NIWA
Taihoro Nukurangi

Exploring Coastal Adaptation Pathways for Tangoio Marae

Modelling Assessment of Climate Change Impacts on Flood Extent and Level

Prepared for The Deep South Science Challenge

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Executive summary

The global climate system is changing and with it New Zealand's climate and environment. These changes will have implications not only for New Zealand's climate and weather systems but also for freshwater availability for downstream users and for hazard exposure (inland and coastal). Due to the nature of climate change, trends will vary across the country, over the course of the century, and among scenarios of climate change. Building on the assessment of future changes in New Zealand's climate (based on six model projections), this report addresses potential impacts of climate change on combined of climate-hydrology and coastal process for three scenarios for the Tangoio Marae area. Those scenarios were built as occurring over the same time period of the Bola event (6-10th March) across three time slices (mid-century- 2040, end of century- 2099, and 2120) and is referred hereafter as 'Bola type event'.

The potential effects of changing climate and sea level rise for each 'Bola type event" scenario for the period considered is summarised as follows:

- By mid-century, peak discharge associated with a "Bola type event" is expected to increase by a maximum of 13% (compared to the peak discharge simulated for the historical event), with no change in the duration for the flood to rise to its peak. Flood depth increases are expected to be localised around the areas of the mouth and upstream of the Tangoio Settlement Road Bridge.

- By end of century, peak discharge associated with a "Bola type event" is expected to increase by a maximum of 22% (compared to the peak discharge simulated for the historical event), with no change in the duration for the flood to rise to its peak. Flood depths are generally increasing throughout the whole valley due to a combination of sea level rise and increased discharge.

- By 2120, peak discharge associated with a "Bola type event" is expected to increase by a maximum of 16% (compared to the peak discharge simulated for the historical Bola event), with no change in the duration for the flood to rise to its peak. The apparent reduction of the peak flow compared to 2090 is associated with changing precipitation patterns. In 2120 storms such as cyclone Bola are expected to be less likely to occur during the modelled period of the first weeks of March than for the same time of year in 2090. However, because of the continuing sea level rise, the coastal flood levels are predicted to increase.

Under the regime of the three climate change scenarios explored in this study, projected flood depths are generally increased compared to cyclone Bola due to a combination of sea level rise and increased discharge. However, the stopbanks around the marae, erected after Cyclone Bola, are not overtopped and the inundation of the marae grounds is substantially reduced compared to the flooding experienced during cyclone Bola. However, the models show a small amount of flood waters flowing over the driveway leading to the marae, bringing flood waters onto the marae grounds. Another effect of the stopbanks is localised deepening of flood inundation upstream of the marae to a distance of about 150 m.

1 Introduction

The *"Exploring Coastal adaptation pathways for Tangoio Marae"* project is a collaboration between the people and Hapū of Tangoio Marae, Maungaharuru-Tangitū Trust and NIWA. Tangoio Marae is located on the flood plain of the Te Ngarue Stream, a known flood hazard area. The marae has been subjected to floods numerous times over the last century.

The project aims to build shared community understandings, strategies and robust community decision making processes that integrate the potential impacts of climate change with community goals and collective capacities of the hapu.

Overall the objective of the project is to develop an Indigenous Climate Change Adaptation Decision Model, and to demonstrate and document an effective approach to climate change adaptation that extends the current research and practice and that provides a useful tool and real world example for other communities to learn from, adapt, develop and apply as appropriate.

One element of the Adaptation Decision Model developed through this project is *"recognising and understanding past and future coastal-river reach processes, hazards and risks"*. Hydrological and hydrodynamic modelling was used to assist with this key element.

The 1988 Cyclone Bola flood event (6th-10th March) was used to calibrate predictions of the coupled hydrological hydrodynamic models from which to test several climate change futures and scenarios. The model calibration used observations of flood extent and flood depth provided by local residents who were present during or following the event. Cyclone Bola was selected as it is the most recent large event and considerable amounts of information about the event (i.e., photographs and local resident observations) is available to assist with the model verification process.

The hydrodynamic modelling of Cyclone Bola was calibrated against peak water levels obtained from photographs (during and after the event) and information supplied by individuals who witnessed the flooding and resulting damage which provided an indication of peak water levels at different locations in and around the marae. The calibrated coupled hydrological-hydro-dynamic model was then used to assess and illustrate:

(i) projected sea-level rise impacts across a range of timeframes, and

(ii) future River flooding coupled with increases in sea-level across different climate change scenarios.

This report documents the hydrological and hydrodynamic modelling investigations completed as part of the "*Exploring Coastal Adaptation pathways for Tangoio Marae project".*

2 Te Ngarue Stream Catchment

2.1 Catchment Description

Te Ngarue Stream (formerly known as Te Ngaru) is located approximately 20km north of Napier in the Tangoio Area. Te Ngarue Stream and it tributaries, including the Rauwirikokomuka and Kareaara Streams, flow from the steep hills north of Tangoio through the Tangoio valley. The Pakuratahi Stream and Te Ngarue Streams converge east of SH2 before discharging to the coast at Tangoio Beach.

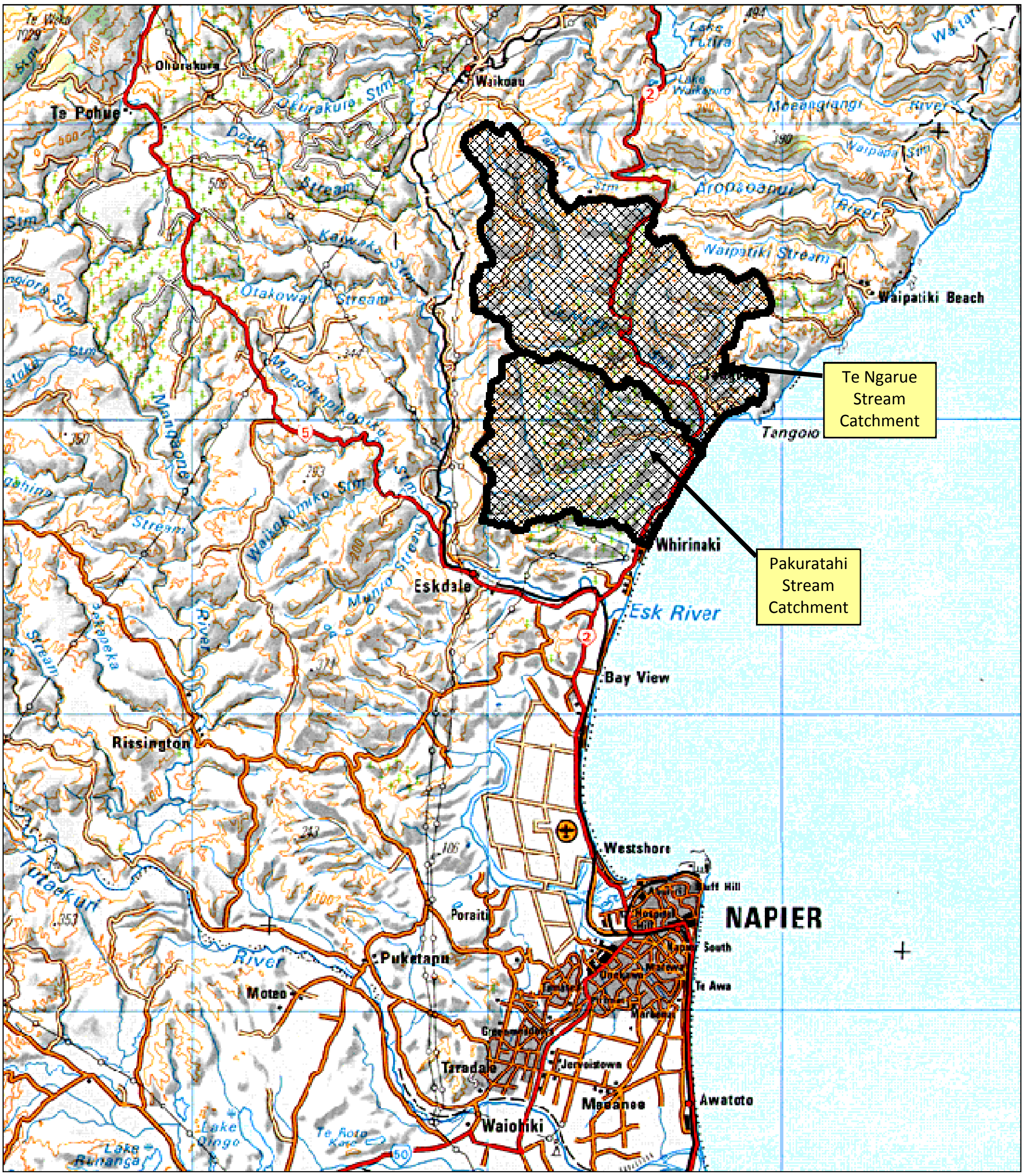

Figure 2-1: Te Ngarue Stream Catchment Boundary (HBRC, 2005).

The Te Ngarue Catchment has an area of approximately 54 km². It extends inland about 13 km, with a stream length of about 16 km (Goodier, 2005). The catchment is steep, ranging from 620m at its highest point down to sea level. The terrain in the steep upper catchment features ravines and gorges that concentrate runoff and drain the catchment into a narrow valley which opens onto a broad floodplain.

The majority of the catchment has been cleared and is farmed, further increasing the speed of runoff and the risk of erosion and landslides. There are several large areas of plantation/production forest as well as pockets of conservation plantings to protect against erosion. A map of landcover types is shown in figure 2.2, while soil type over the catchment are shown in Figure 2-3.

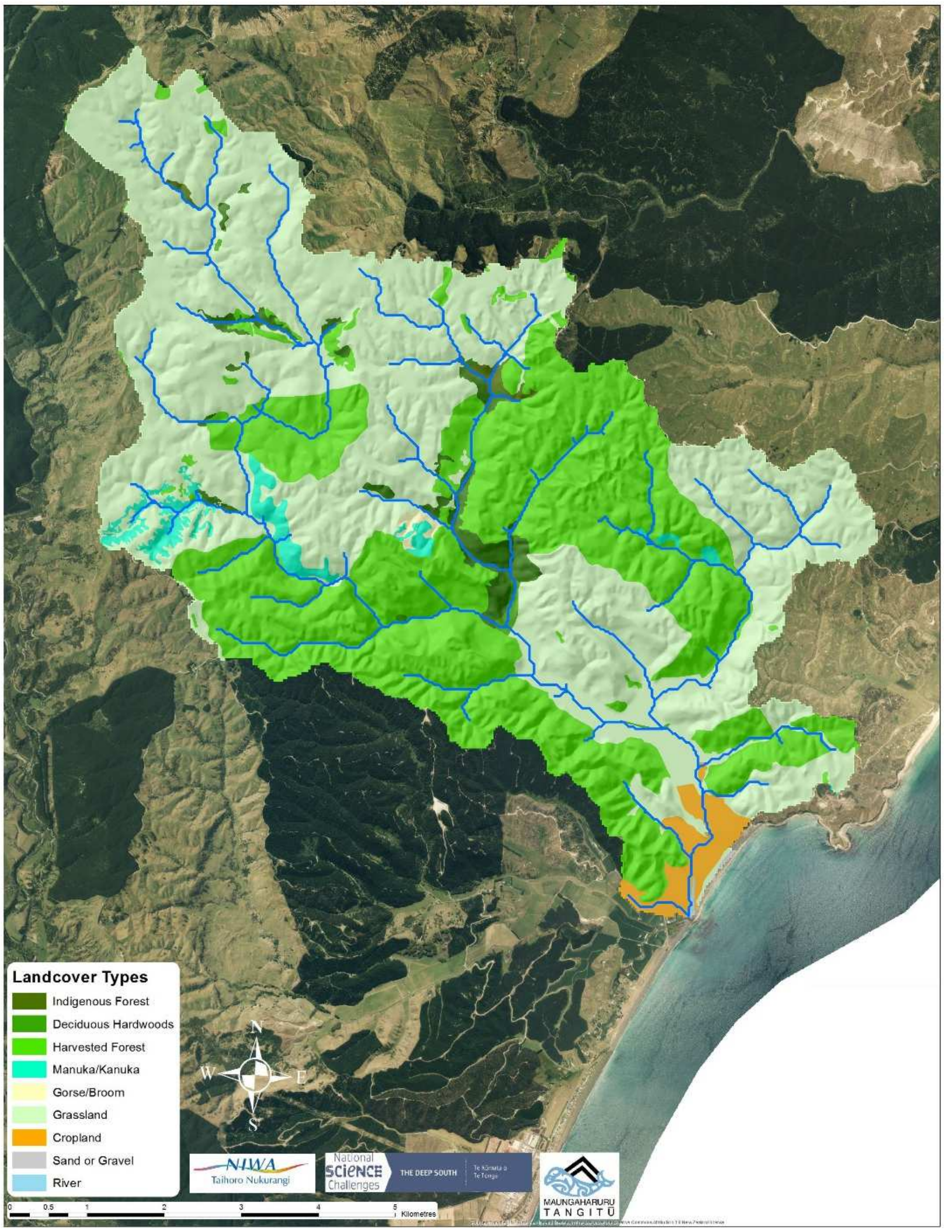

Figure 2-2: Overview of landcover, Te Ngarue Stream Catchment.

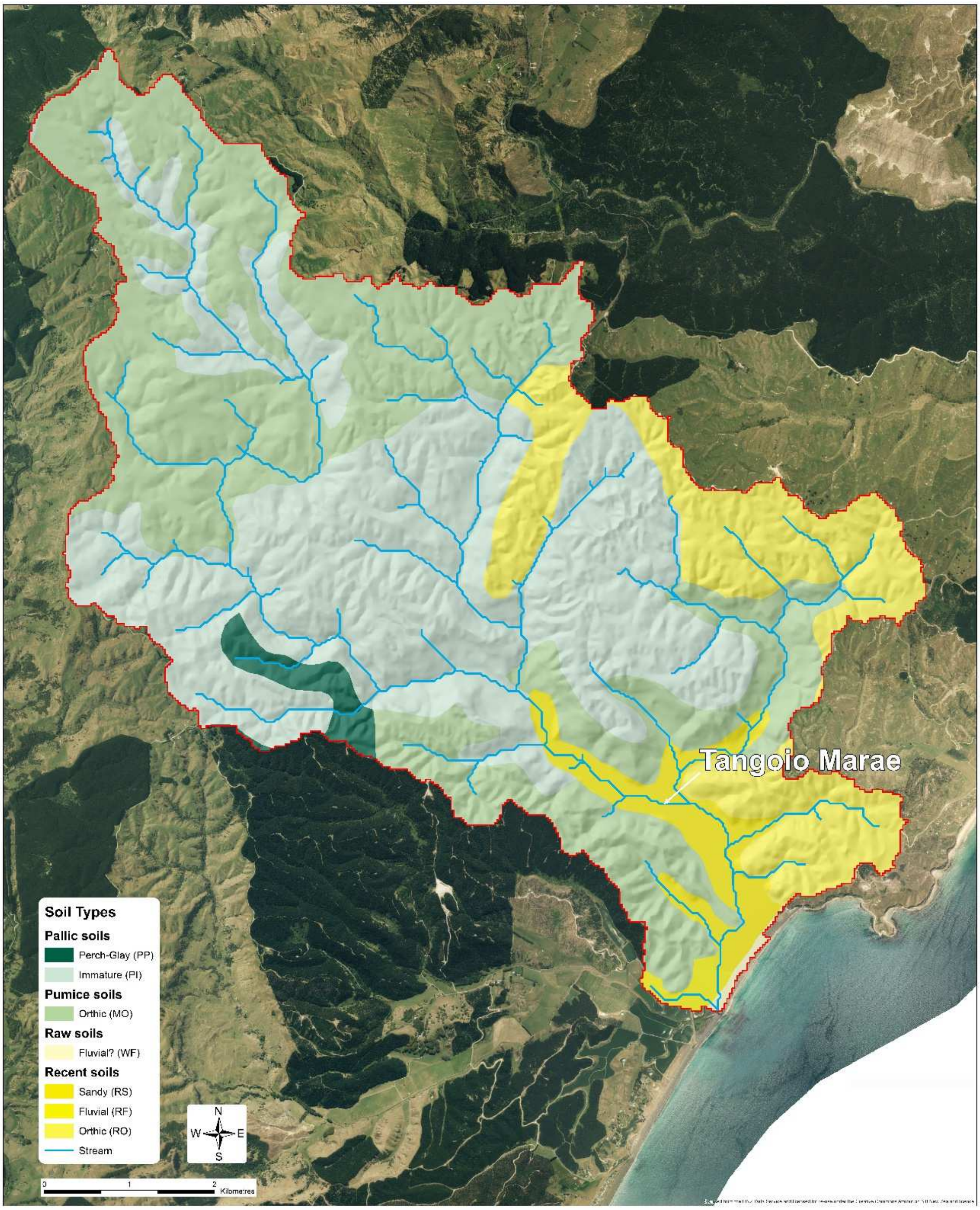

Figure 2-3: Overview of soil type for the, Te Ngarue Stream Catchment. Box indicating the location of the area of interest for flood modelling hazard.

As a result of the steep terrain in the upper catchment, land use and assocaited vegetation cover, as well as a flat low lying flood plain, the lower reach of the catchment is subject to severe flash flooding resulting in floodplain inundation. Regular flooding and associated sediment and silt deposition by storm runoff continue to build up the height of the flood plain.

The Tangoio area, once a bustling community (comprising a marae, school, post office, and normally resident population of over 100 people), is now primarily farm land with a small number of houses and holiday homes. Tangoio Marae is located in the Te Ngarue Stream floodplain immediately upstream of the Tangoio Settlement Rd (at an elevation of around 10m above mean sea level) and adjacent to State Highway 2.

Hawkes Bay Regional Council has established and maintains a flood control scheme alongside the last 3km of Te Ngarue Stream from Tangoio Settlement Rd to the coast. The scheme was established in 1999 to reduce the potential for flooding by keeping the main stream channel clear of unwanted vegetation which could block the channel. The scheme involves removing trees where they impede flow, spraying regrowth on the bed and banks and conducting minor bank stabilisation where required.

The floodplain is separated from the ocean by a shingle barrier beach. The mouth of the Te Ngarue Stream is shared with the Pakuratahi Stream. Heavy seas depositing shingle acorss the mouth have completely blocked it on many occasions as is common for these types of river mouths. The Te Ngarue has a scheme in place to mechanically open the mouth in the event it is blocked by shingle. From 2001 to 2005, the stream mouth was mechncailly opened 40 times (HBRC, Sept 2005).

In the upper catchment, soil are mainly characterised as Pumice soils (upper catchment) and pallic soils (middle catchment) while the lower part of the catchment is covered with recent soils.

2.2 Historic Flooding

The Te Ngarue catchment has been subjected to regular flood events with records dating back to before 1924. The most devastating events on record in the Te Ngarue catchment are the 1938, 1963 and 1988 flood events. However there are many notable events that left considerable destruction.

The history of flooding in the Te Ngarue Stream catchment is captured in a timeline produced by NIWA as part of the *“Exploring Coastal adaptation pathways for Tangoio Marae”* project. The timeline is included as Appendix A. Key references for the timeline included:

- The Hawkes Bay Regional Council Technical Report Te Ngaru Catchment - Flood Hazard Study (September 2005) [ISSN 1174 – 3085] which provides a comprehensive summary of historic flood records in the Te Ngarue Stream catchment.
- “*Tangoio Native School 1902 – 1974 Book”* (Toi Tawhai) which collated flooding records and assocaited correspondance from the NZ Archives and newspaper clippings following flood events.
- *“Transcripts from Tangoio Marae Flood History Interviews” (May 2016)* which provided first hand accounts and experiences of flooding in the area.

3 Physical Research Methods

The modelling presented in this report investigates the effects of climate change on future flooding events. The main factors influencing flooding in the Te Ngarue Catchment affected by climate change are changes in rainfall intensity and sea level rise.

These components (which are described in detail in sections 3.5 and 3.6) were combined to investigate what a historic flood like the one resulting from cyclone Bola would look like in the future. Choosing a flood event that many people can recall allows for flooding projections that can be compared to the personal experiences from 1988.

3.1 Previous Modelling by Hawkes Bay Regional Council (2005)

In 2005, HBRC produced the *Te Ngarue Catchment Flood Hazard Study* which included a hydrologic and a hydrodynamic model of the catchment and floodplain in order to determine the extent of the hazard on the floodplain. The hydrologic model was created using the Mike11-NAM software (Danish Hydraulic Institute, DHI) and the hydrodynamic model was create using the Mike21-HD software (DHI). The models are linked with the output from the hydrologic model used as input to the hydrodynamic model. The hydrodynamic model is a 2-dimensional model created using ground elevations collected from the 2003 HBRC LiDAR survey. The model was calibrated to observations made during Cyclone Bola (March 1988), and comparison of photographs taken during Bola showed a good correlation between model results and observation.

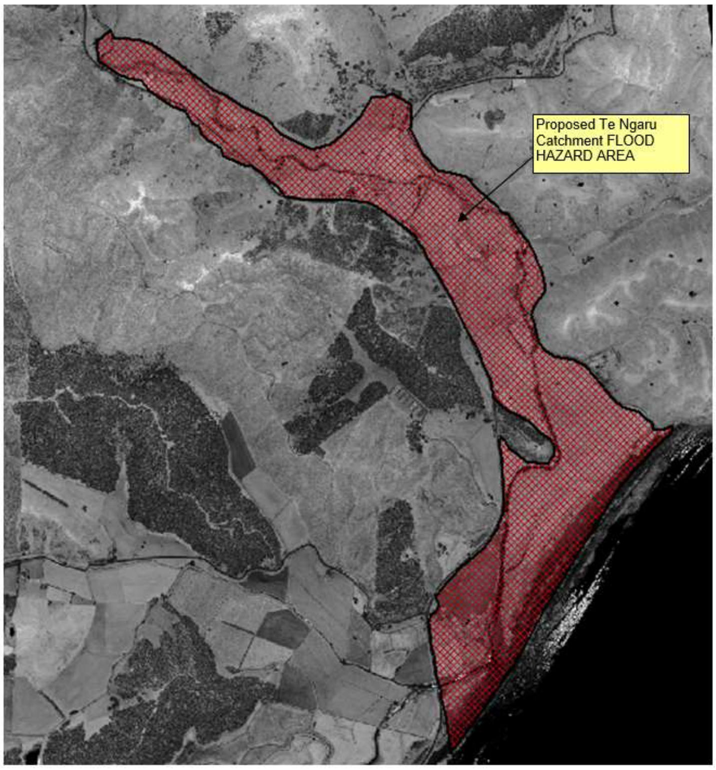

Figure 3-1: Figure from 2005 HBRC Report showing proposed Flood Hazard Area.

A conclusion of the 2005 report was that model results and historical records show the Te Ngarue floodplain to be susceptible to flash flooding, resulting in a recommendation that a flood hazard area be identified as shown in figure 3-1.

3.2 Hydrological modelling

The TopNet hydrological model is routinely used for hydrological modelling applications in New Zealand. It is a spatially distributed, time-stepping model of water balance. It is driven by time series of precipitation and temperature data, and of additional weather elements where available. TopNet simulates water storage in the snowpack, plant canopy, rooting zone, shallow subsurface, lakes and rivers. It produces time series of modelled river flow (under natural conditions) throughout the modelled river network, as well as evaporation. TopNet has two major components; a basin module, and a flow routing module. The structure of the basin module is illustrated in Figure 3-2.

The model combines the TOPMODEL hydrological model concepts (Beven et al. 1995) with a kinematic wave channel routing algorithm (Goring 1994; Clark et al. 2008) and a simple temperature based empirical snow model (Clark et al. 2008). As a result TopNet can be applied across a range of temporal and spatial scales over large watersheds using smaller sub-basins as model elements (Ibbitt and Woods 2002; Bandaragoda et al. 2004). Considerable effort has been made during the development of TopNet to ensure that the model has a strong physical basis and that the dominant rainfall-runoff dynamics are adequately represented in the model (McMillan et al. 2010). TopNet model equations and information requirements are provided by Clark et al. (2008) and McMillan et al. (2013).

Spatial information in TopNet is provided by national datasets on catchment topography (a 30 m digital elevation model), physical characteristics (Land Cover Database version 3, Land Resource Inventory, Newsome et al. 2000) and hydrological properties (River Environment Classification, Snelder and Biggs 2002). In this application, the REC hydrological network version 1 was used (Snelder et al. 2010) and surface water catchment hydrological model is comprised of 132 catchments. The method for deriving TopNet initial parameter estimates from GIS data sources in New Zealand is given in Table 1 of Clark et al. (2008).

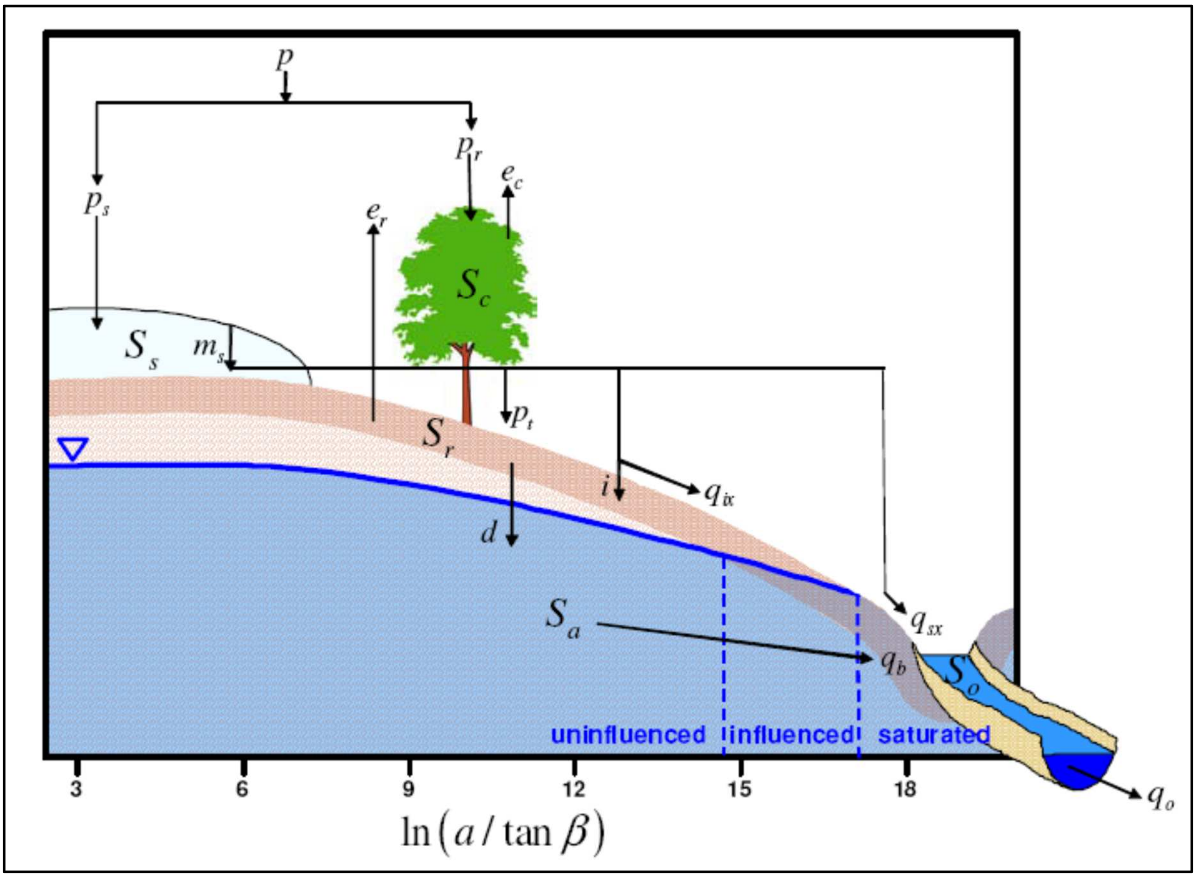

Figure 3-2: TopNet model structure within each sub-basin, showing modelled water fluxes and storages.

3.3 Flood inundation modelling

The modelling of flood inundation involves 5 stages describe hereafter:

- Creating a digital elevation model (DEM) of the model area.
- Creating a hydraulic roughness surface for the model area.
- Implementing the code for the 2D model.
- Calibrating the model to a recorded flood with known flood levels and sea level.
- Running the calibrated model with flood hydrographs and appropriate sea levels for the climate change scenarios under investigation.

3.3.1 Creating the Digital Elevation Model (DEM)

The basis of the model was a LiDAR-derived digital elevation model (DEM) supplied by Hawkes Bay Regional Council (HBRC).

The DEM supplied by HBRC did not include the bathymetry of the river. However, it was decided that the shallow nature of the river did not require a detailed map of river depths, since the overall volume contained in the shallow river throughout most of the domain is negligible in the overall context of the floodplain.

However, to simulate the effect of a likely scouring of the soft sediments forming the river mouth, the mouth was widened and deepened through the sandy beach barrier.

For the modelling, a DEM with a ground resolution of 5 m was generated. The model area is roughly 8 km^2 and extends from 1.3 km upstream of Tangoio Marae to the sea just beyond the river mouth. The datum used for the model DEM is the same as for the 2003 LiDAR collection, which places MSL at 10.0 m.

One complication in using Cyclone Bola for the model calibration is the construction of a stopbank around the marae which happened after the cyclone. The LiDAR data includes the raised ground levels of the stopbank and these will act as an obstruction for future floods. However, to model the conditions during Cyclone Bola, the stopbank around the marae was removed from the DEM for the calibration runs. The stopbank was then inserted again for the future climate change scenarios.

3.3.2 Creating a hydraulic roughness surface

A surface layer representing hydraulic resistance to flow is a required input parameter into every hydrodynamic model. For this study, a uniform roughness over the whole domain was generated with a Manning's n value of 0.0625. This value was chosen to represent an average roughness for the different ground cover types ranging from paddocks to crop fields, brush and trees. It was chosen after running a number of different model runs with various values for Manning's n and comparing the resulting water levels against the observed levels around the marae.

3.3.3 Creating the 2D Model

The modelling software used in this project was Mike Flood. Further information about the model can be found under Goodier 2005.

Two models were built: one model for the calibration of cyclone Bola (which did not include the stopbank around the marae) and one model for the climate change scenarios (with added stopbank).

The bridge at Tangoio Settlement Road just downstream of the marae was blocked with debris during the flood, and this was simulated in the model by raising the stream levels to the height of the bridge in the DEM.Buildings on the marae grounds were included in the model as obstructions to flow, while the small number of buildings throughout the flood plain were removed in the DEM. Their isolated nature (and distance to the main area of focus of this study) would not have affected the hydrodynamic model in a relevant fashion.

The outflow boundary was set to be a constant sea level (without tides), adjusted to the levels specified in section 5.3.

3.3.4 Model calibration

Once set up, the hydrodynamic model is calibrated to a recorded flood with known flood levels and sea level. Calibration procedure and results are discussed in Section 4 of this report.

3.3.5 Scenario simulation

Once the model has been calibrated and validated, scenarios are run using a combination of flood hydrographs and appropriate sea levels for the climate change scenarios under investigation.

4 Model Calibration – Cyclone Bola

4.1 Hydrological modelling

4.1.1 Climate

As there are no weather stations located within the catchment boundary, climate variables were provided as follow:

- Temperature, Mean Seal Level Pressure, Solar radiation, Wind speed and relative Humidity were provided by the Virtual Climate Station Network (VCSN) over the period of interest. The VCSN is a gridded daily climate product, produced operationally by NIWA at a resolution of 0.05 deg. (~ 5km) over the period 01 Jan 1972 to present (Tait et al. 2006).

- Precipitation was provided at hourly time steps by Hawkes Bay Regional Council (Craig Goodier, pers. communication) and was applied at the centroid of the catchment. This provides a precipitation field that is determined and applied in a similar manner as per the hydrodynamic modelling carried out.

4.1.2 TopNet parametrisation

For many applications of TopNet, the estimation of model parameter values currently requires calibration, usually using measured streamflow. The parameters requiring this type of estimation are generally associated with soil hydraulic properties (hydraulic conductivity and water holding capacity of soils). However, careful review of data quality (e.g., precipitation, temperature and streamflow) is a wise first step, before calibration.

There are 31 parameters used in a TopNet model, which represent the physical characteristics of the catchment and are generally assumed not to be subject to temporal variation. These include soil properties, topography, land cover, and channel properties. The derivation of the catchment scale TopNet parameters from nationally available datasets is described in detail in Table 1 of Clark et al. (2008). These catchment scale parameters represent the default parameter values used in the subsequent sections. However due to the paucity of some spatial information at national scales the following parameters in TopNet are set to a unique default value across New Zealand:

- Surface hydraulic conductivity is set to 0.01 m/s.

- Soil water characteristics (i.e., Clapp and Hornberger c exponent and Green-Ampt wetting front suction) are constant across the Te Ngarue catchment and set to 1.0 and 0.3 respectively.

- Overland flow velocity is set to 0.1 m/s.

The depth of soil hydraulically active and the surface hydraulic conductivity are two of the most sensitive and critical parameters in TopNet. The depth of soil hydraulically active is associated with the characterisation of the hydrograph recession, while the surface hydraulic conductivity is associated with recharge to the groundwater and subsurface flow characterisation. As a result those parameters are generally calibrated based on streamflow information. However in this application as no continuous streamflow information is available on the catchment, those parameters were taken as their default value.

Figure 4-1 to Figure 4-3 present the spatial variation of the soil and vegetation related parameters in TopNet (estimated from nationally available datasets). These are presented, per subcatchment, to illustrate the spatial variability of the TopNet parameters across the Te Nagrue watershed and are not further discussed in this report.

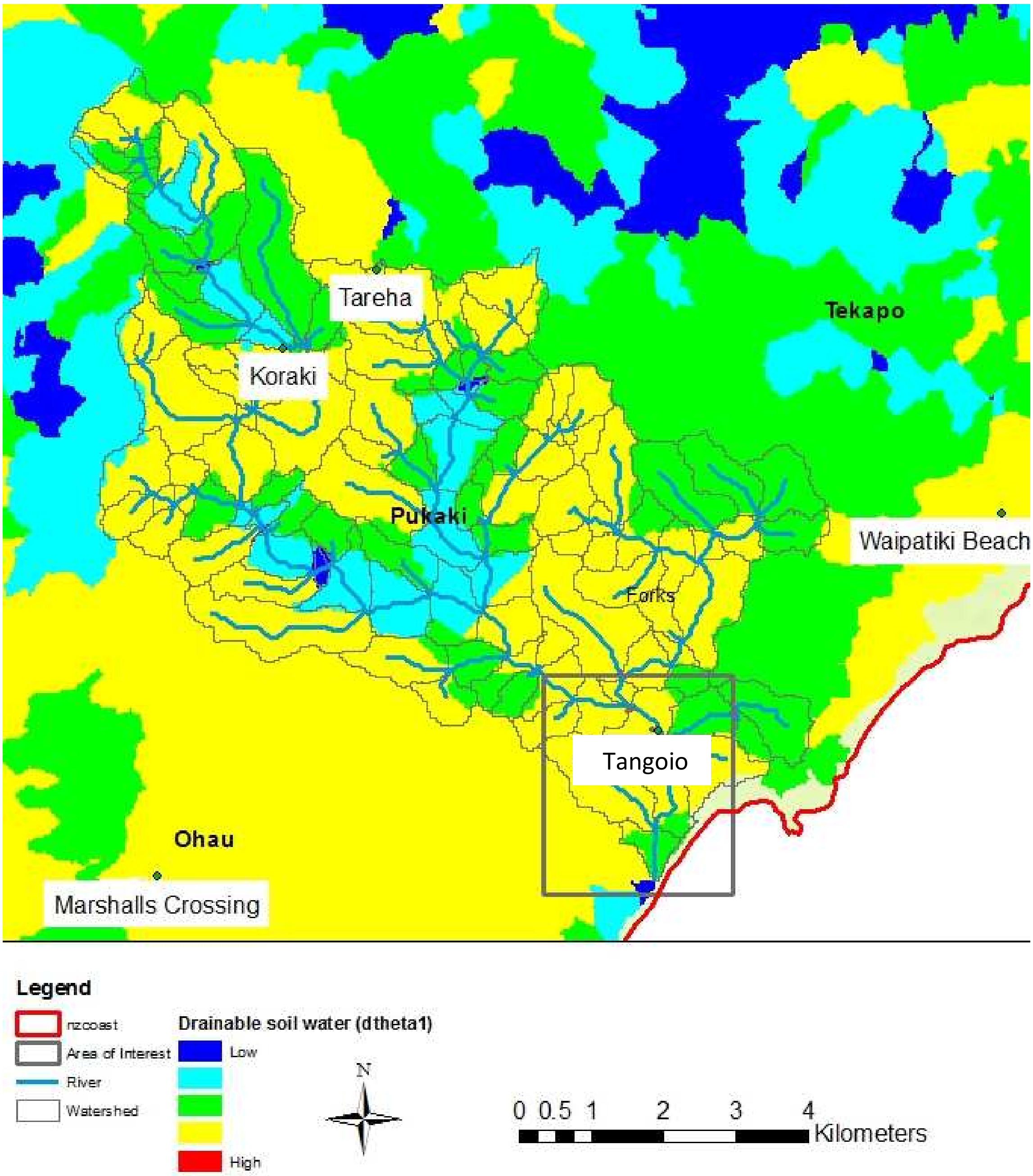

Figure 4-1: Spatial variation of the drainable water (dtheta1) TopNet parameter. Blue colour represents a low value of the parameter, while red colour represents high values.

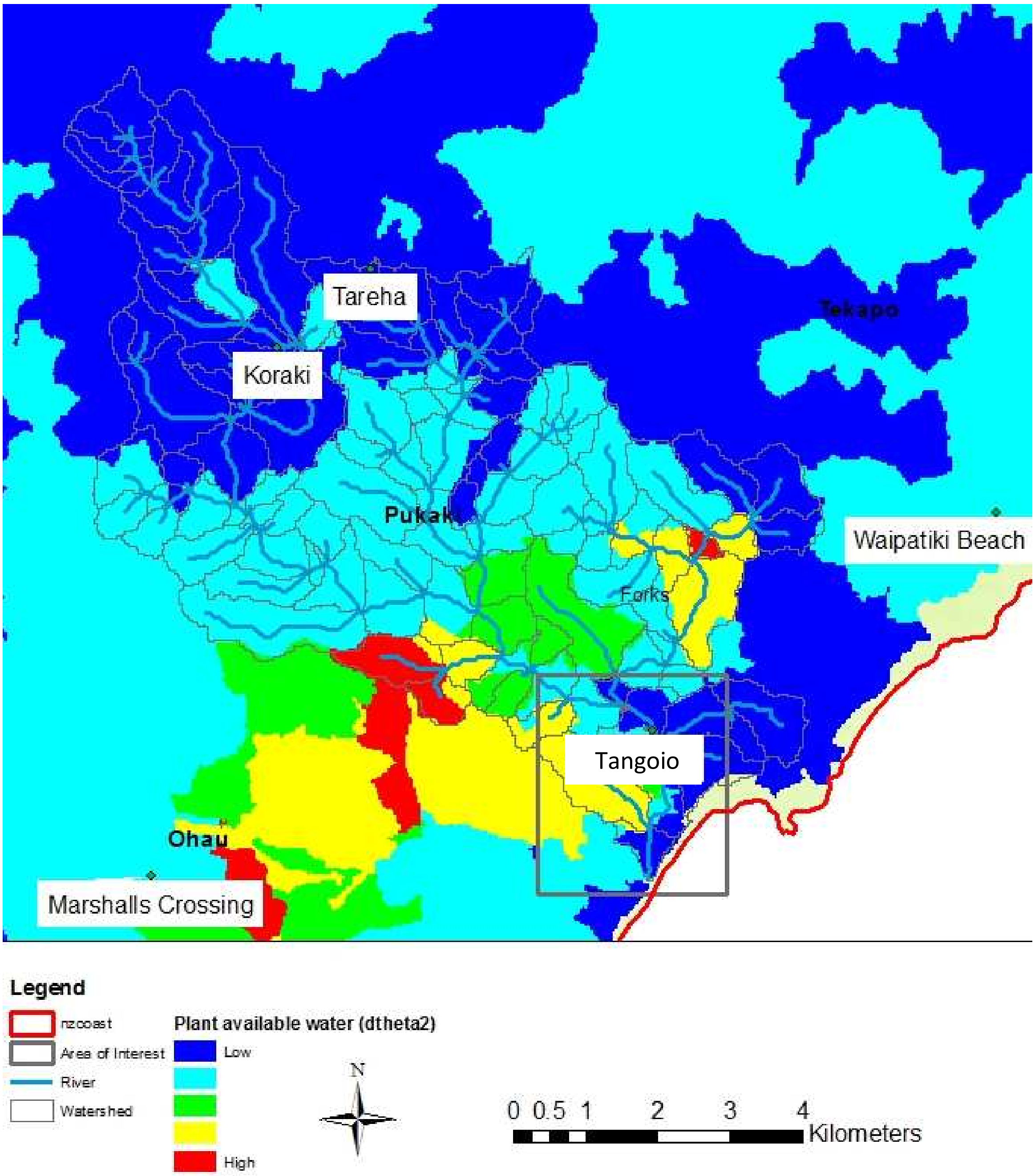

Figure 4-2: Spatial variation of the plant available water (dtheta2) TopNet parameter. Blue colour represents a low value of the parameter, while red colour represents high values.

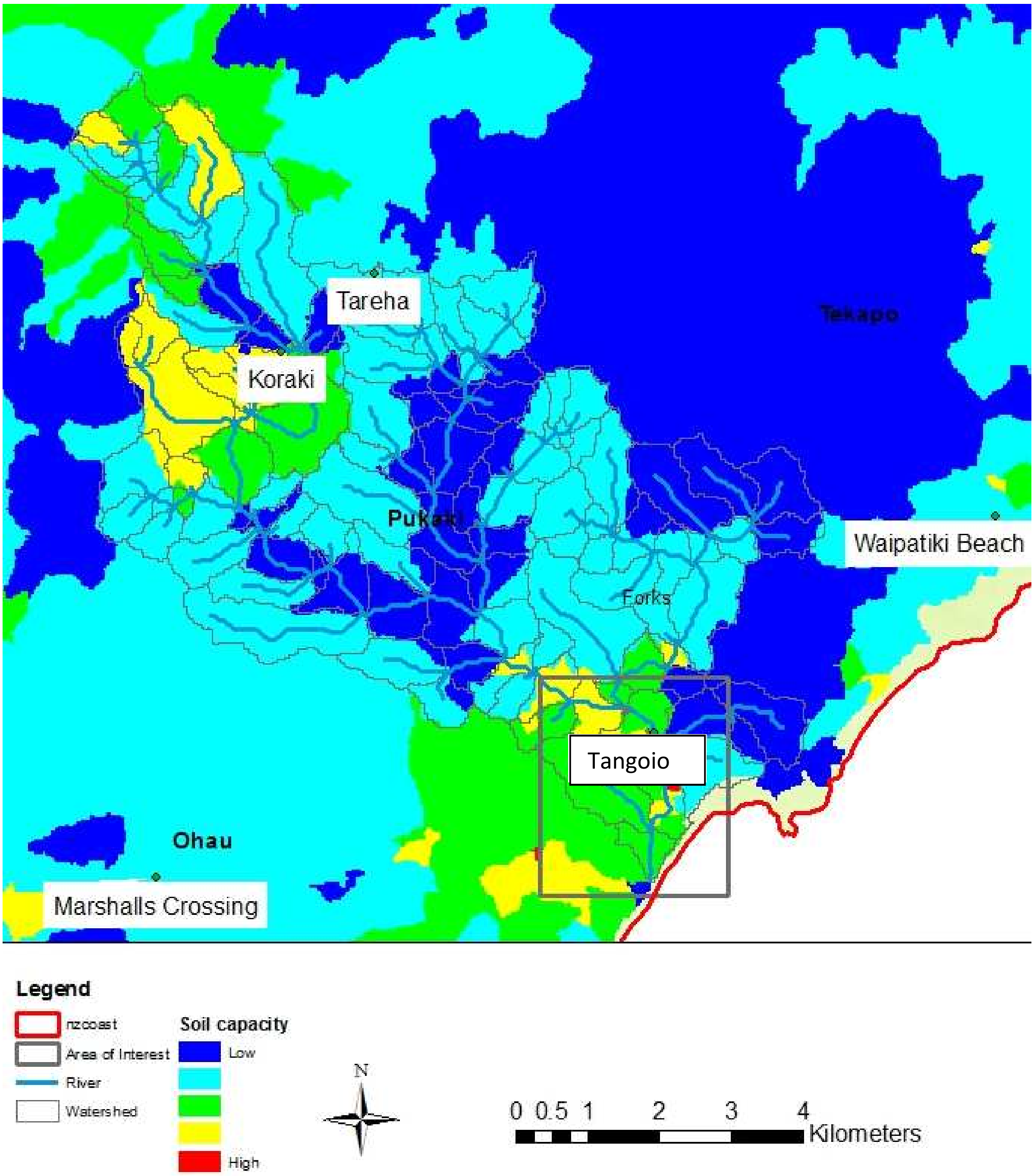

Figure 4-3: Spatial variation of the soil capacity (soilcap), used as a surrogate of the depth of the hydraulically active soil in TopNet. Blue colour represents a low value of the parameter, while red colour represents high values.

4.1.3 Calibration of the TopNet model

TopNet calibration requires the calibration of parameter multipliers, as one of the main assumptions of TopNet is that the spatial distribution of the parameters is a-priori determined from catchment physiographic information from the sources in section above. TopNet requires the calibration of eight parameter multipliers for each sub-catchment, whose initial values are set to a value of 1. As there is no flow observation across the catchment during the Bola event, the following calibration strategy was established:

- Model calibration period is set to 6-10 March 1988.
- Observed flow hydrograph was provided as the flow hydrograph generated at reach 08189910 (TeNgaru @ Tangoio road) by HBRC.
- Uncalibrated simulated TopNet discharge was compared with the observed hydrograph at the reach.
- Based on a review from HBRC, the uncalibrated TopNet discharges were estimated to represent correctly the potential observed hydrograph (including uncertainties).

Table 4-1 presents the typical range of the parameter multipliers used during the calibration process.

Table 4-1: Range of TopNet parameter multipliers used during calibration process.

Parameter name (internal name)	Parameter description	Calibrated range
Saturated store sensitivity (topmodf)	Describes exponential decrease of soil hydraulic conductivity with depth.	[0.01-1] * default[1]
Drainable soil water (swater1)	Range between saturation and field capacity.	[0.1-5] * default
Plant available soil water (swater2)	Range between field capacity and wilting point.	[0.1-5] * default
Hydraulic Conductivity at saturation (hydcond0)		[0.01-999] * default
Overland flow velocity (overvel)		[0.1-10] * default
Manning n	Characterises the roughness of each reach.	[0.1-10]* default
Soil water content (dthetat)	Soil water content.	[0.1-5]* default
Gauge Undercatch (gucatch)	Adjustment for non-representative precipitation.	[0.75-1.5] * default

[1] The default parameter value is derived from the information provided in section 4.1.2

Due to the lack of any time series observations over the catchment, no validation of the discharge hydrograph was carried out for the purpose of this project.

4.1.4 Results at Tangoio at Tangoio Road

Figure 4-4 presents the resulting simulated hydrograph simulated by TopNet for this project. This hydrograph was reviewed by HBRC and deemed acceptable based on HBRC understanding of the Bola event.

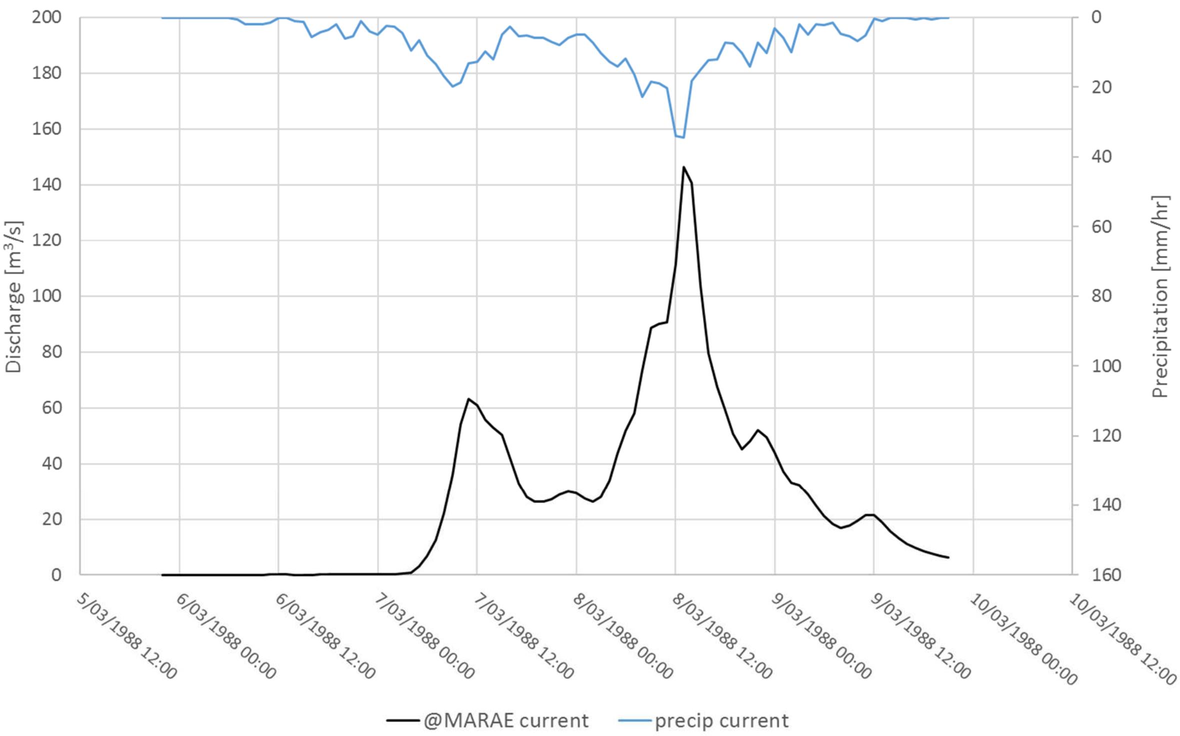

Figure 4-4: Simulated hydrograph (black line) and precipitation (blue line) for Tangoio at Tangoio Road (reach 08189910).

4.2 Hydrodynamic/Flood mapping

Calibration of the model was undertaken by simulating the Cyclone Bola event and comparing modelled water levels and extent to observations made during the event.

No flow gaugings were conducted during Cyclone Bola in Te Ngarue Stream, so estimates of the flood hydrography were generated through the hydrological model (see 3.2 for details).

To compare the model results with local observations of the flood, water levels were checked at two locations around the marae.

Table 4-2: Observed and calibrated water levels.

Location	Modelled WL (m)	Observed WL (m)
Front of Whare Nui	20.89	20.82 - 21.14
Hoani Whare	20.9 – 21.0	21.14

Accuracy of the LiDAR-derived elevations is stated as +/- 0.15 m. The calibration was regarded as achieved when the difference between modelled and observed water levels were within that range of uncertainty.

It should be stated that while there were only 2 observed water level points around the marae to calibrate the model to, the purpose of this investigation was to explore the changes of a large flood event due to climate change, rather than an accurate depiction of Cyclone Bola itself. Minor uncertainties in the absolute water levels of the calibration flood have no impact on the investigated changes due to climate change.

5 Climate change

Future climates and climate-related weather patterns are commonly examined through the analysis of various climate scenarios. The need for scenarios is due to the uncertainty over future emissions of greenhouse gases and aerosols which themselves depend on changes (and uncertainties) in population, economic growth, technology, fossil fuel use and national and international policies, among other factors (IPCC, 2007). Future climate changes generated from such scientific analyses and computer models are therefore called projections, not predictions.

5.1 Climate change projections for Hawkes Bay region

The primary input for the hydrological and hydrodynamic simulations are climate data generated from a suite of Regional Climate Model (RCM) simulations with sea surface forcing taken from Global Climate Models (GCMs). These coupled climate models are driven by natural climate forcing and modelled anthropogenic forcing driven by emissions of greenhouse gases and aerosols based on 4 Representative Concentration Pathways (RCPs), but are otherwise free-running in that they are not constrained by historical climate observations applying data assimilation. As part of the fifth IPCC assessment report (AR5) (IPCC 2014), NIWA validated 41 GCMs from the AR5 model archive for their suitability for the New Zealand region through comparison with large scale climatic and circulation characteristics across 62 metrics (Ministry for the Environment 2016). This analysis provided performance based ranking based on New Zealand's historical climate. The GCMs were then used by NIWA to drive statistically based regional climate simulations for performing change impact assessments across New Zealand. The six best performing independent models, where projections across all four RCPs were available (van Vuuren et al. 2011) up to 2099, were selected for dynamical downscaling. Dynamical downscaling is characterised by the use of sea surface temperatures (SST) and sea ice concentrations to drive an atmosphere-only global circulation model, which in turn drives a higher resolution Regional Climate Model (RCM) over New Zealand. The output data fields are bias-corrected relative to a 1980-1999 climatology and subsequently further downscaled to an approximate 5 km grid (Sood 2014). The RCM output (bias-corrected and downscaled to 5 km) is then provided as input to downstream models.

The NIWA dynamical procedure effectively involves a free-running atmospheric GCM (AGCM) (i.e., not constrained by historical observations), in this case HadAM3P (Anagnostopoulou et al. 2008), forced by SST and sea ice fields from the Coupled Model Intercomparison Project Phase 5 (CMIP5) models (Ackerley et al. 2012). Due to the nature of the climate runs for each GCM, year-to-year variability in the models does not correspond with observed variability; they are a deterministic consequence of the initial conditions and the solar and anthropogenic drivers. Further details on the validation of the six GCMs can be found in Sood (2014) and Ministry for the Environment (2016).

The downscaled climate data used here run from 1971 to 2100. From 2005 onward, as per IPCC recommendations, each GCM is in turn driven by four RCPs that encapsulate alternative scenarios of radiative forcing and reflect alternative trajectories of global societal behaviour with regard to greenhouse gas emissions and other activities. The range of RCPs used can help shed light on the utility of climate change mitigation. Descriptions and trajectories of the four RCPs are provided in Table 5-1 and Figure 5-1. By mid-century, the temperature trajectory of RCP2.6 is the coolest and RCP8.5 the warmest, with RCP4.5 and RCP6.0 producing intermediate warming. While RCP6.0 ends the century with more forcing than RCP4.5, early and mid-century it is RCP4.5 that has higher greenhouse gas emissions and a stronger radiative forcing; this is somewhat reflected by the mid-century temperature change ranges for the New Zealand seven-station network (Table 5-1). RCP6.0

overtakes RCP4.5 after the middle of century. The climatic and hydrological effects of the RCPs are not simply a linear or monotonic progression from the lowest to highest RCP. Furthermore, the spatial patterns of climatic change across New Zealand are different from RCP to RCP.

Table 5-1: Descriptions of the Representative Concentration Pathways (RCPs). Temperature changes are the GCM mean (°C) and, in brackets, the likely ranges.

Representative Concentration Pathway	Description	Seven-station temperature change (Ministry for the Environment 2016)		Global surface temperature change for 2081-2100 (IPCC 2014, Table 2.1)
		2031-2050	2081-2100	
RCP2.6	The least change in radiative forcing considered, by the end of the century, with +2.6 W/m^2 by 2100 relative to pre-industrial levels.	0.7 (0.2, 1.3)	0.7 (0.1, 1.4)	1.0 (0.3, 1.7)
RCP4.5	Low-to-moderate change in radiative forcing by the end of the century, with +4.5 W/m^2 by 2100 relative to pre-industrial levels.	0.8 (0.4, 1.3)	1.4 (0.7, 2.2)	1.8 (1.1, 2.6)
RCP6.0	Moderate-to-high change in radiative forcing by the end of the century, with +6.0 W/m^2 by 2100 relative to pre-industrial levels.	0.8 (0.3, 1.1)	1.8 (1.0, 2.8)	2.2 (1.4, 3.1)
RCP8.5	The largest change in radiative forcing considered, by the end of the century, with +8.5 W/m^2 by 2100 relative to pre-industrial levels.	1.0 (0.5, 1.7)	3.0 (2.0, 4.6)	3.7 (2.6, 4.8)

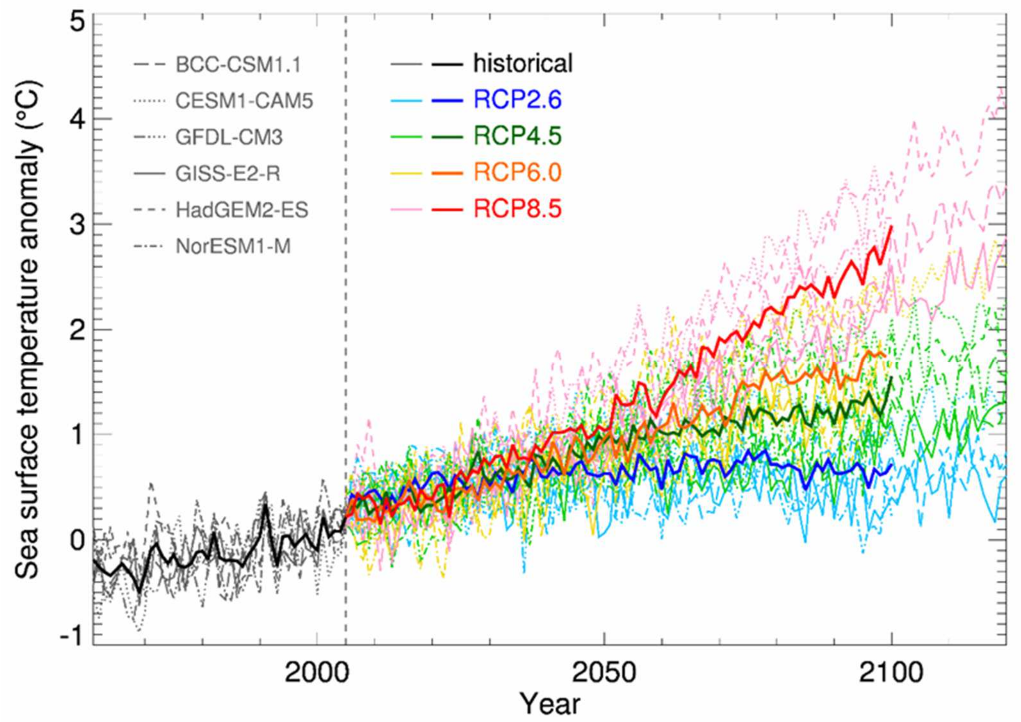

Figure 5-1: Bias-adjusted SSTs, averaged over the RCM domain, for 6 CMIP5 global climate models (2006-2120), the historical simulations (1960-2005), and four future simulations (RCPs 2.6, 4.5, 6.0 and 8.5), relative to 1986-2005 (Sood 2015). Individual models are shown by thin dotted or dashed or solid lines (as described in the inset legend), and the 6-model ensemble-average by thicker solid lines, all of which are coloured according to the RCP pathway.

Expected atmospheric climate change are summarised for the Hawkes Bay region from Ministry for Environment (2016):

- Average annual temperature is expected to increase in average by 0.7 to 1.1 deg C by mid-century (i.e., time slice 2031-2050 and 0.7 to 3.1 deg C by end century (i.e., time slice 2081-2100) (Table 5-6, Ministry for Environment 2016).
- Average annual precipitation is expected to remain stable by mid-century (-2%- 0%) and slightly decrease by the end of the century (-5% to -2%) (Table 10-11, Ministry for Environment 2016).
- Extreme daily precipitation, characterised by change in the 99th percentile[1] of the rain-day distribution (i.e., after eliminating dry days), is expected to increase up to 10 percent in coastal Hawkes Bay by the end of the century for the highest radiative forcing scenario. Inland Hawkes Bay is expected to experience no change in the 99th percentile of the rain-day distribution (Figure 47, Ministry for Environment 2016).

[1] Note that the 99th percentile is a relatively low threshold for engineering purposes (see Ministry for the Environment (2008), chapter 5.2). We would expect that, on average, approximately one day per year would exceed this threshold.

5.2 Climate Change Scenarios

Due to the exploratory nature of the project and to provide a straightforward framework for community discussion and potential adaptation strategies the following assumptions were made to assess climate change impact simulations:

- Climate change impact will not be simulated for the full suite of scenarios and model.
- Climate change assessment will be completed under RCP6.0, which represent a mid-range radiative emission scenario stabilising at the end of the century.
- One assessment will be carried out under the most extreme scenario at the end of the current climate change projections (i.e., 2120) as no projections under RCP6 exist for this time period.
- Only one GCM (GFDL-CM3), for which projections are available up to 2120, will be used to drive climate change simulations.

As a result, the following 3 scenarios are explored as part of this project:

- Climate Change Scenario 1: Cyclone Bola event with increased rainfall associated with 0.8 deg C temperature increase (RCP 6.0 out to 2040).
- Climate Change Scenario 2: Cyclone Bola event with increased rainfall associated with 1.9 deg C temperature increase (RCP 6.0 out to 2090).
- Climate Change Scenario 3: Cyclone Bola event with increased rainfall associated with 3.7 deg C temperature increase (RCP 8.5 out to 2120).

Climate change scenarios are usually applied over a 20 years' time slice (Ministry for Environment 2016). However, for this project the climate change scenarios will be applied for the period 6-10th March of each of the year selected for each scenario.

Change in precipitation are simulated as change in the total March precipitation over the three time slices considered and are summarised in Table 52. However, no effort has been made during this project to assess if a "Bola type event" was projected to occur over each future time period.

Table 5-2: Simulated change in precipitation and temperature. Change in temperature are expressed as difference in March temperature between scenario considered and March 1988. Change in precipitation are expressed as a ratio of the March total precipitation of the scenario considered and March 1988 .

Scenario	Change in Temperature [deg C]	Change in precipitation [-]
Scenario 1	+0.8	1.046
Scenario 2	+1.9	1.110
Scenario 3	+3.7	1.08

In accordance with the climate change scenarios selected for this investigation, climate change scenarios are used as input (for precipitation and temperature only) to the hydrological model to generate hydrographs that are used as lateral boundary conditions to the hydrodynamic model.

5.3 Climate Change Scenarios - Sea Level Rise

One of the major and most certain (and so foreseeable) consequences of increasing concentrations of carbon dioxide[2] and associated warming, is the rising sea level (Parliamentary Commissioner for the Environment, 2015).

The Intergovernmental Panel for Climate Change (IPCC) released its Fifth Assessment Report (AR5) in 2013/14. IPCC found that warming of the climate system is unequivocal, and many of the changes observed since the 1950s are unprecedented over timescales of decades to millennia. The atmosphere and ocean have warmed, the amounts of snow and ice have diminished, and sea level has risen (IPCC, 2014).

On behalf of the Ministry for the Environment, NIWA has led the team working on the revision of the *Coastal Hazards and Climate Change* guidance for local government (MfE, 2017) that was last revised in 2008 (MfE, 2008). It will provide specific guidance on sea-level rise scenarios to use for adapting to coastal climate change Aoatearoa–New Zealand, following on from the IPCC Fifth Assessment Report in 2013-2014 and more recent scientific papers. The coastal guidance is likely to be released by the Ministry by the end of 2017.

5.3.1 Impacts of sea-level rise

The rise in sea level is of great relevance for both short- and long-term decisions made in coastal areas, for three main reasons:

1. The long-term impacts on coastal populations, developments, and environments, are potentially large (e.g., Hinkel et al. 2014, Nicholls et al. 2011), because past coastal developments were built on the notion of a relatively “stable” sea level.

2. The sea-level response to warming of the Earth’s climate system makes it an integrated global indicator – more than 90% of the energy that is stored in the climate system ends up in the oceans (Rhein et al. 2013). Observed sea-level rise up to present, needs to be interpreted in light of substantial lags (decades to millennia) in the ongoing response to warming of the oceans and melting of glaciers and ice sheets (Church et al. 2013; Dangendorf et al. 2014).

3. While sea-level rise is more certain in the short term (e.g., 0.2–0.3 m by 2050), care is needed to avoid making decisions on responses today that will be inflexible later on as sea level rise accelerates, with the rate of change becoming more uncertain.

Rising sea level in past decades is already affecting human activities and infrastructure in some coastal areas, with a higher base mean sea level contributing to increased vulnerability to storms and tsunami. Key impacts of rising sea level are:

- gradual inundation of low-lying marsh and adjoining dry land on spring high tides
- escalation in the frequency of nuisance and damaging coastal-flooding events
- exacerbated erosion of sand/gravel shorelines and unconsolidated cliffs (unless sediment supply increases)
- increased incursion of saltwater in lowland rivers and nearby groundwater aquifers, raising water tables in tidally-influenced groundwater systems

[2] Global average now above 400 ppm.

- raising the tailwater level for river flooding in lowland section of rivers and streams.

These impacts will have increasing implications for most development and communities in coastal areas, along with environmental, societal and cultural effects.

Sea-level rise will have a greater influence on coastal storm inundation and rates of coastal erosion on the central parts of the east coast (Napier/Gisborne) and Cook Strait/Wellington areas (due to their smaller tidal range) than on coastal regions with larger tidal ranges (e.g., west coast – Taranaki, Nelson, Westport).

5.3.2 Trends for sea-level rise (global and New Zealand)

Changes in annual local MSL at the four main ports and for Moturiki (Mt. Maunganui) in New Zealand since 1900 are shown in Figure 5-2. Annual MSL is plotted relative to the average for each time series over the same 1986–2005 baseline period used for IPCC AR5 projections. The initial period of IPCC projections of SLR for RCP 8.5 and RCP 2.6 scenarios in Aotearoa-New Zealand (see next section) are also shown (dashed line) for a general comparison with observations to end of 2015 on how sea level is tracking.

Yearly and decadal variability in the observations from the 3-4 year El Niño-Southern Oscillation and longer 20–30 year Interdecadal Pacific Oscillation (IPO) cycle, partially mask the underlying trend, so makes it difficult to isolate how that underlying rising trend is tracking relative to the projections over short periods (Figure 1). For example, the annual MSL for ports is currently above the RCP projection lines, but in part this is due to the IPO shift to the negative phase in 1999 (Figure 5-2), which raised mean sea level throughout the western Pacific.

The average rate of sea-level rise across Aotearoa-New Zealand from 1900 to 2008 was 1.7 mm/yr (or 0.17 m over the last 100 years). This matched closely with the global average rate of sea-level rise of between 1.1–1.8 mm/yr (Church et al. 2013; Dangendorf et al. 2017). In last few decades since 1993 when satellite measurements of sea level commenced, the rate of global sea-level rise has increased to around 3.3 mm/yr by 2014 (Chen et al. 2017).

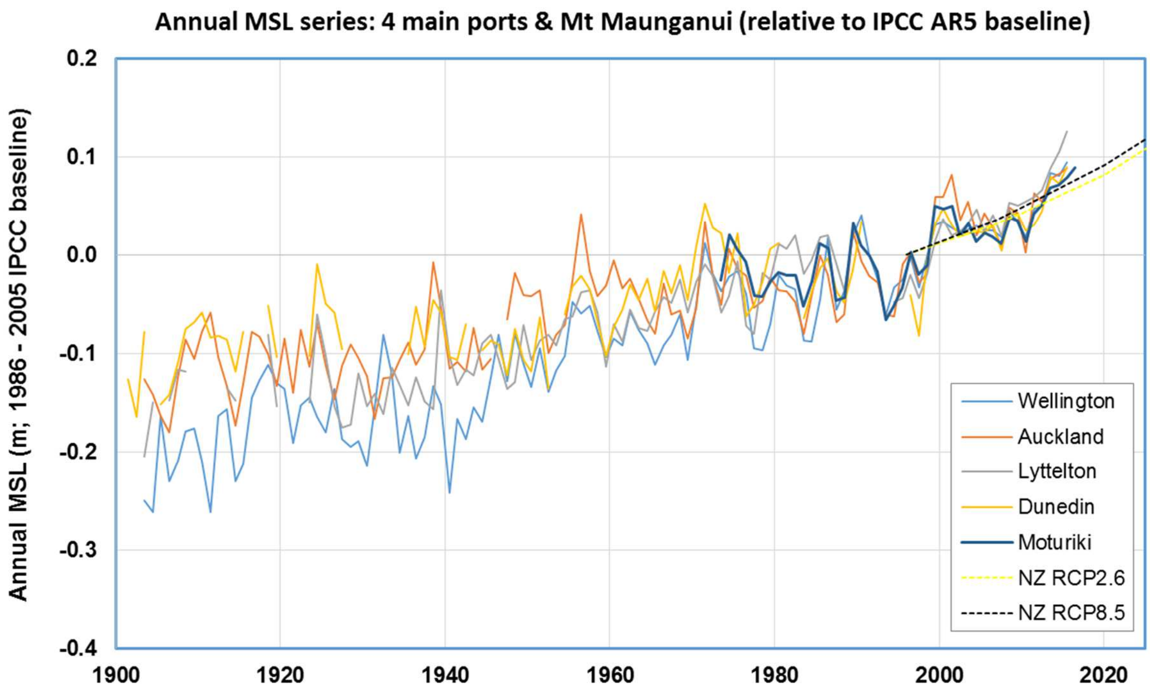

Figure 5-2: Change in annual local MSL for the four main ports and Moturiki (Mauo) from 1900–2015, and initial global-mean SLR projections for RCP2.6 and RCP8.5 to 2020. Relative to the average MSL over the baseline period 1986–2005 (used for IPCC AR5 projections of sea-level rise, with mid-point at 1996). (Source data: MfE (2017); Church et al. (2013)). [Reproduced from MfE (2017)]

5.3.3 Projections for sea-level rise

The primary climate driver for sea-level rise is the increase in global and regional surface temperature, which is strongly influenced by greenhouse gas emissions. With the greenhouse gases currently in the atmosphere and the heat stored in the ocean, the world is already committed to a delayed response in sea-level rise that will continue for several centuries, due to the inertia in the melting of the vast polar ice sheets. Cumulative global emissions to date have already committed the Earth to an eventual 1.6–1.7 m of global SLR relative to the present level (Strauss et al. 2015), even if no further net global emissions occur. However, depending on how continuing emissions track during the rest of this century (particularly the next few decades), realizing this present commitment to SLR could take 1–2 centuries.

The IPCC AR5 (Church et al. 2013) global sea-level projections out to 2100 are provided below. These are derived on process-based climate-ocean model results for the four different Representative Concentration Pathways (or RCPs)[3], and cover only the "likely range" of variability for each RCP, which covers the middle 66% spread (17^{th} and 83^{rd} percentile range) of model results for the particular RCP.[4]

[3] Represent different global greenhouse gas emission pathways, types of land-use change and global population. The lowest RCP2.6 pathways represents a future where global emissions are drastically reduced, reaching zero by 2075 and global population is limited – at the end, the RCP8.5 represents a future where global emissions continue to be high, as they are at present, and global population continues to grow.

[4] That means there is a 33% chance that SLR could lie outside the "likely range" (up or down) for that RCP.

The range of global-average sea-level rise projections derived by IPCC, based on process-based models, is shown in Figure 2, covering the “likely ranges” for the lowest and highest RCP2.6 and RCP8.5 scenarios up to 2100, and all four RCPs for the averaging period 2081–2100 towards the end of this century.

The zero baseline for these projections is the averaging period for MSL from 1986–2005 (same as for Figure 5-2).

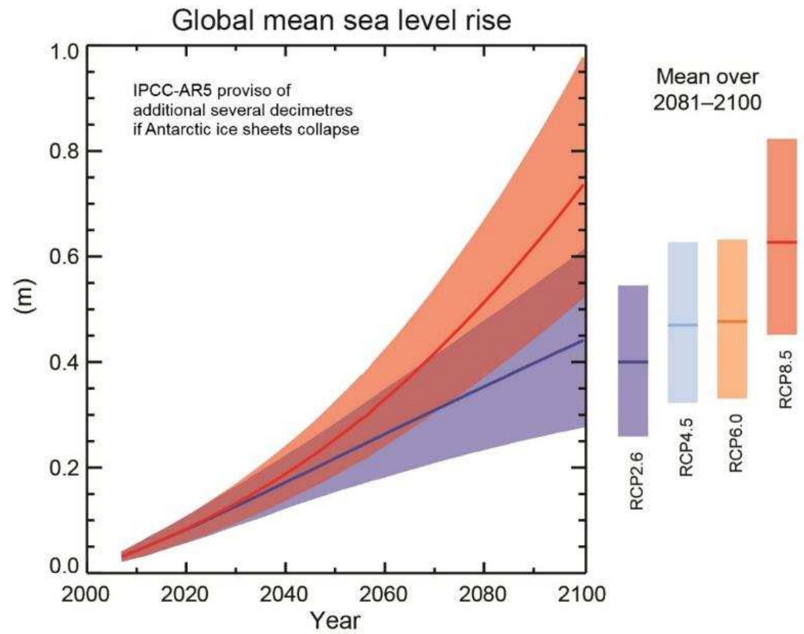

Figure 5-3: IPCC AR5 projections of global-average MSL rise (metres, relative to a base MSL of 1986-2005) covering the range of scenarios from RCP2.6 to RCP8.5. The heavy line shows the median estimate for that RCP, while the shaded area covers the “likely range” projections for the RCP, with a 33% chance SLR could be outside that range. The bars on the right show the median and “likely range” for all four RCPs averaged over the last two decades of this century (2081–2100), hence are lower than projections ending at 2100 in the main plot. (Source: Church et al. 2013).

- Onset of instabilities in the loss of the Antarctic ice sheets could cause global MSL to rise substantially above the *likely* range during the latter part of this century and beyond. While the contribution cannot be precisely quantified, there is *medium confidence* that it would not exceed several tenths of a metre[5] of sea-level rise by 2100 (Church et al. 2013).
- IPCC also stated that it is *virtually certain* that global mean sea-level rise will continue for many centuries beyond 2100, with the amount of rise dependent on future emissions.

The projected rise for the regional seas around Aotearoa-New Zealand are expected to be slightly higher than the rise in global average sea level by around 1–5 cm or up to 10% (Ackerley et al. 2013). So an additional small offset has been added to the global-average projections and applied to seas around Aotearoa-New Zealand, as shown in Figure 5-3.

[5] Or decimetre (one-tenth of a metre).

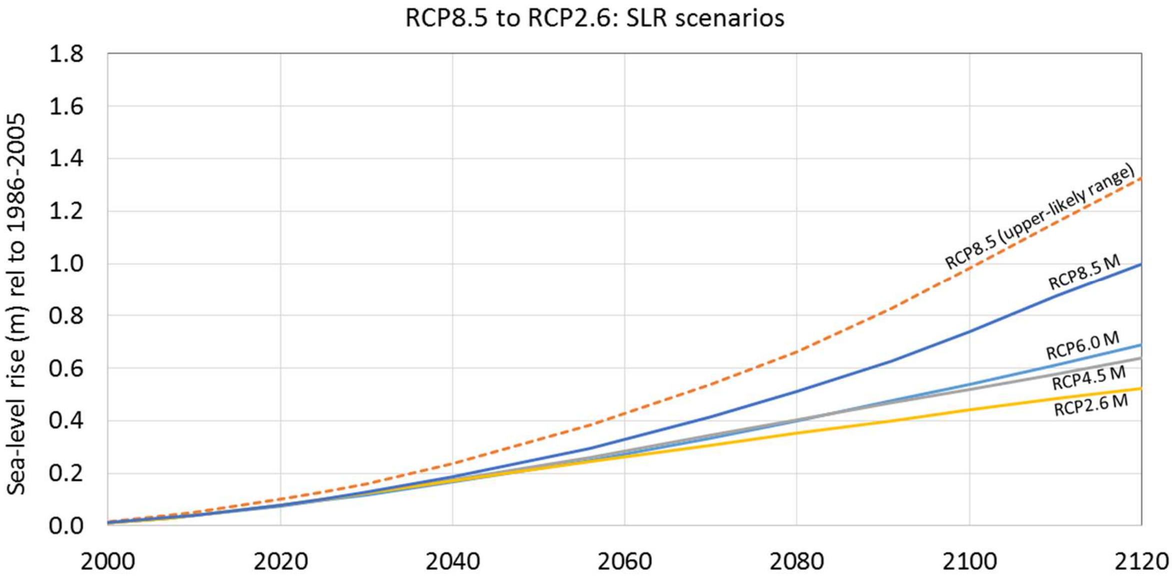

Figure 5-4: Sea-level rise projections for Aotearoa-New Zealand, based on median (M) trajectories for the various RCPs and a higher trajectory for the 83rd percentile RCP8.5 pathway (to cover possible instabilities in polar ice-sheet losses).

Analogous to the change in temperature and weather patterns over time being dependent on the specific climate change scenario applied, the amount of sea-level rise also depends on the assumptions made in the scenario definition. Each scenario stipulates a rate of sea-level rise associated with the increase in temperature.

In accordance with the climate change scenarios selected for this investigation, the following projected increases of sea level were used:

- CC Scenario 1: 0.2 m sea level rise (RCP 6.0 out to 2040).
- CC Scenario 2: 0.5 m sea level rise (RCP 6.0 out to 2090).
- CC Scenario 3: 1.39 m sea level rise (RCP 8.5 out to 2120).

6 Projected sea-level rise and stream flooding assessments

6.1 Hydrological projections

Here we present the change in hydrographs and flood characteristics (peak flow and duration) and give a short analysis for each of the scenarios presented in section 5.

Figure 6-1 presents the simulated hydrographs driven by the 3 climate change scenarios. The hydrographs are plotted against the time stamp of the observed hydrograph to facilitate the potential impact of climate change on the discharge characteristics. Table 6-1 summarised flood characteristics across the 3 scenarios.

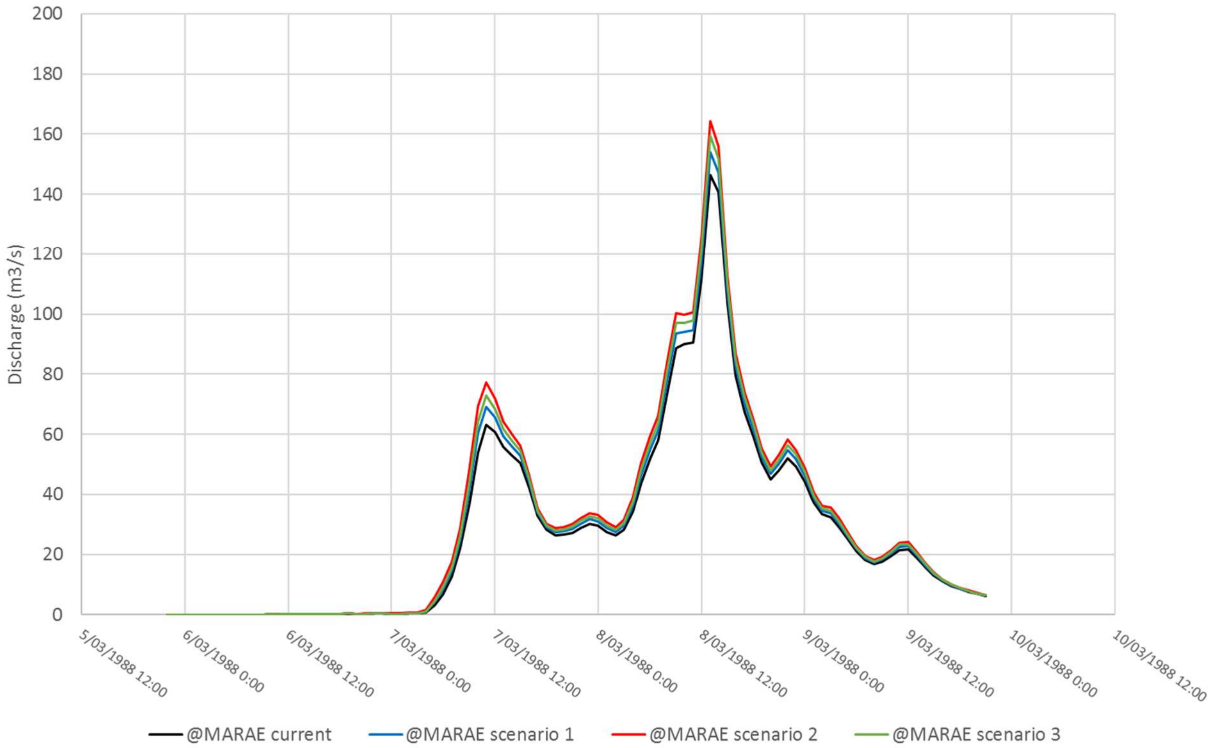

Figure 6-1: Simulated hydrographs for the 3 climate change scenarios.

Analysis of the simulated hydrographs indicates that:

- The shape of the hydrograph under climate change is not modified and is characterised by two successive peaks.
- Timing of the peak discharge is not changed under climate change. This result is expected and associated with the Delta change method used to generate climate change fields.
- The biggest increase in peak flows over the period 6-10th March is expected to increase under climate change by a maximum of 22% (CC Scenario 2, RCP 6.0 2090). By 2040, peak flows are expected to increase by a maximum of 13% (CC Scenario 1, RCP 6.0 2040). Peak flows in 2120 are expected to increase by 16% compared to cyclone Bola (CC Scenario 3, RCP 8.5, 2120).

- The apparent decrease in flood peak discharge by 2120 is likely to be associated with reduced net precipitation in the first weeks of March 2120 (compared to 2090).
- Largest increase in peak discharge is expected to occur over the first peak.
- Recession characteristics are similar under climate change.
- The change in peak flood represented over this analysis is only representative of change in peak floods over the period 6-10th March.

Table 6-1: Flood characteristics under climate change scenario. The characteristics are presented relative to the flood characteristics simulated during the Bola event.

	Scenario 1	Scenario 2	Scenario 3
Peak 1 timing (hr)	< 1hr	<1hr	<1hr
Peak 1 intensity (m3/s)	+8.1	+14.2	+9.7
Peak 2 timing (hr)	< 1hr	<1hr	<1hr
Peak 2 intensity (m3/s)	+7.5	+18.0	+13.1

6.2 Hydrodynamic projections

The differences in water depth of the 3 climate change scenarios in comparison with the observed water depths during Cyclone Bola are shown in figures 6-2 to 6-4.

Around the river mouth area, the influence of sea level rise can be observed through a backwater effect caused by the higher sea levels. However, the zone of influence is relatively localised around the mouth and does only affect the area roughly 600-700m upstream of the mouth.

The increased rainfall/runoff can be seen by a general deepening of the flood waters in most of the modelling domain for scenarios 2 and 3. In scenario 1, the only areas that experience notable changes in flood depth are the areas around the mouth and upstream of the Tangoio Settlement Road Bridge.

However, it is important to note that the stopbanks, which were erected after Cyclone Bola, act as an impediment to the modelled flood waters and result in water depths at the marae which are much lower than the levels observed during Cyclone Bola. While the stopbanks are not overtopped, the model indicates an overflow over the driveway between the marae and the state highway, bringing water onto the marae grounds.

Furthermore, the stopbank causes localised (up to a distance of about 150 m) increases in water depth of up to about 0.5m (compared to the levels of Cyclone Bola) on the outside/upstream side away from the marae.

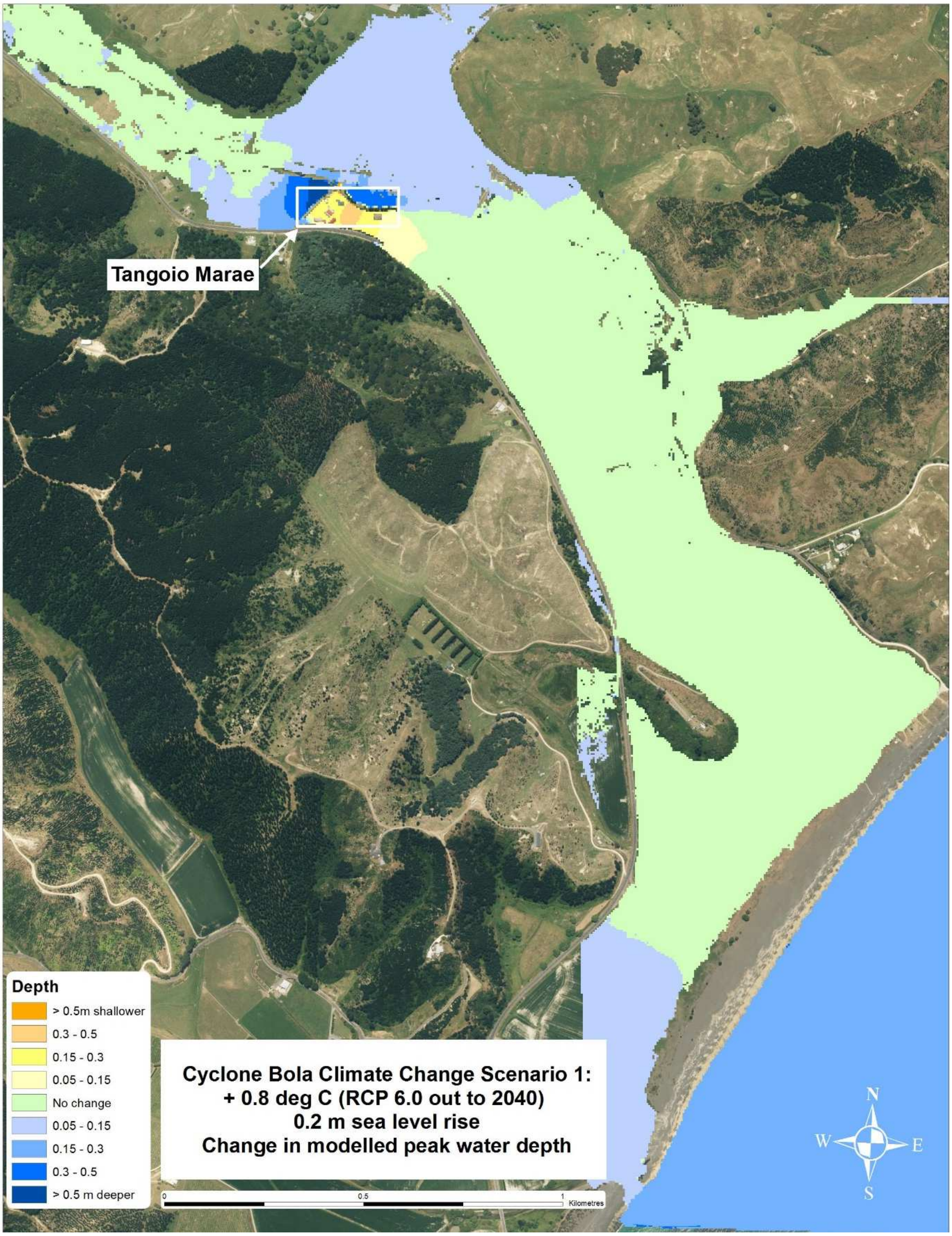

Figure 6-2: Differences in water depth between CC scenario 1 and Cyclone Bola.

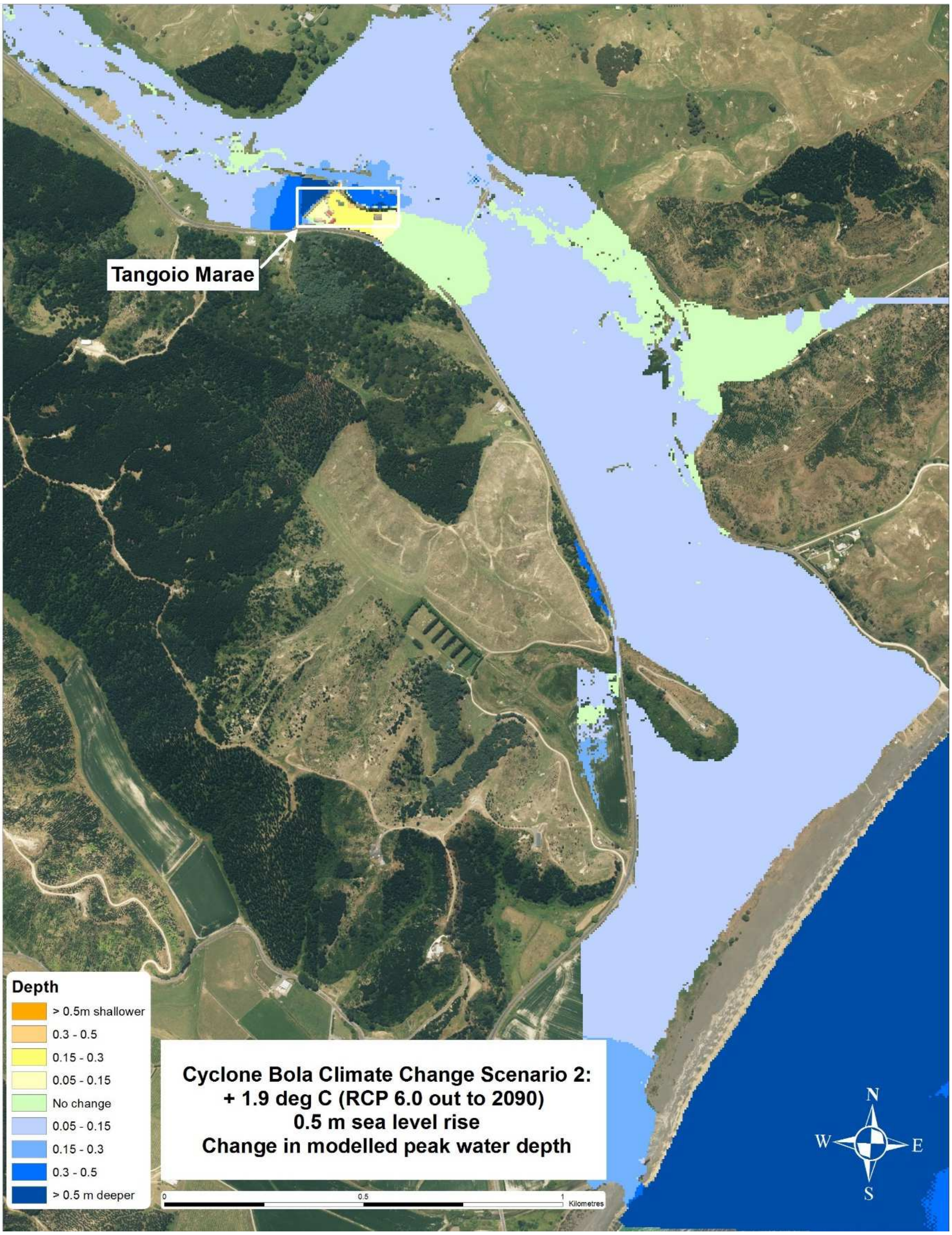

Figure 6-3: Differences in water depth between CC scenario 2 and Cyclone Bola.

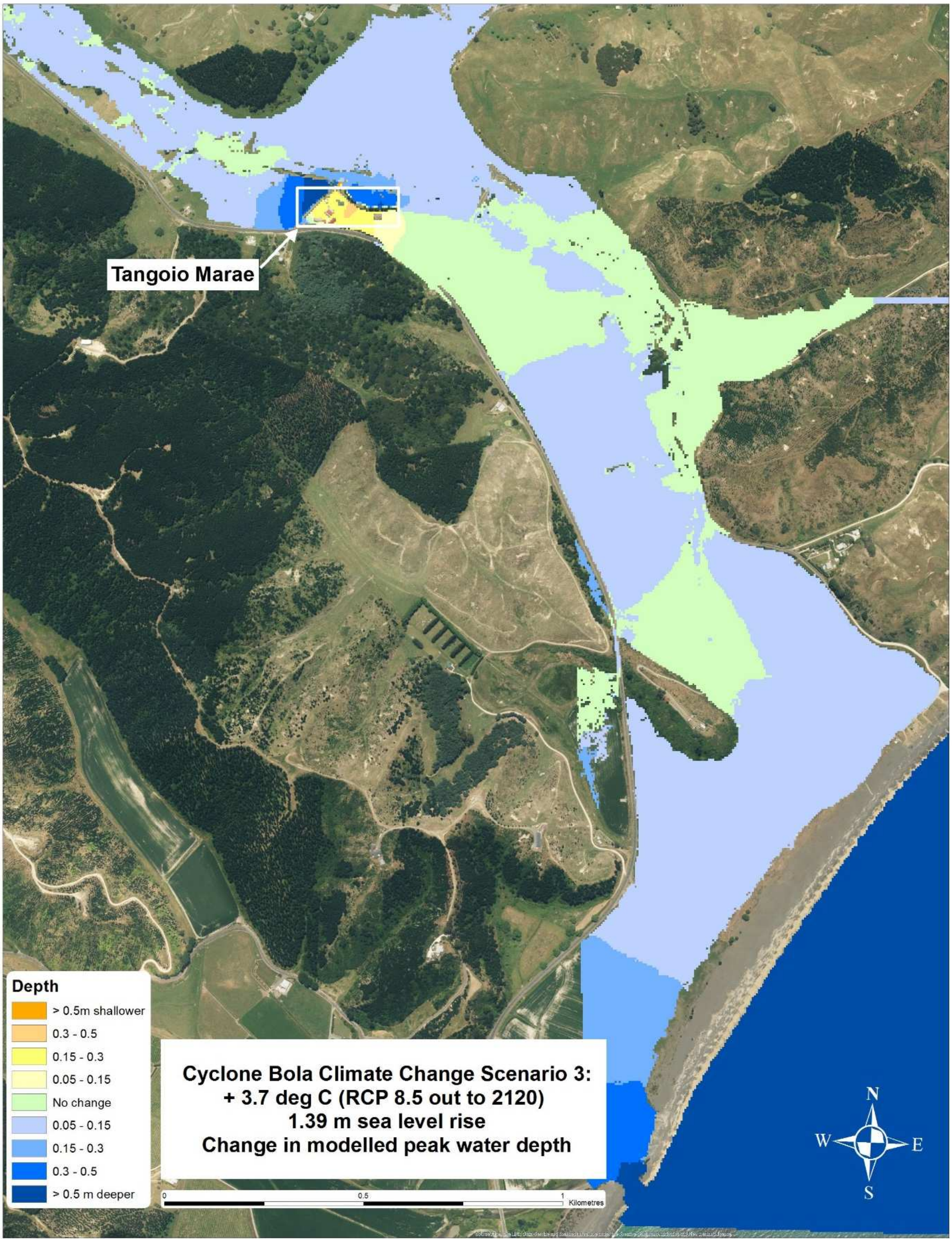

Figure 6-4: Differences in water depth between CC scenario 3 and Cyclone Bola.

7 Summary

The global climate system is changing and with it New Zealand's climate and environment. These changes will have implications not only for New Zealand's climate and weather systems but also for freshwater availability for downstream users and for hazard exposure (inland and coastal). Due to the nature of climate change, trends will vary across the country, over the course of the century, and among scenarios of climate change. Building on the assessment of future changes in New Zealand's climate (based on six model projections), this report addresses potential impacts of climate change on the combination of climate, hydrology and coastal process for three scenarios for the Tangoio Marae area. Those scenarios were built as occurring over the same time period of the Bola event (6-10th March) across three time slices (mid-century- 2040, end of century- 2099, and 2120) and is referred hereafter as 'Bola type event'

The potential effects of changing climate and sea level rise for each 'Bola type event" scenario is summarised as follows:

- By mid-century, peak discharges associated with a "Bola type event" are expected to increase by 13% and 5% (compared to the peak discharge simulated for the historical event), for the first and second flood peak respectively, with no change in the duration for the flood to rise to its peak. Flood depth increases are expected to be localised around the areas immediately upstream of the river mouth and upstream of the Tangoio Settlement Road Bridge.

- By end of century, peak discharges associated with a "Bola type event" are expected to increase by 22% and 12% (compared to the peak discharge simulated for the historical event), for the first and second flood peak respectively, with no change in the duration for the flood to rise to its peak. Flood depths are generally increasing due to a combination of sea level rise and increased discharge. However, the stopbanks, erected after Cyclone Bola, are not overtopped and the predicted flooding is reduced compared to the historically experienced levels during cyclone Bola.

- By 2120, peak discharges associated with a "Bola type event" are expected to increase by 16% and 9% (compared to the peak discharge simulated for the historical event), for the first and second flood peak respectively, with no change in the duration for the flood to rise to its peak. The reduced increase in peak discharge is associated with a reduced increase in early March precipitation (compared to the end of the century) by 2120. Flood depths are generally increasing due to a combination of sea level rise and increased discharge. However, the stopbanks, erected after Cyclone Bola, are not overtopped and the predicted flooding is reduced compared to the historically experienced levels during cyclone Bola.

- All scenarios show water depths shallower than those observed during cyclone Bola on the marae. This is due to the erection of a stopbank around the marae after Cyclone Bola which is effective in protecting against flood waters. A small amount of water is predicted to flow across the access road to the marae, bringing flood waters onto the marae grounds.

The future changes discussed in this report consider differences between the historical period 6-10th March 1988 and three hypothetical future time-slices, 6-10th March 20140, 6-10th March 2090 and 6-10th March 2120. The modelled differences between two time slices should not be attributed solely to climate change, as natural climate variability is also present and may add to or subtract from the climate change effect. The effect of natural variability has not been investigated for this report.

8 Glossary of abbreviations and terms

Term/abbreviation	Definition
99th percentile	The top 1 percent of a population.
Adaptation	The process of adjustment to actual or expected climate and its effects. In human systems, adaptation seeks to moderate or avoid harm or exploit beneficial opportunities. In some natural systems, human intervention may facilitate adjustment to expected climate and its effects.
Annual exceedance probability (AEP)	The probability of a given event (e.g., flood or sea level or wave height) being equalled or exceeded, in any given calendar year. AEP can be specified as a fraction (e.g., 0.01) or a percentage (e.g., 1%).
Anthropogenic emissions	Emissions of greenhouse gases, greenhouse gas precursors, and aerosols caused by human activities. These activities include the burning of fossil fuels, deforestation, land use changes, livestock production, fertilization, waste management, and industrial processes.
AR5	5th Assessment Report of IPCC – published in 2013/14 covering three Working Group Reports and a Synthesis Report.
Atmosphere	The gaseous envelope surrounding the Earth. The dry atmosphere consists almost entirely of nitrogen (78.1% volume mixing ratio) and oxygen (20.9% volume mixing ratio), together with a number of trace gases, such as argon (0.93% volume mixing ratio), helium and radiatively active greenhouse gases such as carbon dioxide (0.035% volume mixing ratio) and ozone. In addition, the atmosphere contains the greenhouse gas water vapour, whose amounts are highly variable but typically around 1% volume mixing ratio. The atmosphere also contains clouds and aerosols.
Average recurrence interval (ARI)	The average time interval (averaged over a very long time period and many “events”) that is expected to elapse between recurrences of an infrequent event of a given large magnitude (or larger). A large infrequent event would be expected to be equalled or exceeded in elevation, once, on average, every “ARI” years, but with considerable variability.
Baseline/reference	The baseline (or reference) is the state against which change is measured. A baseline period is the period relative to which anomalies are computed.
Bias correction	Procedures designed to remove systematic climate model errors.
Climate change	Climate change refers to a change in the state of the climate that can be identified (e.g., by using statistical tests) by changes in the mean and/or the variability of its properties, and that persists for an extended period, typically decades or longer. Climate change may be due to natural internal processes or external forcings such as modulations of the solar cycles, volcanic eruptions and persistent anthropogenic changes in the composition of the atmosphere or in land use.

Climate change scenario	A plausible and often simplified representation of the future climate, based on an internally consistent set of climatological relationships that has been constructed for explicit use in investigating the potential consequences of anthropogenic climate change, often serving as input to impact models. Climate projections often serve as the raw material for constructing climate scenarios, but climate scenarios usually require additional information such as the observed current climate. A climate change scenario is the difference between a climate scenario and the current climate.
Climate model	A numerical representation of the climate system based on the physical, chemical and biological properties of its components, their interactions and feedback processes, and accounting for some of its known properties. The climate system can be represented by models of varying complexity, that is, for any one component or combination of components a spectrum or hierarchy of models can be identified, differing in such aspects as the number of spatial dimensions, the extent to which physical, chemical or biological processes are explicitly represented or the level at which empirical parametrizations are involved. Coupled Atmosphere–Ocean General Circulation Models (AOGCMs) provide a representation of the climate system that is near or at the most comprehensive end of the spectrum currently available. There is an evolution towards more complex models with interactive chemistry and biology. Climate models are applied as a research tool to study and simulate the climate, and for operational purposes, including monthly, seasonal and inter-annual climate predictions.
Climate projection	A climate projection is the simulated response of the climate system to a scenario of future emission or concentration of greenhouse gases and aerosols, generally derived using climate models. Climate projections are distinguished from climate predictions by their dependence on the emission/concentration/radiative forcing scenario used, which is in turn based on assumptions concerning, for example, future socioeconomic and technological developments that may or may not be realized.
Climate variable	An element of the climate that is liable to vary or change e.g., temperature, rainfall.
CMIP5	Coupled Model Inter-comparison Project, Phase 5, which involved coordinating and archiving climate model simulations based on shared model inputs by modelling groups from around the world. This project involved many experiments with coupled atmosphere-ocean global climate models, most of which were reported on in the IPCC Fifth Assessment Report, Working Group I. The CMIP5 dataset includes projections using the Representative Concentration Pathways.

Downscaling (statistical, dynamical)	Deriving local climate information (at the 5 kilometre grid-scale in this report) from larger-scale model or observational data. Two main methods exist – statistical and dynamical. Statistical methods develop statistical relationships between large-scale atmospheric variables (e.g., circulation and moisture variations) and local climate variables (e.g., rainfall variations). Dynamical methods use the output of a regional climate/weather model driven by a larger-scale global model.
Emission scenario	A plausible representation of the future development of emissions of substances that act as radiative forcing factors (e.g., greenhouse gases, aerosols) based on a coherent and internally consistent set of assumptions about driving forces (such as demographic and socioeconomic development, technological change) and their key relationships.
GCM	Global climate model. These days almost all GCMs are AOGCMs (atmosphere-ocean global climate models). See also climate model.
Global mean surface temperature	An estimate of the global mean surface air temperature. However, for changes over time, only anomalies, as departures from a climatology, are used, most commonly based on the area-weighted global average of the sea surface temperature anomaly and land surface air temperature anomaly.
Greenhouse effect	The radiative effect of all infrared-absorbing constituents in the atmosphere. Greenhouse gases, clouds, and (to a small extent) aerosols absorb terrestrial radiation emitted by the Earth's surface and elsewhere in the atmosphere. These substances emit infrared radiation in all directions, but, everything else being equal, the net amount emitted to space is normally less than would have been emitted in the absence of these absorbers. This is because of the decline of temperature with altitude in the troposphere and the consequent weakening of emission. An increase in the concentration of greenhouse gases increases the magnitude of this effect; the difference is sometimes called the enhanced greenhouse effect. The change in a greenhouse gas concentration because of anthropogenic emissions contributes to an instantaneous radiative forcing. Surface temperature and troposphere warm in response to this forcing, gradually restoring the radiative balance at the top of the atmosphere.
Impacts (Consequences, Outcomes)	Effects on natural and human systems. In this report, the term impacts is used primarily to refer to the effects on natural and human systems of extreme weather and climate events and of climate change. Impacts generally refer to effects on lives, livelihoods, health, ecosystems, economies, societies, cultures, services, and infrastructure due to the interaction of climate changes or hazardous climate events occurring within a specific time period and the vulnerability of an exposed society or system. Impacts are also referred to as consequences and outcomes. The impacts of climate change on geophysical systems, including floods, droughts, and sea level rise, are a subset of impacts called physical impacts.

IPCC	Intergovernmental Panel on Climate Change. This body was established in 1988 by the World Meteorological Organisation (WMO) and the United Nations Environment Programme (UNEP) to objectively assess scientific, technical and socioeconomic information relevant to understanding the scientific basis of risk of human induced climate change, its potential impacts and options for adaptation and mitigation. Its latest reports (the Fifth Assessment) were published in 2013/14 (see www.ipcc.ch/).
Mitigation (of climate change)	A human intervention to reduce the sources or enhance the sinks of greenhouse gases.
Projection	A numerical simulation (representation) of future conditions. Differs from a forecast; whereas a forecast aims to predict the exact time-dependent conditions in the immediate future, such as a weather forecast a future cast aims to simulate a time-series of conditions that would be typical of the future (from which statistical properties can be calculated) but does not predict future individual events.
Radiative forcing	A measure of the energy absorbed and retained in the lower atmosphere. More technically, radiative forcing is the change in the net (downward minus upward) irradiance (expressed in W/m^2, and including both short-wave energy from the sun, and long-wave energy from greenhouse gases) at the tropopause, due to a change in an external driver of climate change, such as, for example, a change in the concentration of carbon dioxide or the output of the sun.
Regional Climate Model (RCM)	A numerical climate prediction model run over a limited geographic domain (here around New Zealand), and driven along its lateral atmospheric boundary and oceanic boundary with conditions simulated by a global climate model (GCM). The RCM thus downscales the coarse resolution GCM, accounting for higher resolution topographical data, land-sea contrasts, and surface characteristics. RCMs can cater for relatively small-scale features such as New Zealand's Southern Alps.
Representative Concentration Pathways (RCPs)	Representative concentration pathways. They describe four possible climate futures, all of which are considered possible depending on how much greenhouse gases are emitted in the years to come. The four RCPs, RCP2.6, RCP4.5, RCP6, and RCP8.5, are named after a possible range of radiative forcing values in the year 2100 relative to pre-industrial values (+2.6, +4.5, +6.0, and +8.5 W/m^2, respectively).

Scenario	In common English parlance, a ‘scenario’ is an imagined sequence of future events. The IPCC Fifth Assessment describes a ‘climate scenario’ as: A plausible and often simplified representation of the future climate, based on an internally consistent set of climatological relationships that has been constructed for explicit use in investigating the potential consequences of anthropogenic climate change, often serving as input to impact models. The word ‘scenario’ is often given other qualifications, such as ‘emission scenario’ or ‘socio-economic scenario’. For the purpose of forcing a global climate model, the primary information needed is the time variation of greenhouse gas and aerosol concentrations in the atmosphere.
Sea level change	Sea level can change, both globally and locally due to (1) changes in the shape of the ocean basins, (2) a change in ocean volume as a result of a change in the mass of water in the ocean, and (3) changes in ocean volume as a result of changes in ocean water density.
Sea surface temperature (SST)	The sea surface temperature is the subsurface bulk temperature in the top few metres of the ocean, measured by ships, buoys and drifters.
Simulation	Simulation is the imitation of the operation of a real-world process or system over time. The act of simulating something first requires that a model be developed; this model represents the key characteristics, behaviours and functions of the selected physical or abstract system or process. The model represents the system itself, whereas the simulation represents the operation of the system over time.
SLR	Sea-level rise.
W/m^2	Watts per square meter (a measure of radiation intensity).

9 References

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Appendix A History of Flooding – Te Ngarue Stream