Impacts of Climate Change on Urban Infrastructure & the Built Environment

A Toolbox

Tool 2.1.4: Inundation modelling of present day and future floods

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1. Introduction

1.1 Background

It is expected that future increases in heavy rainfall due to climate change will greatly impact river flow and river flooding in New Zealand. The IPCC Fourth Assessment Report (2007) found that floods in New Zealand are “very likely” to become more frequent and intense, resulting in increased risk to major infrastructure including failure of flood protection measures. The pattern of rainfall over New Zealand will also change, e.g. Eastern areas expected to become drier, Western areas expected to become wetter, leading to regional variations in flood risk changes.

As detailed in [Tool 2.1.1] the third step in estimating the effects of climate change on river floods is to estimate the change in flood inundation.

1.2 Purpose of Tool

To use estimates of river flood flows corresponding to future scenarios of heavy rainfall [Tool 2.1.3] and estimate the corresponding flood inundations. Two case study examples are presented here to demonstrate the tool: possible future flooding of the Buller River (Westport) and of the Heathcote River (Christchurch).

2. Overview of inundation models

A hydrodynamic model is used to calculate water-levels, water-depths and flow velocities across a modelled terrain. Models may be physical scale models of a prototype situation, or computational models using digital representations of reality. The generic setup for a model is shown in Figure 2.1. Due to the reducing cost of computer processing in recent years, computational models are now generally used in preference to physical models. Physical models may give more realistic results where sediment movement causes significant topographic changes during floods.

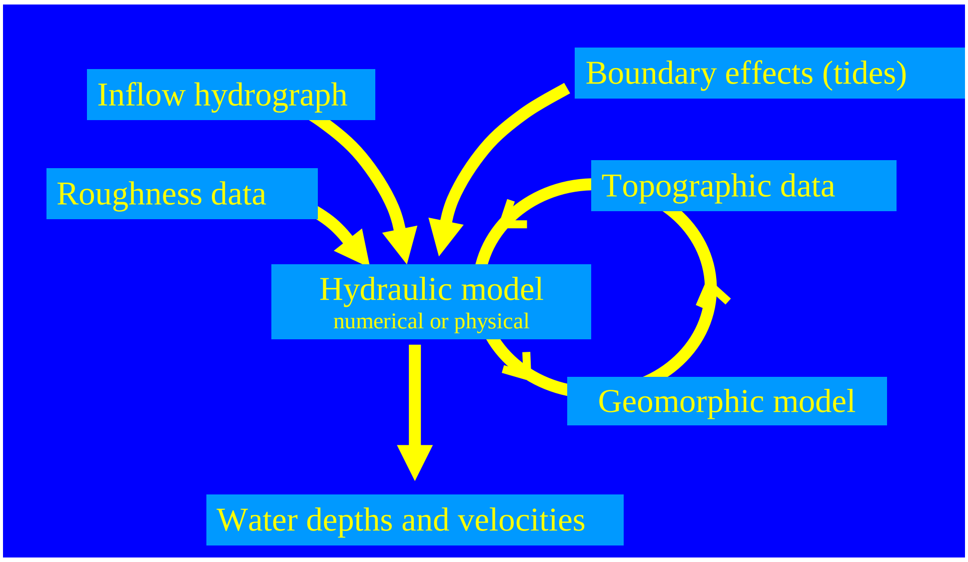

Figure 2.1: Schematic diagram of parameters affecting hydraulic modelling.

2.1 Theoretical Basis of computational hydrodynamic models

Computational models in use in New Zealand are one-dimensional (1D) or two dimensional (2D). The characteristics of these models are compared in Figure 2.2.

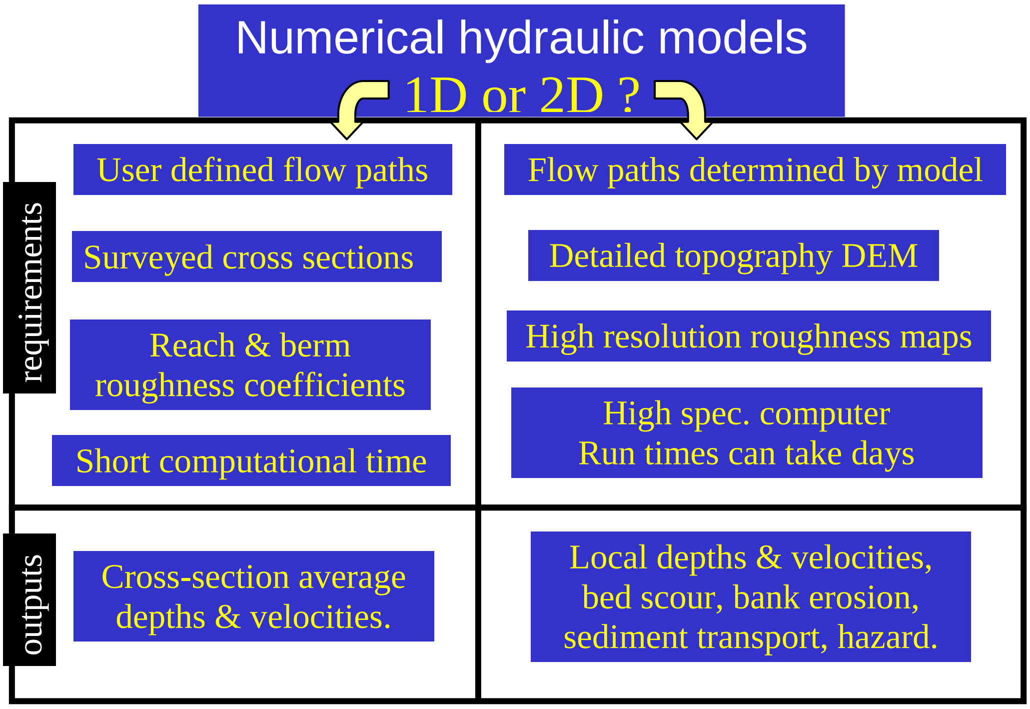

Figure 2.2: Features of one dimensional and two dimensional computational hydraulic models.

The examples presented in this study use computational 2-dimensional (2D) hydraulic models run on personal computers with 2 GHz, 2-core processors and 2GB RAM.

Two dimensional computational models are based on the physics of depth-averaged shallow water flow and solve the Saint-Venant equations. The particular computational model used here is “Hydro 2de”, but there are a number of such models that could be used. Hydro 2de has been widely used by NIWA for flood inundation studies. For the Westport model example in this study, depths and velocities predicted by Hydro 2de were verified by comparison with the Gerris 2D model.

2.2 Model data requirements

The following are the minimum data needs for 2D hydrodynamic modelling for inundation:

- A digital elevation model (DEM) of the model domain (see Section 2.2.1).
- An input hydrograph. [Tool 2.1.2] and [Tool 2.1.3] describe how rainfall and runoff can be generated to provide input hydrographs.
- The hydraulic roughness of the model domain (see Section 2.2.2). This may need to be calibrated (see Section 2.2.4).
- Information on the location of bridges and their soffit levels and the location and dimensions of culverts and major pumping stations (see Section 2.2.3).
- Tide levels for coastal reaches (see Section 2.2.5).

2.2.1 Digital elevation model

DEMs are typically derived from LiDAR which cannot detect underwater areas. Thus it is necessary to add the bathymetry of wet areas such as rivers, lakes, swamps and ocean. Constructing a DEM may involve resampling topographic data to get a mean elevation for the required size of computational cell. Care has to be taken to ensure that critical levels such as the top of the stopbanks or the bottom of narrow channels are preserved in a DEM. This can be an issue where feature widths are of the same order or smaller than the cell size. The Westport model example herein, covers the whole of the Buller River flood plain and is bounded by hills to the south, terraces to the east and west and by the sea to the north. The example Heathcote River Flood model is bounded by Colombo Street in the west, the Avon-Heathcote estuary in the east, the Port Hills in the west and Aldwins/Pages Road to the north. The DEMs are based on airborne LiDAR measurements. The DEM cell size is 4.7 m square for the Buller region and 2 m square for the Heathcote model.

The Heathcote model is based on topography existing prior to the February 2011 Christchurch earthquake and may no longer be representative of future flooding.

2.2.2 Hydraulic roughness

Hydrodynamic models require a roughness value for each computational cell. Roughness values can be obtained from tables, by calibration or by mapping on the basis of remote sensing, aerial photographs or land use databases.

2.2.3 Bridges and culverts

Where these can have an effect on flood flows they must be incorporated into the hydrologic model. The Hydro 2de model used for these examples requires the location of each side of the ends of bridges and bridge soffit levels. For culverts it requires the location of the ends of the culvert, its diameter or width and height.

2.2.4 Model verification and calibration

Models require verification against observed flood events and possible re-calibration. Corrections are usually achieved by changing hydraulic roughness values or digitally altering the DEM to ensure that it correctly represents the true topography during a flood. The Buller case was calibrated using water levels in the town during the August 1970 flood that had an AEP of ~0.02. Heathcote River levels were calibrated using the largest flood recorded at the Buxton Terrace water-level recorder.

2.2.5 Tide levels

The Buller River at Westport and the Heathcote River Christchurch example models are close to the sea, are low-lying and so sea-levels (tide) and any effect of climate change on sea-level needs to be taken into account.

The base tide for the simulations is the pragmatic mean high water springs tide (MHWS10), i.e., the tide that is exceeded 10% of the time. In the simulations, tide and flood peaks were coincident. Buller flood peaks are normally quite broad and long and so there is a good chance that some part of the river flood peak will coincide with high tide. For these studies, no account was taken of the effect of storm surge. Previous work has shown a coincidence of storm surge with river floods in the Buller River in winter. There has been no investigation of the coincidence of storm surge and river floods for the Heathcote River.

For the 2030-2049 (2040) scenarios we have assumed a sea-level rise of 0.4 m and for the 2080-2099 (2090) scenarios a sea-level rise of 0.8 m. These amounts of sea-level rise are similar to those recommended in the MfE (2008) Guidance Manual.

Tide values for the Westport model were taken from the NIWA open ocean tide gauge at Charleston ~25 km south west of the Buller River mouth and for the Heathcote model from the tide record at the Ferrymead Bridge where the Heathcote River enters the mouth of the Avon-Heathcote Estuary.

3. Case study examples

3.1 Westport Scenarios and Results

Table 3.1 shows the modelled climate scenarios, periods, peak flows, the annual exceedance probability (AEP) of the river flood peaks in terms of the current climate, tide levels and the extent of inundation of Westport town (see also Figure 3.1). The Base scenario is the August 1970 flood which came very close to the 0.2% AEP (50 year) flood peak of 8640 m^3s^{-1}.

Table 3.1: The climate scenarios for the Buller/Westport example.

Climate scenario	Period	Peak flow (m^3s^{-1})	AEP for current climate	Average return period (years)	Increase on 1.618 m base tide (m)	Inundation in Westport. % area with depth >0.2 m
Base	Current	8500	0.021	47	0	51
B1	2030-2049	8805	0.015	66	0.4	60
A1B	2030-2049	8977	0.013	76	0.4	63
B1	2080-2099	9017	0.013	78	0.8	67
A2	2030-2049	9200	0.011	90	0.4	64
A1B	2080-2099	9319	0.010	98	0.8	70
A2	2080-2099	9727	0.008	131	0.8	72

Figure 3.1: The red line encloses the area defined as Westport for the calculation of inundation.

3.2 Discussion on assumptions for Westport

The modelled future climate scenarios are based on alterations to the total rainfall while maintaining the hourly distribution pattern that produced the August 1970 flood. Similar daily rainfall totals with different hourly rainfall distributions can result in significantly higher flood peaks and volumes. The degree of inundation of Westport is very sensitive to the duration that the flood is overbank and hydrographs with different shapes and volumes (with the same peak flow) would result in different inundation depths and locations than reported here.

The same area of inundation can result from a range of combinations of tide level and flood peaks, although different locations will be flooded with different water depths and velocities than reported here. The models reported here have the MHWS10 tide peak aligned with the flood peak giving a conservative result. Higher or lower tides and their timing would result different areas and locations of inundation, e.g., in

August 1970 the Buller River flood peak arrived at low tide and inundation was limited by the low tide, even though there was ~0.6 m of storm surge.

3.3 Heathcote Scenarios and Results

Table 3.2 shows the modelled climate scenarios, their periods, peak flows, tide levels, and the AEP of the river flood peaks in terms of the current climate. The AEP estimates for the Heathcote River at Buxton Terrace are debatable as the short record (1991 to present) is for a period with relatively low daily rainfalls compared to the long Christchurch Botanical Gardens rainfall record (from 1873 to present). The ARI estimates in Table 3.2 are based on a frequency analysis with the Buxton Street flow record extended using the Fernihurst Street record that began in 1966. As the flow estimates in Table 3.2 are well beyond the magnitude of measured flows there remains significant uncertainty in the AEP estimates. Table 3.2 also shows the resulting area of overbank inundation (in square kilometres and as a percentage increase on the area which would be flooded should a ~150 year flood occur at present).

Table 3.2: Example climate scenarios for the Heathcote River at Buxton Terrace.

Climate scenario	Period	Peak flow (m^3s^{-1})	AEP for current climate	Average return period (years)	Increase on 0.974 m base tide (m)	Inundated area Km^2	Increase in flooded area
Base	Current	65	0.007	143	0	0.73	0
A1B	2030-2049	77.3	0.0024	417	0.4	1.15	56%
A2	2030-2049	89.2	0.00075	1,333	0.4	1.38	187%
A1B	2080-2099	89.2	0.00075	1,333	0.8	2.19	298%
A2	2080-2099	126	.0000102	98,039	0.8	3.43	467%

Maps of flood inundation in south eastern Christchurch resulting from the different climate scenarios are shown in Figures 3.2 and 3.3.

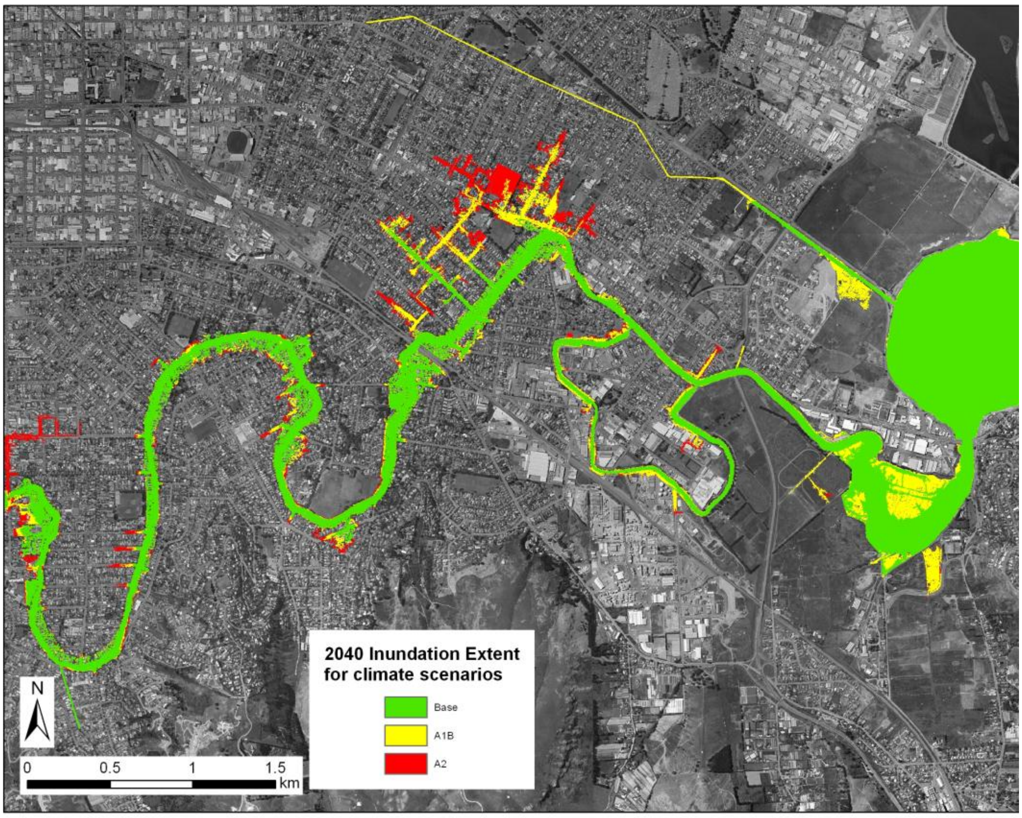

Figure 3.2: Flood inundation of S.E. Christchurch showing scenarios for 2040 in relation to the present scenario (NB pre-earthquake).

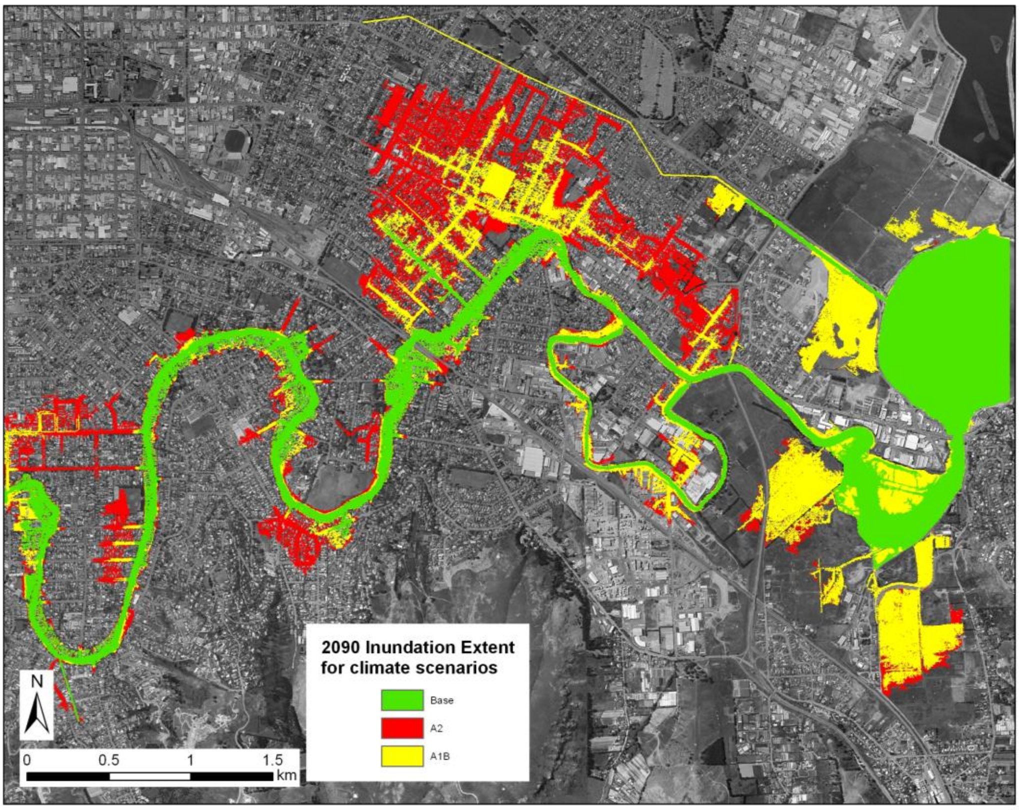

Figure 3.3: Flood inundation of S.E. Christchurch showing scenarios for 2090 in relation to the present scenario (NB pre-earthquake).

As noted in the introduction, the Heathcote model is based on topography existing prior to the 22 February 2011 Christchurch earthquake and may no longer be representative of future flooding. Specifically, comparative LiDAR surveys from before the September 2010 and after the February 2011 earthquakes suggest the Avon-Heathcote estuary and lower reaches of the Heathcote River are now up to 0.4 m higher and the upper reaches of the model are ~0.2 m lower. On this basis, the data presented on the extent and location of inundation and subsequent analysis could be misleading. The data and maps in this tool should therefore be seen only as examples of the methodology and should not used for planning purposes.

As for the Buller River case, daily rainfall estimates are calculated according to best practice, but there is no guidance on how to distribute that rainfall during the day and a wide range of flood peaks could result from differences in that distribution.

Also in common with the Buller River case the relative sizes and timing of the river flood and tide peaks can influence the location depth and extent of inundation.

A difference from the Buller case is the way in which the increases in flooding are quantified. With a clearly defined town such as Westport, the inundated area can be calculated as a percentage of the town area, however in the case of Heathcote River in Christchurch such a parameter is less useful and the inundation likely to occur as a result of climate change is here presented in square kilometres and as a percentage increase on the area which would be flooded in a present-day 150 year flood.

4. How to Apply the Tool

High resolution hydrodynamic 2D modelling is a resource hungry exercise, both for its data requirements (LiDAR) and the expertise and computing power required to carry out the modelling. It is more appropriate where there are extensive assets to protect or a high probability of loss of life from flooding.

5. Example Outputs

The example hydrodynamic model used can output grid files of water depths, x & y vectors or resultant depth averaged velocity, water-levels, bed elevations, hydraulic roughness, bed shear stresses and the duration of inundation for each model cell at each saved time step. The model can also output data on the maximum value (during a model run) for water depths, resultant velocities, water-levels and specific flow calculated for each cell. The example outputs shown below show such maximum values. The extent and depth of inundation and of the Buller River flood plain is shown for the current climate (base) case in Figure 5.1 and the most extreme climate scenario in Figure 5.2.

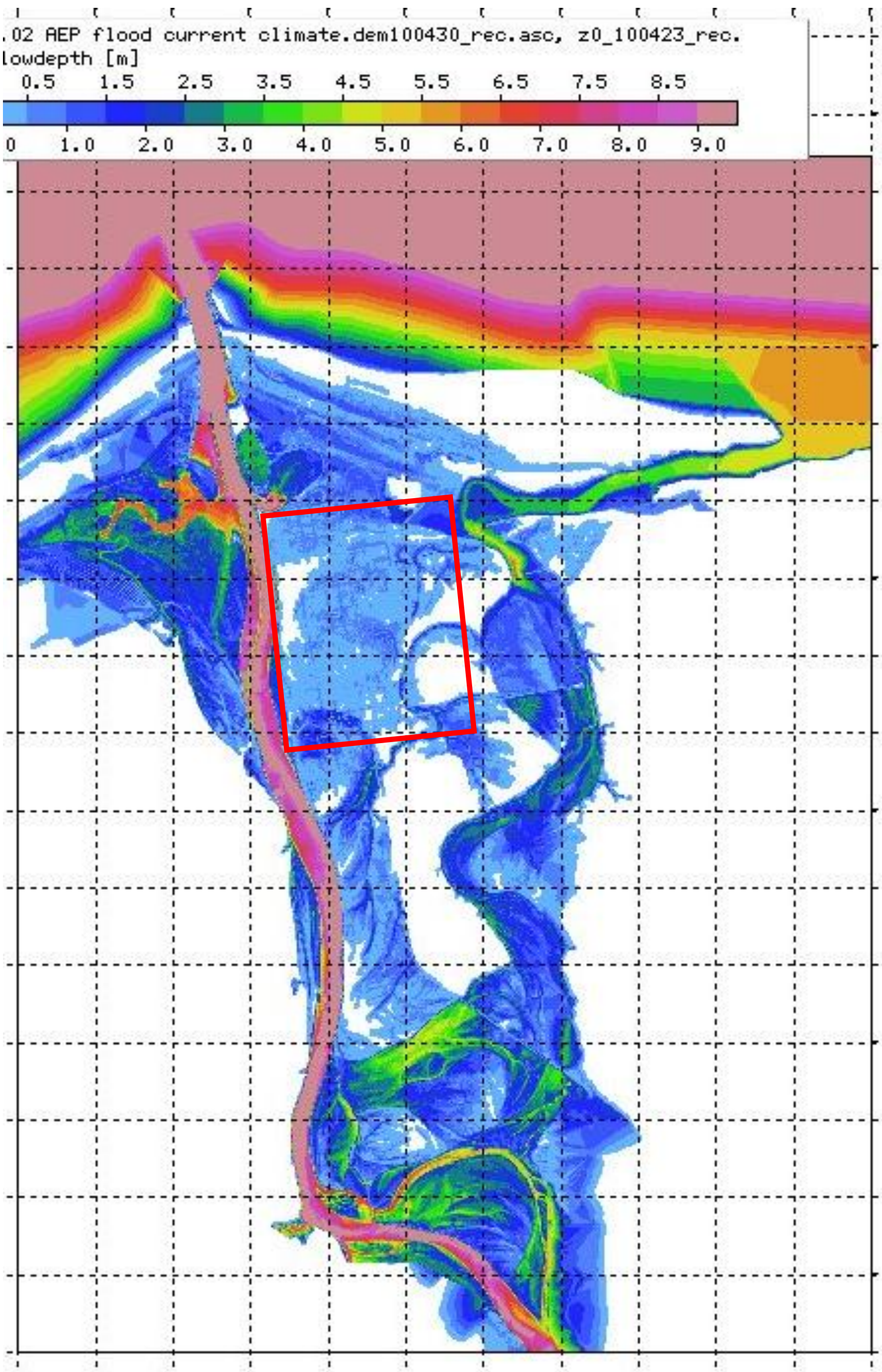

Figure 5.1: The maximum extent of inundation and water depth (in metres shown as a colour scale) of the Buller River flood plain for the current climate with a flood peak of 8500 m^3s^- and coincident tide peak of 1.618 m. The red box shows the approximate location of Westport.

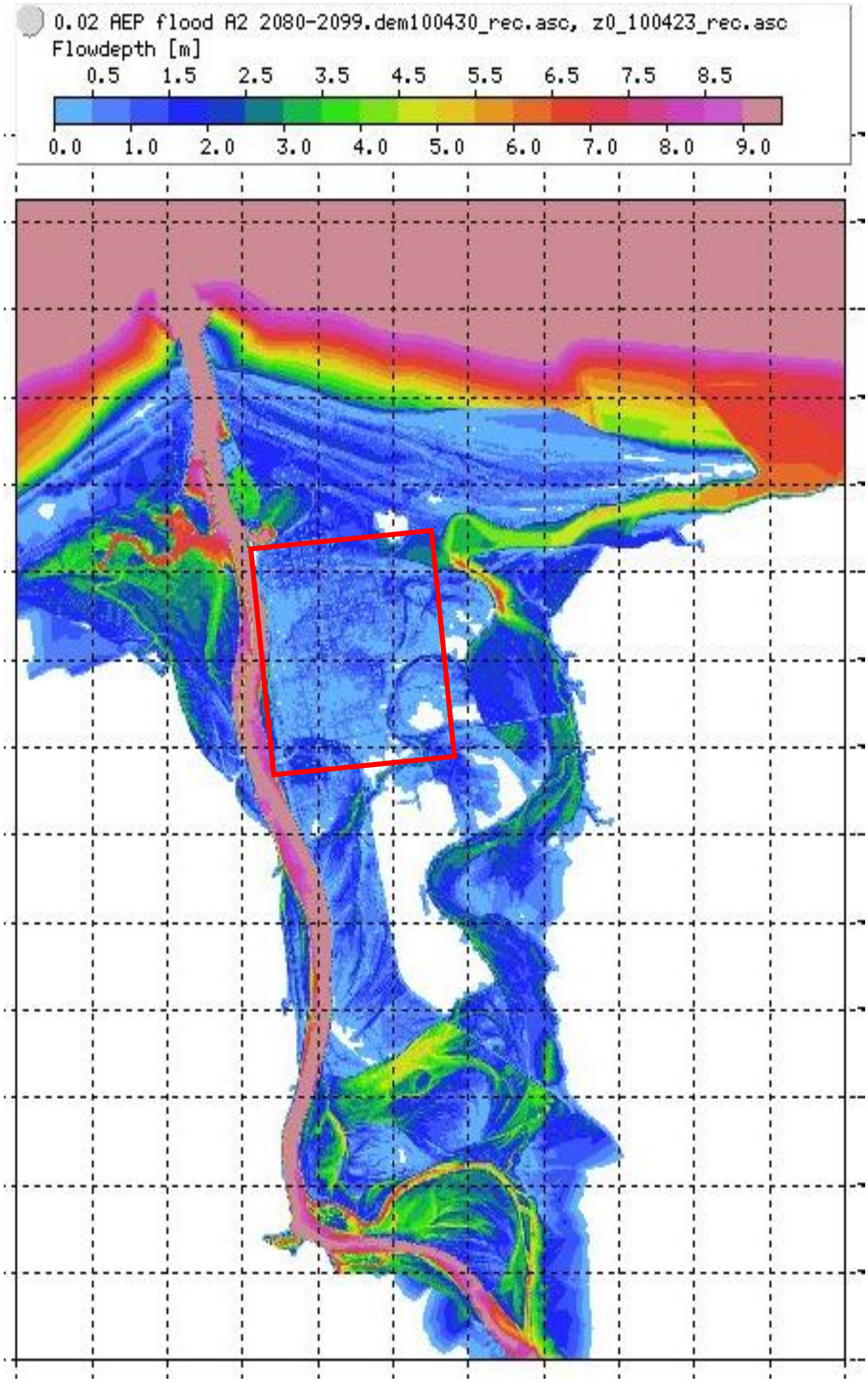

Figure 5.2: The maximum extent of inundation and water depth (in metres shown as a colour scale) of the Buller River flood plain for the A2 2090 scenario with a flood peak of 9727 m^3s^{-1} and coincident tide peak of 2.418 m. The red box shows the approximate location of Westport.

5.1 The Next Steps

Model results can be used to evaluate economic and human losses likely to occur in the sample floods and consequently predict the effects of climate change in relation to the present day situation [see Tool 3.3]. The model can also be used to explore the efficacy of potential mitigation options, e.g., flood banks can be digitally added to the DEM and models rerun to demonstrate the effectiveness and residual risk of such protection measures. Options such as deepening or widening channels or constructing flood bypass channels can similarly be explored [see Tool 4.2].

6. References

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