Modelling Floods for NZ: The Waikanae and Westport testcases

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Climate, Freshwater & Ocean Science

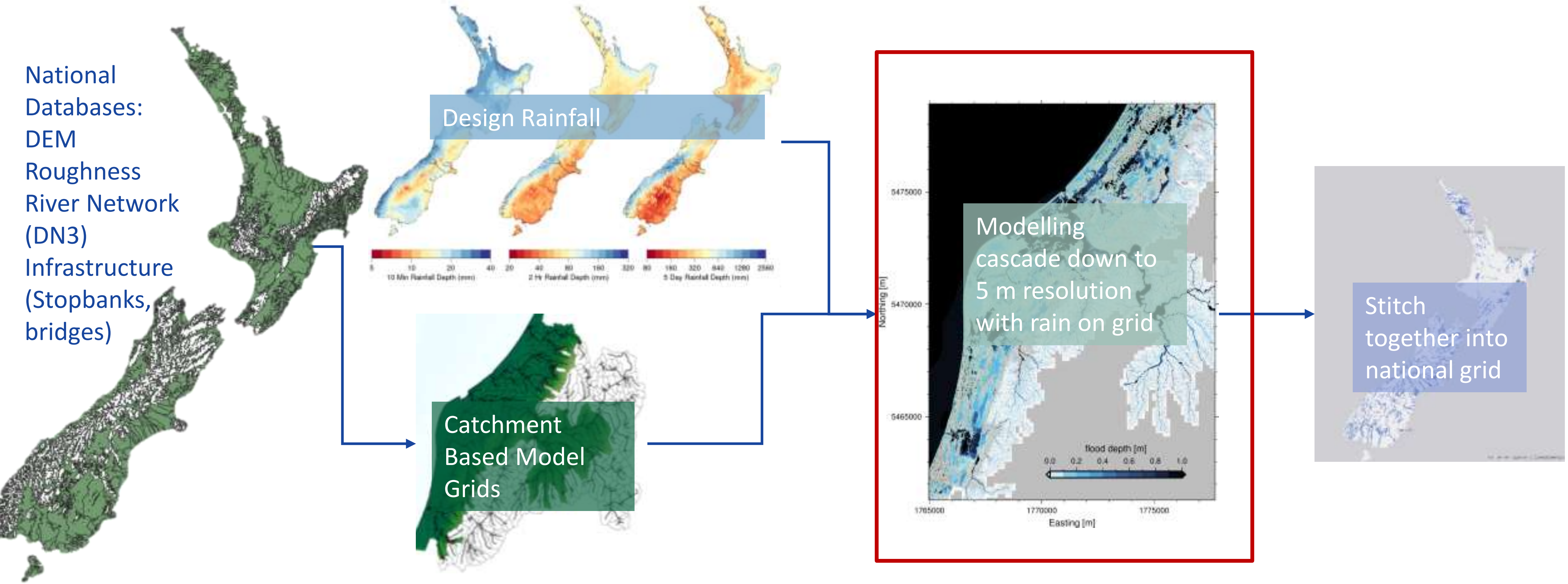
Mā te haumaru ō nga puna wai ō Rākaihautū ka ora mo ake tonu:

Increasing flood resilience across Aotearoa

NIWA
Taihoro Nukurangi

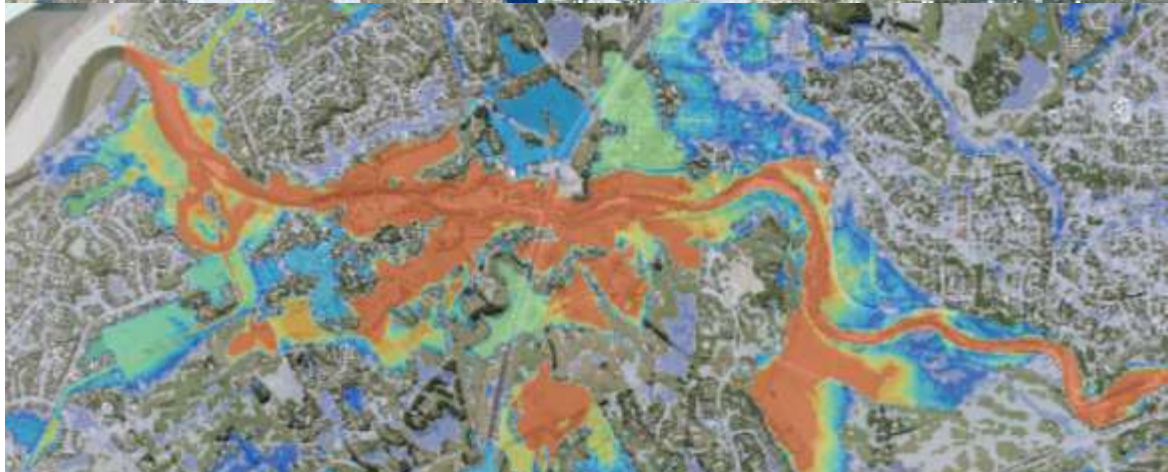
RA1 – National Flood Mapping:

Create a semi-automated system and methodology for nationally consistent flood maps for a range of design storm events, including climate change impacts, validated against a database of historical floods.



Flood Modelling testcases

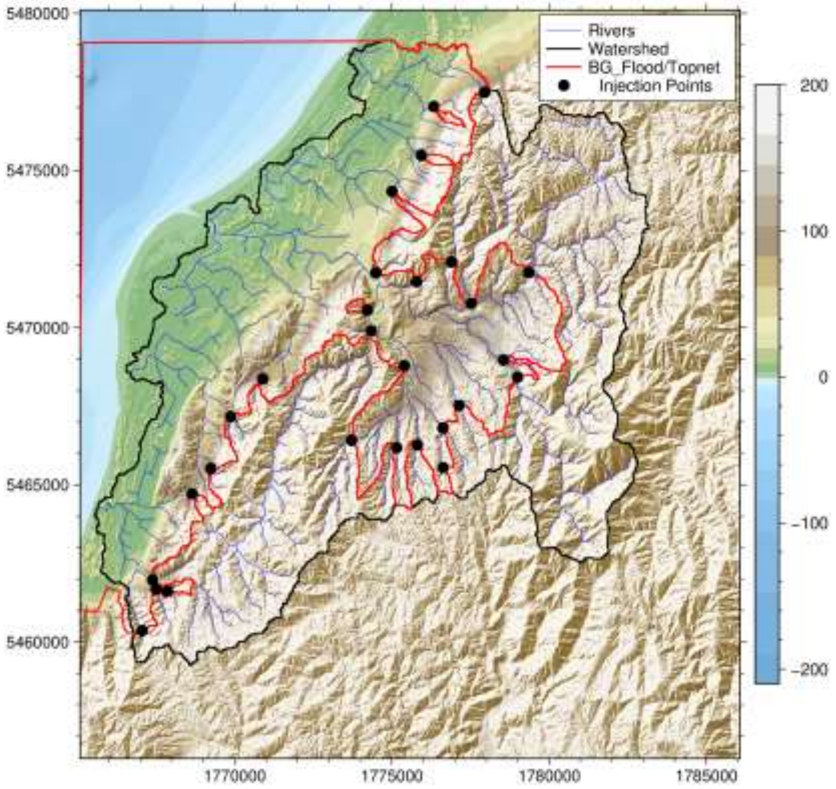
- Flood Modelling workflow
- Westport testcase
- Waikanae testcase
- Showcase design flood



Flood Modelling workflow

Creation of the domains

Creation of simulations domain based on catchments.



Separation in an Upper Catchment and Lower Catchment areas
(based on geographic characteristic and data availability)

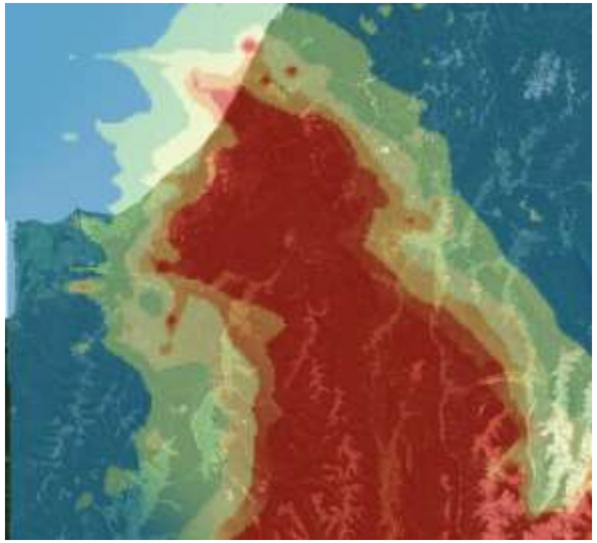
<u>Upper Catchment:</u>
Hydrology code
TopNet (-)

<u>Lower Catchment:</u>
Hydrodynamic code
BG_Flood (-)

Rain input

Validations runs:

- Use of observations interpolated to create space and time varying maps (VCSN)



Ideal floods runs:

- Creation of ideal storms for current and future climate conditions
- Based on HIRDS (High Intensity Rainfall Design System V4)
- Time shape based on catchment accumulation time

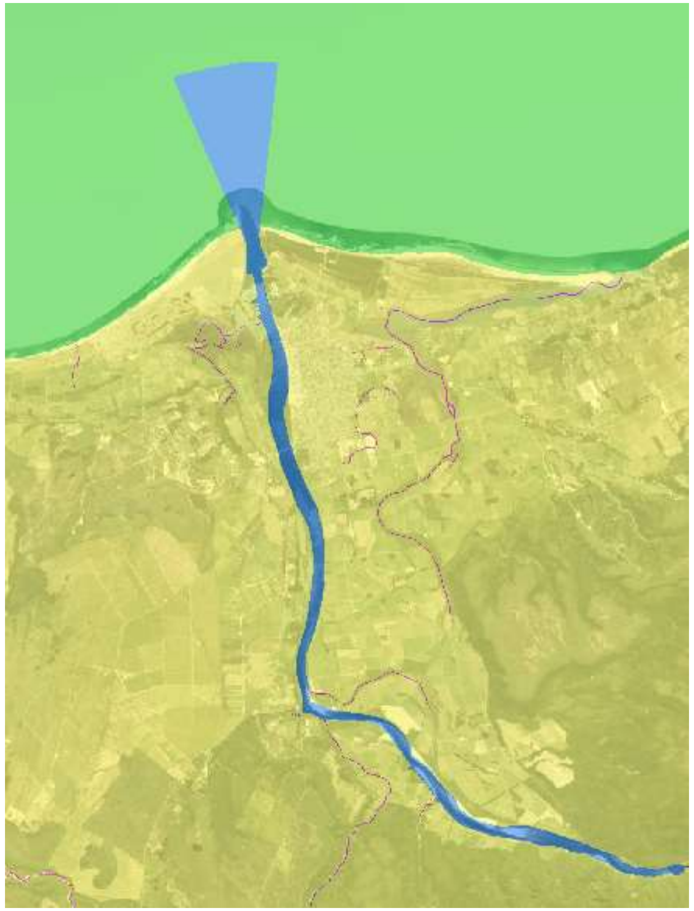
Geofabrics :
Automatic generation of the maps

Creation of an Hydrologically conditioned DEM (Digital Elevation Model)

- Extraction of LiDAR data
- Remove bridges
- Add sea iso-contours
- Estimate the River Bathymetry
- Add estuary fan (for big rivers)
- Adding a river bathymetry
- Using OSM (Open Street Map) to include drains, culvert, streams

Creation of the roughness map

Available on: *https://github.com/rosepearson/GeoFabrics*



Different source origin
(■: LiDAR, ■: River bathymetry,
■: Sea contours, ■: OSM)

Use of Open Street Map to improve hydro-conditioning

Topnet: hydrology model

The NIWA hydrological model, calculating water balance at a reach/catchment unit.
Used uncalibrated with the soil conductivity model (mapped infiltration rate).

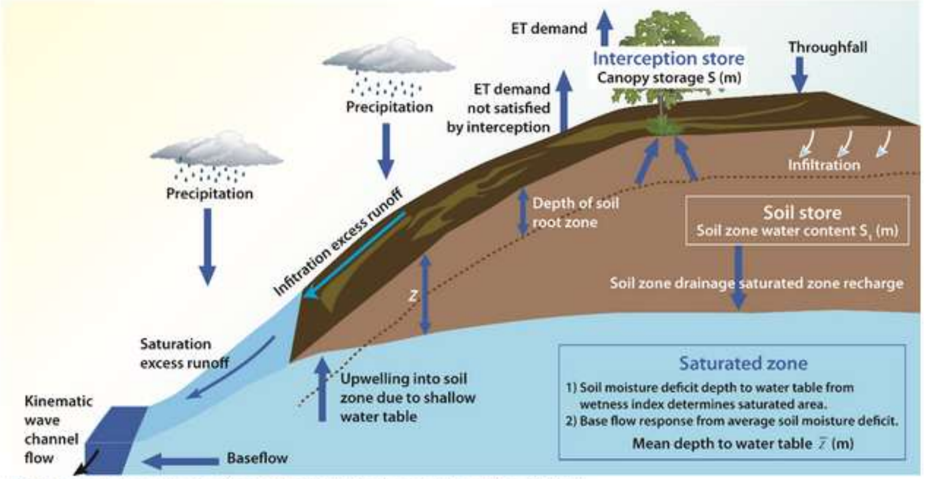
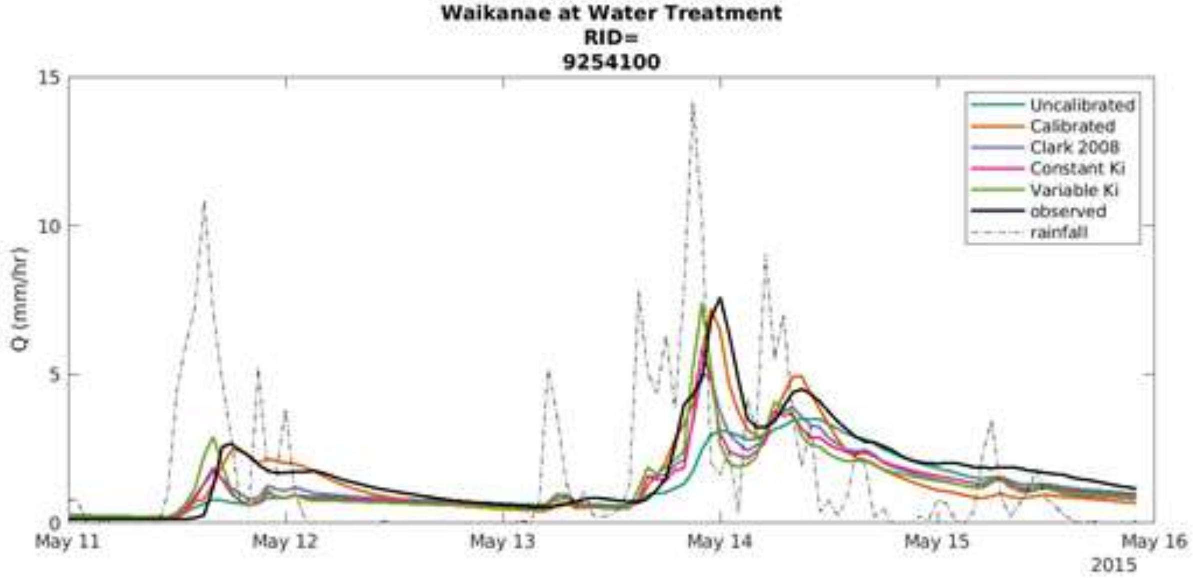
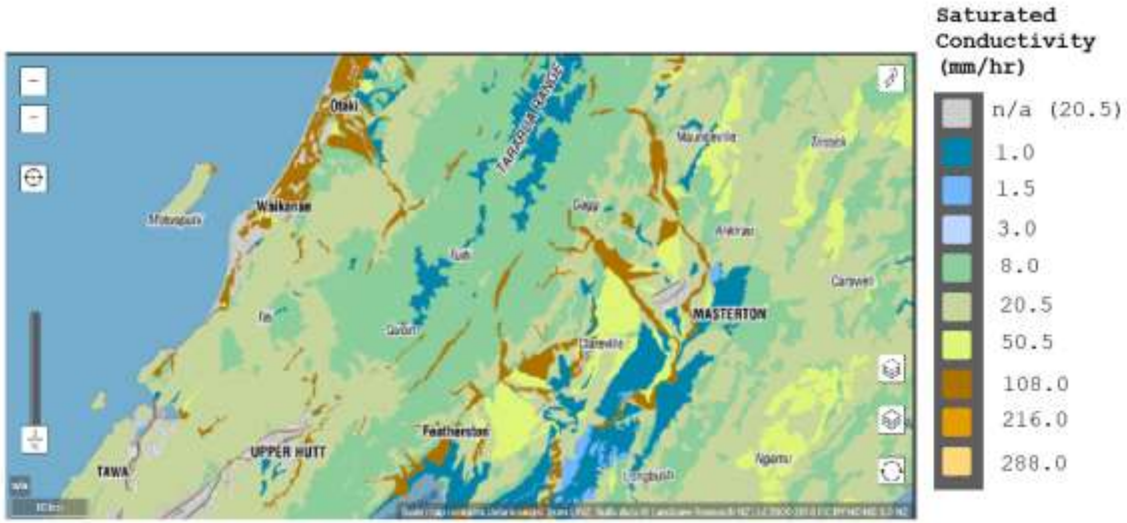


Fig. 1: Schematic representation of the water balance component of TopNet (adapted with permission from Bandaragoda et al., 2004)



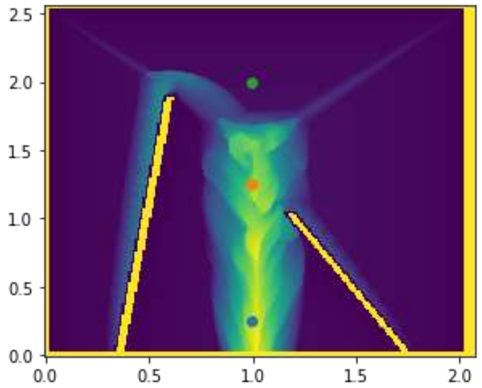


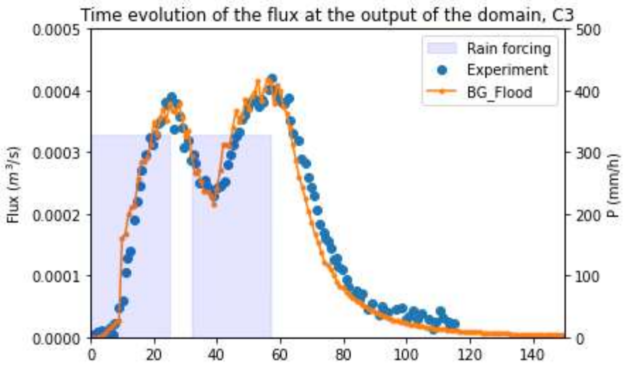
Hydrodynamics model: BG_Flood

Fast, open-source, multi-hazard, inundation model

- Compounding (e.g. Tsunami + storm surge + river flooding + rain) → Shock-capturing SWE
- Short setup time + short run time → GPU + No GUI + BUQ
- No license fee + hackable → Existing open SWE engine?

CEA2008 benchmark test: Uniform rain on grid





Aureli2020 benchmark test: Non-uniform rain on grid

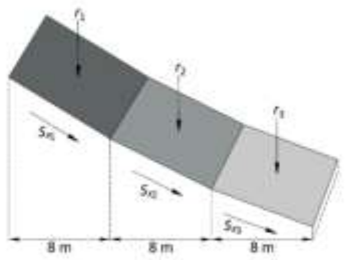
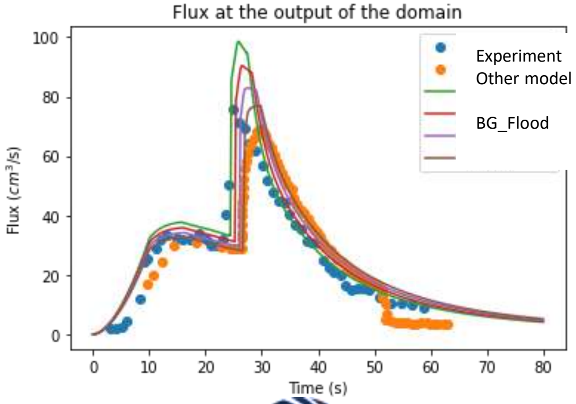


Figure 3. Domain schematization for the three planes cascade test case.



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https://github.com/CyprienBosserelle/BG_Flood

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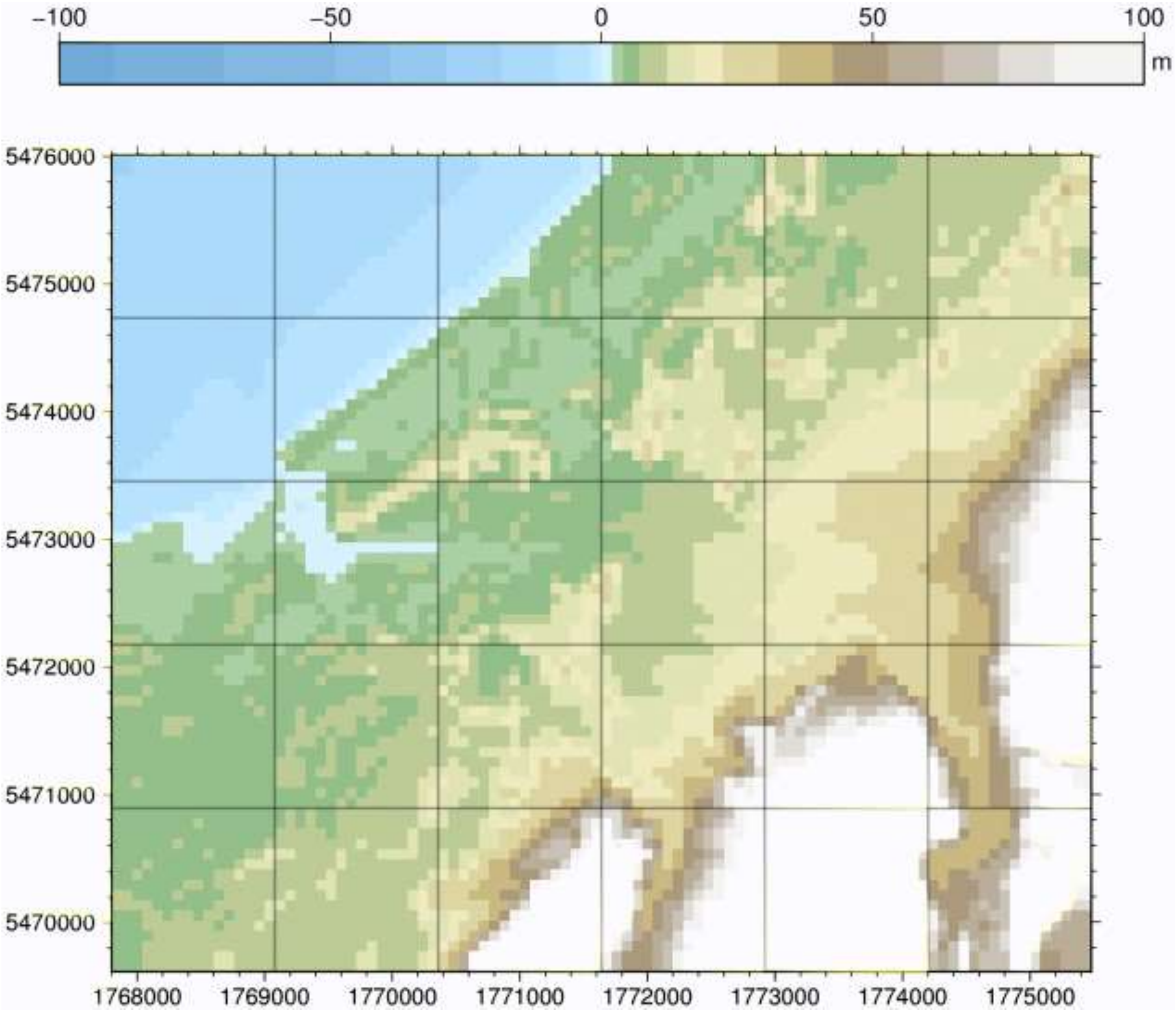
BUQ grid


−100
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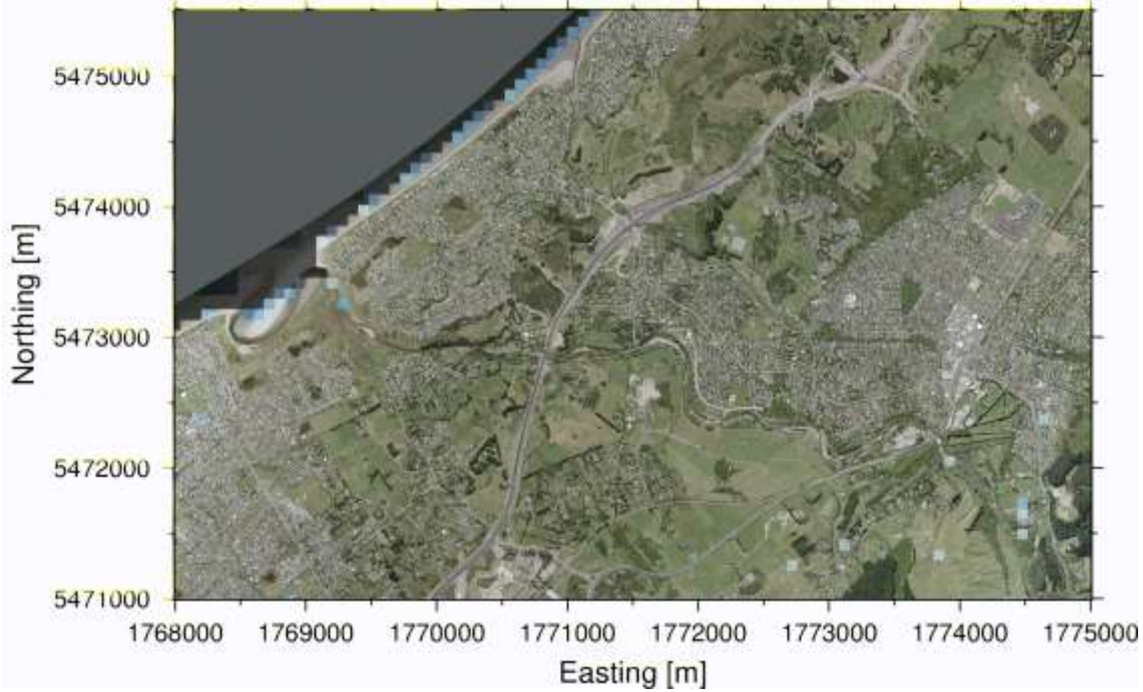
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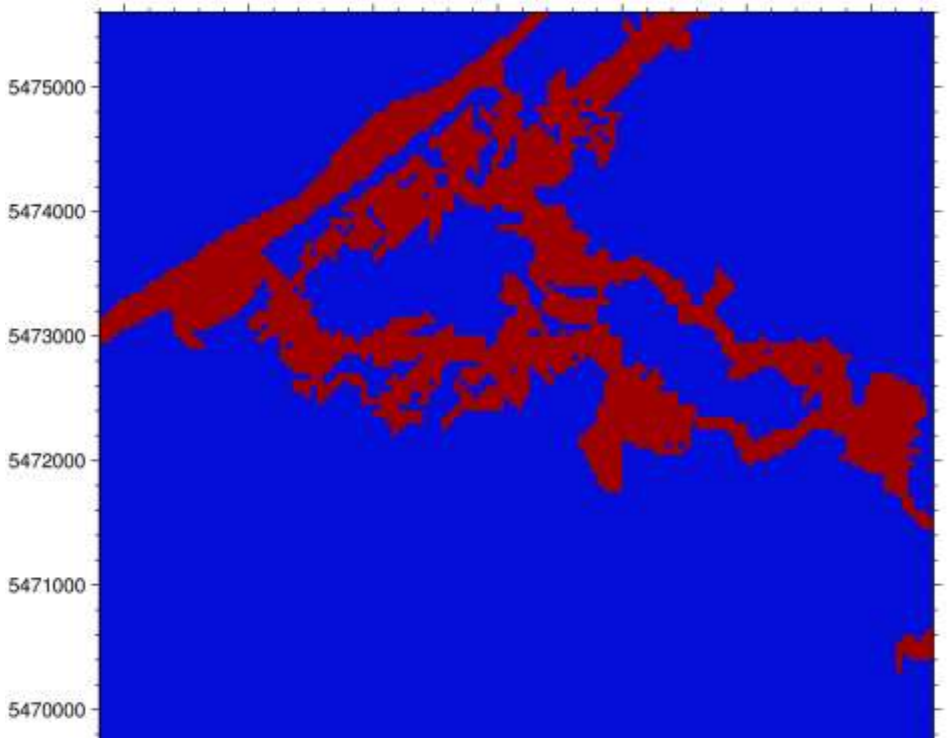
Easting [m]


5475000
5474000
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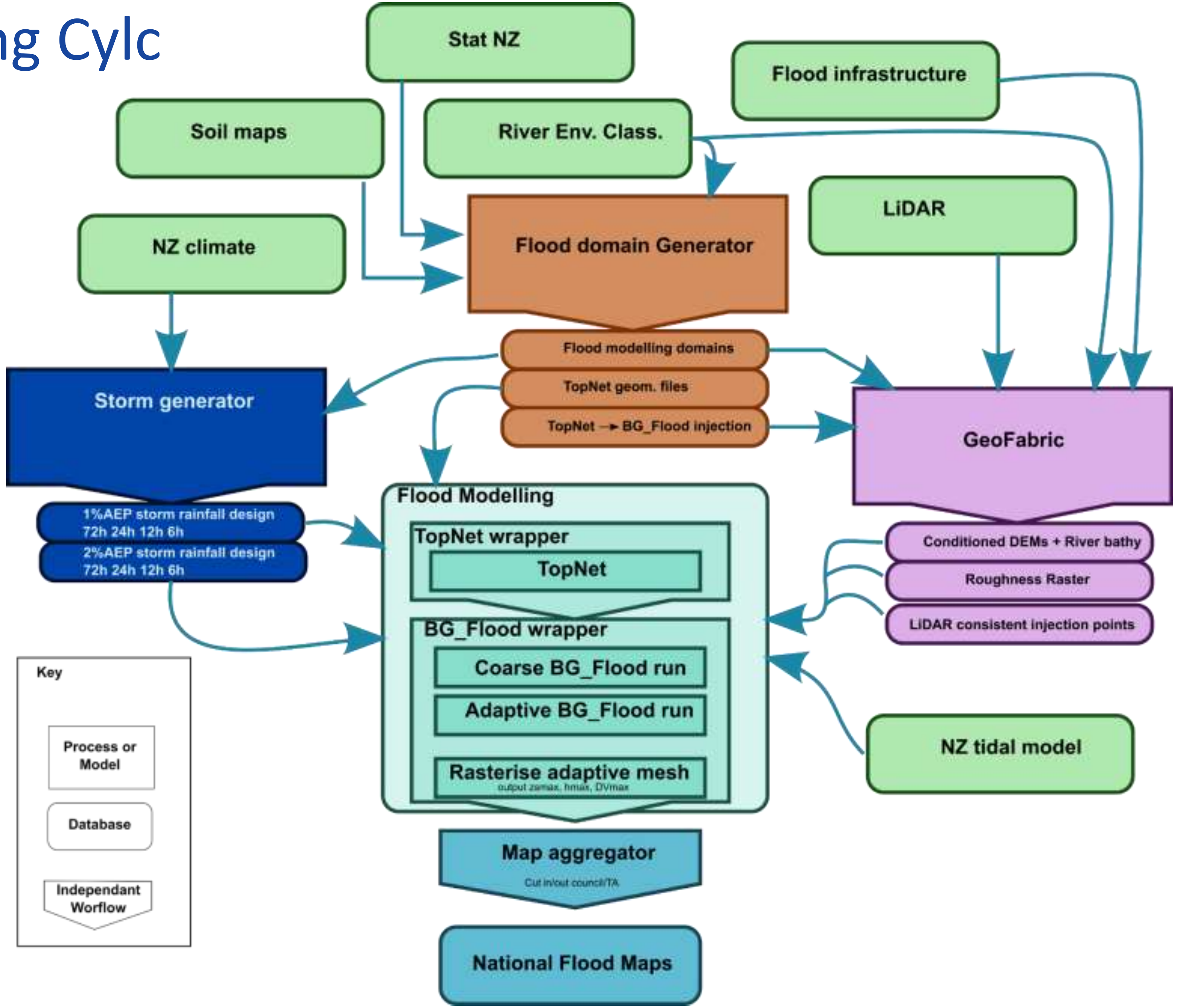
5472000
5471000
5470000

Workflow automation using Cylc

More granularity:

- 5-year TopNet
    - Choose representative antecedent conditions
- BG_Flood hotstarts
- Aligning tide with peak flow



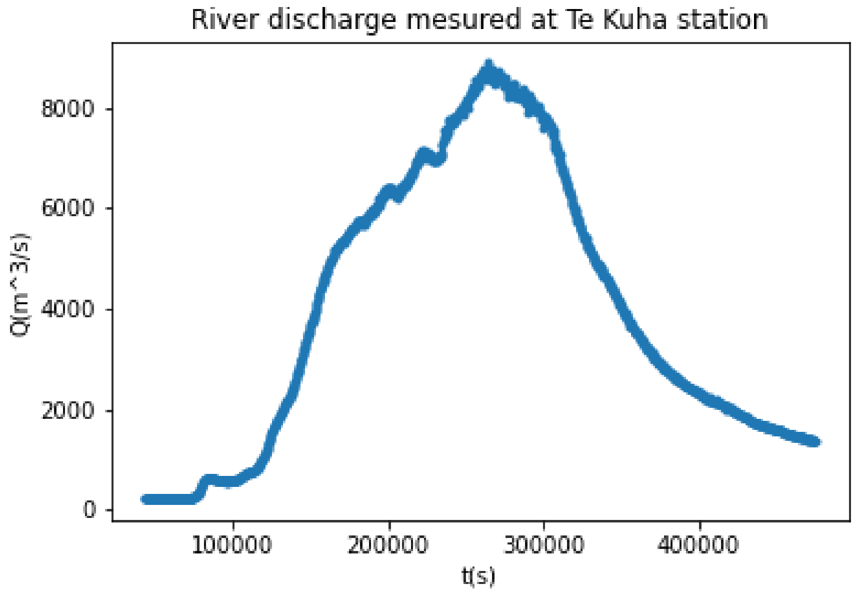
The Westport testcase

Westport test-case: the July 2021 flood event

- Peak flow at Te Kuha (Buller gorges): 8886 m^3/s
- ~ 50 years return period
- Water elevation measurements in the Westport area

Water level measurement locations

Flood maps from observation points



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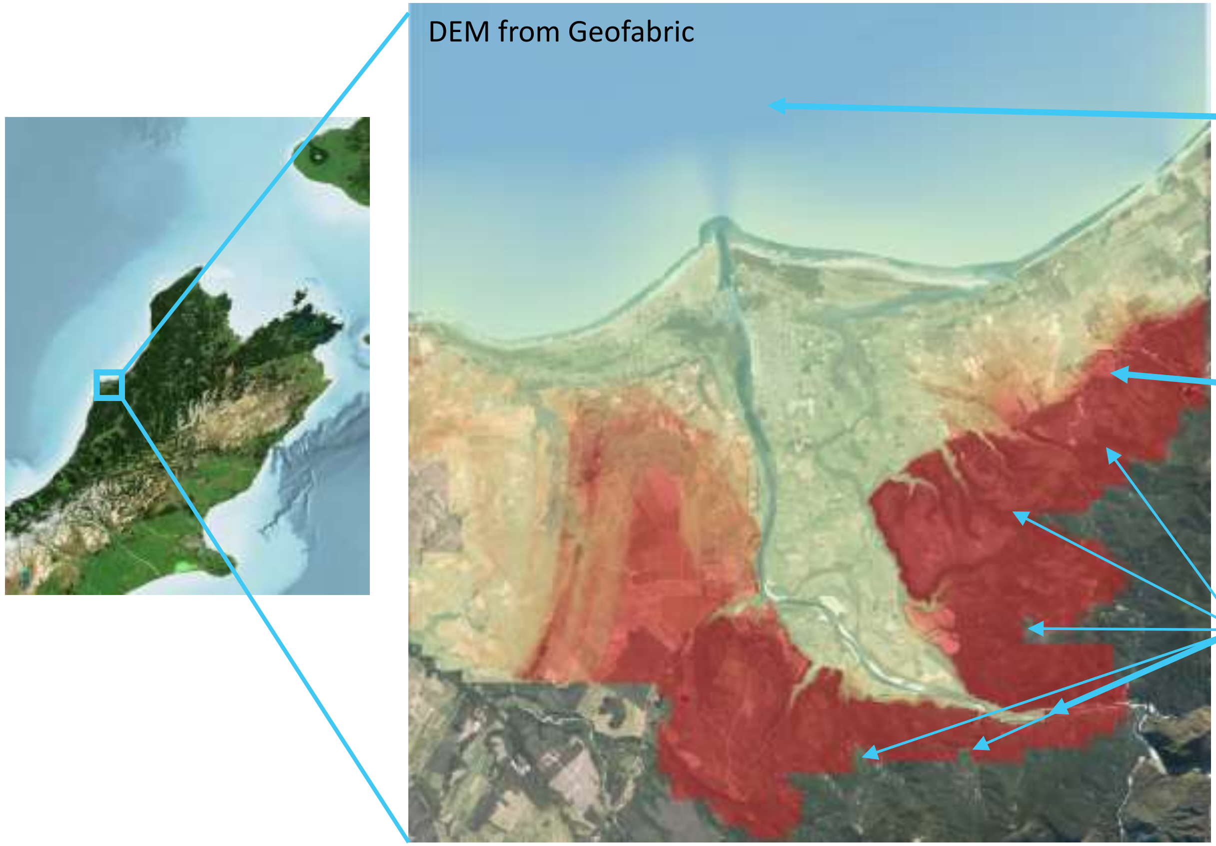
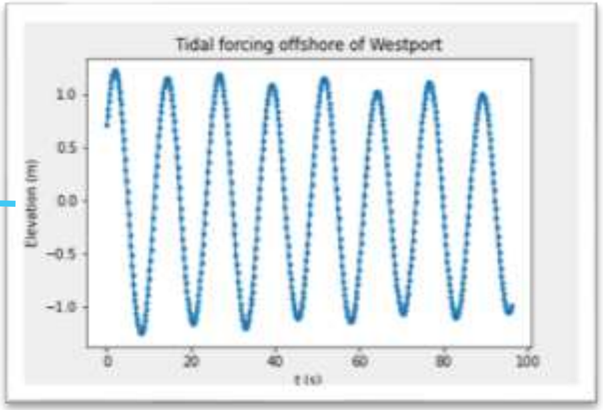
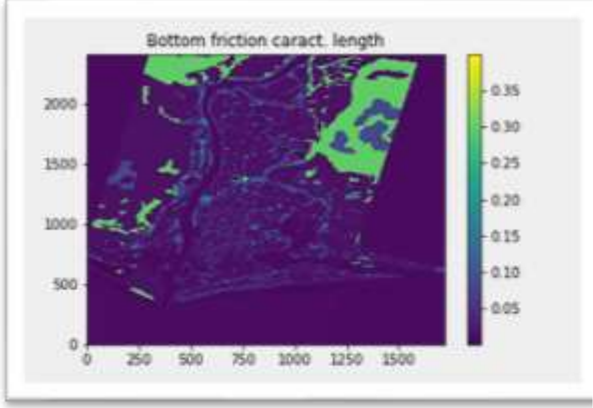
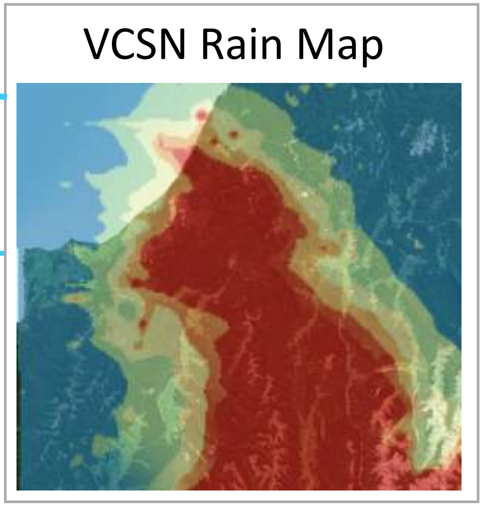
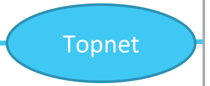
Westport test-case: the July 2021 flood event

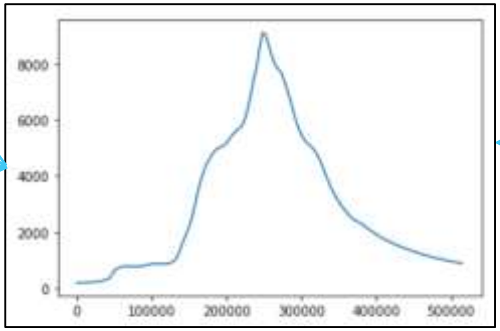






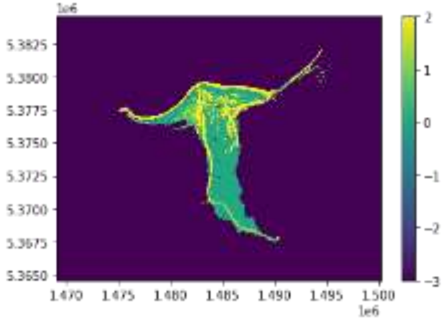






Discharge at Te Kuha

Use of an adaptative mesh,
from 10m (yellow) to 40m (purple) resolution:



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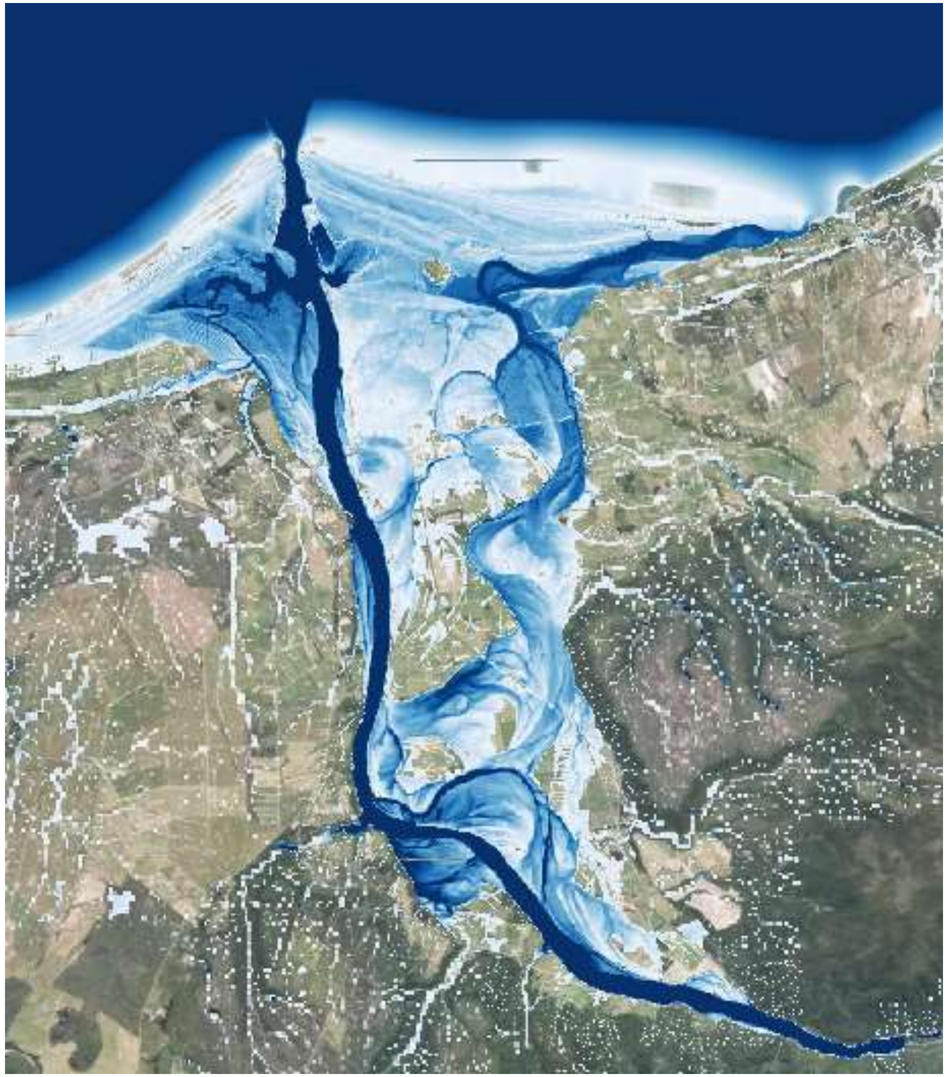
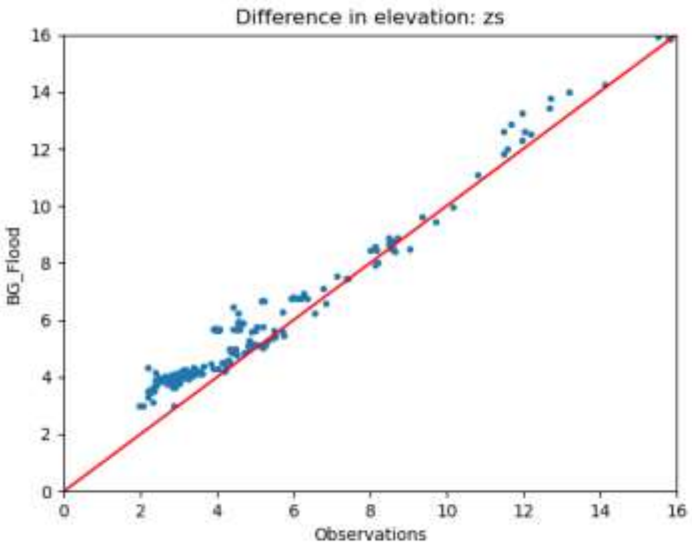
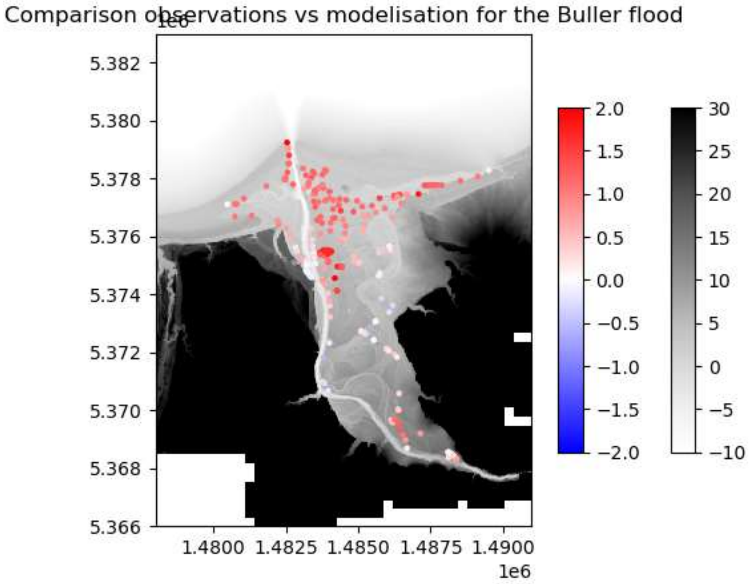
Increasing flood resilience across Aotearoa

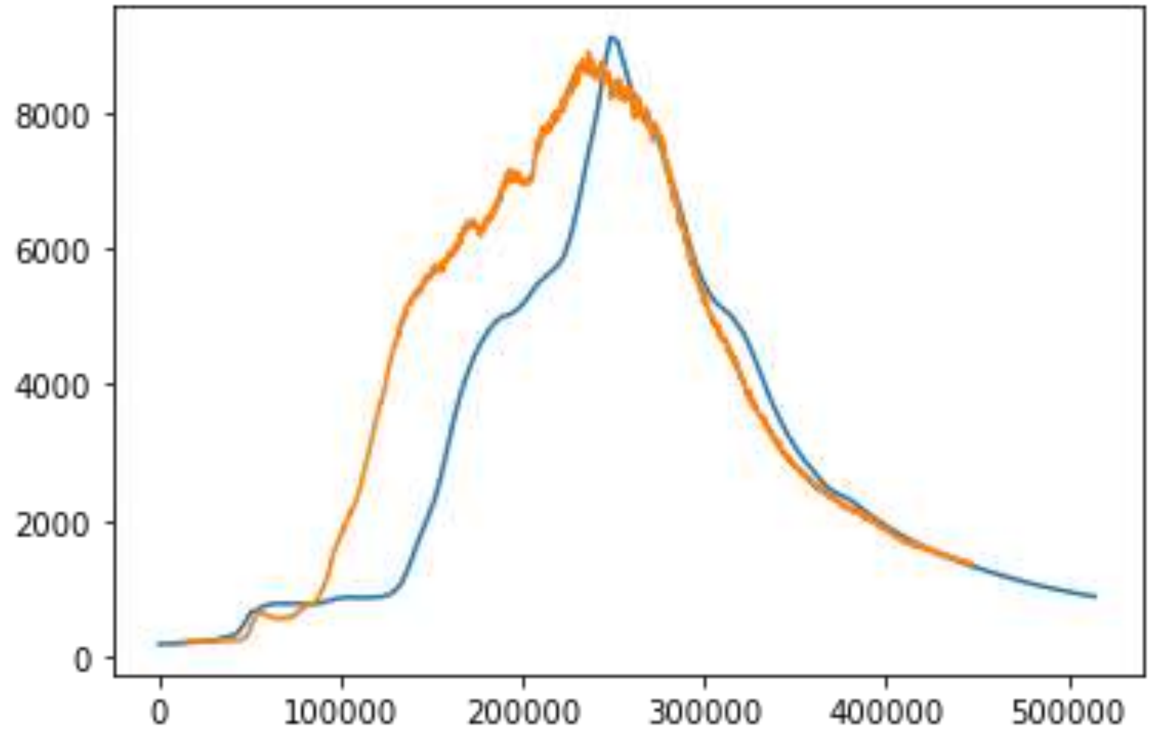
Initial results using VCSN rain forcing, TopNET hydrographs and the automatic DEM generation



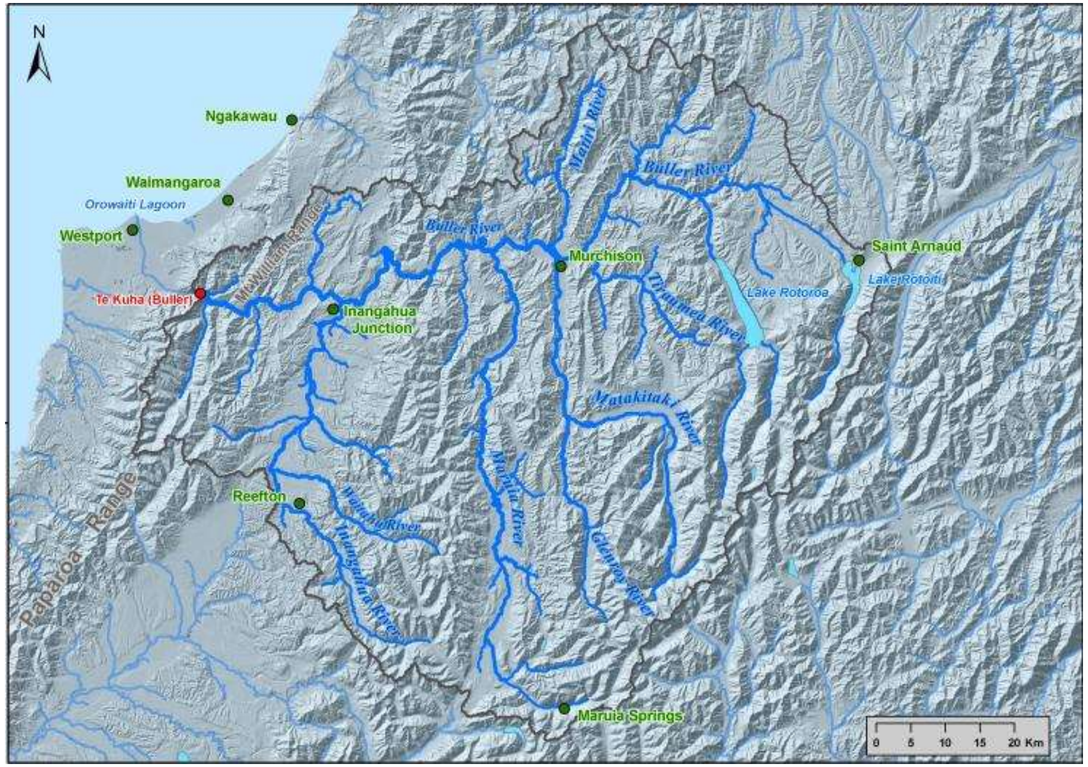




Topnet vs Observation at TE KUHA



Flow rate at Te Kuha; Topnet Ki model, Observations



Map of the Buller catchment, West Coast.

DEM hydrodynamic conditioning and bathymetry creation process by Rose Pearson

- DEM (digital elevation model) based on LiDAR

⇒ Bridges are seen as walls
⇒ does not contained drains (or culverts)
⇒ Usually does not have the river bottom (only water surface)

- River bathymetry is computed using the "natural geomorphology" hypothesis that a bank full flow is the 2.33 years return period flow and the depth and flow are connected by Manning's equation. Bankfull width and slope are from Lidar observations and REC information is used for bottom friction.

$$h = \left(\frac{nQ}{wS^{1/2}}\right)^{3/5}$$

- Limitations:

  River widths may not be "natural", especially:
  - River mouths (outside of REC and tide input)
  - Gorges, modified banks (walls) or other river infrastructure

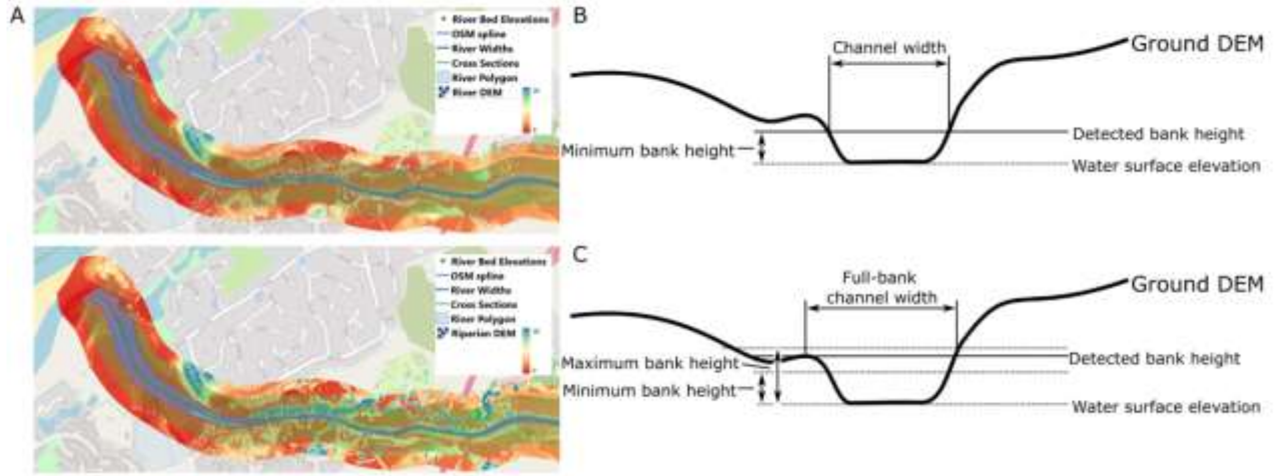
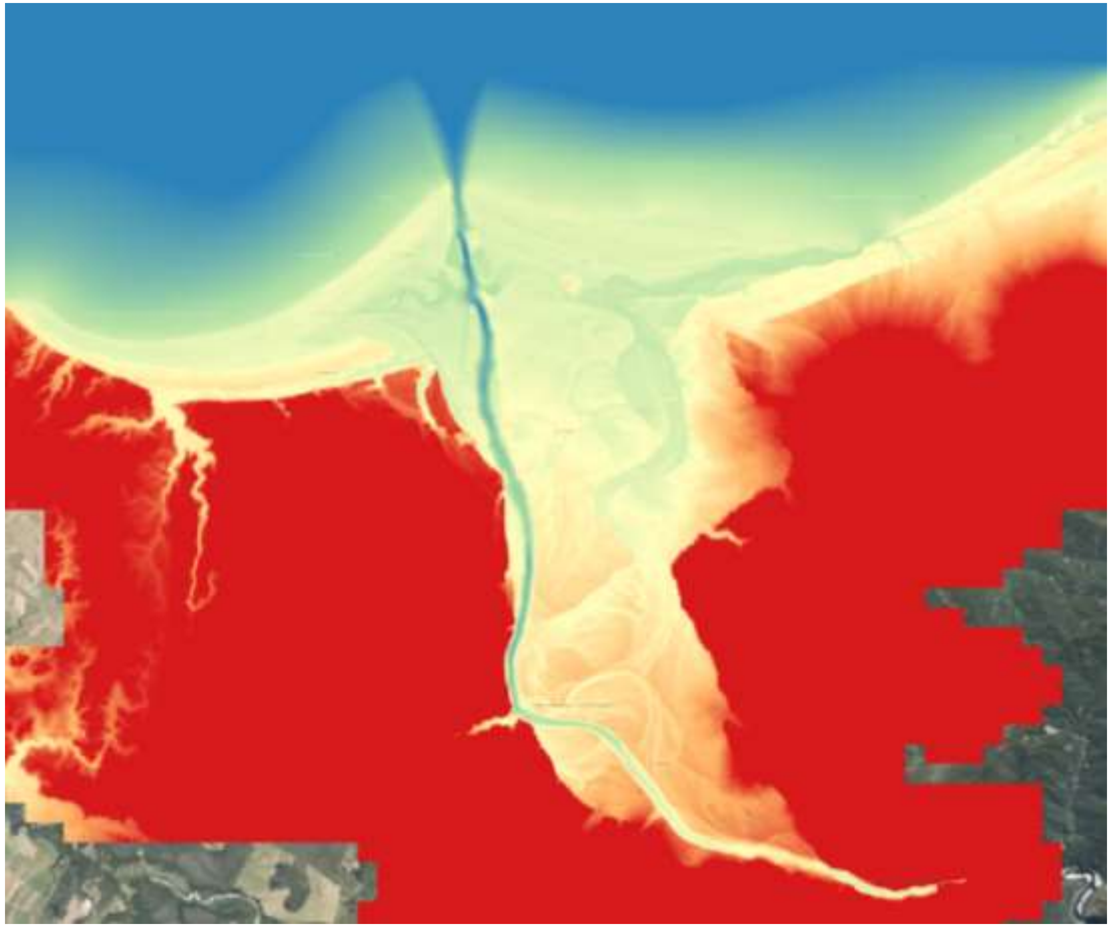


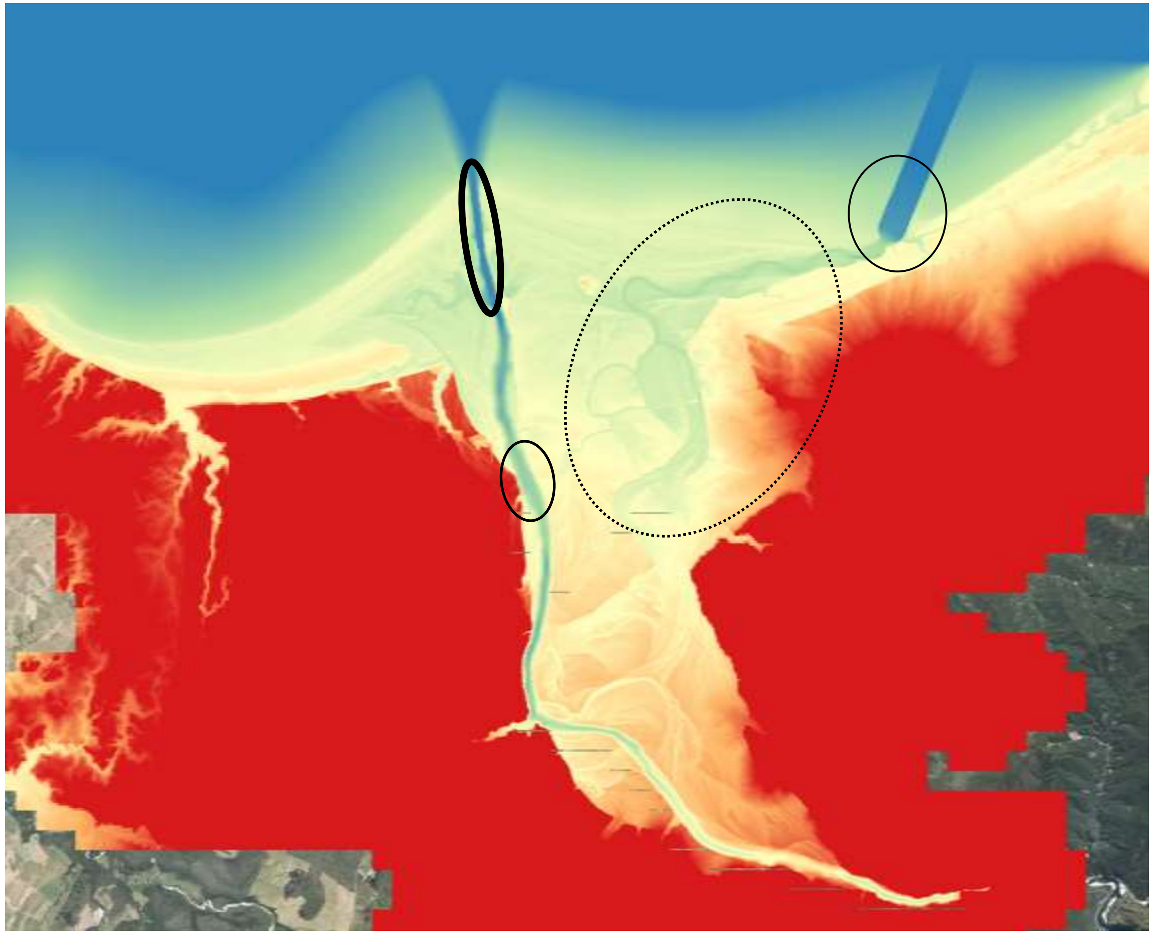
Figure 2: The bank detection algorithm. A. The river (top), and riparian (bottom) DEMs and regularly sampled cross sections. B. The fixed threshold bank detection algorithm applied to each cross section. C. The variable threshold bank-full flow detection algorithm applied to each cross section.

Map of Westport

Manually improvement of the DEM



Automatically created DEM



Manually modified DEM

Evaluation on a 2 years return period flood event

Evaluation on the July21 flood event

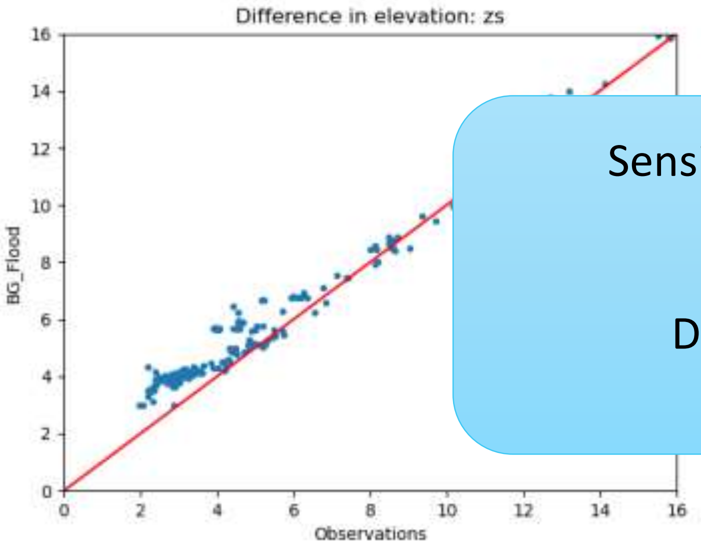
Automatic DEM

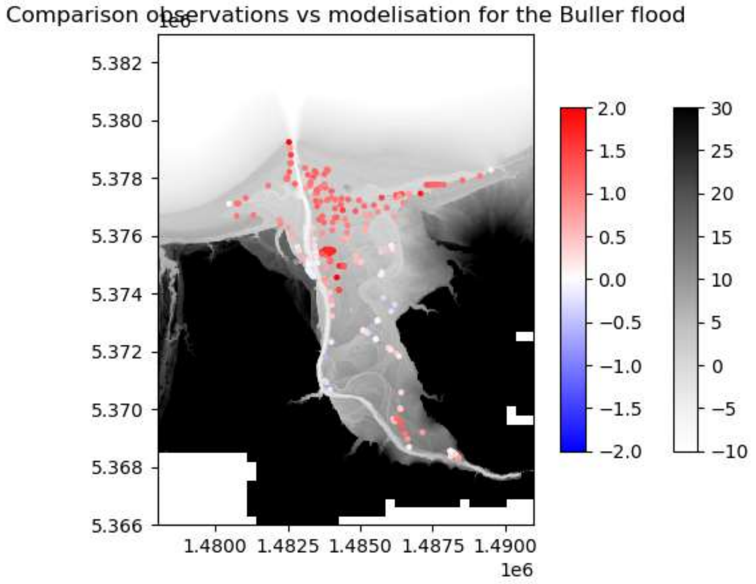
Manually improved DEM

Observations

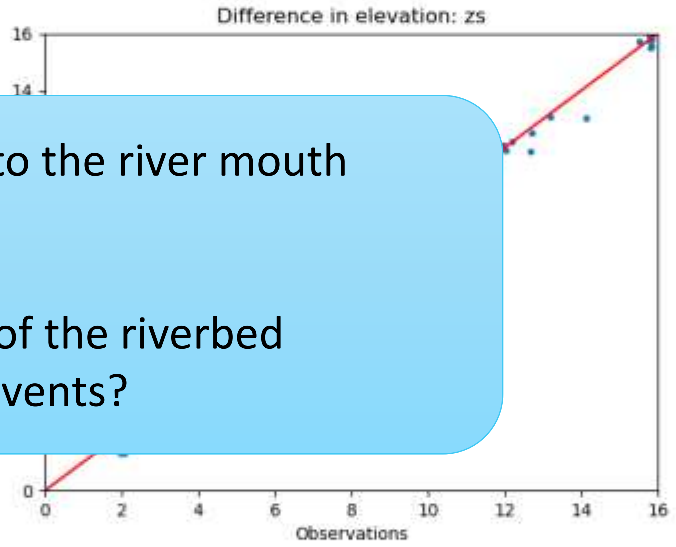
Evaluation on the July21 flood event

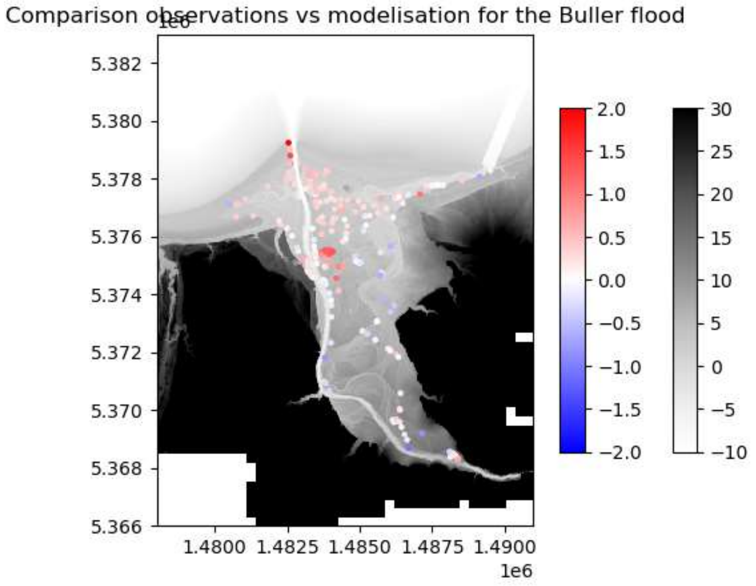
Automatic DEM





Manually improved DEM



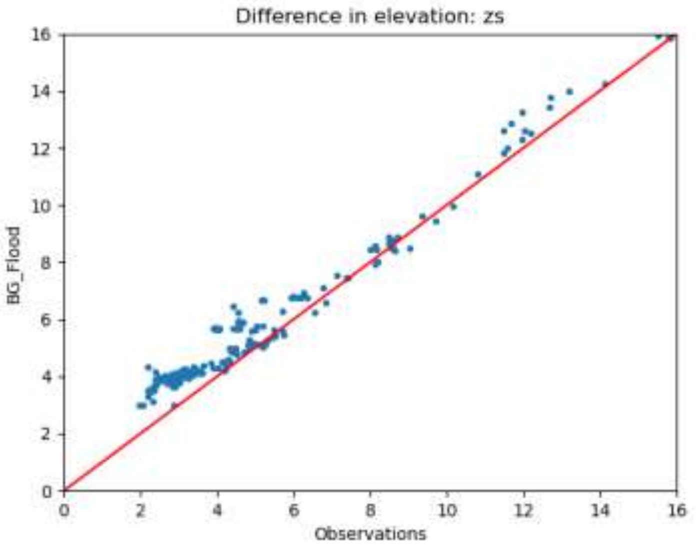


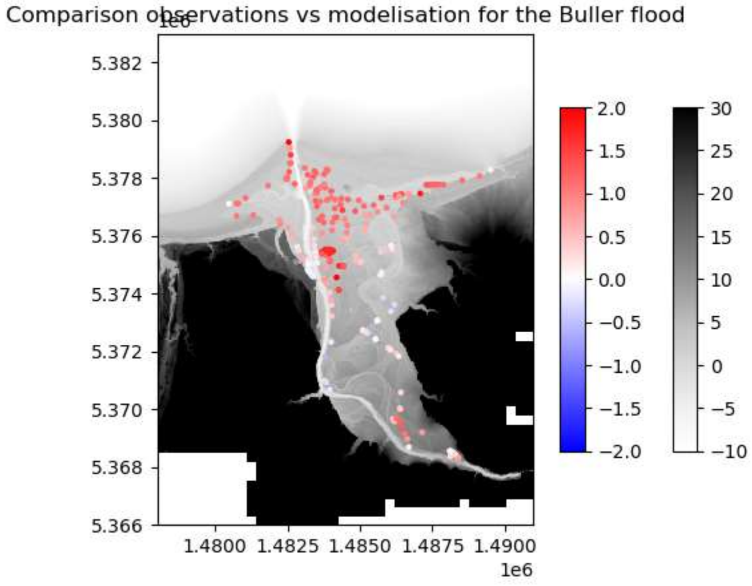
Sensitivity of the flood extend to the river mouth bathymetry

Due to temporary scouring of the riverbed
During large flood events?

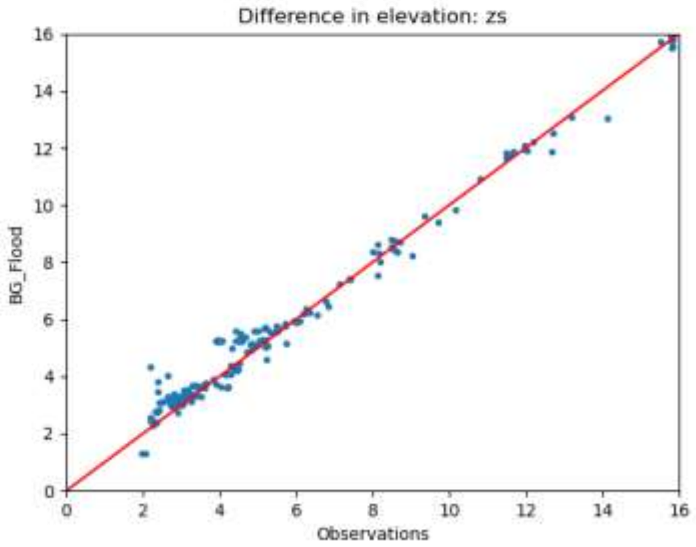
Evaluation on the July21 flood event

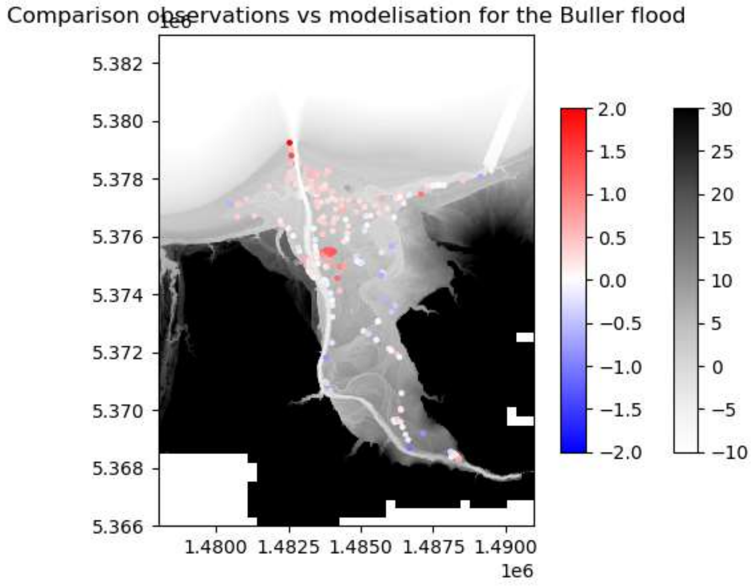
Automatic DEM



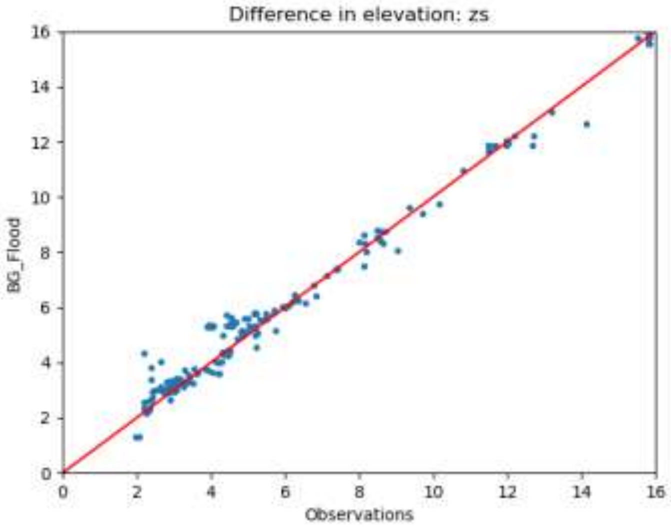


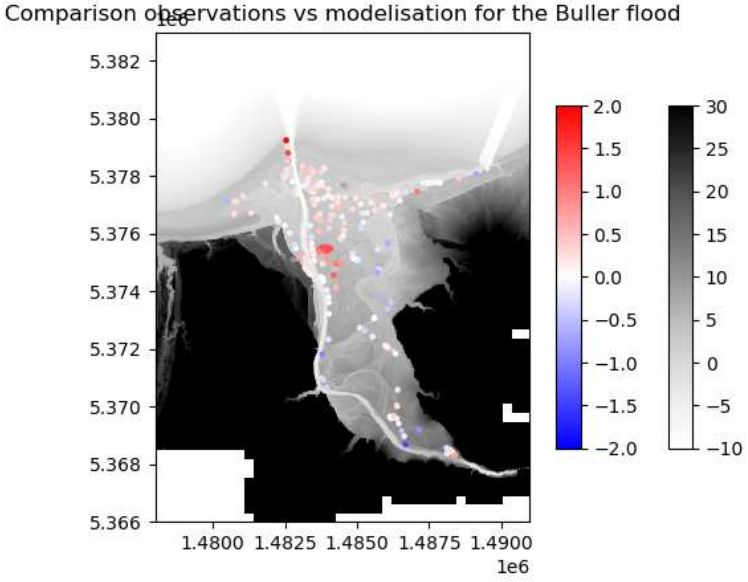
Manually improved DEM



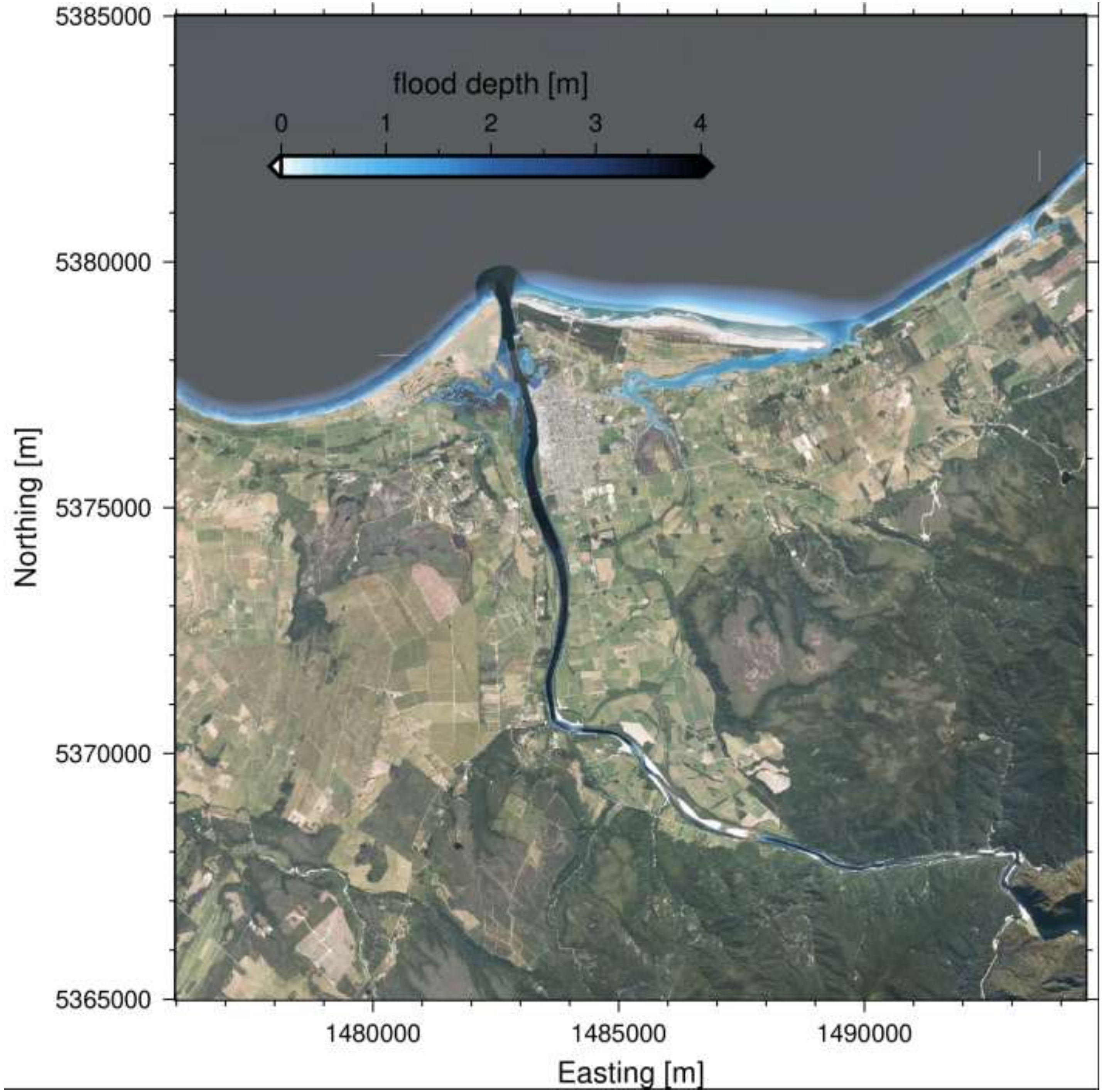


Adding temporary scouring

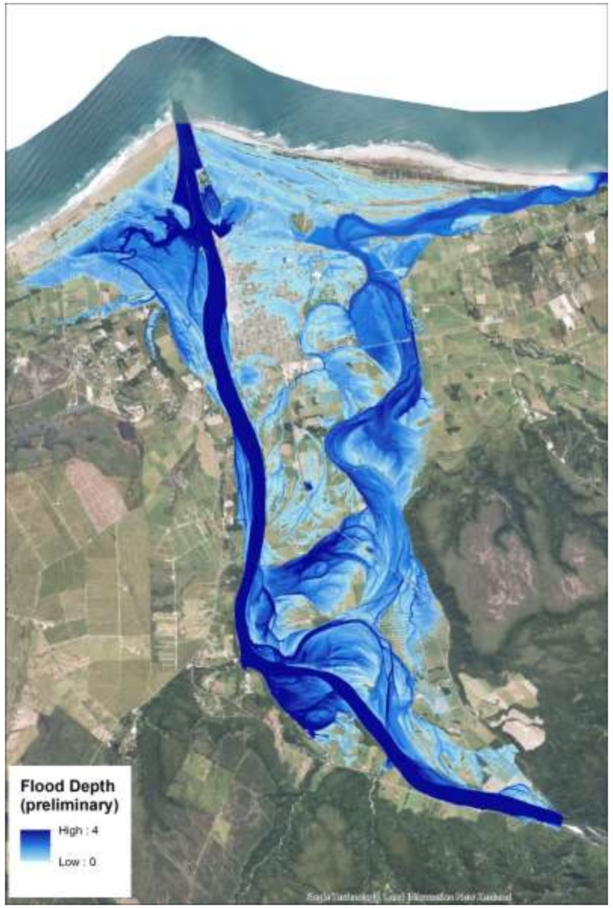


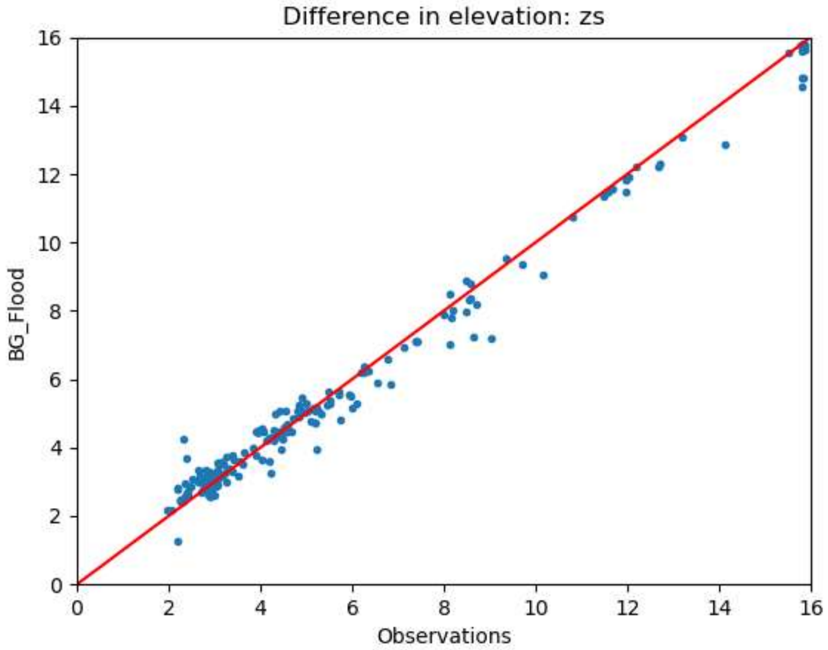


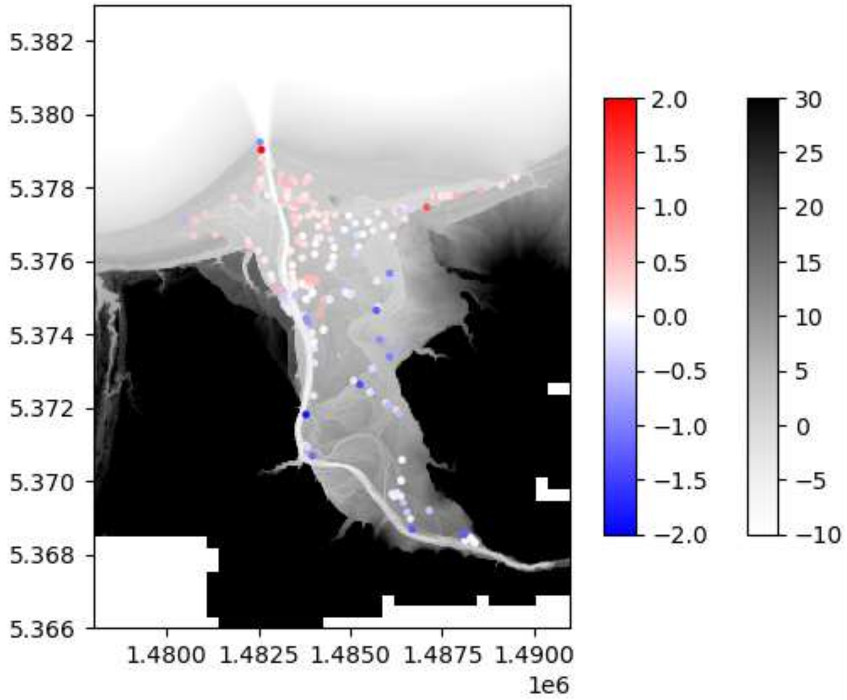
Full simulation using improved automatic DEM generation



Full simulation using improved automatic DEM generation





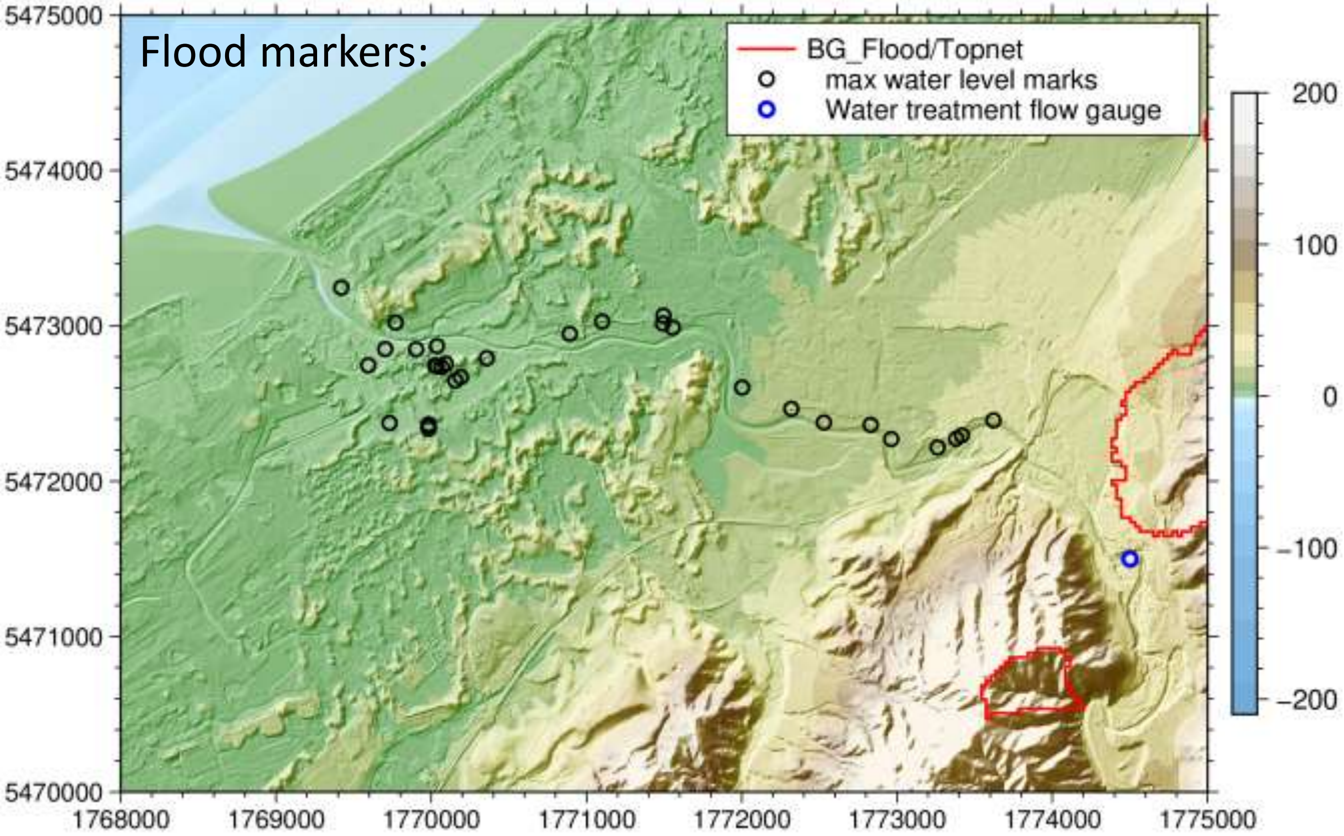


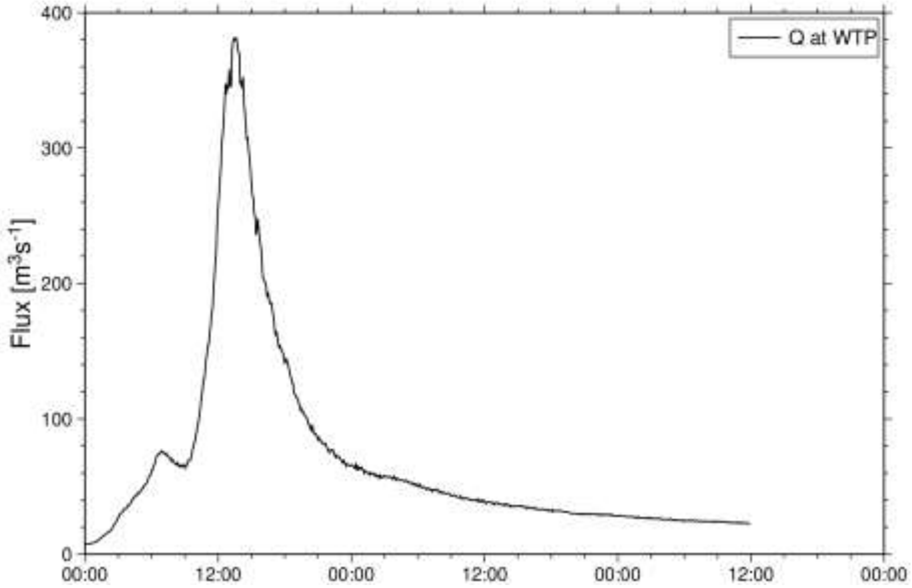
The Waikanae testcase

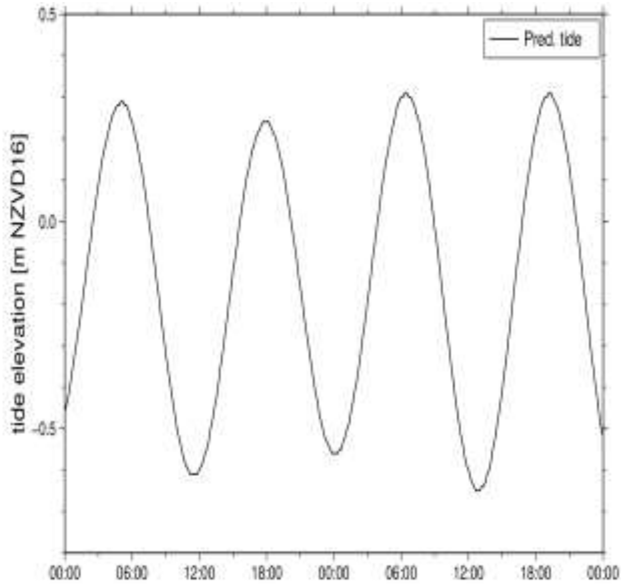
Modelling Validation: 2005 flood event data

~1:80 year return period flow (?)

Peak flow at treatment plant of 380 m^3/s







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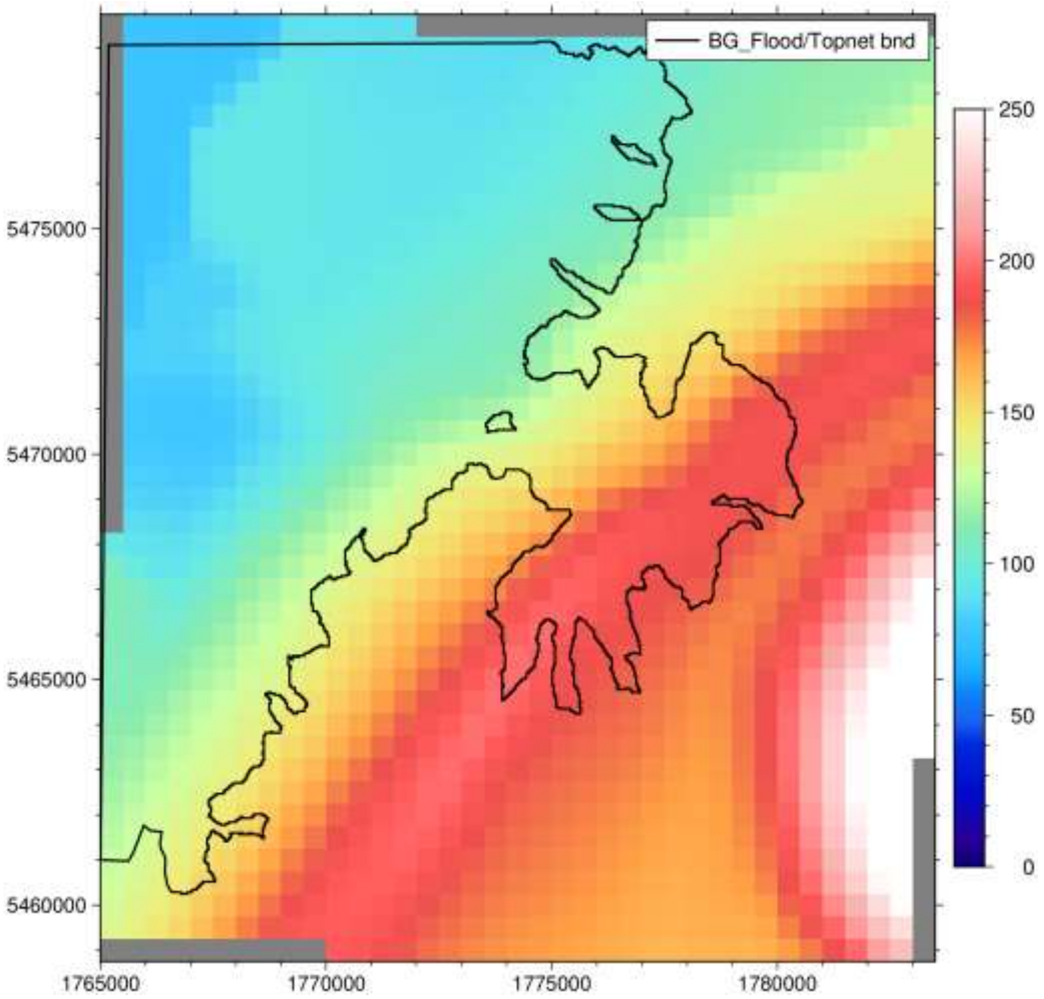
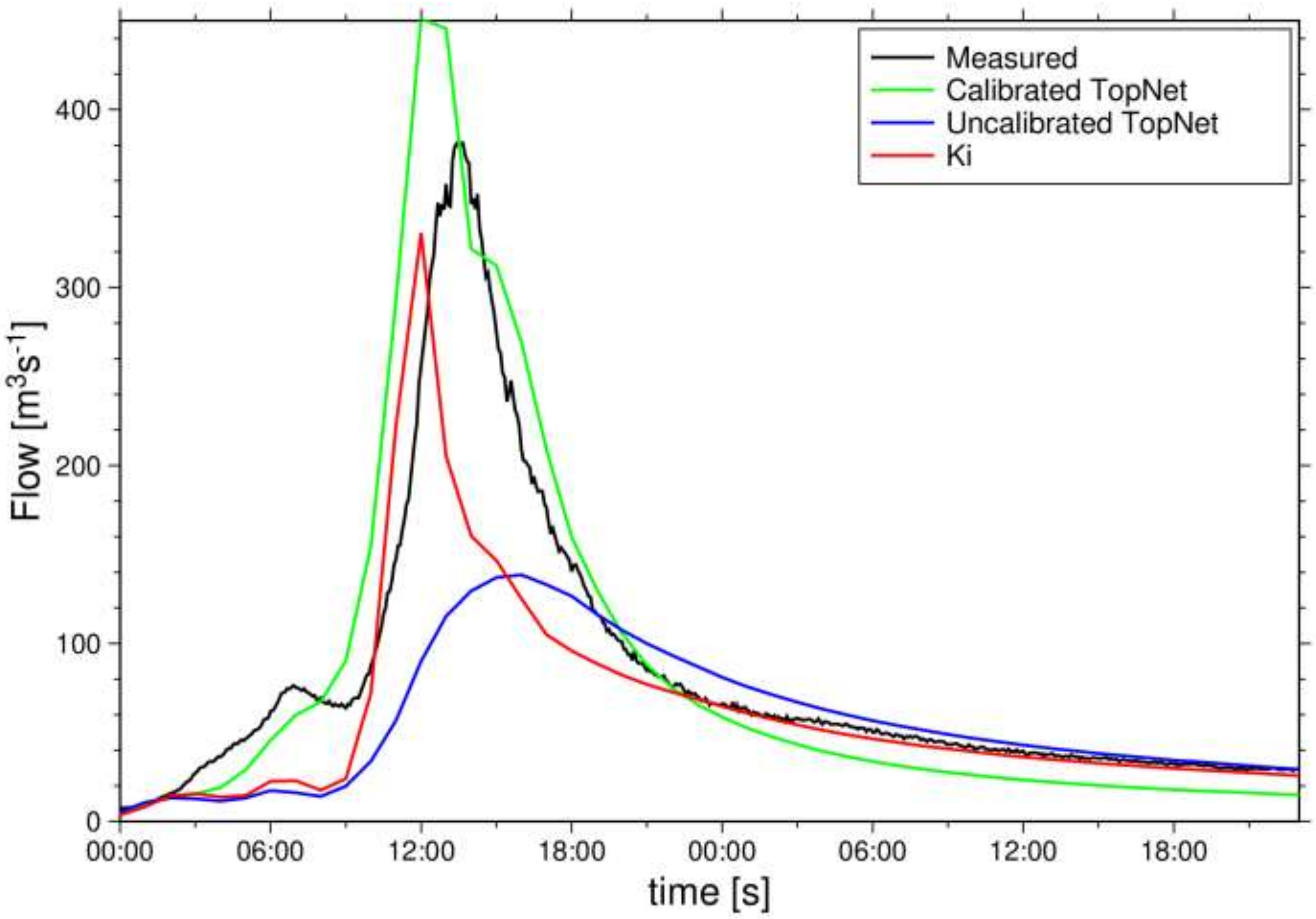
Modelling Validation: 2005 flood event TopNet flows

VCSN rainfall





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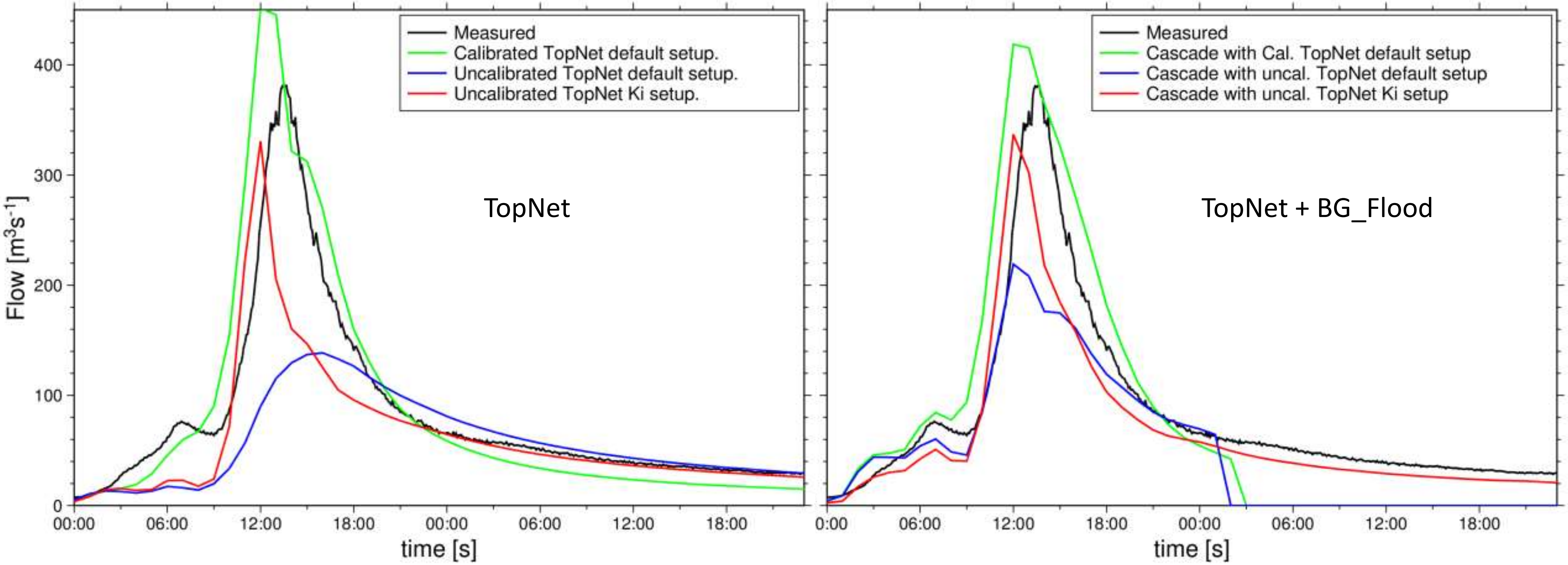
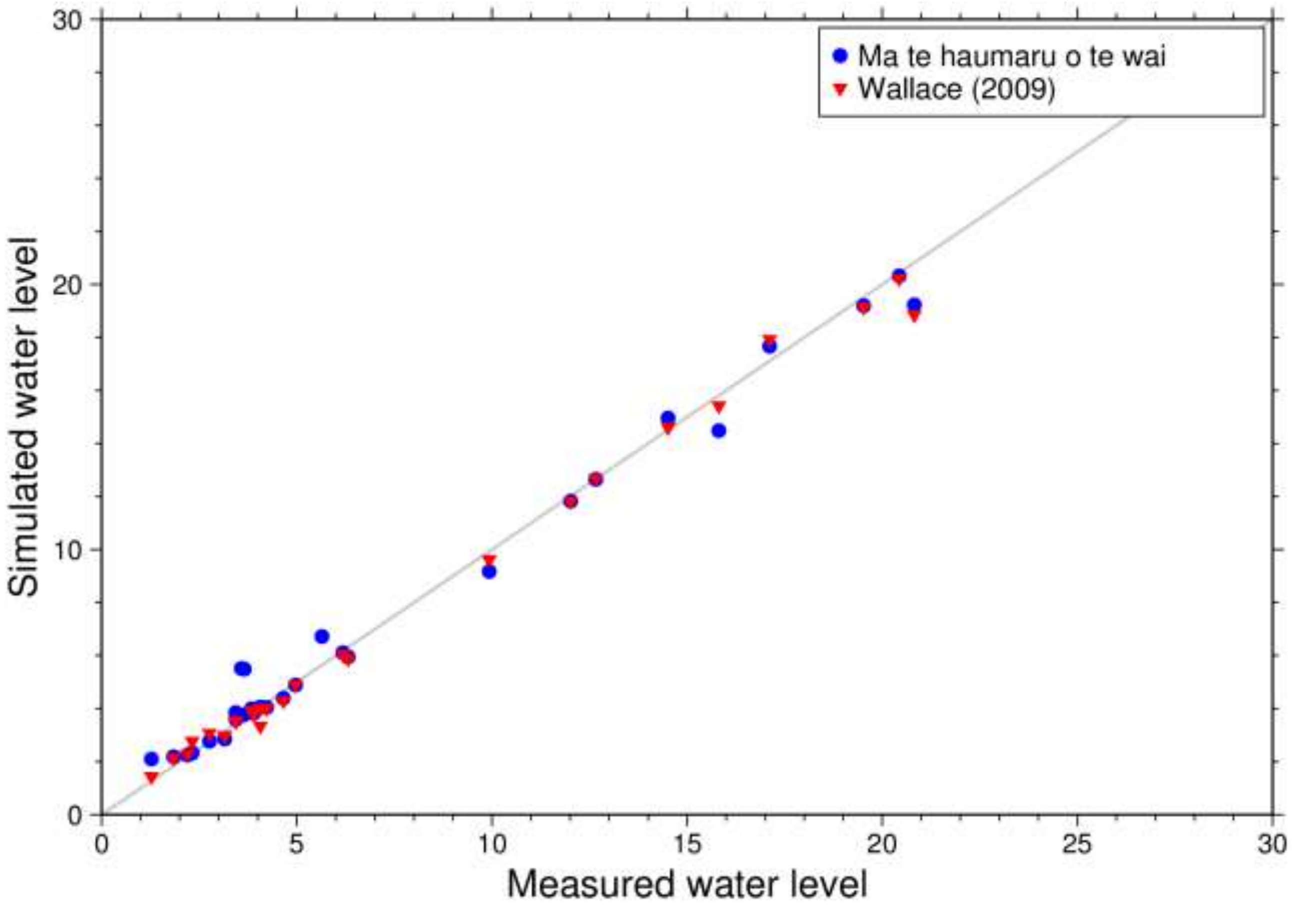
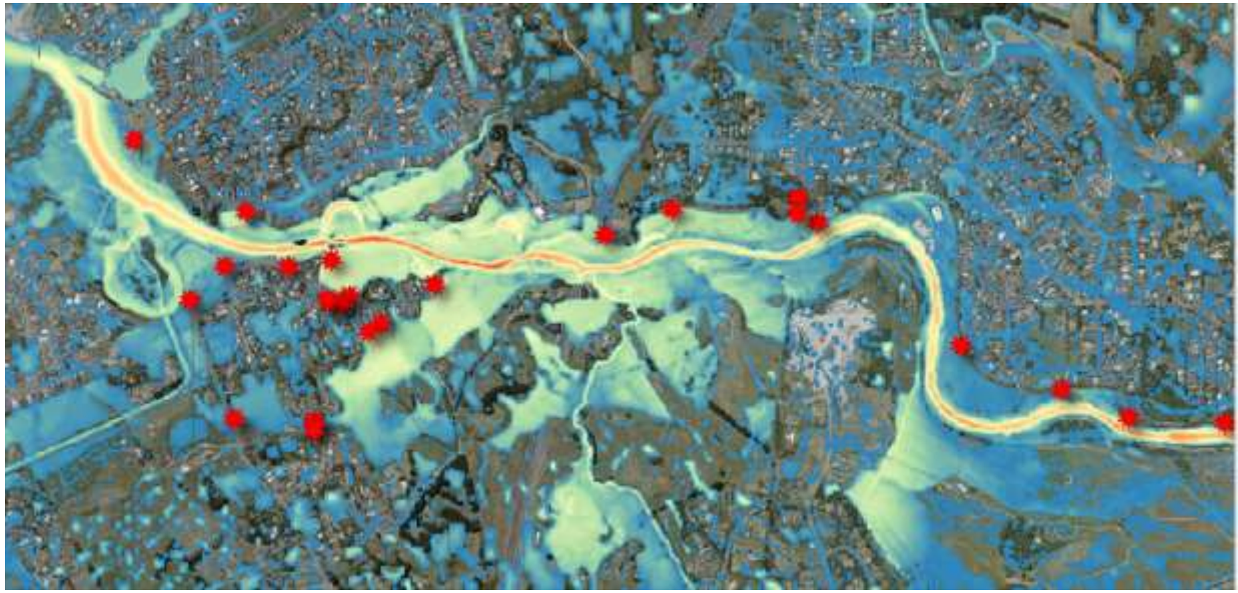
Modelling Validation: 2005 flood event BG_Flood flow



Modelling Validation: 2005 flood level validation



Calibrated (Wallace) vs uncalibrated peak flood levels



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Increasing flood resilience across Aotearoa

A first example of design flood

Design Flood event

- 1% AEP rainfall (12-hrs duration)
- Wet antecedents: TopNET average on 5years

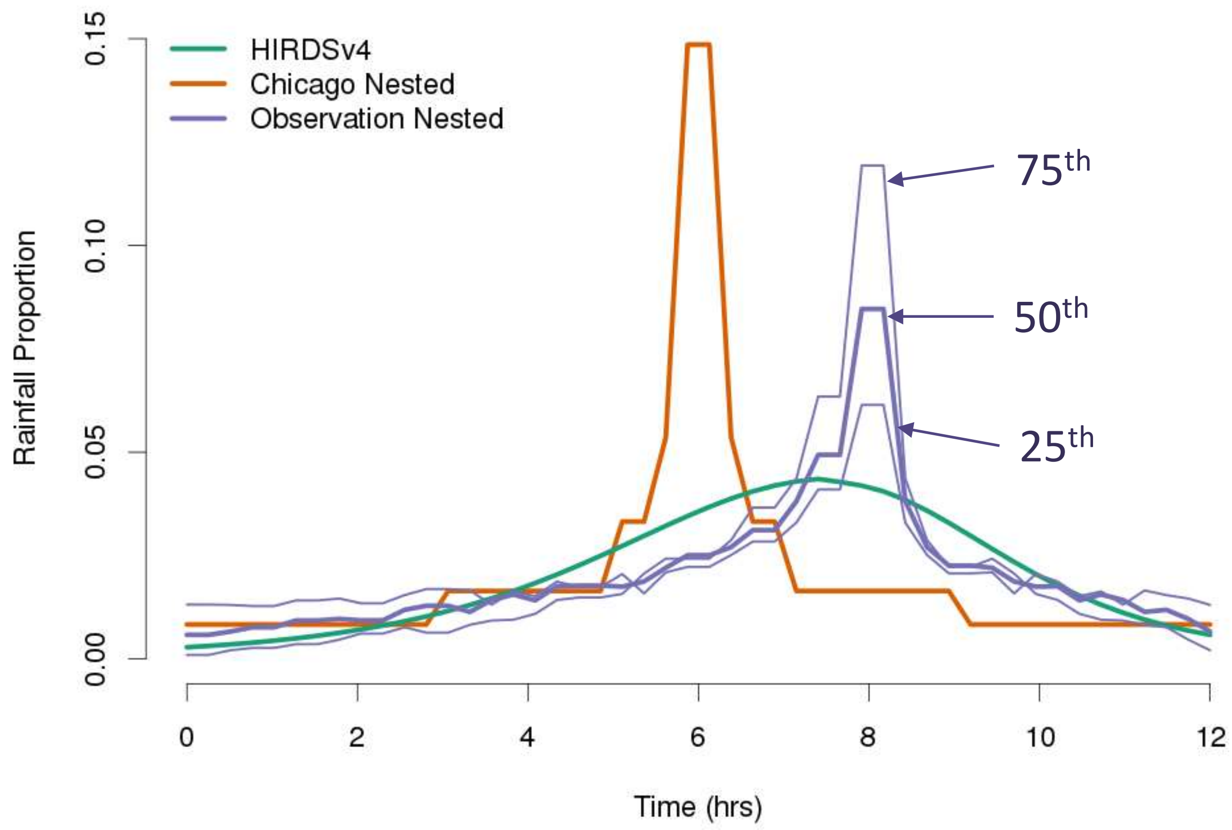
Model for design storm

- HIRDS method too smooth
- "Chicago" nested storm too extreme

Update using observed storms

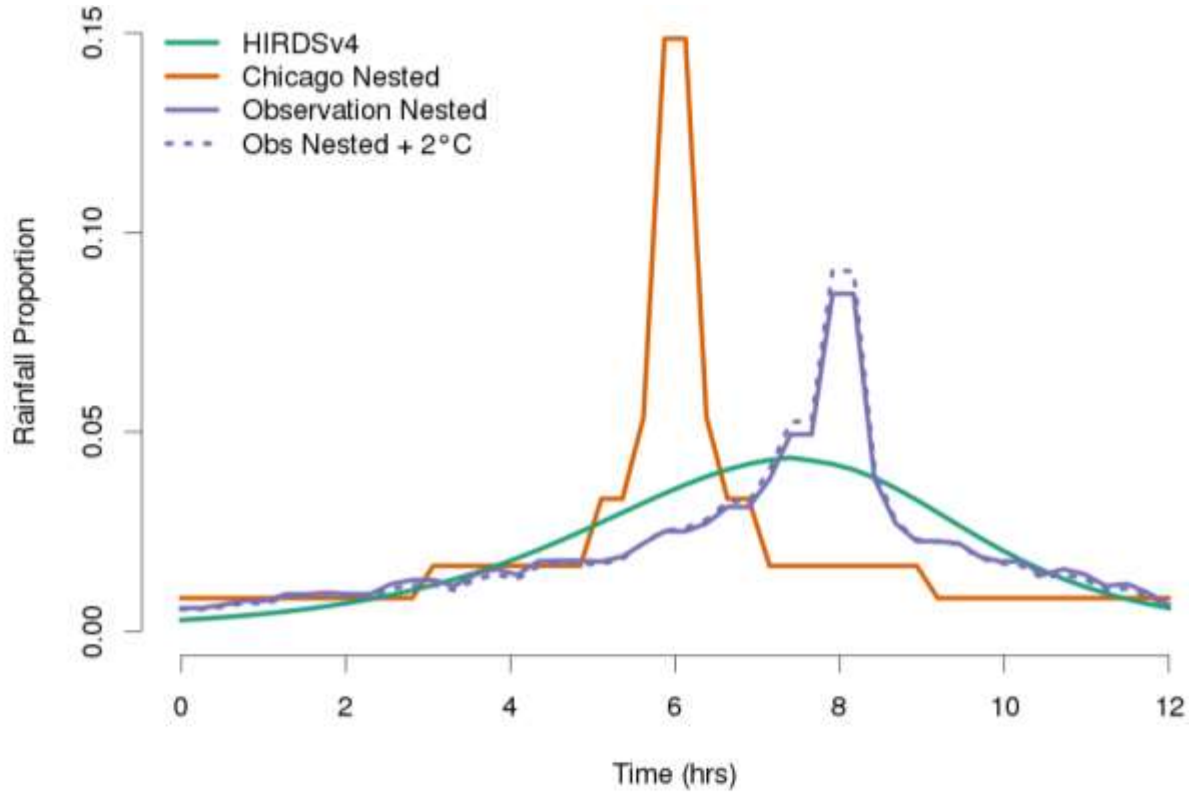
- Set of storms chosen for each duration
- For the largest of each sub-duration:
  + proportion of total depth found
  + location of largest sub-duration
- Non-parametric shape by averaging over storms

Auckland region: 100 year, 12 hour

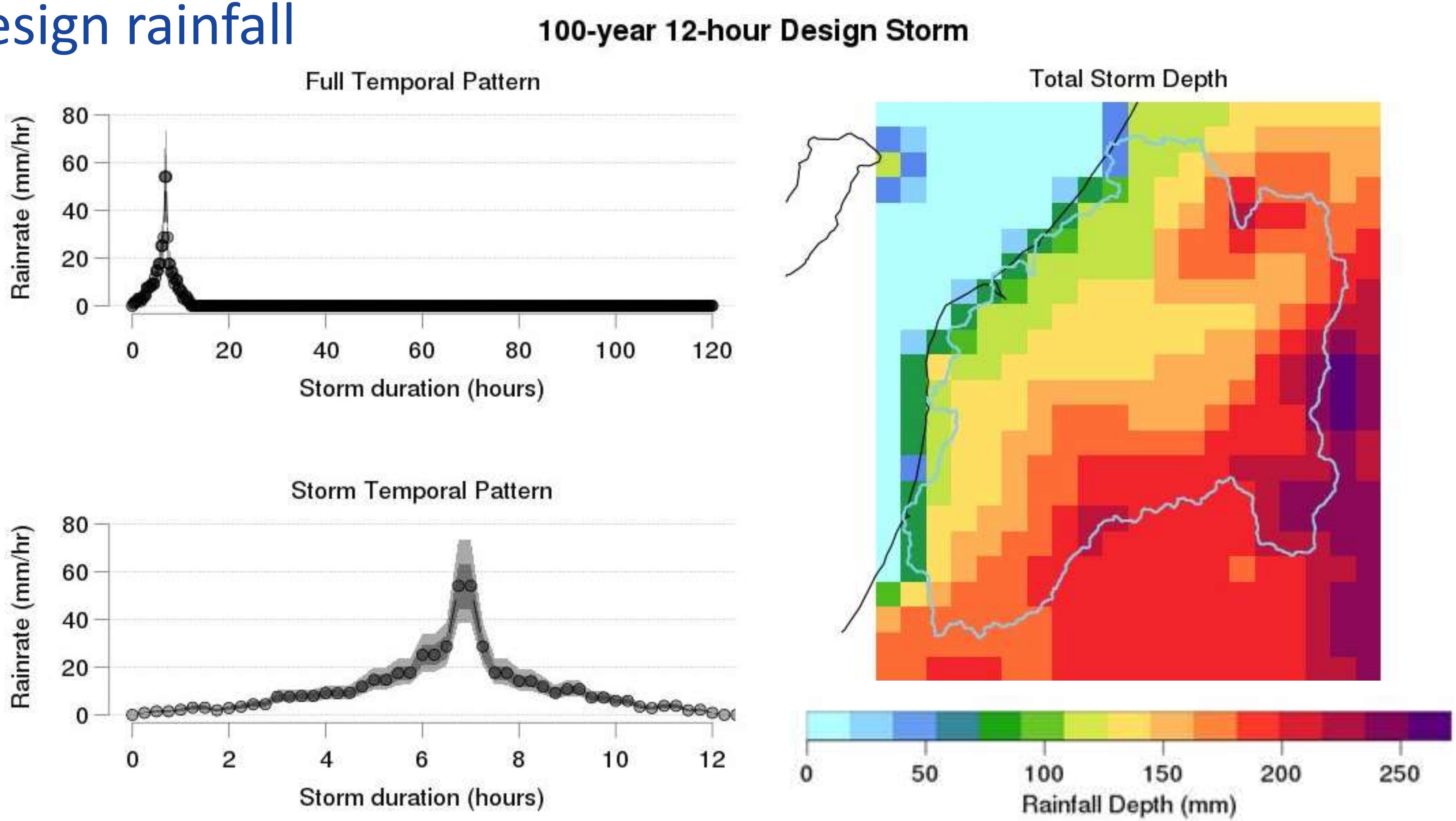


Temperature dependence on storm shape

- An exponential regression models the change in rainfall for each rank as a function of temperature.

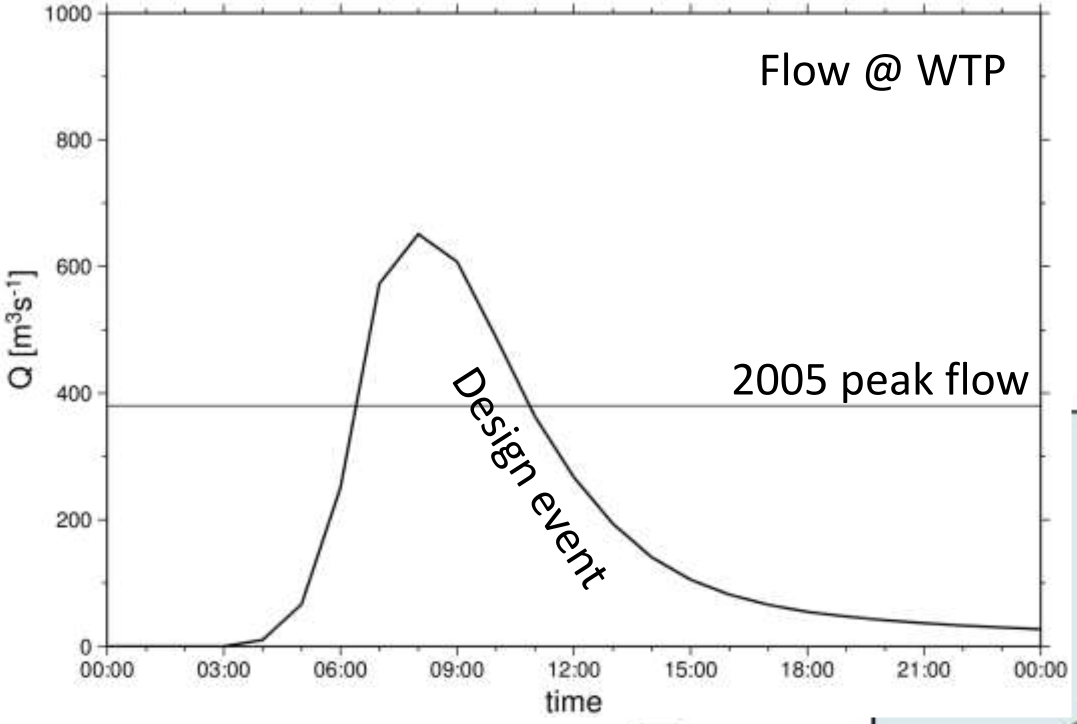


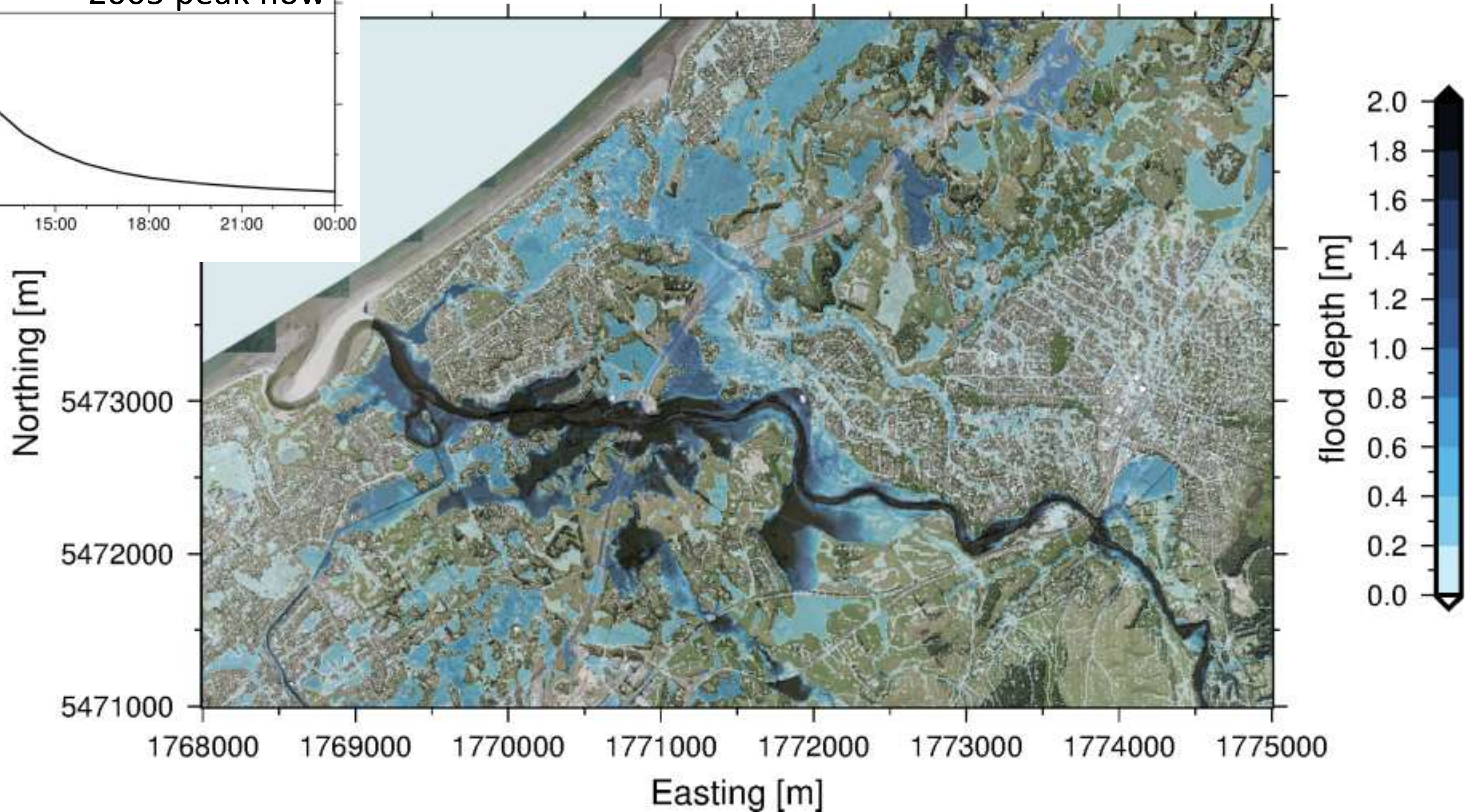
Design rainfall



Design flood event, Present climate

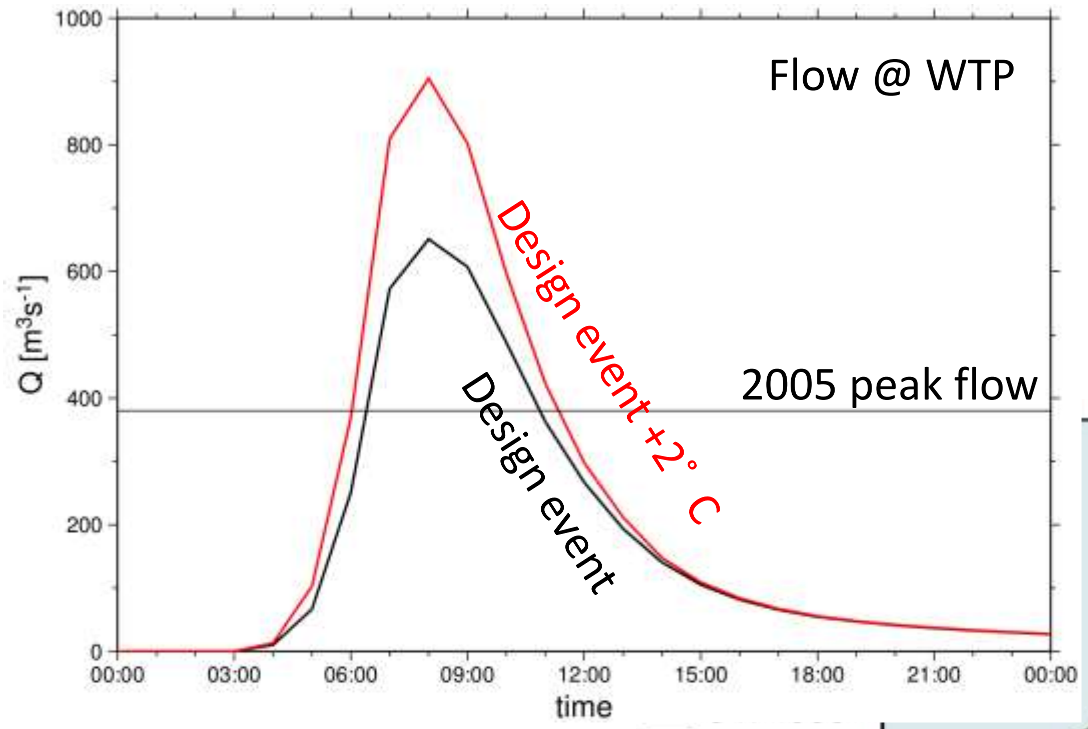
- Peak flow is 70% larger than the 2005 flood

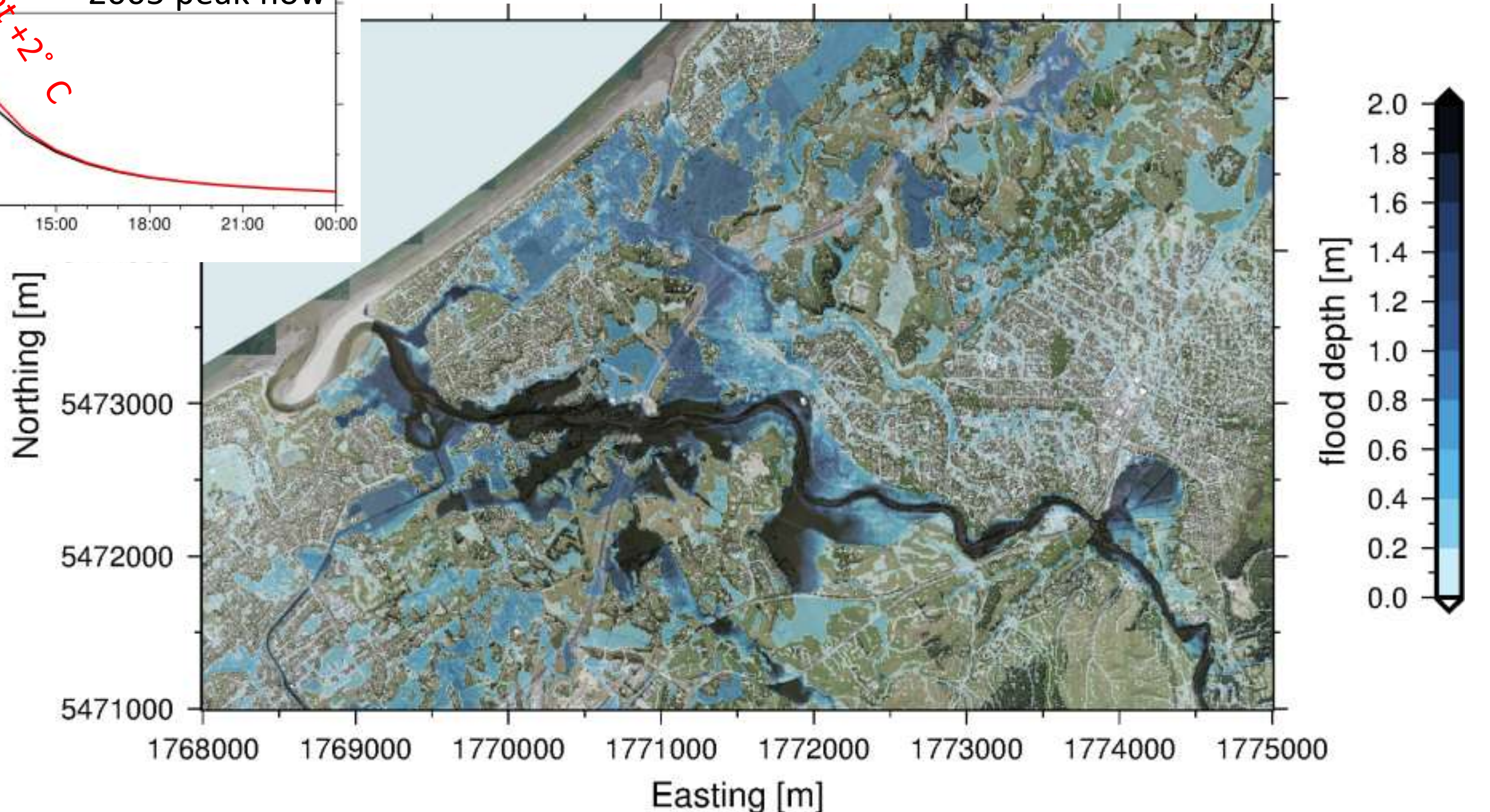




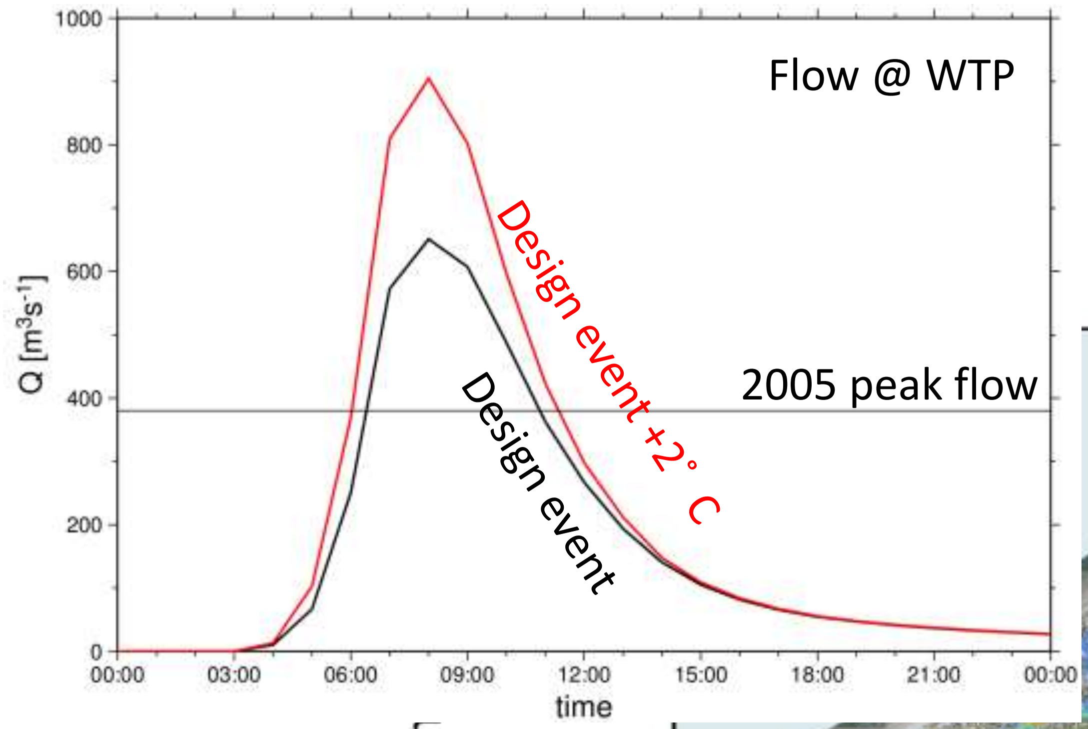
Design flood event, +2° C

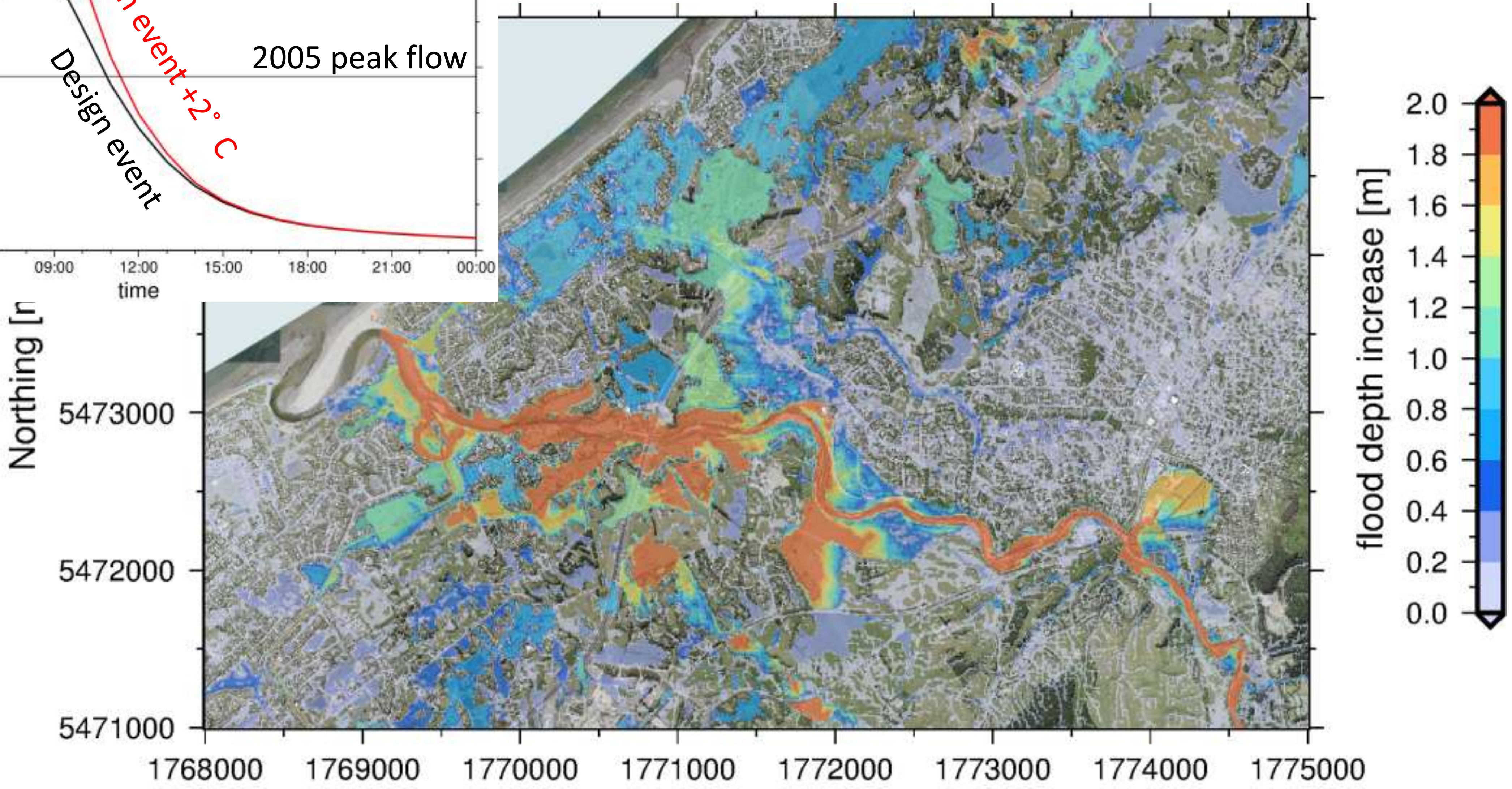
- Peak flow is 140% larger than the 2005 flood
- Peak flow is 40% larger than present climate design storm
- SLR (Sea Level Rise) is not included





Effect of +2˚C warming





Ngā mihi

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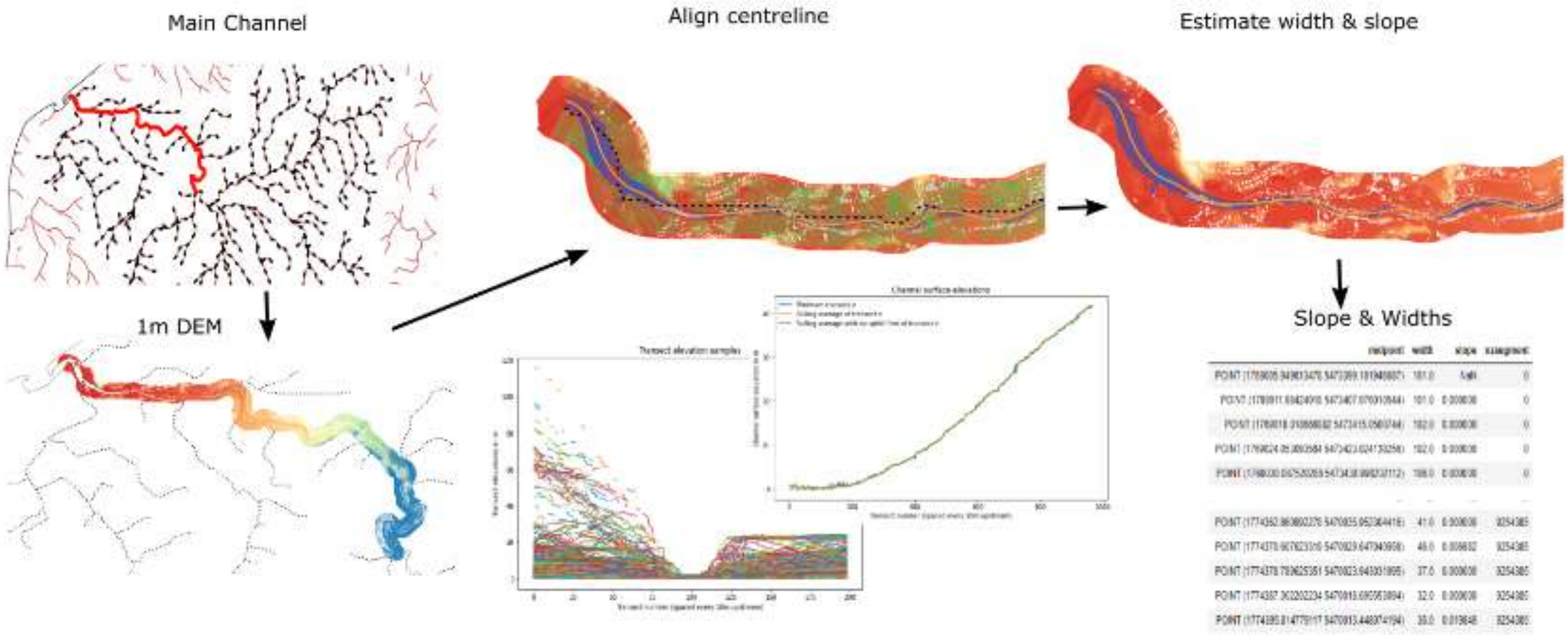
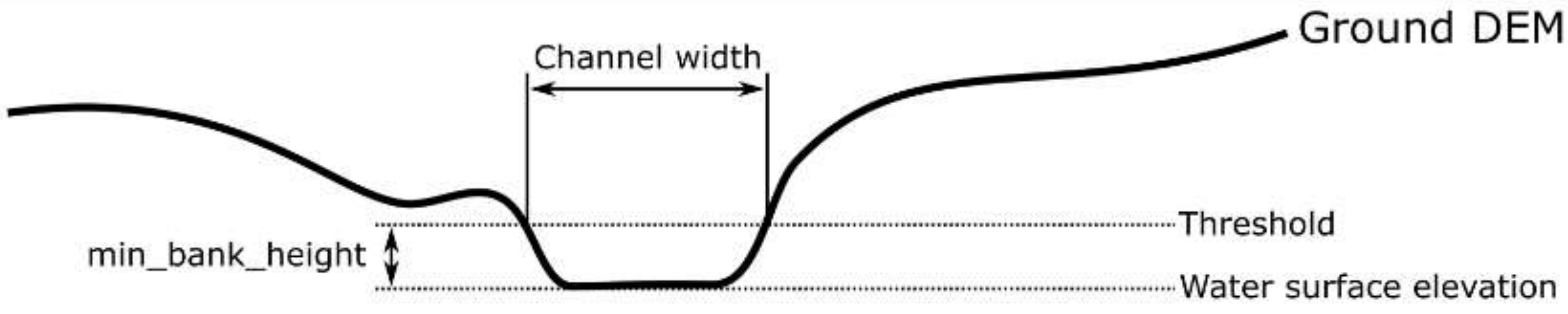
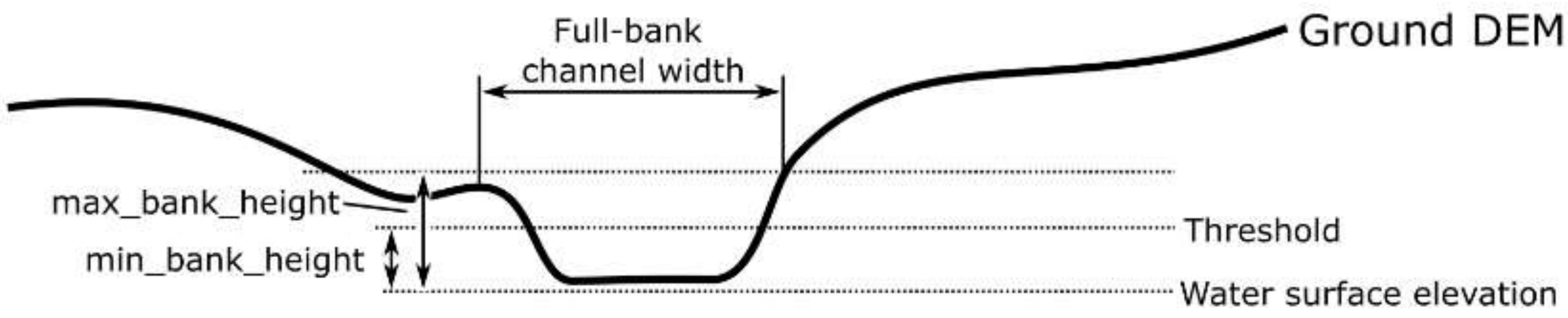
River bathymetry methodology



River bathymetry methodology





Depth calculation

Uniform flow theory - *Neal et al.*

- h = depth
- Q = flow
- S = slope
- w = width
- n = Manning's

$$h = \left(\frac{nQ}{S^{1/2}w}\right)^{3/5}$$

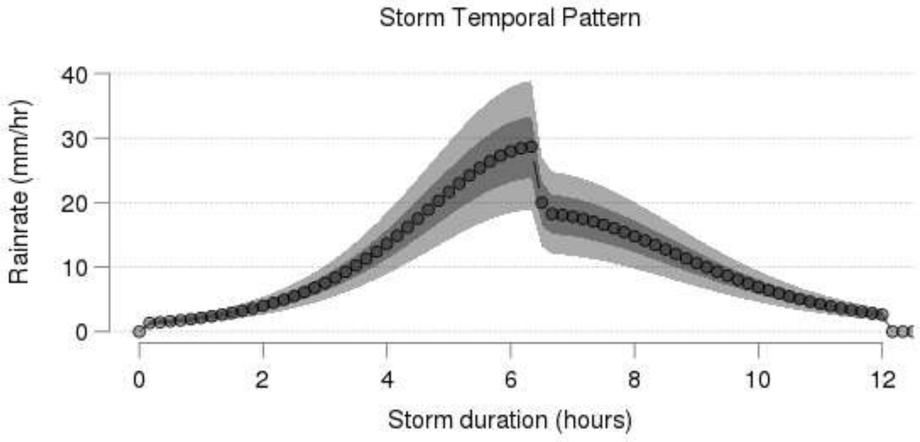
Hydraulic geometry– *Rupp & Smart*

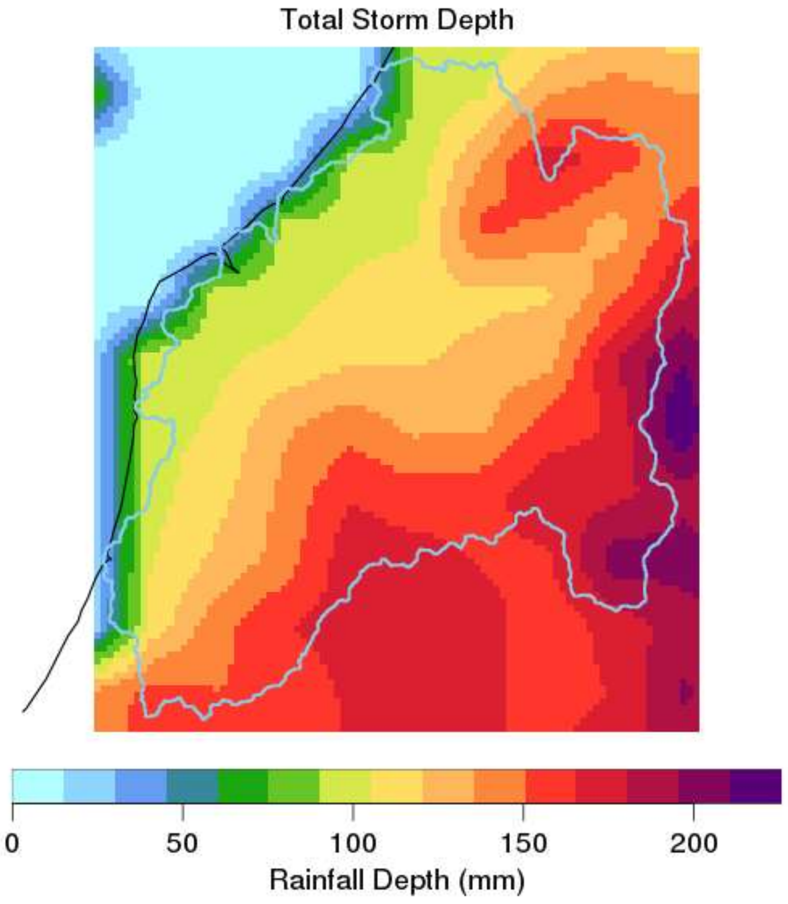
- h = depth
- Q = flow
- S = slope
- w = width
- K_o, β, α - coefficients from tables

$$h = \sqrt[1+\alpha]{\frac{Q}{K_0 S^{\beta} w}}$$

Initial work on design rainfall

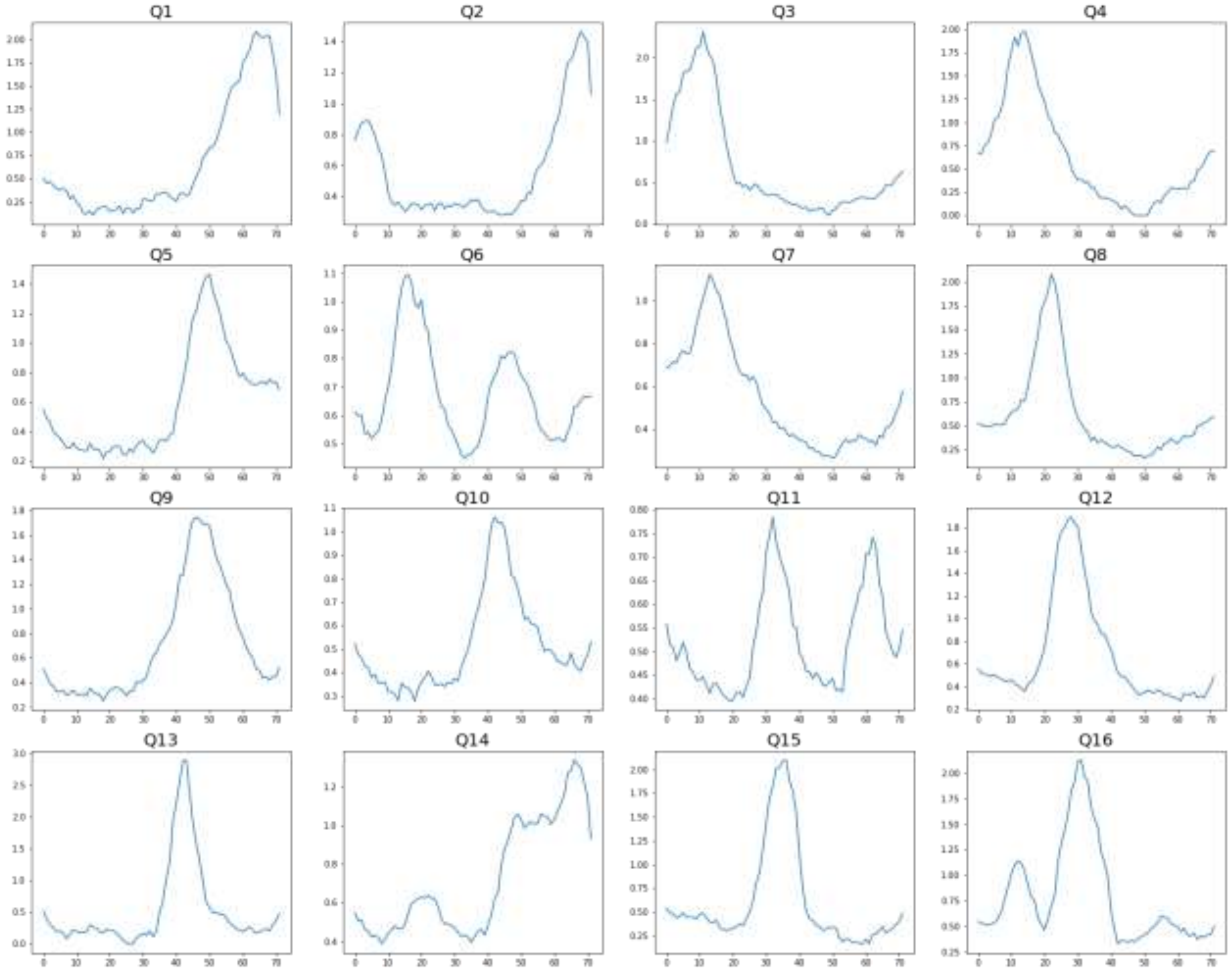
- Developing design storm creation tool:
- Combines various components
- Produces gridded rainfall input for given:
- duration, return period, catchment, temperature increment





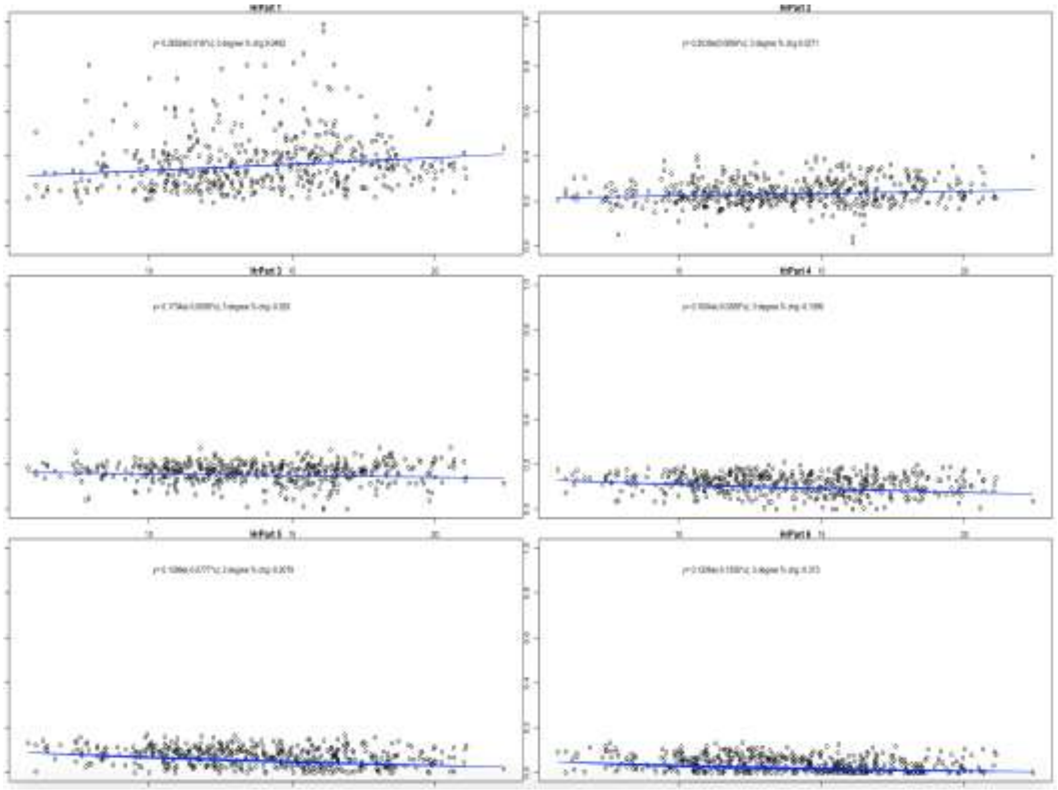
Variational Autoencoder

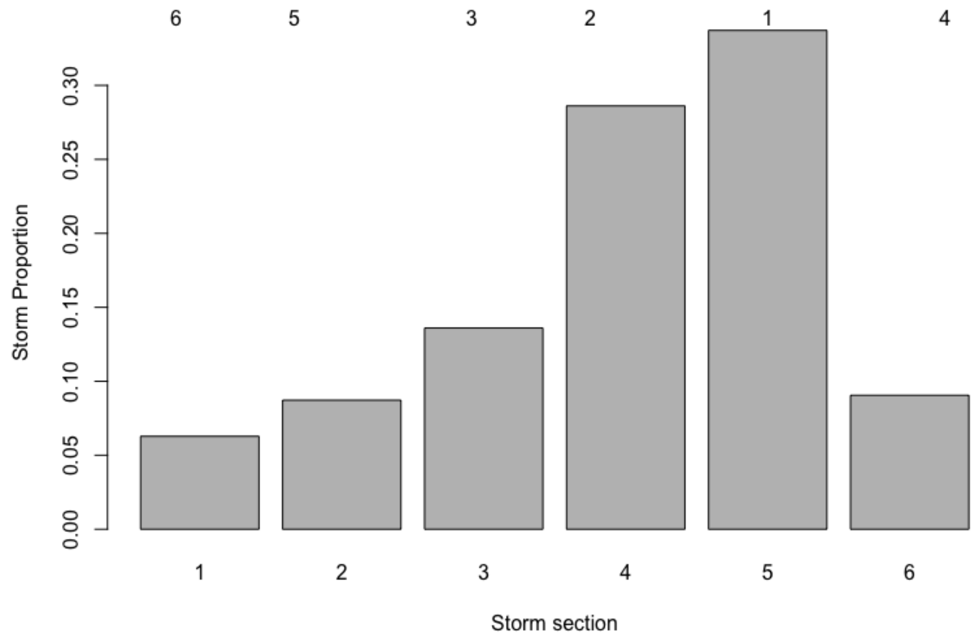
- Trained on 500 (normalised) observed 12-hour storms
- Reduced to 8 latent dimensions
- Exploring this space generates realistic simulated storms



Temperature dependence on storm shape

- Partition each 12-hr storm into N ranked sections





- For each rank, find the relationship between temperature and rainfall proportion

Climate, Freshwater & Ocean Science

NIWA

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