels in each scenario are included as the initial water levels in the 2D model. These have been derived previously using simplified groundwater models and only for the areas around Leithfield Beach and Amberley Beach. The effect of land drainage on the piezometric surface was not included in the estimates and therefore the ponding areas should be treated as indicative.
- Allowances for the effect of climate change on extreme rainfall have been included in the estimates of runoff for the smaller local catchments and of direct rainfall in the study area. For simplicity a mid-range pathway allowance has been adopted for all scenarios. Extreme flows for the larger rivers are based on available flood frequency analyses, extrapolated to the model boundary where needed. Allowances for the effect of climate are not included due to the uncertainty in applying rainfall augmentation factors to the

statistical flow estimates at the downstream ends of the catchments. Any increases in extreme flows due to climate change would tend to increase the predicted flood depths and extents.

- A formal assessment of the joint probability of fluvial and tidal events is outside the scope of the study and a simple "1/10th rule" two-point approach has been adopted.

4. Results

To illustrate the predicted extent and depth of inundation in each scenario, the flood model results have been processed to produce GIS depth grids of the maximum water depth achieved in the 2D model over the entire period of each model simulation. This includes the initial water depths specified in the model due to groundwater ponding which, in some scenarios, are locally slightly higher than the maximum depth attained over the remainder of the run due to equalising of water levels over the ponding area. The flood depth grids for all the scenarios simulated are illustrated in a simple map template in Appendix A.

For comparison purposes, maps showing the initial model water depths in the simulations for each of the four mean sea level rise scenarios (0 m, 0.3 m, 0.5 m, and 1.0 m), representing the initial ponding from groundwater prior to inundation from the sea and from the rivers, are provided in Appendix B.

An overview of the results for each community are presented below.

4.1 Leithfield Beach

4.1.1 Flooding mechanisms

Table 8 presents typical ground levels at key points on flood flow paths to Leithfield Beach and the maximum water level in each of the model simulations relevant to these points, together with the maximum storm tide water level. The water level point locations are shown in Figure 9, which also illustrates the model results for the 2% AEP event with 0.5 m sea level rise. The extent of flooding, water velocities at the time of maximum storm tide level and the main flood flow paths are shown for both the tidally dominated event (Scenario 7) and fluvially dominated event (Scenario 8).

Ground levels at properties in Leithfield Beach typically range between approximately 2 m and 3 m NZVD 2016 such that flooding is predicted to at least some properties in all scenarios simulated. The main access route to the community, Kings Road is also flooded – to a depth of at least 0.3 m – in all scenarios.

Table 8: Maximum water levels and typical ground levels at key points for Leithfield Beach

Location	Typical defence or ground level #		Maximum model water levels #									
		Scenario No.	1	9	3	5	2	10	4	6	7	8
		Sea level rise	*0*	*0.3 m*	*0.5 m*	*1 m*	*0*	*0.3 m*	*0.5 m*	*1 m*	*0.5 m*	
		Tide AEP	*0.5%*				*5%*				*2%*	*20%*
		Flow AEP	*5%*				*0.5%*				*20%*	*2%*
Tidal water level			2.67	2.97	3.17	3.67	2.25	2.55	2.75	3.25	2.91	2.49
Kowai River mouth	2.22 ##		2.79	3.03	3.21	3.68	2.92	2.97	3.03	3.35	2.93	2.77
Kowai River	6.10 ##		6.46	6.46	6.46	6.46	6.64	6.64	6.64	6.64	6.28	6.55
Leithfield Kings Rd	2.41		2.95	3.07	3.23	3.70	3.24	3.24	3.26	3.42	2.79	3.08
Ashley River lagoon	2.60 ###		2.68	2.98	3.18	3.68	2.39	2.60	2.78	3.26	2.91	2.52

m NZVD 2016; ## true right bank low points; ### Ashworths Beach Road level (typical)

Key flood pathways to Leithfield Beach for tidally dominated events are through the Kowai River mouth, Leithfield Beach Lagoon, Leithfield Drain, Ashworths Ponds and Ashley River Lagoon ((a), (c), (d), (e) and (f) on Figure 9).

Opening or overtopping levels are relatively high for the Lagoon and Drain – approximately 3.0 m NZVD2016 respectively at the time of the 2012 LiDAR survey. However, the openings are dynamic natural features, and the Lagoon may also be subject to mechanical cutting so that the crest levels may vary with time. Based on the surveyed levels, tidal inundation through these routes would only occur for more extreme tides – 0.5% AEP with at least 0.5 m sea level rise – or higher sea level rise values – e.g., 1 m or more. In both locations wave runup could however overtop the crests at lower sea levels. The drainage outfall pipes to the Leithfield Drain provide a lower level pathway – invert levels are estimated to be 1.5m NZVD 2016. Flooding from the Drain occurs when the water level exceeds ground levels along the Drain, typically 2.2 m NZVD 2016.

The opening level for the Kowai River mouth and the overtopping level at Ashworths Ponds are relatively low – approximately 1.9 m and 2.3 m NZVD 2016 respectively based on the LiDAR data – but these are also both subject to natural variations. In the case of the Kowai River the mouth may also be mechanically opened. However, inundation from the mouth of the river is controlled by the higher ground levels along the true right bank, at around 2.2 m NZVD 2016. Although inundation through these two routes is predicted in most of the scenarios simulated, the depth of flow for lower sea level rise values – less than 0.5 m – is relatively shallow and the flow paths to Leithfield Beach are relatively long and wide, tending to limit the contribution to inundation in less extreme water level events. Overflow from the Ashley River lagoon at Ashworths Beach Road (level of 2.6 m NZVD 2016) is also predicted for most of the scenarios and contributes to flooding at Leithfield Beach.

All the tidally dominated scenarios include fluvial flood flows of varying magnitude in the Kowai River and this contributes to flooding through overtopping of the true right bank close to the river mouth and further upstream ((a) and (b) on Figure 9).

In fluvially dominated events, overflow from the Kowai River through these routes, in combination with local catchment runoff, is the principal source of flooding in Leithfield Beach. In these events the tidal inlets provide drainage pathways for the flood water.

As shown in the maps in Appendix B, land susceptible to groundwater ponding is limited to potential areas of breakout around Ashworths Road and within Leithfield Beach Lagoon and is not predicted within the community itself.

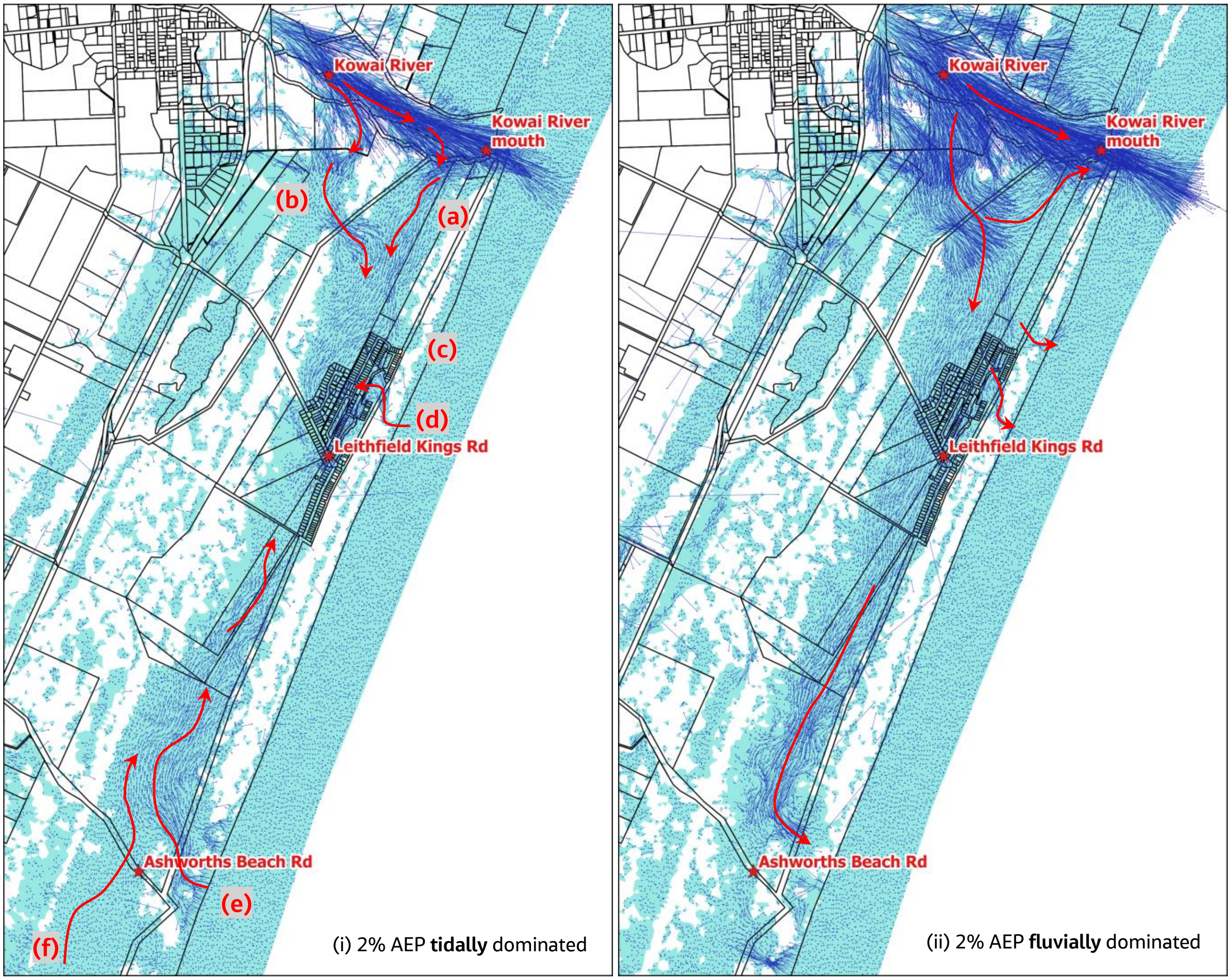

Figure 9: Model flood extents and velocities for (i) Scenario 7 (2% AEP tidally dominated event); and (ii) Scenario 8 (2% AEP fluvially dominated event), both with 0.5 m sea level rise, showing the main flood flow paths for Leithfield Beach.

4.1.2 Effect of sea level rise and fluvial flow

Figure 10 compares the maximum water levels in the model simulations in the Kowai River mouth, the Kowai River further upstream and at Kings Road to the storm tide levels in the model for all the scenarios simulated.

For more extreme events (0.5% AEP), water levels in the Kowai River mouth in fluvially dominated events are relatively insensitive to sea level rise values less than 0.5 m. For tidally dominated events of the same AEP, water levels in the river mouth are very similar to the peak tide level and so respond directly to sea level rise. Water levels for tidally dominated events are higher than for fluvially dominated events at this location for sea level rise of 0.3 m and higher. However, water levels in the Kowai River further upstream towards the SH1 bridge, where significant overflow occurs ((b) on Figure 9), are not influenced by the tide level or sea level rise. This contributes to the greater severity of fluvially dominated flood events at Leithfield Beach for sea level rise values up to around 0.5 m. Water levels in the Kowai River upstream vary by less than 0.4 m over the range of events simulated (20% to 0.5% AEP) because the water level in the river is limited by overflow of the banks in all these events.

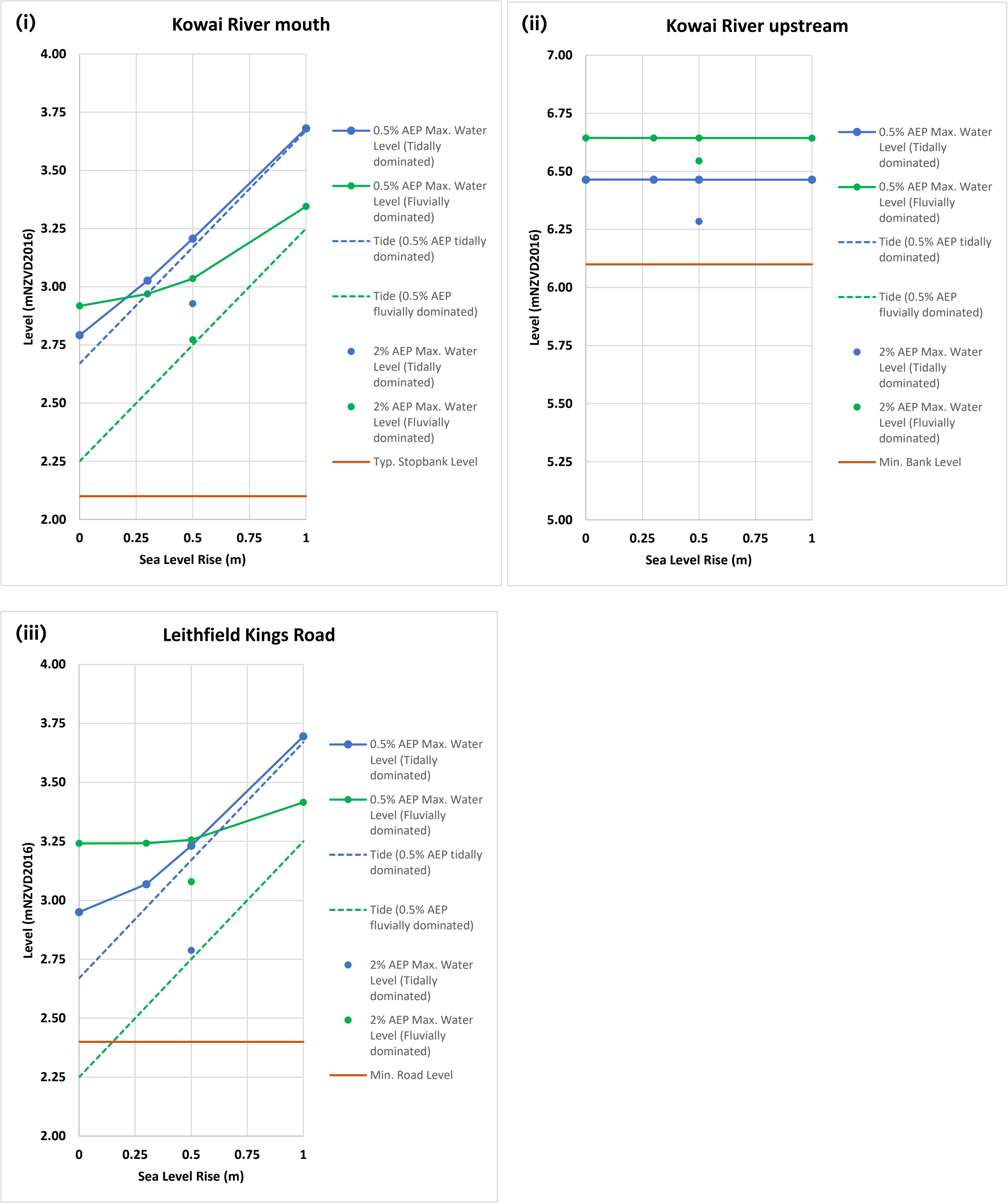

Figure 10: Model maximum water levels in (i) the mouth of the Kowai River; (ii) in the Kowai River further upstream; and (iii) at Kings Road for all scenarios simulated, showing the effect of sea level rise on tidally and fluvially dominated flood levels.

4.2 Amberley Beach

4.2.1 Flooding mechanisms

Table 9 presents typical ground levels at key points on flood flow paths to Amberley Beach and the maximum water level in each of the model simulations relevant to these points, together with the maximum storm tide water level. The water level point locations are shown in Figure 11, which also illustrates the model results for the 2% AEP event with 0.5 m sea level rise. The extent of flooding, water velocities at the time of maximum tide level and the main flood flow paths are shown for both the tidally dominated event (Scenario 7) and fluvially dominated event (Scenario 8).

Ground levels at properties in Amberley Beach typically range between approximately 2 m and 3 m NZVD 2016 such that flooding is predicted to at least some properties in all scenarios simulated. The main access route to the community, Amberley Beach Road is also flooded – to a depth of at least 0.5 m – in all scenarios.

Table 9: Maximum water levels and typical ground levels at key points for Amberley Beach

Location	**Typical defence or ground level #**		**Maximum model water levels #**									
		Scenario No.	**1**	**9**	**3**	**5**	**2**	**10**	**4**	**6**	**7**	**8**
		Sea level rise	***0***	***0.3 m***	***0.5 m***	***1 m***	***0***	***0.3 m***	***0.5 m***	***1 m***	***0.5 m***	
		Tide AEP	***0.5%***				***5%***				***2%***	***20%***
		Flow AEP	***5%***				***0.5%***				***20%***	***2%***
Tidal water level			2.67	2.97	3.17	3.67	2.25	2.55	2.75	3.25	2.91	2.49
Waipara River (at Golf Course)	2.70		3.24	3.28	3.36	3.72	3.76	3.76	3.76	3.81	3.07	3.40
Waipara River (Lagoon)	3.10		3.20	3.25	3.33	3.71	3.65	3.65	3.66	3.73	3.06	3.34
Amberley Beach Rd	2.20		2.72	2.99	3.19	3.68	3.16	3.16	3.18	3.39	2.83	2.88

m NZVD 2016

Key flood pathways to Amberley Beach for tidally dominated events are through the Mimimoto Lagoon and Amberley Beach Lagoon ((a) and (b) on Figure 11). Opening levels were approximately 2.0 m and 2.7 m NZVD2016 respectively at the time of the 2012 LiDAR survey. However, the openings are dynamic natural features and are also subject to mechanical cutting so that the crest levels may vary with time. Based on the surveyed levels tidal inundation through the Mimimoto Lagoon occurs in all the scenarios considered. Tidal inundation through the Amberley Beach Lagoon occurs for the more extreme tidal events and/or higher sea level rise increments. In both cases wave runup could overtop the crests at lower water levels.

The lowest point on the true right bank of the Waipara River from the LiDAR survey, approximately 2.7 m NZVD 2016 adjacent to the golf course, is below the water level in the river for all scenarios simulated although the volume of water overtopping and reaching Amberley Beach is relatively small in some case. All the scenarios include fluvial flood flows of varying magnitude in the river. The water level also depends to some degree on the size of the opening which forms in the bar across the river mouth.

In fluvially dominated extreme events, overflow from the Waipara River through the golf course ((c) on Figure 11) is more significant and contributes to flooding at Amberley Beach, together with runoff from local catchments. In these events the water level in the lagoons is higher than the peak storm tide level and the lagoon mouths provide drainage pathways for the flood water.

Overflow from the Kowai River mouth ((d) on Figure 11) occurs in all the scenarios simulated when the water level in the mouth exceeds the lowest points along the true left bank (around 2 m NZVD 2016). Water from the river flows towards Amberley Beach to combine with the other sources of flooding.

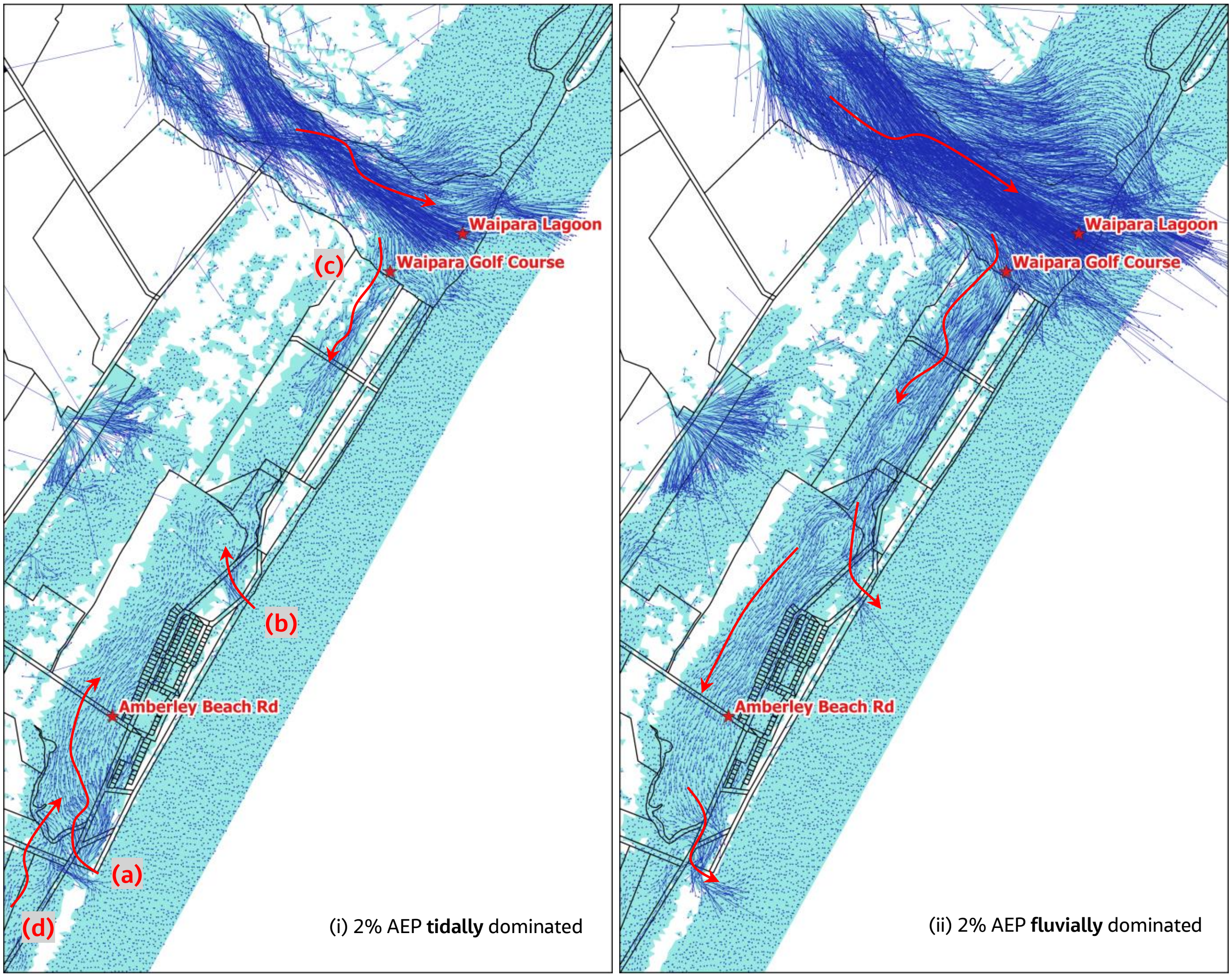

Figure 11: Model flood extents and velocities for (i) Scenario 7 (2% AEP tidally dominated event); and (ii) Scenario 8 (2% AEP fluvially dominated event), both with 0.5 m sea level rise, showing the main flood flow paths for Amberley Beach.

As shown in the maps in Appendix B, land susceptible to groundwater ponding is limited to the low-lying land along the east side of Hursley Terrace road and in the quarries area and is not predicted within the community itself.

4.2.2 Effect of sea level rise and fluvial flow

Figure 12 compares the maximum water levels in the model simulations in the Waipara River and at Amberley Beach Road to the storm tide levels in the model for all the scenarios simulated. For more extreme events (0.5% AEP), water levels in fluvially dominated events are relatively insensitive to sea level rise values less than 0.5 m. For tidally dominated events of the same AEP, flood levels at Amberley Beach Road are very similar to the peak tide level and so respond directly to sea level rise.

Water level in the Waipara River in extreme events is higher in fluvially dominated events than tidally dominated events for all scenarios considered. At Amberley Beach Road tidally dominated flooding starts to become worse for sea level rise above approximately 0.5 m.

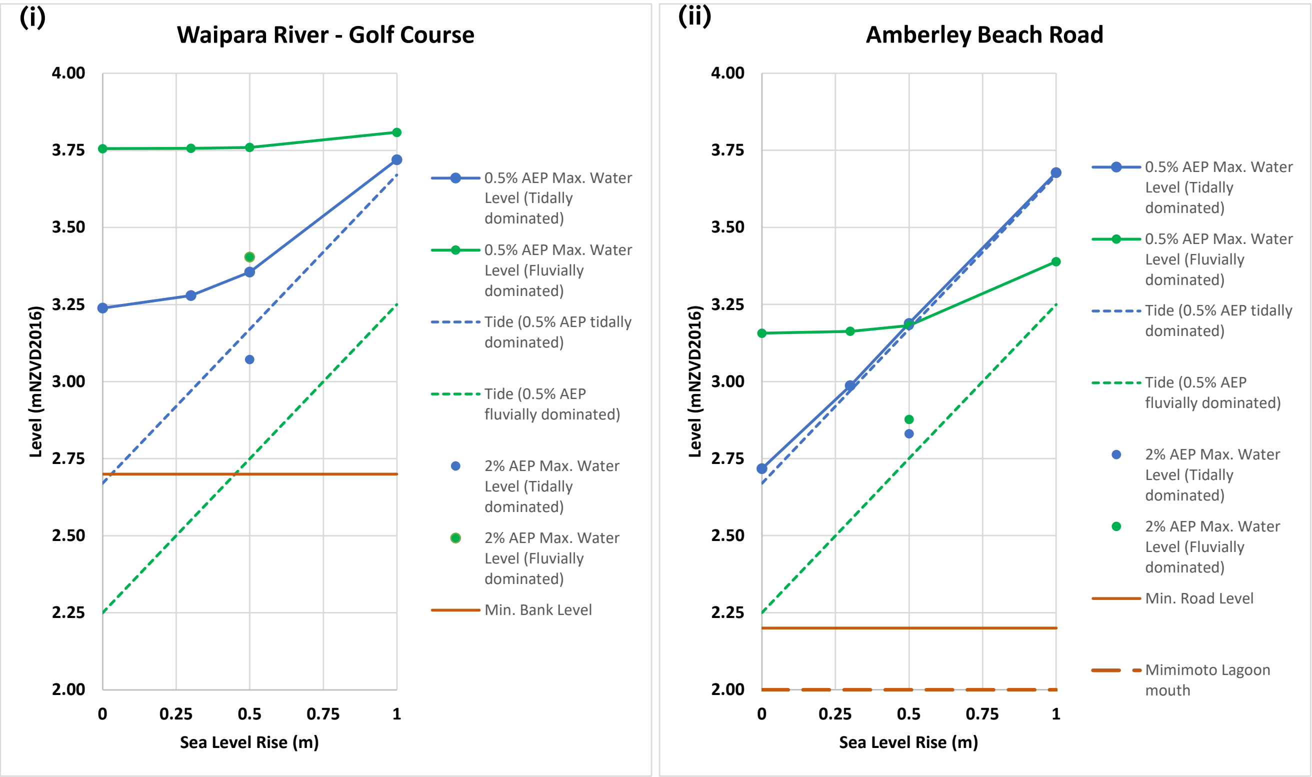

Figure 12: Model maximum water levels in (i) the Waipara River and (ii) at Amberley Beach Road for all scenarios simulated, showing the effect of sea level rise on tidally and fluvially dominated flood levels.

5. Conclusions

This multi hazard assessment confirms the susceptibility of the Leithfield Beach and Amberley Beach communities to flooding from multiple sources.

For both communities the likelihood of flooding is currently relatively high, with widespread flooding predicted in events of 2% AEP and higher AEPs for both tidally and fluvially dominated events. The principal sources of flooding are storm tide and high flows in the Kowai River and Waipara River. Runoff from the smaller local catchments and direct rainfall also contribute to flooding, particularly for higher likelihood events. The extent and depth of flooding for a given likelihood of flooding will increase in the future due to mean sea level rise and increase in rainfall intensity as a result of climate change.

Assessment of groundwater levels suggest that there is less risk of flooding within the settlements due to groundwater breakout although areas inland of them are susceptible to surface ponding from high groundwater levels. High groundwater levels in the settlements could however reduce infiltration and increase runoff from direct rainfall.

The main flood pathways for Leithfield Beach are overflow from the Kowai River and storm tide inundation through the Ashley River mouth, Ashworths Ponds, Leithfield Drain, Leithfield Beach Lagoon and Kowai River mouth. For more extreme events (0.5% AEP), water levels in the Kowai River mouth in fluvially dominated events are relatively insensitive to sea level rise values below 0.5 m. In extreme tidal events, water levels in the river mouth are similar to the peak storm tide level and so respond directly to sea level rise. Water levels for tidally dominated events are higher than for fluvially dominated events at this location for sea level rise of 0.3 m and higher. However, water levels in the Kowai River further upstream towards the SH1 bridge, where overflow occurs in extreme events, are not influenced by the tide level or sea level rise. This contributes to the greater severity of fluvial flooding at Leithfield Beach for sea level rise values up to around 0.5 m.

Key flood pathways to Amberley Beach are overflow of the Kowai and Waipara River and storm tide inundation through the Mimimoto Lagoon and Amberley Beach Lagoon. For sea level rise values of up to 0.5 m, flood levels in Amberley Beach are higher in fluvial events and are relatively insensitive to tide level or sea level rise. Tidally dominated flooding, which increases directly with sea level rise, starts to become worse than fluvial flooding for sea level rise above approximately 0.5 m. Water levels in the Waipara River are higher in fluvial events for all the scenarios considered while water levels in the Kowai River mouth are generally higher for tidally dominated events.

Water levels in the rivers and lagoons, and hence the flooding from them, depend to some degree on the size and depth of cuts or breaches in the bars across their mouths, formed naturally or mechanically excavated. This results in some uncertainty in the predicted flooding. However, for more extreme events and higher sea level rise scenarios, the shape of the openings has less effect on flooding as these features become more deeply submerged.

Wave runup along the frontage of the settlements and at the openings to the lagoons can result in additional temporary flooding. This has not been quantified in this assessment. Although wave overtopping may be locally significant, the overall volumes of inundation are small compared to the tidal or fluvial flows which result in wholesale inundation of the settlements.