Feasibility Study of Nature-based Solutions for Addressing the Flood Risk to Masterton

Prepared for: Greater Wellington Regional Council

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Authors
Tessa Allan
Mark Hooker

Approved by
Bryn Quilter

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Tonkin+Taylor

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Executive Summary

The Waipoua River presents a high flood risk to Masterton, as it flows through its centre and has historically caused flooding in the town. Previous studies have highlighted the potential financial damage a flood event may cause and that 3,600 buildings are at risk from flooding in a 1% annual exceedance probability (AEP) event[1]. The purpose of this Ministry for the Environment-funded assessment was to undertake a feasibility study of the effectiveness of nature-based solutions (NBS) to address the flood risk to Masterton.

From a longlist of potential NBS options, four approaches were selected for further assessment. These were primarily selected based on their expected potential for reducing flood peaks, but consideration was also given to geomorphic, groundwater and other wider benefits. The four selected NBS were:

- Land retirement and afforestation with indigenous vegetation;
- Channel realignment/ "room for the river";
- Small-scale, distributed retention storage; and
- Floodplain re-engagement.

A range of different-scale flood events were considered in the assessments that followed, but the focus was on Greater Wellington Regional Council's design storm for this catchment (a 1% AEP + climate change[2] event).

The selected NBS were assessed using aspirational but plausible scenarios of what form they might take and their spatial extent. In some cases, more than one scenario was considered for each NBS to provide a range of results or illustrate different possibilities in their implementation. The following assessments were carried out:

- A geomorphic assessment to investigate the potential for NBS to contribute to the geomorphic recovery of the river system and to moderate geomorphic processes.
- A flood modelling study, which simulated flood flows using hydrological and hydraulic models to estimate flood peak reductions due to NBS.
- A semi-quantitative valuation and ranking of wider ecological, social, and cultural benefits, based in part on a stakeholder workshop.
- An investigation of the potential for NBS to deliver groundwater recharge and river baseflow benefits, including developing a high-level groundwater model.
- A study of appropriate indigenous vegetation types and planting strategies, considering local knowledge/ mātauranga.
- An estimate of the land area required for each NBS.
- High-level cost estimates and simple cost-benefit analyses for each NBS.
- A review of risks and constraints to the implementation of NBS generally, as well as with particular emphasis on the four NBS being assessed in detail.

The table at the end of this executive summary summarises the outcomes of the above for the four selected NBS.

The feasibility assessment found that nature-based solutions (NBS) can deliver meaningful reductions in flood risk to Masterton, but only if implemented at a large scale. Modelling showed that reductions in peak flood flows from individual NBS scenarios ranged from 0.5% to 3.8% for the 1% AEP + climate change design event. A hybrid approach combining multiple NBS would be required to achieve a more substantial reduction—such as

[1] A flood with a probability of 1% AEP has a 1% chance of occurring in any given year.

[2] Climate change under Representative Concentration Pathway 6.0 (RCP 6.0) to 2100.

the 5% reduction considered by the Waipoua Project Team, or the approximately 20% needed to offset climate change impacts. However, achieving this would require major land-use change, with estimates of at least 100–200 hectares needed per 1% reduction in peak flow.

Cost-effectiveness varied widely across the four NBS assessed. Channel realignment/room for the river was the most cost-effective option in terms of flood damages saved, while small-scale, distributed retention storage was the least cost-effective. None of the NBS approaches delivered a financial return as high as $1 saved in flood damages per $1 spent. However, this narrow financial lens does not capture the full value of NBS, which also provide significant ecological, cultural, and social benefits. It also doesn't consider the different risk profiles of the four NBS. Overall, while NBS are unlikely to replace structural flood protection measures in Masterton, they could play a complementary role—particularly in reducing the risk from geomorphic processes, and delivering broader environmental outcomes.

If implementation of NBS in the Waipoua catchment is pursued, it should follow a staggered, strategic, and integrated approach. A hybrid model combining different NBS approaches is likely to balance short-term and long-term benefits, as well as to spread performance risks of different NBS approaches. For example, small-scale, distributed retention storage can deliver immediate sediment and runoff control, while land retirement and afforestation provide longer-term flood, geomorphic and biodiversity benefits. Planning should prioritise "low-hanging fruit" such as areas with willing landowners, existing restoration efforts, or high ecological potential.

The report recommends aligning NBS implementation with community values and existing projects. Stakeholder engagement revealed strong support for NBS that enhance biodiversity, water quality, and habitat—particularly land retirement and afforestation. Implementation should also leverage existing data and tools, such as geomorphic sensitivity maps and indigenous vegetation mapping, to guide site prioritisation and implementation strategies. Integration with other stakeholders and projects is essential to maximise synergies, avoid duplication and minimise conflict between differing objectives. Clear communication about what NBS can and cannot deliver, and early investment in monitoring and adaptive management, will be critical to building trust and ensuring long-term success.

Further technical investigations could also be taken further. For groundwater recharge, transient modelling and site-specific aquifer data are needed to better understand seasonal dynamics and optimise NBS placement, if Greater Wellington wishes to target groundwater recharge benefits. For flood modelling, further testing of storm variability and dynamic effects—particularly for small-scale storage and channel realignment—is recommended to reduce uncertainty. The use of tools like InVest could help quantify wider benefits such as habitat quality and sediment retention, providing a more balanced view of NBS value. Finally, early establishment of trial catchments and long-term monitoring programmes will be essential to refine designs, build evidence, and support adaptive management over time.

NBS approach	Summary description	Key findings/benefits						
		Geomorphic assessment	Wider benefits assessment	Groundwater recharge and low flows assessment	Indigenous vegetation investigation	Land area required	High-level cost estimate	Cost-benefit analysis
			Heatmap benefits assessment Mean willingness to pay (WTP) Ranking preference (1 = high, 5 = low)		Indigenous vegetation benefits and relevant datasets	Area required per 1% design flood flow reduction	Cost per 1% design flood flow reduction	Cost per $ flood damages saved in the design flood
Land retirement and native afforestation	Retirement of farmland and planting of native forest.	Long-term regulation of sediment supply (reduction) and increase in wood loads in Wakamoekau and Mikimiki catchments.	Moderate to strong benefits across most benefit categories, including those most preferred by stakeholders. Mean WTP: $338 (highest) Ranking: 1.60	Afforestation has the potential to have a negative impact (reduction) in groundwater recharge and baseflows due to increased evapotranspiration and interception of rainfall, however, the findings in literature are mixed, with a lack of consensus.	Potential to stabilise soils and reduce runoff. **Datasets relevant to implementation**: Plant typologies, pre-human and existing vegetation cover, and the historic and current land use.	459 ha	$33M	$15 – $29
Floodplain re-engagement	Lowering adjacent floodplain areas and encouraging flow into former channels. A sub-scenario including planting native vegetation on this land was considered for some of the later assessments.	Moderation of sediment processes and reduction in stream power from Mikimiki downstream to Masterton.	Moderate benefits across approximately half the criteria assessed. Mean WTP: $209 (lowest) Ranking: 2.33	Not assessed in the hydrogeology assessment due to its episodic nature.	Increases water retention, surface roughness, floodplain habitats. **Datasets relevant to implementation**: Plant typologies, historic and current land use, pre-human and existing wetland and vegetation cover.	134 – 336 ha	$121M – $201M	$21 – $63
Floodplain re-engagement + vegetation						88 ha	$21M – $31M	$10 –$27
Small-scale, distributed retention storage	Retention storage in the form of many small ponds, infiltration basins, attenuation wetlands, leaky dams etc. located on flow paths within the catchment but offline from the main river.	Reduction in stream power and moderation of sediment supply, especially fine-grained sediment, in Wakamoekau and Mikimiki catchments.	Moderate benefits across approximately half the criteria assessed. Mean WTP: $217 Ranking: 2.83	Modest potential for increasing groundwater recharge. If these can be designed and located to regularly capture runoff and infiltrate it to shallow groundwater, there may be potential to supplement baseflow in nearby streams/springs.	Filter and trap sediments and pollutants, increase surface roughness and water percolation. **Datasets relevant to implementation**: Plant typologies, soil types and drainage.	17 – 65 ha	$109M – $190M	$34 – $112
Channel realignment/ room for the river	Reducing intervention and allowing the river to widen to its former extents and allowing space for natural river processes such as erosion, meandering and aggradation to reassert themselves.	Reduced stream power downstream of the Kiriwhakapapa confluence, likely triggering aggradation.	Moderate to strong benefits across most benefit categories. Mean WTP: $244 Ranking: 2.83	Greatest potential for groundwater recharge, particularly under scenarios where channel realignment leads to bed aggradation. However, this comes at the cost of river flows.	Act as a buffer in high-flow events, reduce localised flooding, filter runoff, enhance habitat diversity and connectivity. **Datasets relevant to implementation**: Plant typologies.	269 ha	$ 9M	$3 – $6

Glossary

Terminology	Definition
Annual exceedance probability (AEP)	Describes the likelihood of a flood of a certain size in any given year. For example, a 1% AEP has a 1% chance of occurring in any given year.
Channel realignment/ room for the river	Increasing the active channel width through removing willows, relocating stopbanks and reducing management interventions to allow the Waipoua River to widen and “wander” more freely.
Design flood	The design flood event adopted for flood management on the Waipoua River in Masterton (1% AEP + climate change to 2100, using scenario RCP 6.0). For the purposes of this study, this is the modelled flow immediately upstream of the railway bridge.
Floodplain re-engagement	Improving the connection between the Waipoua River and its floodplains through recreating former flow paths and lowering the floodplain to increase flood frequency.
Geomorphic effectiveness	The degree and rate to which the river will change in channel form and function due to the implementation of NBS.
Geomorphic sensitivity	Capacity of a river system to adjust or recover from disturbances.
Hydrograph	A graph showing how flow varies over time, usually showing a defined flood peak.
Land retirement and native afforestation	Changing the land use to native forest.
Low-hanging fruit	Tasks or projects that are easiest to achieve with the fewest barriers, constraints, or effort required. Also known as “quick wins”.
Nature-based solutions (NBS) (adopted definition)	Actions to protect, conserve, restore, sustainably use and manage natural or modified terrestrial, freshwater, coastal and marine ecosystems which address social, economic and environmental challenges effectively and adaptively, while simultaneously providing human well-being, ecosystem services, resilience and biodiversity benefits.
Natural character index (NCI)	A quantitative measure to assess the degree of modification and natural character, comparing the present day and historical river conditions.
RCP 6.0 (representative concentration pathway)	Projections of future greenhouse gas concentrations in the atmosphere. The RCP 6.0 scenario is known as a high emission scenario. There are no likelihoods associated with RCPs.
River behaviour	River dynamic processes that shape and change the river features.
River character	The physical features of the river including landforms, and channel shape.
Selected NBS	The four NBS that were assessed in this feasibility study for the Waipoua catchment.
Small-scale, distributed retention storage	Many smaller runoff storage areas located on drainage paths. They would capture and hold runoff for infiltration, evapotranspiration, or delay of discharge into the downstream catchment.

1.0 Introduction

The Waipoua River presents a high flood risk to Masterton, as it flows through its centre and has historically caused flooding. Previous studies have highlighted the potential financial damage a flood event may cause and that 3,600 buildings are at risk from flooding in a 1% annual exceedance probability (AEP) event. This study assesses the feasibility of using nature-based solutions (NBS) to help to manage flood risk to Masterton.

From a longlist of potential NBS, four approaches were selected for further assessment. For each NBS approach, technical assessments were undertaken regarding indigenous vegetation, groundwater recharge and river baseflows, geomorphology, the wider benefits of NBS, estimates of the land area required, and high-level cost estimates. Finally, risks and constraints were assessed, and the costs were compared to flood damages saved in a design flood event. This report outlines (in Figure 1.1):

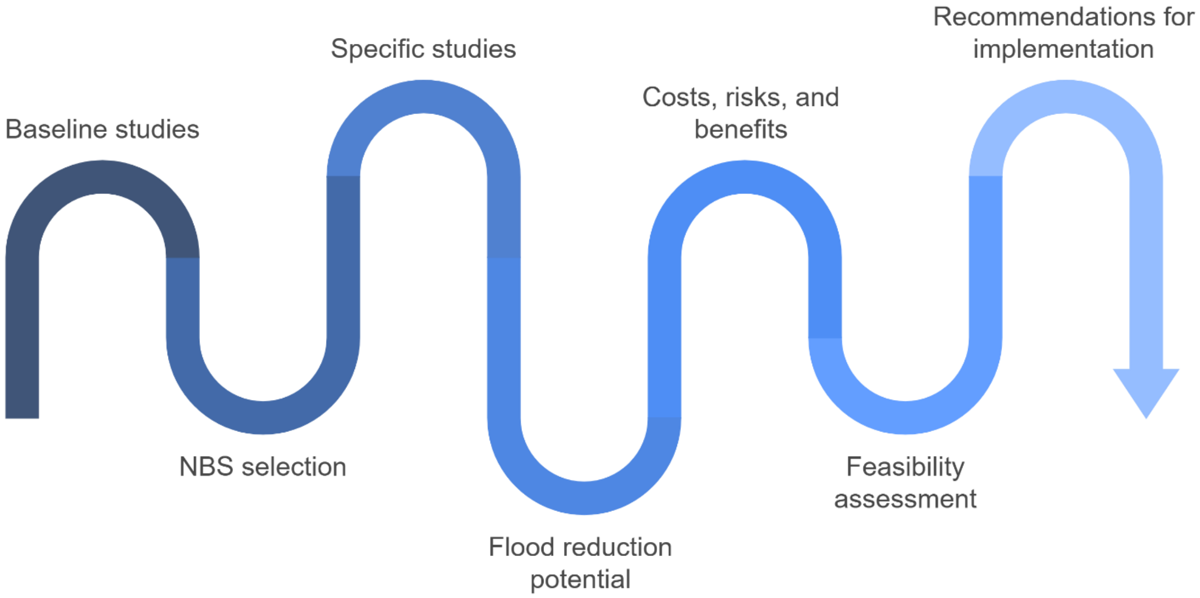

Figure 1.1: Report outline

1.1 Project background

Ministry for the Environment (MfE) established funding for regional and district councils to apply for, to study NBS for flood risk reduction. There was funding allocated for 21 studies, one of which is reported on here. This project commenced in July 2023.

There were multiple studies being undertaken in New Zealand and there was potential for large investments in NBS in the future. Therefore, MfE sought to avoid duplication by undertaking an independent literature review for the various NBS. NIWA was commissioned to undertake a literature review for the feasibility studies to refer to (Griffiths et al., 2024), aiming to improve the cost efficiency of current and future NBS based projects. The literature review focused on:

- Current national and international literature on the use of NBS in flood mitigation and management.
- Existing guidance and case studies for how such measures may be implemented in New Zealand.

Prior to the commencement of the feasibility assessment for the Waipoua catchment, Greater Wellington invested in projects to understand the potential flood extents and damages to the Masterton urban area. The studies and their findings are summarised in Section 2.0. Given this, the Waipoua catchment was identified as an ideal case study for the feasibility assessment of NBS. Greater Wellington commissioned Tonkin & Taylor Ltd (T+T) to lead this feasibility assessment of NBS for the Waipoua catchment.

1.2 Purpose

The purpose of this MfE-funded assessment is to undertake a feasibility study of the effectiveness of nature-based solutions (NBS) to address the flood risk to Masterton, in the lower Waipoua catchment. The study focussed on the design flood event, 1% AEP + climate change (RCP6.0) to 2100, that has been adopted for flood management on the Waipoua River. Additionally, smaller events were also assessed to understand the effectiveness of NBS across a range of flood events.

This project seeks to deliver on the following two outcomes:

- Build stronger communities that are resilient to extreme weather events and the effects of climate change by improving informed decision making; and
- Uphold Te Oranga o te Taiao by investigating ways to protect and enhance the natural environment including improving outcomes for indigenous biodiversity.

1.3 The Waipoua catchment

The following summary of the Waipoua catchment draws largely from the Te Kāuru Upper Ruamāhanga Floodplain Management Plan (Greater Wellington, 2019).

"The Waipoua River has a catchment area of 149 km^2, and the main river channel from its headwaters to its confluence with the Ruamāhanga River is 30 km long. The headwaters originate from the Blue Range of the Tararua Range, flowing on through steep-sided gorges fringed by native forest. A large part of the catchment is in the lower foothills of the range [mainly farmland on the foothills and floodplain]. The Waipoua floodplain soils are formed from greywacke alluvial parent materials from the Tararua Range." A map of the catchment is included below as Figure 1.2.

"The river has three major tributaries: Kiriwhakapapa Stream, Mikimiki Stream and Wakamoekau Creek. These streams join the river as it flows across the Wairarapa Plains, before passing through the Masterton urban area to its confluence with the Ruamāhanga River at Te Oreore."

"[The Waipoua] is a steep gravel-phase river with a relatively stable and narrow single-thread channel. The Mikimiki reach and the urban Masterton reach have historically been straightened, steepened, and shortened." T+T (2024) identified the following stream types along the Waipoua River:

- Confined, low sinuosity cobble/ boulder bed;
- Artificially confined, low sinuosity gravel bed;
- Partly confined, low sinuosity gravel bed;
- Partly confined, moderate/ high sinuosity gravel bed; and
- Unconfined, artificially straightened gravel bed.

"The river's name is attributed to Haunui-a-Nanaia, the great grandson of Kupe, who tested its depth with a stick before making the crossing; 'wai' means water and 'poua' means to plunge a stick. The banks of the Waipoua housed one of the first kāinga visited by Europeans in the region, but the precise location is not known."

"The siting of Kaikōkirikiri Pā close to both the Waipoua and Ruamāhanga Rivers is an indication of the cultural values associated with the area. The closeness of the pā to the Waipoua River indicates that the wider-surrounding environment would have been regularly frequented and used for a range of cultural practices."

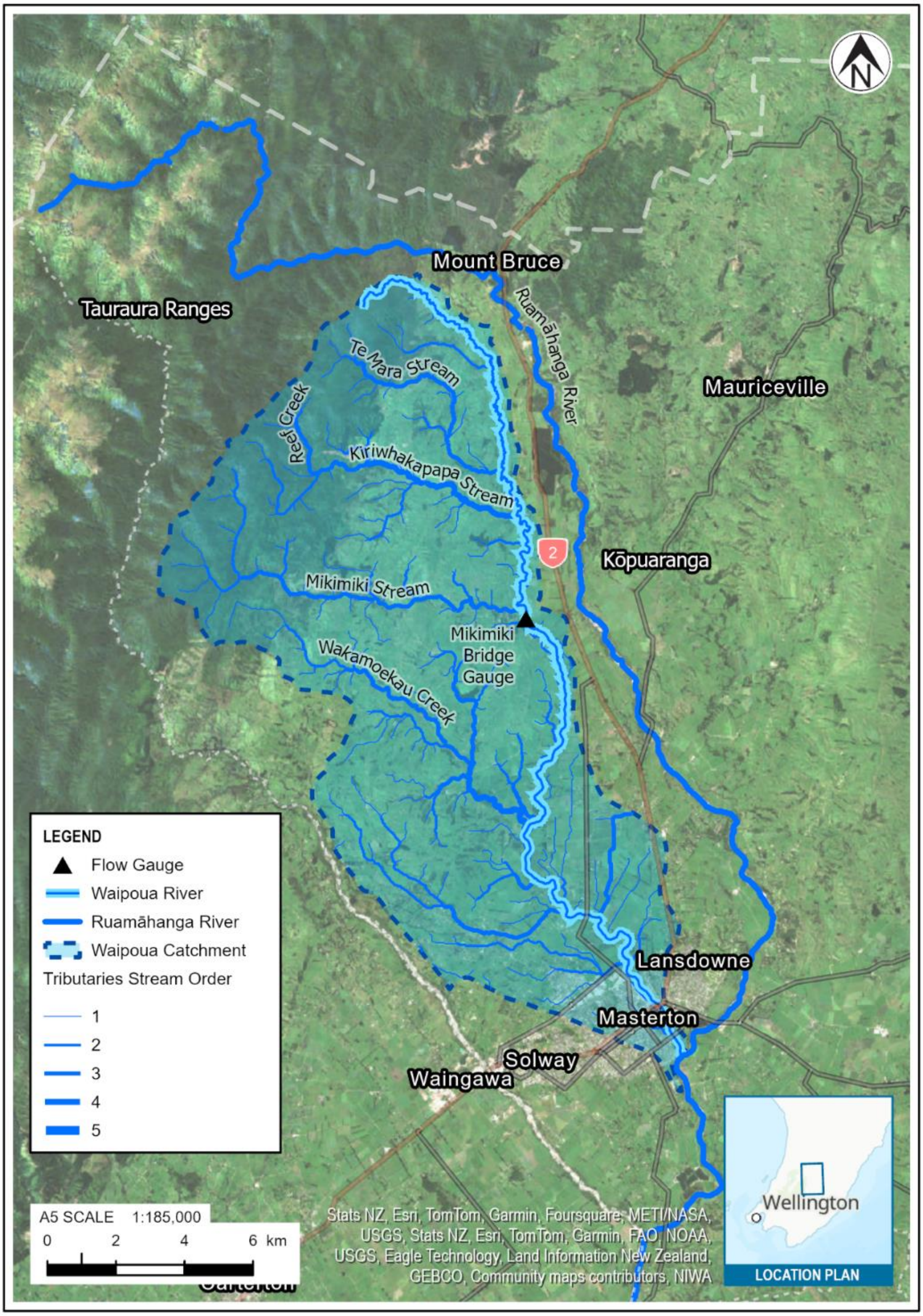

Figure 1.2: Waipoua catchment, tributaries and the location of the Mikimiki flow gauge (T+T, 2024b).

2.0 Baseline studies

Greater Wellington has recently undertaken studies that relate to and support this feasibility assessment of NBS for addressing the flood risk in the Waipoua catchment, Masterton. Previous projects are outlined in Table 2.1. The Stage 1 Geomorphic Assessment and Natural Character Index assessments are included in the work funded by MfE.

Table 2.1: Previous Waipoua River studies

Study title	Purpose	Consultant contracted
Waipoua Hydrology Update	Understand the extent of flooding risk to the Masterton urban area.	Barnett & MacMurray Ltd (2023)
Waipoua River Model Upgrade Report		Land River Sea Consulting Ltd (2023)
Stage 1 Waipoua Geomorphic Assessment	Support prioritisation of flood risk management solutions and explore NBS through a geomorphic understanding.	Tonkin & Taylor Ltd (2024b)
Natural Character Index (NCI) for Waipoua and Mangatarere Rivers	Understand the physical changes of the river and the degree it has maintained its physical characteristics from the late 1940's to 2013.	Carter & Fuller (2024)
Waipoua Flood Damages Assessment	Inform decision making on flood risk management options.	Tonkin & Taylor Ltd (2024a)

2.1 Flood hazard modelling and mapping

Greater Wellington engaged Barnett and MacMurray Ltd to undertake hydrological modelling, and Land River Sea Consulting Ltd to complete hydraulic modelling and mapping of the Waipoua catchment to assess flood hazard. The model starts at the Mikimiki bridge and is described in Barnett & MacMurray (2023) and Land River Sea (2023).

Flood hazard modelling is the process carried out by Greater Wellington to understand flood risk from significant water courses in the Wellington Region. It consists of three key elements: collection of survey information; hydrological modelling; and hydraulic modelling. The flood hazard modelling outputs are the flood maps that are included in district plans, which provide the basis of structural works and river management decision making and inform civil defence and emergency management actions.

Greater Wellington finalised the Flood Hazard Modelling Standard (FHMS) in May 2021 which outlines the protocols to be followed by any person working on Greater Wellington flood hazard modelling projects. The protocols in the FHMS have been developed to ensure that flood hazard modelling projects are undertaken in a robust and consistent way that is in line with accepted industry practice.

A detailed flood hazard assessment for the Waipoua River was completed following the FHMS. Each stage of the FHMS has been completed, including all peer reviews and the independent audit. The independent audit was completed in June 2024.

The data from this detailed modelling is now available and includes flood depth, flood levels, velocity, hazard and shear stress. The design floods that were modelled are listed in Table 2.2.

Table 2.2: Modelled design flood events

Present day	Climate change (2050)	Climate change (2100)
39.35% AEP		39.35% AEP
20% AEP		20% AEP
10% AEP		10% AEP
5% AEP		5% AEP
2% AEP	2% AEP	2% AEP
1% AEP	1% AEP	1% AEP
0.1% AEP		0.1% AEP
		1% AEP Breach scenario 1
		1% AEP Breach scenario 2
		1% AEP Breach scenario 3
		45 individual sensitivity scenarios
		Maximum uncertainty results

The flood depth maps for the 1% AEP event with allowance for RCP 6.0 climate change to 2100, including uncertainties modelling, are shown in Figure 2.1 and Figure 2.2. Approximately 3,600 buildings are impacted by this size flood event.

This data represents the scenario for the flood hazard with present day's catchment characteristics. Section 5.0 describes how NBS could reduce this flood risk.

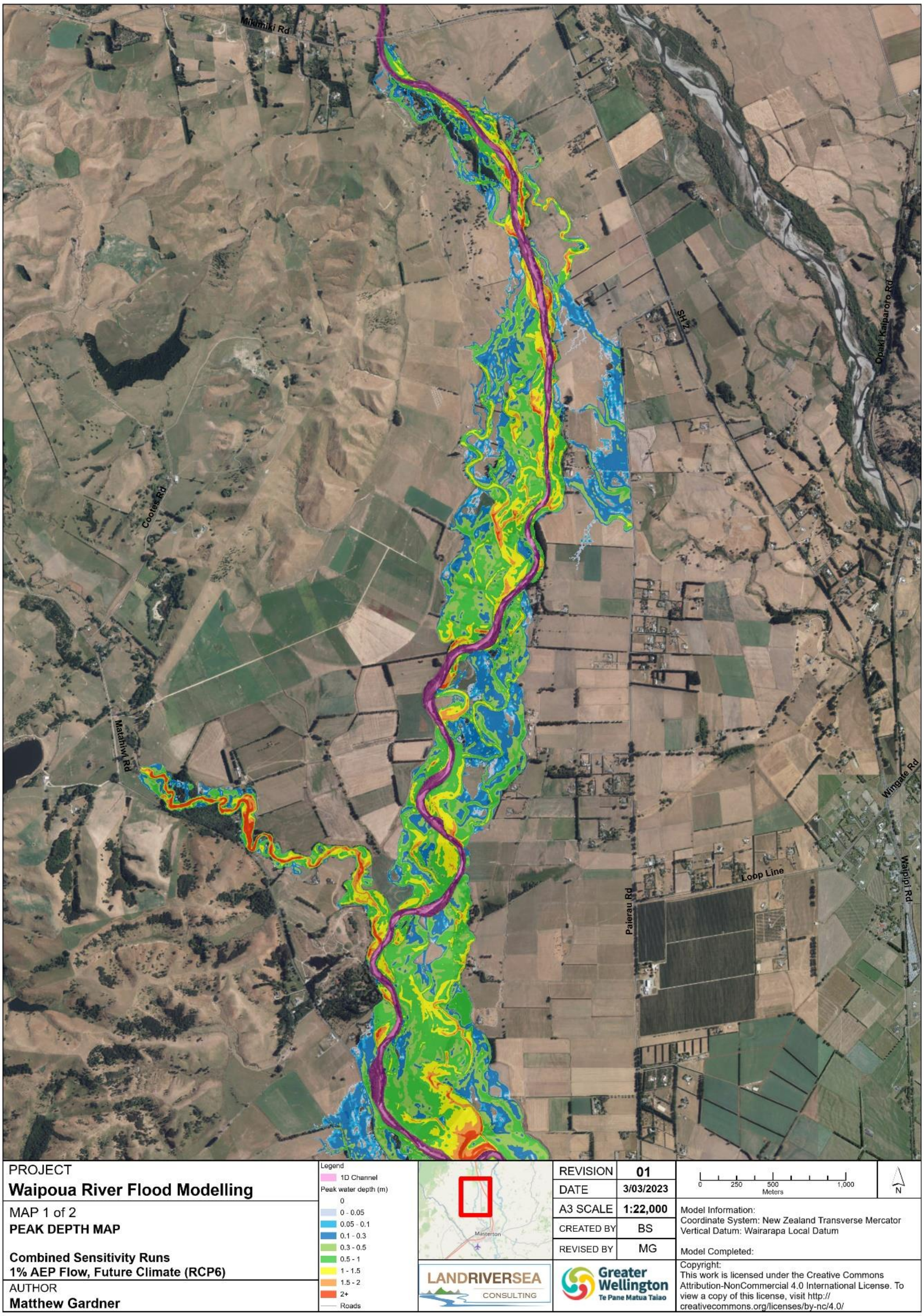

Figure 2.1: Flood hazard through the rural catchment from a 1% annual exceedance probability flood in the Waipoua River (including an allowance for climate change and modelling uncertainties).

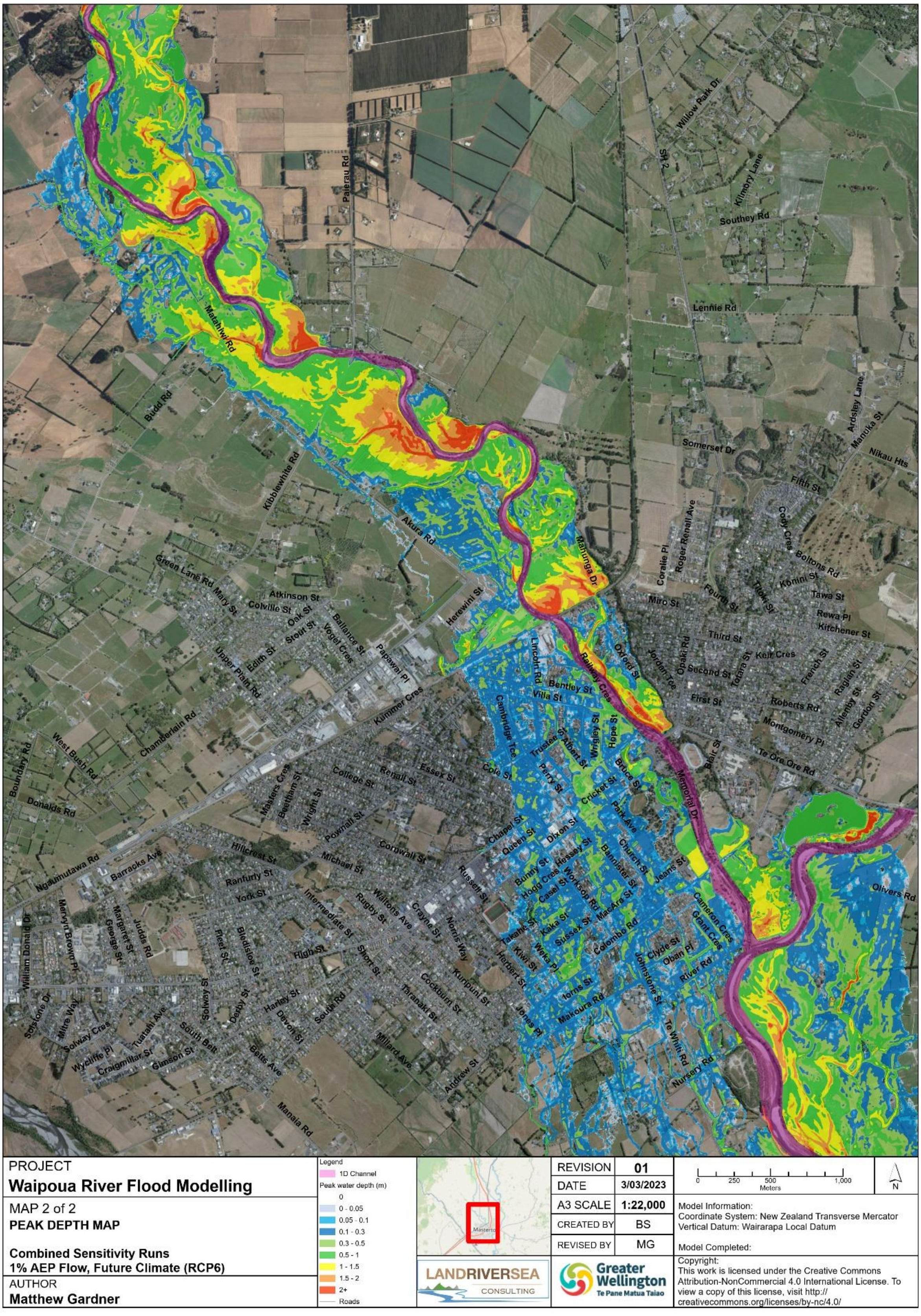

Figure 2.2: Flood hazard through the Masterton urban area from a 1% annual exceedance probability flood in the Waipoua River (including an allowance for climate change and modelling uncertainties).

2.2 Geomorphic assessment

There were two geomorphic assessments previously undertaken for the Waipoua catchment: a desktop geomorphic assessment and a natural character index assessment, as described in the following sections.

2.2.1 Stage 1 Geomorphic Assessment

Greater Wellington engaged T+T to undertake a desktop geomorphic assessment of the Waipoua River (T+T, 2024b).

A modified River Styles assessment was carried out in conjunction with a review of previous reports to determine previous river condition and current river character. High magnitude/ low frequency events, such as floods and tectonic activity were identified to cause shifts in stream type, with subsequent lower magnitude/ higher frequency events (such as smaller flooding) mobilising the large quantities of displaced material in the upper catchment. Five stream types were identified during the high-level desktop assessment:

- Confined, low sinuosity cobble/ boulder bed;
- Artificially confined, low sinuosity gravel bed;
- Partly confined, low sinuosity gravel bed;
- Partly confined, moderate/ high sinuosity gravel bed; and
- Unconfined, artificially straightened gravel bed.

High-level analyses of sensitivity and stream typing were used to provide an overview of the main geomorphic trends and processes occurring in the catchment. This project utilised many data sets and produced analyses and relationships of stream types, stream power, and connectivity within the Waipoua River (Figure 2.3).

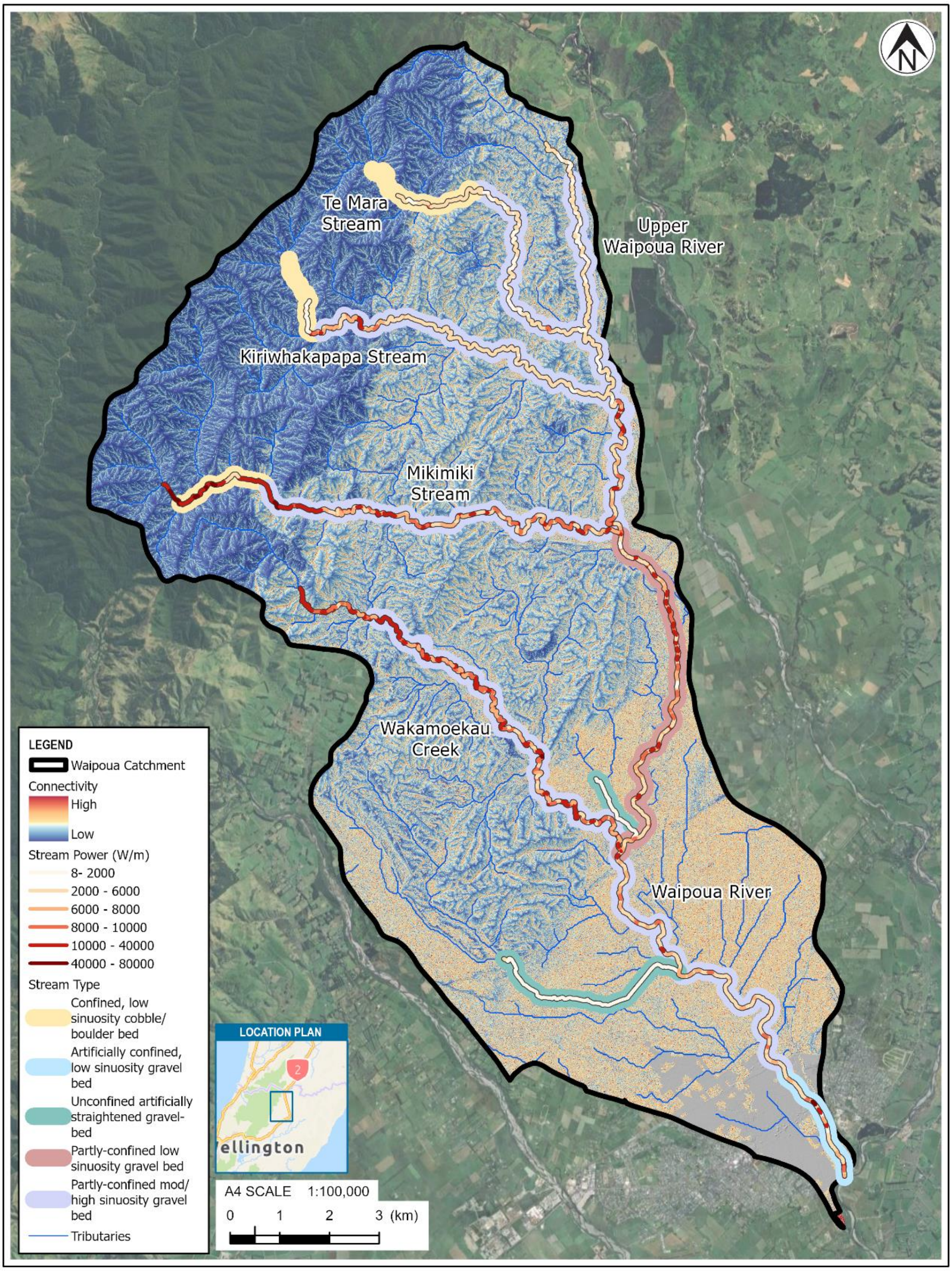

Figure 2.3: The relationship between stream types, stream power, and connectivity within the Waipoua River catchment.

2.2.2 Natural character index assessment

A natural character index (NCI) assessment was undertaken by Massey University for the Waipoua River (Carter & Fuller, 2024). This provides a way of assessing the ratio between the natural character present in historic imagery (late 1940s) and 2013 imagery.

The outcomes of this report identified that, over the time period assessed, the Waipoua River corridor showed:

- A 49% reduction in active channel area;
- A 58% reduction in lightly vegetated bars;
- A 46% reduction in densely vegetated bars;
- A 44% drop in unvegetated bars;
- A 35% drop in wetted channel area; and
- A 34% drop in wetted channel length.

These changes indicate channel rationalisation and homogenisation within a narrowed active channel. The 2013 river no longer displayed the alternating meandering-wandering reaches of the 1940s and is largely straighter and more incised throughout.

2.3 Flood damages assessment

A flood damages assessment (T+T, 2024a) was undertaken for the Waipoua River using the flood hazard modelling outputs.

The purpose of this assessment was to help inform decision making on the flood risk management options for the Waipoua River, including various levels of flood protection. It is intended that it will be used in the future to assess the benefits (flood damages saved) of the preferred flood management option for the Waipoua River. This project estimated annual average damages for flooding from the Waipoua River within a defined area of interest.

Defining and quantifying the different types of flood damages is important for informed decision making and the implementation of effective flood risk management strategies.

Types of flood damages can broadly be categorised as direct and indirect, tangible and intangible, and can also be evaluated in terms of economic damages or financial damages. The scope of the flood damages assessment for the Waipoua covered direct, indirect, and tangible financial losses but not intangible or economic losses. Intangible damages include risk to physical human health, psychological impacts and social/ community impacts.

Table 2.3 presents the financial damages results for each of the flooding scenarios assessed. It is presented as a range, to reflect the uncertainty in the assessment. The following inputs were considered in the assessment:

- Damage to buildings (residential, commercial and industrial);
- Vehicles;
- Contents;
- Cleanup costs;
- Relocation costs; and
- Rural damage.

Table 2.3: Flood damages results

Flood scenario	Lower bound	Upper bound
Present day		
39.35% AEP	$-	$-
20% AEP	$16,000	$33,000
10% AEP	$37,000	$75,000
5% AEP	$644,000	$1,280,000
2% AEP	$4,752,000	$9,725,000
1% AEP	$8,075,000	$16,521,000
0.1% AEP	$27,034,000	$53,694,000
Climate change (2050)		
2% AEP	$5,669,000	$11,602,000
1% AEP	$11,693,000	$23,299,000
Climate change (2100)		
39.35% AEP	$12,000	$28,000
20% AEP	$30,000	$64,000
10% AEP	$474,000	$927,000
5% AEP	$3,515,000	$7,045,000
2% AEP	$10,396,000	$21,017,000
1% AEP	$21,155,000	$41,759,000
0.1% AEP	$91,560,000	$174,591,000
Breach scenarios (1% AEP 2100 climate change)		
Breach 01	$19,300,000	$38,115,000
Breach 02	$24,762,000	$48,046,000
Breach 03	$20,617,000	$40,654,000

An average annual damages assessment was also undertaken. These estimates ranged between approximately $0.4M and $0.7M for the present day, increasing to between $1.1M and $2.2M with climate change out to 2100.

Stage-damage curves were also used to illustrate the relationship between increasing water level ('stage') at a known location and changes in damages. The Waipoua River Railway Bridge was used as the location for plotting a stage-damage curve as shown in Figure 2.4, which depicts the increasing flood damages with increasing flood stage.

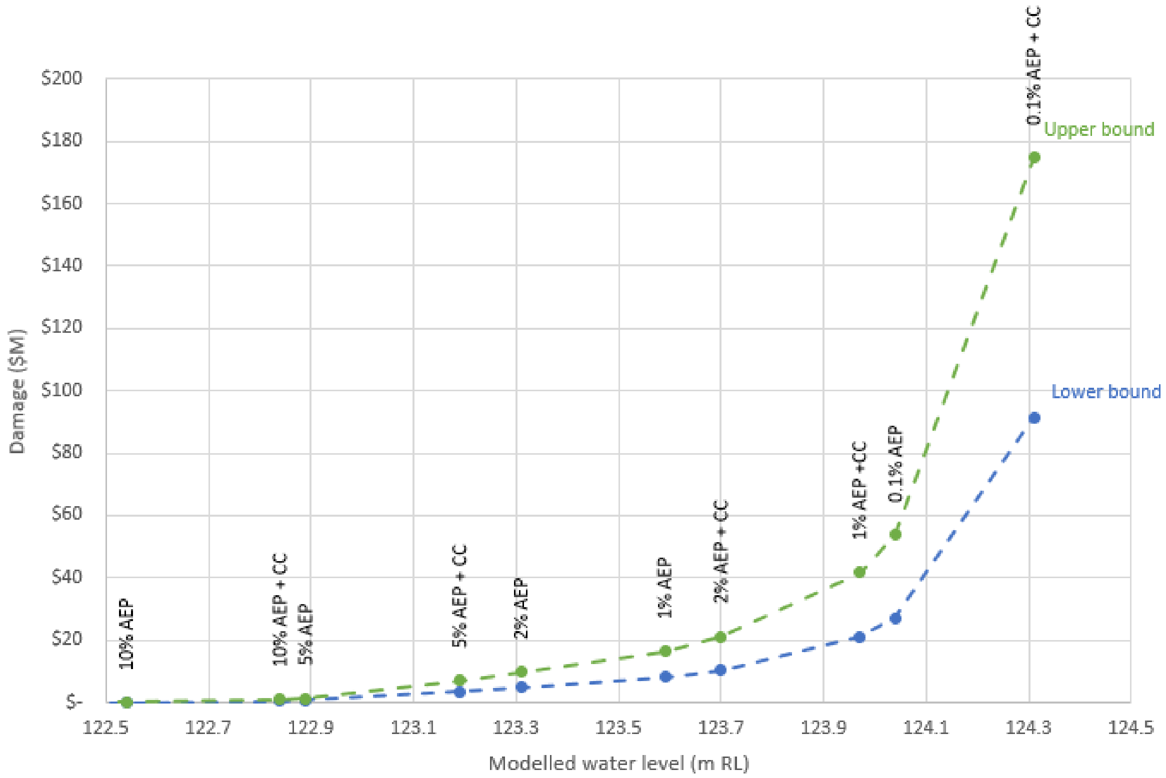

Figure 2.4: Stage-damage curves at the railway bridge.

3.0 Nature-based solutions

Broadly speaking, the use of NBS is a management approach that works with nature and utilises the natural processes of the environment to address societal issues. NBS moves away from engineering as a sole approach to managing societal issues, and instead incorporates the values, processes, and functions of the natural environment. NBS may be used for a variety of outcomes in either rural or urban environments, including, but not limited to, reduced flood risk, improved biodiversity, improved water quality, or climate adaptation.

3.1 Longlist of nature-based solutions

An initial list of NBS options was first developed as part of the Waipoua River Geomorphic Assessment: Stage 1 (T+T, 2024b), which was developed in consultation with the Waipoua Project Team. This is a stakeholder group working with Greater Wellington to develop flood risk management options for Masterton. Further NBS types were then incorporated through consideration of the measures described in (Griffiths et al., 2024), USACE (2021) and CIRIA (2022).

This list was refined (including standardisation of NBS terms, as these differ across the various literature) and specific NBS applicable to the Waipoua catchment were grouped to result in the longlist below (Table 3.1).

Table 3.1: Nature-based solutions longlist

NBS approaches	Specific NBS options
Land retirement and native afforestation	Conversion to (native) permanent forest
Floodplain re-engagement	Stopbank removal
	Stopbank retreat
	Stopbank notching/ sill bank
	Floodplain lowering (possibly berm lowering)
	Two stage channels
	Wetlands
Small-scale, distributed retention storage	Retention devices
	Leaky dams
	Dry ponds/ basins
	Attenuation wetlands
Channel realignment/ room for the river	Stopbank retreat
	Removal of willows
	Re-engaging paleo channels/ flood channels and oxbows
	Conservation tillage
Changes to land management practice	Crop rotation
	Changes to crop/ pasture type
Riparian planting	Native revegetation of buffer strips, possibly supported by battering back slopes
Bed gradient structures	Rock riffles
	Grade control weirs

NBS approaches	Specific NBS options
Gravel management	Targeted additional gravel extraction
	Gravel relocation
	Reducing or ceasing gravel extraction
Urban NBS options	Green stormwater infrastructure
	Rainwater harvesting and reuse

Stopbank retreat and stopbank removal appear under both the floodplain re-engagement and channel realignment/ room for the river NBS approaches, but vary in what they seek to achieve:

- Floodplain re-engagement allows floodwaters to spread across floodplains during (possibly only larger) floods.
- Channel realignment/ room for the river seeks to give the river more space to convey floodwater in-channel, to adjust and to express a range of natural processes.

These two NBS approaches would be expected to provide different benefits, however, stopbank retreat or removal may be required in either case.

3.2 Selected nature-based solutions

In selecting the NBS to assess feasibility, it was important to understand each NBS's benefits. Section 7.0 (Groundwater recharge and low flows) and Section 4.0 (Stage 2 geomorphology) began in parallel with the initial identification and selection of NBS. Potential benefits to groundwater and river processes were understood to be of particular interest to mana whenua and other stakeholders, therefore, the selected NBS were partly chosen based on their expected potential to deliver groundwater, river baseflow, and geomorphic benefits. An initial assessment of the wider benefits (in addition to flood risk management) based on literature review also contributed to the selection.

The longlist of NBS identified were assessed qualitatively on the following factors:

- Flood reduction potential;
- Geomorphic impacts and effectiveness;
- Groundwater recharge/ baseflow impacts; and
- Expected wider benefits based on literature and expert judgement.

From the assessment on the longlist of NBS, the following four NBS approaches were selected (hereafter referred as the "four selected NBS"). The basis for the selection is described in Appendix A.

1. Land retirement and native afforestation with indigenous vegetation.
2. Floodplain re-engagement.
3. Small-scale, distributed retention storage.
4. Channel realignment/ room for the river.

3.3 Nature-based solutions not further assessed

The following NBS approaches were not selected for detailed assessment as part of this feasibility study, with Appendix A providing the basis for these decisions:

- Riparian planting;
- Bed gradient structures;
- Urban NBS;

- Changes to land management practices; and
- Gravel management.

Generally, none of these options are considered likely to deliver a significant reduction in flood flows arriving in the Waipoua urban reach during larger floods, which is the main objective of the feasibility study. However, even though they have been excluded from this specific assessment, it does not mean they shouldn't be considered for implementation in the Waipoua catchment. For example, riparian planting would likely support and complement some of the selected NBS such as channel realignment/ room for the river.

It is worth noting that, unlike in some rivers where aggradation is a driver of increasing flood hazard, in the Waipoua River the predominant trend is degradational. This means that NBS targeting sediment inputs or lateral erosion reduction are relatively less important for flood management, especially of large floods, and the emphasis will be more on storage/ runoff attenuation and "slowing the flow".

T+T agreed with Greater Wellington that urban NBS would not be included in the feasibility assessment, as it would be located at the bottom of the catchment and have less effect on the overall flood risk to Masterton.

3.4 Nature-based solutions scenarios

There were various scenarios initially adopted for the technical assessments to assess the feasibility of the four selected NBS in the Waipoua catchment. The studies ran partly in parallel and partly consecutively. Scenarios are a hypothetical change in land use to represent each NBS and are representative rather than being a specific, detailed proposal affecting particular land parcels. The scenarios have not been discussed with landowners. In some cases, the scenarios differed between the different assessments; either to meet the focus or methodology of the particular assessment, or because the scenarios were refined based on earlier results. Further information on the scenarios used for the technical assessments are provided in the following section.

The groundwater recharge and low flows assessment was the first technical investigation undertaken, followed by the Stage 2 Geomorphology, then hydrology and hydraulic flood modelling. Literature indicates that achieving significant reductions in a 1% AEP floods typically requires substantial land use change at a catchment scale. Based on this, all modelled scenarios were deliberately **'aspirational'**, reflecting a preference to test large-scale interventions that could be scaled back as needed, rather than assessing smaller scenarios that may not demonstrate a measurable impact.

The channel realignment/ room for the river and floodplain re-engagement NBS scenarios were developed in the Stage 2 Geomorphic Assessment as they heavily rely on geomorphic concepts such as river character and behaviour.

3.4.1 Land retirement and afforestation

T+T identified an area of mostly steeper land on the eastern slopes of the Tararua Ranges, within the Waipoua catchment, which is at present mostly farmed. This is shown on

Figure 3.1 and comprises 4,260 ha, approximately 25% of the overall 17,000 ha catchment. This area was adopted for the land retirement and afforestation scenario. Approximately 44% of the land is steeper than 20 degrees (15% is steeper than 30 degrees), and it contains Land Use Capability (LUC) [3] Class 7 (7%) and LUC Class 6 (65%). Class 6 land is more suitable for farming than Class 7 land, so not all of it is likely to be appropriate for retirement. The outputs from the geomorphic assessment indicated that a significant part of this area had high potential to generate sediment.

[3] The Land Use Capability (LUC) is a measure of the land's ability to support, long-term and sustainably, primary land uses. The higher LUC scores generally represent land with more limitations on its use.

On this basis, T+T adopted an aspirational assumption of 40% afforestation for the area of interest (1,700 ha) for the groundwater recharge and low flows assessment, flood modelling, and the land required assessment (Section 9.0). The Stage 2 Geomorphology assessment assessed a slightly different scenario based on the geomorphic drivers, but it largely coincides with this area.

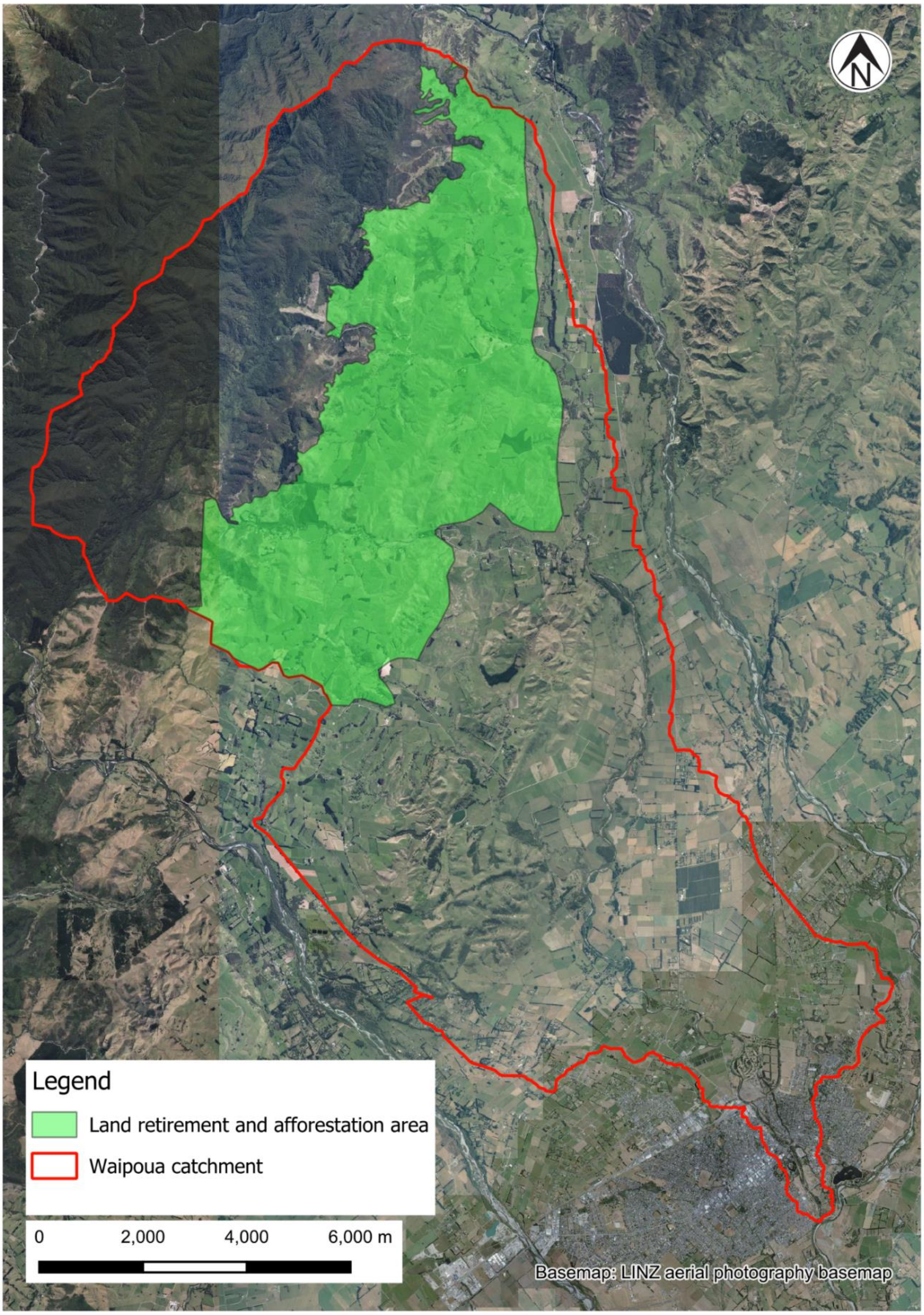

Figure 3.1 Area selected for modelling hypothetical land retirement and afforestation.

3.4.2 Floodplain re-engagement

The floodplain re-engagement scenario was developed during the Stage 2 Geomorphology assessment and informed the flood modelling done by Land River Sea. The scenario was based on the floodplain being lowered to enable more frequent flooding and maximise storage, as well as lowering the existing off-take points of flood channels to develop two-stage channels. These were modelled in the reaches downstream of the Mikimiki bridge on the Waipoua River. The flood channels' take-off points were set to a 2-year flood level and were fully engaged in a 10-year flood. The lowered floodplain was sloped towards the river, to be inundated in flood levels between approximately a 10-year and 50-year flood. A sub-scenario of establishing indigenous vegetation on these areas was also tested in the flood modelling.

Floodplain re-engagement was not assessed in the groundwater recharge and low flows investigation as any effects on groundwater will be very infrequent and episodic in nature, so are unlikely make a significant difference to groundwater recharge or baseflows. Also, transient situations such as floodplain flooding were not able to be represented with the steady-state groundwater modelling approach used.

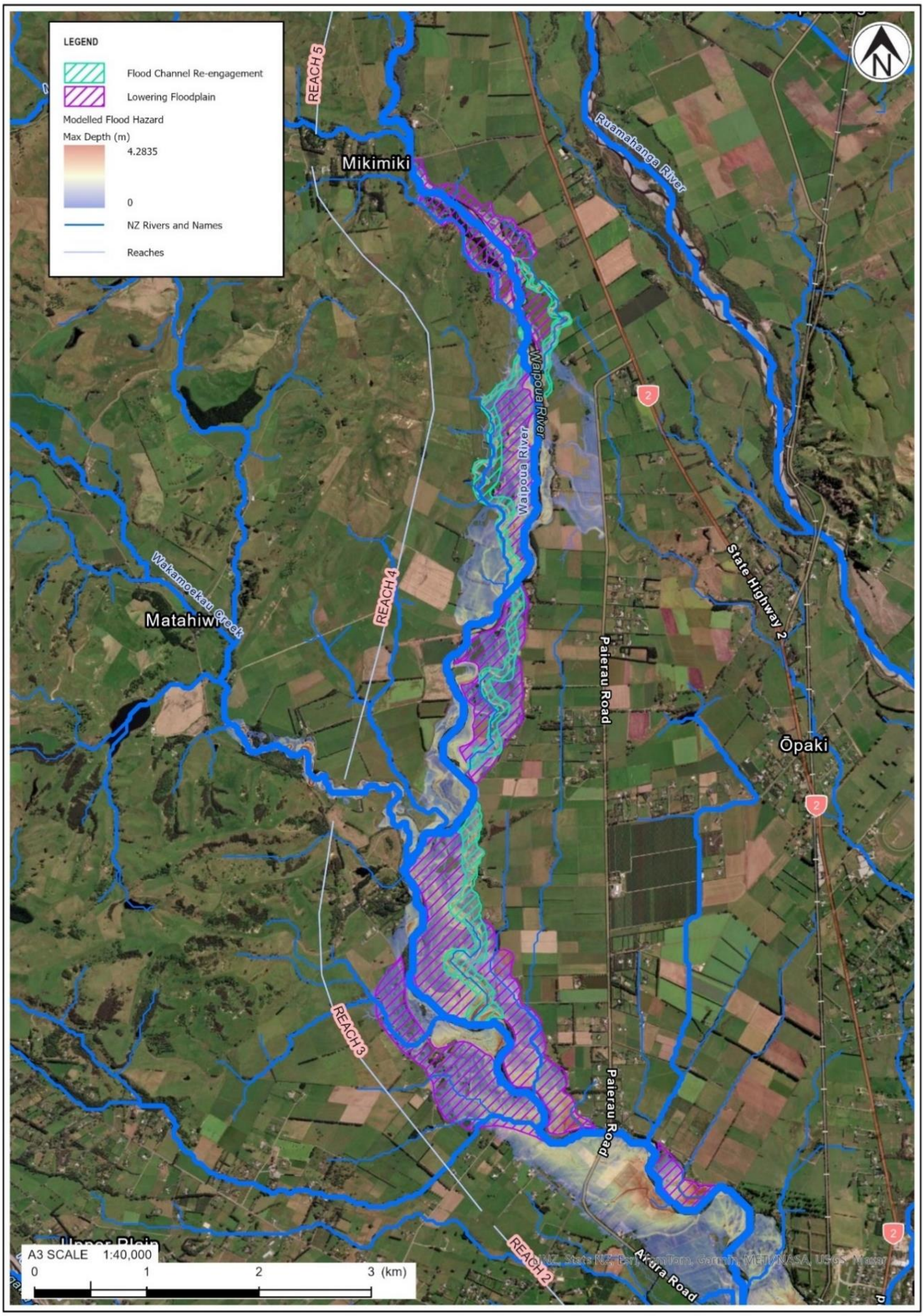

Figure 3.2: Potential zones of flood channel re-engagement and floodplain lowering with the design flood event (1% AEP + climate change) modelled flood depth (see Appendix B). Numbered reaches are described in the geomorphic assessment (Appendix B).

3.4.3 Small-scale, distributed retention storage

Griffiths et al. (2024) notes that storage bunds are best placed on ephemeral flow paths, with undulating to rolling slopes. Steeper landscapes increase the cost and have performance impacts. Given this, an area of lowland catchment was identified to be used for this NBS scenario and is shown in Figure 3.3. This area deliberately aligns with the boundaries of seven of the fourteen sub catchments in the hydrological model (see Section 5.0).

Griffiths et al. (2024) suggests (for detainment bunds) accommodating a ponded area that is at least 1.2% of the upstream catchment and a volume of 120 m^3/ ha catchment area, although these numbers seem aimed at smaller floods. On-farm sediment traps are sized for 1% - 5% of the upstream area. The coverage for "bioretention systems" (often used as a NBS for urban runoff but perhaps comparable to attenuation wetlands in this context) has a suggested target of 2% - 5% of the catchment area.

The identified area comprises approximately 35% of the overall 17,000 ha catchment area. A high-level calculation was performed to estimate how much water would need to be held back within this part of the Waipoua catchment in order to achieve a 20% reduction in flow from these subcatchments (targeting a ~5% reduction in flow from the overall catchment in the design event). This resulted in an estimate of 300 m^3 storage/ ha, higher than that noted in Griffiths et al. (2024), and this storage provision was carried forward into the groundwater recharge and low flow assessment, flood modelling, and land requirement assessments.

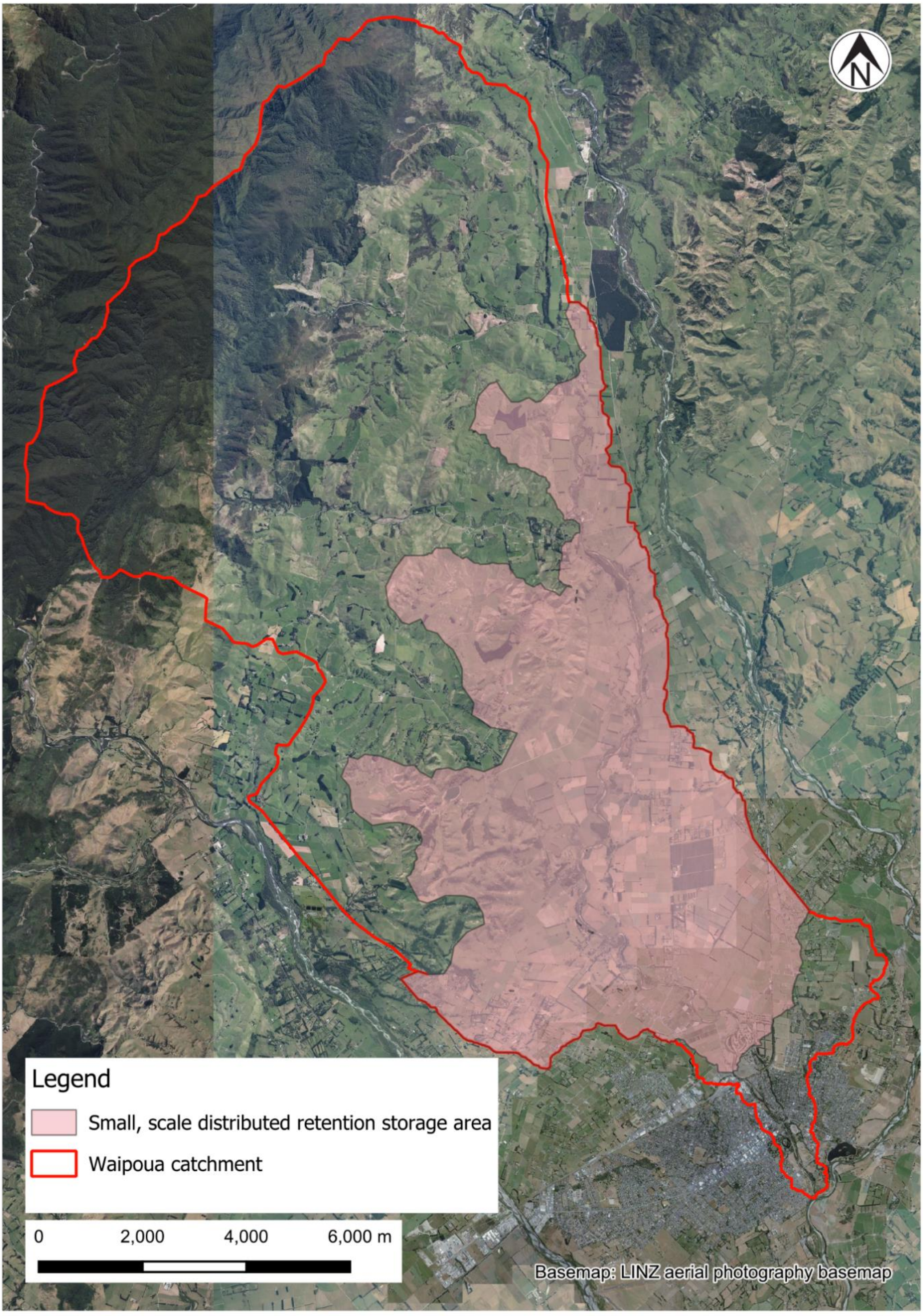

Figure 3.3: Area selected for modelling hypothetical small-scale, distributed retention storage.

3.4.4 Channel realignment/ room for the river

The channel realignment/ room for the river scenario evolved throughout the project. In the groundwater recharge and low flows investigation the scenario was a coarse representation only, as it relied on the initial findings of the Stage 2 Geomorphology assessment, and the groundwater model was coarse. These assessments were undertaken concurrently.

This scenario evolved as the Stage 2 Geomorphology assessment progressed and was based on a "hands off" management approach where willow trees are removed to allow the Waipoua river to wander freely within the 1969 active river channel extent[4]. It also included reconnecting to paleo features such as oxbows, abandoned channels and retreating or removing stopbanks. This channel widening is expected to halt, and long-term, reverse the degradational trend in this reach, which would have geomorphic and flood management benefits. The channel's bed level was therefore increased to reflect this aggradation. The channel widths and bed levels varied with each of the three reaches from Kiriwhakapapa downstream to Masterton, as documented in Appendix B. This scenario fed into the flood models and underpinned the changes in flood risk as discussed in Section 5.6. This scenario is shown on Figure 3.4.

[4] Due to the extensive change in channel form as a result of the 1855 earthquake (as described in the Stage 1 geomorphology report), the channel form visible in the earliest imagery (1940's) is not considered 'representative' of the channel form associated with a catchment sediment yield not impacted by earthquakes. A such a more intermediate channel form has been adopted based on the 1960's channel form.

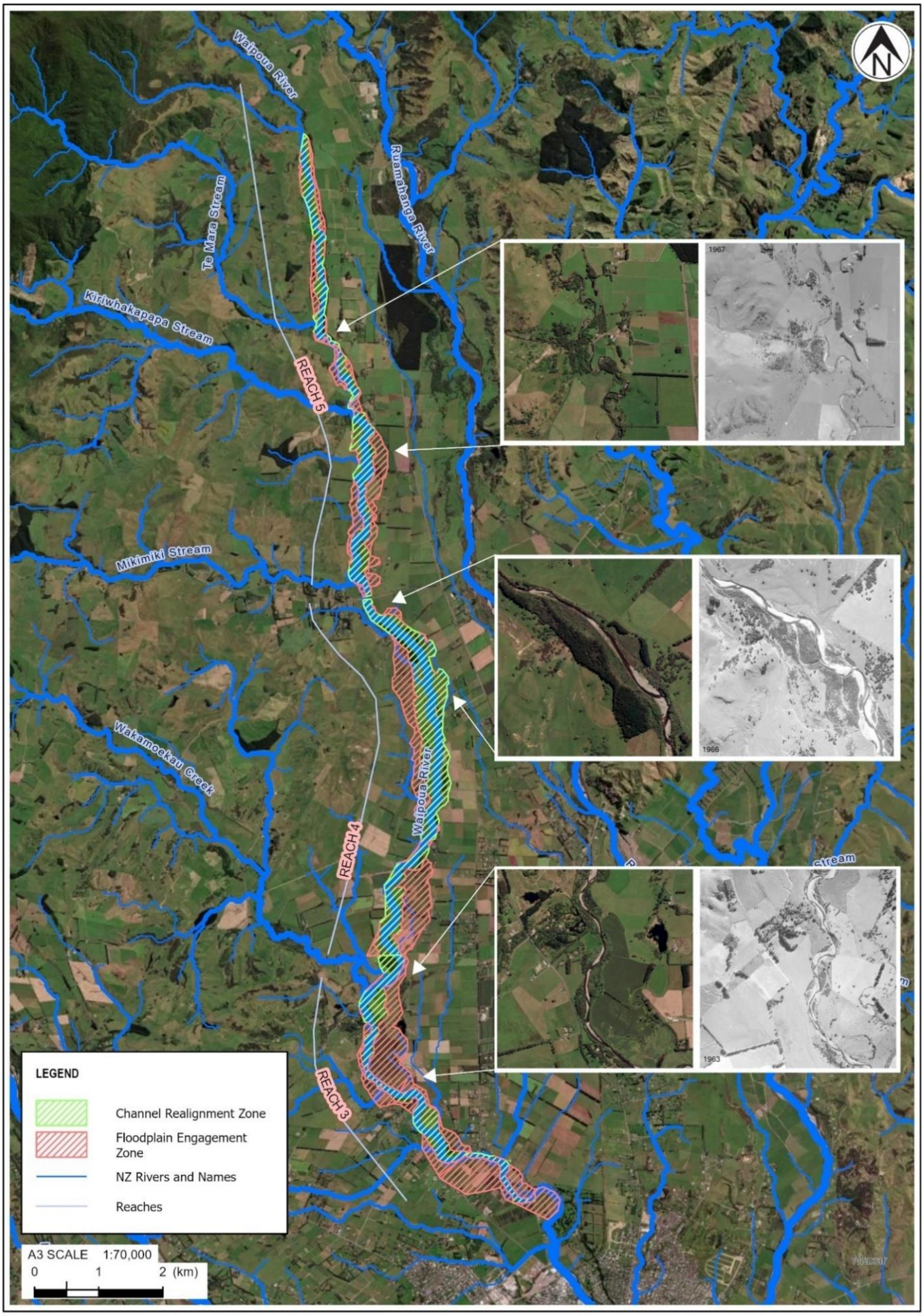

Figure 3.4: Channel realignment scenario, with the insets providing close-up of sections of the Waipoua River, with the 1960's form for comparison (see Appendix B). Numbered reaches relate to the relate to the geomorphic assessment (Appendix B).

4.0 Stage 2 geomorphology

The preliminary findings of the geomorphic assessment fed into the selection of the four NBS investigated, and further work evaluated the effectiveness of these NBS for reducing flood risk to Masterton, through working with or restoring geomorphic processes. The assessment builds on previous work completed in the Stage 1 Assessment (T+T, 2024), which is summarised in Section 2.2.1.

The Stage 2 Geomorphic Assessment was conducted as a desktop assessment and included a kōrero with a member of Rangitāne to provide local knowledge of the past river character and behaviour. The output of the assessment shows that all four selected NBS have the potential to be geomorphically effective within the Waipoua catchment. Geomorphic effectiveness is *the degree and rate to which the river will change in channel form and function due to the implementation of NBS.* For example, a length of stream reverting from a straightened channel form to a wandering form. The assessment also locates possible areas within the catchment that can be prioritised for implementation. The Stage 2 Geomorphic Assessment report is provided in Appendix B.

4.1 Geomorphic effectiveness of nature-based solutions

The four selected NBS were assessed in detail for their potential geomorphic effectiveness, which was determined by geomorphic sensitivity of stream types (Table 4.1). Geomorphic sensitivity is informed by river character and behaviour of stream types (as described in the Glossary) and is tied to the geomorphic drivers of flood risk to Masterton, including sediment supply, wood loading, land use, and stream power. The implementation of NBS may change the balance of these geomorphic drivers, which could change the nature of the river/ stream type and behaviour.

The assessment results showed that the most geomorphically sensitive areas have the highest potential to reduce flood risk because they have the greatest capacity to adjust to changes in catchment conditions, such as sediment supply and flow changes. This fed into a spatial assessment to understand where the four NBS could be best applied in the Waipoua catchment.

Table 4.1: Geomorphic effectiveness of the four selected NBS approaches per stream type

Stream type	NBS approaches			
	Land retirement and afforestation	Small-scale, distributed retention storage	Channel realignment/ room for the river	Floodplain re-engagement
Confined, low sinuosity cobble/ boulder bed	Low	Low	Low	Low
Partly confined, moderate/ high sinuosity gravel bed	Moderate	Low	High	Moderate
Partly confined, low sinuosity gravel bed	Moderate	High	Extreme	High
Unconfined, artificially straightened gravel bed	Low	Low	Low	Low
Artificially confined, low sinuosity gravel bed	High	Moderate	Moderate	Moderate

The assessment also identified wider benefits that each NBS could provide, which were fed into the subsequent wider benefits assessment (Section 6.0). Some of the potential wider benefits identified in the geomorphic assessment were improved wetland, aquatic, and terrestrial biodiversity; improved aquatic habitat; increased baseflows; new recreation sites; reduction in contaminants in groundwater and surface flows; and opportunity for the incorporation of mātauranga māori in the design and implementation.

4.1.1 Land retirement and native afforestation

Revegetation of native forest on hillslopes will have the greatest geomorphic effect on sediment (reduction) and wood loads (increase), of the four selected NBS. This NBS will deliver long-term regulation of sediment supply and transport. Short- and medium-term benefits are less likely, due to the time required to reach forest maturity. It will take 10-20 years after the establishment of plants for the effects to be noticed. It will then take 50-100 years for the effects to fully materialise. This is an important limitation of this NBS and is why it is recommended to be considered in tandem with small-scale, distributed retention storage (Section 4.1.3) to maximise geomorphic effectiveness (as discussed as a hybrid approach in Section 13.4).

The primary areas identified to have high geomorphic benefits (regulation of sediment supply and delivery, and increased wood loads), and therefore, benefits for long term flood risk management, are in the upper Wakamoekau and Mikimiki catchments. In the long term, land retirement and afforestation helps to reduce the risk of sediment pulses within the catchment and consequent aggradation in the urban reach, which helps to manage the flood risk (see Appendix A within the Stage 2 Geomorphology Assessment in Appendix B). The primary areas are mapped in the Stage 2 report (Figure 3.2 in Appendix B), and were identified based on:

- Areas that were capable of generating large sediment pulses;
- Areas that had moderate-high slope-to-river connectivity; and
- Areas where the river had sufficient energy for sediment transportation.

This scenario, with its focus on areas of most geomorphic effect, slightly differs from the broader (and larger) area of afforestation that was tested in the flood modelling.

4.1.2 Floodplain re-engagement

For this NBS, T+T focussed on floodplain lowering, overflow channels, and stopbank removal in the reach from Mikimiki downstream to Masterton. This area has an incised channel, and floodwaters therefore cannot reach the floodplain and flood channels easily. Lowering the floodplain would improve this connectivity. The channel upstream of Mikimiki is less incised and has better connectivity to the floodplains. Stopbank removal also improves the connectivity between the channel and floodplain between Masterton and Mikimiki. This is not considered upstream of Mikimiki as there are no stopbanks.

Floodplain re-engagement was assessed implicitly with channel realignment/ room for the river (as explained below in Section 4.1.4) and standalone. When assessed separately, it had the highest geomorphic effect on sediment processes, including a reduction in stream power and effective moderation of sediment pulses, transport, erosion, and deposition, through flood spread. It utilised two components: flood channel re-engagement (reconnection of former overflow paths) and floodplain lowering through large-scale excavation. The aforementioned geomorphic effects are expected to occur almost immediately.

Both components aim to achieve an increase in the frequency of floodplain engagement to maximise flood storage, resulting in a reduction and delay of the flood peak in Masterton. However, this NBS may result in increased localised flooding in the rural area and requires some stopbanks to be relocated. It is recommended that these approaches are supported by riparian or floodplain planting, especially within flood channels. Two versions of this scenario were assessed in the hydraulic model (Section 5.4); namely, with and without floodplain revegetation. The potential zones for flood channel re-engagement and floodplain lowering are mapped in Figure 3.9 of Appendix B and these were the inputs provided to the flood modellers (Appendix D, Figure 3.2).

4.1.3 Small-scale, distributed retention storage

Small-scale, distributed retention storage was considered in the subcatchments of the Wakamoekau and Mikimiki catchments, which weren't already covered by the land retirement and afforestation NBS. This differs from the scenario used in the flood modelling, with the focus here to assess geomorphic effectiveness.

The assessment shows that this NBS will likely have the greatest impact on reducing stream power and moderating sediment supply, especially fine-grained sediment, through efficient sediment trapping. Specifically, the following two types of retention storage were identified and focussed on as they also provide direct geomorphic benefits:

- Leaky bunds – wood-based bunds, riparian planting.
- Naturalisation of straightened lowland streams – re-meandering of streams, two-stage channel form, wood-based cross-channel features.

Desirable areas for these retention storages were also mapped from a geomorphic restoration perspective in Figure 3.3 of Appendix B, although this geomorphology-based area is different from the larger scenario that was tested in the flood modelling.

The geomorphic effects of small-scale, distributed retention storage, such as improved sediment trapping (reduced sediment transport) and reduced stream power from flow reduction, will occur almost immediately once implemented. Hence, this NBS is desirable to combine with land retirement and afforestation, which will take longer to fully implement. The geomorphic assessment recommends implementing these two NBS primarily the Wakamoekau and Mikimiki catchments, where they would be complementary, resulting in the geomorphic and ecological benefits to primarily accrue in these catchments. Impacts on flood flows are expected to be localised, with less impact on flood flows in Masterton.

4.1.4 Channel realignment/ room for the river

The proposed channel realignment allows the channel to widen downstream of the Kiriwhakapapa confluence through managing/ removing exotic vegetation, reconnecting paleo features such as oxbows and channels, relocating stopbanks and reducing intervention/ gravel extraction. This is expected to lead to a long-term recovery in the channel's bed level. The above aspects of this scenario would be expected to all influence the channel form and function. The greater area available for river processes would be expected, in turn, to moderate sediment transport and stream power due to increasing the flood capacity whilst maintaining or reducing velocity.

The scenario that has been assessed is considered as passive restoration of channel form and function to an earlier state corresponding to the 1969 aerial photographs. This can be achieved through removal of existing willow buffers that constrain the river, and a "hands-off" management approach that no longer forces the channel within a narrow corridor. The scenario allows the Waipoua River to return to wandering freely within the 1969 active channel extent, with potential to have native planting to facilitate natural channel adjustments. This can be coupled with a floodplain re-engagement zone and relocation of some stopbanks to increase the potential frequency and spread of flooding within the current 100-year floodable area. The identified areas for channel realignment/ room for the river and floodplain re-engagement are mapped in the Stage 2 report (Figure 3.4 in Appendix B) and this mapped scenario was applied in the hydraulic model (Section 5.6).

All river reaches are expected to have channel width increases and bed level increases over time, but at varying rates and extents. These will result in reduced stream power. Certain reaches will experience increased sinuosity and stream length, and a potential delay and/ or reduction in flood peaks. This NBS requires significant land use changes, potential relocation of stopbanks, and will likely increase localised flooding within the rural area.

4.2 Discussion on feasibility and implementation

The assessment has highlighted the benefits of how implementing multiple NBS together can be complementary. For example, land retirement and afforestation, and small-scale, distributed retention storage have complementary timeframes (long and short, respectively). Floodplain re-engagement and channel realignment/ room for the river approaches are complementary as they both aim to enhance the natural function of the Waipoua River and give the river more space to flow and dissipate flood water energy.

The Stage 2 Geomorphic Report contains maps that have identified priority/ desirable areas for the four NBS based on delivering geomorphic benefits. These maps and the methodology to identify priority areas can be used to help inform the planning stage for the implementation of NBS in the Waipoua catchment. The Stage 1 and Stage 2 assessments also provide other maps related to stream types, sediment connectivity, stream power, and geomorphic sensitivity which should be considered in the planning stage for implementation.

The Stage 2 report identified potential wider benefits that the four NBS could provide, which has been used in the wider benefits assessment (Section 6.0). The floodplain re-engagement and channel realignment/ room for the river scenarios that were developed from the Stage 2 Geomorphic Assessment, directed the scenarios that were tested in the hydraulic model (as noted in Sections 4.1.2 and 4.1.4).

5.0 Reduction in flooding

High-level flood modelling (hydrological and hydraulic modelling) was carried out on scenarios representing the four selected NBS. The purpose of this modelling was to assess their potential impact in reducing the peak flow in the Waipoua River upstream of Masterton and therefore the risk of flooding to buildings in the urban area. The methodology and findings of that assessment are described in detail in the corresponding reports on the hydrological and hydraulic modelling (Appendix C and Appendix D respectively).

Although the full range of flood magnitudes is of interest, it is only the larger floods (greater than a 2% or 1% AEP) that pose a risk to Masterton itself. Therefore, the discussion of results focusses on the 1% AEP + climate change design storm[5]. This event, with an allowance for uncertainties, is Greater Wellington's design level of service for the urban area.

5.1 Expectations based on literature

The actual performance of NBS in large flood events such as a 1% AEP is seldom reported in the literature, as the focus is often on smaller, more frequent events. However, a common theme in the literature is that NBS – in actual performance or modelled - often fail to make an impact in larger floods such as a 2% or 1% AEP and have the biggest impact on smaller events.

Examples do exist where significant runoff reductions have been modelled. One example is Mei et al (2018), cited in Griffiths et al. (2024). In this modelling study of green infrastructure for stormwater management, the greatest reduction in flows was achieved with a range of green infrastructure practices covering 37% of the catchment, resulting in a reduction in flow of 28% in comparison to the baseline in a 1% AEP event (without allowances for climate change).

As another example, CIRIA (2022) includes the following commentary on afforestation:

> *As well as impacts of planting trees on infiltration, evapotranspiration and surface roughness, modelling landscape-scale tree planting under different climate-change scenarios shows up to a maximum of 40% reduction in peak flows (5% AEP) with flood peaks delayed by 45 minutes.*

The above quote refers to the impact of planting an entire catchment in trees. It should be noted that the Mei et al and CIRIA values are both based on modelling studies, and real-world evidence of NBS impacts on floods of the scale of a 1% plus climate change event is sparse. The quoted maximum values in the studies above would require very large land-use changes within the catchment.

5.2 General modelling approach

The existing Greater Wellington flood model of the Waipoua River consists of:

1. A hydrological model in the Hydstra software package (modelling the runoff from 14 subcatchments). This model was updated in 2023 by Barnett & MacMurray.
2. A hydraulic model in the MIKE Flood software package (modelling these flows along the river, including on the floodplains). This model was updated in 2023 by Land River Sea.

This existing model was designed primarily for modelling and mapping large floods along the river, including in Masterton, and is calibrated to large historic flood events. It was developed following Greater Wellington's Flood Hazard Modelling Standard (2021) and went through various peer reviews and an independent audit. This model remains the most accurate and detailed representation of flood behaviour in Masterton and should continue to be regarded as the reference for flood extents. This is the model on which the existing, adopted flood hazard mapping for the Waipoua River is based. It is also the model that has been used for developing structural

[5] Climate change under Representative Concentration Pathway 6.0 (RCP 6.0) to 2100.

(predominantly stopbank) options within the Masterton urban reach of the river leading up to the selection of a preferred flood risk management option (T+T, 2025). The existing model is most recently described in Barnett & MacMurray (2023) and Land River Sea (2023).

However, the existing model was considered to not be the best approach for assessing the NBS scenarios and therefore the TUFLOW modelling package was utilised for this feasibility study. The flows were calibrated against the previous flows at Mikimiki and the results were considered reasonable and suitable to inform this study. Further information is provided in Appendix F.

The time available for this high-level modelling study did not allow for a detailed evaluation of the scenarios; generally, only one round of iteration or optimisation was carried out on the modelling to refine the results. This level of assessment is considered appropriate to the high level of the four NBS scenarios assessed.

For each scenario modelled, the hydrograph (and from this, the peak flow) was extracted by Land River Sea from the model at a location just upstream of the rail bridge (at the upstream end of Masterton). This location was chosen because the flows are confined at this point with no spills from the river corridor. The following scenarios were modelled (which are a subset of the scenarios from the previous flood modelling):

- 1% AEP current climate;
- 1% AEP plus climate change (RCP6.0) to 2100;
- 2% AEP current climate;
- 2% AEP plus climate change (RCP6.0) to 2100;
- 5% AEP current climate;
- 10% AEP current climate;
- 20% AEP current climate; and
- 39% AEP current climate.

The modelling approaches taken by Barnett & MacMurray and Land River Sea are described in more detail in Appendix C and Appendix D, respectively. Each of the following sections describes briefly how each of the selected NBS was modelled, and the results in terms of peak flows at Masterton.

Reduction in the peak flows at the rail bridge, particularly of the design 1% AEP + climate change event, has been used as a proxy for potential reduction in flood risk, to permit a simple, high-level comparison between options. The flows at this location are those which could potentially flood over the railway embankment or overtop the banks through the urban reach.

5.3 Land retirement and native afforestation

The existing hydrological model was developed to generate runoff time series (hydrographs) for a calibrated flood model, rather than to look at changes or variations in land cover in detail. Forest cover was modelled by adjusting the lag (delay) factor only. Although this was initially modelled and does have the effect of reducing flood peaks from forested areas, the team (T+T, Barnett & MacMurray and Land River Sea) agreed that an approach of including additional infiltration under forest cover would better represent this scenario. Literature was consulted[6] by T+T to determine a reasonable assumption for the additional infiltration rate, and an assumption was made that the infiltration rate tripled (i.e. a 200% increase) under native forest cover. The hydrological parameters adopted were therefore:

- The existing lag factor, that had previously been applied to forest cover, was also applied to the 'new' forest.

[6] For example, Environment Waikato (2008) indicated an increase of up to ten times under exotic forest cover, and Ilsted et al (2007) an increase of 200% under rainforest cover.

- The infiltration rate was tripled from 1.5 mm/ hr to 4.5 mm/ hr under areas of forest cover. This also required rerunning the base scenario with the infiltration rate also increased for existing forest; the flow reductions described below are with reference to this modified 'high infiltration' base scenario.

The forest cover percentage of the model's sub catchments were adjusted in line with the scenario in Section 3.4 (40% of the identified area) and the model was run with the adjustments noted above. The revised results were then fed into the hydraulic model and peak flows upstream of Masterton were extracted.

An additional scenario was also run, where the current forest in the catchment was 'removed' to investigate the benefit being provided by the existing coverage. This was done as part of the early model runs where only the lag factor, not the additional infiltration, was being considered.

5.3.1 Results

The results upstream of Masterton are presented in Table 5.1 below. As expected, based on findings in the literature, the peak flow reduction is proportionally greater for the smaller floods and decreases with increasing magnitude of flood.

Table 5.1: Peak flow reduction for land retirement and afforestation NBS

Return period (ARI)	Annual Exceedance Probability (AEP)	Base scenario with increased forest infiltration	Increased Infiltration, Increased Forest		
		Peak Flow (m^3/s)	Peak Flow (m^3/s)	Change (m^3/ s)	% Change
2 year	**39%**	226.8	205.3	-21.5	-9.5%
5 year	**20%**	318.5	291.0	-27.6	-8.7%
10 year	**10%**	396.2	367.8	-28.4	-7.2%
20 year	**5%**	474.4	444.4	-30.0	-6.3%
50 year	**2%**	580.9	550.6	-30.3	-5.2%
50 year CC	**2% CC**	709.5	679.1	-30.4	-4.3%
100 year	**1%**	657.1	628.5	-28.6	-4.4%
100 year CC	**1% CC**	794.7	765.5	-29.2	-3.7%

The existing forest 'removal' scenario, showing the current benefit provided by the existing forest in the catchment, resulted in peak flow increases from 13.8% (39% AEP) to 5.3% (1% AEP + climate change). These numbers are not directly comparable to the numbers in Table 5.1 above, as those also reflect additional infiltration being included. Based on the results above, the effects of forest 'removal' would be ~ 50% greater if infiltration was also considered as was done for the afforestation scenario.

5.4 Floodplain re-engagement

Floodplain re-engagement was modelled solely via changes in the hydraulic model, using the hydrological inputs from the existing model. As informed by the Stage 2 Geomorphic Assessment (see Section 4.0), the modifications consisted of:

- Lowering selected floodplains in the order of 0.5 to 1.0 m;
- Establishing continuous flow paths along former river channels/ overflow paths, including reconnecting these to the river at their upstream ends through lowering terrain; and
- Removing stopbanks located within the areas of re-engagement from the model (primarily in the Paerau Road area).

The modelling was an iterative process of adjustments until the adjusted terrain was more or less meeting the targets set by the geomorphic assessment.

As recommended by the geomorphic assessment, a further scenario was run that allowed for the re-engaged floodplain areas to be fully vegetated in shrubland-type vegetation, represented by an increase in the land's roughness (Manning's 'n' value). This represents afforestation of these areas.

5.4.1 Results

The flow results upstream of Masterton are presented in Table 5.2 below. The reductions in peak flow are modest for the floodplain lowering/ overflow path reconnection alone. In fact, these measures are modelled to result in a small increase in peak flow in the 20% and 39% AEP events. This is most likely due to more efficient conveyance of flood flows downstream in the partially engaged overflow paths, at magnitudes that are not yet re-engaging the lowered floodplains.

The model scenario with additional vegetation coverage on the re-engaged floodplains resulted in more significant peak flow reductions, due to the water being held up and reaching greater depths on the floodplains/ overflow paths. Reductions in the flood peak in Masterton come at the expense of additional flooding of rural land upstream.

Table 5.2: Peak flow reduction for floodplain re-engagement NBS

Return period (ARI)	Annual Exceedance Probability (AEP)	Base scenario	Floodplain lowering + re-engagement			Floodplain lowering and re-engagement with increased floodplain vegetation		
		Peak Flow (m^3/s)	Peak Flow (m^3/s)	Change (m^3/s)	% Change	Peak Flow (m^3/s)	Change (m^3/s)	% Change
2 year	**39%**	255.6	256.3	0.7	0.3%	237.8	-17.9	-7.0%
5 year	**20%**	348.5	349.6	1.1	0.3%	326.0	-22.5	-6.4%
10 year	**10%**	429.1	429.2	0.1	0.0%	408.7	-20.4	-4.8%
20 year	**5%**	508.8	507.3	-1.5	-0.3%	485.2	-23.6	-4.6%
50 year	**2%**	613.3	610.1	-3.2	-0.5%	584.9	-28.4	-4.6%
50 year CC	**2% CC**	741.6	737.1	-4.6	-0.6%	711.0	-30.6	-4.1%
100 year	**1%**	688.2	684.5	-3.6	-0.5%	658.7	-29.5	-4.3%
100 year CC	**1% CC**	825.0	820.6	-4.4	-0.5%	793.8	-31.2	-3.8%

5.5 Small-scale, distributed retention storage

Small-scale, distributed retention storage was modelled via changes in the hydrological model. This revised hydrology was then run through the hydraulic model to route the flows and determine the changes compared to the base scenario.

As described in Section 3.4 and further in Appendix C, seven out of the fourteen hydrological subcatchments were identified for testing retention storage at a rate of 300 m^3 storage/ ha. This high-level modelling was done via the simple approach of including a single, large, lumped storage unit per subcatchment in the model. Stage-volume and stage-discharge relationships were developed for the lumped storages based on an assumed geometry for a 'typical' basin. Two iterations carried out to optimise the storage performance across the seven subcatchments in the 1% AEP event, so that they filled completely without spilling. This was largely successful with minor spilling in most subcatchments in a 1% AEP + climate change event, and the reservoirs failing to fill beyond around 2/3 height in a 5% AEP event. The modelling approach represents any possible combination of distributed retention storage types such as dry ponds, attenuation wetlands, leaky dams etc. located online on drainage pathways.

5.5.1 Results

The resulting flows upstream of Masterton are presented in Table 5.3 below. Although initially optimised for a 1% AEP flow, the scenario also performed well for the 2% AEP + climate change scenario and performed best in the 2% AEP historical climate scenario. Performance dropped off for the 1% AEP + climate change scenario, likely due to spilling from some subcatchments coinciding with the flood peak from the upstream catchment. Further optimisation, either of the stage-discharge relationship or the storage volume, would be required to improve performance in the 1% AEP + climate change event.

Interestingly, flows in the smaller 39% and 20% AEP events were increased in this scenario. The percentage increase was almost the same magnitude as the percentage reduction in the 1% AEP/ 1% AEP + climate change events, respectively. This is due to delayed flood peaks in catchments with additional storage then coinciding with flood peaks from upstream. This was not an entirely unexpected result, as this is a known problem when designing storage elements in the lower portion of a catchment.

Table 5.3: Peak flow reduction for small-scale, distributed storage NBS

Return period (ARI)	Annual Exceedance Probability (AEP)	Base scenario	Storage Scenario 2		
		Peak Flow (m^3/s)	Peak Flow (m^3/s)	Change (m^3/s)	% Change
2 year	**39%**	255.6	265.8	10.2	4.0%
5 year	**20%**	348.5	354.2	5.7	1.6%
10 year	**10%**	429.1	427.0	-2.1	-0.5%
20 year	**5%**	508.8	495.1	-13.7	-2.7%
50 year	**2%**	613.3	585.0	-28.3	-4.6%
50 year CC	**2% CC**	741.6	711.1	-30.5	-4.1%
100 year	**1%**	688.2	659.2	-29.0	-4.2%
100 year CC	**1% CC**	825.0	813.1	-11.9	-1.4%

5.6 Channel realignment/ room for the river

The channel realignment/ room for the river NBS was modelled solely via changes in the hydraulic model, using the hydrological inputs from the existing model. As informed by the Stage 2 Geomorphic Assessment (see Section 4.0), the modifications consisted of:

- Increasing the active channel width (gravel bed) to similar extents to the 1969 aerial photography;
- Removing stopbanks in the vicinity of Paerau Road;
- Forming a sinuous channel within the new active river extent; and
- Simulating aggradation to differing degrees in different identified reaches (which is expected to occur as a consequence of allowing the river to adopt a wider, more wandering form).

5.6.1 Results

Results upstream of Masterton for this NBS scenario are presented in Table 5.4 below. This scenario resulted in an increase in flood flows for floods smaller than and including a 5% AEP event, but a reduction for larger floods.

The increase in smaller events occurs despite more floodwaters being pushed up onto the floodplains by the aggraded riverbed, and results from water bypassing channel meanders across the adjacent floodplain and arriving downstream sooner.

Table 5.4: Peak flow reduction for the channel realignment/ room for the river NBS

Return period (ARI)	Annual Exceedance Probability (AEP)	Base scenario	Channel realignment/ room for the river		
		Peak Flow (m^3/s)	Peak Flow (m^3/s)	Change (m^3/s)	% Change
2 year	**39%**	255.6	262.3	6.7	2.6%
5 year	**20%**	348.5	358.8	10.3	3.0%
10 year	**10%**	429.1	438.8	9.7	2.3%
20 year	**5%**	508.8	513.5	4.7	0.9%
50 year	**2%**	613.3	609.3	-4.0	-0.7%
50 year CC	**2% CC**	741.6	727.1	-14.5	-2.0%
100 year	**1%**	688.2	677.3	-10.9	-1.6%
100 year CC	**1% CC**	825.0	811.7	-13.3	-1.6%

5.7 Discussion of results

The reductions in flood peak across all NBS scenarios are summarised in Table 5.5 below. The 1% AEP + climate change design storm is shaded, as this is the design flood event and was the focus of the subsequent assessments. These results were adopted in the following sections to represent reductions in the flood risk to Masterton. The consequent reduction in flood damages is discussed in Section 11.0.

Table 5.5: Summary of flood peak % reduction at Masterton across all NBS

Return period (ARI)	Annual Exceedance Probability (AEP)	Land retirement and reafforestation	Floodplain reengagement	Floodplain reengagement with vegetation	Small-scale, distributed storage	River channel realignment/ room for river
		% Change	% Change	% Change	% Change	% Change
2 year	**39%**	-9.5%	0.3%	-7.0%	4.0%	2.6%
5 year	**20%**	-8.7%	0.3%	-6.4%	1.6%	3.0%
10 year	**10%**	-7.2%	0.0%	-4.8%	-0.5%	2.3%
20 year	**5%**	-6.3%	-0.3%	-4.6%	-2.7%	0.9%
50 year	**2%**	-5.2%	-0.5%	-4.6%	-4.6%	-0.7%
50 year CC	**2% CC**	-4.3%	-0.6%	-4.1%	-4.1%	-2.0%
100 year	**1%**	-4.4%	-0.5%	-4.3%	-4.2%	-1.6%
100 year CC	**1% CC**	-3.7%	-0.5%	-3.8%	-1.4%	-1.6%

The following points are relevant to consider. Some of these are elaborated on further by Barnett & MacMurray (2025) and Land River Sea (2025):

- Only one storm pattern has been modelled, being the design storm adopted for the previous flood hazard modelling. In reality, every storm (even those with the same AEP) is different in terms of its spatial distribution, temporal distribution and its duration. Antecedent conditions also vary. This will affect the performance of the NBS and in particular, those that show catchment-dynamic effects such as the distributed storage and channel realignment/ room for the river NBS. Designing storage elements that can perform effectively across a range of different storms, without unintended effects, is a key consideration when designing for flood risk management.
- Peak flows from the channel realignment/ room for the river scenario showed itself to be sensitive to the assumptions made about riverbed aggradation.
- Based on its performance in the hydrological model and the amount of storage not fully utilised, the distributed storage scenario could likely have been further optimised to achieve a flood peak reduction approaching 4% for the 1% AEP + climate change design event (as observed for the 1% AEP historical climate event). However, T+T has adopted the value of a 1.4% reduction as shown above, as a high degree of optimisation results in an ideal assessment that doesn't match real-world conditions. Performance of this NBS is less certain, as it is more subject to dynamic/ timing effects in the catchment and would require considerable design and maintenance effort to ensure performance at the ideal values assessed above. There is also a risk that the number of suitable sites may be more limited than modelled.
- Barnett & MacMurray (2024) also noted: Optimising the storage is also a balancing act across the different sub catchments. The reservoir in Dist2 fills the most in each event and Dist 4 consistently has the lowest level. This is because each sub catchment has a unique rainfall and topography producing different runoff volumes and intensities.
- Afforestation scenarios (retirement and reafforestation, or floodplain engagement with vegetation) seem to offer the most consistent reduction in flood peaks across a range of AEPs. The existing forest in the Tararua Forest Park was also shown to be providing a significant reduction in peak flow compared to the forest "removal" scenario.
- The floodplain re-engagement and river channel realignment/ room for the river NBS result in additional/ deeper flooding on rural land upstream of Masterton. These NBS achieve a reduction in flood flows at Masterton by using this land to hold floodwaters back – essentially transferring risk.
- Flood risk does not relate solely to the peak flow in the river. Geomorphic factors such as aggradation, degradation and debris loading can play in important role in some cases. These risks were not assessed in this modelling work but are a relevant consideration and were also discussed in Section 4.0. For example, NBS, such as afforestation, that reduce flows across a range of smaller AEPs, will also reduce the threat from bed degradation or lateral erosion to existing flood defences in the urban reach. Similarly, NBS that help to moderate sediment delivery and transport processes may help to avoid pulses of sediment that could otherwise trigger an aggradation trend in critical reaches.
- As well as reductions in peak flow, some of the NBS scenarios showed potential to delay the flood peak. Most of the changes were insignificant, but the storage scenario and the floodplain re-engagement + revegetation scenario showed delays in the order of 15 to 30 minutes. Such delays would have the potential to improve the effectiveness of flood warning and emergency management measures. However, a delay in flood peaks may result in flood peaks coinciding and increasing the flood risk, as explained in Section 5.5.1 and in Appendix D.

6.0 Wider benefits of nature-based solutions

The main objective of the feasibility assessment was to investigate the feasibility of NBS reducing the Waipoua River flood risk to Masterton, with particular focus on the 1% AEP + climate change design event. However, flood reduction is only one of the benefits NBS can provide. It is important to understand the wider benefits, such as ecological, cultural, and social benefits, that NBS may also provide. As noted during the wider benefits assessment in the following quote:

> *"The major flood benefits only occur in a 100-year flood, but wider benefits are every day" – workshop participant*

The assessment of wider benefits aimed to understand, rank, and quantify the potential wider benefits of the selected NBS. An important aspect was to understand what ecosystem services were valued the most by the local community (including mana whenua) and stakeholders, beyond flood reduction; this was achieved via a workshop. The full assessment is included in Appendix E.

6.1 Wider benefits approach

The wider benefits assessment used a combined approach of a semi-quantitative heat map assessment and stakeholder economic valuation to understand the value NBS can provide wider than flood risk reduction. This provided an opportunity for stakeholders to describe what is important to them.

6.1.1 Semi-quantitative heatmap assessment

A semi-quantitative heatmap assessment was used to visually and comparatively evaluate the extent of the benefits the four selected NBS provide across the 18 categories of Nature's Contributions to People (NCP). NCP is an internationally recognised framework, derived from the ecosystem services concept, that recognises the diverse ways in which nature supports human well-being. Examples include habitat creation, water quality regulation, climate regulation, and cultural identity. The heat map provided insights for the direction (positive or negative) and extent of the impact the four NBS have on NCP, as seen in Table 6.1. Greater Wellington subject matter experts contributed to the scoring. Further discussion of how each NCP category was assessed is provided in Appendix E.

Table 6.1: Heatmap of the wider benefits provided by each NBS across the 18 NCP categories

	Habitat creation and maintenance	Pollination and dispersal of seeds and other propagules	Regulation of air quality	Regulation of climate	Regulation of ocean acidification	Regulation of freshwater quantity, location and timing	Regulation of freshwater and coastal water quality	Formation, protection and decontamination of soils and sediments	Regulation of hazards and extreme events	Regulation of detrimental organisms and biological processes	Energy	Food and feed	Materials, companionship and labour	Medicinal, biochemical and genetic resources	Learning and inspiration	Physical and psychological experiences	Supporting identities	Maintenance of options
Land retirement and afforestation	Strong positive	Strong positive	Positive	Strong positive	Positive	Neutral/ mixed	Strong positive	Strong positive	Neutral/ mixed	Neutral/ mixed	Positive	Neutral/ mixed	Positive	Positive	Positive	Strong positive	Strong positive	Strong positive
Floodplain re-engagement	Positive			Positive			Positive	Positive				Neutral/ mixed			Strong positive	Strong positive	Positive	Positive
Small-scale, distributed retention storage	Strong positive	Positive		Positive		Positive	Positive	Positive		Neutral/ mixed		Neutral/ mixed	Positive	Positive	Positive	Positive	Positive	Positive
Channel realignment/ room for the river	Strong positive	Positive		Positive		Neutral/ mixed	Strong positive	Positive		Negative		Neutral/ mixed		Positive	Positive	Strong positive	Positive	Strong positive

Legend:

NBS scoring:

● Strong positive ● Positive ● Neutral/ mixed ● Negative

The blank cells are where the NCPs were not applicable to the given NBS and were not assessed.

6.1.2 InVest tool

The wider benefits assessment initially considered using the InVest tool to undertake biophysical modelling to quantitatively (monetary – depending on data availability) assess NCP and wider benefit of NBS. This would have complemented the heatmap assessment. The tool showed considerable promise however, the tool was "data hungry", input data required a lot of pre-processing, knowledge from subject matter experts was required, and model outputs would potentially need debugging. Therefore, an economic valuation method was adopted for this study, to better fit with the timeframes and data available.

6.1.3 Stakeholder economic valuation

Stakeholder economic valuation was used to quantify how much value stakeholders place on the wider benefits of the four NBS. The economic valuation was carried out during a workshop held in Masterton, where 20 participants from the local community, stakeholder organisations and mana whenua attended. Three workshop exercises were used to deliver the economic valuation as outlined in Table 6.2 below.

Table 6.2: Description of the three methods used in the economic valuation approach for assessing how local stakeholders value NCP and NBS

Method	Description
Contingent valuation and willingness to pay	• Assesses stakeholders' willingness to pay (as household annually) for environment improvement/ outcomes in a hypothetical scenario from each NBS. • This method is helpful for NCP that lack market prices, such as water quality improvements.
Importance method	• Stakeholders used a 5-point importance scale for each NCP to rate how much they valued each NCP.
Preference ranking method	• Stakeholders ranked all four NBS from most to least preferred without monetary considerations.

6.2 What did stakeholders value?

The four approaches used to assess wider benefits (heat map, willingness to pay, NCP importance method, and NBS preference ranking) all provided a consistent narrative that land retirement and afforestation provide the broadest benefits, which were most valued by the stakeholders. The alignment between the heat map assessment and what the community values reinforces the credibility of the findings and supports a clear direction for future implementation of NBS based on the wider benefits.

The semi-quantitative heat map highlighted the land retirement and afforestation NBS as delivering strong positive impacts across the widest range of NCPs, particularly in habitat creation, climate regulation, water quality, and protection of soils and sediment (Table 6.2). This strongly aligns with stakeholders rating these wider benefits as the most important to them, without consideration of the associated NBS.

- Regulation of water quality received the highest average importance rating (4.65 out of 5), with 76.5% of stakeholders rating it as highly important.
- Habitat creation and maintenance was also prioritised (4.61 out of 5), and 61.1% of stakeholders rating it with high importance.
- Climate regulation had an importance rating of 4.06 out of 5, with 61.1% rating it as highly important. This indicates strong community awareness of climate benefits gained from NBS.
- Soil protection was the next-highest valued NCP with the highest average importance rating of 4 out of 5.

Additionally, the above wider benefits strongly align with stakeholders' preference for overall ecological health and biodiversity as the most important value in the Waipoua catchment. This was emphasised through stakeholders' comments in the workshop, such as:

> *"How much would I pay to see a huia? I'd sell my house…in fact I'd sell my kids!" – workshop participant*

The value of ecological health and biodiversity is strongly related to NCP 1 - habitat creation and maintenance; 2-pollination and dispersal of seeds; and 10 - regulation of detrimental organisms and biological processes. Throughout the workshop stakeholders frequently used words and phrases associated with these values (Figure 6.1).

Figure 6.1: Word cloud shows the most used word or phrases related to NCP's 1, 2, and 10.

Channel realignment/ room for the river was also assessed to have benefits related to habitat creation and water quality, aligning with the stakeholders rating of importance for wider benefits.

The preference ranking exercise validated the above outputs with stakeholders strongly preferring the land retirement and afforestation NBS, with 65% of participants ranking it as the highest priority NBS and 80% ranking it in their top two choices. However, channel realignment/ room for the river was the least preferred option with only 5.6% ranking it as the highest priority NBS, and 55.6% rating it as the lowest priority.

All of the assessment results described above are reinforced with the willingness to pay exercise, with the "basket of outcomes" associated with the land retirement and afforestation NBS having the highest mean value at $338. Nearly half (44%) of the respondents were willing to pay the maximum value of $500+ annually for this option, although participants were not explicitly told which of the four selected NBS each "basket of outcomes" represented.

The channel realignment/ room for the river NBS had the second highest mean value for willingness to pay at $244 per household annually, and the wider benefits of this NBS (as identified in the heatmap assessment) were also rated to be of high priority by stakeholders. However, it is interesting that when participants ranked the four selected NBS explicitly, this NBS was ranked the lowest.

Generally, all four NBS had strong community support for implementation as the mean willingness to pay ranges between $209 and $338 per household annually. This narrative was also captured qualitatively where one attendee said:

> *"You pay tax, but you don't know what portion of that tax goes towards education. So, would I invest in education without exactly knowing how much goes where? Yes. Would I invest in the environment without specifically knowing how much goes where? Yes." – workshop participant*

It is important to keep in mind that although all NBS had at least some stakeholder support, not all of the four NBS provide the preferred wider benefits which stakeholders identified in the importance ranking exercise.

Although the sample size of stakeholders and community members at the workshop was small, it still provides some insights into what the community values. Full results are provided in the appended report (Appendix E).

6.3 Discussion on implementation

The wider benefits assessment clearly identified that land retirement and afforestation received the highest stakeholder support and willingness to pay values. It was also the NBS that was identified to have the largest array of wider benefits in the heat map assessment. These wider benefits were based on ecological health and biodiversity such as water quality, habitat creation and maintenance, and climate regulation.

The stakeholder valuation results provide strong evidence that NBS align with community values and priorities in the Waipoua catchment, and that there is likely to be at least a degree of local community backing for the four selected NBS.

The wider benefits identified should be prioritised when considering the implementation of NBS, and local community and mana whenua should further be engaged with. The findings of this assessment will allow future NBS implementation to focus on delivering benefits which have clear stakeholder support, which may also align with other funding sources than just flood resilience/ risk reduction funding. There is evidence of strong community support for funding and implementation partnerships, given the demonstrated willingness to contribute financially to NBS implementation and the fact that many of the stakeholders are already "hands-on" in environmental restoration or enhancement projects.

7.0 Groundwater recharge and low flows

A key aspect of the feasibility study was to understand the potential influence that the selected four NBS may have on shallow groundwater and baseflows. This technical assessment was scoped in partnership with Ngāti Kahungunu and carried out by T+T using a conceptual groundwater model of the catchment. The assessment identified the potential for the selected NBS to influence groundwater levels and mean flows (both positively and negatively). The results of this assessment can be used to help inform the selection and location of NBS to maximise groundwater benefits, if this is a priority for implementation.

Generally, a positive outcome for the assessment is considered to be an increase in groundwater levels or an increase in mean river flows. However, it should be noted that there is a direct hydrological connection between the shallow groundwater and the river; when one component increases (e.g., river baseflows), there must be a corresponding decrease (e.g., groundwater flows). The water mass balance was held constant in the assessment.

7.1 Nature-based solutions included in the assessment

Prior engagement with mana whenua and the Waipoua Project Team highlighted that aquifer recharge was important to stakeholders. Therefore, aquifer recharge has been specifically investigated for NBS options. Of the four selected NBS the following three were assessed for the hydrological assessment:

- Land retirement and afforestation;
- Small-scale, distributed retention storage; and
- Channel realignment/ room for river.

This was based on the following potential hydrological benefits that were identified:

- Land retirement and afforestation may increase water storage and infiltration through soil organic matter and tree roots, and enable a gradual recharge to aquifers through absorption and slow release of water. However, forests also reduce surface water runoff and typically reduce the mean annual flow due to their evapotranspiration.
- Small-scale, distributed retention storage could have the potential to increase infiltration into the underlying aquifer.
- Channel realignment/ room for the river can increase the connectivity between the surface and groundwater due to greater area of coverage and slower flows. This could result in greater transfer of flow in both directions (i.e. either to, or from, the aquifer).

Floodplain re-engagement was not included in this assessment as explained in Section 3.4.2.

7.2 Methods

The analysis focused on identifying the relative effects of each NBS on groundwater recharge and average river flows through comparing the potential hydrogeological benefits for each NBS against a high-level base model. Multiple scenarios for the three assessed NBS (a total of seven scenarios) were developed to capture the range of potential hydrological responses in the Waipoua catchment to inform implementation approaches. These scenarios are described in detail in Appendix F. PASTAs[7] and MODFLOW 6[8] were used to undertake the hydrogeological assessment and steady-state conditions were applied to represent annual average hydrogeological conditions. Detail on the method, models, NBS scenarios, and assessment limitations is provided in Appendix F.

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[7] PASTAS is an open-source Python package for processing, simulating and analysing groundwater time series.

[8] MODFLOW is the U.S. Geological Survey's modular finite-difference flow model, which is software that solves the groundwater flow equation. The program is used by hydrogeologists to simulate the flow of groundwater through aquifers.

7.3 Discussion on feasibility and implementation

As discussed, there needs to be a balance between the groundwater flows and level, and the river flows and level, to keep the water system in equilibrium. In broad terms, an increase in one component will result in a decrease in another. For example, an increase in groundwater levels will need to be achieved via transferring large volumes of water from the river or from rainfall to the aquifer system on an ongoing basis. The hydrogeological modelling undertaken shows that where groundwater levels and flows decrease, it is mostly due to surface water being intercepted by vegetation or evaporated from wetlands. Where river baseflows decrease it is either due to surface water being intercepted by vegetation in the upper catchment or increases in riverbed levels.

Based on the modelling undertaken, generally there is a decrease or minimal change to the Waipoua River flows for all NBS assessed (Appendix F, Table 7.1). Additionally, five of the seven scenarios show a decrease in groundwater flows through the south-eastern border of the model, balanced in some cases by increases in flows in the Waipoua River. This is partly a result of the high-level nature of the modelling; the steady-state approach is not able to represent seasonality - such as the role of groundwater supporting baseflows during times of low flows. It is also not able to model episodic events such as the capture of runoff and the infiltration of surface water over a period of hours or days.

The modelled results indicate that either average groundwater levels or average flows at Masterton have the potential to be reduced by the majority of the NBS scenarios considered. The two scenarios that do not show decreased groundwater flows are:

- Small-scale, distributed retention storage where the wetland water levels are consistent with the surrounding groundwater system in the base model. No significant changes were expected to the groundwater or river base flows, due to the water levels being in equilibrium and remaining similar to the base model.
- Channel realignment with a bed level increase shows an increase in groundwater flow in the Waipoua catchment. A long-term bed level increase means that there is a larger hydraulic head from the Waipoua River into the groundwater system. This increases the groundwater flows and reduces the river flows, compared to the base model.

The channel realignment NBS has the most potential for enhancing shallow groundwater recharge, because increasing channel width improves the connectivity and interactions between the river and groundwater. It provides a larger riverbed surface area to transfer water from the river into the groundwater system (or vice versa). However, any additional recharge comes at the expense of flows in the river, which may increase the lengths of river that run dry during the summer. The results are very sensitive to riverbed levels, and there is a similarly large potential for the river to accumulate flows from groundwater if the expected aggradation doesn't occur (or further bed degrade occurs). The modelling suggests that there is no scenario that promises significant increase in the average flow in the Waipoua River. Only the native afforestation scenario with recharge reduced by 30% results in a slight increase in average river flows.

The concept of 'managed aquifer recharge' represents the capture or diversion of water for augmenting groundwater levels. This is typically done on a large scale, such as large infiltration basins or, in some cases, with pumped reinjection. This approach requires either the diversion of flows from rivers and streams, or the capture of surface runoff on a regular, ongoing basis and its subsequent infiltration. This was not modelled in the steady-state model but is a concept that could be incorporated in future NBS implementation, if desired. This concept fits best with the small-scale, distributed storage NBS, which could be applied in a way that captures runoff from most rainfall events and infiltrates it to ground. High level principles for this are described in the following section.

7.4 Storage locations for increasing groundwater recharge and baseflow

The location of small-scale, distributed retention storage is most desirable upstream of the Masterton and Mokonui faults, as river baseflow and groundwater levels are increased due to decreased thickness of the upper aquifer unit. This improves the potential for infiltrated water to contribute to raised baseflow in nearby streams/springs. The two faults act as low permeability groundwater flow barriers and have resulted in numerous springs in the lower catchment. River baseflow is increased in these areas where the river stage is lower than adjacent groundwater levels. This water level difference causes water to flow from the shallow aquifer to the river through the sides and base of the riverbed. The geology of the catchment, along with the location of known fault lines, is shown on Figure 7.1, below (taken from the Stage 1 Geomorphic Assessment).

The location of small-scale, distributed retention storage is also dependent on whether increased baseflow or groundwater recharge is desired:

- If increased baseflow is desired, then distributed storage structures should be in areas near rivers where the depth to groundwater is relatively shallow. Therefore, it is easier for groundwater to transfer to the river.
- If shallow groundwater recharge is desired, then distributed storage structures can be constructed in permeable areas where the groundwater depth is always below the proposed basin depth.

Wetlands will typically not be suitable forms for attenuation storage, if infiltration to groundwater is desired. Wetlands will either need to be supported (fed) from high groundwater levels to remain wet or will need to regularly capture surface runoff and hold this water in a low-permeability basin.

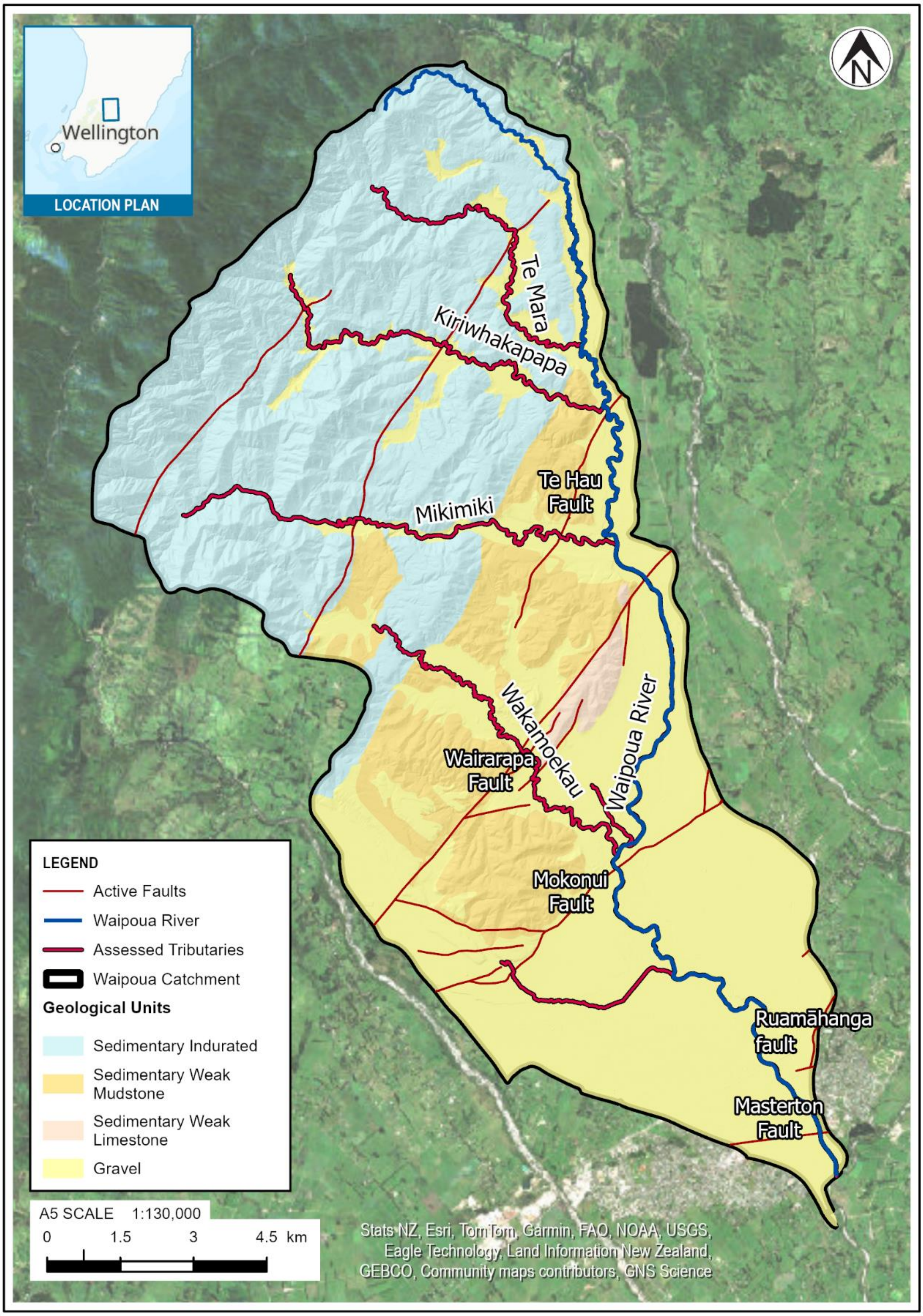

Figure 7.1: Geology and known fault lines in the Waipoua River Basin.

7.5 Further investigations

To have a greater understanding of the effect of various NBS measures on groundwater recharge and river baseflows, it is recommended to:

- First establish with the community the desired objectives, e.g. increasing spring flows.
- Develop and use transient modelling (e.g., coupled groundwater/ surface water model) for an options assessment to better capture the temporal variations of groundwater flow and river baseflows.
- Plot cross-sections across fault lines to understand the excavation depths required for potential wetlands or storage elements.
- Delineate river networks based on topography and flow accumulation to better represent the hydrological complexity of the system.
- Refine aquifer property distributions with site-specific field data.
- Model other types of small-scale, distributed retention storage.

Further investigations could look at the likely range in performance of native forest in delaying runoff and/ or infiltration to groundwater. This was assessed in the steady-state modelling based on high-level assumptions only.

8.0 Indigenous vegetation investigation

Greater Wellington commissioned WSP to undertake an investigation, jointly scoped with Ngāti Kahungunu, into indigenous plant species found in the Waipoua catchment and how these could play a role in NBS. The investigation was desktop-based, assessing the natural ecosystems of the Waipoua catchment and identifying a range of indigenous plant species that are appropriate to mitigate the effects of flooding and improve indigenous biodiversity. Key to this investigation was applying a holistic, mātauranga approach, which emphasised the interconnectedness between water (wai), land (whenua), and people (ngākau). Collaboration with mana whenua integrated mātauranga into the plant species list. The vegetation assessment can be used to inform the implementation of NBS, including the location, plant types based on ecosystems, and planting strategies. The following sections summarise WSP's key outcomes and findings, as they relate to the implementation of NBS. This work was also used to inform T+T's wider benefits assessment (see Section 6.0).

8.1 Indigenous vegetation for nature-based solutions

The indigenous vegetation investigation highlighted many data sources that can be used to inform those areas that are most appropriate for NBS to mitigate flood risk. The investigation also identified a list of plant species that are recommended to be used in the Waipoua catchment. The key data sources include:

- Soil type and drainage;
- Pre-human and existing wetland and vegetation cover; and
- Historic and current land use.

Sections 8.1.1 to 8.1.4 below, describe briefly specific points relating to each of the selected NBS.

8.1.1 Land retirement and native afforestation

Indigenous vegetation is important for stabilising soil and reducing erosion, especially on hillslopes. Changes in land use and removal of vegetation has increased the soil erosion from rain and wind due to increased exposure, and smaller root systems able to stabilise the slopes and retain water. This has also increased runoff within the upper catchment of the Waipoua.

Typically, revegetation of native forest occurs first in the upper catchment on steeper slopes, but specific areas and plant types can be prioritised using the pre-human and existing vegetation cover datasets, and the historic and current land use datasets, to emphasise restoration of what was, or is already there.

8.1.2 Floodplain re-engagement

Re-establishment of lowland forests could occur on the Waipoua River floodplain, converting it from agricultural land. This conversion or addition of vegetation will have multiple benefits including:

- An increased water-holding capacity in the soil and ability for water to percolate down into the soil and aquifers, reducing the flood water volume.
- Increased surface roughness, which may decrease/ delay peak flood flows.
- An increase in floodplain habitats for a wide range of species and to improve biodiversity.

The historic and current land use datasets, as well as the pre-human and existing wetland and vegetation cover datasets can be used to identify the extent of historical floodplain areas for re-engagement. The list of plant typologies can be utilised to identify which species fit the environment – specifically species that have flexibility and stability to survive dry periods and short wet periods.

8.1.3 Small-scale, distributed retention storage

Planting usually occurs either within or on the perimeter of the retention storage, depending on the type of storage utilised. Indigenous vegetation can filter and trap sediments and pollutants, helping to improve water quality. Vegetation can increase surface roughness, and the ability for water to percolate down into the soil and aquifers, which both help reduce flood volumes and peaks.

Soil type and drainage datasets can be used to identify suitable locations that will support different retention storage measures. Which benefits are sought, will determine whether poor or good soil drainage is required. For example, if groundwater is to be augmented, good drainage is required for infiltration. The list of plant typologies can also be utilised, as different retention storages will require different plant types (e.g., wetlands will require “wet” plant typologies).

8.1.4 Channel re-alignment

Indigenous vegetation planting will likely occur as riparian planting along the active channels and paleochannels for when they are engaged in larger flood events. It will act as a buffer in high-flow events and may reduce localised flooding, filter runoff, and enhance habitat diversity and connectivity.

The list of plant typologies can be used to identify the appropriate species for the environment. Species should ideally be fit for intermittent dry and wet environments.

8.2 Implementation approach

The implementation approach outlined in the indigenous vegetation report recommends reintroducing indigenous vegetation through a type of succession planting - whānau cluster planting. This approach draws on the interconnectedness of ecosystems and a mātauranga approach. Vegetation is planted in a group that mimics natural ecosystem structures—comprising of canopy trees, sub-canopy layers, shrubs, and ground cover. Each cluster is designed to function like a family unit, with older, established trees at the centre (symbolising grandparents) and younger plants surrounding them (representing children and grandchildren).

Planting in the Waipoua catchment can be done using specific typologies where plants are suited to the soil type, ecosystem type, and context conditions such as historic and present-day land use and vegetation cover. This means the typologies used for each NBS will differ, as shown in the following three figures.

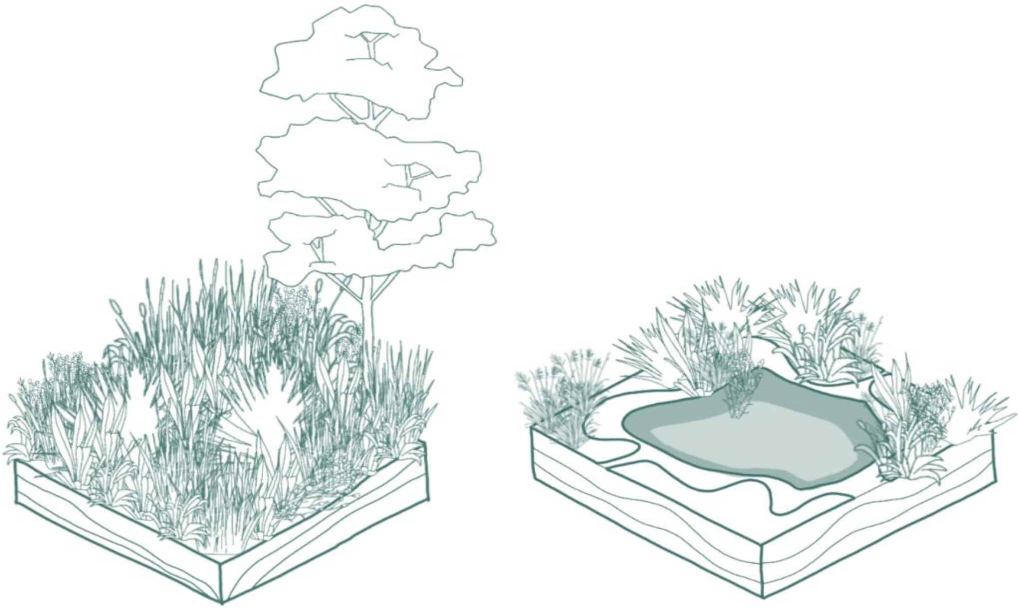

Figure 8.1: Whānau planting for small-scale, distributed retention storage – clustered wetland planting with dry, wet, and submerged plant typologies (left), and clustered detention planting with dry and wet typologies (right).

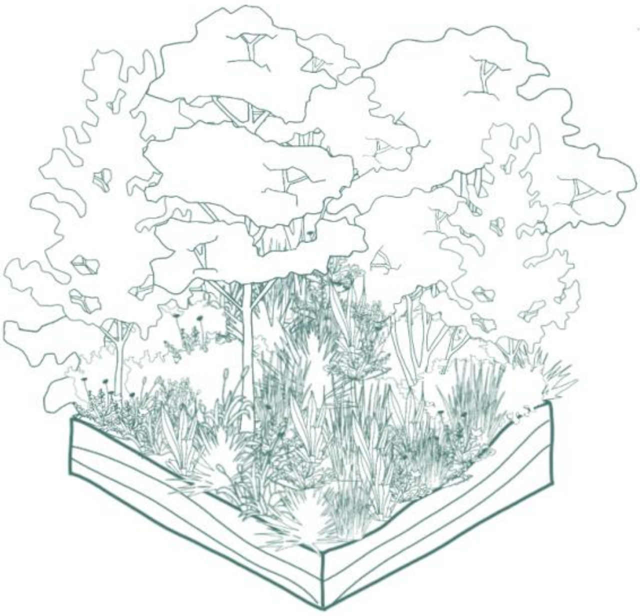

Figure 8.2: Whānau planting for land retirement and afforestation – clustered forestation planting, forest canopy, and under canopy planting. Whānau planting for land retirement and afforestation – clustered forestation planting, forest canopy, and under canopy planting.

Figure 8.3: Whānau planting for channel realignment and floodplain re-engagement – clustered awa corridor planting, both wet and dry typologies, low maintenance and robust planting.

It is recommended to leverage the data used in the indigenous vegetation assessment, and to lean upon mana whenua expertise to help with future work. Initial priority zones have been identified, based on indigenous vegetation. These priority zones can also be interpreted as a catchment phased approach for planting implementation. Three priority areas were established based on soil type, drainage capacity, and historical ecosystem data (Table 8.1). The upper and middle reaches of the catchment were the focus, as they influence the hydrology and flood behaviour in Masterton.

Table 8.1: Priority zones for planting native vegetation for flood mitigation

Priority zones	Location details	Benefits
Priority zone 1 – immediate flood-prone areas	River margins and areas historically occupied by wetlands. Utilise planting strategies.	Indigenous vegetation will help stabilise banks, filter runoff, and mitigate localised flooding.
Priority zone 2 – wider landscape	Extends beyond river margins into adjacent farmland and pasture. Involves retiring grazing land to allow for ecosystem restoration and soil stabilisation.	Support biodiversity and connectivity between habitats, stabilise soil. Mitigate some wider flooding.
Priority zone 3 – long-term landscape retirement	Major land use changes, wider than the adjacent farmland.	Restore large-scale indigenous ecosystems and help mitigate wider spread flooding.

8.3 Next steps

The indigenous vegetation investigation provides detail on the types of vegetation that would be of benefit to have in the Waipoua catchment for each ecosystem type, and an approach for implementation (whānau planting and priority areas). The investigation can be used to inform the future implementation of NBS. The data used in the investigation should be leveraged to help identify and prioritise areas for implementation.

A further detailed assessment should be undertaken to ground truth specific location typologies. Further collaboration will need to take place with mana whenua to identify taonga species and their previous locations.

9.0 Land area required for nature-based solutions

The potential land area required by each NBS has been assessed based on illustrative scenarios, broadly aligned with the scenarios adopted for the flood modelling in Section 5.0. Essentially, the land area required depends on the degree to which the NBS forces a change in land use away from farming, or a change to a less productive or more difficult farming operation. Land was not considered to be “required” by the NBS if farming could be continued largely without impact.

In some cases, the degree of impact on the productive land use will depend on what form the NBS takes. For example, retention storage in the form of dry basins may be compatible with ongoing farming, whereas attenuation wetlands will not, as the wetland replaces pasture and stock must be excluded. For these NBS, T+T has provided alternative sub-scenarios to illustrate a potential range in land requirements.

The modelled scenarios from Section 5.0 are not directly comparable to each other, due to their differences in scale/ impact of flood reduction. All the land requirements have therefore been normalised to allow a comparison. This has been done on the basis of how many hectares would be required to provide a 1% reduction in the design flood flow at Masterton (Table 9.1). This is a reasonable simplification to make, as all the assessed NBS can be scaled in their extent and the impact will be more or less proportional to the amount of land used.

A stakeholder raised that some of the land that might be required by NBS is also land that would be lost or damaged in large floods (either by erosion or sediment deposition and flood damage to farm assets). This would be particularly applicable to the channel realignment/ room for the river NBS and the floodplain re-engagement NBS, as the land identified would be particularly subject to erosion and damage. This hasn’t been specifically reflected in this high-level analysis, however, susceptibility to flooding and erosion is a factor that is implicitly included in the costs of purchasing this land, which are described in Section 9.1.

The estimated land required and the assumptions that this is based on for each scenario is provided in Table 9.1 below.

Table 9.1: Land required for a range of NBS scenarios

Scenario		Land required (ha)	Design flood flow % reduction[9]	Area per 1% design flood flow reduction (ha)	Assumptions and derivation of land area required
Land retirement and afforestation		1,700	3.7%	459	40% of the 4,257 ha area identified for afforestation, in line with the modelled scenario.
Floodplain re-engagement (no vegetation)	Low estimate – 20% of identified area	67	0.5%	134	Following floodplain lowering and reinstatement, farming continues as before. 20% of the land is permanently impacted; regular flooding, poorer drainage or similar. The total area earmarked for the floodplain re-engagement NBS scenario was 335 ha.
Floodplain re-engagement (no vegetation)	Mid estimate – 50% of identified area	168	0.5%	336	As above, but 50% of the land is impacted. This could also represent a scenario where some of the land is planted or wetlands are re-established.
Floodplain re-engagement (floodplains re-vegetated)	High estimate – 100% of identified area	335	3.8%	88	The floodplains are planted in native vegetation, so 100% of the land is taken up.
Small-scale, distributed retention storage	Low estimate	24	1.4%	17	300 m^3 storage per ha, as adopted in Section 3.4.3. Assuming a typical depth of approximately 2 m, this gives approximately 150 m^2/ ha basin footprint – increased to 200 m^2/ ha to allow for the footprint of the bund itself. The total catchment area for this NBS was 6,031 ha, so the potential NBS footprint is 121 ha. Low estimate: dry basins that can largely be farmed (20% of total NBS footprint is unfarmable).
Small-scale, distributed retention storage	Mid estimate	61	1.4%	44	As above, but 50% of NBS footprint is unfarmable.
Small-scale, distributed retention storage	High estimate	91	1.4%	65	Wetlands are established in 50% of the storage sites (60 ha). Overall, 75% is unfarmable (91 ha).
Channel realignment/ room for river		431	1.6%	269	Based on outcomes of the geomorphic assessment and the scenario modelled. It was assumed that all of this land ultimately becomes part of a wider river channel. This corresponds to the 1969 extent.

[9] From Section 5.0

9.1 Discussion

Small-scale, distributed storage appears to the be the most "efficient" NBS in terms of land use, with 17 to 65 ha land required per 1% reduction in the design flood. However, as noted in Section 12.0, the modelled flood reduction of this option is probably the least certain and comes at a risk of non-performance unless the whole system is designed and maintained very well. Lowered and revegetated floodplains also required relatively less land, at 88 ha per 1% flow reduction. Land retirement and afforestation would require the most land, at an estimated 486 ha per 1% reduction.

Assuming some sort of hybrid NBS implementation, it is reasonable to imagine an overall land requirement in the range of 100 – 200 ha per 1% design flood flow reduction, or 500 – 1,000 ha for a 5% reduction[10]. More significant reductions (for example, on the scale of predicted climate change increases of approximately 20%) would require proportionally more land. This finding is consistent with other literature. For example, in the study of urban green infrastructure modelled by Mei et al (2018), scenarios with land coverage of up to 37% were considered. These figures represent major land-use change within the catchment, which is perhaps not always appreciated or communicated in discussions around NBS.

In most cases, the land "required" by the NBS equates to the land that would need to be purchased (or in some other way be compensated) to implement NBS. This is further expanded on in the cost estimates in Section 10.0.

[10] It is noted that a 5% reduction in flow was adopted as a potential target for NBS as part of the work of the Waipoua Project Team considering flood risk management options for the Masterton urban reach of the Waipoua River.

10.0 High-level cost estimates

T+T prepared high-level cost estimates to indicate the likely range in costs for the selected NBS. These have been prepared in line with industry standard approaches, including:

- Allowances for design and construction supervision costs.
- Construction costs where applicable, including contractor's overhead, profit and risk margins.
- Risk allowances (i.e. "contingency"). A 20% allowance was considered generally appropriate given the scale of work and high-level assumptions, but for the channel realignment/ room for the river scenario, a higher contingency allowance of 40% was adopted to reflect the far smaller quantum of work.

The cost estimates have been completed in such a way that all the likely major costs have been included and key uncertainties in them have been considered. The high-level cost estimates are not exhaustive and were intended primarily for use in comparing between the four selected NBS, as well as giving an indication of costs. The cost estimates are not suitable for budgeting purposes. They have been based on simplified costing scenarios and broad assumptions only.

A full table with the cost estimate breakdown is provided in Appendix F, along with some additional clarifications.

The three broad categories of costs are:

- **Physical works costs:** These costs relate to the floodplain re-engagement (floodplain lowering) and small-scale, distributed storage NBS. All physical works have been built-up from first principles based upon nominal productivities per day for the likely labour, plant and material operations.
- **Land Costs:** A rural real estate agent based near Masterton kindly provided indications of the value of different types of land within the catchment based on his own market intelligence and recent sales. He indicated rough estimates of:
  - $30,000 - $40,000 per hectare for good to excellent, fertile, highly improved land;
  - $15,000 - $20,000 per hectare for average to good land by a river, depending on location/ improvements/ flood risk;
  - $8,000 - $9,000 per hectare for 'easy to medium' grazing land (around the edges of the ranges); and
  - $7,000 - $8,000 per plantable hectare for forestry land.

The amount of land required for each scenario was linked to the areas estimated in Section 9.0.

- **Planting costs:** A principal restoration ecologist at T+T provided per hectare costs based on his experience across a range of projects, including wetland creation and hill country land retirement and reafforestation. These were also prepared with reference to costs provided in MPI (2016) and Te Uru Rākau (2022). The costs included allowances for:
  - Fencing;
  - Plants and planting including site preparation; and
  - Releasing (weed control) and pest management, each for a period of three years;

Planting costs were provided on the basis of all activities being undertaken by commercial operators. T+T assessed the opportunities for savings with volunteer inputs to be limited because of the scale of the work. Also, T+T has estimated costs based on planting 100% of each block, i.e. complete planting of each area. Where native revegetation needs to occur on a large scale, "cluster" or "seed island" planting is sometimes applied (although it is not a standard approach). This is where small clusters of native plants are established, leaving unplanted gaps in between. Typically, approximately 10% of an area may actually be planted. The benefit of this is much cheaper planting costs; the negatives are that it takes much longer (decades) for native plants to cover an area (by seed dispersal) with the result that the benefits are not accrued for much longer, and there can be substantial invasive weed issues to manage over that time. The concept of "whanau" planting referred to in WSP's indigenous vegetation report (Appendix G) may be consistent with this.

10.1 Cost scenarios

Key points and assumptions for each of the NBS costing scenarios are described in the sections below, all based on the design flood event (1% AEP + climate change).

10.1.1 Land retirement and native afforestation

A single scenario was assessed based on 40% (1,700 ha) of the identified area being purchased and afforested. A land value of $9,000/ ha was adopted on the basis of the advice above for forestry land and 'easy to medium' grazing land around the edges of the ranges.

10.1.2 Floodplain re-engagement

Four scenarios were assessed, based on combinations of:

- Lower earthworks costs for the floodplain lowering (disposal of excavated material within 5 minutes haulage) and higher earthworks costs (disposal of excavated material within 30 minutes haulage).
- Low land requirements and high land requirements based on the values adopted in Section 9.0, Table 9.1.
- Land costs of $15,000/ ha were adopted on the basis of the advised *"$15,000 - $20,000 per hectare for average to good land by a river, depending on location /improvements/ flood risk"*, as this land is likely to be the more flood-prone and less improved land generally.

10.1.3 Small-scale, distributed retention storage

Physical works costs per m^3 of storage were developed by estimating the costs for a single 2,000 m^3, 2 m-high 'model basin' with allowances for an outlet structure. This model basin is representative of a range of storages that may be greater or lesser in volume. These costs were then multiplied up by the total 1,800,000 m^3 storage that was modelled for this scenario in the hydrological model, to represent many individual storages.

Land costs of $30,000 per hectare were adopted from the lower end of the $30,000 to $40,000 category, on the basis that the selected sites are likely to be in existing drainage paths and therefore likely to be less improved, and that site selection can perhaps avoid areas of the highest-value land.

The following two scenarios were estimated, with land requirements referring to the estimates in Section 9.0:

- Low estimate. Storage elements can be created through cut-to-fill within the subject site. 20% (24 ha) of the overall footprint is required to be purchased. There is no planting.
- High estimate. Retention bunds must be constructed from imported fill. 50% (60 ha) of the basins are built with wetlands in their base. 75% (91 ha) of the overall footprint must be purchased.

10.1.4 Channel realignment/ room for the river

A single scenario was costed, as land is likely to be by far the biggest cost and it has been assumed that 100% of the land occupied by the river must be purchased or similarly compensated. Per-metre costs for the 37 km of willow removal were built up based on typical costs provided by Greater Wellington. Riparian planting of half this length to a width of 15 m has been assumed.

10.2 Cost estimates

The total costs (including contingency) are presented in Table 10.1 below. As with the land requirements in Section 9.0, the costs have also been normalised on a '$ per percentage reduction in the design flood' basis to allow a direct comparison between the scenarios.

Table 10.1: Cost estimate summary table

Cost scenario	Total cost incl. contingency	Reduction in design flood flow	$ per percent reduction
Land retirement and afforestation	$ 123M	3.7 %	$ 33M
Floodplain re-engagement (no vegetation) - low estimate	$ 61M	0.5 %	$ 121M
Floodplain re-engagement (no vegetation) - high estimate	$ 100M	0.5 %	$ 201M
Floodplain re-engagement – (floodplains re-vegetated) - low estimate	$ 80M	3.8 %	$ 21M
Floodplain re-engagement (floodplains re-vegetated) - high estimate	$ 117M	3.8 %	$ 31M
Small-scale, distributed retention storage - low estimate	$ 152M	1.4 %	$ 109M
Small-scale, distributed retention storage - high estimate[11]	$ 266M	1.4 %	$ 190M
Channel realignment/ room for river	$ 14M	1.6 %	$ 9M

10.3 Operational costs and income

Operational/ ongoing costs have not been assessed for the selected NBS, as the broad assumptions made about their form and how they might be implemented don't allow this level of detail. The operational requirements for monitoring and maintenance of the small-scale, distributed storage NBS, in particular, are likely to be significant.

One aspect of ongoing cost that came up repeatedly at the wider benefits stakeholder workshop was the issue of pest control. It wasn't assessed whether pest control alone may deliver significant benefits in terms of increased forest health and water-holding capacity in the soil, and this could be investigated in further, more detailed assessments. However, this may indeed be needed to achieve the full biodiversity benefits and the fully restored forest ecosystem sought by some stakeholders. Ongoing management of predators (possums, mustelids, rats, cats) for biodiversity benefit, based on the above literature and T+T's project experience, could be expected to cost at least $150/ ha/ year. These costs would include control of deer and goats to moderately low levels.

Additional income streams resulting from implemented NBS (e.g., manuka honey, tourism, carbon credits etc.) could occur but have not been assessed. The ability of landowners to derive income from NBS could be an important factor in their willingness to implement them and would be worth exploring in implementation planning.

[11] This scenario additionally allows for wetlands in 50% of the storage basins, but the additional costs associated with this are minor in comparison to the construction costs

11.0 Cost-benefit analysis

To allow a comparison of the potential cost-effectiveness of the selected NBS, and to give an overall indication of what financial value NBS could offer for flood risk reduction to Masterton, T+T carried out a limited cost-benefit analysis. The assessment is limited in the sense that it is not a full economic cost-benefit analysis, rather, a comparison of the available information, namely:

- High-level costs provided in Section 10.0; and
- Flood damages assessed previously (T+T, 2024a).

This assessment compared the construction/ establishment costs against the estimated financial flood damages from a 1% AEP + climate change event. However, not enough data points were available to support a meaningful assessment of reduction in average annual damages. T+T (2024a), focussed on assessing direct damages and some indirect damages as shown in Table 11.1 and Table 11.2, below. Intangible damages were discussed but not quantified. The previous flood damages were provided in terms of an upper and lower bound.

Table 11.1: In-scope items (T+T, 2024a)

Direct damage	Indirect damage
Building damage (residential, industrial, commercial, outbuildings)	Residential relocation costs
Residential contents	
Vehicles	
Commercial/ industrial contents	
Cleanup costs	
Costs of remediating areas of deposition and/ or erosion on agricultural land	

Table 11.2: Out of scope items (T+T, 2024a)

Direct damage	Indirect damage
Transport, 3 Waters and other utility assets	Personal or business disruption costs and/or loss of income
River management/ flood protection/ river monitoring assets	Business displacement/ relocation
Community facilities	Emergency management costs
High potential loss sites	Economic consequences/ analysis
Hazardous material facilities	Liabilities of any party
Rural damages besides buildings and deposition/ erosion e.g., fencing, roading, stock losses	Assessment of any economic benefits (as opposed to costs) of flooding
Differences in losses due to longer or shorter warning time	
Undefended (banks down) losses	

Because the high-level modelling carried out under this NBS project used a different flood model, which gave slightly different flows at Masterton compared to the previous work, a direct comparison with the flow/ damage relationship from the previous work was not possible. Instead, T+T assigned the data points from the previous work in terms of AEP and $ damage to the new flow/ AEP data provided by Land River Sea. This allowed a correlation to be plotted between river flow and damages (see Figure 11.1). A polynomial curve gave the best fit at the upper end of flows, which is the area of interest, so this was adopted (although it does not fit the lower end of the data).

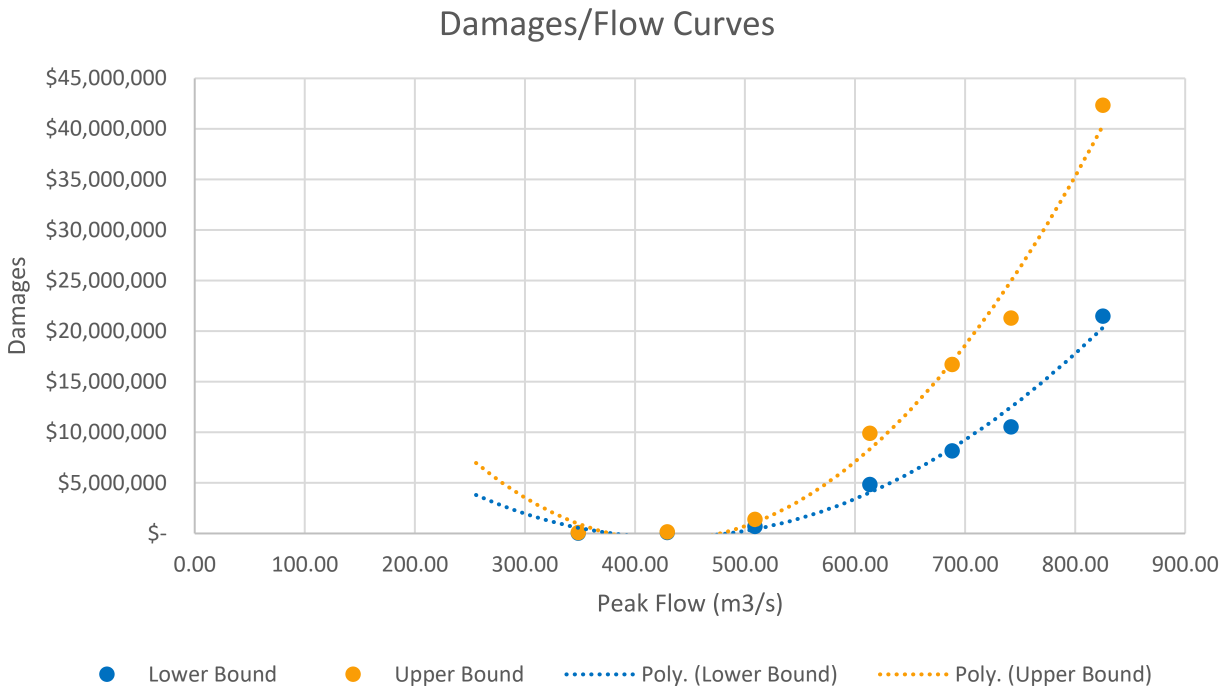

Figure 11.1 Flow-damages relationship.

With the reliance on the previous flow/ damages relationship, the flood damages do not allow for the increased rural damage that will occur due to higher flood levels on some rural land upstream of Masterton, under some of the selected NBS. However, the rural flood damages are a relatively minor component of the overall damages (previously assessed to be ~ 5% of the damages when climate change is included) and in some cases this increased damage will be negated by the purchase of the subject land as part of implementing that NBS.

Using this relationship allowed the calculation of the following damage reductions (Table 11.3). The damages in the design flood event were compared against the implementation costs; this is not a true cost-benefit analysis, but rather gives an indication of the scale of return on investment and allows a comparison between the selected NBS. This comparison spread was calculated based on a lower combination (lower cost bound divided by upper saved damages value) and an upper combination (higher cost bound – if available – divided by the lower saved damages value).

Table 11.3: Cost-benefit in terms of damages saved

NBS scenario	% Flow Adjustment	Peak Flow (m3/s)	Damages ($)		Costs ($)		$ cost per $ flood damage saved	
			Lower Bound	Upper Bound	Low estimate	High estimate	Lower combination	Higher combination
Base scenario (1% AEP + climate change 2100)	-	825	$ 21M	$ 42M				
Land retirement and afforestation	-3.7 %	795	$ 17M	$ 34M	$ 123M		$ 15	$ 29
Floodplain re-engagement (no vegetation)	-0.5 %	821	$ 20M	$ 39M	$ 61M	$100M	$ 21	$ 63
Floodplain re-engagement (floodplains re-vegetated)	-3.8 %	794	$ 17M	$ 34M	$ 80M	$ 117M	$ 10	$ 27
Small-scale, distributed retention storage	-1.4 %	813	$ 19M	$ 38M	$ 152M	$ 266M[12]	$ 34	$ 112
Channel realignment/ room for the river	-1.6 %	812	$ 19M	$ 38M	$ 14M		$ 3	$ 6

[12] This scenario additionally allows for wetlands in 50% of the storage basins, but the additional costs associated with this are minor in comparison to the construction costs

11.1 Discussion

In this high-level assessment, the channel realignment/ room for the river NBS gives the best result in terms of value of damages potentially saved for each dollar of cost. The small-scale, distributed storage NBS gives the worst value result (by over an order of magnitude). The overall flow reduction results of the two NBS (at 1.6% and 1.4% respectively) are actually very similar; the difference is driven by the difference in costs.

These results do not take into account other important factors, such as risks/constraints or wider benefits, which are discussed in other sections of this report. They also don't take into account other flood benefits such as the reduction in geomorphic risks (aggradation pulses, debris generation etc.) or delays in flood peaks; they are based solely on the reduction in the peak flow of the design flood as a proxy for reduction in flood risk.

In reality, this comparison is somewhat hypothetical, because the preferred flood management option for the Masterton urban reach of the river is a combination of upgraded and new structural measures, mainly stopbanks. The greatest part of the costs and quantum of these upgrades is estimated to lie in the provision of stopbanks with a geometry meeting Greater Wellington's design standards and sufficient freeboard above modelled flood levels. This means that a reduction in design flows does not necessarily translate to a similar reduction in costs for the stopbanks, and in fact changes in the order of 100-200 mm in water level (as could perhaps be delivered by NBS) do not have a huge impact on stopbank costs.

The greatest value for NBS may lie in the wider benefits they can deliver, as covered in Section 6.0 and further discussed in Section 13.0.

12.0 Risks and constraints

The technical assessments have outlined the range of benefits that the four selected NBS can provide in the Waipoua catchment, particularly the wider benefits in Section 6.0. As well as reducing flooding, enhancing ecological health and biodiversity emerged as key benefits that can be provided by NBS and were highly valued by stakeholders. However, it is important to identify the risks associated with NBS to understand the feasibility of implementation. The following section outlines the key risks and constraints that are generally associated with NBS, followed by specific risks and constraints for each of the four selected NBS.

12.1 General risks of and constraints on nature-based solutions

A number of important risks have emerged through the technical assessments carried out under this project. T+T has compared these with those noted in the literature, including Bridges et al. (2021), Griffiths et al. (2024), and Wren et al. (2022). Generally, the risks identified in the literature have aligned well with those highlighted through the course of the assessments, with no unique risks apparent in the Waipoua catchment. In Sections 12.2 to 12.5, T+T has emphasised how these risks particularly apply to the Waipoua catchment for the NBS assessed.

12.1.1 Performance uncertainty

The performance of NBS for reducing flood risk is complex and uncertain as they rely on natural processes such as soil infiltration, water retention, hydrological connectivity, and vegetation interception/evapotranspiration. All of these processes inherently have temporal and spatial variability, and this influences the certainty of NBS performance.

Most commonly, multiple NBS are implemented together in order to increase their flood reduction impact. However, this comes with challenges as they are multi-faceted systems that interact and influence each other and may have different types of responses to changes in catchment condition such as climate, land use, and sediment. This can impact the predictability of hydrological responses, such as the timing of flood peaks and flood volume. There is a risk that delayed flood peaks in sub-catchments may coincide downstream, potentially exacerbating flooding downstream rather than alleviating it.

Unlike conventional, engineered structures (e.g., stopbanks), NBS do not have widely used design standards or models. Levels of service may be difficult to define, and performance is more difficult to measure. NBS are dynamic in order to work with nature, and site-specific conditions make data difficult to transfer between catchments, making it harder to quantify and compare their effectiveness in flood reduction with confidence.

Another key risk within performance uncertainty is managing community expectations around the effectiveness of NBS. The community may expect NBS to have a higher performance than what they actually do or not understand the scale and extent to which they would need to be implemented to gain the desired flood reduction outcomes. This poses a risk of community expectations not being met or taking longer to achieve than anticipated.

12.1.2 Timeframes and delayed benefits

The community may also expect flood risk to be reduced immediately once implemented. This is perhaps achievable for some NBS such as small-scale, distributed retention storage and floodplain re-engagement. However, other NBS that require natural vegetation will take a long time (decades) to become fully effective.

12.1.3 Funding and economic viability

The initial implementation of NBS may attract funding from multiple, diverse sources such as for afforestation, riparian planting, flood reduction etc. However, it is difficult to secure long term investment with there being a lack of clarity around who should fund the longer-term maintenance of NBS and the uncertainty of long-term financial returns. Traditional funding streams, such as central government infrastructure budgets, may not be well-suited to NBS as they often fall outside conventional infrastructure definitions.

NBS may also be difficult to fit into a traditional river management/flood management rating system, with rates collected on the basis of a benefits classification on land. Identifying the benefits and who exactly receives them would be complicated, especially in a situation where some landowners may be asked to give up land to implement NBS. However, the recent change to a catchment-wide rating approach for the Te Kāuru (Upper Ruamāhanga) area (including the Waipoua River) alleviates this complexity somewhat.

12.1.4 Land access and use conflicts

NBS typically require significant land area, which conflicts with existing land uses and will likely require large-scale land acquisition and landowner buy in. Some landowners and stakeholders may reject the implementation of NBS, especially if projects involve perceived land loss, increased erosion, or increased flooding of rural properties. Therefore, availability of land may affect the feasibility and effectiveness of NBS. T+T has assumed that any land acquisition would have to be on a "willing buyer, willing seller" basis in assessing the feasibility of NBS and making recommendations for implementation.

12.1.5 Liability

There is ambiguity around who owns and is responsible of the maintenance of NBS, as there are likely to be multiple parties involved, including multiple landowners, councils, and agencies. This creates ambiguity in maintenance responsibilities and potentially a liability risk if the NBS do not perform as expected; it also creates the potential difficulty of needing to demonstrate that the NBS are not responsible for worsening flooding elsewhere, if this is attributed to the NBS.

12.1.6 Consenting implications

The selected NBS will trigger different needs for consenting, which in some cases may be a hurdle for implementation. A full consenting assessment has not been undertaken, but in broad terms the following consenting considerations have been identified:

- Land retirement and reafforestation will not require consents per se, although minor consents may be required for enabling infrastructure such as access tracks or culverts.
- Floodplain re-engagement as envisaged in the modelled scenario as approximately 0.5 to 1.0 m of floodplain lowering, totalling 1,000,000 m3 over extensive lengths of floodplain, as well as modifying stopbanks. This would be a moderate to major consenting challenge, particularly if this resulted in worse flooding of upstream, downstream or adjacent rural land (as predicted herein for some NBS).
- Small-scale, distributed retention storage would have only minor consenting requirements if the scale of individual storages is kept small. These would fit within the permitted activity standards of the current Regional Plan if they:
  - Occur within an ephemeral watercourse;
  - Involve disturbance of less than 3,000 m^2;
  - Have a storage volume of less than 20,000 m^3; and
  - Have a depth less than 3 m (amongst other conditions).

Any dam higher than 4 m has the potential to trigger more onerous requirements under the Building Act/Dam Safety Regulations.

- Channel realignment/ room for the river NBS approaches would likely have minor consenting implications, as the removal of existing exotic vegetation and “non-action” in terms of reducing/ceasing gravel extraction and erosion protection interventions would not trigger the need for consents. However, Greater Wellington would likely have requirements to review the Waipoua River Management Scheme and define/agree changed levels of service/performance standards to reflect this change in approach.

12.2 Land retirement and afforestation

Land retirement and afforestation has three main risks and constraints for implementation.

12.2.1 Performance uncertainty

The performance of the NBS is dependent on achieving higher soil infiltration rates under forest cover and delays to the flood peak due to retaining water in soil and slowing overland flows. Literature provides a range of results for how much increase in infiltration can be expected, with few studies measuring actual performance in large flood events or assessing performance in New Zealand indigenous forest. This performance depends not just on the forest cover but on the underlying soils and geology. The results of hydrological modelling predicting the performance of this NBS are sensitive to the assumptions made.

12.2.2 Delayed effectiveness

Native vegetation will take decades to become effective at reducing or slowing runoff. This delay poses challenges for planning, funding, and maintaining stakeholder support, especially when short-term results are prioritised.

12.2.3 Resistance to land purchase

This NBS has been identified as having the highest land requirement per percent reduction in the design flood. In addition, the planting of trees on farms impacts their viability as a viable unit; although only part of a farm may be identified as a priority for retirement and tree planting, removing this land from production may tip the balance of the farm into no longer being economic. This may require purchase of the entire property, leading either to increased costs or landowner resistance.

12.3 Floodplain re-engagement

There are two main risks associated with implementing floodplain re-engagement in the Waipoua catchment.

12.3.1 Land use and agricultural disruption

The floodplain re-engagement scenario requires significant land modifications, such as lowering floodplain surfaces and altering flood channels to restore natural connectivity. This can lead to a permanent reduction in productive agricultural land area, or land that is only suitable for a much lower intensity of agricultural activity due to more frequent flooding/siltation. This also introduces the potential for stock losses and maybe even risk to farmers, given the increased frequency of flooding of this land and the relatively short flood warning times available for this catchment. The concept of overflow paths that activate more regularly means that there will be riverside land that is cut off by these channels in relatively small floods. These issues together may mean that the land, in large part, is no longer suitable for farming. This potentially pushes this NBS in the direction of the alternative option that was modelled, of also revegetating the lowered floodplain areas. This land use change, on highly visible and productive floodplain farms, may face strong resistance.

12.3.2 Hydraulic and morphological uncertainty

Re-engaging floodplains is technically complex, and if poorly designed, it can inadvertently increase localised and / or downstream flood risk. For example, as demonstrated by the scenario used in Section 5.4.1 (without a vegetated floodplain), it could increase downstream peak flows in 20% and 39% AEP events due to increased conveyance of flood flows in overflow paths, possibly leading to increased channel incision, bank erosion and flooding.

There is uncertainty in the response of sediment transport dynamics and the long-term morphological responses such as aggradation rates, which further complicates the design, and increases the risk of maladaptation. Floodplain lowering and changes in riverbed elevation alter the frequency and extent of floodplain inundation. This can either result in the floodplain flooding too often or not enough to sustain desired habitats and fully restore floodplain connectivity/flood response. Long-term, sedimentation of the floodplains may be an issue (especially if afforested), as the riverbed levels and floodplain levels adjust in response to each other.

12.4 Small-scale, distributed retention storage

Small-scale, distributed retention storage has three key risks and constraints.

12.4.1 Maintenance and operational challenges

Small-scale, distributed retention storage requires the highest degree of maintenance compared to the other selected NBS, due to risks associated with blockage/ hydraulic performance and sedimentation. Vegetation growth and sediment accumulation may reduce the capacity of the storage structures, ability to function, cause blockage of inlets and outlets, increase scouring, and cause structural damage or increase the deterioration of the retention storage. Maintenance checks will need to be carried out on a regular basis to ensure performance. Larger structures may trigger more stringent requirements under current or future versions of New Zealand's Dam Regulations.

12.4.2 Hydrological design challenges

All storms have different spatial and temporal patterns, and it's not possible to optimise or design storages to deal with every possible event. The scenario-based hydraulic modelling that was undertaken (as described in Section 5.5) has highlighted the risk of small-scale, distributed storage delaying the timing of the flood peak, which increases the flood risk downstream for certain events. This possibility is a recognised problem in flood management.

The storage modelled was optimised for a 1% AEP event, and therefore, there is uncertainty of its performance across other storm events. The results from the single set of storms that were modelled indicate that this will be variable. In reality, the actual performance of a flood retention element (or catchment-scale implementation of multiple storages) will be considerably less than its ideal performance due to these factors.

In a hydrological sense, the storages are unlikely to be suitable for any multi-use application (e.g. combined irrigation reservoir and flood detention), as these uses conflict in their requirements; attenuation storage needs to be empty or largely empty at the beginning of a storm.

12.4.3 Scale limitations and land ownership

For small-scale, distributed retention storage to achieve the desired reduction in flooding, it requires there to be potentially hundreds of distributed storage features throughout the catchment. This presents logistical challenges for gaining approval by a large number of landowners to build, access, and maintain the hundreds of storage features (or to buy the land).

12.5 Channel realignment/ room for the river

There are two main risks associated with implementing channel realignment/ room for the river NBS's in the Waipoua catchment.

12.5.1 Uncertainty in the hydrological and morphological response

The flood peak reduction of this NBS scenario in large floods (described in Section 5.6.1), occurs largely as a result of expected bed aggradation pushing more water onto floodplain areas. The degree of aggradation is expected as a long-term response to the river having more space to adopt a wandering, more sinuous form (as well as reductions or ceasing of gravel extraction). This aggradation may take decades to occur or may never fully eventuate, depending on the cycle of storms, how the NBS is implemented and how the river responds. Therefore, the long-term performance of this NBS is uncertain.

The scenario modelled, resulted in increased flood peaks during smaller, more frequent events, up to the 5% AEP flood events. If flow conveyance is increased in one part of the system, it can unintentionally shift flood risk or cause channel instability elsewhere. The redistribution of flood risk can raise legal and liability concerns, especially if downstream communities are adversely affected.

12.5.2 Morphological and sediment dynamics

Increased sediment storage/ retention upstream from channel realignment/ room for the river or other NBS's such as land retirement and afforestation, may cause changes in the sediment regime and dynamics by reducing sediment delivery downstream. This could lead to further channel incision or bank instability. Some of the selected NBS have the potential to hold back fine sediment rather than bed load. The potential interaction of the different NBS, or the effects of upstream channel realignment/room for the river approaches on downstream reaches, is not yet well understood. Hence, channel realignment must be carefully planned and changes monitored. Riparian and floodplain planting may play a critical local role in reducing flow velocities, and the potential for erosion.

13.0 Key findings and conclusions

This section summarises T+T's key findings on the feasibility and implementation of NBS in the Waipoua catchment, as well as recommendations for further work.

13.1 Feasibility of nature-based solutions for reducing flood risk to Masterton

The preceding sections included estimates of:

- The potential flood reduction benefits of the selected NBS;
- The potential flood damages reduction that corresponds to that flood peak reduction;
- The land required by each NBS; and
- The cost to implement each NBS.

Because the above work was done for different scenarios for each NBS, these tested scenarios are not all the same scale. To allow a comparison, it was therefore necessary to normalise the results based on:

- Hectares or cost ($) per 1% reduction in the design flood peak flow; and
- Cost ($) per dollar of flood damages saved in the 1% AEP design flood event.

These were, in most cases, reported as an upper or lower bound based on the different scenarios assessed. The above is summarised in Table 13.1 below.

Table 13.1: Land use, cost and cost-benefit summary table

Scenario	Area required per 1% design flood flow reduction (ha)[13]	Cost per 1% design flood flow reduction[14]	Cost per $ flood damages saved in the design flood[15]
Land retirement and afforestation	459	$ 33M	$15 – $29
Floodplain re-engagement	134 – 336	$ 121M – $ 201M	$21 – $63
Floodplain re-engagement + vegetation	88	$ 21M – $ 31M	$10 –$27
Small-scale, distributed retention storage[16]	17 – 65	$ 109M – $ 190M	$34 – $112
Channel realignment/ room for river	269	$ 9M	$3 – $6

One way of considering feasibility, is the scale at which NBS can deliver a reduction in flood hazard, where that is measured by a reduction in the peak flow of the design flood. Prior to this study, there was significant uncertainty regarding the potential scale of reduction in flows. As part of the work of the Waipoua Project Team to assess flood risk management options for the Masterton urban reach, a reduction was 5% was hypothesised as being achievable. At a more aspirational level, the potential for NBS to offset the increased flows due to climate change for the 1% AEP design storm was also discussed, which would correspond to a reduction of approximately 20%.

13 See Section 9.0

14 See Section 10.0

15 See Section 11.0

16 The upper bounds of land and cost for this scenario are based on inclusion of wetlands in 50% of the basins. However, the associated costs are relatively minor compared to the construction costs.

Based on these discussions, the scale of reduction in flows deliberated was within the order of 5 – 20%. A hybrid approach of multiple NBS is likely to be needed to deliver this. As noted in Section 9.0, if a hybrid approach required 100 – 200 ha per 1% flood peak reduction, then 500 – 1,000 ha would be required to deliver a 5% reduction. This represents 3% to 6% of the catchment (or 4% to 8% of the land lying outside the Tararua Forest Park, which is perhaps a more useful comparison). By extension, to deliver a reduction equating to adopted climate change increases (~20% reduction), NBS might require 16% to 32% of the land outside of the Tararua Forest Park. This suggests that NBS could be feasible to deliver a significant flood peak reduction, but only through very large-scale land-use change.

The costs of NBS are also significant. Channel realignment/ room for the river was estimated to have the lowest cost to implement, but even this is estimated to cost $14M to deliver a 1.6% reduction in peak flow in the design event. This compares against high-level estimates (T+T, 2025) of ~ $20M for structural (stopbank) measures targeting the design flood in the urban reach. As a crude comparison (not a full benefit-cost assessment), none of the NBS even approach saving $1 from the estimated damages in the design flood, for $1 spent (a benefit-cost ratio of 1); estimates ranged from $3 to $112 cost per $1 damages saved. There is no requirement for public sector investment decisions to deliver a particular benefit-cost ratio, or even a benefit-cost ratio of greater than 1, but these are often used in prioritising the investment decisions within an organisation. As an example of this, NZTA/Waka Kotahi has an "uneconomic transport infrastructure policy" which guides investment decisions on "uneconomic" investments (i.e., a benefit-cost ratio of less than 1). Rural roads often have a monetised benefit-cost ratio of less than 1 but are still constructed and maintained because they provide important non-monetised and/or social benefits. There is an important parallel here for NBS and their delivery of non-monetised flood benefits, as well as wider benefits.

There are a range of risks and potential barriers to NBS, as described in Section 12.0. This is due to either uncertainty in the effectiveness of the NBS or uncertainty in the geomorphic trajectory that it relies on to deliver its full benefits. It should be noted that structural approaches (stopbanks, spillways and the like) can also be vulnerable to geomorphic changes such as aggradation, which can then lead to a need for further intervention.

The above indicate that, although technically feasible to deliver a flood benefit, NBS alone will not be able to replace stopbanks in managing Masterton's flood risk to achieve the level of service required. Nor will NBS be a replacement for an upgrade to the existing stopbanks, which are currently estimated to begin overtopping around a 2% AEP flood (historic climate). However, where NBS may have a stronger role in managing Masterton's flood risk, is:

- Reducing the level of risk posed by geomorphic processes. Some NBS would be effective at reducing the size of floods across the whole spectrum of flooding. For example, the land retirement and afforestation NBS scenario reduced the 1% AEP + climate change flood peak by 3.7%, but the 2% AEP flood event by 9.5%. This reduction across the whole range of floods will reduce lateral erosion, bed degradation and the associated threat to stopbanks from series of smaller floods. NBS may also moderate sediment generation and transport, reducing the potential for future pulses of sediment that could cause aggradation problems in the downstream reach.
- Complementing stopbanks. Future upgrades of the stopbanks (beyond the scope of Greater Wellington's current preferred option) could be driven by ongoing and/or greater than expected climate change impacts, a higher expectation for level of service, or perhaps more stringent freeboard requirements. Further upgrades are likely to be more difficult, riskier and more expensive. As stopbanks are built higher, the consequences of a stopbank failure grow. Under this scenario, the risk and cost of NBS may become more favourable in comparison to other options. This would also fit well with the longer timeframes needed to fully implement most NBS.
- Delaying flood peaks. Although the flood modelling results indicate a modest delay, this could nevertheless be important for improving warning times and the effectiveness of flood warning/emergency management measures. This would be particularly relevant for areas not protected by structural flood protection, or for in a potential overdesign event.

All of the above feasibility discussion is based solely on the potential of NBS to reduce flood risk to Masterton. As described in Section 6.0, there is a whole range of wider benefits which NBS could also deliver.

13.2 Commentary on wider benefits

From the stakeholder workshop, it was clear that the wider benefits of NBS were the primary benefit in the view of many participants, with the reduced flooding benefits being secondary. It was also clear that stakeholders placed high value on these benefits that natural systems provide, as evidenced by the time, money or land many of them invest personally in restoration efforts, or their stated willingness to pay for these wider benefits.

Delivering wider benefits that align with the community's priorities (in this case, mainly around ecosystem health, habitat provision and biodiversity) may be a way to engage stakeholder/ landowner support and access additional funding streams than those available just for flood risk reduction. These particular wider benefits may also be well aligned with mana whenua cultural values/ mātauranga practices, but this would require further discussion to ascertain. Ways to implement NBS with a focus on aligning with wider benefits is discussed further in Section 13.4, below.

13.3 Reflections on NBS not assessed

Some NBS that were not selected for further assessment in this study (see Section 3.0) resurfaced in discussions in the stakeholder workshop with proponents of these approaches. Although these approaches were not assessed alongside the four selected NBS, they do have potential to be included in future implementation; especially if there is stakeholder enthusiasm and landowner willingness for these approaches. The following brief commentary has been made:

- Permaculture and other changes in land management to build up soil organic content or water-holding capacity. This may have the potential to have similar benefits to afforestation or distributed storage if implemented at a similarly large scale, although it is unlikely to encourage rain infiltration into deeper soil in the same way that tree roots are expected to. There may be particular soil types, such as peaty soils, where this approach would show the most promise and still be able to be combined with economic use of the land. However, further research would be needed on this approach's potential in large floods.
- Pest control in existing forest areas (for example, a focus on possums and goats in the Tararua Forest Park). This would be expected to have benefits in terms of the development of a healthy, full understorey with deeper organic matter on the forest floor and more stems per m^2. In terms of the potential for flood reduction this is difficult to assess, but as a comparison the results in Section 5.0 show that the existing forest cover in the Tararua is providing at least an effective 5% reduction in flood flows in the design flood. Assessing the potential for improving this may require reviewing historical NZ Forest Service publications and overseas research as well as additional model scenarios and sensitivity testing. This is also an NBS approach that would lend itself to monitoring within a trial catchment.
- Riparian planting. There seems to be general acceptance by stakeholders, that riparian planting itself doesn't have a major role to play in reducing the flood risk to Masterton. However, during the course of this study, opportunities have become apparent to incorporate riparian planting (and its associated wider benefits) into some of the selected NBS, for example channel realignment/ room for the river or floodplain re-engagement.
- Changes in the gravel management/ extraction regime. This was not selected as a stand-alone NBS, or initially as a significant part of any other NBS. However, following the Stage 2 Geomorphic Assessment, a reduction in gravel extraction may form an important part of the bed aggradation that is a driver of flood risk reduction in the river alignment/ room for the river NBS.

13.4 Recommendations for implementation

NBS are technically feasible in the Waipoua catchment but achieving a 5–20% flood peak reduction would require implementation at a very large scale, and at a cost that may be hard to justify for flood benefits alone. To maximise effectiveness and value, a strategic, catchment-wide approach is needed that integrates multiple NBS types (Griffiths et al., 2024). Commonly, where one NBS falls short or is limited in one aspect, another NBS can be complementary. For example, land retirement and afforestation offers long-term reductions in fine sediments and stream power as vegetation matures over decades, while small-scale, distributed retention storage can provide these immediately. Careful planning will be essential to ensure NBS are implemented efficiently, cost-effectively, and in a way that delivers the wider benefits and flood risk reduction.

The following list and sections explore recommendations for the elements of an implementation plan:

1. Provide a systems approach to ensure NBS work in harmony and do not worsen flooding or compromise the potential wider benefits over the entire catchment. A systems approach considers long term environment and social outcomes (Bridges et al., 2021).
2. Ensure individual NBS are prioritised and placed strategically to achieve their objectives (e.g., flood reduction, improve groundwater recharge or river baseflows, reduce sedimentation, improve habitat connectivity). They should also be accessible to implement and maintain. Their placement needs to consider their interactions with other NBS.
3. Consider a staggered approach for implementation, starting with "low-hanging fruit" or "quick wins" that have the fewest constraints or barriers to gain immediate benefits. This could include trial catchments. Planning and implementing solutions that have longer timeframes (e.g., afforestation), could be undertaken concurrently.
4. Be integrated with other existing or proposed plans, projects, and schemes that are undertaken in or influence the Waipoua catchment.
5. Consider how NBS in the Waipoua catchment, would impact the Ruamāhanga River (positively, negatively, or no impact).
6. Use a collaborative approach by working with community stakeholders, landowners, community groups, and mana whenua in the early stages of planning, implementation, and maintenance/ management (Wren et al., 2022).
7. Identify potential funding streams and mechanisms to implement and maintain NBS. Some NBS could be designed to match funding opportunities (Wren et al., 2022). Some NBS may be able to generate income streams for landowners.
8. Establish long-term maintenance programmes with responsibilities defined.
9. Establish long-term monitoring to assess the effectiveness of NBS and allow for adaptive management (United Nations Environment Assembly, 2022).
10. Utilise the data and information available including those specific to this feasibility study for the Waipoua catchment.
11. Use clear communication about what NBS is intended to deliver and not deliver.

Some of the above points are expanded on in the following sections. Numbers in brackets are cross-references to the points listed above, provided for convenience.

13.4.1 Staggered implementation approach and low-hanging fruit (3)

It is recommended that NBS are implemented in a staggered approach (3) and strategically placed over time with consideration of other NBS (2), to:

- **Enable adaptive management** to support a learning-by-doing approach, where early phases can inform later design and implementation (Raymond et al., 2017; Bridges et al., 2021).

- **Reduce upfront costs** and spread investment over time, allowing time to secure further funding and utilise different funding streams (Climate Policy Initiative, 2024).
- **Build stakeholder confidence** by demonstrating the benefits of the project in the early phases or through trial catchments (Nesshöver et al., 2017).
- **Improve integration with existing land uses** by providing flexibility to accommodate current land use and property constraints and prioritising areas to undertake NBS (Keesstra et al., 2022).

Several low-hanging fruit have been identified in the project and are described in the following subsections, for example building on what is already there (existing wetlands, forest remnants). The low-hanging fruit can help manage the risks around land access and use conflicts, stakeholder confidence, and the potential delayed benefits of the NBS.

13.4.1.1 Landowner cooperation and willingness

Implementation of NBS requires stakeholder engagement and cooperation as implementation will need large areas of land that is currently not in public ownership. In making these recommendations, T+T has assumed that the purchase of property for NBS will be entirely on a willing seller, willing buyer basis. Any NBS activities that don't involve property purchase, are also expected to be on a willing landowner basis. There are three types of landowners that should be identified and approached to improve availability of land and reduce land use conflicts (Wren et al., 2022).

1. Landowners in the mid-upper catchment areas are already using small-scale solutions to reduce localised flood risk and improve water quality. With support, they may be willing to expand existing measures on their properties, and help with longer-term maintenance.
2. Other landowners may not currently have NBS but be cooperative and willing to implement NBS on their properties, with support.
3. Other landowners may be willing to sell land or partner with Greater Wellington to give Council the first purchase rights of land in the future. Council could establish this process in high-priority areas to support long-term strategic land acquisition, supported by a strategic land purchase fund.

Therefore, it is important to identify and approach these landowners to suggest a direction of what NBS seems most appropriate, based on the strategic planning that would be undertaken. It is important to understand what work is already underway on their properties.

13.4.1.2 Targeting nature-based solutions aligned with community values

Another low-hanging fruit is targeting NBS that deliver the wider benefits that are highly valued by the community as well as reducing flood risk to Masterton (Bridges et al., 2021). These NBS will most quickly be accepted and get buy-in from community stakeholders. Using the initial results from the wider benefits workshop, land retirement and afforestation was the preferred NBS by community stakeholders as well as the benefits it could deliver including habitat creation, climate regulation, and water quality. Existing datasets can help focus on delivering particular wider benefits; for example, maps of high slope and connectivity areas to reduce sediment supply (Stage 2 Geomorphology report), and areas of historic/pre-historic vegetation, and high permeability soils (indigenous vegetation report).

13.4.1.3 Working with what's already there

The technical investigations and wider benefits workshop emphasised the value of building on existing or historical forest and wetland areas. It is recommended to adopt an Assisted Natural Regeneration approach (Assisted Natural Regeneration Alliance, n.d.), which combines active planting and passive restoration, and prioritise existing or former forest and wetland areas. These areas already support ecosystem functions and reduce fragmentation by creating ecological corridors. Established vegetation shelters and accelerates regenerating vegetation, lowers maintenance needs, and reduces implementation and maintenance costs.

The indigenous vegetation investigation presented maps with extents of wetlands and native vegetation pre-human settlement and in the present day. It is recommended to assess the potential to extend the native vegetation and habitat corridors in these areas, to prioritise natural ecosystem restoration.

Additionally, the fault system in the Waipoua catchment has increased groundwater levels upstream of the Masterton and Mokonui faults, due to thinning of the upper aquifer unit. Where these areas coincide with permeable soils, the antecedent conditions may be suitable for implementing small-scale, distributed retention storage that focuses on infiltration and groundwater recharge.

13.4.2 Integration with existing plans and projects (4)

To deliver NBS effectively, it is key to integrate with other existing plans and projects (4). It is recommended that a stocktake of what's already happening in the catchment area or planned is undertaken, including projects that are driven by regional council, district council, individuals (property-based), catchment groups and community, such as the upper catchment Kaitiaki Group. This stocktake will provide an overall understanding of what is happening or planned in the catchment and the purpose (the why), so implementation on various scales can be aligned.

13.4.3 Integrating data and information from the technical studies (10)

As previously mentioned, the technical investigations have provided data, information, and maps that could be utilised to inform the planning for implementing NBS.

- The Stage 2 Geomorphology assessment (Appendix B) includes maps showing locations for each selected NBS, based on maximising geomorphic effectiveness.
- The hydrogeological investigation (Appendix F) recommends the NBS that show the most promise to improve groundwater recharge in the Waipoua catchment, with broad discussion of suggested locations.
- The indigenous vegetation investigation (Appendix G) provides plant typologies for different ecosystem types, which are based on soil type and context conditions such as historic and present-day land use and vegetation cover. Maps of past land-uses and forest/wetland cover are also included. Planting methods, such as succession planting or whānau cluster planting, are also suggested and should be considered in the implementation approach.

13.4.4 Other recommendations for implementation

The following are specific recommendations to reduce the risks identified in Section 12.0.

13.4.4.1 Timeframes to match delayed benefits

A hybrid approach of complementary NBS, as noted above, is one way of addressing the issue of some NBS taking decades to realise their benefit. Another approach would be to use the flood reduction benefits of NBS to partially offset the expected impacts of climate change, which is also a longer-term, ongoing, uncertain process.

13.4.4.2 Supporting resource consenting

Consent processes can be a key constraint to implementing NBS, especially if the consenting cost or difficulty is seen as disproportionate to the project scale. Greater Wellington may wish to investigate what support can be given to NBS in regional consenting/ planning processes. Alternately, NBS can be targeted at a scale which meets permitted activity standards or otherwise gives an easier consenting pathway (for example, the size of earthworks to be undertaken).

13.4.4.3 Evaluate performance holistically

The performance of NBS should be assessed across multiple dimensions, such as reducing flood risk and providing wider benefits, to reduce the risk of performance uncertainty (Bridges et al., 2021; United Nations Environment Assembly, 2022). It is recommended to monitor performance in the project's early stages or in a pilot study to evaluate effectiveness and help gaining community/ stakeholder confidence. Monitoring should be designed with a long-term perspective to support ongoing assessment and adaptive management. Long-term maintenance programmes are also essential to optimise system performance.

13.4.4.4 Funding

Catchment-scale implementation of NBS is a long term, relatively expensive commitment compared to structural responses (e.g., stopbanks). Therefore, to improve economic viability, multiple funding streams should be utilised including those set aside for flooding and the wider benefits, such as riparian planting, water quality and biodiversity outcomes.

Funding could be sought through all stages of implementation including planning, retirement of existing land/ buying land/ consenting, establishment, and maintenance.

13.4.4.5 Uncertainty and liability

The performance of NBS, particularly those that are dependent on geomorphic responses, may be less certain than traditional structural approaches. This risk can be mitigated by further researching the expected performance and considering a range of possible assumptions/ trajectories to give a realistic expectation of the performance envelope (similar to the sensitivity scenario approach used to set stopbank freeboard by Greater Wellington). A hybrid approach of complementary NBS, as noted above, is recommended to spread/ dilute risk. Use of trial catchments aligned with the "low-hanging fruit" approach, combined with monitoring, will help support adaptive implementation.

As noted in Section 13.1, NBS may be most feasible when combined with structural measures. This helps reduce the risk of non-performance, and in fact is a recommendation in much of the literature on NBS (e.g., United Nations Environment Assembly, 2022). To reduce liability, it is important to clearly communicate realistic outcomes, and limitations of NBS.

13.5 Further investigations

From the work undertaken to understand the feasibility of NBS in the Waipoua catchment, further investigations have been identified to help inform implementation planning and further decision-making.

- Undertake two or three quantification (monetary) assessments for wider benefits using the InVest tool:
  - Sediment Delivery Ratio and Habitat Quality were identified by T+T as potentially the most promising due to being the least "data hungry", requiring less data preparation, and requiring less input from subject matter experts.
  - Habitat Quality, in particular, aligns with the benefits most valued by stakeholders at the wider benefits workshop.
- Further investigations on groundwater recharge and river baseflows (see Section 7.5) could be undertaken using a transient model, that is able to reflect seasonal or episodic conditions.
- Undertake further indigenous vegetation assessments:
  - Carry out detailed assessments to ground truth specific location typologies.
  - Collaborate with mana whenua to identify taonga species, previous locations of where they existed, and where the reside now, if they still exist in the catchment.
- Undertake further flood modelling, including:

  - A variety of storm spatial/ temporal patterns, to better understand NBS performance and reduce the risks of superimposing the flood peaks from upstream catchments.
  - Model the potential immediate, short-term, and medium-term implications of implementing channel realignment/ room for the river NBS, as well as the impacts of a range of possible future trajectories.
- Further research into the amount of water that can be absorbed/ infiltrated by native forest in comparison to farmland:
  - Include consideration of recent research done by Scion at nearby Titoki Forest, which is an exotic plantation but may have some results that inform the assessment.
  - Research into the difference that additional pest control could make on native forest's ability to absorb/ infiltrate water.
  - Early establishment of trial catchments may yield useful long-term results.

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Appendices

Appendix A. Assessed and not assessed nature-based solutions

Table A.1: Selected nature-based solutions

Nature-based solutions	Erosion reduction/ promote sediment retention	Flood reduction potential	Groundwater recharge and baseflow	Wider benefits
Land retirement and native afforestation	- Established woody forests contribute to soil conservation via their extensive root systems, providing structural integrity to soil and reducing susceptibility to erosion. - Dense and extensive woody root systems physically bind soil and minimize the potential for mass movement. - Forest canopy interception and well developed humic (leaf litter) layer reduces rainfall impact and surface runoff. This reduces the frequency and magnitude of sediment-generating erosional processes. - Woody debris (arising from adjacent forests) is an important component in moderating sediment transport through fluvial systems, particularly in smaller, steeper headwater streams. - Depending on changes in discharge (see "Flood reduction potential" column) there may be a reduction in stream power. This could reduce bank erosion effects, and change when different sediments are entrained and transported through the fluvial system, effectively moderating sediment transport processes. - Moderating sediment generation and transport may reduce event-based aggradation in the mid-catchment areas.	- Root systems of woody forest vegetation facilitate water infiltration into the soil, decreasing surface run-off during rain events, but potentially slightly elevating baseflow levels in other times. - Forest canopy influences the hydrological cycle by intercepting rainfall, reducing and/ or delaying precipitation reaching the ground, reducing flood peaks, and/ or delaying flood peak convergence in the larger rivers. - Native plants from the eco-district are likely to be better adapted to local rainfall patterns and soil types, potentially increasing the likelihood of successful outcomes for flood risk reduction. - If sediment transport processes are moderated, this may create more long term flood storage in the catchment's mid sections rather than funnelling flows through to Masterton.	- Native vegetation increases soil organic matter, which may increase soil porosity and permeability, facilitating water storage and infiltration into the groundwater system. - Tree roots and organic matter prevent compaction of soil, maintaining its ability to absorb and store water effectively. - Forests help maintain a balance between groundwater recharge and discharge, stabilizing baseflows in nearby streams and rivers. - Deep root systems of native trees and shrubs enhance the soil's ability to store water, providing a slow and steady recharge to groundwater. Tree roots can create pathways in the soil (macropores) that increase water movement and infiltration into deeper soil layers and aquifers. - Forests may reduce the intensity of higher frequency/ lower magnitude flood peaks by absorbing water and releasing it slowly, which can enable more gradual recharge to aquifers rather than contributing to runoff i.e. when the infiltration overwhelms the system. - Forest cover shades the ground, reducing direct solar heating and evaporation, which conserves moisture in the soil.	- Biodiversity within native forests, including various organisms from microorganisms to larger fauna. - Improved soil health and structure by cycling nutrients and organic matter. - Improved quality of aquatic habitat as the quantity of fine grained sediments entering the streams is likely reduced. - Stream shading has the potential to reduce water temperature which will improve water quality and aquatic ecology. Certain lengths of the river corridor will need to be planted to effectively reduce temperatures. - Potential recreation spaces and native species conservation.
Floodplain re-engagement	- Reduced flood velocities will encourage fine grained deposition within the floodplain, reducing overall sediment yield to Masterton. - Space to allow the natural recovery of natural form and function. - Decreases hillslope connectivity in non-stop banked areas and increases floodplain/ channel connectivity. - Reduces volume of fine grained sediments in the stream. - Two-stage channels in particular have the potential to reduce suspended sediment loads by 15-80%.	- Reduces flood peaks by dispersing water across a higher area and increasing floodplain storage. - Reduces stream power by containing water in a wider cross sectional area and increasing channel roughness. - Allows more infiltration as slower velocities and a greater wetted area encourage infiltration.	- An increased flood area can increase infiltration and therefore recharge. Greater recharge over a wider area can contribute to greater baseflow stability. - Reconnecting rivers to a wider floodplain enables water to spread and infiltrate into the soil more effectively. Increased infiltration from floodwaters supports aquifers, which may help sustain baseflows over longer periods. - Areas can be targeted with higher permeability (e.g., faults/ fractures) or low water table.	- Increases biodiversity by providing access to riverine species such as birds and fish. Also, provides opportunity for plant species which tolerate wet environments. - Reduces risk to infrastructure by allowing flow to spread across greater areas, reducing the velocity, and possibly the opportunity to avoid concentrating flow around infrastructure such as bridges. - Cultural amenity by increasing connectedness with nature, and contributing to climate change adaptation. - Improves aquatic habitat by reducing fine grained sediments.
Small-scale, distributed retention storage	- Retention storage traps and stores fine-grained sediments, preventing them from being delivered to the main stream from smaller tributaries. - Slowing fine grained sediment transport, which mimics natural functions of woody debris and other roughness elements.	- Small retention storage devices, including ponds, wetlands, and bio-swales capture and store rainwater or runoff, thereby reducing the volume of water that rapidly enters the larger water system during storms (detention). - Detention storage systems typically release water slowly over longer periods, smoothing out peak flow in water bodies that usually leads to floods. - Many small storage devices enhance the ground's water absorption ability. For instance, rain gardens or bio-swales use vegetation and soil or other porous materials to facilitate water absorption and reduce surface runoff (retention). - Can slow tributary inputs into the main stream which helps to reduce the flood peak.	- Increased aquifer storage and enhanced baseflow via 'sponge effect' (temporary surface storage). - Increased time for infiltration leading to increased baseflow and recharge. - Small local effect for each site may add up to catchment-scale benefits across many sites.	- Re-establishment of wetland habitats which can increase biodiversity. - Potential to create recreational areas and native species conservation. - Reducing fine grained sediments helps improve aquatic habitats.
Channel realignment/ room for the river	- Recovery of natural form and function of the river, allowing sediments to spread out and settle across the floodplain. - Increasing sinuosity can help 'slow the flow', by increasing channel length and reversing historic shortening. This can help increase sediment deposition in the form of mid channel and point bars. - Restores natural form and function of the river to allow for more naturalised erosion patterns to occur. This increases geomorphic diversity which can help moderate sediment transport processes. - Restoring semi-braided and wandering gravel bed river forms can create additional backwater areas, which can help trap fine grained sediments and provide flood storage.	- Reduces flood peak by encouraging flood dispersal across a wider river corridor. - Slows the flow by increasing sinuosity, channel roughness, and changing slope. - Encourages infiltration by spreading flows across a wider area and creates a more diverse geomorphic environment with back channels and pools. - Creating more storage in the mid sections of the catchment.	- Increased connectivity between surface and groundwater due to greater area coverage and reduced velocities. - Altering channel morphology could change flow paths and water residence times, influencing the opportunity for infiltration and recharge.	- Re establishment of wetland habitats in oxbow and flood channel environments. - Cultural benefits such as increasing connectedness with nature, and creating potential areas for recreational activities. - Increases biodiversity by encouraging terrestrial habitat and aquatic habitats, such as pools, riffles and undercutting.

Table A.2: Nature-based solutions excluded from further assessment

Nature-based solutions	Erosion reduction/ promote sediment retention	Flood reduction potential	Groundwater recharge and baseflow	Wider benefits	Reasons to exclude from a geomorphic perspective	Reasons to exclude from a groundwater recharge/ baseflow perspective
Riparian planting	- Prevents bank erosion and incision by increasing roughness, and limits sediment entering the stream from adjacent hillslopes by acting as a buffer. - It can reduce bank erosion by deterring stock trampling in banks and wading in channels.	- Help slow flows entering the stream through increasing land cover roughness. - Impact (reduction in flood peaks) is likely to be limited, as will not significantly reduce runoff or increase storage. - Likely local impacts on flood reduction, such as debris straining, deflecting flows/ keeping more water in-channel. This may provide local benefits but are not expected to significantly impact the downstream hydrograph. - Scale of planting is unlikely to provide significant hydrological benefits, such as reduction in runoff.	- Riparian planting can increase recharge due to improved filtration. - Baseflows may also increase from stored water in riparian organic material.	- Improve aquatic and terrestrial habitats through contributing large woody debris and providing shade for aquatic fauna. It promotes bird life and restores biodiversity in stream environments. - Improved water quality by filtering out contaminants and sediment entering the river, stabilising/reducing water temperatures, and reducing erosion.	- Riparian buffers can impede flows from shallow surface flow immediately adjacent to the stream, but are not considered to provide flood reduction benefits in Masterton. - Riparian buffers may be able to benefit certain erosion hotspots, but it has been assessed that lateral erosion that could be addressed by native planting is not a major geomorphic or flooding driver in this catchment.	- The primary benefits are focussed on water quality, and have minimal impacts on recharge on baseflow. Riparian buffers are typically limited to immediate river surrounds.
Bed gradient structures	- Help stabilise bed and banks. - The Waipoua River is currently in a sediment deficit, and bed gradient structures can help trap gravel.	- No significant impact on reducing flood flows, as bed gradient structures are more of a tool to manage degradation and resulting lateral erosion.	- Where gradient structures increase upstream water levels there is the potential for increased recharge in the upstream pools (similar to increased recharge that may occur during flood events).	- Can potentially provide aquatic habitats, protection to upstream infrastructure.	- Bed gradient structures are not effective at reducing flood flows or preventing fine sediment transport (catchment is dominated by fine grained sediment). - Structures are unlikely to survive high river power environments in main stream without major maintenance.	- The residence time of water may increase in each of the pooled reaches, potentially resulting in additional considerations to control water temperature.
Gravel management	- Can help regulate/ maintain sediment transport and supply.	- No significant impact on reducing flood flows, as the reach upstream of and through Masterton is currently experiencing degradation and is unlikely to revert to an aggradation trend through gravel management changes alone.	- Extraction could provide a benefit through a potential increase of measurable baseflow as river is deepened. - Allowing aggradation to occur could have the opposite effect.	- Limits disturbance in the river corridor if gravel extraction is reduced or ceased.	- Gravel management (extraction) can increase flood capacity and alleviate flooding. Flood capacity can be reduced when an over supply of sediment results in aggradation. The Waipoua River is currently in a sediment deficit so this has been excluded. - Additionally, changes in gravel management (especially relocating gravel or increasing extraction) are unlikely to be seen as NBS. - Allowing targeted aggradation is included in the selected NBS under floodplain re-engagement.	- Deepening the channel likely increases groundwater discharge to river, with little/ no change in groundwater recharge via rainfall. Reduced potential recharge from the lowered river bed.
Urban NBS options	- Can help slow and reduce sediment entering the stream through promoting sediment to settle in water sensitive urban design devices (such as rain gardens). - Slower flows have less capacity to transport sediment.	- Helps slow and reduce flows entering the stream by increasing infiltration, detention and retention of stormwater flows.	- Small scale implementations (e.g., infiltration trenches, swales) can be an effective means for increasing recharge that would otherwise diverted to runoff from impervious surfaces.	- Can improve biodiversity by providing habitat within urban areas.	- For the Waipoua, urban NBS options are typically located at the bottom of the catchment. NBS in the Waipoua catchment is likely to be the most effective in the mid-upper catchments where flood peaks can be reduced.	- The majority of the catchment is in a rural area and the urban area is a relatively small part at the downstream end of the area of interest.
Changes to land management practice	- Conservation tillage aims to build increased soil depth and quality, partly through avoiding loss of soil. - Potential reductions in fine sediment runoff, with risks of increases following working of soil. - Potential reductions in fine sediment runoff, with risks of increases following harvesting of agroforestry or some crops.	- Possible flood reduction due to greater infiltration and water holding capacity of soils, or small-scale on-contour storage.	- Change in farm management practices including ploughing/ tilling along the contours rather than up and down contours. - Change in farm management practices including reducing the use/ rate of flow of subsoil drains and surface drains to increase potential for aquifer recharge.	- Possibility of economic benefits from increased/ more sustainable crop production being realised.	- Limited evidence of these methods having an ability to significantly lower flood peaks, benefits, and suitable approaches to modelling them.	- There is a lack of evidence at a catchment scale to support an assessment of these methods. - Agroforestry may negatively impact recharge and baseflow, as well as flood peaks being higher post-harvesting.

Appendix B. Stage 2 geomorphology assessment

REPORT

Waipoua Geomorphic Assessment

Stage 2 - Nature Based Solutions

Prepared for

Greater Wellington Regional Council

Prepared by

Tonkin & Taylor Ltd

Date

July 2025

Job Number

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Executive summary

Greater Wellington Region Council (GW) are exploring Nature Based Solutions (NBS) for Flood Risk Management to Masterton in the Wairarapa. Through a two-stage project, Tonkin & Taylor Limited (T+T) assessed the river character and behaviour and geomorphic sensitivity of the Waipoua River to help identify the geomorphic drivers of flood risk in the catchment to inform geomorphically appropriate NBS options.

As geomorphic processes are longitudinally connected, there is often a difference between localised flood risk within a reach, and flood risk to Masterton which is at the downstream end of the catchment. Subsequently, there is, at times, a conflict between effects on river form and function and effects on localised flood risk. Because of this, the co-benefits of NBS options (i.e. additional benefits that do not relate to flood risk) were also considered alongside the flood risk benefits to match the intent of 'Nature Based'.

Four NBS options were prioritised for the Waipoua catchment, based on their 'geomorphic effectiveness' which relied upon the river character and behaviour, geomorphic sensitivity, and the expected geomorphic response to the NBS options.

Two of the NBS options were focussed on the Wakamoekau and Mikimiki Catchments and included retirement of hillslopes and conversion to permanent forest, and small-scale distributed retention including leaky bunds and naturalisation of straightened drains. These options are expected to primarily manage sediment processes that contribute to flood risk in Masterton. However, they have a very high number of co-benefits that can improve ecological, amenity, and Mātauranga objectives.

The last two NBS options focussed on three reaches in the main-stem of the Waipoua River. These included the passive restoration of channel form and function to a previous channel state, and floodplain lowering / flood channel reengagement. These options present the greatest opportunity for geomorphic effectiveness of flood risk reduction to Masterton, primarily through managing sediment processes (sediment load and stream power) and run-off (discharge) through flood spread and 'slowing the flow'. Several co-benefits were also identified for these options, with an increase in the number of co-benefits if riparian or floodplain planting was included.

1 Introduction

Greater Wellington Region Council (GW) are exploring Nature Based Solutions (NBS) for Flood Risk Management to Masterton in the Wairarapa. As part of the Flood Risk Management project, a two-stage geomorphic assessment process has been undertaken to better understand how river character and behaviour has changed through time, and to identify possible geomorphic drivers of flood risk in the Waipoua Catchment. This report forms Stage 2 of the Waipoua Geomorphic Assessment which assesses the ‘effectiveness’ of NBS options in the Waipoua Catchment.

1.1 Stage 1 background

As part of GW’s NBS for Flood Risk Management project, Tonkin & Taylor Limited (T+T) prepared the Stage 1 Waipoua Geomorphic Assessment. A modified River Styles assessment was carried out in conjunction with a review of a previous report[1] to determine river character and behaviour, which in turn informed geomorphic sensitivity of each reach type to changing catchment conditions or disturbance events (e.g. changes in catchment drivers, gravel extraction, floods, earthquakes) (Table 1.1, Figure 1.1).

The Stage 1 assessment found that in general, high magnitude/low frequency events (such as floods and tectonic activity) caused rapid shifts in river character, with lower magnitude/higher frequency events (such as smaller flooding) responsible for long-term river recovery and geomorphic maintenance.

Through consultation with the community-led Waipoua Project Team during Stage 1, the primary outcomes expected from the NBS was to reduce flood risk to Masterton, as well as increasing aquifer recharge across the catchment. The Stage 1 high-level analyses of geomorphic sensitivity were therefore used to identify the main geomorphic trends and processes that may contribute to flood risk and aquifer recharge in the Waipoua Catchment, and a high-level toolbox of NBS options was developed, linked to each of the five stream types. Many of the options suggested to incorporate the concept of making ‘room for the river’.

At the completion of Stage 1, Mana Whenua (Ngāti Kahungunu ki Wairarapa and Rangitāne o Wairarapa) identified a desire to weave mātauranga Māori into the NBS tool-box options, to achieve improvements in the mauri of the awa in the catchment. In particular, Mana Whenua saw restoration of channel form as a priority.

[1] T+T (2024). Waipoua River Geomorphic Assessment: Stage 1. Report prepared for Greater Wellington Regional Council.

Table 1.1: Summary of the Stage 1 geomorphic assessment

Stream type	Drivers of change	Potential envelope of river responses	Overall sensitivity
Confined, low sinuosity, cobble/boulder bed	Hillslope vegetation and high magnitude / low frequency co-seismic and rainfall (flood) events.	Reach based responses e.g. changes to geomorphic units, some bank scour, beds armoured by large sediment, not likely to result in a shift in stream type given confinement.	Low
Partly confined moderate/high sinuosity gravel bed	High magnitude / low frequency co-seismic and rainfall (flood) events. Available sediment generated in upper reaches and rates and volumes of gravel extraction.	Further meander migration where margin allows. Reactivation of paleo channels is low due to margin constraints. High magnitude, low frequency episodic events likely to generate pulses of sediment may result in a switch towards a wandering/braided stream type.	Low/medium
Partly confined, low sinuosity gravel bed	High magnitude / low frequency co-seismic and rainfall (flood) events. Channel modification, gravel extraction.	Potential to reactivate paleo channels and cause a change in stream type during a high magnitude flood event. Given this stream type also crosses two faults, significant fault movement could result in a shift in river behaviour through a change in gradient, avulsion, or sediment pulse generated from the catchment.	Medium/high
Unconfined, artificially straightened gravel bed	High magnitude / low frequency co-seismic and rainfall (flood) events. Channel modifications.	The channel is heavily modified, therefore would require some form of intervention to establish a new channel alignment. A change may occur (e.g. avulsion) as a result of a high magnitude rainfall event or significant co-seismic sediment pulse.	Low/ medium
Artificially confined low-sinuosity gravel bed.	High magnitude / low frequency co-seismic and rainfall (flood) events. Artificial confinement, channel modification, gravel extraction,	Mean bed level changes often associated with flood events, depending on sediment pulse, the bed may aggrade or incise. If flood flows were to breach stopbanks, paleo channels may be reactivated with variable and as yet uncertain consequences.	Low/medium

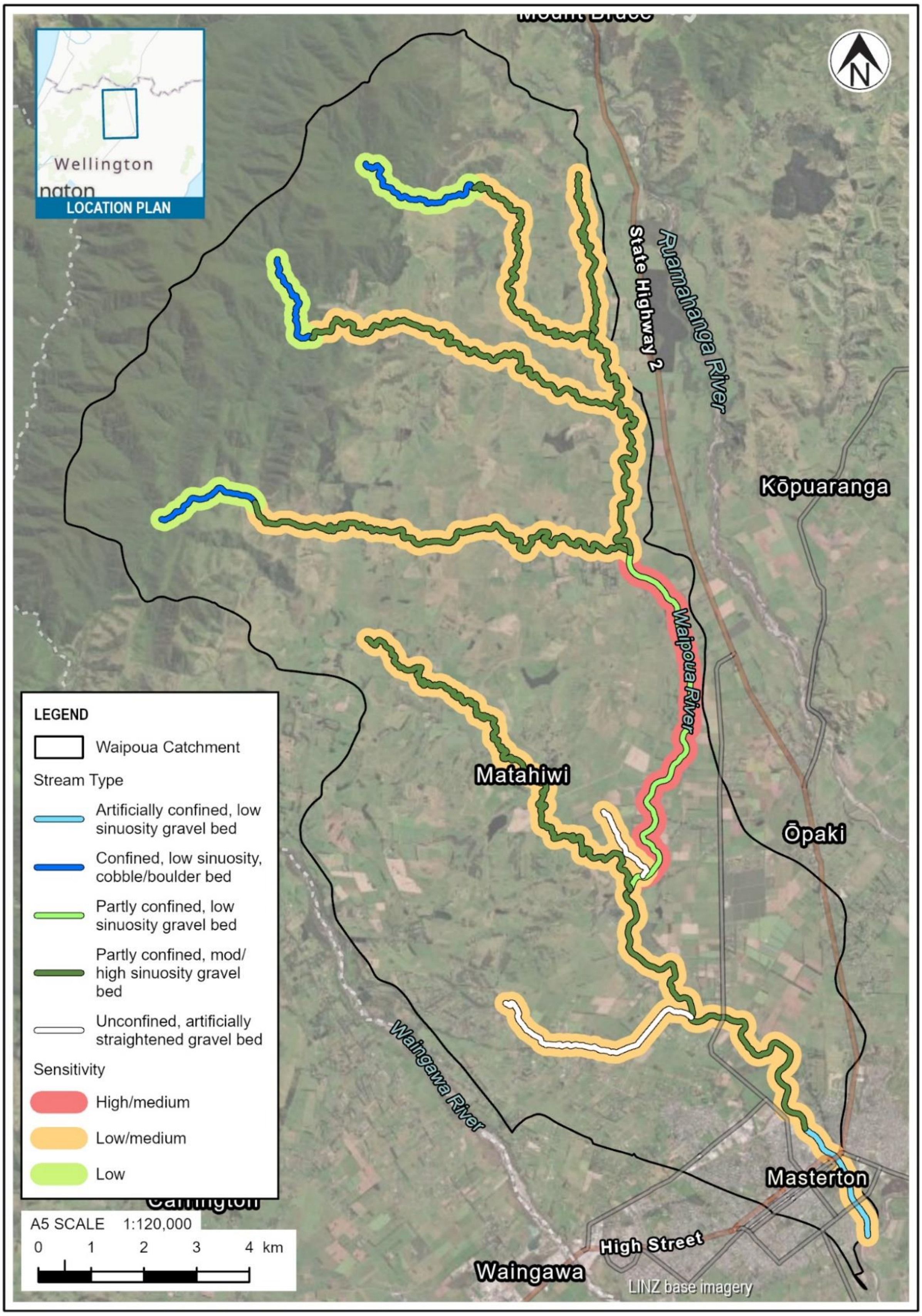

Figure 1.1: Stream types and geomorphic sensitivity as defined in Stage 1 of the Waipoua Geomorphic Assessment.

1.2 Stage 1 - NBS options summary

The Stage 1 report identified that there is often no "silver bullet" solution to a flooding problem and a range of NBS options is usually needed, and that it is important to fully understand the sources, pathways, and drivers of flood risk to select the right measures to address the flood risk problems at their source[2].

Based on the Stage 1 assessment, four primary geomorphic drivers of changes in flood risk to Masterton were identified (Table 1.2).

As geomorphic processes are longitudinally connected, there is often a difference between localised flood risk within a reach, and flood risk to Masterton, which is at the downstream end of the catchment. For example, increasing sediment storage in the upstream reaches of the catchment, may increase flood risk in those locations, but with less sediment passing into the downstream reaches, channel capacity may temporarily increase as a result, thereby reducing flood risk in those downstream reaches. In addition, the resulting upstream reach channel form with increased planform diversity and roughness would also likely 'slow the flow' and may contribute to flood peak reduction in downstream reaches.

Subsequently, there is, at times, a conflict between effects on river form and function and effects on localised flood risk. For example, where channel incision results in an adverse change in river character and behaviour (loss of river form and function), it may have a beneficial effect on localised flood risk (greater channel capacity to contain flood flows). Because of this, the co-benefits of NBS options (i.e. additional benefits that don't relate to flood risk) should also be considered alongside the flood risk benefits to match the intent of 'Nature Based'.

By characterising the reach scale geomorphic character and behaviour, and geomorphic sensitivity to change, a long list of eleven NBS options[3] were identified that could manage geomorphic processes contributing to flood risk in Masterton.

The long list options included:

1 Revegetation of hillslopes.
2 Riparian planting.
3 Retirement of hillslopes (low-value farmland).
4 Floodplain engagement/offline storage.
5 Wetland creation.
6 Channel realignment/reconnection of oxbows/increasing channel sinuosity.
7 Two-stage channels/floodplain lowering.
8 Rock riffles (grade control).
9 Gravel management.
10 Relocation of stopbanks.
11 Improving aquifer recharge.

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[2] Bridges, T. S., J. K. King, J. D. Simm, M. W. Beck, G. Collins, Q. Lodder, and R. K. Mohan, eds. 2021. International Guidelines on Natural and Nature-Based Features for Flood Risk Management. Vicksburg, MS: U.S. Army Engineer Research and Development Centre.
[3] Refer to Chapter 18 of the USACE NNBF guidelines for detailed descriptions of the options.

Table 1.2: Geomorphic drivers of flood risk to Masterton

Geomorphic drivers of flood risk	Positive effect on flood risk to Masterton	Negative effect on flood risk to Masterton
Sediment supply	Decrease in sediment supply as a result of reforestation and channel naturalisation results in a slower rates of sediment delivery and transport through the network limiting the risk of aggradation from enhanced sediment supply and conveyance.	Increase in sediment supply as a result of land-use change and / or co-seismic or storm induced landsliding results in channel aggradation and loss of channel capacity to contain flood flows Localised decrease in sediment supply as a result of gravel extraction potentially increases bed and bank erosion4, which may contribute to channel aggradation farther downstream and loss of channel capacity to contain flood flows.
Wood loading	Increase in wood loading (particularly in headwater streams) increases sediment storage and moderates sediment transport to downstream reaches, limiting the risk of aggradation from enhanced sediment conveyance.	Decrease in wood loading (particularly in headwater streams) facilitates rapid sediment transport to downstream reaches, increasing the risk of aggradation from enhanced sediment conveyance.
Land use	Increase in diverse woody vegetation on the hillslopes reduces magnitude and frequency of run-off, and moderates sediment supply to river network by reducing slope erosion risk and moderating slope-channel coupling (connectivity).	Decrease in diverse woody vegetation on the hillslopes increases magnitude and frequency of run-off, and increases sediment supply to river network by increasing slope erosion risk and slope-channel coupling (connectivity).
Stream power*	Decrease in stream power by attenuating discharge reduces transport of sediment through the river network, and may promote sediment storage in reaches upstream of Masterton.	Increase in stream power from rapid catchment runoff enables effective transport of sediment through the river network, and may promote a downstream progressing erosion and incision 'wave' in upstream reaches increasing the risk of aggradation near Masterton in the short to medium term.

Note: Stream power is the ability of a river to perform geomorphic work and is a measure of the main driving forces acting within the channel, i.e. the joint effect of channel gradient and discharge. Stream power is commonly used to assess sediment transport and geomorphic patterns, as total and specific stream power decreases, the potential for sediment transport is reduced and sediment is more likely to be stored (deposited) within the Waipoua system.

1.3 Stage 2 - Purpose

The Stage 2 Waipoua Geomorphic Assessment (this report) leads on from the Stage 1 assessment. The purpose of the Stage 2 assessment is to rate the 'effectiveness' of the NBS options at reducing flood risk to Masterton, with the most effective options mapped to specific areas within the Waipoua Catchment, where they are most likely to have the greatest impact.

In addition, to help better understand how the NBS options could improve the mauri of the awa, the potential co-benefits of the options were identified at a high level. The high level co-benefits fed into

[4] Previous estimates that bank erosion may contribute up to 50% of the Waipoua 'gravel budget' in some reaches. Christensen. (2013). Te Kāuru Upper Ruamāhanga Floodplain Management Plan (Phase 1 Geomorphology). Greater Wellington Regional Council.

the '*Wider Benefits of Nature Based Solutions – Waipoua Catchment'* report[5], which further quantified and ranked the wider co-benefits of the NBS options in more detail.

2 NBS Effectiveness

A key outcome of the Stage 2 Geomorphic Assessment was to identify the 'effectiveness' of the eleven NBS options in reducing flood risk to Masterton. For the purposes of the Stage 2 Geomorphic Assessment, the effectiveness of the options was based on 'geomorphic effectiveness' which relied upon the river character and behaviour of the five stream types identified, their geomorphic sensitivity, and the expected geomorphic response to the NBS options.

This approach provides an understanding of the geomorphic drivers of flood risk in the Waipoua Catchment across a range of spatial and temporal scales (as opposed to just focusing on flood risk itself). Therefore, the NBS effectiveness outlined in this report has contributed to the overall NBS option prioritisation outlined in the '*Feasibility study of nature-based solutions for addressing the flood risk to Masterton'*[6].

To determine the magnitude of geomorphic effectiveness of the NBS options, a modified version of Table 3 and Table 4 of the Draft FMP Guideline Module 16: Geomorphology[7] was used (Table 2.1).

Table 2.1: Definitions of reach sensitivity and geomorphic effectiveness

Rating value	Extreme	High	Moderate	Low
Reach sensitivity rating	High sensitivity to change, and has historically demonstrated large scale change in channel form and function.	High sensitivity to change, with localised or minor change to channel form and function demonstrated.	Moderate sensitivity to change, with localised or minor change to channel form and function likely.	Low sensitivity to change, and no or very minor change to channel form likely.
Geomorphic effectiveness	NBS option likely to cause a rapid and /or permanent change in in channel form and function.	NBS option likely to have a major influence on channel form and function, and is likely to occur gradually overtime.	NBS option likely to have a minor influence on channel form and function, and is likely to occur gradually overtime.	NBS option to have little/no influence on channel form and function.

Of the eleven NBS options identified in the Stage 1 assessment, gravel management and grade control structures (e.g. rock riffles) were excluded from the assessment as they were not considered to meet the intent of 'Nature Based Solutions' for the purpose of this report. The remaining nine options were considered have considerable cross-over, and were grouped into the following seven categories:

1 Retirement of hillslopes / permanent revegetation of hillslopes.
2 Small scale distributed retention (off-line storage).
3 Channel realignment / reconnection of oxbows / room for the river.

[5] T+T (2025) Wider Benefits of Nature Based Solutions – Waipoua Catchment.
[6] T+T (2025) Feasibility study of nature-based solutions for addressing the flood risk to Masterton.
[7] Guidelines for Floodplain Management Planning Module 16: Geomorphology was issued as a draft to GWRC in June 2023. Module 16 was intended to assess the risk of geomorphic processes to infrastructure and assets using a combination of reach sensitivity, geomorphic hazard exposure rating and geomorphic vulnerability.

4 Floodplain lowering / engagement.
5 Improving aquifer recharge.
6 Riparian planting.
7 Wetland creation.

As the five stream types identified in the Stage 1 assessment had different geomorphic sensitivity, the geomorphic effectiveness of the options differed spatially within the Waipoua Catchment. The options with a high geomorphic effectiveness in at least one of the five stream types were progressed for further consideration (Table 2.2; Appendix A).

Riparian planting, wetland creation and aquifer recharge were not found to have high geomorphic effectiveness. The four NBS options progressed in this report (and in the *Feasibility study of nature-based solutions for addressing the flood risk to Masterton'*[8] report) do provide opportunities for these to occur/or may enhance the effectiveness of the options, and are considered in the co-benefits assessment (discussed in Section 3).

Table 2.2: Geomorphic effectiveness of the four short listed NBS options per stream type

Stream type	NBS option			
	Retirement / permanent revegetation of hillslopes	Small-scale distributed retention storage	Channel realignment / reconnection / room for the river	Floodplain re-engagement
Confined, low sinuosity cobble/boulder bed	Low	Low	Low	Low
Partly confined, moderate/high sinuosity gravel bed	Moderate	Low	High	Moderate
Partly confined, low sinuosity gravel bed	Moderate	High	Extreme	High
Unconfined, artificially straightened gravel bed	Low	Low	Low	Low
Artificially confined, low sinuosity gravel bed	High	Moderate	Moderate	Moderate

[8] T+T (2025) Feasibility study of nature-based solutions for addressing the flood risk to Masterton.

3 Shortlist NBS Options

Four high-level NBS options were identified as having a high geomorphic effectiveness in at least one of the five stream types (Table 2.2; Appendix A), and at a very high level the stream types indicate where in the catchment these options could be applied (Figure 1.1).

The specific scenarios considered for each option, and where they could apply, relied on reach-based river character and behaviour to enable the options to be geomorphically feasible and tied to the geomorphic drivers of flood risk to Masterton. The decision tree for option refinement is provided in Figure 3.1. The resulting option descriptions and locations are described in detail in the following sub-sections.

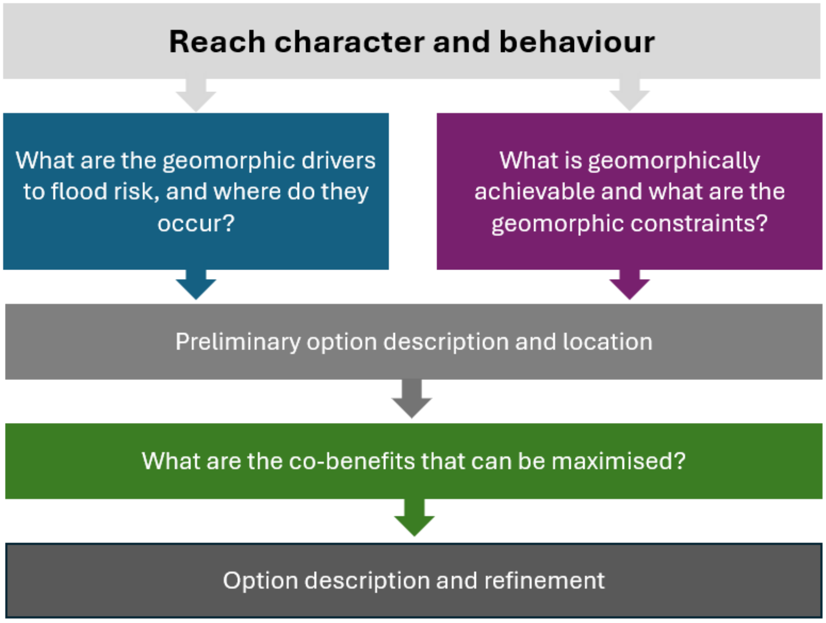

Figure 3.1: Decision tree for determining the components of each NBS option and refinement of the option details and locations.

3.1 Retirement of hillslopes/permanent revegetation of hillslopes

This option primarily assessed the geomorphic effect of conversion of steep hillslopes to permanent forest with a diverse canopy structure (i.e. indigenous forest). The high-level geomorphic effectiveness assessment identified that this option was likely to have the greatest geomorphic effect on sediment and wood load, with moderate geomorphic effect on run-off (discharge) and stream power (Appendix A).

To identify areas where this option was likely to have the most impact on managing flood risk to Masterton, the assessment focused on areas that:

- Were capable of generating large pulses of sediment (slope steepness greater than 25 degrees that weren't in diverse indigenous forest).
- Had pathways where sediment could be easily transported into the river network (moderate to high slope-to-river network sediment connectivity).
- Had a river network with sufficient energy to transport sediment to downstream reaches near Masterton (moderate to high stream power).

The primary areas for retirement of hillslopes and conversion to permanent forest with a diverse canopy are located in the Wakamoekau and Mikimiki Catchments (see Figure 3.2 below).

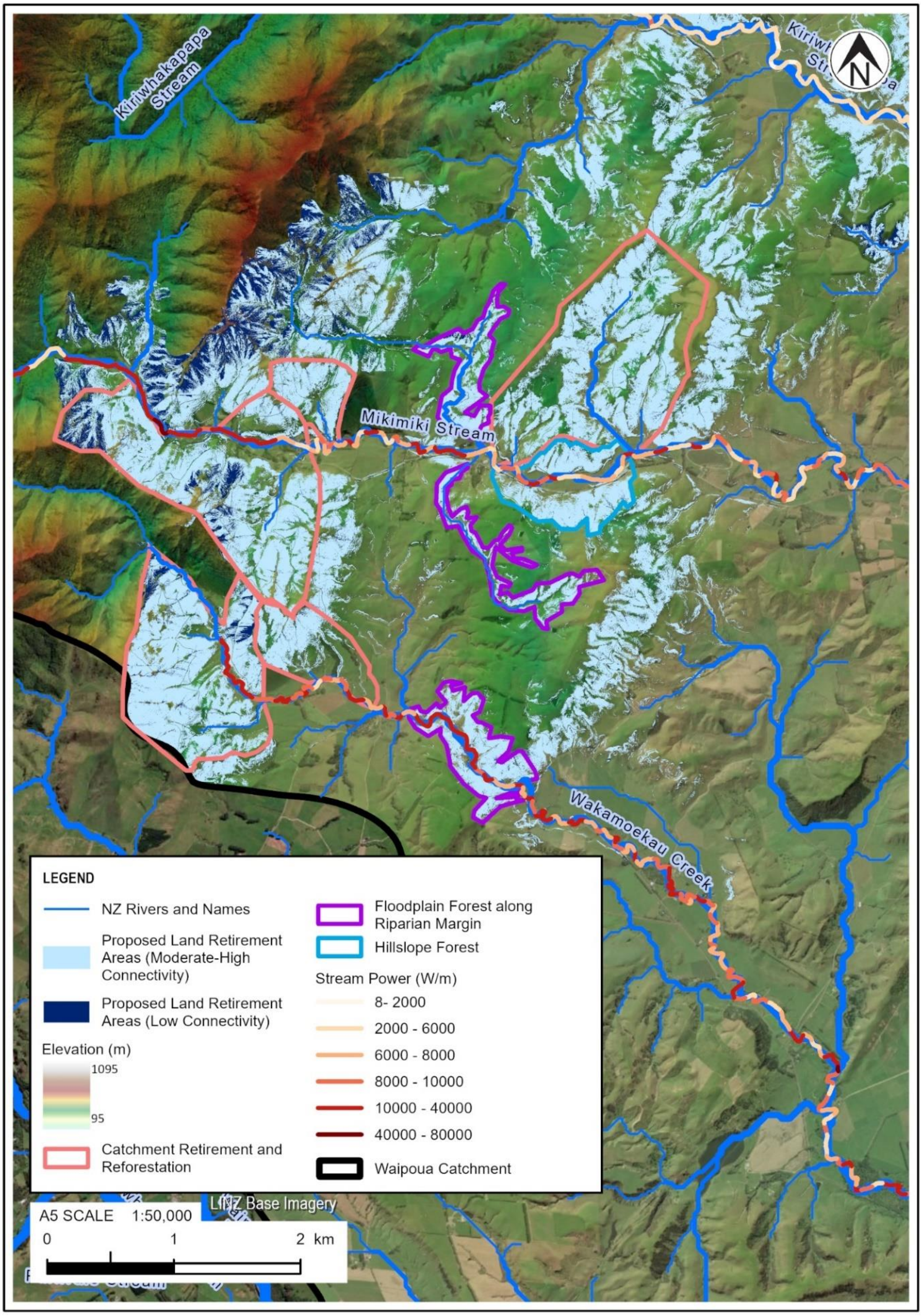

Figure 3.2: Proposed areas of farmland to retire and implement floodplain forest and reforestation.

3.1.1 Potential geomorphic effectiveness on flood risk reduction

The retirement of hillslopes and conversion to permanent forest in the Wakamoekau and Mikimiki Catchments is expected to slowly reduce the volume and frequency of sediment contributions from hillslopes to the river network as the forest matures. This process is likely to become effective within 10-20 years of plant establishment, and will continue to provide benefit as long as the forest is in place.

As the sediment sources diminish overtime, it is likely the existing sediments in the river network within these catchments will be slowly moved through the system, and passed out into the Ruamāhanga River. The timeframe for this process is linked to flood magnitude and frequency, but is likely to be in the order of 50 to 100 years. This process is not expected to change the existing flood risk to Masterton (as the sediments already in the system are part of the current sediment regime).

Once the forest is mature, large wood is expected to start entering the river network. As the streams are relatively narrow in the focus areas, this wood is expected to remain largely immobile in the channels, and will contribute to sediment trapping and storage. This process is expected to slow and moderate the on-going delivery of sediment into the downstream reaches near Masterton, creating a 'jerky conveyor belt'[9] of sediment delivery in contrast to the current rapid sediment transport regime.

Hydrological and hydraulic flood modelling scenarios to test the effectiveness of large scale retirement of hillslopes and conversion to permanent forest was undertaken as part of the '*Feasibility study of nature-based solutions for addressing the flood risk to Masterton'*[10].The Stage 2 Geomorphic Assessment focused on targeted areas that were tied to the geomorphic drivers of flood risk to Masterton. Because of the differing drivers, the scale of revegetation and conversion of hillslopes assessed in this Stage 2 report are much smaller than the scenarios tested in the flood models. As such, the hydrological and hydraulic results have not been used to inform the geomorphic effectiveness assessment presented here.

3.1.2 Co-benefits

While the primary focus of this option is on geomorphic effectiveness for flood risk reduction to Masterton, there are several additional co-benefits that can improve ecological, amenity, and Mātauranga objectives, including:

- Improved biodiversity values within forested areas including microorganisms to larger fauna.
- Restoration of river form and function, towards a 'pre-clearance' state.
- Improved quality of aquatic habitat through:
  - Complex habitat structure including diverse bed forms.
  - Increase organic material supporting sustainable aquatic food webs.
  - Reduction in the amount of fine-grained sediment (typically associated with lower habitat values).
  - Potential for increased shading and reduction of water temperatures.
  - Reduction in contaminants in groundwater and surface flows.
- Potential increase in baseflows, with less flow lost to evaporation and sustained near-surface groundwater contributions (due to improved soil conditions).
- Potential recreation spaces and native species conservation.

[9] Ferguson R.I. , 1981. Channel form and channel changes. In British Rivers , Lewin J (ed). Alley: London; 91–125
[10] T+T (2025) Feasibility study of nature-based solutions for addressing the flood risk to Masterton.

- Opportunities for the incorporation of Mātauranga Māori in the design and implementation of the planting plan.

3.2 Small scale distributed retention (off-line storage)

This option primarily focussed on managing run-off and sediment transport pathways in the sub-catchments of the Wakamoekau and Mikimiki Catchments which weren't already captured by the conversion of steep hillslopes to permanent forest option (Section 3.1), (see Figure 3.3 below) (Appendix A). The Wakamoekau and Mikimiki Catchments were chosen for the same reasons outlined in Section 3.1.

The small scale distributed retention option therefore had two scenarios:

- Leaky bunds in small headwater streams – This component looks to 'slow the flow' from steep but small contributing tributaries, and help trap and store sediments. The intent is that several wood based 'leaky bunds' are installed in sequence, and would require some form of riparian planting to reduce flow velocity, increase absorption and sediment deposition, and increase the resilience of the structures.
- Naturalisation of straightened lowland streams – This component looks to increase stream length / sinuosity to increase flood travel times, reduce velocities, and increase sediment trapping and storage. The option would include re-meandering of streams, two-stage channel form, and wood based cross-channel features to help slow the flow by increasing channel roughness, increase sediment trapping and restore a more natural stream function.

The high-level geomorphic effectiveness assessment showed these options would likely have the greatest impact on run-off (discharge) and associated stream power and a moderate impact on sediment load, and it would mainly change fine-grained sediment loads (as opposed to coarse bed load).

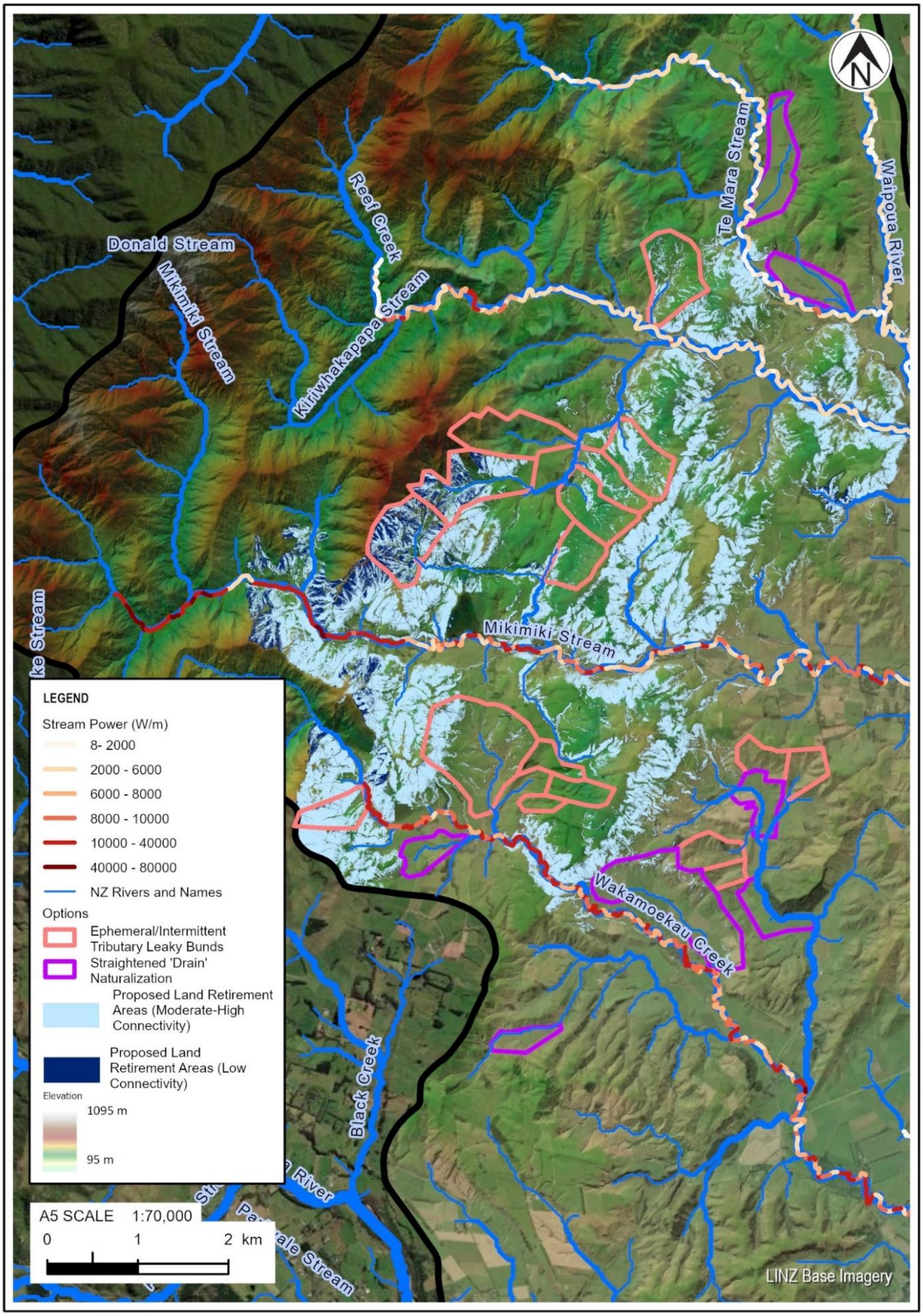

Figure 3.3: Potential areas to implement bunds and drain naturalisation.

3.2.1 Potential geomorphic effectiveness on flood risk reduction

The combination of leaky bunds and stream naturalisation in the Wakamoekau and Mikimiki Catchments is expected to have a reasonably rapid effect on run-off (discharge) and sediment transport and fine-grained sediment loads once implemented. Given the small scale and localised distribution of the option, its likely to have the greatest impact on flood risk in the Wakamoekau and Mikimiki Catchments, by reducing the frequency and magnitude of smaller flood events (such as 2 and 10 year floods) to downstream lowland areas, and potentially delaying flood peaks in the Wakamoekau and Mikimiki rivers.

Hydrological and hydraulic flood modelling scenarios to test the effectiveness of the 'small scale retention' scenario was modelled as part of the '*Feasibility study of nature-based solutions for addressing the flood risk to Masterton'*[11].The components of this NBS option were different between the Stage 2 Geomorphic Assessment and the flood scenarios feasibility study[12]. As such, the hydrological and hydraulic results have not been used to inform the geomorphic effectiveness assessment presented here.

This option may only have a minimal, or negligible, impact on flood risk reduction in Masterton. However, the option is expected to have several positive co-benefits (discussed further in Section 3.2.2 below).

3.2.2 Co benefits

While this option is likely to have minimal or negligible impact on the geomorphic effectiveness for flood risk reduction to Masterton, there are several additional co-benefits that can improve ecological, amenity, and Mātauranga objectives, including:

- Improved aquatic biodiversity values within naturalised streams, including:
  - Complex habitat structure including diverse bed forms.
  - Increase organic material supporting sustainable aquatic food webs.
  - Reduction in the amount of fine-grained sediment (typically associated with lower habitat values).
  - Potential for increased shading and reduction of water temperatures.
- Improved wetland and terrestrial biodiversity values within the 'leaky bund' areas.
- Reduction in contaminants in groundwater and surface flows through infiltration and assimilation of nutrients.
- Enables adjacent agricultural landuse to be maintained and continue to be used as productive land.
- Potential increase in baseflows if water can be retained in areas of high permeability, with less flow lost to evaporation and sustained near-surface groundwater contributions.
- Potential recreation spaces and native species conservation.
- Opportunities for the incorporation of Mātauranga Māori in the design and implementation of the supporting planting and stream naturalisations.

[11] T+T (2025) Feasibility study of nature-based solutions for addressing the flood risk to Masterton.

[12] The feasibility assessment looked at generalised small-scale, distributed retention storage areas (such as attenuation wetlands, retention ponds, and infiltration basins), covering 5% of the floodplain in an area that aligned with the boundaries of seven of the 14 sub catchments in the hydrological model.

3.3 Channel realignment / reconnection of oxbows / room for the river

This option presents the greatest opportunity for geomorphic effectiveness of flood risk reduction to Masterton, primarily through managing sediment processes (sediment load and stream power) and run-off (discharge) through floodplain widening (Appendix A).

The assessment of the geomorphic effectiveness of this option relied upon how sediment transport and flow dynamics have changed with the historical changes in river form and function through four reaches of the Waipoua River main stem (described in the Stage 1 report and the NCI assessment[13]). This option therefore considered a passive restoration of channel form and function to a previous channel state and included two components:

- Channel realignment zone – Through management of existing exotic vegetation within the historic 1969 active channel extent[14], the river will be enabled to wander freely and adopt a more naturalised form. No active erosion management or river training would occur in this zone. Appropriate native planting could be considered which would facilitate natural channel adjustments and increase roughness to 'slow the flow'.
- Floodplain reengagement zone – This zone currently includes the 100 year floodable area, and expected changes in channel form in the channel realignment zone will likely increase the frequency of flooding in these areas, and can be coupled with floodplain re-engagement options (Section 3.4). Some relocation of stopbanks is suggested to increase flood spread and reduce the severity of localised flood effects.

The primary areas for 'room for the river' focus on four specific reaches of the Waipoua River which have different stream types (see Figure 3.4 below):

- Reach 5 – from where the Waipoua River exits the Tararua range to Mikimiki Road bridge – Partly confined high sinuosity gravel bed river.
- Reach 4 – from Mikimiki Road bridge to Wakamoekau Stream – Partly confined low sinuosity gravel bed river.
- Reach 3 – from Wakamoekau Stream to approximately 2.5 km upstream of Budd Road - Partly confined moderate sinuosity gravel bed river.
- Reach 2 – from approximately 2.5 km upstream of Budd Road to the rail bridge upstream of Masterton - Partly (artificially) confined moderate sinuosity gravel bed river.

[13] Carter, C., and Fuller, I. (2024). Natural Character Index (NCI) for Waipoua and Mangatarere Rivers (DRAFT). Report prepared for Greater Wellington Region Council.
[14] Due to the extensive change in channel form as a result of the 1855 earthquake (as described in the Stage 1 report), the channel form visible in the earliest imagery (1940's) is not considered 'representative' of the channel form associated with a catchment sediment yield not impacted by earthquakes. A such a more intermediate channel form has been adopted based on the 1960's channel form.

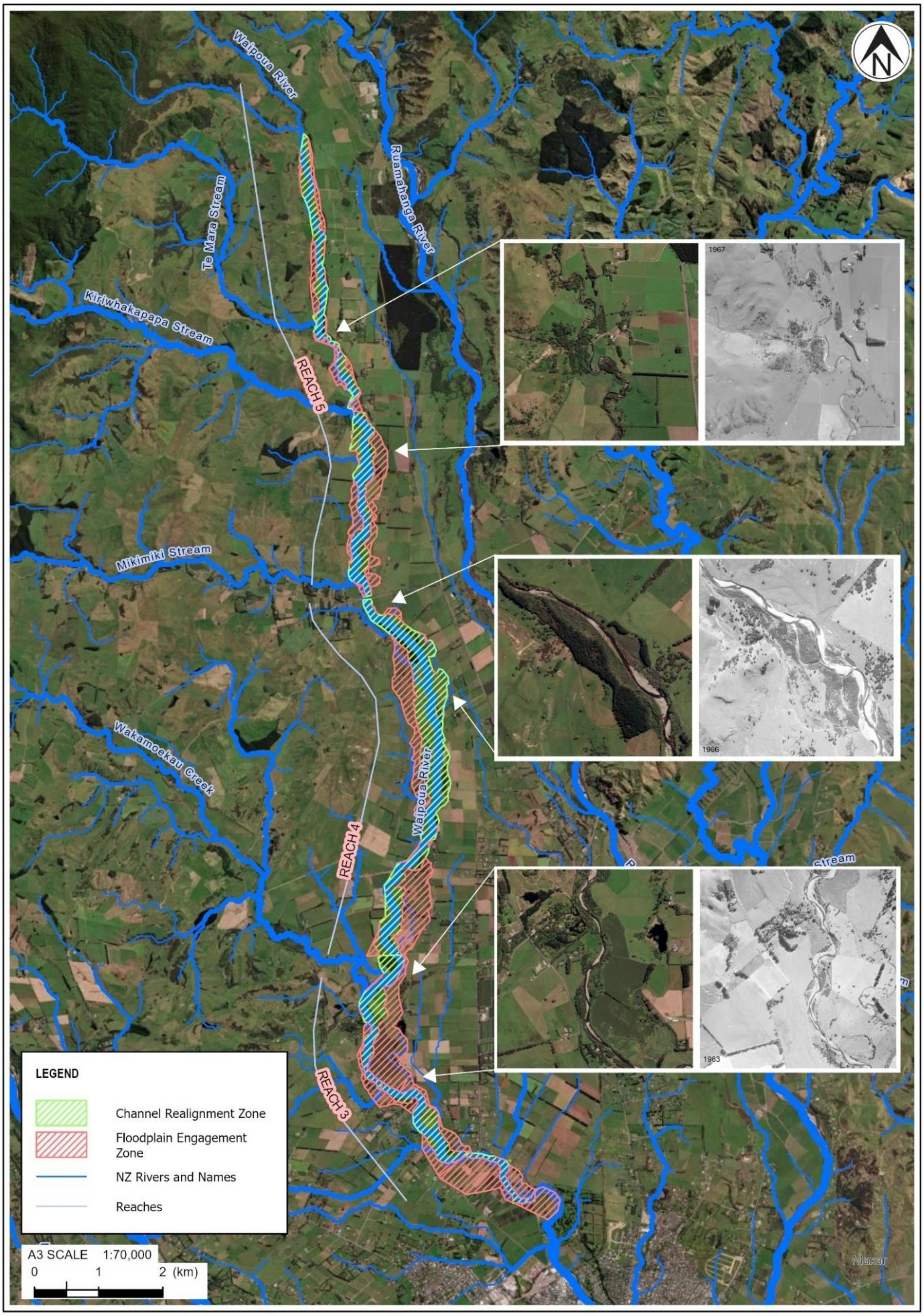

Figure 3.4: Areas proposed for floodplain re-engagement and channel realignment.

3.3.1 Potential geomorphic effectiveness on flood risk reduction

The expected geomorphic response (and therefore effect on flood risk reduction to Masterton) of the Waipoua River to the 'room for the river' option varies depending on stream type:

- Reach 5 – from where the Waipoua River exits the Tararua range to Mikimiki Road bridge – Partly confined high sinuosity gravel bed river:
  - An expected increase in average active channel width by up to 20 m, resulting in a reduction in specific stream power by increasing channel roughness, and increased in-stream sediment deposition and storage.
  - An expected increase in average bed level by approximately 0.4 m[15] as a result of a reduction in stream power.
  - Increased sediment storage with less sediment transported out of this reach into adjacent downstream reaches.
- Reach 4 – from Mikimiki Road bridge to Wakamoekau Stream – Partly confined low sinuosity gravel bed river:
  - An expected increase in average active channel with by up to 40 m, resulting in a reduction in specific stream power by increasing channel roughness, and increased in-stream sediment deposition and storage.
  - An expected increase in average bed level by approximately 0.7 m[15] as a result of a reduction in stream power.
  - Increased sediment storage with less sediment transported out of this reach into adjacent downstream reaches.
- Reaches 3 and 2 – from Wakamoekau Stream to the rail bridge upstream of Masterton - Partly confined moderate sinuosity gravel bed river:
  - An expected increase in average active channel with by up to 15 m, resulting in a reduction in specific stream power by increasing channel roughness, and increased in-stream sediment deposition and storage.
  - An expected increase in average bed level by approximately 0.5 m[15] as a result of a reduction in stream power.
  - A potential reduction or delay in flood peaks as a result of a wider channel cross section, and increased floodplain areas (where stopbanks are relocated in Reach 2).

The 'room for the river' scenarios were tested in a hydraulic model to understand, at a high level, the potential impact on flood dynamics. The results suggest that the room for the river scenario may result in a slight increase in flood peaks[16] in the 2, 5, 10 and 20 year flood events (between 0.9-3.3% increases). However, in the larger flood events (50 and 100 year), flood peaks are likely to reduce by up to 1.9% (see Figure 3.5 below).

[15] Based on the Mean Bed Level Analysis undertaken by WSP in 2019 and presented in the Stage 1 report.
[16] At the Rail Bridge upstream of Masterton, which was used to assess flow changes within the Masterton urban area.

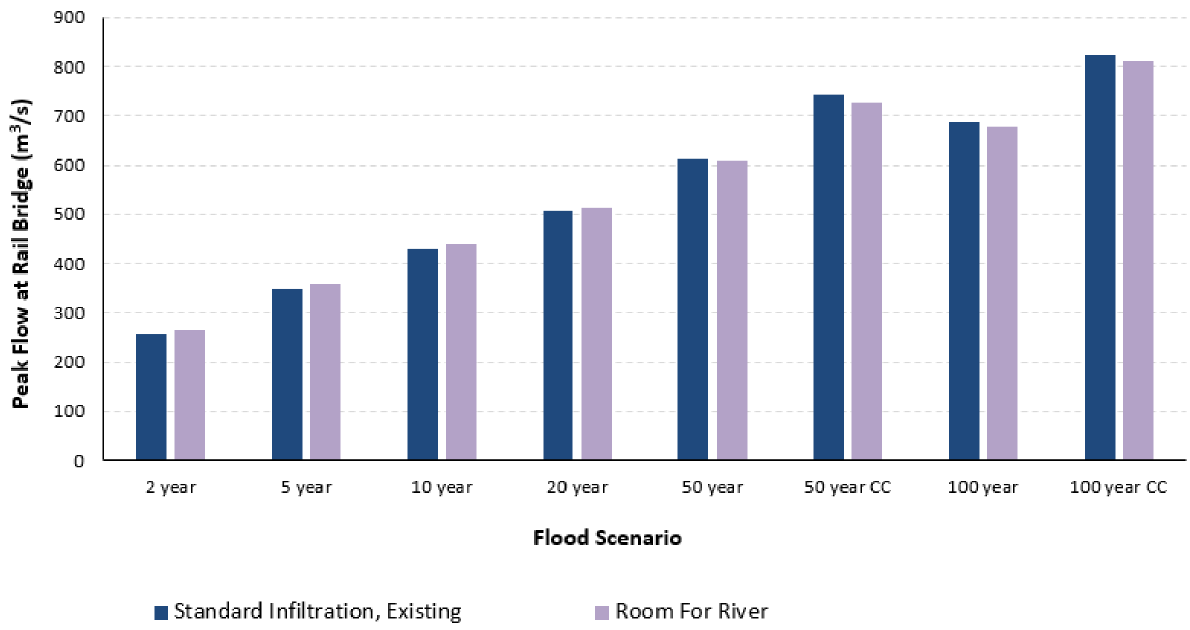

Figure 3.5: Indicative flood peaks at the Rail Bridge upstream of Masterton under existing conditions and the 'room for the river' scenario.

Floodplain engagement is likely to increase throughout all four reaches of the Waipoua River, with flood depths increasing particularly in the 2, 5, 10 and 20 year flood events (Figure 3.6 and Figure 3.7). In addition, the velocity of floodwater across the floodplain is also likely to increase in all flood scenarios tested. The greatest increases in velocity are around the Mikimiki Bridge at the downstream extent of Reach 5 (Figure 3.6 and Figure 3.8), with some indication that channel avulsion through some of the existing flood channels may be possible (i.e. a return to historic river character and behaviour as described in the Stage 1 report).

The velocity of floodwater on the floodplain is likely to decrease as roughness increases i.e. pasture grasses on the floodplain are likely to result in higher velocities than floodplain forest. Changes in floodplain roughness were not modelled, the results presented in Figure 3.6 are for the existing landuse.

The velocity difference within the channel suggests that passive restoration of channel form is likely in Reaches 3 and 4, with a switch to a more depositional environment in Reaches 2 (i.e. immediately upstream from Masterton).

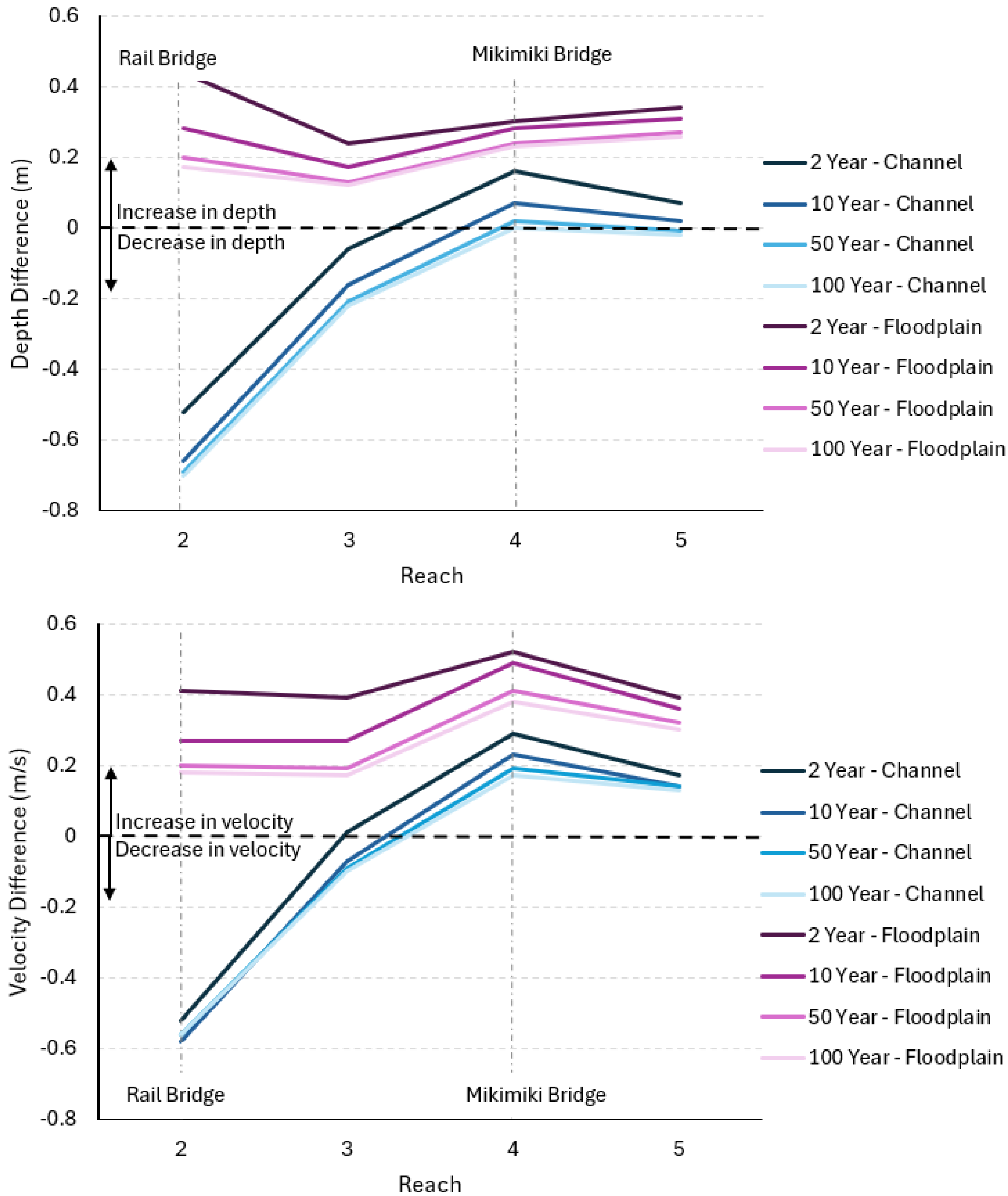

Figure 3.6: Reach average flood depth difference (top) and velocity difference (bottom) between existing conditions and the 'room for the river' option.

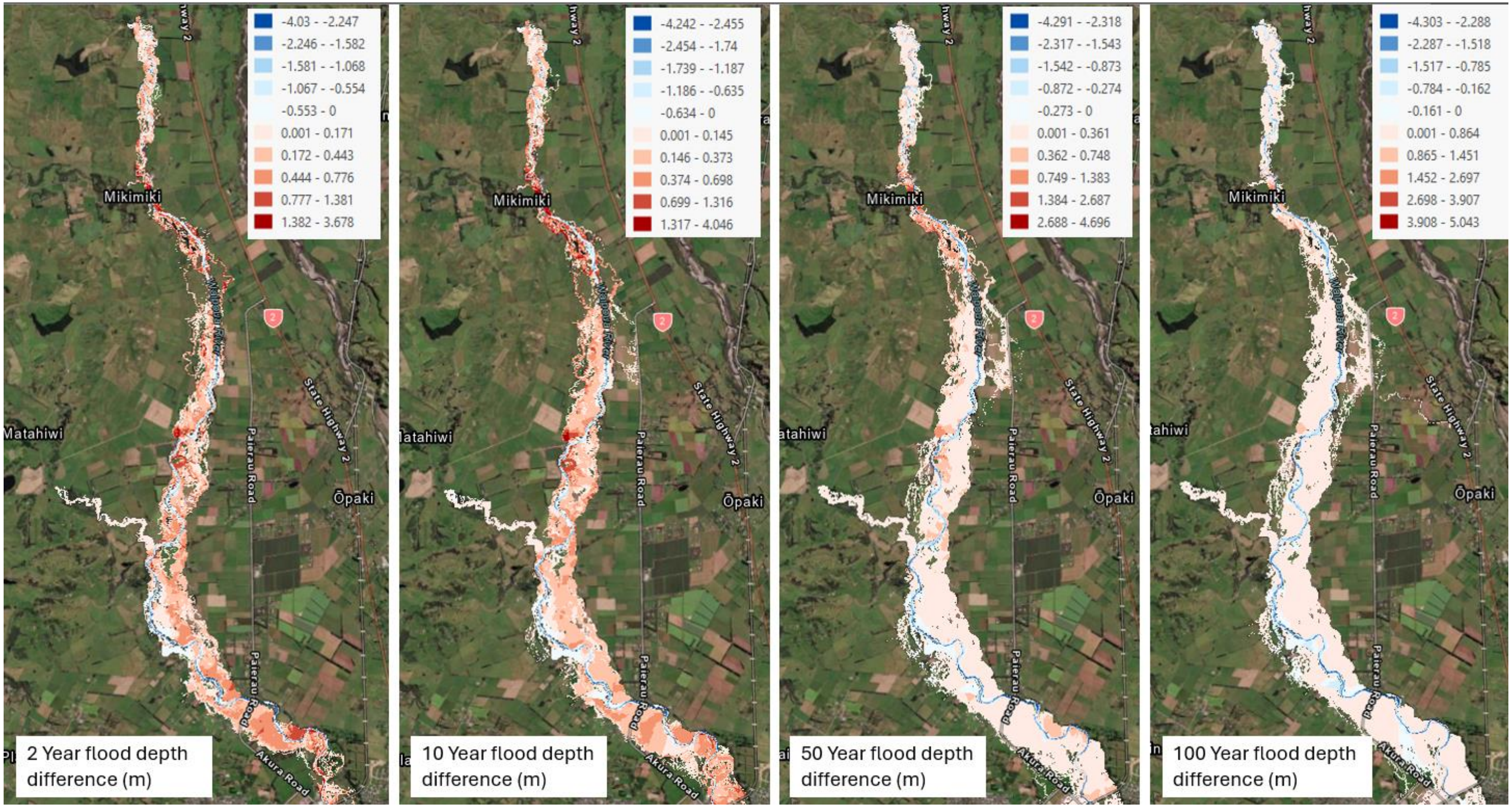

Figure 3.7: Indicative flood depth differences for the 2, 10, 50 and 100year flood events between existing conditions and the 'room for the river' scenario.

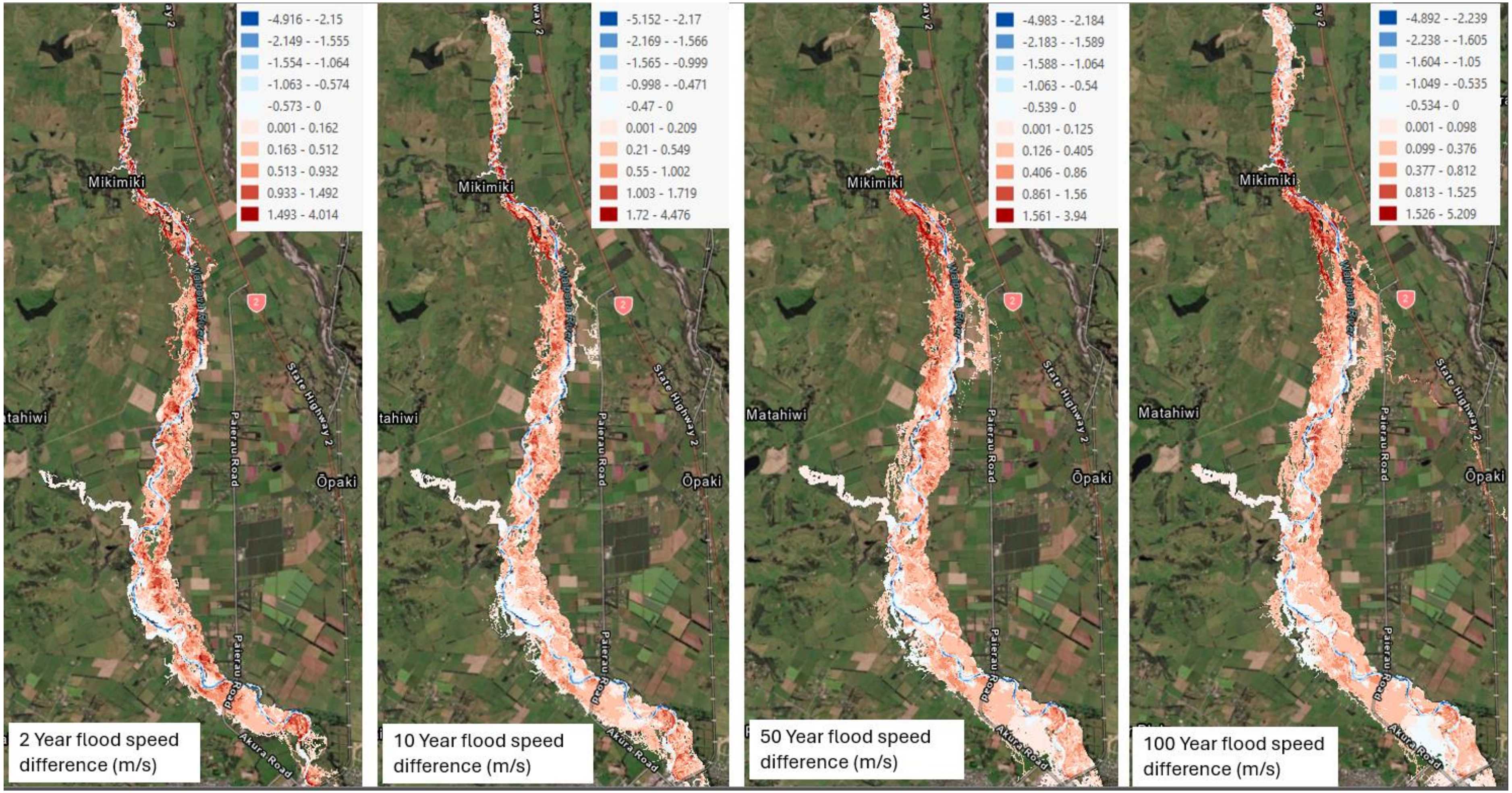

Figure 3.8: Indicative flood speed differences for the 2, 10, 50 and 100year flood events between existing conditions and the 'room for the river' scenario.

3.3.2 Co-benefits

This option is expected to have a high geomorphic effectiveness on flood risk reduction to Masterton. In addition, there are a number of additional co-benefits that can improve ecological, amenity, and Mātauranga objectives, including:

- Restoration of a more naturalised channel form and function similar to historic conditions.
- Improved aquatic biodiversity values within the Waipoua River, including:
- Complex habitat structure including diverse bed forms:
  - Increased opportunities for refuge pools to form and be maintained.
  - Increase organic material supporting sustainable aquatic food webs.
  - Reduction in the amount of fine-grained sediment (typically associated with lower habitat values).
- Opportunities to re-establish wetland habitats on the edge of the active channel, existing oxbows and flood channel environments.
- Opportunities to re-establish indigenous riparian forest type habitats on the edge of the active channel.
- Opportunities for the incorporation of Mātauranga Māori in the design and implementation of the supporting planting and stream naturalisations.
- Potential to create recreational areas and native species conservation.

3.4 Floodplain lowering / engagement

The option for floodplain lowering / engagement was considered in isolation from the 'room for the river' option. However, they could be implemented together to maximise geomorphic effectiveness of flood risk reduction to Masterton.

Floodplain lowering / engagement had the greatest geomorphic effect on sediment processes (sediment load and stream power) and run-off (discharge) through floodplain widening (Appendix A). This option focussed on the three reaches downstream of the Mikimiki Bridge (Reaches 2 to 4) identified in the 'room for the river' option (as described in Section 3.3 above) (see Figure 3.9 below).

Given a large proportion of the floodplain in the three reaches is already engaged in the 100-year flood event, the options for floodplain lowering / engagement included two components:

- Flood channel re-engagement – This component looks to increase the frequency of engagement in the existing flood channels, and increase the amount of water able to be contained in these channels. The intent is that the existing off-take points17 of the flood channels would be lowered, and a two-stage channel cross-section would be created along the full length, with lower flood channel set to 2 year flood level and the full channel cross-section is engaged in 10 year flood level.
- Lowering existing floodplain surfaces – This component looks to increase the frequency of floodplain engagement, and maximise flood storage. The intent is that the floodplain surfaces near the active channel would be lowered to match the existing 10 year flood level, and the remaining floodplain surface lowered to the 50 year flood level. The existing floodplain topography lower than these flood levels would be maintained, and any stopbanks in these areas would be relocated to the far edge of the floodplain.

[17] Where the flood water first moves from the main channel into the flood channel.

Both options can be supported by some form of riparian planting to reduce flow velocity, increase infiltration and sediment deposition, and increase erosion resilience. However, the priority for riparian planting should be within the flood channels.

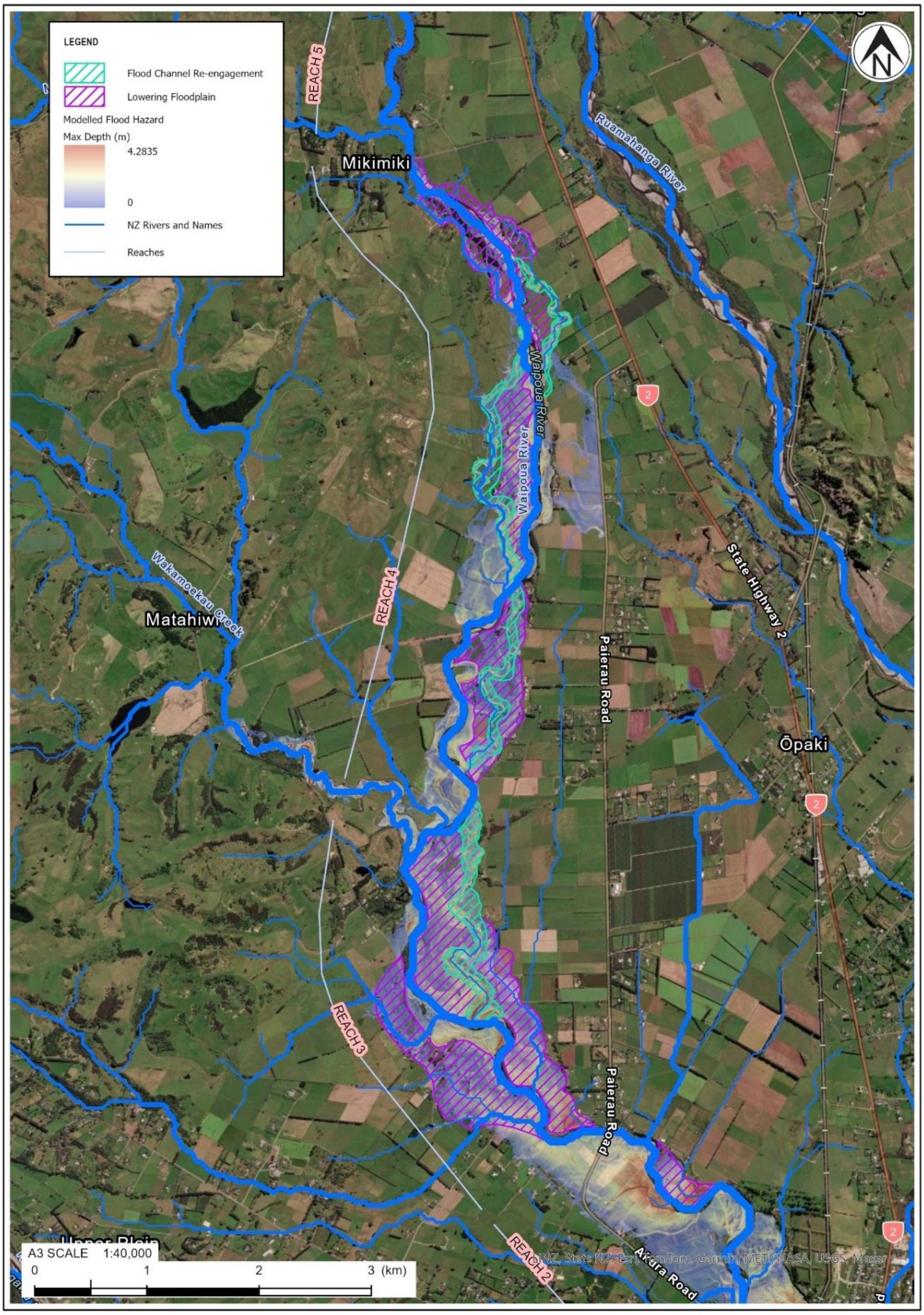

Figure 3.9: Potential zones of flood channel re-engagement and floodplain lowering with 100-year modelled flood depth.

3.4.1 Potential geomorphic effectiveness on flood risk reduction

Once implemented, the combination of the floodplain lowering and flood channel reengagement along reaches 2-4 of the Waipoua River is expected to have a reasonably rapid effect on peak flow at Rail Bridge due to the increase in the frequency of floodplain engagement, flood storage, and increased infiltration.

There may be a slight change in the sediment regime within the Waipoua River itself, with a slight lowering of stream power reducing sediment transport effectiveness. In addition, there is likely to be some diversion of sediment load into the flood channels. As the flood channels are longer than the corresponding sections of the Waipoua River, this sediment is likely to take longer to move through the flood channels (than if it was still in the Waipoua River). Some of this sediment is likely to be trapped and stored within the flood channels, removing it from the overall Waipoua sediment budget. The timeframe for this process is linked to flood frequency, but is likely to be in the order of 10 to 50 years to be realised.

The floodplain lowering and flood channel reengagement scenarios were tested in a hydraulic model to understand, at a high level, the potential impact on flood dynamics. The results suggest that the floodplain lowering and flood channel reengagement scenarios are more effective at reducing flood peaks in all flood scenarios if the flood channels are vegetated[18], with between 4-7% reduction in flood peaks (refer Figure 3.10 below).

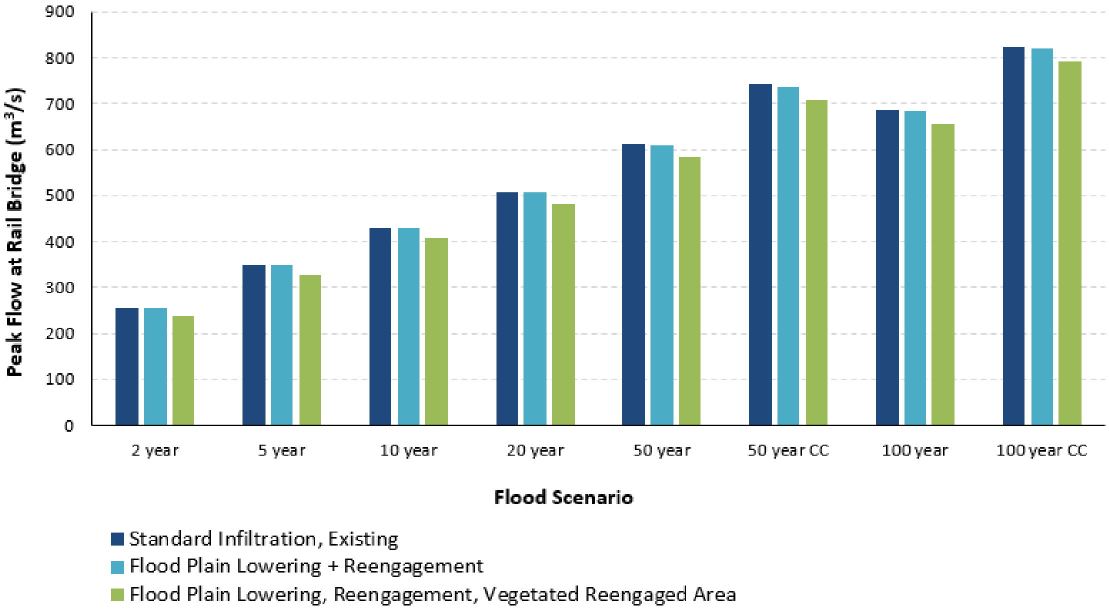

Figure 3.10: Indicative flood peaks at the Rail Bridge upstream of Masterton under existing conditions and the floodplain lowering and flood channel reengagement scenarios.

The floodplain lowering and flood channel reengagement scenarios resulted in changes in flood depth, with the expected increases in flood depth primarily in the flood channels in Reach 2 and 3, and some increases in flood depth on the floodplain in Reach 3 and 4 outside of the flood channels in the 2 and 10-year events (refer Figure 3.12 below). In flood events greater than the 10-year, flood depths across the floodplain generally decrease, with the greatest depth decreases occurring in the 50-year event (Figure 3.11 and Figure 3.12 below). The difference in flood velocity generally shows a large increase in 2-year event, and then similar minor increases in all other events (Figure 3.11 and Figure 3.13 below).

[18] Mannings 'n' = 0.12 which correlates to trees or more densely planted vegetation (such as flaxes).

In all events, flood depth and velocity decreases within the channel, with the greatest decreases observed during a 2-year event in Reach 3 (refer Figure 3.11, Figure 3.12, and Figure 3.13 below).

This supports the theory that there may be a slight reduction in sediment transport efficiency, with the most pronounced changes likely in Reach 2 and 3 (i.e. immediately upstream of Masterton).

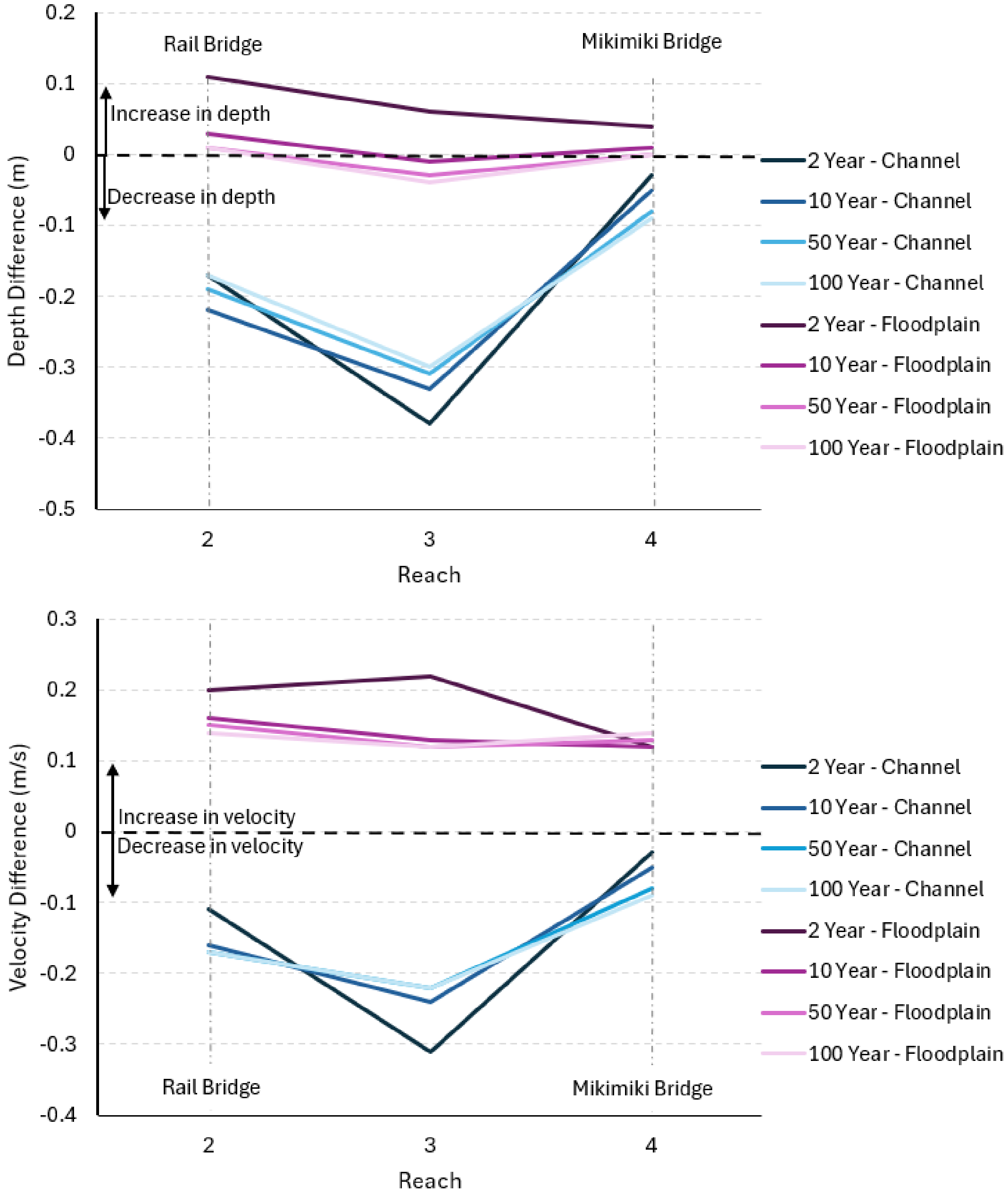

Figure 3.11: Reach average depth difference (top) and velocity difference (bottom) between existing conditions and the 'floodplain lowering and flood channel reengagement' scenarios. Note: All results presented assume the flood channels are vegetated with trees.

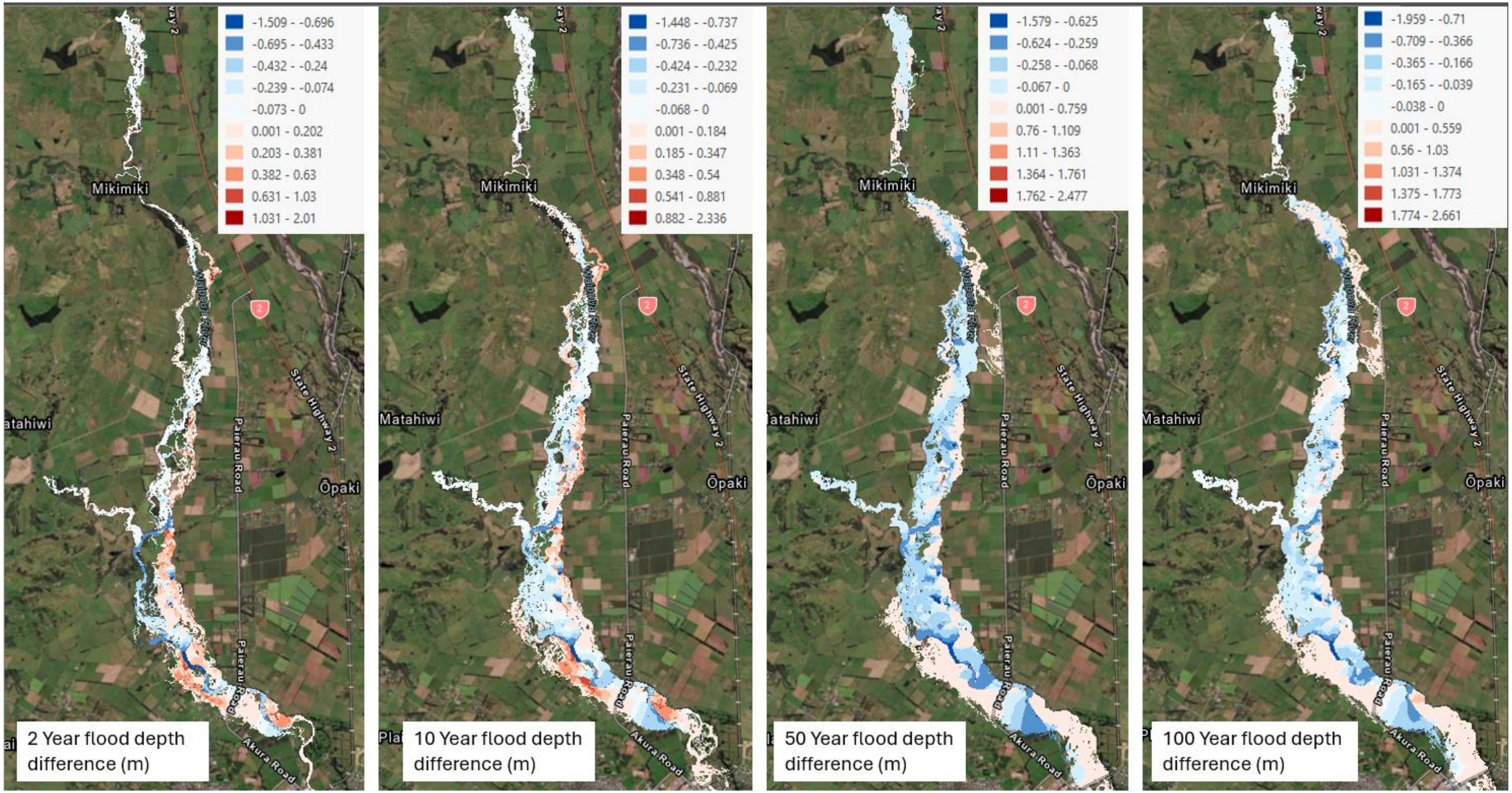

Figure 3.12: Indicative flood depth differences for the 2, 10, 50 and 100-year flood events between existing conditions and the floodplain lowering and flood channel reengagement scenarios.

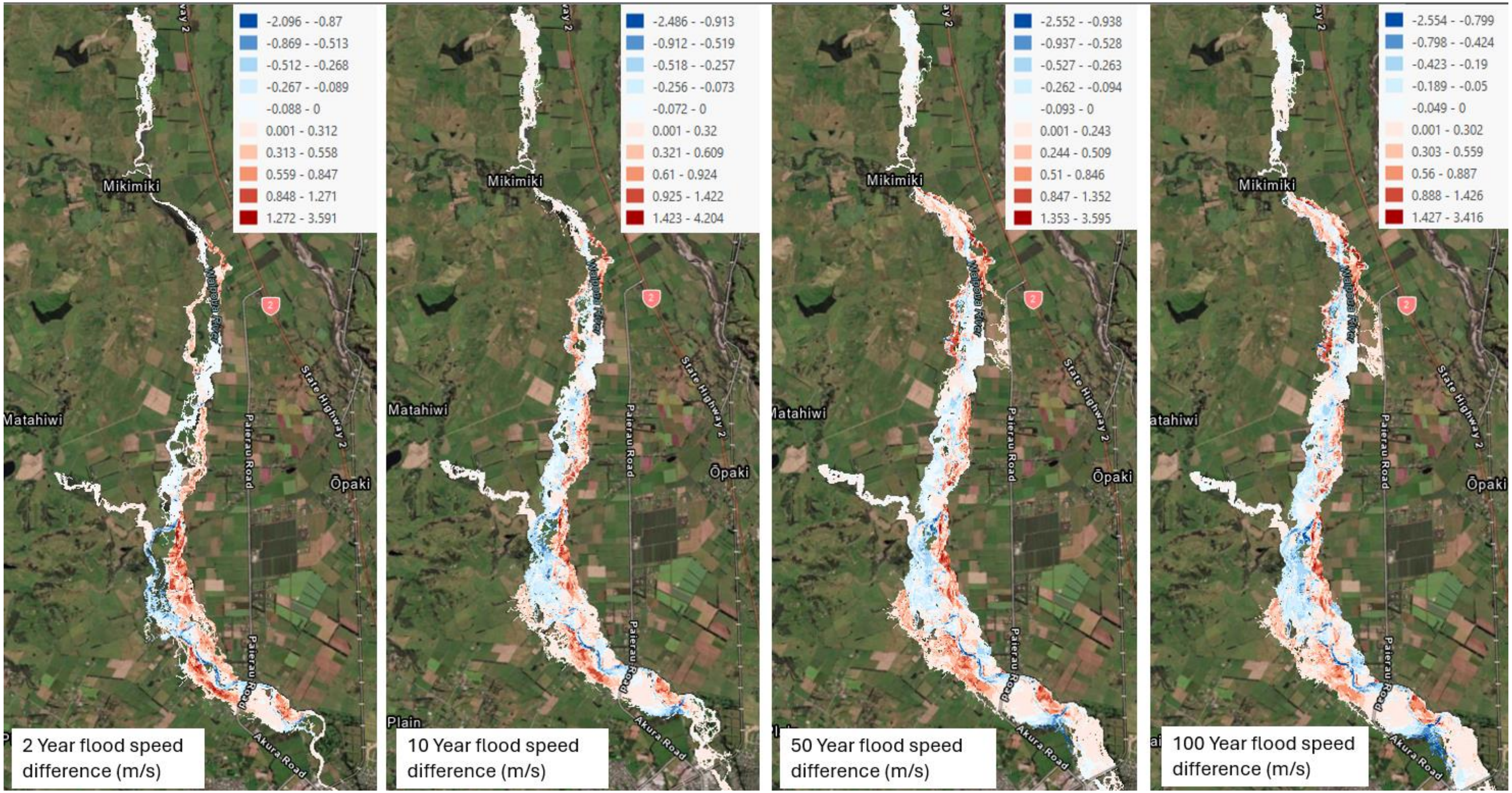

Figure 3.13: Indicative flood speed differences for the 2, 10, 50 and 100-year flood events between existing conditions and the floodplain lowering and flood channel reengagement scenarios.

3.4.2 Co-benefits

This option is expected to have a high geomorphic effectiveness on flood risk reduction to Masterton. In addition, there are a number of additional co-benefits that can improve ecological, amenity, and Mātauranga objectives, including:

- Improved biodiversity values by providing additional areas of, and more frequently wet, floodplains.
- Improved aquatic biodiversity values within the Waipoua River, including:
  - Increase organic material supporting sustainable aquatic food webs.
  - Reduction in the amount of fine-grained sediment (typically associated with lower habitat values).
- Opportunities to re-establish wetland habitats in the flood channels.
- Opportunities to re-establish indigenous riparian forest type habitats.
- Adjacent agricultural landuse could still be maintained and continue to be used as productive land.
- Depending on adjacent land use, there is the potential for a reduction in contaminants in groundwater and surface flows with more surface area available more frequently for infiltration and assimilation of nutrients.
- Potential increase in baseflows, with more surface area available more frequently for infiltration to near surface groundwater aquifers.
- Opportunities for the incorporation of Mātauranga Māori in the design and implementation of the supporting planting and stream naturalisations.
- Potential to create recreational areas and native species conservation.

4 Limitations and Assumptions

The Stage 2 Waipoua Geomorphic Assessment has focused on the geomorphic drivers of flood risk across the Waipoua Catchment, not on flood risk reduction to Masterton.

The Stage 2 Waipoua Geomorphic Assessment has also not looked at land ownership or cost constraints, but is intended to inform feasibility and cost benefit analyses of the location specific options[6].

In addition, the hydraulic model was originally set up to model flooding in larger flood events (50 and 100 year floods), and therefore there is less confidence in the results of the smaller flood events (e.g. 2, 5, 10 and 20 year floods). The primary purpose of the indicative results presented in this report as to illustrate the relative changes associated with different Nature-Based Solutions. They should be considered as indicative only, and not replied upon for understanding flood risk or extent.

5 Applicability

This report has been prepared for the exclusive use of our client Greater Wellington Regional Council, with respect to the particular brief given to us and it may not be relied upon in other contexts or for any other purpose, or by any person other than our client, without our prior written agreement.

Tonkin & Taylor Ltd
Environmental and Engineering Consultants

Report prepared by:	Authorised for Tonkin & Taylor Ltd by:
....	....
Selene Conn Fluvial Geomorphologist	Bryn Quilter Project Director

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Appendix A Geomorphic Response and Effectiveness Summary

Table Appendix A.1: Expected geomorphic response and geomorphic effectiveness of the key benefits of 'retirement of hillslopes (low-value farmland)/Permanent revegetation of hillslopes'

Key geomorphic benefit	Confined, low sinuosity cobble/boulder bed		Partly confined, moderate/high sinuosity gravel bed		Partly confined, low sinuosity gravel bed		Unconfined, artificially straightened gravel bed		Artificially confined, low sinuosity gravel bed	
	Expected geomorphic response	Geomorphic effectiveness	Expected geomorphic response	Geomorphic effectiveness	Expected geomorphic response	Geomorphic effectiveness	Expected geomorphic response	Geomorphic effectiveness	Expected geomorphic response	Geomorphic effectiveness
Reduction in sediment load	Potential for the channel to incise within reach in the short term. Possible minor increase in sediment delivery to downstream reaches in the medium term. Long term reduction in sediment delivery to downstream reaches.	NBS option to have little/no influence on channel form and function within the reach. Minor influence on channel form and function to downstream reaches.	Reach likely to incise or aggrade where the sediment is being disconnected in the short term. Possible major reduction in sediment delivery to the reach and downstream reaches in the medium term. Long term reduction in sediment delivery within reach and downstream reaches.	NBS option likely to have a minor influence on channel form and function within and downstream of reach immediately and is likely to occur gradually overtime.	Reduction in sediment load from increased trapping in the hillslopes likely to contribute to incision within the reach in the short term. Minor reduction in sediment load within the reach and downstream in the medium term. Long term reduction in sediment delivery and supply within the reach and downstream reaches.	NBS option likely to have a major influence on channel form and function within the reach, and is likely to occur gradually overtime. Likely to have a minor influence on form and function to downstream reaches.	Potential to respond by lowering bed level within the reach in the medium to long term. Likely to have minor impacts in transport of sediment downstream given location of these stream types.	NBS option to have little/no influence on channel form and function within and downstream of this reach.	Minor impacts on this reach in the short term due to delays in response in sediment supply/production. Potential reduction in sediment supply likely to contribute to bed incision, especially through Masterton in the medium term. Long term incision if alternative sediment supply not activated.	NBS option likely to have a major influence on channel form and function, and is likely to occur gradually overtime within the reach. Downstream reaches have not been assessed (Ruamāhanga confluence).
Increase in wood loading	Woody debris recruitment from forested hillslopes limited to existing forested slopes in the short term. Possible increase in woody debris recruitment in the medium term, Long term, sustained supply and establishment of woody debris into channel form.	NBS option to have little influence on channel form and function within the reach. Minor influence on channel form and function to downstream reaches.	Wood loading unlikely to adversely affect the reach unless volumes are significant which may result in blockages. Unlikely to influence form and function downstream.	NBS option likely to have a minor influence within reach on channel form and function, and is likely to occur gradually overtime. Minor/no influence on channel form and function to downstream reaches.	Wood loading likely to cause increased geomorphic diversity in the short, medium and long term.	NBS option likely to have a minor influence on channel form and function within the reach, and is likely to occur gradually overtime. Minor influence on channel form and function to downstream reaches.	These reaches are narrow and likely to cause jams/blockage in culverts resulting in localised flooding in the short, medium and long term.	NBS option likely to a major influence on channel form and function, and is likely to occur gradually overtime. Not likely to have impacts on form and function of downstream reaches.	Wood may help to stabilise the channel and create habitat. But also potentially increase localised flooding in the short, medium and long term.	NBS option likely to have a minor influence on channel form and function, and is likely to occur gradually overtime. Downstream reaches have not been assessed (Ruamāhanga confluence).
Reduction in runoff	Potential to locally aggrade if there is insufficient flow to transport /mobilise gravel in the short term. Potential reduction in runoff as infiltration increases. Long term increase in infiltration resulting in decrease if runoff.	NBS option to have little/no influence on channel form and function within the reach. Likely to have major downstream effects on channel form and function.	Limited adjustment expected in the short term and vegetation begins to establish Potential to aggrade as flows are reduced to flush sediment through the system in the medium/long term.	NBS option likely to have a minor influence on channel form and function within the reach, and is likely to occur gradually overtime. Likely to have flow on effects on form and function in downstream reaches.	Likely minor/no changes to runoff in the short term As forest matures (medium/ long term lower surface runoff entering the stream causes a lower potential to flush sediments through the system – aggradation.	NBS option likely to have a minor influence on channel form and function within the reach, and is likely to occur gradually overtime. Likely to have minor effects on downstream reaches.	River channel runs through farmland and are likely to retain form in response to changes in runoff in the short, medium and long term.	NBS option to have little/no influence on channel form and function within and downstream of reach	Lowers flood levels and velocities through Masterton. Potential to slow the on-going delivery of sediment into the downstream reaches near Masterton.	NBS option likely to have a major influence on channel form and function within the reach, and is likely to occur gradually overtime. Downstream reaches have not been assessed (Ruamāhanga confluence).

Key geomorphic benefit	Confined, low sinuosity cobble/boulder bed		Partly confined, moderate/high sinuosity gravel bed		Partly confined, low sinuosity gravel bed		Unconfined, artificially straightened gravel bed		Artificially confined, low sinuosity gravel bed	
	Expected geomorphic response	Geomorphic effectiveness	Expected geomorphic response	Geomorphic effectiveness	Expected geomorphic response	Geomorphic effectiveness	Expected geomorphic response	Geomorphic effectiveness	Expected geomorphic response	Geomorphic effectiveness
Reduction in stream power	Potential to aggrade if runoff is insufficient to transport /mobilise gravel in the short, medium and long term.	NBS option to have little/no influence on channel form and function within the reach Likely to contribute to an overall reduction in stream power in downstream reaches.	Lower stream powers are likely to occur as flows are reduced in the medium to long term.	NBS option likely to have a minor influence on channel form and function, and is likely to occur gradually overtime within and downstream of the reach.	Reduction in stream power helps to stabilise bed and banks and reduces sediment transport. Likely to occur in the medium/long term and vegetation establishes.	NBS option likely to have a minor influence on channel form and function within and downstream of the reach, and is likely to occur gradually overtime.	Likely to retain channel form arising from a change in stream power, increased sediment loading may result as flows insufficient to mobilise sediment in the medium to long term.	NBS option to have little/no influence on channel form and function within and downstream of the reach.	Reduces erosion potential through Masterton in the medium/long term.	NBS option likely to a major influence on channel form and function, and is likely to occur gradually overtime. Downstream reaches have not been assessed (Ruamāhanga confluence).
Average score	**Moderate**	**Low**	**Moderate**	**Moderate**	**Moderate**	**Moderate**	**Low**	**Low**	**Moderate**	**High**

Table Appendix A.2: Expected geomorphic response and geomorphic effectiveness of the key benefits of 'floodplain lowering / engagement (including relocation of stopbanks)'

Key geomorphic benefit	Confined, low sinuosity cobble/boulder bed		Partly confined, moderate/high sinuosity gravel bed		Partly confined, low sinuosity gravel bed		Unconfined, artificially straightened gravel bed		Artificially confined, low sinuosity gravel bed	
	Expected geomorphic response	Geomorphic effectiveness	Expected geomorphic response	Geomorphic effectiveness	Expected geomorphic response	Geomorphic effectiveness	Expected geomorphic response	Geomorphic effectiveness	Expected geomorphic response	Geomorphic effectiveness
Reduction in sediment load	Reaches not typically stopbanked/ (artificially) disconnected from floodplain.	NBS option to have little/no influence on channel form and function.	Enables fine grain sediment to settle across the floodplain in the short term and promotes a medium to long term enhancement of floodplain processes.	NBS option likely to have a minor influence on channel form and function within the reach, and is likely to occur gradually overtime. Likely to have a minor influence on form and function downstream.	Increased sediment generation and connectivity to floodplain sediment sources and ability to deposit sediment on floodplains during high magnitude events in the short term. Medium to long term enhancement of floodplain processes, such as sediment reworking.	NBS option likely to have a minor immediate influence on channel form and function within the reach, and is likely to occur gradually overtime. Minor impacts on form and function in downstream reaches.	Reaches not stopbanked	NBS option to have little/no influence on channel form and function within and downstream of target reach.	Able to access the floodplain and encourage sediment settlement in the short term. Encourages medium to long term sediment deposition within Masterton.	NBS option to have minor influence on channel form and function within the reach. Downstream reaches have not been assessed (Ruamāhanga confluence).
Increase in wood loading	Reaches not typically stopbanked/ (artificially) disconnected from floodplain	NBS option to have little/no influence on channel form and function.	Wood likely to be recruited from hillslopes but unlikely to effect river character and behaviour.	NBS option to have little/no influence on channel form and function within and downstream of the target reach.	Potential increase in wood recruitment from lateral sources in the short term. Medium to long term floodplain and channel enhancement through establishment of wood structures.	NBS option to have little/no influence on channel form and function within and downstream of the target reach.	Reaches not stopbanked	NBS option to have little/no influence on channel form and function.	NBS unlikely to contribute to wood loading.	NBS option to have little/no influence on channel form and function. Downstream reaches have not been assessed (Ruamāhanga confluence).
Reduction in runoff	Reaches not typically stopbanked/ (artificially) disconnected from floodplain	NBS option to have little/no influence on channel form and function.	NBS not targeted at reducing runoff.	NBS option to have little/no influence on channel form and function.	Reducing quantity and velocities of flow through increased flood storage in the short, medium and long term.	NBS option likely to have a major influence on channel form and function within and downstream of the target reach, and is likely to occur gradually overtime.	Reaches not stopbanked	NBS option to have little/no influence on channel form and function.	Increased flood storage for the target reach in the short, medium and long term.	NBS option likely to have a major influence on channel form and function, and is likely to occur gradually overtime. Downstream reaches have not been assessed (Ruamāhanga confluence).
Reduction in stream power	Reaches not typically stopbanked/ (artificially) disconnected from floodplain	NBS option to have little/no influence on channel form and function.	Allows flows to be distributed across a larger cross-sectional area. Medium to long term utilisation of additional flood storage.	NBS option likely to have a minor influence on channel form and function, and is likely to occur gradually overtime.	Lower flows across a wider surface area in the short term. Medium to long term utilisation of additional flood storage.	NBS option likely to have a minor influence on channel form and function within the reach. Likely to influence form and function in lower reaches by reducing stream powers.	Reaches not stopbanked	NBS option to have little/no influence on channel form and function.	Increased flood storage area to encourage reducing stream power.	NBS option likely to have a major influence on channel form and function, and is likely to occur gradually overtime. Downstream reaches have not been assessed (Ruamāhanga confluence).
Average score	**Low**	**Low**	**Moderate**	**Moderate**	**High**	**Moderate**	**Low**	**Low**	**Moderate**	**Moderate**

Table Appendix A.3: Expected geomorphic response and geomorphic effectiveness of the key benefits of 'small scale distributed retention (off-line storage)'

Key geomorphic benefit	Confined, low sinuosity cobble/boulder bed		Partly confined, moderate/high sinuosity gravel bed		Partly confined, low sinuosity gravel bed		Unconfined, artificially straightened gravel bed		Artificially confined, low sinuosity gravel bed	
	Expected geomorphic response	Geomorphic effectiveness	Expected geomorphic response	Geomorphic effectiveness	Expected geomorphic response	Geomorphic effectiveness	Expected geomorphic response	Geomorphic effectiveness	Expected geomorphic response	Geomorphic effectiveness
Reduction in sediment load	Ability to reduce fine grained sediments if storage located in top of headwaters but not likely to cause adjustment. Trapping effectiveness likely to stay similar overtime.	NBS option to have little/no influence on channel form and function within the target reach. Potential to reduce sediment supply to downstream reaches and alter channel form and function.	Strategically placed storage devices could contribute to trapping fine grained sediment in short, medium and long term.	NBS option to have little/no influence on channel form and function within the target reach. Likely to have minor influence on downstream reaches.	Likely to help trap some fine grained sediments in the short, medium and long term.	NBS option likely to have a minor influence on channel form and function, and in downstream reaches and is likely to occur gradually overtime.	Likely to trap some sediment before entering these streams in the short to long term time frames.	NBS option to have little/no influence on channel form and function within target reach. May have minor effect on form and function in downstream reaches.	Likely to reduce sediments from entering DS areas in the short term, could trigger incision from reduction in sediments in the medium to long term.	NBS option likely to have a minor influence on channel form and function, and is likely to occur gradually overtime. Downstream reaches have not been assessed (Ruamāhanga confluence).
Increase in wood loading	NBS not targeted at increasing wood.	NBS option to have little/no influence on channel form and function.	Likely won't contribute to wood trapping or recruitment.	NBS option to have little/no influence on channel form and function.	NBS not targeted at increasing wood.	NBS option to have little/no influence on channel form and function.	NBS not targeted at increasing wood.	NBS option to have little/no influence on channel form and function.	NBS not targeted at increasing wood.	NBS option to have little/no influence on channel form and function. Downstream reaches have not been assessed (Ruamāhanga confluence).
Reduction in runoff	Can help reduce flows but not likely to cause geomorphic adjustment. Reduction in runoff likely to stay similar overtime.	NBS option likely to have a minor influence on channel form and function in downstream reaches, and is likely to occur gradually overtime.	Strategically placed storage devices will act to detain flows and reduce flood peaks in the short term by increasing flood storage.	NBS option to have a minor influence on channel form and function.	Reduced flows by detaining and retaining flows from smaller tributaries in upstream reaches.	NBS option likely to have a minor influence on channel form and function, and within the target reach is likely to occur gradually overtime. Not likely to alter form and function in downstream reaches.	Able to buffer some flow before entering these stream types. May result in aggradation in medium to long term.	NBS option likely to have a minor influence on channel form and function within the target reach, and is likely to occur gradually overtime. Unlikely to impact form and function of downstream reaches.	Can help retain and detain flows before reaching these stream types. May encourage aggradation in the medium to long term.	NBS option likely to have a minor influence on channel form and function, and is likely to occur gradually overtime. Downstream reaches have not been assessed (Ruamāhanga confluence).
Reduction in stream power	Can lower stream power but not likely to cause geomorphic adjustment as these reaches have low capacity for adjustment.	NBS option likely to have a minor influence on channel form and function in downstream reaches, and is likely to occur gradually overtime.	Reducing and delaying discharge will reduce stream power in the short term and potential for geomorphic change through aggradation in the medium to long term.	NBS option to have minor influence on channel form and function within and downstream of target reaches.	Reducing stream power through reducing discharge in the short to medium term. Reduction in flows may encourage minimal aggradation in the long term.	NBS option likely to have a minor influence on channel form and function within and downstream of the target reach, and is likely to occur gradually overtime.	Able to buffer some flow before entering these stream types in the short term. Potential to encourage aggradation in the long term.	NBS option likely to have a minor influence on channel form and function within the target reach, and is likely to occur gradually overtime. Not likely to alter form and function in downstream reaches.	Can help retain and detain flows before reaching these stream types. Potential to encourage aggradation in the long term.	NBS option likely to have a minor influence on channel form and function, and is likely to occur gradually overtime. Downstream reaches have not been assessed (Ruamāhanga confluence).
Average score	**Low**	**Moderate**	**Low**	**Low**	**Moderate**	**Moderate**	**Low**	**Low**	**Moderate**	**Moderate**

Table Appendix A.4: Expected geomorphic response and geomorphic effectiveness of the key benefits of 'channel realignment/reconnection of oxbows/Room for the river (including relocation of stopbanks)'

Key geomorphic benefit	Confined, low sinuosity cobble/boulder bed		Partly confined, moderate/high sinuosity gravel bed		Partly confined, low sinuosity gravel bed		Unconfined, artificially straightened gravel bed		Artificially confined, low sinuosity gravel bed	
	Expected geomorphic response	Geomorphic effectiveness	Expected geomorphic response	Geomorphic effectiveness	Expected geomorphic response	Geomorphic effectiveness	Expected geomorphic response	Geomorphic effectiveness	Expected geomorphic response	Geomorphic effectiveness
Reduction in sediment load	Reaches not typically (artificially) disconnected/ realigned	NBS option to have little/no influence on channel form and function.	Likely to alter river character and behaviour by reactivating sediment sources in the short term and enabling channel adjustment in the medium to long term.	NBS option likely to have a major influence on channel form and function within and downstream of target reach, and is likely to occur gradually overtime.	Allows sediment to be distributed and settle across the floodplain in the short term. Reduced sediment delivery to downstream reaches in the medium to long term.	NBS option likely to have a major influence on channel form and function within and downstream of target reach, and is likely to occur gradually overtime.	Unlikely to impact these stream types	NBS option to have little/no influence on channel form and function.	Helps to dissipate sediments across the floodplain in the short term. Reduction in fine grained sediment in upper reaches could trigger incision in the long term.	NBS option to have little/no influence on channel form and function. Downstream reaches have not been assessed (Ruamāhanga confluence).
Increase in wood loading	Reaches not typically (artificially) disconnected/ realigned.	NBS option to have little/no influence on channel form and function.	Not likely to influence wood loading.	NBS option to have little/no influence on channel form and function.	Increased wood sources.	NBS option to have little/no influence on channel form and function.	Unlikely to impact these stream types.	NBS option to have little/no influence on channel form and function.	Unlikely to contribute to wood loading.	NBS option to have little/no influence on channel form and function. Downstream reaches have not been assessed (Ruamāhanga confluence).
Reduction in runoff	Reaches not typically (artificially) disconnected/ realigned.	NBS option to have little/no influence on channel form and function.	Reducing discharge through spreading water across a larger area in the short to long term.	NBS option likely to have a major influence on channel form and function within and downstream of the target reach and is likely to occur gradually overtime.	Dissipates flows across the floodplain and encourages floodplain storage. Enhances geomorphology of floodplain over time, including the reactivation of previous channel alignments.	NBS option likely to cause a rapid and /or permanent change in in channel form and function within the reach. Likely to have follow on effects to form and function in downstream reaches.	Unlikely to impact these stream types.	NBS option to have little/no influence on channel form and function.	Creates greater sinuosity and slows flows. Alleviates flood risk in the long term.	NBS option likely to have a minor influence on channel form and function, and is likely to occur gradually overtime. Downstream reaches have not been assessed (Ruamāhanga confluence).
Reduction in stream power	Reaches not typically (artificially) disconnected/ realigned.	NBS option to have little/no influence on channel form and function.	Channel widening and reactivation of channels and floodplains can help reduce stream power and alter the planform of the reach.	NBS option likely to have a major influence on channel form and function within and downstream of the target reach, and is likely to occur gradually overtime.	Channel widening and reactivation of channels and floodplains can help reduce stream power and alter the planform of the reach.	NBS option likely to cause a rapid and /or permanent change in in channel form and function within the reach. Likely to have flow on effects to form and function in downstream reaches.	Unlikely to impact these stream types.	NBS option to have little/no influence on channel form and function.	Creates greater sinuosity and slows flows. Reduces ability for floods to cause geomorphic reworking, such as degradation and bank erosion.	NBS option likely to have a minor influence on channel form and function, and is likely to occur gradually overtime. Downstream reaches have not been assessed (Ruamāhanga confluence).
Average score	**Low**	**Low**	**High**	**High**	**High**	**Extreme**	**Low**	**Low**	**Moderate**	**Moderate**

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Appendix C. Hydrological modelling report

Waipoua land use change hydrology

Greater Wellington Regional Council

June 2025

BARNETT & MACMURRAY

LIMITED

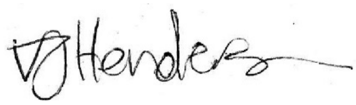
River, stormwater and coastal hydraulics • Onsite wastewater design

Quality control page

TITLE: WAIPOUA LAND USE CHANGE HYDROLOGY

CLIENT: GREATER WELLINGTON REGIONAL COUNCIL

JOB NUMBER BM1-504-2

Prepared by: 

Vicki Henderson, Hydraulic engineer

Status	Author (s)	Reviewed	Issue Date
Draft	Vicki Henderson	Hugh MacMurray	23 May 2025
Final			18 June 2025

Use and liability statement:

Cover picture: Forested slopes in the upper Waipoua catchment

Greater Wellington Regional Council
Waipoua land use change hydrology

Contents

1. Introduction

Barnett & MacMurray Ltd (BM) was engaged by Greater Wellington Regional Council (GW) to undertake modelling of land use changes in the Waipoua catchment.

The aim of the work is to assess the feasibility of nature-based solutions in the Waipoua catchment, which has included the use of hydrological and hydraulic models. Nature-based solutions have a number of benefits, but the focus of this work is their potential for flood reduction. A number of nature-based solutions were shortlisted as being most practical and likely to be successful in the Waipoua catchment (Tonkin & Taylor, Jan 2025). This report is concerned with the nature-based solutions which can be assessed using a hydrological model. These are:

- Retirement of hillslope land and revegetation with native forest; referred to in this report as forest scenarios;
- Small scale, distributed detention storage, described in this report as distributed detention scenarios.

These approaches have been investigated using an existing hydrological model of the Waipoua catchment. This was developed in Hydstra software and has been used to produce historical and design flood hydrographs. The flood flows produced by the Hydstra model are used as input for a 2 dimensional hydraulic model of the Waipoua River and floodplain.

1.1 Model

The hydrological model of the Waipoua was built in Hydstra, a flexible catchment process simulation software. Key elements of the Waipoua model are:

- Model is made up of 14 subcatchments, linked by a channel network
- Loss model is initial and constant loss
- Catchment overland flow is non-linear storage routing
- Channel flow is non-linear storage routing

The calibrated Waipoua hydrological model from 2023 has been used as the baseline for the current land use change modelling. The current modelling baseline uses model version K6 for the existing situation. In version K6 some parameters differ between the hills and plains subcatchments. For more details on the hydrological model see Section 3 of the Waipoua hydrology update (BM, 2023).

1.2 Events

The scenarios were run with 6 present day design events and two future events allowing for climate change. The events were:

- 1% AEP (100 year), with and without climate change,

- 2% AEP (50 year), with and without climate change,
- 5% AEP (20 year),
- 10% AEP (10 year),
- 20% AEP (5 year),
- and 39% AEP (2 year),

where AEP stands for annual exceedance probability.

The climate change events were the 1 and 2% AEP storms, assuming warming driven by IPCC's Representative Concentration Pathway 6 (RCP6) emission scenario to the period 2081-2100 (IPCC, 2014). This is a medium-high emissions scenario, with emissions peaking in 2080 and then declining. Design rainfall depths for each storm were taken from NIWA's High Intensity Rainfall Design System version 4. They have been scaled to 90% as used in the earlier calibration. Details of the design rainfall application in the Waipoua model can be found in the report Waipoua Hydrology Update (BM, 2023).

2. Forest

2.1 Forest scenarios

The hydrological model has been used to see what effect current and increased forest has on the catchment runoff. In the hydrology model a forest fraction can be applied at each catchment node. The model uses the forest fraction to derive a factor which slows the runoff routing across the catchment. This lag factor, k, is related to the fraction of forest, F in this way:

$$k \propto (1 + F)^2$$

This means that forest in a catchment will slow down the water running off to the river. The model does not distinguish between different sorts of forest. Forest area in the model has no effect on runoff volume, because the model uses a simple initial and constant loss method to calculate runoff volume before it is routed. The routing only affects how fast the water runs off over the catchment. However, real forests do have some effect on runoff volume, increasing initial detention area with their branches and leaves and enhancing soil uptake of moisture by increasing pore space and humus. This effect is difficult to quantify, and has been investigated by a number of research groups. The widely used US Soil Conservation Service curve number method (SCS, 1986) estimates a runoff percent from rainfall based on soil type and land cover. For a 1% AEP storm in the Waipoua this method estimates forest to have 2.2 times the infiltration rate of grazed pasture land in fair condition, and 3.6 times the infiltration rate of crop land. A short term experiment conducted in Invercargill compared the infiltration rates of adjacent pasture, restored forest with trees up to 20 years old and old growth Kahikatea forest (Schwarz, 2020). While there were complicating factors in the experimental setup and infiltration varied widely, it was clear that the forest areas had higher infiltration rates. The infiltration rate in the restored forest was twice that in the pasture. Some of the infiltration rates measured in the Kahikatea forest area were very high, leading to questions about the robustness of the measurement method. But even considering the near-steady infiltration

rate after 1.5 hours, the average rate in the Kahikatea forest was around 7 times higher than the long term rate in the pasture. A longer term study in the UK investigated the effect of retiring plots of improved grassland from grazing, and of planting them in trees (Marshall et al, 2014). This study is relevant because it has examined exactly the process of reforesting that is proposed for the Waipoua. The study was based in temperate upland Wales, in an area with lower rainfall than the Waipoua catchment. Five years after the land use changes were made, median infiltration rates in the plots with planted trees were 67 times greater than infiltration rates in the grazed pasture plots. Surface runoff was also reduced by retiring the pasture from grazing, although the effect was less than half that of planting trees. The researchers acknowledged that by including small rainfall events in their analysis the results may overestimate the effects on runoff in large storms.
For this Waipoua catchment modelling it has been assumed that forest might increase the local infiltration rate by 3 times.
Two main forest scenarios and two infiltration sensitivity tests were investigated:

a) No forest
All the forest was removed from the model. This scenario demonstrates the effect that existing forest area has on catchment runoff, compared to no forest.

b) Forest increased to 35%.
The increased area of forest was based on what was considered practically achievable. A hillslope band across the catchment was identified by Tonkin and Taylor (T&T), in which land could be retired and revegetated in forest. This is shown in Figure 1. The target was for 40% of this area to become forest. The band was split across the underlying subcatchments of the hydrological model and 40% of each sub area was added to the total forest area of that subcatchment. Forest area was increased in 7 subcatchments. The effect was an increase in total forest area of about 1,700 hectares. The fraction of the Waipoua catchment in forest increased from 25% to 35%.

c) Existing forest – high infiltration
The existing forest in the Waipoua amounts to 25% of the total catchment area. The infiltration rate in these areas was increased to 4.5mm/hr, which is 3 times the background infiltration rate of 1.5mm/hr. An area weighted infiltration rate taking into account the increased infiltration in forest was calculated for each subcatchment.

d) Increased forest - high infiltration
The forest area was increased to 35%, as for scenario b). Then the infiltration rate in the forested areas was increased to 4.5mm/hour, which is 3 times the background infiltration rate of 1.5mm/hour. An area weighted infiltration rate was calculated for each subcatchment.

The forest area and infiltration rates for each scenario are shown in Table 1. Only those subcatchments with parameter changes are shown. There is no forest in the lower Waipoua.

Table 1: Afforestation scenario parameters

	Percentage area in forest		Effective infiltration rate with higher infiltration rate in forest (mm/h)	
Scenario	a	b	c	d
Subcatchment	Existing forest	Existing + new forest	Existing forest	Existing + new forest
0	3%	18%	1.59	2.04
1	50%	63%	3	3.39
2	46%	67%	2.88	3.51
3	96%	98%	4.38	4.43
4	15%	49%	1.95	2.98
5	51%	67%	3.03	3.50
6	17%	35%	2.01	2.55
7	0%	6%	1.5	1.68
Total	**25%**	**35%**		

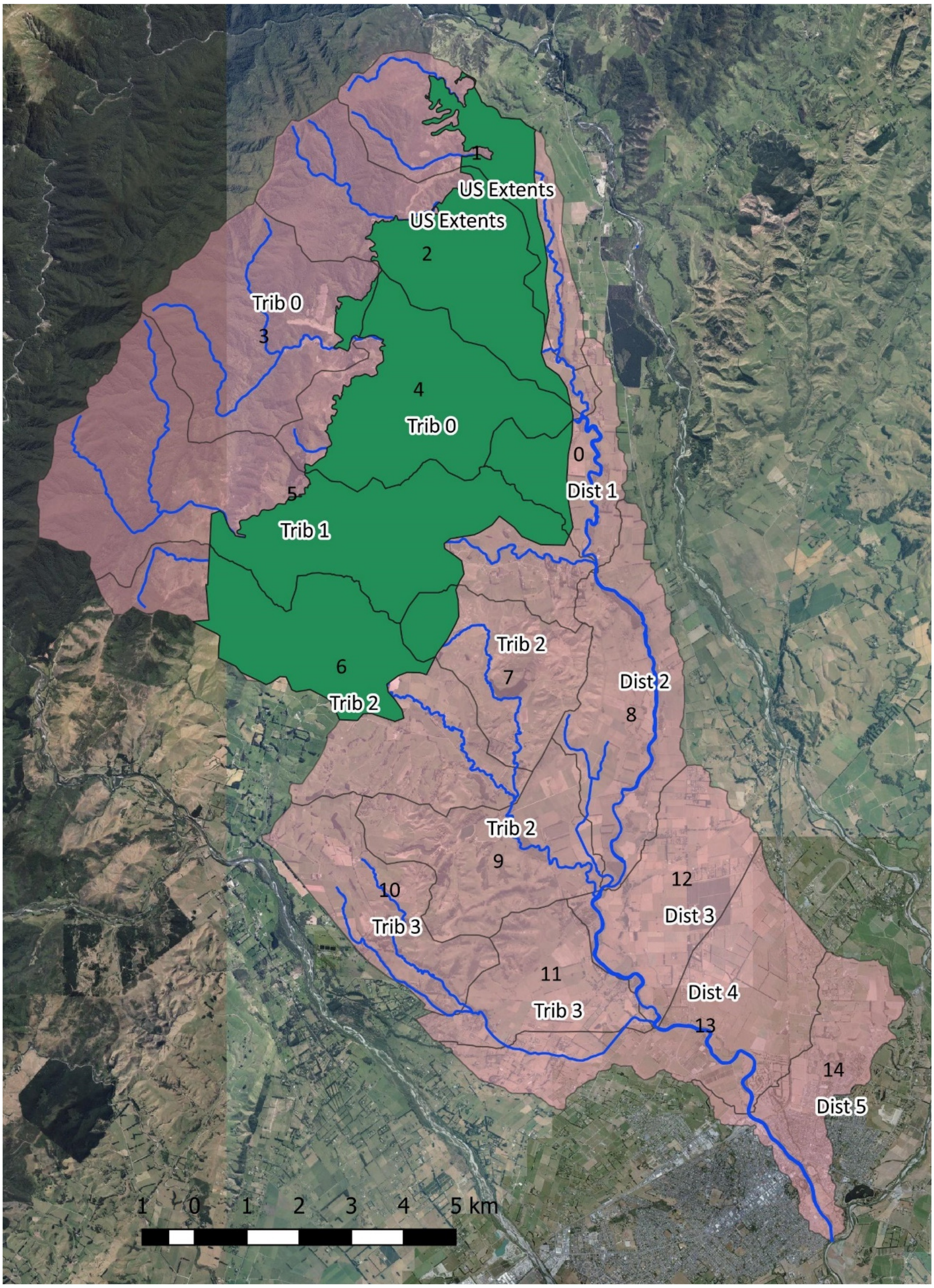


Figure 1: Waipoua catchment; area of increased forest shown in green, hydrological catchments in plain black text, hydraulic model catchments in black text with white background.

The subcatchments vary in size, so that even if the forest fraction is large, the actual forest area may be quite small. The actual forest areas in each subcatchment are shown in Figure 2. The increase in forest area is greatest in catchments 2, 4, 5 and 6. Catchment 5 has both the largest existing forest area and the greatest increase in forest area. In the model the increased forest scenario adds about 1,700 hectares of new forest to the Waipoua catchment. The no forest scenario represents removal of about 4,180 hectares of forest.

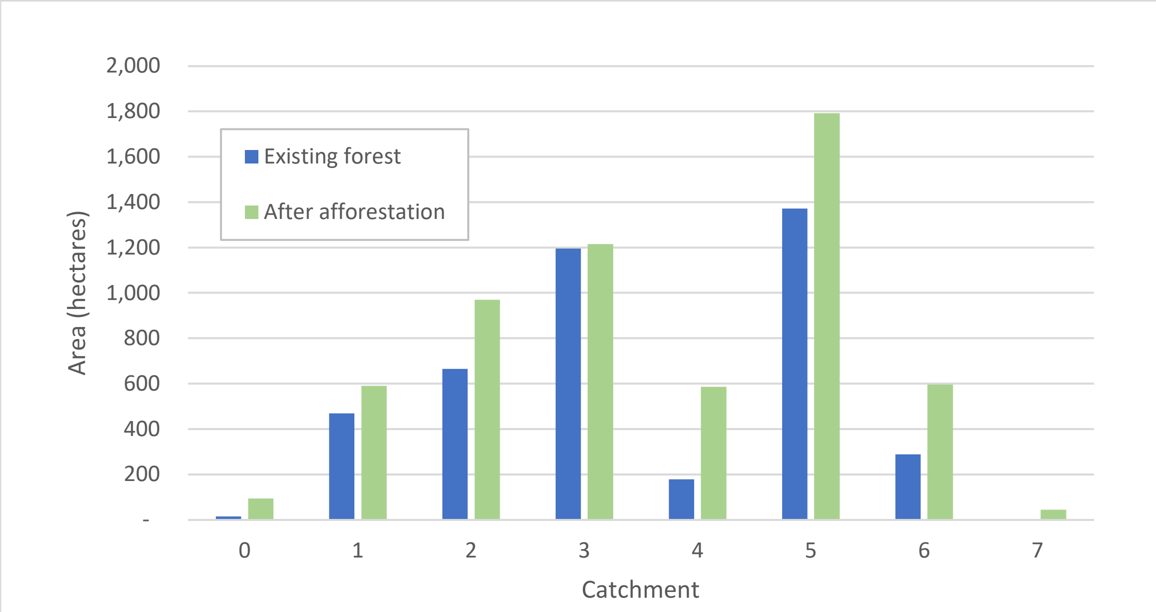


Figure 2: Forest areas in the upper Waipoua catchment

2.2 Forest outcomes

The no forest scenario represents a 25% loss in Waipoua forest area, while the increased forest scenario means 35% forest; a 10% increase from the existing forest area. Design peak flows were increased in the no forest scenario and slightly reduced in the 35% forest scenario. This result reflects the scale of change in forest area. Greater reductions in peak flows were experienced with an increase in forest infiltration. The higher infiltration rate in forest reduced the runoff volume and the peak flows. As an example, the 1 % AEP peak flows from the catchments with adjusted forest parameters are shown in Figure 3. A similar pattern occurs in the other design events. The effects of the forest scenarios on the 1% AEP peak flows are in Table 2.

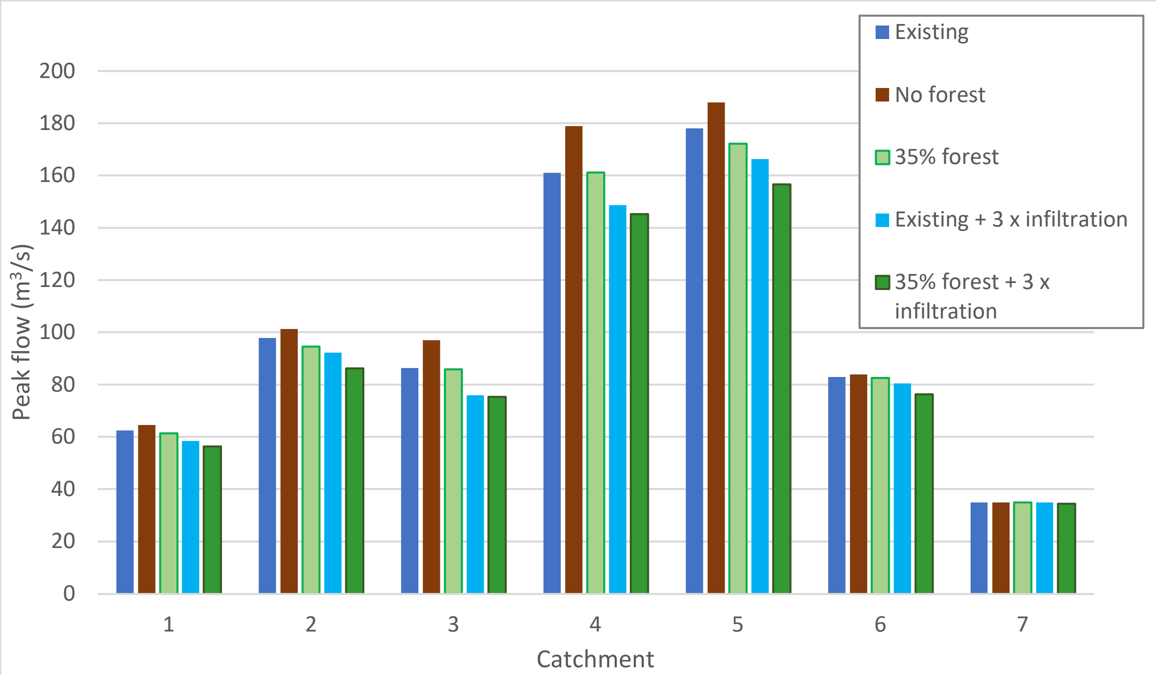


Figure 3: Waipoua 1% AEP existing climate peak catchment flows for afforestation scenarios

Table 2: Hydraulic model 1% AEP existing climate peak inflows and percentage differences for afforestation scenarios.

Hydraulic model catchment flows were used in the Waipoua hydraulic model (Land River Sea, 2025). Hydstra catchment names are those used in the hydrology model

Scenario		Existing	No forest	35% forest	Existing	35% forest
Infiltration		Standard			3 x	
Catchment		Peak flow (m^3/s)	Percent difference from existing peak flow*			
Hydraulic	Hydstra					
US_Extent	1 + 2	144	4%	-3%	-7%	-12%
Trib_0	3 + 4	158	11%	0%	-8%	-10%
Trib_1	5	165	6%	-3%	-7%	-13%
Trib_2	6 + 7 + 9	143	1%	-1%	-2%	-6%
Dist_1	0	25	0%	-1%	-1%	-4%

*A percentage above 0 means the peak flow was greater than existing peak flow (cells shaded red) and a negative percentage means the peak flow was less than existing (cells shaded green).

Forest changes had the most effect on peak flows from subcatchments 4 and 5. No forest increased 1% AEP peak flows by up to 11%. The increased forest area scenario reduced 1% AEP peak flows by up to 3%. The existing forest area with forest infiltration rate 3 times the standard rate reduced 1% AEP peak flows by up to 8%. A combination of increased forest area with 3 times the infiltration rate in forest reduced 1% AEP peak flows the most – by up to 13%.

Increased forest area delayed the catchment flood peak by about 15 minutes in the 1% AEP design event. The no forest area scenario accelerated the catchment flood peak by about 30 minutes in the 1% AEP event. Because the design rainfalls all have a 12 hour duration, there were similar changes to peak times in the other design events.
The 1% AEP hydrographs for Trib 1 (coming from catchment 5), are shown for the various scenarios in Figure 4. Trib1 is the input for the 2d hydraulic model which has the highest peak flow.

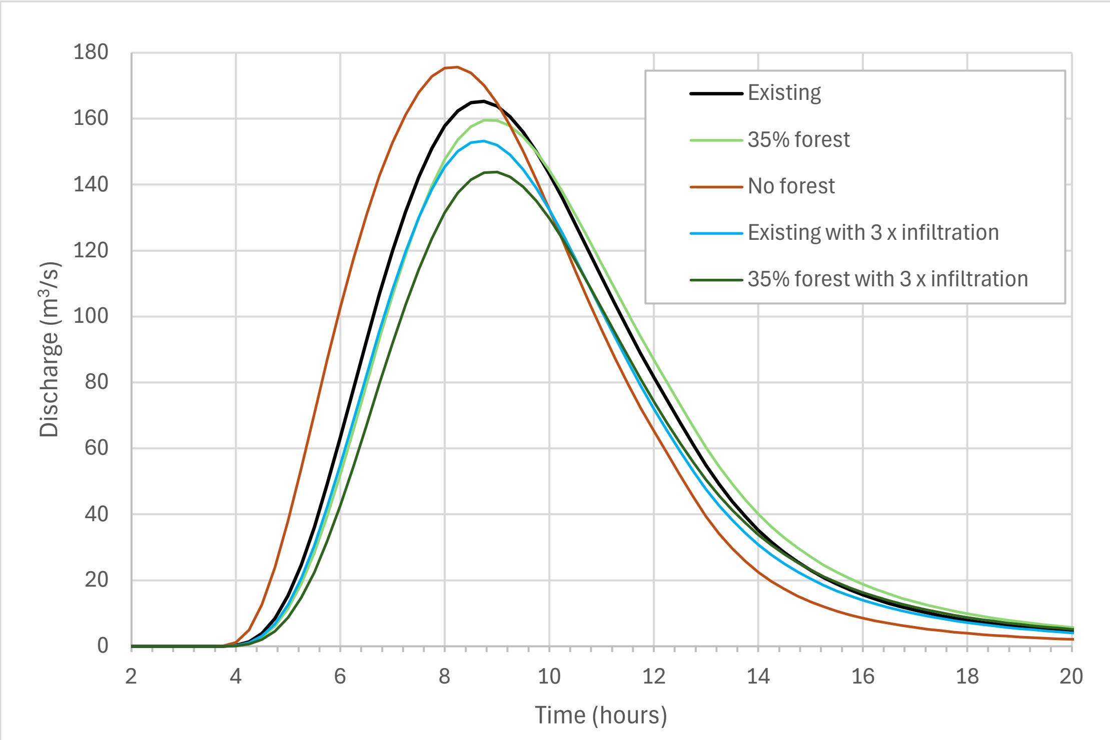


Figure 4: 1 % AEP runoff hydrographs for Trib 1 (from catchment 5)

The no forest case increased the peak 1% AEP flow by 6% and the increased forest case reduced the peak flow by 3%. The greatest decrease in 1 % AEP peak flow was 13% for the increased forest case with a threefold increase in forest infiltration. The other hydraulic model input hydrographs with adjusted forest parameters also had reduced peak flows, but Trib1 showed the greatest reductions. The effect of parameter changes on peak flows was greatest for the minor events. For example, in the 39% AEP event in Trib1, peak flow was reduced by 29% with increased forest and a threefold increase in forest infiltration.

The 1% AEP runoff yields (runoff volume / rainfall volume) for the whole catchment are in Figure 5.
Results for no and 35% forest with standard forest infiltration have the same runoff volume as existing because in the model the change in forest area affects runoff **routing**, but not runoff **volume**.

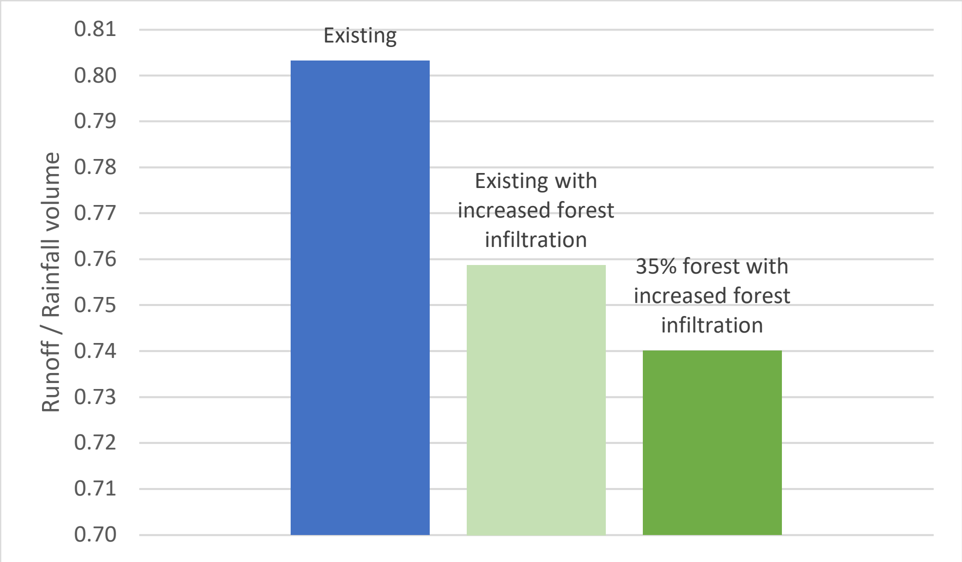


Figure 5: Waipoua 1% AEP runoff yields, afforestation scenarios

With increased forest infiltration, total runoff yield for the 1% AEP event was reduced by 4%. When forest area was increased to 35% combined with increased forest infiltration, total runoff yield decreased by a further 2%. As absolute volumes, the 1% AEP runoff volume reduced by 1,094,000m^3 and 1,554,000m^3 (for existing forest with increased infiltration and 35% forest with increased forest infiltration respectively).

The runoff yield for all design events is given in Table 3.

Table 3: Waipoua runoff yields all design events

	Percent runoff volume / rainfall volume		
Scenario	Existing		35% forest
Forest infiltration	1 x	3 x	3 x
Design event			
1% AEP + climate change	83%	79%	77%
2% AEP + climate change	81%	77%	75%
1% AEP	80%	76%	74%
2% AEP	78%	73%	71%
5% AEP	75%	69%	67%
10% AEP	71%	65%	63%
20% AEP	67%	60%	57%
39% AEP	61%	54%	51%

Overall, a threefold increase in forest infiltration reduced runoff yield by 4% for the biggest storms and by 7% for the smallest storms. With 35% forest area and a threefold infiltration increase, runoff yield decreased by a further 2-3%.

3. Distributed detention

Distributed detention is the practice of forming many small elements across the catchment which store water and slow and attenuate flows. Examples include leaky dams, wetlands and retention devices. A woody dam is shown in Figure 6.

Figure 6: One of a series of woody dams installed in Cumrew beck to reduce flooding in Cumrew Village, near Carlisle, UK. © Eden Rivers Trust

Apart from reducing flood flows, distributed detention has other effects including trapping sediment, increasing stream environment diversity, spilling water out of channel into nearby floodplain areas during high flows and developing braided channels and other flowpaths over time. These effects have not been considered in this hydrological modelling.

3.1 Detention scenarios

T&T provided a starting point for the detention scenarios, based on practical factors, such as where detention could be added to streams. Three hundred cubic metres of detention storage per hectare was allowed in 7 mid and lower elevation Waipoua subcatchments. The area where detention storage was allocated in the model is highlighted in Figure 7. The detention volume per subcatchment was calculated and is in Table 4.

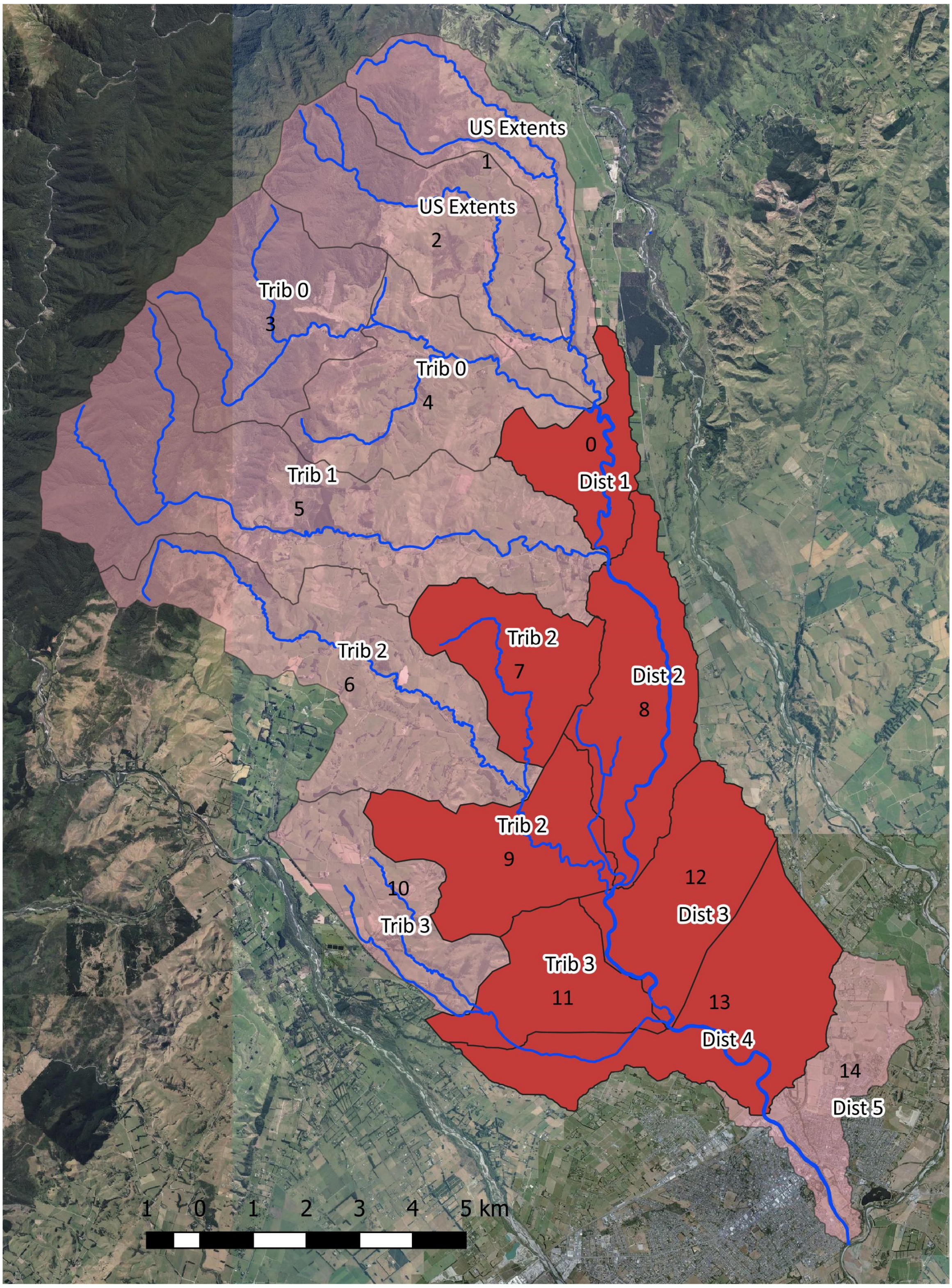


Figure 7: Waipoua catchments with distributed detention; hydrological catchments in plain black text, hydraulic model catchments black text with white background.

Table 4: Detention storage volumes attributed to Waipoua catchments

Catchments			
Hydraulic	Hydstra	Area (hectares)	Detention (m^3)
Dist 1	0	520	155,876
Trib 2	7	734	220,080
Dist 2	8	1061	318,182
Trib 2	9	932	279,588
Trib 3	11	649	194,782
Dist 3	12	843	252,988
Dist 4	13	1295	388,534
Total			**1,810,029**

The flow timeseries collected from the Hydstra hydrology model are applied to the hydraulic model under different names. These names are provided for reference in Table 4. The applied detention amounts to about 1.8 million cubic metres of storage.

The detention was envisaged as being many small leaky dams, only 1.5m high with a certain low level outlet, allowing low flows to pass through, but restricting higher flows and storing them until the dam overflowed.
T&T provided a depth – storage relationship corresponding to a typical small dam. This is in Table 5.

Table 5: Typical depth - storage relationship for a small dam.

Depth (m)	% cumulative volume
0	0
0.25	2.7
0.5	12.1
0.75	27.5
1	47.3
1.25	71.4
1.4	88.6
1.5	100

The depth – storage volume relationship was used to size the unit storage in initial testing and the catchment scale storages in the Hydstra model.

The characteristics of the small dams were developed using a small Aulos (produced by Hydra Software) hydraulic model. A representative small detention was built, with a particular low level outlet pipe. This provided the level – discharge relationship for a "Unit" detention, equivalent to 10 hectares of catchment, with 3,000m^3 of total storage volume (300 x 10ha following the rule of thumb for detention storage across catchment area).
Two detentions with different size outlets were built in the "Unit" model:

- 375mm nominal diameter outlet passing up to 520 Litres/s (Scenario 1)

- 300mm nominal diameter outlet passing up to 370 Litres/s (Scenario 2)

Each had a crest level at 1.5m high. If the detention filled up, water would also overflow the crest. At that point outflow from the detention would equal inflow.

In the Hydstra model, the distributed detention was represented as a single detention element in each affected subcatchment. The level – flow and storage relationship from the Aulos "Unit" model was scaled up relative to each subcatchment area in the Hydstra model. Each of the detentions with it's different outflow was tested in the Hydstra model to see which had the most effect on flood peaks.
A schematic of the model showing the detention elements is in Figure 8.

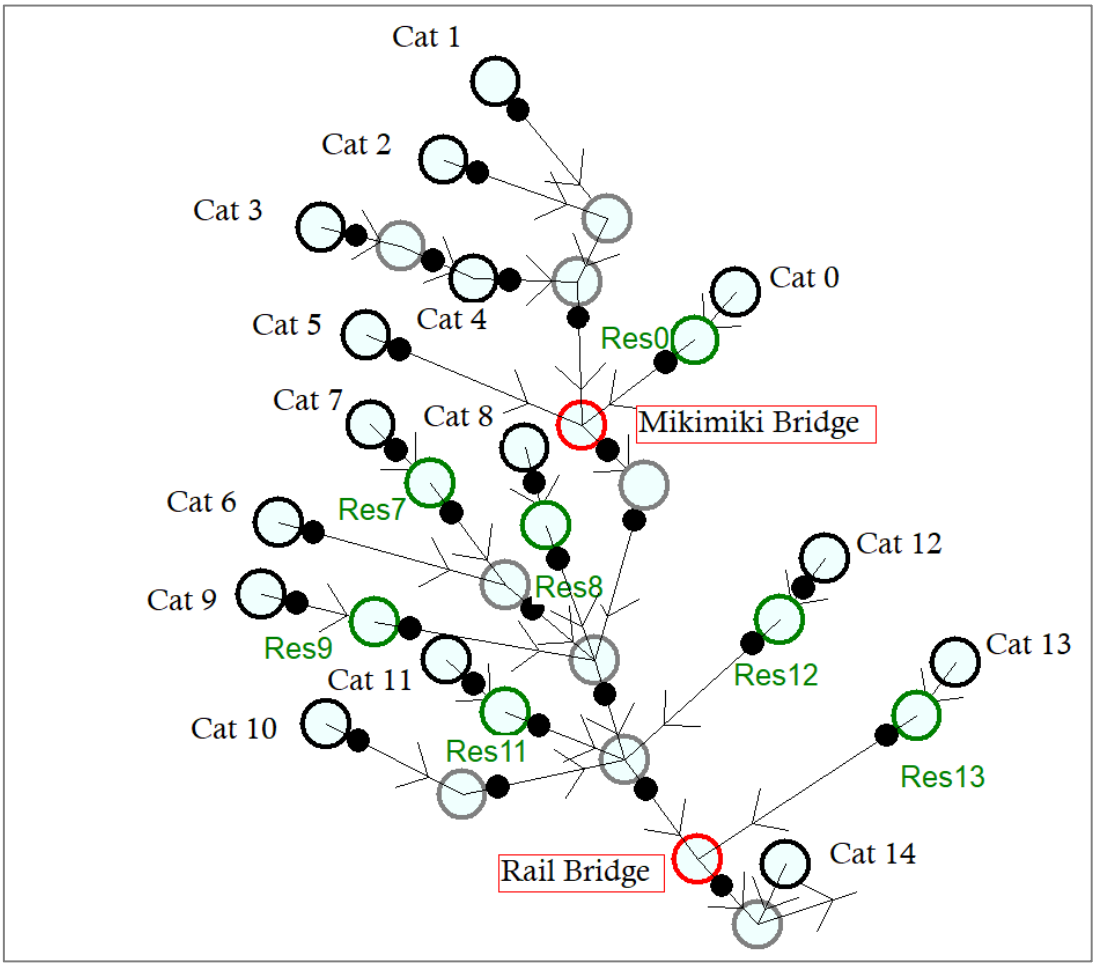


Figure 8: Waipoua Hydstra distributed detention model schematic

Detention elements are in green, catchments in black and landmarks are in red.
The two different outlet models were tested with the 1% AEP design event in the Hydstra model. The smaller outlet arrangement, with a top flow of 370 Litres /s through the low outlet for a unit detention produced the best outcomes across the hydrology subcatchments in the 1% AEP design event. This detention arrangement, called S2, was then run for the full set of design events.

3.2 Detention outcomes

The chosen detention scenario allows for 300m^3 of storage per hectare applied across 7 Waipoua catchments. The detention elements represent many small dams, with a depth of 1.5m and a low level outlet pipe. For every 10 hectares of contributing area, the dams allow up to 370 litres per second to escape through the low level outlet before overtopping.

3.2.1 Best use of detention

The detention elements in the hydrology model have been optimised for the 1% AEP present day event. This means that the detention elements were sized to fill up in this event.
The detention dams in the Waipoua subcatchments were best utilised in the 1 and 2% AEP events. This is demonstrated by the top water levels in the model detention dams shown in Table 6.

The top level in the detention dams before they overflow is 1.5 metres. Events where a dam overtopped are shaded pink.

Table 6: Comparison of top detention dam fill levels, storage scenario S2

The number of each dam refers to the hydrology subcatchment where it is located.

		Top detention dam level (m)							
	Event AEP	39%	20%	10%	5%	2%	1%	2% +CC	1% +CC
Dam	Hydraulic model inflow								
Res0	Dist 1	0.59	0.76	0.93	1.08	1.30	1.47	1.49	1.51
Res7	Trib 2	0.67	0.83	0.98	1.13	1.32	1.48	1.49	1.51
Res8	Dist 2	0.78	0.95	1.12	1.28	1.48	1.51	1.51	1.52
Res9	Trib 2	0.62	0.78	0.93	1.08	1.28	1.44	1.48	1.51
Res11	Trib 3	0.56	0.70	0.85	0.99	1.18	1.32	1.36	1.49
Res12	Dist 3	0.56	0.71	0.85	1.00	1.19	1.33	1.37	1.49
Res13	Dist 4	0.51	0.64	0.78	0.92	1.10	1.24	1.27	1.43

Just one dam overtopped in the 1% AEP event. The rest of the dams were fairly close to full. In the 2% AEP event, none of the dams overtopped, but a few were nearly full.
The bigger flows in the 1% AEP + climate change event caused four of the dams to overtop. The dams in this detention scenario are not as effective at reducing the flow in this climate change event because more of the detentions overflow and the outflow is no longer controlled by the outlet pipe. This trend would continue for even larger events. In smaller events, the outlet pipe does less to throttle the lower peak flows, leading to smaller reductions in peak flow as the events become milder.
The greatest reduction in peak flows was achieved in the 1% AEP existing climate design flood because the detention was optimised for this scale of flow. It would also be possible

to optimise the detention for more or less severe floods by adjusting the depth- storage-discharge relationship.

Optimising the detention is also a balancing act across the different subcatchments. The detention dam in Dist2 (outflow from catchment 8) fills the most in each event and that in Dist4 (outflow from catchment 13) consistently has the lowest level. This is because each subcatchment has a unique rainfall and topography producing different runoff volumes and intensities.

3.2.2 Detention results

The detention elements added to the catchments affected the size of peak flows and delayed the peak flows. In the model the runoff volume was not affected, although real distributed detention may increase local infiltration. The effect on the catchment hydrographs varied.

The maximum flow and storage for the detention scenario S2, which had the best outcome is shown below.

Table 7: Peak 1% AEP values for detention elements for storage model S2

The number of each dam refers to the hydrology subcatchment where it is located.

Storage model S2							
Dam	Inflow	Outflow	Level	Time of inflow	Time of outflow	Outflow / inflow	Delay
	(m^3/s)	(m^3/s)	(m)	(hours)	(hours)	(%)	(hours)
Res0	25.4	16.8	1.47	7.5	9.75	66%	2.25
Res7	34.6	26.1	1.48	7.75	9.25	76%	1.5
Res8	58.0	53.7	1.51	7.75	8.75	93%	1
Res9	42.5	29.3	1.44	8	9.25	69%	1.25
Res11	27.0	19.5	1.32	7.75	9.75	72%	2
Res12	35.4	25.5	1.33	7.75	9.75	72%	2
Res13	49.8	36.7	1.24	7.75	9.5	74%	1.75

Across all the detention elements, peak flows into and out of the dams were reduced by 26% on average in the 1% AEP event. In the 1% AEP + climate change, peak flows were only reduced by 13% on average.

Peak level achieved in most of the dams was between 1.3 and 1.5m, where the dam crest is at 1.5m. Only one dam overtopped in the 1% AEP event (Res8, in catchment 8, which contributes to the Dist2 hydraulic model inflow). Peak outflow was reduced in most cases by around 30%, and delayed by 1-2 hours.

Note that these results are for the detention in the hydrological model. The inflows to the hydraulic model are different because they may be altered, combined and concentrated as they move downstream in the channels of the hydrology model.

Trib2 (the combined outflow from catchments 6, 7 + 9) yielded the highest peak flows from an area with detention storage added. Effects on the peak flows for Trib2 for the range of design events are in Table 8. The detention storage was in catchments 7 and 9 (see Figure 8).

Table 8: Detention effects on hydraulic model inflow Trib2

	Peak flows (m^3/s)		Percent difference to existing peak flow
Event	Existing	Storage 2	Storage 2
1% AEP RCP6	171	159	-7%
2% AEP RCP6	150	129	-14%
1% AEP	143	123	-14%
2 % AEP	124	108	-13%
5% AEP	101	90	-11%
10 % AEP	84	77	-8%
20% AEP	68	64	-6%
39% AEP	53	51	-3%

In the Storage 2 case, the peak discharge for Trib2 is reduced by 14% in the 1% AEP design event. This is the greatest percent reduction across the design events and slowly becomes less for both larger and smaller events. This is because the detention has been optimised for the 1% AEP event. Design events down to the 5% AEP still have peak discharge reduced by at least 10%.

<u>What is the detention effect on the flood hydrographs?</u>
A range of results are presented here, including those for the catchments with the biggest and the smallest flow and also an outflow which combines subcatchments with and without detention. Plots for the 1% AEP flood in Trib2, Dist1 and Trib3 are shown in the following figures. Hydrographs for the Storage 1 scenario are included in the plots for comparison. The S1 scenario generally achieved some reductions in peak flow, but not as much as the S2 scenario.

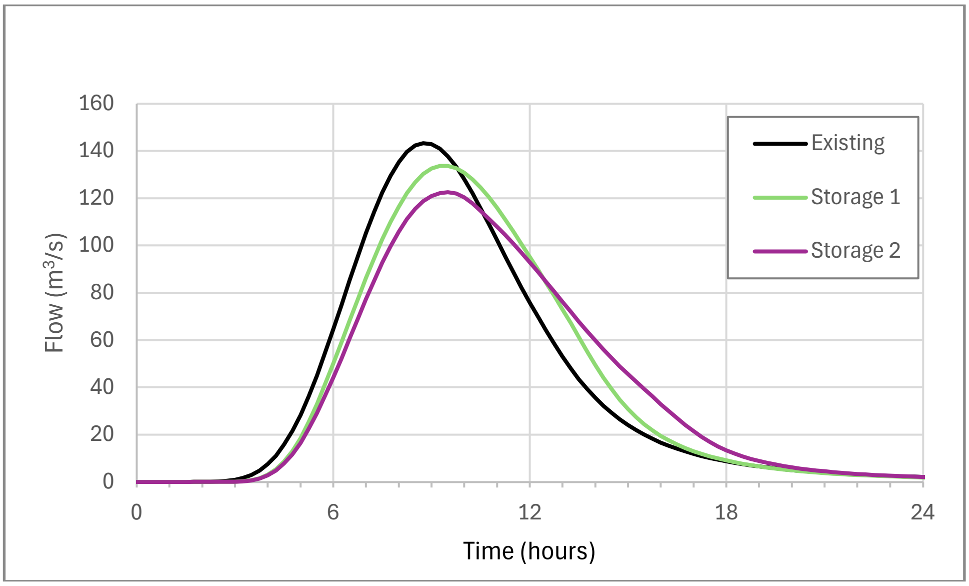


Figure 9: Distributed storage effects - Trib 2- 1% AEP

Trib2, (the combined outflow from catchments 6, 7 and 9); which had the biggest outflow of all the catchments; had a 7% reduction in peak flow in Storage 1 scenario and 14% reduction in Storage 2 scenario.

The effect of detention on the outflow for Dist1 (outflow from catchment 0) is even stronger than for Trib2 – a 33% reduction in peak flow in the Storage 2 scenario. Dist1 also had the lowest peak flow of all the catchments to start with: 25m^3/s.

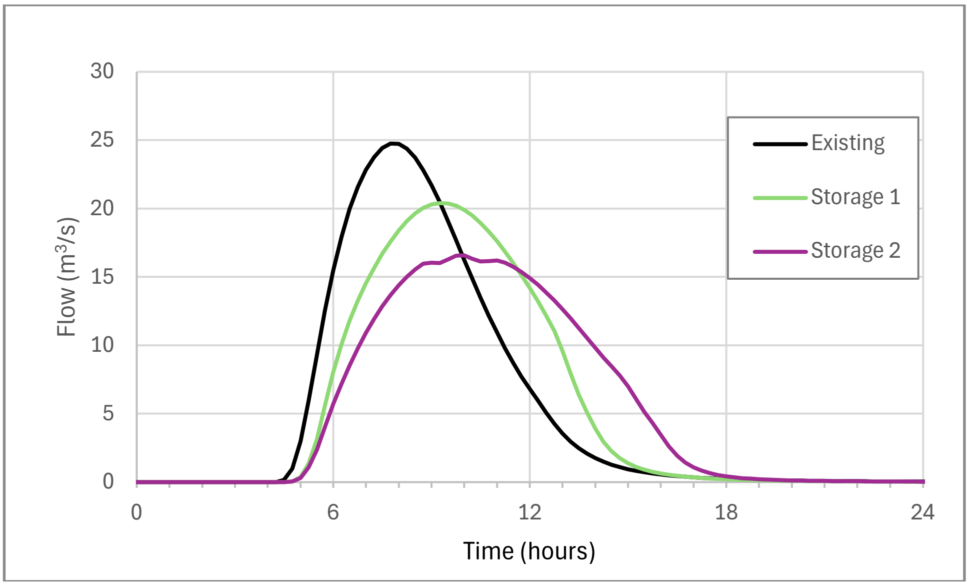


Figure 10: Distributed storage effects - Dist1 - 1% AEP

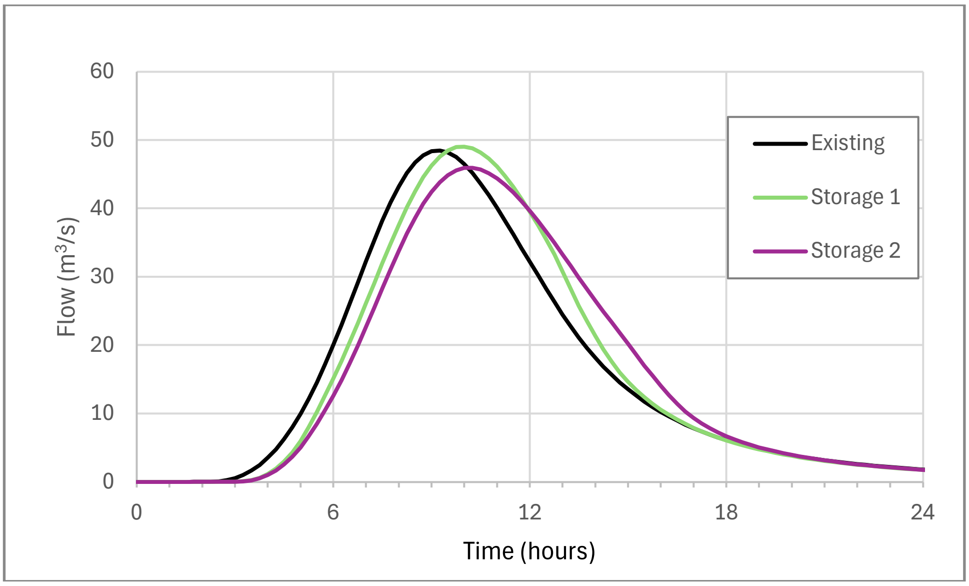


Figure 11: Distributed storage effects - Trib3 - 1% AEP

Trib3 (the combined outflow from catchments 10 and 11), demonstrates one of the potential complications of modelling the distributed detention approach. In Trib3 hydrographs, the detention does not seem to have much effect on the peak flow– in the Storage 1 case, the peak outflow is actually higher than existing. This is because Trib3 involves the outflow from two separate catchments – catchment 10 upstream and catchment 11 downstream. Adding a detention element in catchment 11 slows down the runoff, so that the peak runoff from catchment 10 catches up with the downstream flood. The result is a peak flow with detention that is similar to the existing case, despite the peak flow from catchment 11 being reduced.

The detention elements detain flood water and slow flood peaks. The effect on time to peak for all the hydraulic model inflows in the 1% AEP event is shown in Figure 12 .

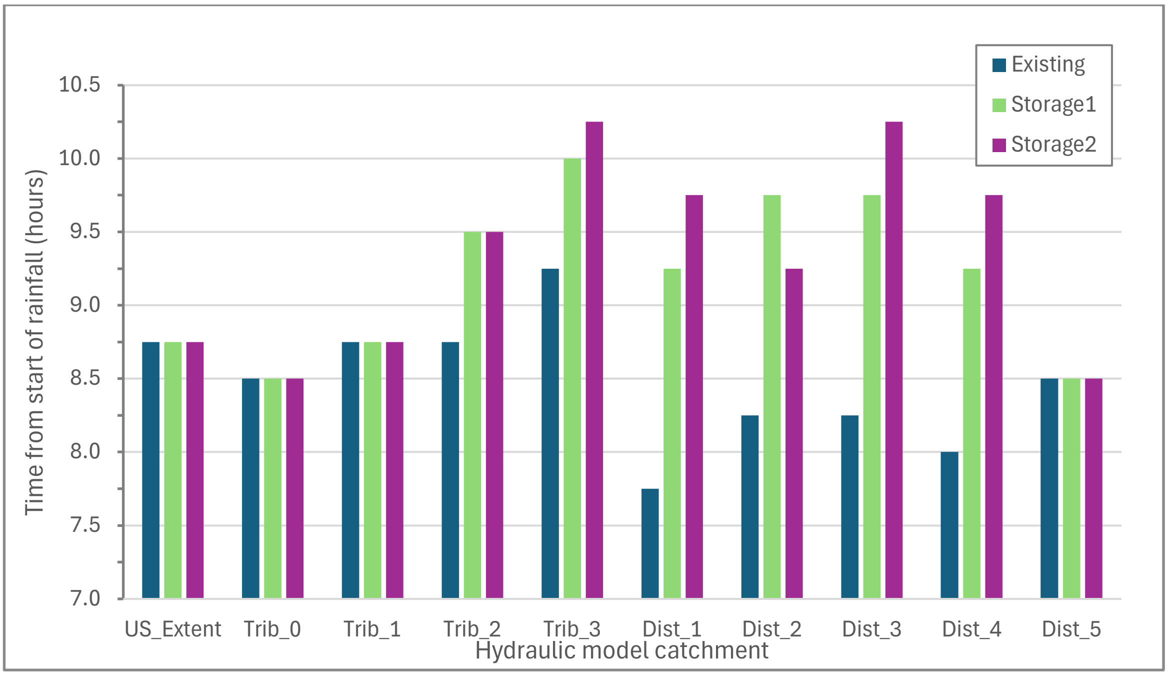


Figure 12: Waipoua hydraulic model inflows - time to peak in 1% AEP design storm

The hydraulic model inflows where the time to peak stays the same are those without detention storage. There is some delay in the bigger flows from Trib2 and Trib3 and a longer delay in the smaller flows from all the Dist inflows. The interaction of the delayed flows after they reach the Waipoua River, and in particular the reach in Masterton, needs careful consideration. What might be a valuable local reduction in flood peak for a subcatchment may contribute to a higher flood peak downstream – for example at the Rail Bridge. This can occur if delays in flood peaks cause more subcatchment peak flows to arrive downstream at the same time. The hydrological model has indicated that this is occurring, but the definitive results come from the hydraulic model, which includes the floodplain and a more accurate channel representation (Land River Sea, 2025).
The delay caused by detention elements has been calculated collectively across all the Waipoua catchments. The mean and standard deviation of the time to peak are given for each scenario in Table 9. The forest scenarios are included for comparison.

Table 9: Time to peak statistics, 1% AEP design storm

All catchments	Time to peak (hours)			
Scenario	Mean	Std. dev.	Min	Max
Existing	8.48	0.41	7.75	9.25
35% forest	8.58	0.42	8	9.25
No forest	8.33	0.40	7.75	9.25
Storage 2	9.33	0.64	8.50	10.25

Note that these statistics include the outflows from catchments which have not been altered for the land use change modelling. The detention scenarios have delayed the average time to peak by a reasonable margin – around ¾ of an hour. The standard deviation of time to peak for the various catchments is also increased, meaning they are

more spread out. The effect of the 35% forest scenario on average time to peak was a delay of just 6 minutes. No forest resulted in a faster average time to peak by about 10 minutes.
The hydrology model uses one possible rainfall pattern, and a storm duration lasting 12 hours. These are the same for all the subcatchments. Other rainfall patterns are possible, and would affect the relative timing of flood peaks.

4. Conclusions

An existing hydrology model has been used to investigate the effects of nature-based solutions in the Waipoua catchment. The main aim of the solutions was to reduce flood effects. The land use changes simulated in the hydrological model were:

- Changes to forest area
- Increase in infiltration in forested areas
- Distributed detention.

4.1 Forest changes

The following conclusions were made for the forest land use changes in the hydrological model:

1) The no forest scenario increased 1% AEP peak flows by up to 11%.
2) An increase in Waipoua forest area from 25 to 35% reduced 1% AEP peak flows by up to 3%.
3) The existing forest area with forest infiltration rate 3 times the background rate reduced 1% AEP peak flows by up to 7%.
4) A combination of increased forest area with 3 times the infiltration rate in forest reduced 1% AEP peak flows the most – by up to 13%.
5) Increased forest area and increased infiltration rate in forest had more effect on peak flows in smaller events.
6) Catchment flood peaks were accelerated by about 30 minutes in the no forest scenario and delayed by about 15 minutes in the 35% forest scenario.
7) Across the whole Waipoua catchment a threefold increase in forest infiltration reduced runoff yield by 4% for the biggest storms and by 7% for the smallest storms. With 35% forest area and a threefold infiltration increase, runoff yield decreased by a further 2-3%.

4.2 Detention

The following conclusions were made for the distributed detention land use changes in the hydrological model:

1) A level – storage – discharge relationship was derived based on practical parameters for distributed detention. These included an allocation of 300m^3 / hectare of

detention in the mid to lower catchment. The detention was based on 1.5m high dams and the typical depth- storage relationship was supplied by T&T (see Table 5). An outflow layout was optimised to nearly fill most reservoirs in the 1% AEP event. The chosen option assumed a low level outflow of up to 370 litres per second per every 10 hectares of contributing area, and outflow = inflow once the dam was overtopped. Lumped detention elements were added to seven catchments in the hydrology model.

2) The greatest reduction in peak flows was achieved in the 1% AEP existing climate design flood. This was because the detention was optimised for this scale of flow. It would also be possible to optimise the detention for more or less severe floods.
3) Peak 1% AEP flows were reduced by 26% on average by travel through the detention elements. Peak flows in the more severe 1% AEP + climate change event were reduced by 13% on average.
4) The detention effect on peak flows was affected by the intensity and volume of the applied rainfall. This varied per catchment due to topography and location.
5) The detention elements caused a delay in peak flows of 1-2 hours.
6) The changes in flood peak timing meant that sometimes detention was less effective in reducing flood peaks than expected.
7) Peak flow reductions seen at the detention elements did not always translate to peak flow reductions in the hydraulic model. Flow combination and routing effects as flows moved downstream sometimes caused unexpected effects.
8) For example, sometimes the delay in peak flows through detention in the lower catchments caused them to coincide with peak flows from upstream catchments further away.

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Appendix A Model log

Hydstra hydrology land use change model simulations

Event ARI (years)	Model name	Climate change?	Parameter set	Land use change	Rain scale
Existing case, present day, 90% design rainfall					
100	Waipoua Model 2020_Des100y12ha_K6.tso		K6		0.9
50	Waipoua Model 2020_Des50y12ha_K6.tso		K6		0.9
20	Waipoua Model 2020_Des20y12ha_K6.tso		K6		0.9
10	Waipoua Model 2020_Des10y12ha_K6.tso		K6		0.9
5	Waipoua Model 2020_Des5y12ha_K6.tso		K6		0.9
2	Waipoua Model 2020_Des2y12ha_K6.tso		K6		0.9
Existing case, climate change, 90% design rainfall					
100	Waipoua Model 2020_Des100y_CC6_12ha_K6.tso	RCP 6.0	K6		0.9
50	Waipoua Model 2020_Des50y_CC6_12ha_K6.tso	RCP 6.0	K6		0.9
Existing case, present day, 90% design rainfall; 3x infiltration in forest areas					
100	Waipoua Model 2020_Des100y12ha_K9.tso		K9		0.9
50	Waipoua Model 2020_Des50y12ha_K9.tso		K9		0.9
20	Waipoua Model 2020_Des20y12ha_K9.tso		K9		0.9
10	Waipoua Model 2020_Des10y12ha_K9.tso		K9		0.9
5	Waipoua Model 2020_Des5y12ha_K9.tso		K9		0.9
2	Waipoua Model 2020_Des2y12ha_K9.tso		K9		0.9
Existing case, climate change, 90% design rainfall; 3x infiltration in forest areas					
100	Waipoua Model 2020_Des100y_CC6_12ha_K9.tso	RCP 6.0	K9		0.9

Event ARI (years)	Model name	Climate change?	Parameter set	Land use change	Rain scale
50	Waipoua Model 2020_Des50y_CC6_12ha_K9.tso	RCP 6.0	K9		0.9
No forest case, 90% design rainfall					
100	Waipoua25_Des100y12ha_K6F0.tso		K6	F0	0.9
50	Waipoua25_Des50y12ha_K6F0.tso		K6	F0	0.9
20	Waipoua25_Des20y12ha_K6F0.tso		K6	F0	0.9
10	Waipoua25_Des10y12ha_K6F0.tso		K6	F0	0.9
5	Waipoua25_Des5y12ha_K6F0.tso		K6	F0	0.9
2	Waipoua25_Des2y12ha_K6F0.tso		K6	F0	0.9
No forest climate change design events to 2100, 90% design rainfall					
100	Waipoua25_Des100y_CC6_12ha_K6F0.tso	RCP 6.0	K6	F0	0.9
50	Waipoua25_Des50y_CC6_12ha_K6F0.tso	RCP 6.0	K6	F0	0.9
Increased forest case, 90% design rainfall					
100	Waipoua25_Des100y12ha_K6F35.tso		K6	F35	0.9
50	Waipoua25_Des50y12ha_K6F35.tso		K6	F35	0.9
20	Waipoua25_Des20y12ha_K6F35.tso		K6	F35	0.9
10	Waipoua25_Des10y12ha_K6F35.tso		K6	F35	0.9
5	Waipoua25_Des5y12ha_K6F35.tso		K6	F35	0.9
2	Waipoua25_Des2y12ha_K6F35.tso		K6	F35	0.9
Increased forest case, climate change events, 90% design rainfall			K6	F35	0.9
100	Waipoua25_Des100y_CC6_12ha_K6F35.tso	RCP 6.0	K6	F35	0.9
50	Waipoua25_Des50y_CC6_12ha_K6F35.tso	RCP 6.0	K6	F35	0.9

Event ARI (years)	Model name	Climate change?	Parameter set	Land use change	Rain scale
Increased forest case, 90% design rainfall; 3x infiltration in forest areas					
100	Waipoua25_Des100y12ha_K9F35.tso		K9	F35	0.9
50	Waipoua25_Des50y12ha_K9F35.tso		K9	F35	0.9
20	Waipoua25_Des20y12ha_K9F35.tso		K9	F35	0.9
10	Waipoua25_Des10y12ha_K9F35.tso		K9	F35	0.9
5	Waipoua25_Des5y12ha_K9F35.tso		K9	F35	0.9
2	Waipoua25_Des2y12ha_K9F35.tso		K9	F35	0.9
100	Waipoua25_Des100y_CC6_12ha_K9F35.tso	RCP 6.0	K9	F35	0.9
50	Waipoua25_Des50y_CC6_12ha_K9F35.tso	RCP 6.0	K9	F35	0.9
Distributed storage case events, 90% design rainfall					
100	Waipoua25_Des100y12ha_K6S1.tso		K6	S1	0.9
100	Waipoua25_Des100y12ha_K6S2.tso		K6	S2	0.9
50	Waipoua25_Des50y12ha_K6S2.tso		K6	S2	0.9
20	Waipoua25_Des20y12ha_K6S2.tso		K6	S2	0.9
10	Waipoua25_Des10y12ha_K6S2.tso		K6	S2	0.9
5	Waipoua25_Des5y12ha_K6S2.tso		K6	S2	0.9
2	Waipoua25_Des2y12ha_K6S2.tso		K6	S2	0.9
Distributed storage case, climate change events, 90% design rainfall					
100	Waipoua25_Des100y_CC6_12ha_K6S2.tso	RCP 6.0	K6	S2	0.9
50	Waipoua25_Des50y_CC6_12ha_K6S2.tso	RCP 6.0	K6	S2	0.9

March – April 2025	Number of runs: 33	Timestep:	15 minutes	Simulation length:	2 days
	Temporal distribution: DesRainDurationR_12hr.tsf				

Appendix D. Hydraulic modelling report

Waipoua River

Nature Based Solutions – Hydraulic Modelling Report

11 July 2025

Client: Greater Wellington Regional Council

Report by: Matthew Gardner
Land River Sea Consulting Limited
www.landriversea.com

Land River Sea CONSULTING

Greater Wellington Te Pane Matua Taiao

REVISION HISTORY

Author:	Matthew Gardner Water Resources Engineer, CMEngNZ, CPEng
Signature:	
Date:	11 July 2025
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Authorised by:	Francie Morrow
Signature:	
Organisation:	Greater Wellington Regional Council
Date:	

Land River Sea Consulting Limited

5/245 St Asaph Street

Christchurch

M: +64 27 318 9527

E: matthew@landriversea.com

W: landriversea.com

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1. INTRODUCTION

1.1. SCOPE

A design team comprising Land River Sea, and Barnett and McMurray Ltd. has been established by Greater Wellington Regional Council (GW) and Tonkin & Taylor (T&T) to investigate proposed nature-based solutions (NBS) in the upper Waipoua River catchment, with Land River Sea being engaged to undertake the hydraulic modelling for this project.

The scope of work consists of constructing a 2D hydraulic model, simulating various nature-based options (as proposed by T&T) and assessing their effectiveness at minimising flooding in Masterton.

This report details the model setup as well as provides a brief commentary on the results for a wide range of Average Recurrence Interval (ARI) storms, comparing the Base Scenario (existing scheme) and proposed NBS options.

This report is structured as follows:

- Hydraulic model build and validation (Section 2)
- Modelled Scenarios and Results (Section 3 and 4)
- Conclusions (Section 5)

1.2. LIMITATIONS OF STUDY

This study has been carried out using the information and data made available to the author at the time of this study. There are some uncertainties that should be acknowledged, which include but are not limited to:

- LiDAR data – whilst there is good coverage, LiDAR data comes with a degree of vertical uncertainty typically considered to be in the range of +/-0.15m.
- The model is a fixed bed and does not allow for bed sediment mobilisation / gravel transport.

2. HYDRAULIC MODEL SETUP

An existing, detailed 1D/2D hydraulic MIKE model of the Waipoua River, has been formally published and peer reviewed (Gardner, 2023). This model remains the most accurate and detailed representation of flood behaviour in Masterton and should continue to be regarded as the reference source for flood extents. However, due to time constraints and the complexity of representing the proposed NBS scenarios – many of which involve floodplain and channel modifications better suited to a purely 2D framework – a decision was made to convert the model to a fully 2D setup within the TUFLOW modelling package. This was necessary because several of the proposed interventions occur within the active channel or along the boundaries of lateral links, where 1D/2D interfaces are less suited to capturing fine-scale changes. TUFLOW was selected for its efficient model setup process, faster run times, and the ability to incorporate 2D bridges and floodplain modifications with greater flexibility.

2.1. 2D MESH GENERATION

Rather than using a flexible mesh setup as is the case in the existing MIKE model, the model has been represented using a fixed regular grid size of 5m. However, the sub-grid sampling option has been utilised to capture a higher level of detail still.

Sub-grid sampling in TUFLOW refers to a technique used to improve the accuracy of terrain representation and volume calculations within each computational cell of a 2D model.

Instead of assuming that each 2D cell has a uniform elevation based on a single point (e.g. the cell centre), sub-grid sampling divides each cell into multiple smaller samples and uses these to better capture elevation variations within the cell. This improves the estimation of flow paths, water depths, and storage volumes, particularly in areas with complex topography or rapidly varying terrain, without increasing the overall cell resolution or model size.

In essence, sub-grid sampling enhances model accuracy while maintaining efficient run times. A sub-grid sampling size of 1 m has been adopted for this model build.

2.2. MODEL FEATURES

Several important floodplain features such as stopbanks, bunds and road/rail embankments are represented using 1D breaklines within the software. A majority of these are located within the urban reach. Locations of modelled banks are presented in Figure 2-1. Modelling these features as '2D_Zshape' in the software allows us to ensure the exact crest levels control the flow, rather than taking the height from a sampled DEM which typically underestimates the height of the crest. The crest levels were set to a height using crest level survey data where available, otherwise were extracted manually from the 1m DEM.

A newly included feature in the 2D Model is the Whitipoua swingbridge, which was not present in the 2023 Waipoua Model as it was constructed after model build had started and the LiDAR was flown.

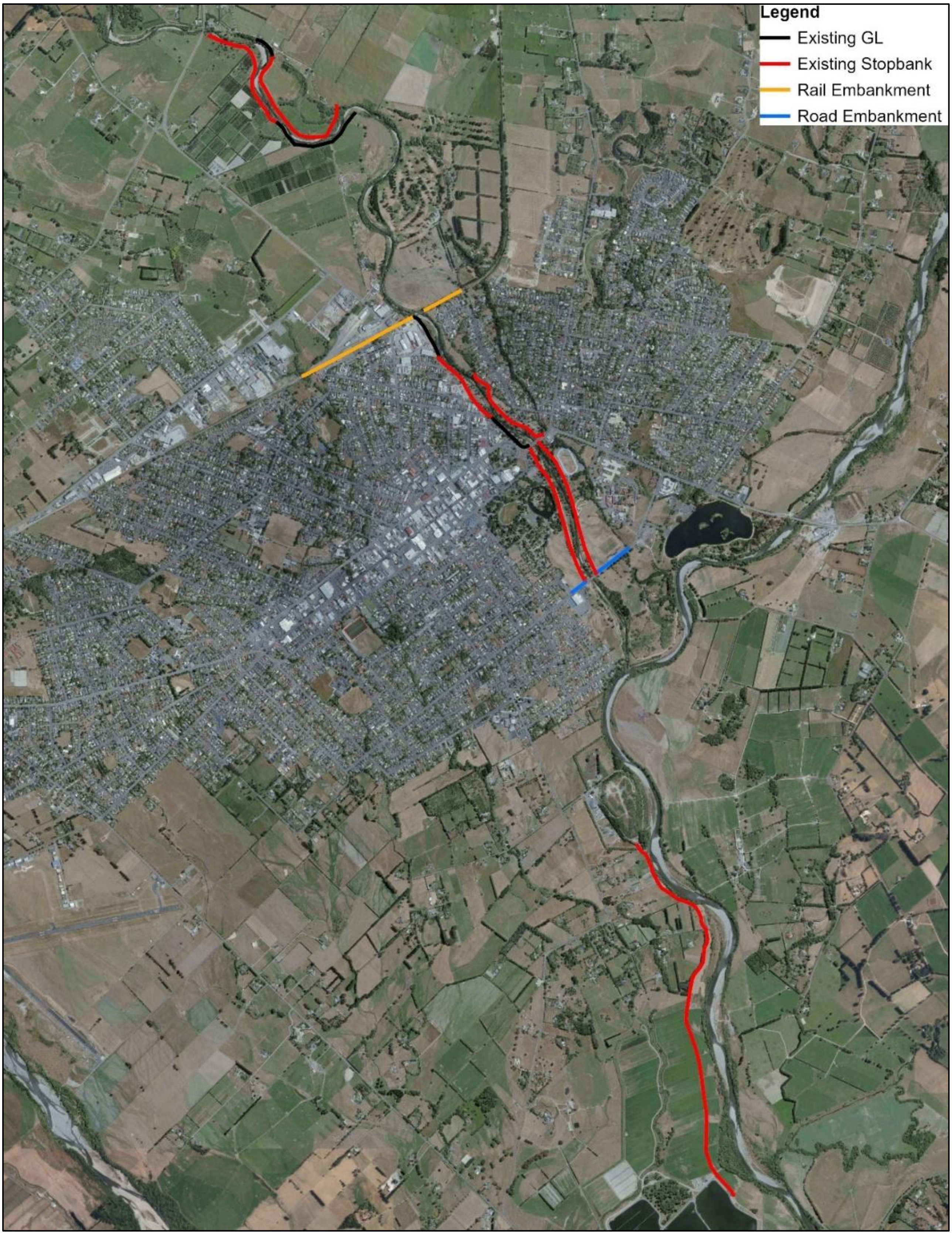

Figure 2-1: Locations of the modelled stopbanks.

2.3. FLOODPLAIN RESISTANCE

To account for varying roughness – or resistance to flow – across the floodplain, spatially varying Manning's 'n' coefficient values were assigned to areas based on the land-use type, as determined by aerial imagery. For the floodplain, roughness values used in the 2023 model were adopted. A raster of grid size of 1 m was created with each cell assigned a Manning's 'n' value. For the river channel, roughness values were simplified and also reduced on average by 30%, except for immediately upstream and downstream of the Colombo Rd (chainage 31150 to 32059), where the original roughness from the 1D/2D model is used to fit the calibration event.

It is standard practice when converting a 1D model into a 2D model to lower the roughness in the river channel due to the fact that in a 1D model, flow is averaged over the cross-section, therefore Manning's *n* must account for everything, including bed roughness, channel irregularities, bends, turbulence, lateral momentum losses, etc. Since these energy losses aren't explicitly modelled in a 2D model, the *n* value is often inflated to compensate.

In a 2D model, flow is resolved in two horizontal directions (x and y), so it captures lateral momentum exchange, eddies, flow separation, and other complex features directly. Energy losses are modelled inherently via the flow equations (especially with fine grids), and therefore, there is no need to allow for additional energy losses in Manning's *n* as the physical processes are already simulated.

Finer resolution models (such as this one – 2 to 5m), capture small-scale features like:

- Banks and berms
- Minor channel meanders
- Buildings, roads, and banks, ditches and depressions

Whereas a coarse grid (e.g., 10m–30m or more) smooths over those features and the flow "sees" a flatter, more generalised landscape.

It is for this reason that fine grid 2D models use an even lower Manning's 'n' value. A reduction in the order of 30% is within the standard range for a fine resolution 2D model.

2.4. MODEL CALIBRATION – OCTOBER 1998 EVENT

The model was calibrated to the October 1998 event, which had a flow at the upstream Mikimiki gauge of 356 m^3/s which is rated in the order of a 70-year ARI event, however, according to the flow statistics, the return period of the estimated flow of 412 m3/s at the Colombo Rd bridge further downstream only has an ARI in the order of a 20-year event (Gardner, 2023). This 2D model utilised the calibrated flows from the 2023 Hydraulic Model for the Waipoua & Ruamahanga Rivers.

The model calibrated well with the 1998 event with an average error of -0.04m and an absolute average error is 0.04 m. A full comparison of the modelled results and the debris levels is presented in Table 2-1, with cross section locations (and difference in metres) provided in Figure 2-2. Whilst these calibration results are not quite as good as was achieved in the MIKE Flood model nor the reduced extent MIKE2D model, they are still considered reasonable and suitable for use in this project.

The most significant difference between the models is the peak water level at the bridges, despite using relatively high pier loss factors within the 2d bridge module within TUFLOW, the model is still underpredicting water levels at the bridges.

The model results show the relative difference between each NBS scenario in relation to flood levels and extent, rather than exact results. This was not refined further due to the project timeframe constraints; however, it does not impact the main purpose of the modelling.

The focus area for this project is the reach upstream of the urban area.

Table 2-1: Calibrated model results compared to surveyed debris levels from the Oct 1998 flood

River Name	Chainage	Debris level	Modelled WL	Difference	Absolute Difference
WAIPOUA	29224	122.96	122.63	-0.33	0.33
WAIPOUA	29272	122.96	122.05	-0.91	0.91
WAIPOUA	29598	121	120.99	-0.01	0.01
WAIPOUA	29872	119.65	119.61	-0.04	0.04
WAIPOUA	30131	118.73	118.80	0.08	0.08
WAIPOUA	30425	117.32	117.07	-0.25	0.25
WAIPOUA	30646	115.41	115.40	-0.01	0.01
WAIPOUA	30882	114.13	114.54	0.41	0.41
WAIPOUA	30899	114.13	112.87	-1.26	1.26
WAIPOUA	31150	113.56	113.44	-0.12	0.12
WAIPOUA	31405	112.24	111.80	-0.44	0.44
WAIPOUA	31712	110.78	110.48	-0.30	0.30
WAIPOUA	32020	109.99	109.44	-0.55	0.55
			Average	**-0.14**	**0.23**

Figure 2-2: Map of the difference (in unit m) between calibrated 2D Waipoua model water levels and the surveyed debris levels from the Oct 1998 flood event

3. MODELLED SCENARIOS

The base scenario was first simulated for the following range of events as summarised in Table 3-1

Table 3-1 – Summary of simulated base scenarios as well as flows at Mikimiki and the Railway Bridge

ARI	AEP	Peak Flow – Mikimiki	Peak Flow – Upstream of Railway Bridge
2 year	50%		256
5 year	20%		348
10 year	10%		429
20 year	5%		509
50 year	2%		613
50 year (Future Climate)	2% (Future Climate)		742
100 year	1%		688
100 year (Future Climate)	1% (Future Climate)		825

The following NBS scenarios were then simulated for the same flows adopted in the base scenario. A summary of the modelled options is provided in Table 3-2.

Table 3-2 – Summary of modelled NBS scenarios

NBS Scenario #	Description
1	Standard Infiltration, No Forest
2	Standard Infiltration, Increased Forest
3	Increased Infiltration, Existing
4	Increased Infiltration, Increased Forest
5	Standard Infiltration, Storage Scenario 1
6	Standard Infiltration, Storage Scenario 2
7	Floodplain Lowering + Reengagement
8	Floodplain Lowering, Reengagement, Vegetated Reengaged Area
9	Room For River

NBS scenarios #1 to 6 were simulated with the flows provided by Vicki Henderson of Barnett & MacMurray which were based on her rainfall runoff modelling and were simply run through our hydraulic model. Further details of the hydrological modelling are provided in Barnett & MacMurray, 2025. Scenarios 7 & 8 (Floodplain Lowering + Reengagement) and 9 (Room For River) however were based on significant modifications to the underlying DEM. The design for this was provided by Selene

Conn of T&T, who completed a geomorphic assessment of the Waipoua River (T&T, 2025). The original concepts were provided in pdf format and are attached in Appendix A. The model setup for these scenarios is explained in the following section.

3.1. FLOOD CHANNEL RE-ENGAGEMENT AND LOWERING THE FLOODPLAIN

Flood channel re-engagement and lowering the floodplain

The objective of the flood channel re-engagement scenario is to lower and widen the existing historic flood channels. Two-stage channels were constructed within the areas outlined by the blue polygons (Figure 3-1). The lower channels were set to the 2-year flood level, and the channels were modified to ensure full engagement during a 10-year flood event.

To achieve this, cross sections were created at a 5 meters interval in the designated areas, perpendicular to their corresponding centrelines. For each cross section, the lowest 10-year flood level surface was identified, and all the material above this surface was removed. The start and end zones of the new channels were manually adjusted to ensure smooth water flow. Similarly, the channel edges were smoothed for a gentle transition. Multiple simulations were run for both the 2-year and 10-year flood scenarios. Based on the results, further modifications were iteratively made to the DEM. These included lowering or smoothing sections of the new channels where the 2-year flood did not flow smoothly or where the 10-year flood was not fully engaged.

Figure 3-2 presents a comparison between the original DEM and the new DEM in four cross section locations, one in each new channel.

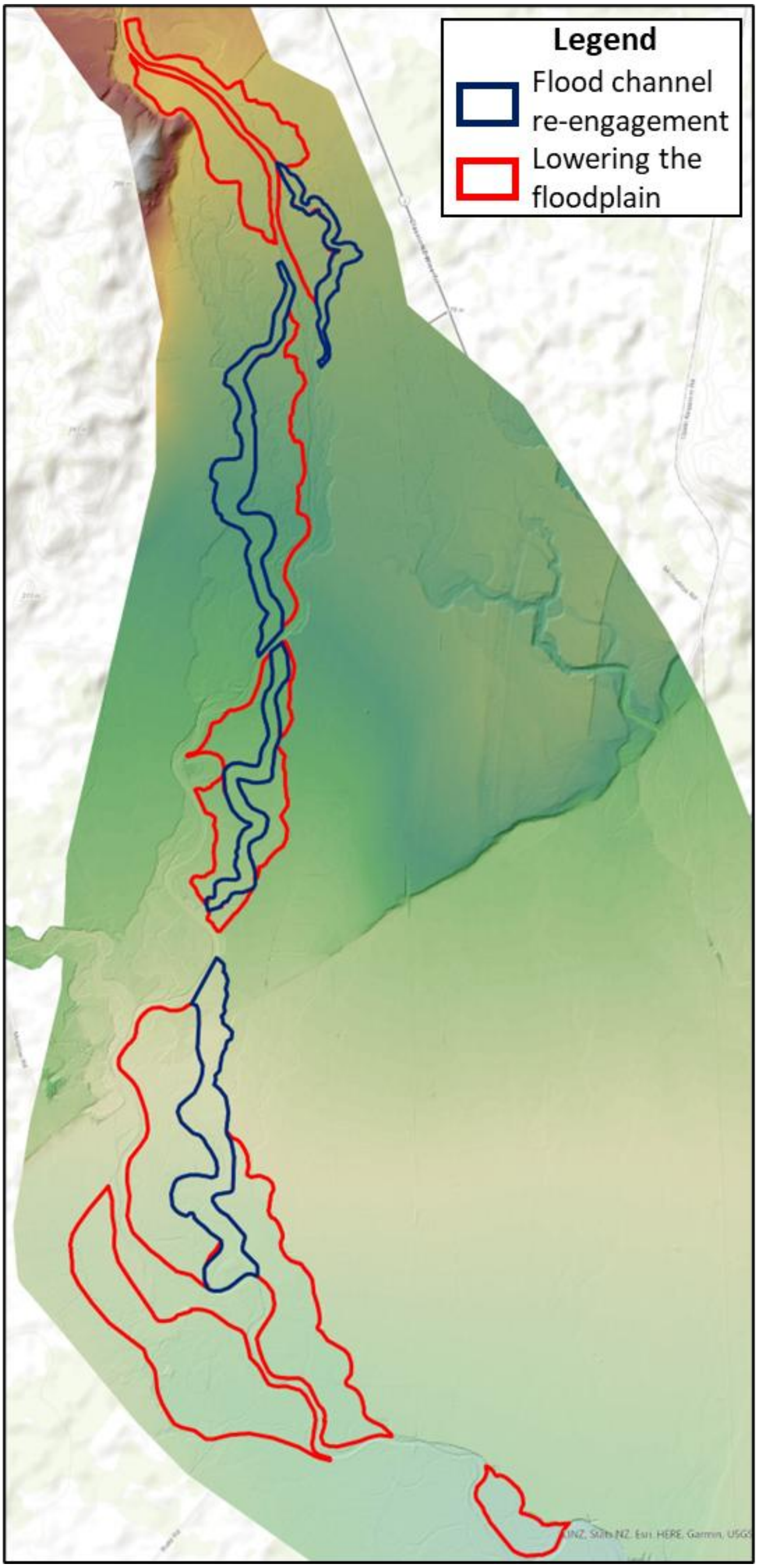

Figure 3-1 - Flood channel re-engagement and lowering the floodplain modified areas.

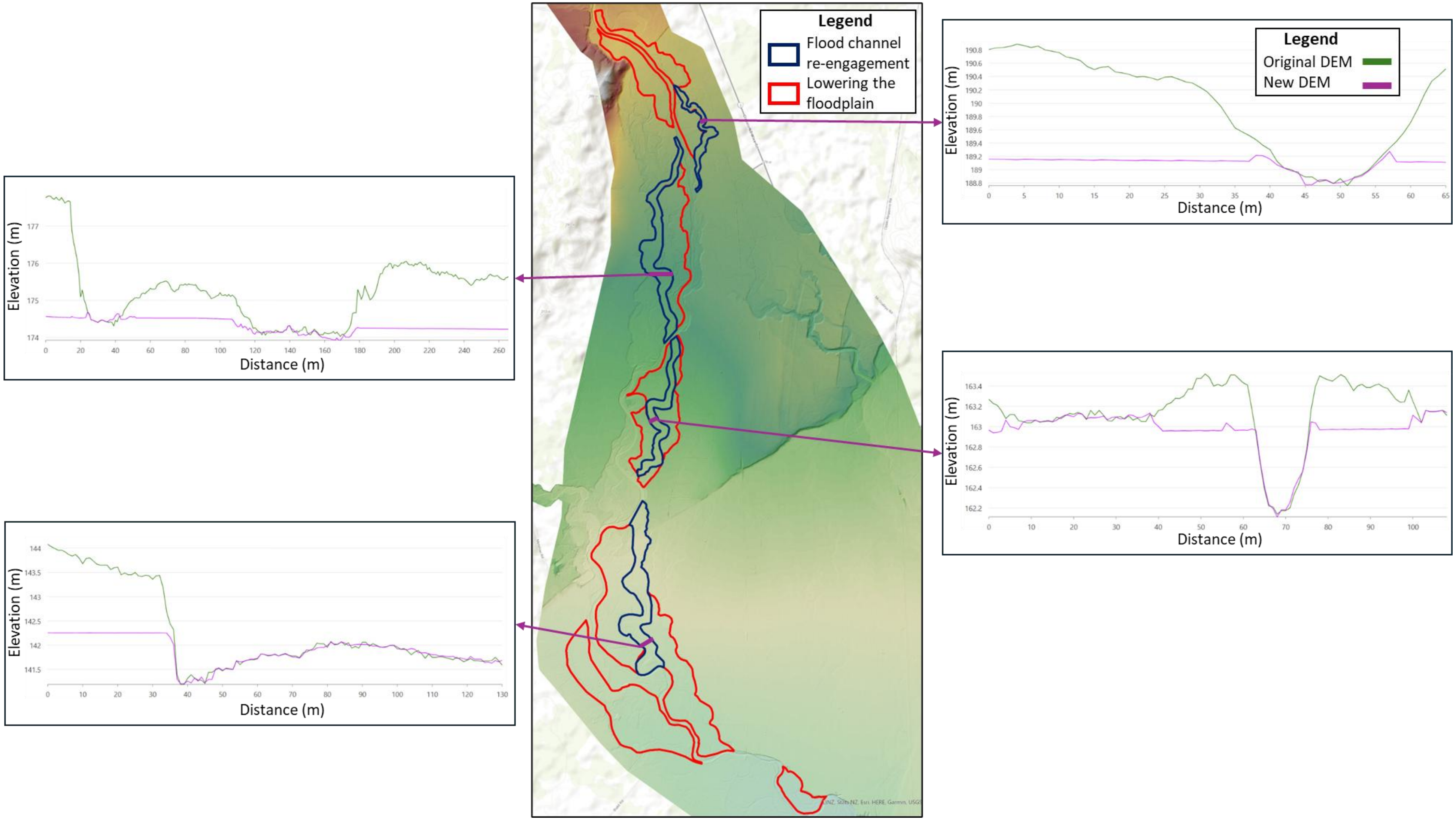

Figure 3-2 - Flood channel re-engagement cross sections.

The floodplain was also lowered to achieve a gentle batter. The areas within the red polygons (Figure 3-3) were lowered to the 10-year flood level on the sides adjacent to the river and lowered to the 50-year flood level on the outside edge, ensuring a smooth transition between both levels.

Following this the DEM was modified to keep the inundation surface value if it was lower than the DEM and left the DEM unmodified if the inundation surface was higher. Additionally, the stopbanks within the highlighted polygons were removed. Figure 3-3 presents a comparison between the original DEM and the new DEM in four profile locations.

To achieve this,

- Points were added along the boundaries of the polygons at a one-meter interval.
- Points were intersected on the side of the polygons adjacent to the river with the 10-year and 50-year inundation surfaces. (These surfaces were obtained from simulations using the DEM that incorporated the flood channel re-engagement modifications described previously).
- The points on the riverside were assigned the 10-year flood level, while the points on the opposite side were assigned the 50-year level, based on the intersected values from the river-adjacent points.
- Once all points had an assigned water level, an inundation surface was generated based on all of them.
- The DEM was the modified by replacing its values with those from the inundation surface (e.g., removing the material above the inundation surface) wherever the inundation surface was lower than the DEM. If the inundation surface was higher, the DEM was not modified.
- Stopbanks located within the polygons were removed.

Figure 3 presents a comparison between the original DEM and the updated DEM across four cross sections.

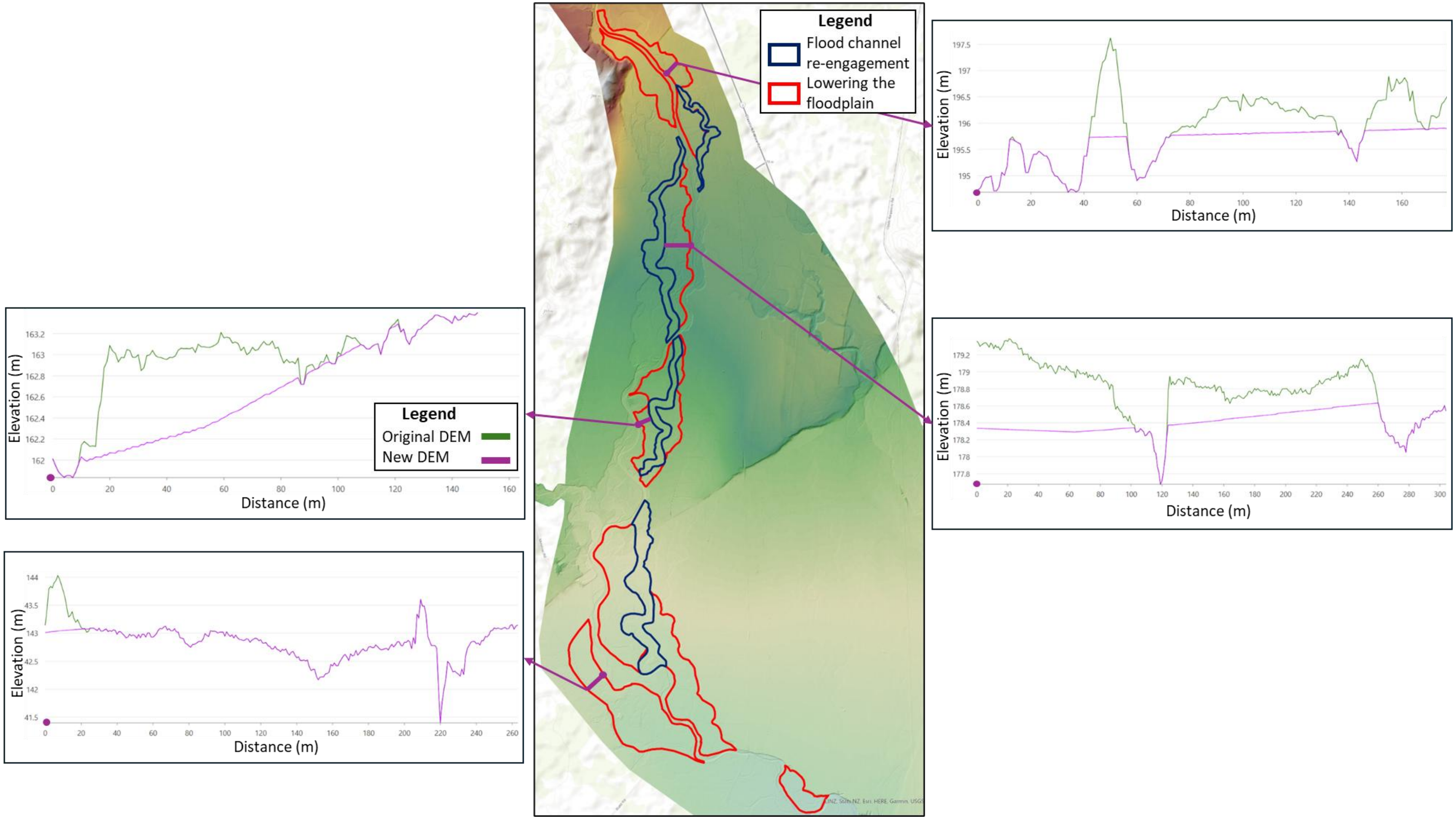

Figure 3-3 - Lowering the floodplain cross sections.

Lastly, the DEM including the flood channel re-engagement modifications and the DEM including the lowering of the floodplain modifications were combined to create the final DEM.

3.2. FLOOD CHANNEL RE-ENGAGEMENT AND LOWERING THE FLOODPLAIN PLUS REVEGETATION

This option is identical to the previous option however has also included vegetating the areas of altered floodplain as well as reengaged floodplain.

Vegetation has been simulated using a blanket Manning's 'n' value of 0.12 which would simulate something such as shrubland with interspersed trees and tall grasses. This is likely an upper estimate for roughness for these areas and results should be interpreted accordingly.

3.3. ROOM FOR THE RIVER

This option explores changes in flood levels by modifying the current active channel based on the 1961 active channel alignment.

- The current wet channel was first delineated and flattened.
- The areas covering the flattened channel and the 1961 active channel (polygons in Figure 3-4) were raised based on the provided values (0.4, 0.5 or 0.7 meters, depending on the location and taken on the Waipoua geomorphic assessment report (T&T, 2025)).
- The boundary between the raised area and the original DEM was graded into a gentle slope to ensure a smooth transition.
- A new channel with a uniform width of 12 meters and a depth of 0.5 meters was burnt along the 1961 channel centreline (red line in Figure 3-4 and Figure 3-5).
- After burning the channel, the transitions between cross sections were smoothed to delete any bumps.

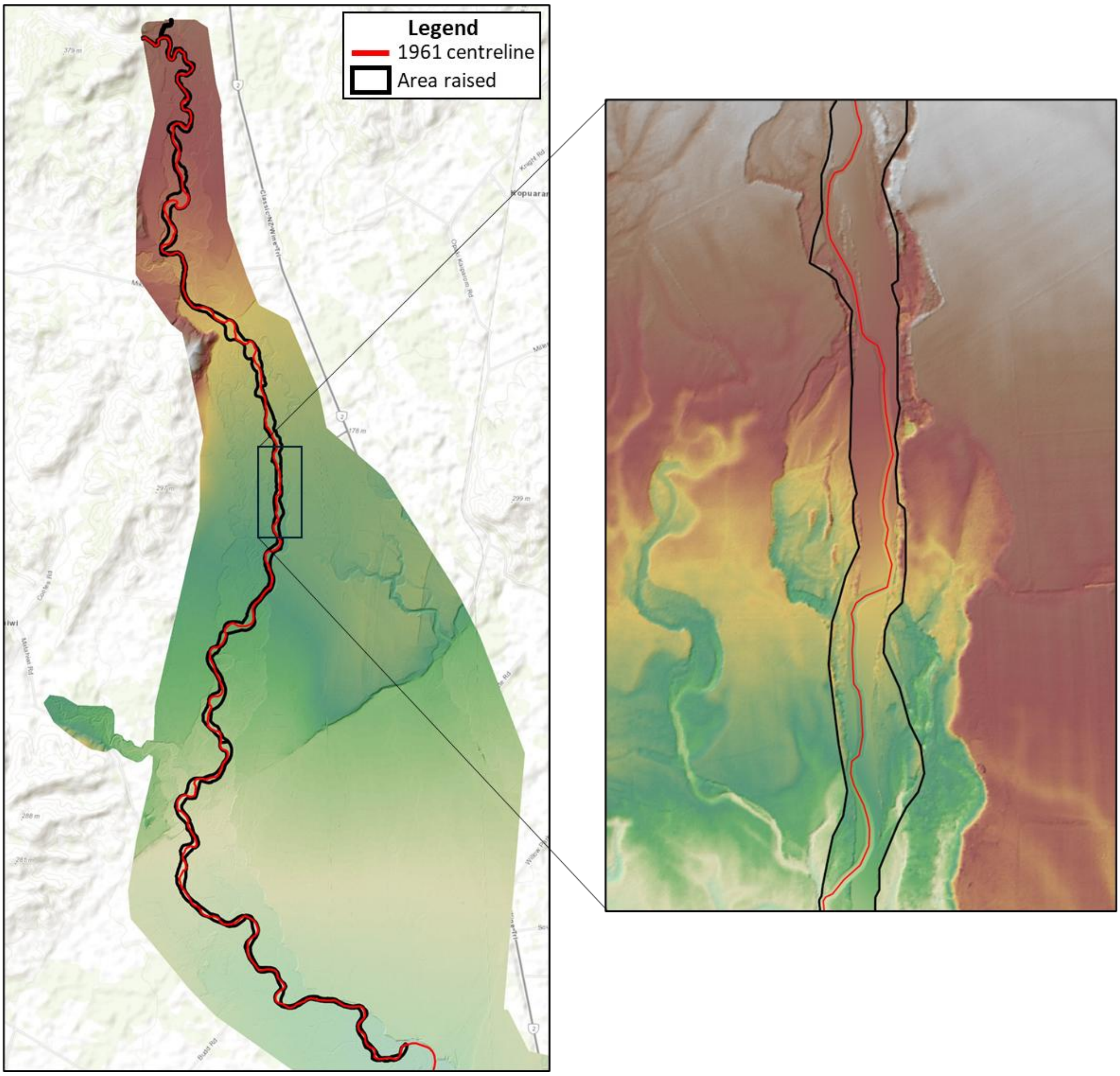

Figure 3-4 - Room for the river scheme

Figure 3-5 includes the final DEM surface profiles of 3 cross sections, highlighting in red the new excavated channel.

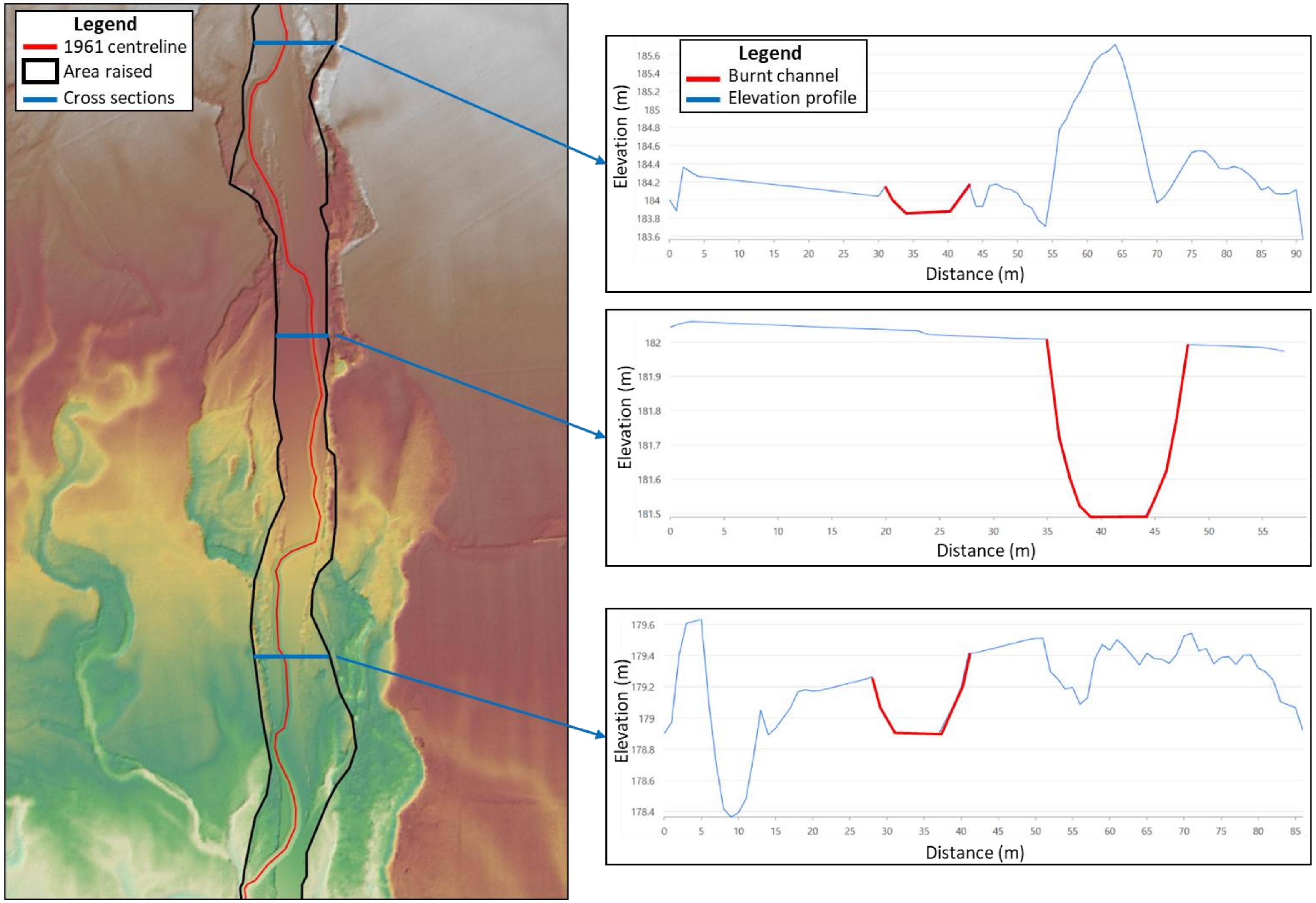

Figure 3-5 - Room for the river cross sections

4. RESULTS

The key metric adopted for determining the efficiency of each option has been taken as the percentage change in flow immediately upstream of the railway bridge, which is located immediately upstream of the Masterton urban area.

The following section provides a brief commentary on the results for each option.

4.1. NBS SCENARIO 1 - STANDARD INFILTRATION, NO FORESTS

In this scenario, all existing forest cover (25% of the catchment) was removed in the hydrological model to understand the baseline influence of current forest on runoff. The outcome showed a significant increase in flood peak flows, with the 1% AEP (100-year event) peak flows rising by up to 11%. Additionally, the timing of the flood peak advanced by around 30 minutes, indicating faster runoff due to the absence of forest cover. The impact on flow at the railway bridge is summarised in Table 4-1.

Table 4-1 – Impact on peak flow at the Railway Bridge for NBS Scenario 1

	Base Scenario	Standard Infiltration, No Forest		
	Peak Flow (m^3/s)	**Peak Flow ($m^{3/}$)**	**Change ($m^{3/}$)**	**% Change**
2 year	256	290.94	35.31	13.8%
5 year	348	387.58	39.10	11.2%
10 year	429	473.14	44.00	10.3%
20 year	509	552.96	44.15	8.7%
50 year	613	655.53	42.19	6.9%
50 year CC	742	783.91	42.29	5.7%
100 year	688	730.42	42.25	6.1%
100 year CC	825	868.34	43.34	5.3%

Analysis of the model outputs shows an increase in flood depth in the order of 0.05 to 0.2 metres over all events as well as a slight increase in flood extent and velocity.

4.2. NBS SCENARIO 2 - STANDARD INFILTRATION, INCREASED FOREST

This scenario simulated afforestation by increasing forest coverage to 35% through replanting in selected hillslope areas identified as suitable for retirement. The results showed modest benefits, with up to a 3% reduction in 1% AEP peak flows and a 15-minute delay in peak timing. However, the effect on runoff volume was negligible, as forest type did not influence infiltration in the base model.

The impact on flow at the railway bridge in the hydraulic model is summarised in Table 4-2.

Table 4-2 - Impact on peak flow at the Railway Bridge for NBS Scenario 2

	Base Scenario	Standard Infiltration, No Forest		
	Peak Flow (m^3/s)	**Peak Flow ($m^{3/}$)**	**Change ($m^{3/}$)**	**% Change**
2 year	256	244.12	-11.51	-4.5%
5 year	348	336.10	-12.37	-3.5%
10 year	429	414.70	-14.44	-3.4%
20 year	509	493.36	-15.45	-3.0%
50 year	613	597.95	-15.38	-2.5%
50 year CC	742	725.44	-16.19	-2.2%
100 year	688	672.49	-15.68	-2.3%
100 year CC	825	808.48	-16.52	-2.0%

Across all event scenarios, the results predominantly show slight reductions in flood depths along key reaches of the Waipoua River. The flood depth difference results reinforce the conclusion that afforestation, even with modest infiltration improvements, reduces flood risk incrementally and consistently across storm sizes. Notably, the approach does not create new risk areas, and it brings noticeable benefits for more frequent, smaller floods.

4.3. NBS SCENARIO 3 - EXISTING FOREST WITH INFILTRATION

Assuming that existing forested areas enhance infiltration, this scenario tripled the infiltration rate (from 1.5 mm/h to 4.5 mm/h) within forest zones. This adjustment reduced peak flows by up to 8% and slightly lowered runoff volume. It demonstrated the role of soil and vegetation in increasing water retention capacity without changing forest area.

The impact on flow at the railway bridge in the hydraulic model is summarised in Table 4-3.

Table 4-3 - Impact on peak flow at the Railway Bridge for NBS scenario 3

	Base Scenario	Standard Infiltration, No Forest		
	Peak Flow (m^3/s)	**Peak Flow ($m^{3/}$)**	**Change ($m^{3/}$)**	**% Change**
2 year	256	226.80	-28.83	-11.3%
5 year	348	318.53	-29.95	-8.6%
10 year	429	396.23	-32.92	-7.7%
20 year	509	474.38	-34.43	-6.8%
50 year	613	580.88	-32.46	-5.3%
50 year CC	742	709.49	-32.13	-4.3%
100 year	688	657.08	-31.09	-4.5%
100 year CC	825	794.72	-30.28	-3.7%

Model results shows a clear positive effect on flood mitigation, particularly for frequent to moderately severe flood events (e.g., 2-year to 10-year ARI). By enhancing soil absorption, the intervention:

- Reduces peak flood depths by up to 0.3–0.5 m in places,
- Shrinks inundation footprints particularly on flood-sensitive rural land,
- Delays flood peaks, providing potential co-benefits downstream in urban flood timing.

However, for rare extreme events (1% AEP and under future climate), the reductions are more spatially limited.

4.4. NBS SCENARIO 4 - INCREASED FOREST AREA WITH HIGHER INFILTRATION

Combining both afforestation (35% coverage) and increased infiltration (triple rate), this scenario delivered the most substantial reductions in peak flows—up to 13%—and a total runoff volume reduction of 6% for the 1% AEP event. The effect was even more pronounced in smaller storm events, showing up to 29% peak flow reduction in the 2-year (39% AEP) event, emphasising cumulative benefits of forest area and soil properties. .

Table 4-4 - Impact on peak flow at the Railway Bridge for NBS Scenario 4

	Base Scenario	Standard Infiltration, No Forest		
	Peak Flow (m^3/s)	**Peak Flow ($m^{3/}$)**	**Change ($m^{3/}$)**	**% Change**
2 year	256	205.29	-50.34	-19.7%
5 year	348	290.95	-57.52	-16.5%
10 year	429	367.82	-61.32	-14.3%
20 year	509	444.36	-64.45	-12.7%
50 year	613	550.62	-62.72	-10.2%
50 year CC	742	679.14	-62.49	-8.4%
100 year	688	628.50	-59.67	-8.7%
100 year CC	825	765.55	-59.45	-7.2%

Results from this scenario demonstrate:

- Flood depths are reduced by 0.1–0.5 m, particularly across overbank areas and secondary flow paths.
- Upstream and rural zones show the largest gains.
- In urban Masterton, the intervention still provides benefits particularly with a significant reduction in the volume overflowing the railway embankment.

4.5. NBS SCENARIO 5 – DISTRIBUTED DETENTION (S1)

This scenario applied distributed detention structures (e.g., leaky dams) across seven subcatchments with 300 m^3/ha of storage and a 375 mm outlet pipe (520 L/s max outflow). While some peak flow reductions were observed (around 7% for key subcatchments), storage was not fully optimized across the board. Delays in peak timing were moderate, and overall reduction in flow was less than with the optimized version (S2).

The impact on flow at the railway bridge in the hydraulic model is summarised in Table 4-5

Table 4-5 - Impact on peak flow at the Railway Bridge for NBS scenario 5

	Base Scenario	**Distributed Detention S1**		
	Peak Flow (m^3/s)	**Peak Flow ($m^{3/}$)**	**Change ($m^{3/}$)**	**% Change**
100 year	688	681.32	-6.85	-1.0%

The results for this scenario showed minimal impact on flood levels and velocities.

4.6. NBS SCENARIO 6 – DISTRIBUTED DETENTION (S2)

An improved version of Scenario 1, this model used smaller 300 mm outlets (370 L/s) for greater throttling of peak flows. It reduced peak 1% AEP flows by an average of 26% across detention elements and up to 33% in the most responsive catchments. Peak flows were delayed by 1–2 hours, and time to peak across the catchment increased by 45 minutes on average. This setup was found to be most effective for flood peak attenuation but less so under climate change scenarios due to overflow of detention capacity.

The impact on flow at the railway bridge in the hydraulic model is summarised in Table 4-6

Table 4-6 - Impact on peak flow at the Railway Bridge for NBS scenario 6

	Base Scenario	Distributed Detention S1		
	Peak Flow (m^3/s)	Peak Flow ($m^{3/}$)	Change ($m^{3/}$)	% Change
2 year	256	265.81	10.18	4.0%
5 year	348	354.19	5.71	1.6%
10 year	429	427.01	-2.13	-0.5%
20 year	509	495.13	-13.68	-2.7%
50 year	613	584.99	-28.35	-4.6%
50 year CC	742	711.13	-30.49	-4.1%
100 year	688	659.19	-28.98	-4.2%
100 year CC	825	813.15	-11.85	-1.4%

Results show:

- Increased flood depths for smaller (frequent) events like the 2-year and 5-year floods.
- These depth increases likely result from delayed but overlapping flows, causing peak amplification or backwater effects downstream.
- Only for moderate to large events (5–2% AEP) does the scenario begin to show small areas of benefit, and even then, the improvements are localized and inconsistent.
- Under future climate scenarios (RCP6), the system appears functionally saturated, with limited to no reduction in peak flood depth, likely due to basin overflow or capacity exceedance.

4.7. NBS SCENARIO 7 – FLOODPLAIN LOWERING AND REENGAGEMENT

This scenario investigates the impact of reengaging remnant flood channels by modifying the terrain to allow the 2 year and 10 year flows to entirely engage the channels whilst additionally lowering the floodplain so that more flow can enter the floodplain.

The impact on flow at the railway bridge in the hydraulic model is summarised in Table 4-7.

Table 4-7 - Impact on peak flow at the Railway Bridge for NBS scenario 7

	Base Scenario	Floodplain Lowering and Reengagement		
	Peak Flow (m^3/s)	Peak Flow ($m^{3/}$)	Change ($m^{3/}$)	% Change
2 year	256	256.32	0.69	0.2%
5 year	348	349.59	1.12	0.3%
10 year	429	429.21	0.07	0.0%
20 year	509	507.35	-1.46	-0.3%
50 year	613	610.11	-3.23	-0.5%
50 year CC	742	737.06	-4.57	-0.6%
100 year	688	684.52	-3.65	-0.5%
100 year CC	825	820.59	-4.41	-0.5%

Results of this run show that despite minimal impact on the flood peak at the railway bridge, there are significant reductions in peak levels (up to 0.5m) over extended areas, due to a diversion of flood flows away from the main floodplain. Some areas are also worse off as a result, including several residential properties. Impacts are most pronounced in the more frequent, lower magnitude events, however, are still visible even in 1%AEP events.

4.8. NBS SCENARIO 8 – FLOODPLAIN LOWERING AND REENGAGEMENT, VEGETATED REENGAGED AREA

This scenario is the same as scenario 7, however, also includes vegetating the reengaged floodplain channels and lowered floodplain area.

The impact on flow at the railway bridge in the hydraulic model is summarised in Table 4-8.

Table 4-8 - Impact on peak flow at the Railway Bridge for NBS scenario 8

	Base Scenario	Standard Infiltration, No Forest		
	Peak Flow (m^3/s)	**Peak Flow ($m^{3/}$)**	**Change ($m^{3/}$)**	**% Change**
2 year	256	237.76	-17.87	-7.0%
5 year	348	326.02	-22.45	-6.4%
10 year	429	408.70	-20.44	-4.8%
20 year	509	485.21	-23.60	-4.6%
50 year	613	584.95	-28.39	-4.6%
50 year CC	742	711.05	-30.58	-4.1%
100 year	688	658.67	-29.50	-4.3%
100 year CC	825	793.76	-31.24	-3.8%

Results show a modest reduction in flow within urban Masterton for all events and hence a decrease in flood level and extent, however also show a significant increase in flood level within rural areas in many locations as a result of the water being slowed over the flooding.

The addition of vegetation to reengaged floodplains and channels introduces both hydraulic benefits and trade-offs. While effective at reducing flood depths in targeted urban areas and enhancing ecological and sediment co-benefits. It can also cause backwater effects and depth increases upstream and mid-reach during moderate to extreme floods. The results are therefore mixed:

Pros

- Urban Masterton benefits modestly, particularly in smaller to mid-size events, with reductions in depth likely due to delayed and desynchronised peaks.
- Vegetation enhances surface roughness, which helps slow and attenuate flows — contributing to peak delay and mild reductions downstream.

Cons

- In upstream and mid-catchment zones, vegetation increases resistance and causes slower drainage and greater local retention, leading to:
    - Higher water levels near reengaged channels
    - Prolonged inundation in floodplain edges

4.9. NBS SCENARIO 9 – ROOM FOR THE RIVER

This scenario looks at allowing more room for the river by increasing the sinuosity of the main channel, widening the active channel and removing stopbanks within the active channel area.

The impact on flow at the railway bridge in the hydraulic model is summarised in Table 4-9.

Table 4-9 - Impact on peak flow at the Railway Bridge for NBS scenario 9

	Base Scenario	Standard Infiltration, No Forest		
	Peak Flow (m^3/s)	**Peak Flow ($m^{3/}$)**	**Change ($m^{3/}$)**	**% Change**
2 year	256	262.31	6.68	2.6%
5 year	348	358.77	10.30	3.0%
10 year	429	438.83	9.69	2.3%
20 year	509	513.55	4.74	0.9%
50 year	613	609.31	-4.03	-0.7%
50 year CC	742	727.09	-14.54	-2.0%
100 year	688	677.26	-10.91	-1.6%
100 year CC	825	811.72	-13.28	-1.6%

Results from this scenario surprisingly show an increase in flow at the rail bridge for events up to a 5%AEP even, largely due to more water being pushed onto the floodplain which bypasses the channel meander and appears to speed up the flow reaching the railbridge. However results are most effective for large events (2% and 1% AEP) where a reduction in flood peak is evident at the railway bridge.

Pros

- Creates valuable flood storage in designated upstream areas, helping to attenuate and delay peak flows.
- Most effective for moderate to large floods (5–2% AEP), where peak shaping matters most.

Cons

- Comes at the cost of increased flooding in rural, low-lying floodplain areas upstream (typically ~0.1–0.5 m).
- Under climate change scenarios, storage thresholds are stressed, leading to wider areas of depth increase.

5. CONCLUSIONS

This modelling assessment has evaluated nine Nature-Based Solution (NBS) scenarios for the Waipoua River, under both historic and future climate conditions. The hydraulic response of each intervention was tested across a full suite of design flood events using a high-resolution 2D TUFLOW model.

The results show that NBS measures can deliver meaningful reductions in flood peaks and extents, particularly for low to moderate events. The most effective scenarios in terms of peak flow reduction at the Railway Bridge were:

- Scenario 4 (Afforestation + High Infiltration): peak flow reductions of up to 20% for 2-year events and 8–13% for 50–100-year events.
- Scenario 8 (Reengagement + Vegetated floodplain): moderate reductions in urban areas, but increased ponding in upstream rural areas.

Conversely, some scenarios (e.g., Room for the River and Detention S2) had mixed or adverse impacts, particularly under small storm events or when storage capacity was exceeded.

These findings reinforce that:

- Combinations of land-use change and soil improvement offer the most scalable benefits.
- Morphological changes (like reengagement) must be carefully targeted to avoid transferring risk.
- Climate change reduces the relative effectiveness of many measures and will require integrated responses.

The following table provides a basic summary of the results from the simulations.

Scenario	Description	Peak Flow Reduction at 1% AEP	Flood Depth Impact	Urban Benefit	Rural Trade-offs	Climate Change Robustness	Key Notes
1	Standard infiltration, no forest	+6.1% (worsening)	+0.05–0.2 m	Worsened	Worsened	Negative	Baseline to test forest removal
2	Standard infiltration, increased forest	−2.3%	Minor (≤0.1 m)	Minor improvement	No adverse effects	Modest	Simple afforestation, low complexity
3	Increased infiltration (existing forest)	−4.5%	0.1–0.3 m	Moderate benefit	Rural attenuation	Modest	Improved retention without new forest
4	Increased forest + infiltration	−8.7%	0.1–0.5 m	Significant	Effective storage upstream	Good	Best overall NBS performer across events
5	Distributed detention (S1)	−1.0% (100 yr only)	Minimal	Weak	No adverse	Poor under CC	Underperforming; poorly optimised sizing
6	Distributed detention (S2, optimised)	−4.2%	Mixed: ↑ in small events	Patchy benefits	Mixed	Weak under CC	Only effective for 10–100 yr events
7	Floodplain lowering & reengagement	−0.5%	Up to 0.5 m in places	Spatial reductions	Some areas worse	Mixed	Strong spatial effect but neutral overall flow

Land River Sea
CONSULTING

8	Reengagement + vegetation	−4.3%	Reduced Urban; Increased Rural (0.1–0.5 m)	Delayed peaks help Masterton	Prolonged inundation upstream	Mixed	Benefits in town, but complex dynamics
9	Room for the River (widening + old channel)	−1.6%	Reduced For large events	Best for 2–1% AEP	Rural flooding ↑ 0.1–0.5 m	Mixed	Strong in major floods, weak in small ones

6. REFERENCES

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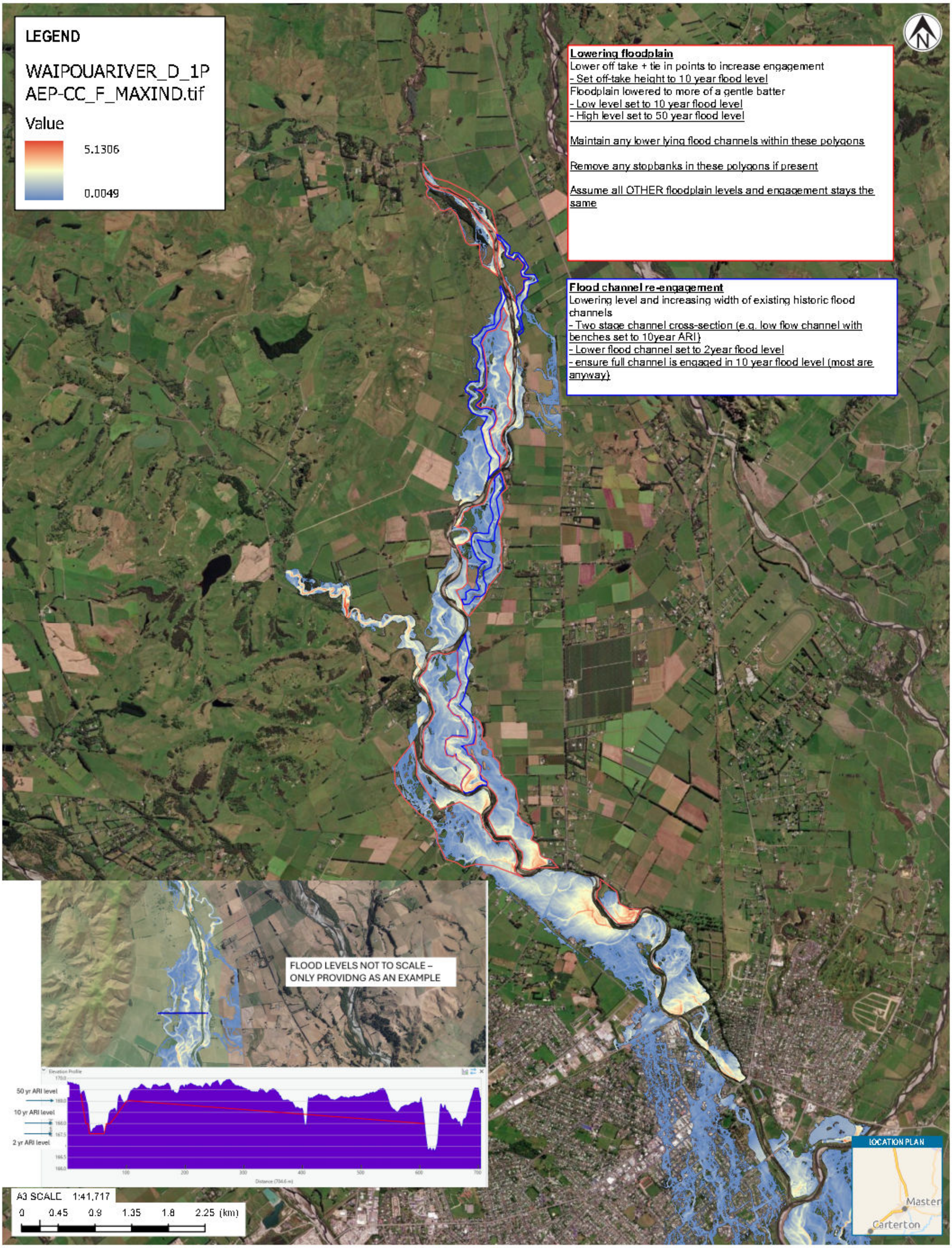
7. APPENDIX A



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NOTES:
Basemap: World Imagery: Masterton DC, Maxar, NZ Navigation Map, Eagle Technology, LINZ, StatsNZ, NIWA, Natural Earth, © OpenStreetMap contributors

PROJECT No.	1234567.1000	
DESIGNED	SECO	MAR.25
DRAWN	SECO	MAR.25
CHECKED		

REV	DESCRIPTION	GIS	CHK	DATE	APPROVED	DATE
0	First version	XXXX	YYYY	D/M/Y		

CLIENT CLIENT GOES HERE
PROJECT PROJECT NAME GOES HERE
TITLE TITLE GOES HERE

SCALE (A3) 1:41,717 FIG No. FIGURE 1. REV 0

Increase active channel with by 20m.
Increase bed level by approx 0.4m
Reduce channel roughness in new active channel width to bare gravels (no vegetation)
Reduce channel roughness on all other surfaces within the 2-year flood envelope to low lying + flexible sedges, grasses and occasional low shrubs.
No reference state provided.
Matt to send Selene the 2-year flood envelope + 10-year flood envelope once the above is done to confirm any further actions. These may include:
- Lowering of floodplain surfaces around tight meander bends
- Revegetation of all remaining surfaces towards 'floodplain forest'
1967
Increase active channel with by 40m.
Increase bed level by approx 0.7m
Reduce channel roughness in new active channel width to bare gravels (no vegetation)
Reduce channel roughness on all other surfaces within the 2-year flood envelope to low lying + flexible sedges, grasses and occasional low shrubs.
NICE TO HAVE: Increase sinuosity index for Thalweg to 1.5 (or alternatively increase thalweg length by 1,000m) (refer to 1961 centerline shapefile)
Reference state for modeling is 1966 aerial
Matt to send Selene the 2-year flood envelope + 10-year flood envelope once the above is done to confirm any further actions. These may include:
- Some lowering of surfaces in the red polygon
- Some stopbanking between red and white polygon
- Increasing channel length through re-engaging ox-boxs at DS end of reach
1966
Increase active channel with by 15m.
Increase bed level by approx 0.5m
Reduce channel roughness in new active channel width to bare gravels (no vegetation)
Reduce channel roughness on all other surfaces within the 2-year flood envelope to low lying + flexible sedges, grasses and occasional low shrubs.
Move stopbanks to edge of red polygon + set to existing 100year flood level
NICE TO HAVE: Assume a slight increase in thalweg sinuosity (or increase in thalweg length of 250m) (refer to 1961 centerline shapefile)
Reference state for modeling is 1963 aerial
Matt to send Selene the 2-year flood envelope + 10-year flood envelope once the above is done to confirm any further actions. These may include:
- Lowering of surfaces in the red polygon
1963
Aspirational floodplain engagement zone – Current floodplain extent bounded by terraces. Options could include this being an agreed 'floodable' area using planning controls only. Possible locations for wetlands.
Floodplain engagement zone – Currently within the 100 year floodable area as determined by the flood modelling, and allows for increased flood risk arising from channel realignment. Options could include floodplain lowering, formed spillways. Re-engagement of paleo channels and ox-bows, wetland formation, native plantings.
Channel realignment zone – Considered the most recent 'active channel' extent. Options include exotic plant removal (e.g. willows) to allow the channel to wander freely within this area without active erosion management. Could be supported with native plantings.
LOCATION PLAN
LEGEND
Wairarapa Flood Assets Polygons
STOPBANK
WILLOW
Waipoua Catchment
A3 SCALE 1:25,000
0 0.55 1.1 1.65 2.2 2.75 (km)
State Highway 2
West Road
Mikimiki Road
Lansdowne
Masterton Golf Course
N

Appendix E. Wider benefits report

REPORT

Wider benefits of Nature-based Solutions

Waipoua catchment

Prepared for
Greater Wellington Regional Council
Prepared by
Tonkin & Taylor Ltd
Date
July 2025
Job Number
1096651 v2.0

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Document control

Title: Wider benefits of Nature-based Solutions – Waipoua catchment					
Date	**Version**	**Description**	**Prepared by:**	**Reviewed by:**	**Authorised by:**
05 June 2025	1.0	Report for inclusion in draft Feasibility Report	Dr Eva Siwicka	Marta Karlik-Neale	Bryn Quilter
18 July 2025	2.0	Report for inclusion in final Feasibility Report	Dr Eva Siwicka	Mark Hooker	Bryn Quilter

Distribution:

Greater Wellington Regional Council 1 PDF copy

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Executive summary

Tonkin & Taylor Ltd (T+T) has been commissioned by Greater Wellington Regional Council to investigate the feasibility of using nature-based solutions (NBS) to reduce flood risk from the Waipoua River to Masterton. A key part of this broader assessment was to understand, rank and attempt to quantify the potential wider benefits of the NBS specific to the Waipoua catchment, such as the ecological and social benefits.

This study examined the wider benefits of NBS in the Waipoua catchment. A semi-quantitative heatmap assessment was undertaken using the Nature's Contributions to People framework to evaluate the four selected NBS approaches: land retirement and afforestation, floodplain re-engagement, small-scale distributed retention storage, and channel realignment/ room for the river.

The heatmap assessment demonstrated that land retirement and afforestation delivers the most comprehensive benefits across the majority of Nature's Contributions to People categories. This approach demonstrates strong performance in habitat creation and maintenance, climate regulation, water quality improvement, and soil protection. Floodplain re-engagement shows positive impacts on water-related regulatory services and cultural benefits through landscape connectivity. Small-scale distributed retention storage offers targeted benefits for freshwater quantity regulation and habitat creation through wetland establishment. Channel realignment demonstrates variable performance with high benefits in habitat creation and cultural services.

To complement the heatmap assessment, the study conducted stakeholder economic valuation with 20 community representatives, through:

- Contingent valuation (willingness to pay for environment improvements/ outcomes).
- Preference ranking of the four NBS.
- Importance assessment of the Nature’s Contributions to People.

The contingent valuation revealed the mean willingness to pay for the selected NBS ranged from $209 to $338 per household annually across the four options. Land retirement and afforestation had the highest mean value at $338 per household with nearly half (44%) of the respondents being willing to pay the maximum value of $500+ annually for this option. Participants were not explicitly told which of the four selected NBS each “basket of outcomes” represented.

The preference ranking confirmed land retirement and afforestation as the most preferred NBS with 65% first-place rankings, followed by floodplain re-engagement, small-scale retention storage, and channel realignment. The importance assessment identified water quality regulation and habitat creation and maintenance as the highest community priorities with 76.5% and 61.1% of stakeholders, respectively, rating it as highly important.

1 Purpose

Tonkin & Taylor Ltd (T+T) has been commissioned by Greater Wellington Regional Council to investigate the feasibility of using nature-based solutions (NBS) to reduce flood risk in the Waipoua catchment to Masterton. A key part of this broader assessment was to understand, rank and attempt to quantify the potential wider benefits of the NBS specific to the Waipoua catchment such as the ecological and social benefits. This report presents that work.

2 Introduction

The wider project selected four NBS to investigate further, based on their potential to reduce erosion and flooding, enhance groundwater recharge and river baseflow, and provide wider benefits to the catchment. The following four NBS were assessed in the wider benefits workstream.

- **Land retirement, and revegetation of native forest on hillslopes** - involves conversion of land within the catchment to forest.
- **Floodplain re-engagement** - this wider benefits assessment took into account the following options: stopbank removal, stopbank retreat, floodplain lowering, stopbank notching.
- **Small-scale, distributed retention storage** - involves new retention storage such as retention dams, wetlands, leaky dams etc located within drainage pathways.
- **Channel realignment/ room for the river** - involves room for river principles such as re-widening, re-engagement of paleo channels/ flood channels and oxbows.

The approach for assessing the wider benefits of the selected NBS included applying the Nature's Contribution to People framework to undertake a semi-quantitative heat map assessment (Section 3, investigate the InVest tool to complete a full quantitative assessment (Section 4), and understand the value that NBS could provide for stakeholders (Section 5).

3 Semi-quantitative heatmap assessment

The purpose of the semi-quantitative heatmap was to start quantifying the wider benefits of the selected NBS. This was done through applying the Nature's Contributions to People framework (as described in Section 3.1), leaning on expert knowledge, and incorporating local stakeholder values. High-level scoring of the benefits and disbenefits was done for each NBS.

3.1 Nature's Contributions to People framework

The framework used to define the wider benefits, Nature's Contributions to People, is derived from the concept of ecosystem services – benefits people derive from nature. Nature's Contributions to People is a framework developed by IPBES (Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services) recognising the diverse ways ecosystems support people's wellbeing. It is the most up-to-date and internationally recognised classification of benefits (or disbenefits) from nature.

Figure 3.1 below outlines how value is derived from nature. Specific biomes or ecosystems, through ecological processes, generate specific benefits for people. For example, trees sequester carbon, and this process helps regulate the climate. This 'service' or 'contribution' has value for humans by reducing the scale of climate change impacts e.g. reduced damage to property from extreme events. This value can be quantified through a range of methodologies.

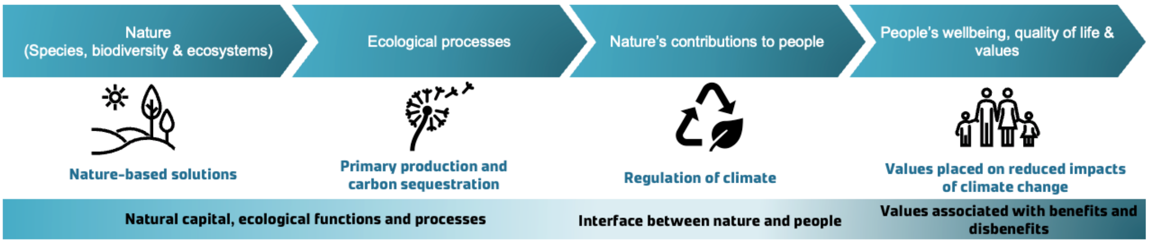

Figure 3.1: A conceptual diagram showing a flow of nature's benefits to people using the example of primary production and carbon sequestration.

The Nature's Contributions to People framework consists of the following 18 categories (Table 3.1):

Table 3.1: Eighteen Nature's Contributions to People Categories

1. Habitat creation and maintenance.
2. Pollination and dispersal of seeds and other propagules.
3. Regulation of air quality.
4. Regulation of climate.
5. Regulation of ocean acidification.
6. Regulation of freshwater quantity, location and timing.
7. Regulation of freshwater and coastal water quality.
8. Formation, protection and decontamination of soils and sediments.
9. Regulation of hazards and extreme events.
10. Regulation of detrimental organisms and biological processes.
11. Energy.
12. Food and feed.
13. Materials, companionship and labour.
14. Medicinal, biochemical and genetic resources.
15. Learning and inspiration.
16. Physical and psychological experiences.
17. Supporting identities.
18. Maintenance of options.

On top of original global definitions provided in the original framework, local definitions were generated that account for the context specific to the Waipoua catchment (the resultant local definitions are detailed in Table 3.2). These definitions were expanded on in a stakeholder workshop, where participants identified further local examples of nature's contributions for three groupings of services. The workshop focussed on the Nature's Contributions to People that had the most relevance to the shortlisted NBS and the Waipoua Catchment; these are discussed further below.

3.1.1 Nature's Contributions to People categories 1,2,10

Nature's Contributions to People 1, 2 and 10 are those that contribute: pollination and dispersal of seeds and other propagules; habitat creation and maintenance; and regulation of detrimental organisms and biological processes.

Participants explored how nature contributes to human wellbeing within these categories. The discussion highlighted both the strengths and challenges facing the catchment's ecological functions (a word cloud summary is provided in Figure 3.2).

Participants emphasized the crucial role of native birds, bats, moths, and insects in pollination and seed dispersal. They have also highlighted vulnerability of these animals to habitat destruction e.g. some species of moths requiring complex forest structure for reproduction. Birds and bats, often migrating through key areas like the Tararua ranges and Pūkaha, help connect fragmented habitats. The riverbanks and surrounding wetlands were seen as vital for supporting these ecological processes, though many noted that small streams were often overwhelmed by grass cover, reducing their effectiveness.

Habitat maintenance was closely linked to riparian planting, forest regeneration, and soil health. Participants stressed the importance of native bush and remnant ecosystems, advocating for a shift from narrow planting efforts to broader forest establishment. Maintaining fencing and promoting soil health through diverse plantings were seen as long-term commitments requiring patience and community involvement.

The group also discussed pest management, highlighting the detrimental impacts of species like perch, deer, pigs, and goats. These pests threaten native flora and fauna and undermine ecosystem stability. The conversation reflected deep awareness of climate change, water quality decline, and the underexplored role of microbial and fungal communities, pointing to a need for more research and adaptive management rooted in both science and mātauranga Māori.

Figure 3.2: Word cloud shows the most used word or phrases for Nature's Contributions to People 1, 2, and 10.

3.1.2 Nature's Contributions to People categories 11-14

Nature's Contributions to People 11-14 are those contributing energy, food and feed; materials; companionship and labour; and medicinal, biochemical and genetic resources.

Participants shared knowledge of both traditional and contemporary uses of the environment, encompassing a blend of cultural, ecological, and economic values (a word cloud summary is provided in Figure 3.3).

Food provisioning featured prominently in the discussion. Fertile alluvial soils support farming, while the river and wetlands provide sources of kai, including tuna (eel), flounders, and koura (freshwater crayfish). However, it was noted that tuna numbers have declined, reflecting wider ecological pressures. Duck shooting and trout fishing are also practiced, though trout are acknowledged as an introduced predator, disrupting native species.

Material and energy resources were also key themes. Participants referenced the historical extraction of peat, moss, and timber (notably in the 1950s), and current use of pine trees, though views on pine plantations were mixed due to environmental concerns. Gravel from the river is used but its extraction is considered detrimental in some respects. Micro-hydro power was mentioned as a localised energy source.

Native plant species such as tōtara, mātaī, kahikatea, kanuka, and flax are valued for their traditional and practical uses. Manuka and other medicinal plants were noted for their health and cultural significance. The role of biodiversity—including honeybees, flies, butterflies, birds, and wetland habitats—was seen as critical for ecological resilience.

The workshop also acknowledged the negative impacts of invasive species such as deer, pigs, and goats. Effective control of these animals was linked to restoring native biodiversity. Overall, the discussion underscored a deep interconnection between people and the environment, rooted in both mātauranga Māori and local land-based experience.

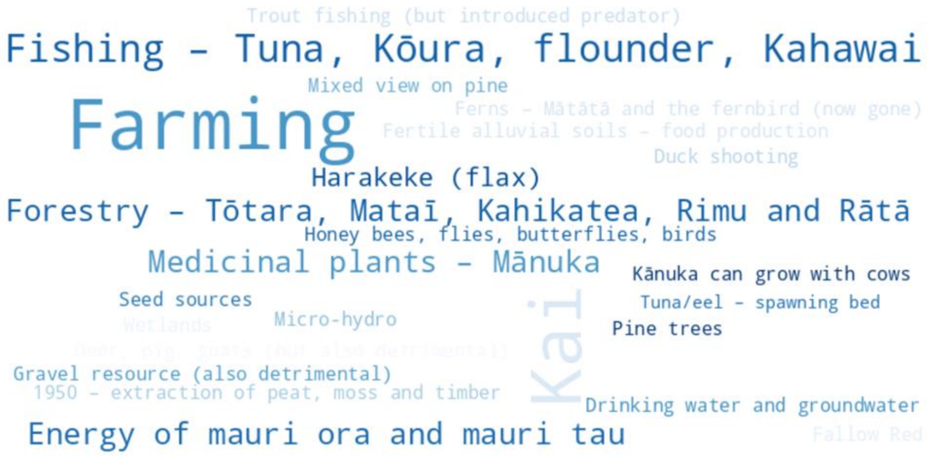

Figure 3.3: Word cloud shows the most used word or phrases used for Nature's Contributions to People 11-14.

3.1.3 Nature's Contributions to People 15-17

Nature's Contributions to People 15-17 are those that contribute: learning and inspiration; physical and psychological experiences; and supporting identities.

Participants shared rich insights into the many ways nature contributes to their lives, highlighting key ecosystem services such as learning and inspiration, physical and psychological experiences, and the support of cultural and personal identities (a word cloud summary is provided in Figure 3.4).

The river and its surrounding landscape were described as places of learning and spiritual connection, offering opportunities for study, citizen science (e.g., field studies on shading), and cultural education, including wānanga (Māori learning gatherings) and hikoi (educational walks). Participants emphasized the importance of storytelling, whakapapa (genealogy), and sacred sites like confluences and historical pā (fortified villages), which anchor personal and collective identities.

Nature in the Waipoua catchment also supports wellbeing through recreational and spiritual practices. Activities like swimming, tramping, camping, and walking are cherished for their calming, immersive qualities—though concerns like toxic algae and landowner stress in times of flooding were noted. Sacred water uses such as water birthing, tohi (blessing of children), and baptisms underscore the spiritual dimensions of the river.

Places such as swimming holes (e.g., Tank's Pool), marae, and school hikoi routes help maintain intergenerational connections and community bonds. Despite environmental challenges, the continuity of land ownership and traditions speaks to a resilient relationship with place, emphasizing both ecological and cultural stewardship of the catchment.

Figure 3.4: Word cloud shows the most used word or phrases for Nature's Contributions to People 15-17.

3.2 Results

The semi-quantitative heatmap assessment reveals distinct patterns in how the four selected NBS deliver Nature's Contributions to People across different categories. The analysis demonstrates that each NBS option provides a unique suite of benefits, with some solutions specialising in specific areas while others offer more balanced contributions across multiple categories. The results are summarised below, with the localised definitions and wider benefits heatmap in the following tables (Table 3.2 and Table 3.3). Appendix A contains a comprehensive heatmap, description table, and an assessment of how feasible it might be to quantify each contribution.

- Land retirement and revegetation of native forest on hillslopes emerges as the most comprehensive solution, delivering high levels of benefit across the majority of Nature's Contributions to People categories.
- Floodplain re-engagement demonstrates a positive impact on water-related regulatory services. This option shows positive impact on habitat creation by reconnecting aquatic and terrestrial ecosystems. It also delivers cultural benefits through landscape connectivity and traditional ecological relationships.
- Small-scale, distributed retention storage offers a more targeted but effective approach, providing moderate to high benefits across several key categories. This solution particularly contributes to freshwater quantity regulation through enhanced water storage and infiltration, and provides measurable benefits for habitat creation through wetland establishment. While the individual impact of each installation may be modest, the cumulative effect across multiple sites generates meaningful catchment-scale benefits.
- Channel realignment/ room for the river shows variable performance across Nature's Contributions to People categories, with high benefits in specific areas such as habitat creation through geomorphic diversity and moderate contributions to hazard regulation. This option scored high in cultural services by restoring natural river forms and traditional relationships with waterways, though its implementation may require careful consideration of trade-offs with existing land uses.

While the heatmap assessment provides valuable insights into the relative benefits of different NBS across ecosystem service categories, decision-makers require more detailed quantification to support investment decisions and cost-benefit analyses. The heatmap identifies which benefits each

NBS provides and their relative strengths, but does not quantify how much these benefits are worth to the community or how they compare in economic terms.

To address this need, the study explored two main approaches to quantify the wider benefits identified in the heatmap assessment:

- Biophysical Modelling - Using tools like InVEST to model and quantify ecosystem service flows in physical units (e.g., tonnes of carbon sequestered, cubic meters of water filtered) and potentially convert these to economic values using established valuation coefficients.
- Economic Valuation - Directly measuring community preferences and willingness to pay for the ecosystem service benefits through stakeholder engagement, providing economic values that reflect local priorities and contexts.

Sections 4 and 5 describe the investigation of these approaches and the rationale for the final methodology selected for quantifying wider benefits in the Waipoua catchment.

Table 3.2: Localised definitions of Nature's Contributions to People in Waipoua catchment

Adapted definition to the context of Waipoua catchment	
Habitat creation and maintenance	The formation and ongoing support, by ecosystems and their constituent organisms, of ecological conditions necessary or favourable for living beings of direct or indirect importance to humans. This includes: • Maintaining habitat connectivity, such as providing passage for migratory indigenous freshwater fish species throughout a catchment. • Preserving areas of high ecological significance, like the Tararua Forest and critically endangered forest remnants in the Ruamāhanga Valley of the Waipoua catchment. • Sustaining the mauri (life essence) of waterways such as the Waipoua River and their surrounding ecosystems. • Supporting the presence of taonga species such as tuna/ eel, patiki/ flounder and lizard/ mokomoko. • Supporting the presence and health of indigenous vegetation which contributes to overall ecosystem function and resilience. The wider benefits assessment excludes exotic species such as willows and poplars.
Pollination and dispersal of seeds and other propagules	The facilitation by animals of movement of pollen among flowers, and dispersal of seeds, larvae, or spores of organisms beneficial or harmful to humans. In the Waipoua catchment context, this ecosystem service: • Supports the retention of indigenous biodiversity through natural reproductive processes. • Is enhanced by forest remnants in the Ruamāhanga Valley that enable birds to transfer seeds and pollen from the Tararua Ranges. • Creates ecological connectivity that complements conservation efforts at Mt Bruce and potentially extends to coastal ecosystems.
Regulation of air quality	Regulation by ecosystems of atmospheric gases including oxygen, carbon dioxide, ozone, sulfur oxide, and nitrogen oxide, as well as volatile organic compounds, particulates, aerosols, and allergens. Ecosystems filter, fix, degrade, or store these pollutants that affect human health or infrastructure. For the Waipoua catchment, this service is particularly valuable in Masterton, where it helps address historical airshed pollution problems, especially those caused by in-home fires. Recognising the mauri in hau and its life giving properties.
Regulation of climate	Climate regulation by ecosystems (including regulation of global warming) through: • Carbon sequestration by forests. • Methane emissions by wetlands. • Evapotranspiration and moisture retention that creates local cooling effects. • Reduction of the urban heat island effect.
Regulation of ocean acidification	Regulation of atmospheric CO_2 concentrations and so seawater pH, that can be detrimental to marine ecosystems. Not directly regulated by NBS for Waipoua river.
Regulation of freshwater quantity, location and timing	Regulation by ecosystems of the quantity, location and timing of both surface and groundwater flows. This includes management of high flow events (flooding) and low flow conditions (drought), directly affecting water-dependent natural habitats such as wetlands, ponds, rivers, lakes, and swamps. In the Waipoua catchment, this service is critical for mitigating both drought conditions and flood events. Effective water quantity regulation connects to land use planning aimed at reducing overallocation of water resources. The scope of 'Regulation of freshwater quantity, location and timing' assessment is focused on low flows and river freshes. Comprehensive assessment of the NBS potential to mitigate risk of flooding is covered in other sections of the "Feasibility Study of Nature-Based Solutions for Addressing the Flood Risk to Masterton" Report .
Regulation of freshwater and coastal water quality	Regulation, through filtration of particles, pathogens, excess nutrients, and other chemicals by ecosystems of the quality of waimaori/ freshwater used directly (e.g. drinking, swimming) or indirectly (e.g. aquatic foods, irrigated food and medicinal plants). This includes management of groundwater quality issues such as nitrate contamination. The mauri (life essence) of water contributes to the mauri of other ecosystems that it passes through or naturally mixes with. Regulation of water that can sustain cultural practices as it has done in the past.
Formation, protection and decontamination of soils and sediments	Formation and long-term maintenance of soil structure and processes by plants, soil organisms and soil mauri (life essence). This includes the capacity of soil ecosystems to capture and process nutrients such as nitrogen. In the wider Wairarapa region, this service is demonstrated through Manuka trials conducted northwest of Lake Wairarapa with mana whenua, which have shown promising results for managing soil nitrates. The community has identified improving soil organic content as a priority for enhancing this ecosystem service.
Regulation of hazards and extreme events	Amelioration, by ecosystems, of the impacts on humans or their infrastructure caused by severe events linked to heat waves, wildfires, landslides. The scope of 'Regulation of hazards and extreme weather events' assessment excludes flooding. Comprehensive assessment of the NBS potential to mitigate risk of flooding is covered in other sections of the "Feasibility Study of Nature-Based Solutions for Addressing the Flood Risk to Masterton" Report.
Regulation of detrimental organisms and biological processes	Regulation of the direct detrimental effect of organisms on people. In the Waipoua catchment, this includes: • Control of toxic algae blooms that impact recreational activities and human health, which are fueled by excess nitrogen inputs, slow flows, and lack of shade in certain areas. • Enhancement of waterway health through NBS that improve in-stream habitat, support invertebrate communities, and establish riparian vegetation. • Maintenance of adequate water flows to support ecological regulation processes. • Utilization of healthy ecosystems such as wetlands to regulate pest outbreaks, particularly invertebrates that affect human health and agricultural crops.

Adapted definition to the context of Waipoua catchment	
Energy	Production of biomass-based fuels. Not relevant to Waipoua catchment.
Food and feed	Provision of kai, including taonga species such as kakahi/ freshwater mussels, koura, tuna (eel), inanga, lamprey, whitebait, flounder/ Patiki. Provision of other food or sport species such as trout, deer, pigs, ducks. Provision of wild foods like berries and water cress.
Materials, companionship and labour	Production of materials derived from organisms such as using harakeke for use in raranga/ weaving of fern roots. Carving and building wood, flax, raupo, kiekie, punga.
Medicinal, biochemical and genetic resources	Production of materials derived from organisms used for medicinal purposes. Specific medicinal plants and uses are not fully disclosed due to sensitive local matauranga.
Learning and inspiration	Provision, by landscapes, habitats, or organisms, of opportunities for the development of capabilities that allow humans to prosper through education, acquisition of knowledge, and development of skills for well-being. This includes learning from natural systems to design NBS that address environmental challenges while providing multiple benefits to communities. These ecosystems offer information and inspiration for art, cultural expression, ecological innovation, and technological design that mimics or works harmoniously with natural processes.
Physical and psychological experiences	Provision of opportunities for physically and psychologically beneficial activities, healing, relaxation, recreation, leisure, tourism and aesthetic enjoyment based on close contact with nature. In the Waipoua catchment, this ranges from extensive tramping and nature-based recreation in the Tararua Forest Park to daily enjoyment of smaller bush blocks closer to town. The river itself serves multiple recreational purposes including dog walking, swimming, fishing, kai gathering, and observing native wildlife such as eels, creating accessible connections with nature for local communities. Historically, it had swimming holes which were important recreational river assets for mana whenua.
Supporting identities	Provisioning of opportunities by nature for people to develop a sense of place, belonging, rootedness or connectedness, basis for narratives, rituals and celebrations, and source of satisfaction derived from knowing that a particular habitat or species exists. For the Waipoua catchment, this includes deep cultural connections such as the historic use of the river confluence for birthing rituals. It encompasses the wairua (spiritual dimension) of the river and supports the process of ecological restoration that transitions from introduced species like willows toward native vegetation, helping to reconnect the landscape with its indigenous identity.
Maintenance of options	Capacity of ecosystems, habitats, species or genotypes to keep options open in order to support a good quality of life. Examples include benefits (including those for future generations) associated with the continued existence of biodiversity, ecosystem resilience, ecosystem integrity in the face of environmental change and variability.

Table 3.3: Heatmap of the wider benefits provided by each NBS across the 18 Nature's Contributions to People categories (refer to Appendix A for more details)

	1 Habitat creation and maintenance	2 Pollination and dispersal of seeds and other propagules	3 Regulation of air quality	4 Regulation of climate	5 Regulation of ocean acidification	6 Regulation of freshwater quantity, location and timing	7 Regulation of freshwater and coastal water quality	8 Formation, protection and decontamination of soils and sediments	9 Regulation of hazards and extreme events	10 Regulation of detrimental organisms and biological processes	11 Energy	12 Food and feed	13 Materials, companionship and labour	14 Medicinal, biochemical and genetic resources	15 Learning and inspiration	16 Physical and psychological experiences	17 Supporting identities	18 Maintenance of options
Feasibility of quantification & valuation																		
Land retirement, and revegetation of native forest on hillslopes	++	++	+	++	+	-/+	++	++	-/+	-/+	+	-/+	+	+	+	++	++	++
Floodplain re-engagement	+			+			+	+				-/+			++	++	+	+
Small-scale, distributed retention storage	++	+		+		+	+	+		-/+		-/+	+	+	+	+	+	+
Channel realignment/ room for the river	++	+		+		-/+	++	+		-		-/+		+	+	++	+	++

Legend:

NBS scoring:

Strong positive (++) Positive (+) Neutral/ mixed (+/-) Negative (-) Not applicable

Feasibility of quantification and valuation:

High Moderate Low

4 Geospatial quantification - InVest

The preliminary review of the benefits and quantification options suggested that for a subset of relevant Nature's Contributions to People, T+T could undertake quantitative (monetary - depending on data availability) assessment using the InVest tool.

The InVest Tool is one of the tools noted in the NIWA NBS literature review[1]. GIS models available in InVest which might be relevant to the project include Sediment Delivery Ratio, Seasonal Water Yield, Annual Water Yield, Nutrient Delivery, Habitat Quality and Carbon Storage and Sequestration Models. The documentation on the InVest tool indicated that several global datasets were available.

On further investigating the InVest tool, T+T found it to be a well thought out, well-built and well-documented piece of software. It is also free and open source. It shows considerable promise for quantifying and comparing the benefits of NBS. T+T looked specifically at the models for Sediment Delivery Ratio, Seasonal Water Yield, and Habitat Quality as these seemed to represent wider benefits of particular interest, with lower data needs. However, in terms of quantifying some Nature's Contributions to People within the project timeframes, T+T had the following challenges:

- The models generally are still "data hungry", requiring at minimum two or three input GIS layers and additional tabular data.
- The global datasets don't have global coverage, including in the area of interest; although national or local databases may be available, there would be extra effort in obtaining and potentially processing these to a suitable format for the model.
- Preparing the spatial inputs more generally would require considerable GIS effort, including to represent each of the four selected NBS spatially in a consistent way (e.g. for some models, representing the future land cover).
- In addition to the geospatial data, input would be needed from subject matter experts (e.g. hydrologist, geomorphologist, ecologist) to fully understand and set up the model inputs.
- In some cases, the model outputs appeared buggy and T+T would need to allow some time for debugging, depending on the model and input data. This reduced the confidence in obtaining meaningful results in a short timeframe.

While it was not possible to overcome the above challenges within the timeframes of this project, the tool shows promise for the future. The challenges encountered with biophysical modelling approaches like InVEST highlighted the need for an alternative quantification strategy that could:

- Work within project constraints - Deliver meaningful results within the available timeframe and budget without requiring extensive data collection or technical model setup.
- Capture local values - Reflect community priorities and preferences specific to the Waipoua catchment.

Stakeholder-based economic valuation emerged as the most suitable approach because it directly addresses these limitations. The following section describes the design and implementation of this stakeholder valuation approach.

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[1] Griffiths, J., Semadeni-Davies, A., Borne, K., & Tanner, C. (2024). *Nature-based solutions for flood management: Literature Review* (2024141CH). National Institute of Water & Atmospheric Research Ltd.

5 Economic valuation of Nature's Contributions to People – Stakeholder valuation

The semi-quantitative heatmap assessment provided a foundation for understanding which NBS deliver which types of benefits. Given the limitations of biophysical modelling approaches (such as InVest), the study adopted a stated preference economic valuation method, specifically contingent valuation, to quantify community willingness to pay for ecosystem service benefits from NBS.

5.1 Approach

The **Contingent Valuation Method** is a survey-based economic technique that creates a hypothetical market for non-market environmental goods and services. In this application, the Contingent Valuation Method directly asked stakeholders about their willingness to pay for specific environmental improvements resulting from each of the four selected NBS options.

The method involves presenting respondents with detailed scenarios describing the environmental outcomes and asking them to state their maximum willingness to pay (as an annual household contribution) to secure these benefits. This approach is particularly suitable for valuing complex ecosystem services that lack market prices, such as biodiversity conservation, water quality improvements, and flood risk reduction.

The **Preference Ranking Method** was used alongside contingent valuation to capture relative preferences between NBS options independent of monetary considerations. This approach asked participants to rank all four NBS from most to least preferred, providing insights into stakeholder priorities that may not be influenced by income constraints or payment vehicle concerns. Preference ranking serves as a complementary method that can validate monetary valuation results while revealing the underlying preference structure that drives willingness to pay responses.

The wider benefits **Importance Assessment** evaluated stakeholder priorities across different categories of Nature's Contributions to People using a 5-point importance scale. This method measured how much participants valued different types of environmental benefits (such as habitat creation, water quality regulation, climate benefits, and cultural significance) before they considered specific NBS options. By establishing baseline importance ratings for different ecosystem services, this approach provides explanatory context for understanding why certain NBS options received higher willingness to pay values or preference rankings, helping to identify which wider benefits most strongly influence community support for NBS.

5.2 Contingent valuation, preference ranking & wider benefits importance assessment design

The stakeholder valuation was conducted through a workshop using three different approaches to understand how participants valued the NBS. Each method captured different aspects of stakeholder preferences and together provided strong evidence for decision-making.

The survey was run as a structured workshop with 20 stakeholders who had different relationships with the Waipoua catchment. The stakeholders included community representatives such as local rural landowners, QE2 Trust, Sustainable Wairarapa, Upper Waipoua Kaitiaki group, Ngāti Kahungunu, Rangitāne, and the Waipoua River Management Advisory Group. The survey moved through four main sections:

- Part 1: Background Information - Collected information about participants including how well they knew the catchment, their concerns about flooding, how often they visited natural areas, and what they valued most about the catchment.
- Part 2: Willingness to Pay Exercise - The main economic valuation using four "voting cards".

- Part 3: Preference Ranking - Comparing the four NBS options.
- Part 4: Wider benefits Importance Assessment - Rating different environmental benefits.
- Additional Comments - Space for other feedback.

The survey is presented in Appendix B.

5.2.1 Contingent valuation & willingness to pay

The willingness to pay exercise used four voting cards, each showing one of the NBS options. Each card showed:

- Ten Nature's Contributions to People categories, including habitat creation and maintenance, pollination and dispersal of seeds, air quality regulation, climate regulation, regulation of water quality, soil protection, materials provision, medicinal resources, educational and learning opportunities, recreational opportunities and cultural significance.
- Ten categories of benefits from nature were shown using simple icons (leaf for habitat, bee for pollination, water droplet for water quality, etc.).
- Each environmental benefit was described using clear language:
  - "Strong improvement/ benefits" (shown with two icons).
  - "Some improvement/ benefits" (shown with one and a half icons).
  - "No or very low improvement" (shown with one icon).
- Annual household payment ranging from $0 to $500+ in set amounts ($0, $25, $50, $75, $100, $150, $200, $300, $500+).

Card-specific benefits included:

- Card 1 (Land Retirement/ Forest Revegetation): Showed strong benefits for most categories including habitat creation, climate regulation, water quality, and soil protection.
- Card 2 (Floodplain Re-engagement): Highlighted educational and recreational benefits with moderate improvements elsewhere.
- Card 3 (Small-scale Retention Storage): Featured strong habitat creation with moderate benefits across other categories.
- Card 4 (Channel Realignment): Showcased strong habitat creation, water quality, and recreational benefits.

The participants were not presented with the name of the NBS option they were valuing, to obtain their views on wider benefits.

5.2.2 Preference ranking

The ranking exercise provided a direct comparison between options that worked alongside the monetary valuation by showing relative preferences regardless of ability or willingness to pay.

Participants ranked all four NBS options (land retirement and native forest revegetation; floodplain re-engagement; small-scale, distributed retention storage; channel realignment and room for the river) from most preferred (1) to least preferred (4).

5.2.3 Wider benefits importance assessment

The importance rating exercise measured what stakeholders cared most about across different Nature's Contributions to People, providing background information about which ecosystem services stakeholders valued most. The rating scale was a five-point scale from 1 (Not important) to 5 (Very important). Participants assigned the importance number to each of these Nature's Contributions to People.

This method provided baseline information about participant values that could explain patterns in willingness to pay and ranking results.

5.3 Stakeholder profile and engagement

The contingent valuation workshop engaged 20 stakeholders with diverse relationships to the Waipoua River catchment. The participant profile reveals a highly engaged and knowledgeable stakeholder group, with 55% very familiar with the catchment through regular visits or residence, and an additional 35% somewhat familiar with the area (Figure 5.1). Notably, no participants indicated unfamiliarity with the catchment, suggesting the consultation captured perspectives from those with direct experience and investment in the area's outcomes.

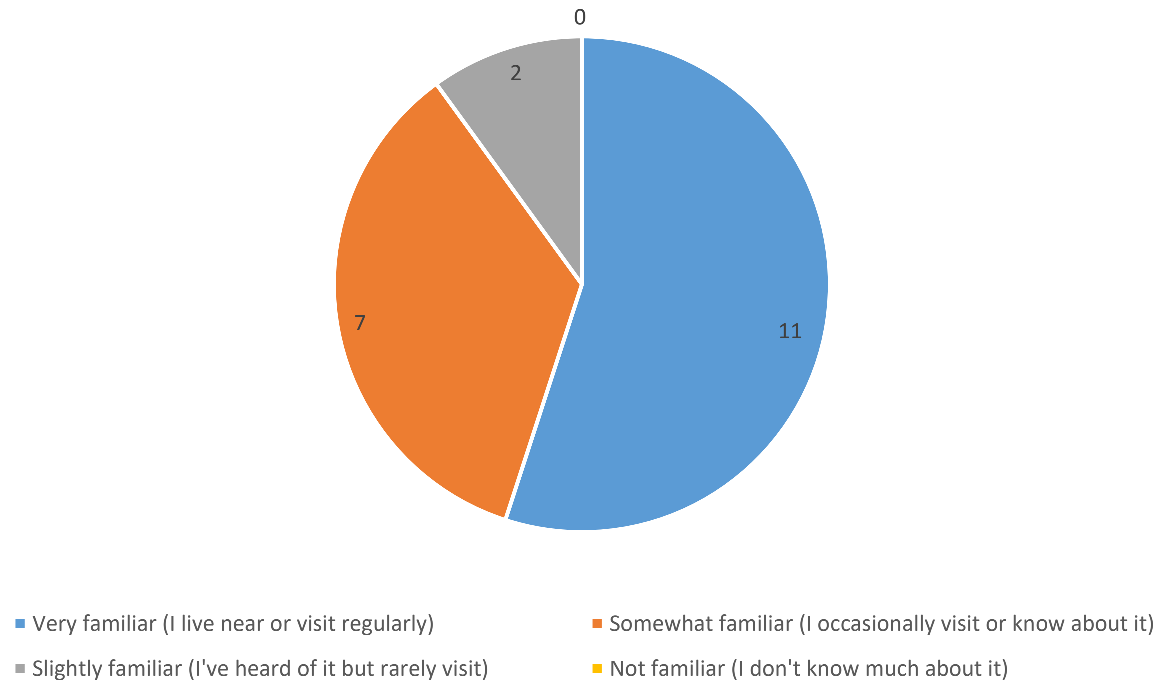


Figure 5.1: Level of stakeholder familiarity with the Waipoua catchment.

Figure 5.2 shows the concern levels about flooding in Masterton are substantial, with 75% of participants expressing moderate to high concern (45% somewhat concerned, 30% very concerned). This aligns with the focus of the wider feasibility study on flood risk management and validates its relevance for addressing community priorities.

The high level of engagement is further evidenced by 70% of participants interacting with the Waipoua River or surrounding natural areas on a monthly or more frequent basis (Figure 5.3). The stakeholders also indicate a strong preference (54% of responses) for ecological health and biodiversity as the most important value for the Waipoua catchment (Figure 5.4); stakeholders were able to select up to two options to rate as 'most important'.

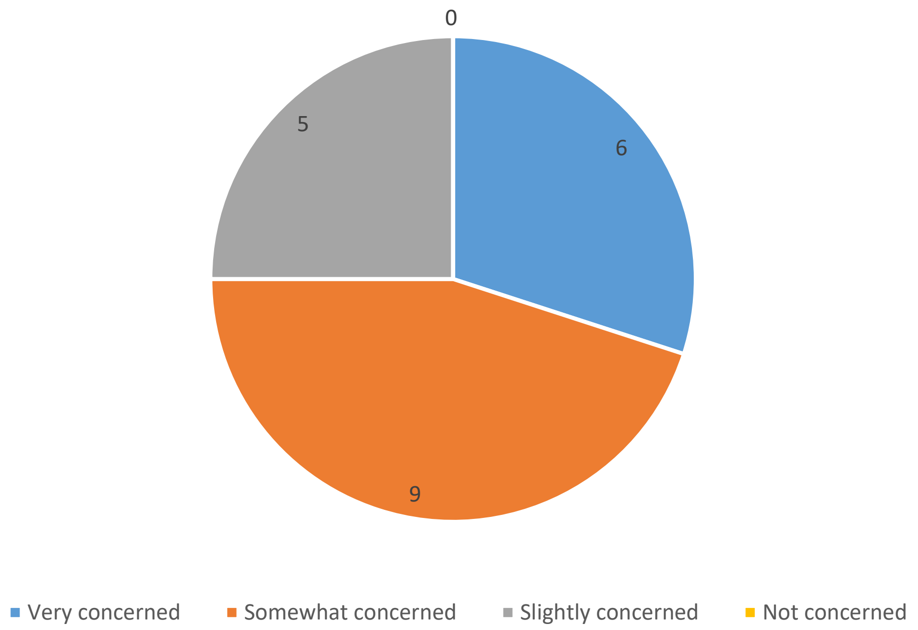


Figure 5.2: Level of stakeholder concern about flooding in Masterton.

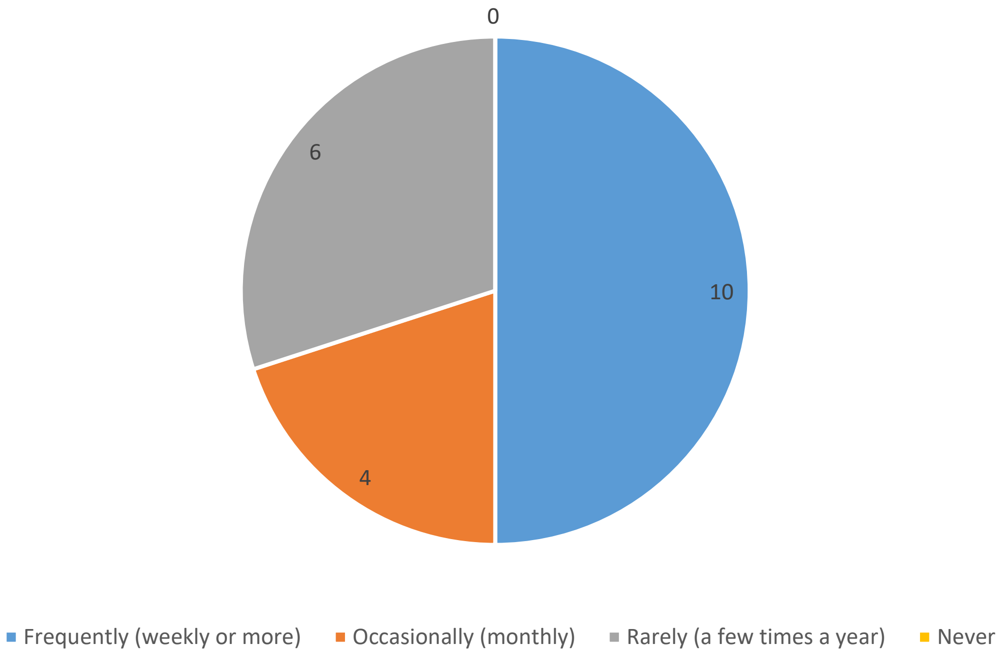


Figure 5.3: Frequency of stakeholder engagement with the Waipoua River and surrounding natural areas.

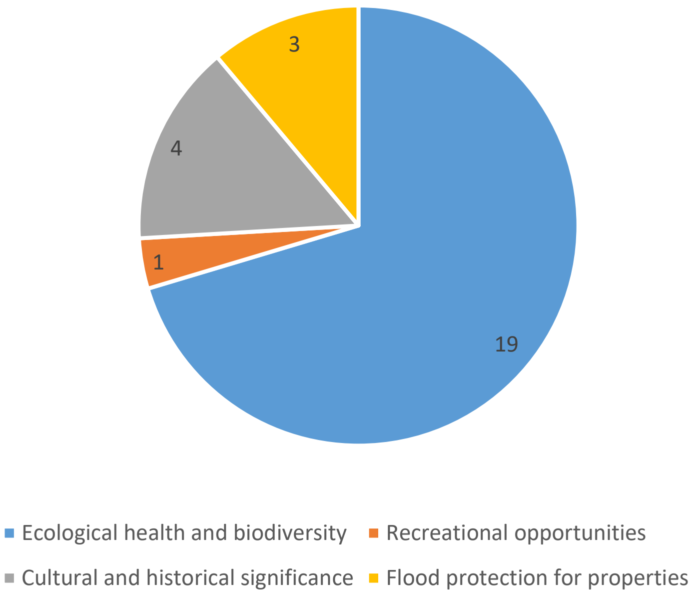


Figure 5.4: Values that stakeholders rated as most important for the Waipoua catchment.

5.4 Outcomes of the willingness to pay exercise

The contingent valuation exercise (Table 5.1) revealed strong community support for all four NBS, with mean willingness to pay (WTP) ranging from $161 to $355 per household annually.

Land retirement and revegetation of native forest on hillslopes generated the highest mean WTP at $338. Nearly half (44%) of the respondents were willing to pay $500 or more annually for this NBS option. Channel realignment and room for the river showed the second-highest mean WTP at $244. Small-scale, distributed retention storage generated moderate support with a mean WTP of $216. Finally, floodplain re-engagement received the lowest mean WTP at $209 (median $100). To reiterate, the participants were valuing a 'basket' of benefits, rather than explicitly valuing a known NBS.

Table 5.1: Willingness to pay results

NBS option	Mean WTP (in $)	Median WTP (in $)	Range	% Zero responses
Land Retirement and Native Forest Revegetation	$338	$300	$50-$500+	0%
Floodplain Re-engagement	$209	$100	$25-$500+	0%
Small-scale, Distributed Retention Storage	$217	$200	$25-$500+	0%
Channel Realignment and Room for the River	$244	$200	$0-$500+	5.9%

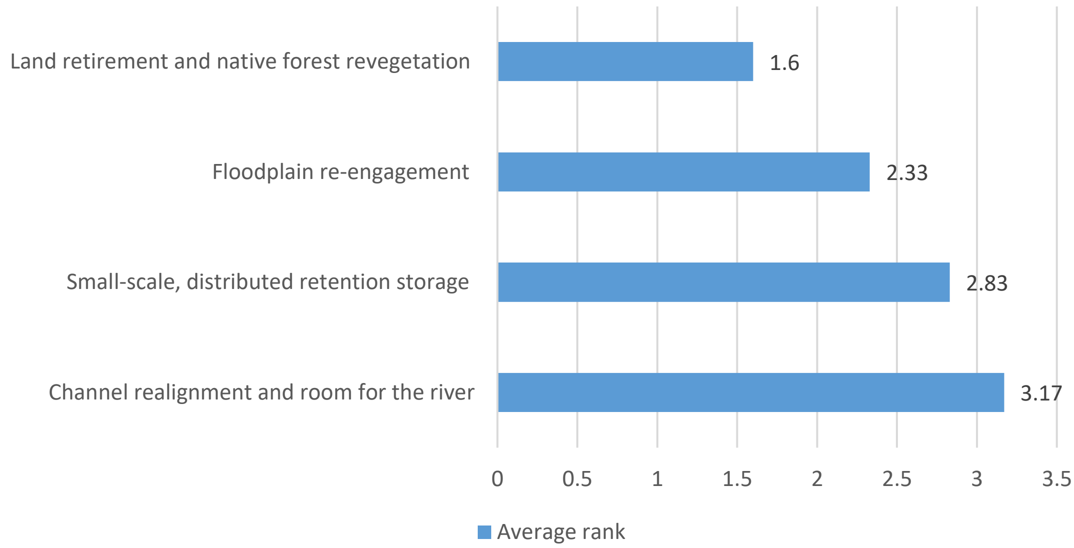
5.5 Outcomes of the ranking preferences

The ranking exercise (Table 5.2) reinforced the WTP findings, with land retirement and revegetation strongly preferred, ranked first by 65% of participants and achieving an average rank of 1.60. This option was consistently preferred, with 80% ranking it in their top two choices.

Floodplain re-engagement ranked second overall (average rank 2.33), with 55.6% of participants placing it in their top two preferences, despite it having the lowest mean value in the previous exercise. This indicates that aspects other than the wider benefits may be influencing their preferences – for example, a perceived association of this option with the potential for wetland creation or groundwater recharge. Small-scale retention storage achieved a middle ranking (average rank 2.83), while channel realignment was least preferred overall (average rank 3.17), with 55.6% ranking it last.

The ranking results show strong consensus around forest restoration as the preferred option, while revealing more mixed views on river channel modifications.

Table 5.2: Ranking NBS results



NBS option	Average rank	% Ranked #1 (first)	% Ranked #2	% Ranked #3	% Ranked #4 (last)
Land Retirement and Native Forest Revegetation	1.60	65.0%	15.0%	15.0%	5.0%
Floodplain Re-engagement	2.33	16.7%	38.9%	38.9%	5.6%
Small-scale, Distributed Retention Storage	2.83	16.7%	16.7%	33.3%	33.3%
Channel Realignment and Room for the River	3.17	5.6%	27.8%	11.1%	55.6%

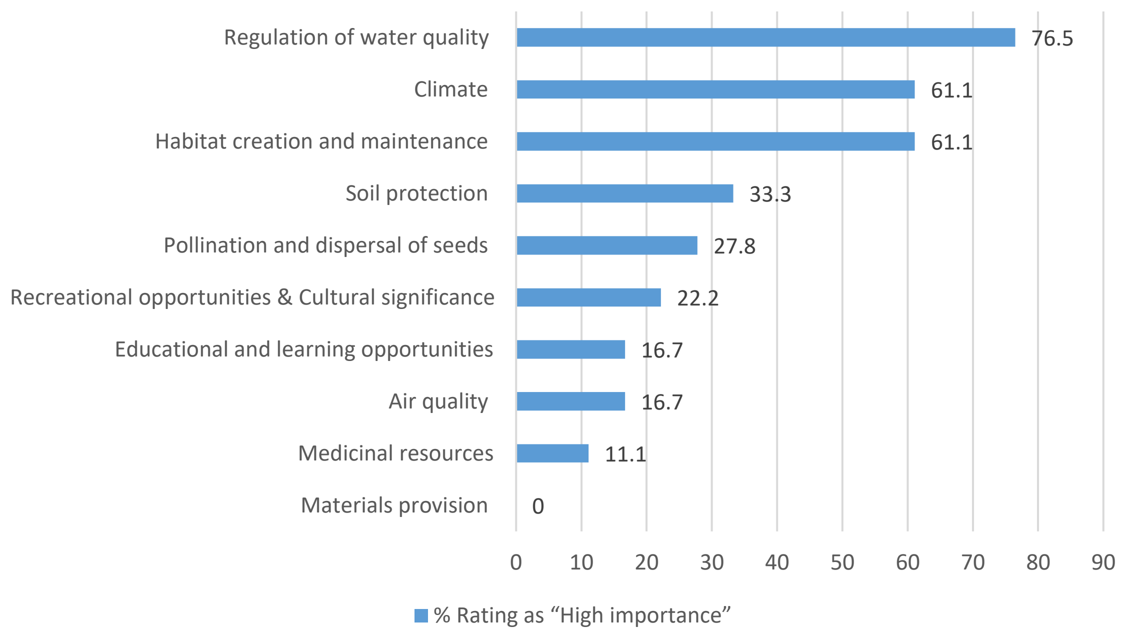
5.6 Outcomes of the wider benefits importance assessment

The assessment of wider benefit importance (Table 5.3) reveals stakeholder priorities that align closely with the technical wider benefits analysis. Regulation of water quality received the highest importance rating (average 4.65/ 5, with 76.5% rating it as highly important), directly supporting the technical assessment that identified water quality improvements as a key NBS benefit.

Habitat creation and maintenance was equally prioritized (average 4.61/ 5, 61.1% high importance), reinforcing the earlier finding that ecological health is the community's top priority. Climate regulation also scored highly (average 4.06/5, 61.1% high importance), indicating strong community awareness of climate wider benefits from NBS.

Soil protection (average 4.00/ 5) and recreational opportunities & cultural significance (average 3.78/ 5) were also valued, though to a lesser extent. Lower-priority benefits included materials provision (average 2.28/ 5), medicinal resources (average 2.67/ 5), and air quality regulation (average 3.11/ 5).

Table 5.3: ***Wider benefits importance ranking results***



	Average Rating	% Rating as “High importance”
Habitat creation and maintenance	4.61	61.1%
Pollination and dispersal of seeds	3.39	27.8%
Air quality	3.11	16.7%
Climate	4.06	61.1%
Regulation of water quality	4.65	76.5%
Soil protection	4.00	33.3%
Materials provision	2.28	0%
Medicinal resources	2.67	11.1%

	Average Rating	% Rating as "High importance"
Educational and learning opportunities	3.11	16.7%
Recreational opportunities & Cultural significance	3.78	22.2%

5.7 Conclusions

Based on the stakeholder opinions expressed via the valuation activity, the following conclusions can be drawn:

- Forest restoration initiatives emerge as the flagship NBS component for these stakeholders, given the highest stakeholder support and willingness to pay values.
- Integrated implementation of hybrid approaches that combine forest restoration with complementary solutions like retention storage may be worthwhile, to optimise the balance between technical effectiveness and community value. This was also suggested by workshop participants.
- Water quality, habitat and biodiversity wider benefits align most closely with community priorities and should be prioritised in communications and NBS implementation.
- There is evidence of strong community support for funding and implementation partnerships, given the demonstrated willingness to contribute financially to NBS implementation. Several of the stakeholders are also volunteering considerable amounts of their own time and resources already in initiatives such as restoration planting.

The stakeholder valuation results provide strong evidence that NBS align with community values and priorities in the Waipoua catchment, supporting both the technical feasibility and social support for the proposed approaches.

6 Applicability

This report has been prepared for the exclusive use of our client Greater Wellington Regional Council, with respect to the particular brief given to us and it may not be relied upon in other contexts or for any other purpose, or by any person other than our client, without our prior written agreement.

Tonkin & Taylor Ltd
Environmental and Engineering Consultants

Report prepared by:

Dr Eva Siwicka
Climate, Nature & Biodiversity Consultant

Authorised for Tonkin & Taylor Ltd by:

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Bryn Quilter
Project Director

Appendix A Comprehensive Wider Benefits Definitions & Descriptions Table

Appendix A Table 1: Nature's Contributions to People (NCP) definitions

Nature's Contributions to People categories	(Diaz et al. 2018)	Adapted definition to the context of Waipoua catchment	Feasibility of quantification and valuation (in the context of assessed NBS)	Other methods (not in scope)
Habitat creation and maintenance	The formation and continued production, by ecosystems or organisms within them, of ecological conditions necessary or favourable for living beings of direct or indirect importance to humans. E.g. growing sites for plants, nesting, feeding, and mating sites for animals, resting and overwintering areas for migratory mammals, birds and butterflies, roosting places for agricultural pests and disease vectors, nurseries for juvenile stages of fish, habitat creation at different soil depths by invertebrates.	The formation and ongoing support, by ecosystems and their constituent organisms, of ecological conditions necessary or favourable for living beings of direct or indirect importance to humans. This includes: • Maintaining habitat connectivity, such as providing passage for migratory indigenous freshwater fish species throughout a catchment. • Preserving areas of high ecological significance, like the Tararua Forest and critically endangered forest remnants in the Ruamahanga Valley of the Waipoua catchment. • Sustaining the mauri (life essence) of waterways such as the Waipoua River and their surrounding ecosystems. • Supporting the presence of taonga species such as tuna/ eel, patiki/ flounder and lizard/ mokomoko. • Supporting the presence and health of indigenous vegetation which contributes	**Quantification:** High **Market-based valuation:** Low **Non-market based valuation:** Moderate	**Quantification:** species diversity (richness, abundance, evenness), Bayesian belief networks. **Market-based valuation:** biodiversity credit market prices. **Non-market based valuation:** Choice experiment.

Nature's Contributions to People categories	(Diaz et al. 2018)	Adapted definition to the context of Waipoua catchment	Feasibility of quantification and valuation (in the context of assessed NBS)	Other methods (not in scope)
		to overall ecosystem function and resilience. The co-benefits assessment excludes exotic species such as willows and poplars.		
Pollination and dispersal of seeds and other propagules	Facilitation by animals of movement of pollen among flowers, and dispersal of seeds, larvae or spores of organisms beneficial or harmful to humans.	The facilitation by animals of movement of pollen among flowers, and dispersal of seeds, larvae, or spores of organisms beneficial or harmful to humans. In the Waipoua catchment context, this ecosystem service: • Supports the retention of indigenous biodiversity through natural reproductive processes. • Is enhanced by forest remnants in the Ruamahanga Valley that enable birds to transfer seeds and pollen from the Tararua Ranges. • Creates ecological connectivity that complements conservation efforts at Mt Bruce and potentially extends to coastal ecosystems.	**Quantification:** Moderate **Market-based valuation**: Moderate **Non-market based valuation:** Moderate	**Quantification:** pollinator abundance survey. **Market-based valuation:** replacement cost for manmade pollination service. **Non-market based valuation**: contingent valuation.
Regulation of air quality	Regulation (by impediment or facilitation) by ecosystems, of CO2/ O2 balance, O3, sulphur oxide, nitrogen oxides (NOx), volatile organic compounds (VOC), particulates, aerosols, allergens. Filtration, fixation, degradation or storage of pollutants that directly affect human health or infrastructure.	Regulation by ecosystems of atmospheric gases including oxygen, carbon dioxide, ozone, sulfur oxide, and nitrogen oxide, as well as volatile organic compounds, particulates, aerosols, and allergens. Ecosystems filter, fix, degrade, or store these pollutants that affect human health or infrastructure. For the Waipoua catchment,	**Quantification:** Moderate **Market-based valuation**: Moderate **Non-market based valuation**: Moderate	**Quantification:** deposition velocity measurements, particulate matter capture quantification, leaf area index correlations. **Market-based valuation:** avoided health cost.

Nature's Contributions to People categories	(Diaz et al. 2018)	Adapted definition to the context of Waipoua catchment	Feasibility of quantification and valuation (in the context of assessed NBS)	Other methods (not in scope)
		this service is particularly valuable in Masterton, where it helps address historical airshed pollution problems, especially those caused by in-home fires. Recognising the mauri in hau and its life giving properties.		**Non-market based valuation:** contingent valuation.
Regulation of climate	Climate regulation by ecosystems (including regulation of global warming) through: (i) positive or negative effects on emissions of greenhouse gases (e.g. biological carbon storage and sequestration; methane emissions from wetlands); (ii) positive or negative effects on biophysical feedbacks from vegetation cover to atmosphere, such as those involving albedo, surface roughness, long-wave radiation, evapotranspiration (including moisture-recycling) and cloud formation; (iii) direct and indirect processes involving biogenic volatile organic compounds (BVOC), and regulation of aerosols and aerosol precursors by terrestrial plants and phytoplankton.	Climate regulation by ecosystems (including regulation of global warming) through: • Carbon sequestration by forests. • Methane emissions by wetlands. • Evapotranspiration and moisture retention that creates local cooling effects. • Reduction of the urban heat island effect.	**Quantification:** High **Market-based valuation:** High **Non-market based valuation:** Moderate	**Quantification:** carbon sequestration measurements (tCO_2e/ha/yr), greenhouse gas flux monitoring, albedo effect measurements, Bayesian belief networks. **Market-based valuation:** carbon credit market prices, avoided carbon tax cost. **Non-market based valuation:** contingent valuation.
Regulation of ocean acidification	Regulation, by photosynthetic organisms (on land or in water), of atmospheric CO2 concentrations and so seawater pH, which affects associated calcification processes by many marine organisms important to humans (such as corals).	Regulation of atmospheric CO2 concentrations and so seawater pH, that can be detrimental to marine ecosystems. Not directly regulated by NBS for Waipoua river.	**Quantification:** Low **Market-based valuation:** Low **Non-market based valuation:** Low	**Quantification:** blue carbon storage measurement. **Market-based valuation:** none. **Non-market based valuation:** contingent valuation.

Nature's Contributions to People categories	**(Diaz et al. 2018)**	**Adapted definition to the context of Waipoua catchment**	**Feasibility of quantification and valuation** **(in the context of assessed NBS)**	**Other methods (not in scope)**
Regulation of freshwater quantity, location and timing	Regulation, by ecosystems, of the quantity, location and timing of the flow of surface and groundwater used for drinking, irrigation, transport, hydropower, and as the support of non-material contributions (NCP 15, 16, 17). Regulation of flow to water-dependent natural habitats that in turn positively or negatively affect people downstream, including via flooding (wetlands including ponds, rivers, lakes, swamps). Modification of groundwater levels, which can ameliorate dryland salinisation in unirrigated landscapes.	Regulation by ecosystems of the quantity, location and timing of both surface and groundwater flows. This includes management of high flow events (flooding) and low flow conditions (drought), directly affecting water-dependent natural habitats such as wetlands, ponds, rivers, lakes, and swamps. In the Waipoua catchment, this service is critical for mitigating both drought conditions and flood events. Effective water quantity regulation connects to land use planning aimed at reducing overallocation of water resources. The scope of 'Regulation of freshwater quantity, location and timing' assessment is focused on low flows and river fresh. Comprehensive assessment of NBS potential to mitigate risk of flooding is covered in other sections of the report.	**Quantification:** High **Market-based valuation**: High **Non-market based valuation**: High	**Quantification:** flood peak reduction measurement, baseflow contribution analysis, hydrological modelling of watershed retention, Bayesian belief networks. **Market-based valuation:** avoided cost method for flood prevention. **Non-market based valuation:** contingent valuation and choice experiment.
Regulation of freshwater and coastal water quality	Regulation – through filtration of particles, pathogens, excess nutrients, and other chemicals – by ecosystems or particular organisms, of the quality of water used directly (e.g. drinking, swimming) or indirectly (e.g. aquatic foods, irrigated food and fiber crops, freshwater and coastal habitats of heritage value).	Regulation, through filtration of particles, pathogens, excess nutrients, and other chemicals by ecosystems of the quality of waimaori/ freshwater used directly (e.g. drinking, swimming) or indirectly (e.g. aquatic foods, irrigated food and medicinal plants). This includes management of groundwater quality issues such as nitrate contamination. The mauri (life essence) of water contributes to the mauri of other ecosystems that it passes through or	**Quantification:** Moderate **Market-based valuation**: Moderate **Non-market based valuation**: Moderate	**Quantification:** nutrient and sediment removal rate measurements, turbidity reduction quantification **Market-based valuation:** replacement cost for water treatment, avoided treatment cost, hedonic pricing for waterfront properties.

Nature's Contributions to People categories	(Diaz et al. 2018)	Adapted definition to the context of Waipoua catchment	Feasibility of quantification and valuation (in the context of assessed NBS)	Other methods (not in scope)
		naturally mixes with. Regulation of water that can sustain cultural practices as it has done in the past.		**Non-market based valuation:** contingent valuation.
Formation, protection and decontamination of soils and sediments	Formation and long-term maintenance of soil structure and processes by plants and soil organisms. Includes: physical protection of soil and sediments from erosion, and supply of organic matter and nutrients by vegetation; processes that underlie the continued fertility of soils important to humans (e.g. decomposition and nutrient cycling); filtration, fixation, attenuation or storage of chemical and biological pollutants (pathogens, toxics, excess nutrients) in soils and sediments.	Formation and long-term maintenance of soil structure and processes by plants, soil organisms and soil mauri (life essence). This includes the capacity of soil ecosystems to capture and process nutrients such as nitrogen. In the Waipoua region, this service is demonstrated through Manuka trials conducted northwest of Lake Wairarapa with mana whenua, which have shown promising results for managing soil nitrates. The community has identified improving soil organic content as a priority for enhancing this ecosystem service.	**Quantification:** Low **Market-based valuation:** Low **Non-market based valuation**: Low	**Quantification:** erosion prevention metrics (t/ha/yr avoided). **Market-based valuation:** replacement cost for soil remediation. **Non-market based valuation:** contingent valuation.
Regulation of hazards and extreme events	Amelioration, by ecosystems, of the impacts on humans or their infrastructure caused by e.g. floods, wind, storms, hurricanes, heat waves, tsunamis, high noise levels, fires, seawater intrusion, tidal waves. Reduction or increase, by ecosystems or particular organisms, of hazards like landslides, avalanches.	Amelioration, by ecosystems, of the impacts on humans or their infrastructure caused by severe events linked to heat waves, wild fires, landslides. The scope of 'Regulation of hazards and extreme weather events' assessment excludes flooding. Comprehensive assessment of the NBS potential to mitigate risk of flooding is covered in other sections of the report.	**Quantification:** Moderate **Market-based valuation:** High **Non-market based valuation:** Moderate	**Quantification:** flood attenuation measurements, Bayesian belief networks. **Market-based valuation:** avoided damage, replacement cost, hedonic pricing (insurance premiums). **Non-market based valuation:** contingent valuation.

Nature's Contributions to People categories	(Diaz et al. 2018)	Adapted definition to the context of Waipoua catchment	Feasibility of quantification and valuation (in the context of assessed NBS)	Other methods (not in scope)
Regulation of detrimental organisms and biological processes	Regulation, by organisms, of pests, pathogens, predators or competitors that affect humans (materially and non-materially), or plants or animals of importance for humans. Also the direct detrimental effect of organisms on humans or their plants, animals or infrastructure. These include e.g.: (i) Control by predators or parasites of the population size of animals important to humans, such as attacks by large carnivores, or infestation by liver fluke, on game or livestock); (ii) Regulation (by impediment or facilitation) of the abundance or distribution of potentially harmful organisms (e.g. venomous, toxic, allergenic, predators, parasites, competitors, pathogens, agricultural weeds and pests, disease vectors and reservoirs) over the landscape or seascape; (iii) Removal, by scavengers, of animal carcasses and human corpses (e.g. vultures in Zoroastrian and some Tibetan Buddhist traditions); (iv) Biological impairment and degradation of infrastructure (e.g. damage by pigeons, bats, termites, strangling figs to buildings); (v) Direct physical damage to crops, forest plantations, livestock, poultry and fisheries by mammals, birds and reptiles; (vi) Damage caused by invertebrates as pests of agriculture, horticulture, forest, and stored products, and by affecting health	Regulation of the direct detrimental effect of organisms on people. In the Waipoua catchment, this includes: • Control of toxic algae blooms that impact recreational activities and human health, which are fueled by excess nitrogen inputs, slow flows, and lack of shade in certain areas. • Enhancement of waterway health through NBS that improve in-stream habitat, support invertebrate communities, and establish riparian vegetation. • Maintenance of adequate water flows to support ecological regulation processes. • Utilization of healthy ecosystems such as wetlands to regulate pest outbreaks, particularly invertebrates that affect human health and agricultural crops.	**Quantification:** Low **Market-based valuation:** Moderate **Non-market based valuation:** Moderate	**Quantification:** invasive species spread. **Market-based valuation:** avoided cost of pest control. **Non-market based valuation:** contingent valuation.

Nature's Contributions to People categories	(Diaz et al. 2018)	Adapted definition to the context of Waipoua catchment	Feasibility of quantification and valuation (in the context of assessed NBS)	Other methods (not in scope)
	of domestic animals; (vii) Direct damage caused by organisms to humans by e.g. frightening, hurting, killing, or transmitting diseases; (viii) Regulation of the human immune system by a diverse environmental microbiota.			
Energy	Production of biomass-based fuels, such as biofuel crops, animal waste, fuelwood, agricultural residue pellets, peat.	Production of biomass-based fuels. Not relevant to Waipoua catchment.	**n/a**	**n/a**
Food and feed	Production of food from wild, managed, or domesticated organisms, such as fish, bushmeat and edible invertebrates, beef, poultry, game, dairy products, edible crops, wild plants, mushrooms, honey. Production of feed (forage and fodder) for domesticated animals (e.g. livestock, work and support animals, pets) or for aquaculture, from the same sources.	Provision of kai, including taonga species such as kakahi/ freshwater mussels, koura, tuna (eel), inanga, lamprey, whitebait, flounder/ Patiki, Provision of other food or sport species such as trout, deer, pigs, ducks. Provision of wild foods like berries and water cress.	**Quantification:** Moderate **Market-based valuation**: Moderate **Non-market based valuation**: Low	**Quantification:** arable land area converted to restoration. **Market-based valuation:** direct market price. **Non-market based valuation:** contingent valuation and choice experiment.
Materials, companionship and labour	Production of materials derived from organisms in cultivated or wild ecosystems, for construction, clothing, printing, ornamental purposes (e.g. wood, peat, fibers, waxes, paper, resins, dyes, pearls, shells, coral branches). Live organisms being directly used for decoration (i.e. ornamental plants, birds, fish in households and public spaces), company (e.g. pets), transport, and labour	Production of materials derived from organisms such as using harakeke for use in raranga/ weaving of fern roots. Carving and building wood, flax, raupo, kiekie, punga.	**Quantification:** Moderate **Market-based valuation:** Moderate **Non-market based valuation:** Low	**Quantification:** harvest measurement. **Market-based valuation:** direct market price. **Non-market based valuation:** contingent valuation.

Nature's Contributions to People categories	(Diaz et al. 2018)	Adapted definition to the context of Waipoua catchment	Feasibility of quantification and valuation (in the context of assessed NBS)	Other methods (not in scope)
	(including herding, searching, guidance, guarding).			
Medicinal, biochemical and genetic resources	Production of materials derived from organisms (plants, animals, fungi, microbes) used for medicinal, veterinary and pharmacological (e.g. poisonous, psychoactive) purposes. Production of genes and genetic information used for plant and animal breeding and biotechnology.	Production of materials derived from organisms used for medicinal purposes. Specific medicinal plants and uses are not fully disclosed due to sensitive local matauranga.	**Quantification**: Moderate **Market-based valuation:** Moderate **Non-market based valuation:** Low	**Quantification:** species diversity measures. **Market-based valuation:** market price for developed products. **Non-market based valuation:** contingent valuation.
Learning and inspiration	Provision, by landscapes, seascapes, habitats or organisms, of opportunities for the development of the capabilities that allow humans to prosper through education, acquisition of knowledge and development of skills for well-being, information, and inspiration for art and technological design.	Provision, by landscapes, habitats, or organisms, of opportunities for the development of capabilities that allow humans to prosper through education, acquisition of knowledge, and development of skills for well-being. This includes learning from natural systems to design NBS that address environmental challenges while providing multiple benefits to communities. These ecosystems offer information and inspiration for art, cultural expression, ecological innovation, and technological design that mimics or works harmoniously with natural processes.	**Quantification:** Low **Market-based valuation:** Low **Non-market based valuation:** Moderate	**Quantification:** volume of scientific research. **Market-based valuation:** travel cost method for educational visits. **Non-market based valuation:** contingent valuation, choice experiment.
Physical and psychological experiences	Provision, by landscapes, seascapes, habitats or organisms, of opportunities for physically and psychologically beneficial activities, healing, relaxation, recreation, leisure, tourism and aesthetic enjoyment based on	Provision of opportunities for physically and psychologically beneficial activities, healing, relaxation, recreation, leisure, tourism and aesthetic enjoyment based on close contact with nature. In the Waipoua catchment, this	**Quantification:** Moderate **Market-based valuation:** Moderate	**Quantification:** visitor metrics. **Market-based valuation:** travel cost method, entry fee.

Nature's Contributions to People categories	(Diaz et al. 2018)	Adapted definition to the context of Waipoua catchment	Feasibility of quantification and valuation (in the context of assessed NBS)	Other methods (not in scope)
	the close contact with nature (e.g. hiking, recreational hunting and fishing, birdwatching, snorkelling, diving, gardening).	ranges from extensive tramping and nature-based recreation in the Tararua Forest Park to daily enjoyment of smaller bush blocks closer to town. The river itself serves multiple recreational purposes including dog walking, swimming, fishing, kai gathering, and observing native wildlife such as eels, creating accessible connections with nature for local communities. Historically, it had swimming holes which were important recreational river asset for the local iwi.	**Non-market based valuation:** High	**Non-market based valuation:** contingent valuation, choice experiment.
Supporting identities	Landscapes, seascapes, habitats or organisms being the basis for religious, spiritual, and social-cohesion experiences: (i) Provisioning of opportunities by nature for people to develop a sense of place, belonging, rootedness or connectedness, associated with different entities of the living world (e. g. cultural, sacred and heritage landscapes, sounds, scents and sights associated with childhood experiences, iconic animals, trees or flowers); (ii) Basis for narratives, rituals and celebrations provided by landscapes, seascapes, habitats, species or organisms (iii) Source of satisfaction derived from knowing that a particular landscape, seascape, habitat or species exists.	Provisioning of opportunities by nature for people to develop a sense of place, belonging, rootedness or connectedness, basis for narratives, rituals and celebrations, and source of satisfaction derived from knowing that a particular habitat or species exists. For the Waipoua catchment, this includes deep cultural connections such as the historic use of the river confluence for birthing rituals. It encompasses the wairua (spiritual dimension) of the river and supports the process of ecological restoration that transitions from introduced species like willows toward native vegetation, helping to reconnect the landscape with its indigenous identity.	**Quantification:** Low **Market-based valuation:** Low **Non-market based valuation:** Moderate	**Quantification:** richness of culturally significant species. **Market-based valuation:** none. **Non-market based valuation:** participatory and deliberative valuation approaches.

Nature's Contributions to People categories	(Diaz et al. 2018)	Adapted definition to the context of Waipoua catchment	Feasibility of quantification and valuation (in the context of assessed NBS)	Other methods (not in scope)
Maintenance of options	Capacity of ecosystems, habitats, species or genotypes to keep options open in order to support a good quality of life. Examples include: (i) Benefits (including those of future generations) associated with the continued existence of a wide variety of species, populations and genotypes. This includes their contributions to the resilience and resistance of ecosystem properties in the face of environmental change and variability; (ii) Future benefits (or threats) derived from keeping options open for yet unknown discoveries and unanticipated uses of particular organisms or ecosystems that already exist (e.g. new medicines or materials); (iii) Future benefits (or threats) that may be anticipated from ongoing biological evolution (e.g. adaptation to a warmer climate, to emergent diseases, development of resistance to antibiotics and other control agents by pathogens and weeds).	Capacity of ecosystems, habitats, species or genotypes to keep options open in order to support a good quality of life. Examples include benefits (including those for future generations) associated with the continued existence of biodiversity, ecosystem resilience, ecosystem integrity in the face of environmental change and variability.	**Quantification:** Low **Market-based valuation:** Low **Non-market based valuation:** Low	**Quantification:** ecological integrity. **Market-based valuation:** none. **Non-market based valuation:** choice experiment.

Appendix A Table 2: Descriptions tables: Land retirement, and revegetation of native forest on hillslopes

	Land retirement, and revegetation of native forest on hillslopes	Heatmap rating	Relationship description	Confidence level
1	Habitat creation and maintenance	++	• Converting degraded or agricultural land to native forest directly creates new habitat structure. • Native tree species support a wider diversity of associated flora and fauna than managed landscapes. • Multi-layered forest structure (canopy, understory, ground layer) creates diverse microhabitats. • Creating riparian corridors enhances habitat connectivity. • Root systems and fallen woody debris provide additional habitat niches. • Biodiversity within native forests, including various organisms from microorganisms to larger fauna.	High *High confidence due to extensive ecological research demonstrating biodiversity increases following forest restoration.*
2	Pollination and dispersal of seeds and other propagules	++	• Native forests support diverse pollinator communities (bees, butterflies, moths, birds, bats, and lizards/ mokomoko). • Increased floral diversity enhances pollinator habitat and food resources. • Forest connectivity facilitates movement of seed dispersers (birds, mammals). • Creates stepping stones and corridors in fragmented landscapes.	High *High confidence based on documented relationships between native vegetation and pollinator/ disperser abundance.*
3	Regulation of air quality	+	• Trees filter particulate matter through leaf surfaces. • Forest canopies capture airborne pollutants.	Low *Low confidence due to limited human proximity to areas receiving air regulation benefits.*

	Land retirement, and revegetation of native forest on hillslopes	Heatmap rating	Relationship description	Confidence level
4	Regulation of climate	++	• Forests sequester carbon in biomass and soil organic matter. • Forests moderate local temperature extremes. • Reduced albedo in some regions (context-dependent). • Forest cover shades the ground, reducing direct solar heating and evaporation, which conserves moisture in the soil.	High *High confidence based on extensive climate science research.*
5	Regulation of ocean acidification	+	• Indirect benefit through carbon sequestration. • Reduced erosion limits sediment and nutrient runoff to waterways and oceans. • Limited direct impact on ocean chemistry.	Low *Low confidence due to the indirect nature of the relationship and distance from oceanic systems.*
6	Regulation of freshwater quantity, location and timing	-/+	• Root systems of woody forest vegetation facilitate water infiltration into the soil, decreasing surface run-off during rain events, but potentially slightly elevating baseflow levels at other times. • However, additional tree transpiration also reduces soil moisture and may reduce streamflows. • Forest canopy influences the hydrological cycle by intercepting rainfall, reducing and or delaying precipitation reaching the ground, reducing flood peaks, and/ or delaying flood peak convergence in the larger rivers. • Native plants from the eco-district are likely to be better adapted to local rainfall patterns and soil types, potentially increasing the likelihood of successful outcomes for flood risk reduction. • If sediment transport processes are moderated, this may create more long term flood storage in the catchment's mid sections rather than funnelling flows through to Masterton. • Forests help maintain a balance between groundwater recharge and discharge, stabilising baseflows in nearby streams and rivers (albeit that in some cases, these baseflows are reduced). • Woody debris helps with moisture during low flows.	Medium *Medium confidence based on general scientific consensus.*

	Land retirement, and revegetation of native forest on hillslopes	Heatmap rating	Relationship description	Confidence level
			• Effects highly variable depending on forest composition and surrounding landscape – effects may be negative or positive.	
7	Regulation of freshwater and coastal water quality	++	• Improved quality of aquatic habitat as the quantity of fine grain sediments entering the streams is likely reduced. • Stream shading has the potential to reduce water temperature which will improve water quality and aquatic ecology. Certain lengths of the river corridor will need to be planted to effectively reduce temperatures. • Reduced erosion decreases turbidity in waterways. • Nutrient uptake reduces leaching to groundwater. • Riparian forests create buffer zones.	High *High confidence based on watershed management studies.*
8	Formation, protection and decontamination of soils and sediments	++	• Established woody forests contribute to soil conservation via their extensive root systems, providing structural integrity to soil and reducing susceptibility to erosion. • Dense and extensive woody root systems physically bind soil and minimize the potential for mass movement. • Forest canopy interception and well developed humic (leaf litter) layer reduces rainfall impact and surface runoff. This reduces the frequency and magnitude of sediment-generating erosional processes. • Woody debris (arising from adjacent forests) is an important component in moderating sediment transport through fluvial systems, particularly in smaller, steeper headwater streams. • Depending on changes in discharge (see Flood column) there may be a reduction in stream power. This could reduce bank erosion effects, and change when different sediments are entrained and transported through. • the fluvial system, effectively moderating sediment transport processes. • Moderating sediment generation and transport may reduce event-based aggradation in the mid-catchment areas.	High *High confidence based on soil science and forestry research.*

	Land retirement, and revegetation of native forest on hillslopes	Heatmap rating	Relationship description	Confidence level
			• Native vegetation increases soil organic matter, which may increase soil porosity and permeability, facilitating water storage and infiltration into the groundwater system. • Tree roots and organic matter prevent compaction of soil, maintaining its ability to absorb and store water effectively. • Improved soil health and structure by cycling nutrients and organic matter.	
9	Regulation of hazards and extreme events	-/+	• Root systems stabilise slopes and reduce landslide risk. • Forests buffer against extreme weather events. • Might lead to enhanced risk of fire.	Medium *Medium confidence because effectiveness depends on forest age, type, and hazard magnitude.*
10	Regulation of detrimental organisms and biological processes	-/+	• Increased native biodiversity may enhance natural pest control. • Might enhance the population of invasive species (e.g., possums, rats). • Greater habitat complexity can limit disease vector populations. • Effects highly variable depending on forest composition and surrounding landscape.	Low *Low confidence due to complex ecological interactions and context-dependency.*
11	Energy	+	• Future potential use of a woody debris for energy production.	Low *Low confidence due to uncertain future discoveries and benefits.*
12	Food and feed	-/+	• Reduces agricultural production if converting farmland. • Enhanced wild food harvesting. • Limited food production in natural forests (some wild foods and game).	Medium *Medium confidence based on clear trade-off with agriculture and wild food harvesting, though context-dependent.*

	Land retirement, and revegetation of native forest on hillslopes	Heatmap rating	Relationship description	Confidence level
13	Materials, companionship and labour	+	• Provision of materials such as using harakeke, wood, flax, raupo, kiekie, punga.	Low *Low confidence due to location specific use of materials.*
14	Medicinal, biochemical and genetic resources	+	• Preservation of genetic diversity. • Potential for undiscovered medicinal compounds. • Conservation of traditional medicinal plants. • Comes down to the choice of plant (e.g., shade giving, medicinal or soil stabilising plants).	Low *Low confidence due to uncertain future discoveries and benefits.*
15	Learning and inspiration	+	• Educational opportunities for ecological understanding. • Inspiration for art, design, and innovation. • Research opportunities.	Medium *Medium confidence as benefits depend on accessibility and educational programs.*
16	Physical and psychological experiences	++	• Recreational opportunities (hiking, wildlife watching, ecotourism and hunting). • Mental health benefits from nature exposure. • Aesthetic enjoyment. • Highly valued recreational site by the local communities.	High *High confidence due to a known importance of Waipoua Catchment to the local communities.*
17	Supporting identities	++	• Connection to place and cultural heritage. • Support for traditional ecological knowledge. • Highly valued cultural site by the local communities.	High *High confidence due to a known importance of Waipoua Catchment to the local communities.*

	Land retirement, and revegetation of native forest on hillslopes	Heatmap rating	Relationship description	Confidence level
18	Maintenance of options	++	• Preservation of biodiversity for future use and adaptation. • Conservation of ecosystem processes. • Maintaining evolutionary potential.	High *High confidence due to high significance of Waipoua catchment to the locals.*

Appendix A Table 3: Descriptions table | Floodplain re-engagement lowered or removed stop banks

	Floodplain re-engagement lowered or removed stop banks	Heatmap rating	Relationship description	Confidence level
1	Habitat creation and maintenance	+	• Increases biodiversity by providing access to riverine species such as birds and fish. Also, provides opportunity for plant species which tolerate wet environments. • Improves aquatic habitat by reducing fine grained sediments. • Restores natural hydrological processes essential for riparian and wetland habitat formation. • Creates a mosaic of wet and dry habitats supporting diverse vegetation communities and wildlife. • Reestablishes natural disturbance regime that drives ecological succession. • Forms microhabitats (backwaters, shallow pools, sediment deposits) that support biodiversity. • Stronger interventions (removal/ retreat) create larger habitat areas than partial interventions (notching). • Reconnects fragmented habitats along river corridors. • Limited opportunities due to farmed land.	Moderate *Moderate confidence due to extensive empirical evidence, consistent outcomes and direct observable relationship however limited opportunity for implementation in the context of Waipoua.*
2	Pollination and dispersal of seeds and other propagules	n/a	n/a	n/a

	Floodplain re-engagement lowered or removed stop banks	Heatmap rating	Relationship description	Confidence level
3	Regulation of air quality	n/a	n/a	n/a
4	Regulation of climate	+	• Contributes to carbon sequestration in wetland soils and riparian vegetation. • Anaerobic wetland environments can effectively store carbon. • Benefits modest at typical project scales. • More extensive interventions create larger carbon sinks. • Minimal emissions from reduced mechanical maintenance compared to engineered solutions.	Low *Low confidence due to limited benefits delivered at typical project scales.*
5	Regulation of ocean acidification	n/a	n/a	n/a
6	Regulation of freshwater quantity, location and timing	n/a	n/a	n/a
7	Regulation of freshwater and coastal water quality	+	• Functions as natural filter for water flowing through floodplain. • Facilitates sediment deposition, removing fine-grained sediment. • Enables nutrient uptake by riparian vegetation (particularly N and P). • Supports microbial communities that break down contaminants. • Slower water velocities allow particles to settle rather than transport downstream. • Larger reconnected areas provide greater water quality improvement capacity.	Low *Low confidence due to evidence for filtration processes, variable by pollution levels, however the benefits are periodic.*
8	Formation, protection and decontamination of soils and sediments	+	• Reduced flood velocities will encourage fine grained deposition within the floodplain, reducing overall sediment yield to Masterton. • Space to allow the natural recovery of natural form and function. • Decreases hillslope connectivity in non-stop banked areas and increases floodplain/ channel connectivity. • Reduces volume of fine grained sediments in the stream.	Medium *Medium confidence as the outcomes vary by sediment loads and due to limited long-term monitoring.*

	Floodplain re-engagement lowered or removed stop banks	Heatmap rating	Relationship description	Confidence level
			• Two-stage channels in particular have the potential to reduce suspended sediment loads by 15-80%. • Alternating wet/ dry conditions foster diverse microbial communities. • Accelerates decomposition and nutrient cycling. • Sequesters or transforms certain contaminants through filtration and biogeochemical processes. • Counteracts soil erosion in riparian zones.	
9	Regulation of hazards and extreme events	n/a	n/a	n/a
10	Regulation of detrimental organisms and biological processes	n/a	n/a	n/a
11	Energy	n/a	n/a	n/a
12	Food and feed	-/+	• May enhance fisheries and other traditional freshwater kai through improved aquatic habitat. • Reduces agricultural production if converting farmland.	Low *Low confidence due to do indirect effect and minimal evidence.*
13	Materials, companionship and labour	n/a	n/a	n/a
14	Medicinal, biochemical and genetic resources	n/a	n/a	n/a
15	Learning and inspiration	++	• Provides opportunities for environmental education. • Creates living laboratories for scientific research. • Demonstrates natural river processes and ecological relationships. • Larger interventions create more dramatic visual and ecological transitions. • Offers stronger educational narratives and research opportunities.	Medium *Medium confidence as benefits depend on accessibility and educational programs.*

	Floodplain re-engagement lowered or removed stop banks	Heatmap rating	Relationship description	Confidence level
			• Enables observation of natural recovery processes.	
16	Physical and psychological experiences	++	• Enhances recreational opportunities (bird watching, fishing). • Improves landscape aesthetics through more natural river features. • Natural river landscapes have high scenic value. • Provides restorative psychological benefits.	Medium *Medium confidence due to dependence on accessibility and cultural factors.*
17	Supporting identities	+	• Cultural amenity by increasing connectedness with nature, and contributing to climate change adaptation. • Natural river landscapes often have cultural significance. • Can strengthen community identity and sense of place. • May reconnect iwi and hapu with historical relationships to rivers.	Low *Low confidence due to high cultural variability and subjective valuation.*
18	Maintenance of options	+	• Preserves future choices through biodiversity conservation. • Increases ecosystem resilience to changing conditions. • Maintains ecological complexity that preserves options for future ecosystem services. • Enhances adaptability to climate change and other stressors.	Medium *Medium confidence as benefits depend on accessibility and educational programs.*

High level principles that determine the difference in Nature's Contributions to People:

- **Stopbank Removal** provides the strongest positive impacts for habitat creation, flood hazard regulation, and freshwater regulation, but has the most significant negative effects on food production.
- **Stopbank Retreat** offers similar but somewhat reduced benefits compared to complete removal, with fewer trade-offs for agricultural production.
- **Floodplain Lowering** delivers moderate benefits for habitat and flood regulation while maintaining some existing land uses.
- **Stopbank Notching** has the mildest impacts overall, offering slight improvements for flood regulation and habitat with minimal disruption to existing land uses.
- All interventions show strong positive impacts for **regulation of hazards and extreme events** and **freshwater quantity regulation**.
- The strongest trade-offs are observed in the **food and feed** and **materials** categories due to changes in land use.

Appendix A Table 4: Descriptions table – Small-scale Distributed Retention Storage

	Small-scale Distributed Retention Storage	Heatmap rating	Relationship description	Confidence level
1	Habitat creation and maintenance	++	• Re-establishment of wetland habitats which can increase biodiversity. • Reducing fine grained sediments helps improve aquatic habitats. • Creates new aquatic and transitional habitats that support diverse species. • Establishes varied hydrological conditions that increase habitat heterogeneity. • May provide opportunities for additional riparian planting on tributaries.	High *High confidence based on extensive research documenting biodiversity increases in created wetlands.*
2	Pollination and dispersal of seeds and other propagules	+	• Wetland and riparian vegetation provides resources for pollinators. • Semi-aquatic corridors facilitate seed dispersal along waterways.	Medium *Medium confidence as effects are more localised than with extensive forest restoration.*
3	Regulation of air quality	n/a	n/a	n/a
4	Regulation of climate	+	• Wetlands function as carbon sinks, particularly for soil carbon. • May emit methane, partially offsetting carbon benefits.	Medium *Medium confidence due to competing processes and variability across wetland types.*
5	Regulation of ocean acidification	n/a	n/a	n/a
6	Regulation of freshwater quantity, location and timing	+	• Small retention storage devices, including ponds, wetlands, and bio-swales, capture and store rainwater or runoff, thereby reducing the volume of water that rapidly enters the larger water system during storms (detention).	High *High confidence as this is the primary designed function with well-documented effectiveness.*

	Small-scale Distributed Retention Storage	Heatmap rating	Relationship description	Confidence level
			• Detention storage systems typically release water slowly over a longer period, smoothing out peak flow in water bodies that usually leads to floods. • Many small storage devices enhance the ground's water absorption ability, especially if located in pervious soils and designed for this purpose. • Increased aquifer storage and enhanced baseflow via 'sponge effect' (temporary surface storage). • Increased time for infiltration leading to increased baseflow and recharge. • Small local effect for each site may add up to catchment-scale benefits across many sites, although noting that significant groundwater effects would require the detention and infiltration of large amounts of water, potentially impacting on surface water flows.	
7	Regulation of freshwater and coastal water quality	+	• Traps sediments and filters pollutants through physical settlement. • Processes nutrients through plant uptake and microbial activity.	Moderate *Moderate confidence based on extensive research on wetland water purification functions however limited opportunities to implement.*
8	Formation, protection and decontamination of soils and sediments	+	• Retention storage traps and stores fine-grained sediments, preventing them from being delivered to the main stream from smaller tributaries. • Slowing fine grained sediment transport, which mimics natural functions of woody debris and other roughness elements. • Accumulation of organic matter contributes to soil formation.	High *Medium confidence due to variable effectiveness across different system designs.*
9	Regulation of hazards and extreme events	n/a	n/a	n/a

	Small-scale Distributed Retention Storage	Heatmap rating	Relationship description	Confidence level
10	Regulation of detrimental organisms and biological processes	-/+	• Possible introduction of undesirable plant species that would require different maintenance protocols than the current ecosystem.	Low *Low confidence due to highly context-dependent and variable effects.*
11	Energy	n/a	n/a	n/a
12	Food and feed	-/+	• Reduces agricultural production if converting farmland. • Temporary ponding may allow pastures to be used as productive land in between rare periods of inundation.	Low *Low confidence due to highly context-dependent and variable effects.*
13	Materials, companionship and labour	+	• Provision of materials such as flax, raupo, kiekie and punga.	Low *Low confidence due to wetlands not being extensive enough to provide materials.*
14	Medicinal, biochemical and genetic resources	+	• Potential of native wetlands to support medicinal plants.	Low *Low confidence due to do benefits being context dependent.*
15	Learning and inspiration	+	• Provides educational opportunities about hydrology and ecology. • Demonstration sites can inspire similar interventions.	Medium *Medium confidence as benefits depend on accessibility and programs*
16	Physical and psychological experiences	+	• Potential to create recreational areas and native species conservation. • Offers recreational value for wildlife watching and walking. • Contributes to landscape aesthetics and blue-green space.	Medium *Medium confidence due to dependence on design and accessibility.*

	Small-scale Distributed Retention Storage	Heatmap rating	Relationship description	Confidence level
17	Supporting identities	+	• May support connection to traditional water management practices. • Cultural significance varies greatly by community.	Low *Low confidence due to high cultural variability and subjective valuation.*
18	Maintenance of options	+	• Contributes to hydrological resilience and landscape diversity. • Helps conserve specialised wetland species.	Medium *Medium confidence due to inherent uncertainty about future values.*

Appendix A Table 5: Descriptions table – Channel realignment/ room for the river

	Channel realignment/ room for the river	Heatmap rating	Relationship description	Confidence level
1	Habitat creation and maintenance	++	• Re-establishment of wetland habitats in oxbow and flood channel environments. • Increases habitat diversity and likely therefore biodiversity by encouraging diverse terrestrial habitat and aquatic habitats, such as pools, riffles and undercutting. • Particularly benefits fish, amphibians, and riparian species.	High *High confidence based on extensive research documenting biodiversity benefits.*
2	Pollination and dispersal of seeds and other propagules	+	• Enhances riparian vegetation corridors that support pollinators. • Rivers and floodplains function as natural corridors for plant propagule movement.	Medium *Medium confidence as benefits are more constrained to riparian zones.*
3	Regulation of air quality	n/a	n/a	n/a
4	Regulation of climate	+	• Increases carbon sequestration in riparian soils and vegetation. • Natural river processes restore sediment deposition enhancing carbon storage.	Medium

	Channel realignment/ room for the river	Heatmap rating	Relationship description	Confidence level
			• Newly inundated areas may emit methane, partially offsetting benefits.	*Medium confidence due to competing processes and variable emissions.*
5	Regulation of ocean acidification	n/a	n/a	n/a
6	Regulation of freshwater quantity, location and timing	-/+	• Slows the flow by increasing sinuosity, channel roughness, and changing slope. • Encourages infiltration by spreading flows across a wider area and creates a more diverse geomorphic environment with back channels and pools – however, may also lead to more surface water infiltration to groundwater (drop in river baseflow). • Creating more storage in the mid sections of the catchment. • Increased connectivity between surface and groundwater - increased connectivity between surface and groundwater due to greater area coverage and reduced velocities. • Altering channel morphology could change flow paths and water residence times, influencing the opportunity for infiltration and recharge. • Increases lag time between precipitation and downstream discharge. • Impacts during typical flows are unlikely to significant, groundwater impacts are uncertain and could be considered either positive or negative.	Medium *Medium confidence based on general scientific consensus.*
7	Regulation of freshwater and coastal water quality	++	• Improves water quality through sediment deposition (reduction in fine-grained sediment) and nutrient processing. • Increased residence time enhances natural purification processes. • Floodplains effectively filter phosphorus, nitrogen, and other pollutants.	High *High confidence based on well-documented water quality improvements.*

	Channel realignment/ room for the river	Heatmap rating	Relationship description	Confidence level
8	Formation, protection and decontamination of soils and sediments	+	• Recovery of natural form and function of the river allows sediments to spread out and settle across the floodplain. • Increasing sinuosity can help 'slow the flow', by increasing channel length and reversing historic shortening This can help increase sediment deposition in the form of mid channel and point bars. • Restores natural form and function of the river to allow for more naturalised erosion patterns to occur. This increases geomorphic diversity which can help moderate sediment transport processes. • Restoring semi-braided and wandering gravel bed river forms can create additional backwater areas, which can help trap fine grained sediments and provide additional flood storage. • Periodic inundation deposits nutrient-rich sediments. • Can lead to an increased erosion of tracks through increased river meandering.	Medium *Medium confidence due to variability across different river systems.*
9	Regulation of hazards and extreme events	n/a	n/a	n/a
10	Regulation of detrimental organisms and biological processes	-	• Possible introduction of undesirable plant species that would impede river flow resulting in higher maintenance needs.	Low *Low confidence due to highly context-dependent and variable effects.*
11	Energy	n/a	n/a	n/a
12	Food and feed	-/+	• Often converts agricultural land to floodplain. • Periodic flooding may disrupt certain agricultural practice. • Enhanced wild food harvesting.	Low *Low confidence due to the effects being context dependent.*
13	Materials, companionship and labour	n/a	n/a	n/a

	Channel realignment/ room for the river	Heatmap rating	Relationship description	Confidence level
14	Medicinal, biochemical and genetic resources	+	• Potential of native wetlands to support medicinal plants.	Low *Low confidence due to do benefits being context dependent.*
15	Learning and inspiration	+	• Provides educational opportunities about river ecology and natural flood management. • Demonstration sites become focal points for learning.	Medium *Medium confidence as benefits depend on accessibility and programs.*
16	Physical and psychological experiences	++	• Creates attractive, more continuous blue-green spaces for recreation. • Supports activities such as walking, fishing and wildlife watching. • Restored rivers often become highly valued community assets.	Medium *Medium confidence despite strong effects due to dependence on accessibility.*
17	Supporting identities	+	• May strengthen cultural connections to rivers and traditional practices/ connectedness with nature. • Rivers have strong cultural significance.	High *High confidence due to significance to local iwi and hapū.*
18	Maintenance of options	++	• Restores natural river processes that maintain evolutionary potential. • Supports diverse riparian ecosystems and hydrological functions. • Maintains options for future ecosystem services.	Medium *Medium confidence due to inherent uncertainty about future values.*

Confidence levels:

High Confidence: Strong scientific consensus exists with clear cause-effect relationships that are well-documented across multiple studies and contexts. The ecological mechanisms are well understood and consistently observed.

Medium Confidence: Moderate scientific evidence exists, but with some contextual variability or knowledge gaps. Effects may depend on specific implementation factors or local conditions.

Low Confidence: Limited scientific evidence or significant knowledge gaps exist. The relationships are often indirect, highly variable across contexts, or involve complex interactions that are not fully understood.

Appendix B Survey Design

Below is the survey that was used to undertake the valuation of wider benefits for the Waipoua River.

B1 Waipoua River nature-based solutions wider benefits valuation survey

Thank you for participating in this important survey about nature-based solutions for the Waipoua River catchment.

Greater Wellington Regional Council is investigating approaches to manage flood risk while providing additional environmental, social, and cultural benefits.

This survey focuses on understanding how much value your community places on these wider benefits beyond flood prevention. Your responses will help inform decision-making about the feasibility of these approaches in the Waipoua catchment.

B1.1 Part 1: Background Information

1 How familiar are you with the Waipoua River catchment?

- ☐ Very familiar (I live near or visit regularly)
- ☐ Somewhat familiar (I occasionally visit or know about it)
- ☐ Slightly familiar (I've heard of it but rarely visit)
- ☐ Not familiar (I don't know much about it)

2 How concerned are you about flooding in the Masterton area?

- ☐ Very concerned
- ☐ Somewhat concerned
- ☐ Slightly concerned
- ☐ Not concerned

3 How often do you engage with the Waipoua River or surrounding natural areas?

- ☐ Frequently (weekly or more)
- ☐ Occasionally (monthly)
- ☐ Rarely (a few times a year)
- ☐ Never

4 Which of these values do you consider most important for the Waipoua catchment? (Select up to 2)

- ☐ Ecological health and biodiversity
- ☐ Recreational opportunities
- ☐ Cultural and historical significance
- ☐ Flood protection for properties
- ☐ Economic uses (e.g., agriculture, tourism)

☐ Aesthetic and natural beauty

B1.2 Part 2: Willingness to pay for wider benefits

For each voting card, please indicate the maximum amount your household would be willing to pay annually to support their implementation.

Table Appendix B.1: Voting card 1

Habitat creation and maintenance	Strong improvement to habitat creation
Pollination and dispersal of seeds	Strong improvements to pollination
Air quality	Some improvements to air quality
Climate	Strong climate regulation benefits
Regulation of water quality	Strong improvement to water quality
Soil protection	Strong improvements to soil protection
Materials provision	Some provision of raw materials materials
Medicinal resources	Some potential for medicinal plants
Educational and learning opportunities	Some educational opportunities
Recreational opportunities & Cultural significance	Strong recreational opportunities and cultural significance
The maximum amount my household would be willing to pay annually to support this option?	☐ $0 ☐ $25 ☐ $50 ☐ $75 ☐ $100 ☐ $150 ☐ $200 ☐ $300 ☐ $500+

Table Appendix B.2: Voting card 2

Habitat creation and maintenance	Some improvement to habitat creation
Pollination and dispersal of seeds	No or very low improvements to pollination
Air quality	No or very low improvements to air quality
Climate	Some climate regulation benefits
Regulation of water quality	Some improvement to water quality
Soil protection	Some improvements to soil protection
Materials provision	No or very low potential for materials provision
Medicinal resources	No or very low potential for medicinal plants
Educational and learning opportunities	Strong educational opportunities
Recreational opportunities & Cultural significance	Strong recreational opportunities and cultural significance
The maximum amount my household would be willing to pay annually to support this option?	☐ $0 ☐ $25 ☐ $50 ☐ $75 ☐ $100 ☐ $150 ☐ $200 ☐ $300 ☐ $500+

Table Appendix B.3: Voting card 3

Habitat creation and maintenance	Strong improvement to habitat creation
Pollination and dispersal of seeds	Some improvements to pollination
Air quality	No improvements to air quality
Climate	Some climate regulation benefits
Regulation of water quality	Some improvement to water quality
Soil protection	Some improvements to soil protection
Materials provision	Some provision of raw materials materials
Medicinal resources	Some potential for medicinal plants
Educational and learning opportunities	Some educational opportunities
Recreational opportunities & Cultural significance	Some recreational opportunities and cultural significance
The maximum amount my household would be willing to pay annually to support this option?	☐ $0 ☐ $25 ☐ $50 ☐ $75 ☐ $100 ☐ $150 ☐ $200 ☐ $300 ☐ $500+

Table Appendix B.4: Voting card 4

Habitat creation and maintenance	Strong improvement to habitat creation
Pollination and dispersal of seeds	Some improvements to pollination
Air quality	No improvements to air quality
Climate	Some climate regulation benefits
Regulation of water quality	Strong improvement to water quality
Soil protection	Some improvements to soil protection
Materials provision	No or very low potential for materials provision
Medicinal resources	Some potential for medicinal plants
Educational and learning opportunities	Some educational opportunities
Recreational opportunities & Cultural significance	Strong recreational opportunities and cultural significance
The maximum amount my household would be willing to pay annually to support this option?	☐ $0 ☐ $25 ☐ $50 ☐ $75 ☐ $100 ☐ $150 ☐ $200 ☐ $300 ☐ $500+

If you selected $0 for any of these options, please tell us why:

- ☐ I support the option but cannot afford to pay
- ☐ I don't believe I should have to pay for this
- ☐ I don't value the benefits described
- ☐ Other (please specify): ____________________

B1.3 Part 3: Preference Ranking

Please rank these four nature-based solution options from most preferred (1) to least preferred (4):

___ Land retirement and native forest revegetation

___ Floodplain re-engagement

___ Small-scale, distributed retention storage

___ Channel realignment and room for the river

Briefly explain why you ranked your top choice as #1:

____

____

____

____

____

____

____

B1.4 Part 4: Importance of Wider Benefits

Please rate how important each wider benefit is to you (1 = Not important, 3 = Moderately important, 5 = Very important)

- Habitat creation and maintenance: 1 2 3 4 5
- Pollination and dispersal of seeds: 1 2 3 4 5
- Air quality: 1 2 3 4 5
- Climate: 1 2 3 4 5
- Regulation of water quality: 1 2 3 4 5
- Soil protection: 1 2 3 4 5
- Materials provision: 1 2 3 4 5
- Medicinal resources: 1 2 3 4 5
- Educational and learning opportunities: 1 2 3 4 5
- Recreational opportunities & Cultural significance: 1 2 3 4 5

B1.5 Part 7: Additional Comments

Please share any additional thoughts you have about nature-based solutions or winder benefits quantification for the Waipoua catchment:

Appendix F. Groundwater recharge and river low flow report

REPORT

Tonkin+Taylor

Waipoua Nature-Based Solutions: Low-flow and Recharge

Prepared for

Greater Wellington Regional Council

Prepared by

Tonkin & Taylor Ltd

Date

May 2025

Job Number

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Distribution:

Greater Wellington Regional Council	1 PDF copy
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Executive Summary

This report presents the findings of a groundwater recharge and low-flow assessment study completed for the Greater Wellington Regional Council (Greater Wellington) as part of a broader feasibility study on using nature-based solutions to manage flood hazard risk in the Waipoua catchment. The objective of this assessment study was to understand the impacts of three selected nature-based solutions on river baseflows and shallow groundwater levels, and to identify areas that may be suitable for implementation of these solutions.

The nature-based solutions studied included

- Land retirement supplemented by native forest revegetation on hillslopes (reafforestation; NbS1);
- Small-scale distributed retention storage (storage; NbS2); and
- Channel realignment/reconnection, providing space for the river (channel realignment; NbS3).

The analysis comprised use of a high-level, steady-state comparative groundwater modelling assessment using MODFLOW 6. The results of a base model representing average summer hydrogeological conditions in the catchment were compared against the shortlisted nature-based solutions scenarios and related variations.

Key findings indicate that the selected nature-based solutions scenarios show mixed effects on groundwater flows and associated baseflow in the Waipoua River. The reafforestation scenarios all showed decreases in the water balance relative to the base model due to the interception of water by forest canopy. The storage and channel realignment scenarios showed mixed effects on the water balance relative to the base model. Overall, the channel realignment scenarios showed the most promise for boosting shallow groundwater recharge, and perhaps baseflow increases if an additional water source, such as stored and/or diverted water, could be introduced at appropriate times.

While these results offer valuable insights into the impact of nature-based solutions on groundwater recharge and baseflows, it is important to consider the associated limitations. The steady-state assumption provides a useful approximation of regional groundwater flow; however, transient/episodic variations caused by stresses such as seasonal recharge fluctuations, pumping dynamics, extreme weather events, or climate variability are not captured. While the model does not account for detailed datasets and analyses which could enhance its precision, the steady-state assumption allows rapid comparison and assessment of a variety of scenarios.

The conclusions drawn offer insight that can inform regional water management approaches, but caution should be exercised when applying the results for detailed water management decisions at finer spatial and temporal scales.

Undertaking further work including transient analyses and extensions of this model would likely provide improved understanding of seasonal variations in the water balance and enhanced characterisation of hydrological responses during extreme events, such as the 1 % Annual Exceedance Probability (AEP) flood event. More detailed information and analysis is expected to be needed to support detailed water management decisions in relation to the adoption and implementation of nature-based solutions at the reach and catchment scale.

1 Introduction

Tonkin & Taylor Ltd (T+T) has been commissioned by Greater Wellington Regional Council (Greater Wellington) to investigate the feasibility of using nature-based solutions to reduce flood hazard risk in the Waipoua catchment, Wairarapa. As part of this broader assessment, a study was conducted to evaluate the impact of various nature-based interventions on river baseflows[1] and groundwater recharge during periods of low flow.

As part of the wider project, a shortlisting process was conducted, resulting in the selection of four nature-based solutions to be assessed in the feasibility study. These were chosen based on their potential to reduce erosion and flooding, enhance groundwater recharge and river baseflow, and provide additional co-benefits. The short list of nature-based solutions is:

- Land retirement, and revegetation of native forest on hillslopes (reafforestation; NbS1);
- Small-scale, distributed retention storage (storage; NbS2);
- Channel realignment/room for the river (channel realignment; NbS3); and
- Floodplain engagement (NbS4).

It is noted that while floodplain re-engagement is included in the broader feasibility study, it is excluded from this low flow and recharge assessment. This is because the effects of floodplain re-engagement on groundwater were assessed as negligible due to the intermittent nature of floodplain re-engagement and because the model used in this assessment was configured to simulate average hydrogeological conditions during summer.

This report presents the findings of the assessment on river baseflow and groundwater recharge and addresses the following questions:

- Which nature-based solutions show the most promise for shallow groundwater recharge;
- What degree of impact could these nature-based solutions be expected to have; and
- Broadly speaking, where would nature-based solutions best be located?

2 Objectives

The outcome of this assessment is intended to give insights into the following for each of the selected nature-based solutions:

- Impacts on river baseflow and shallow groundwater levels; and
- Generalised locations that are assessed to be optimal for implementation.

3 Method

3.1 Literature review

The literature review methodology involved a targeted assessment of peer-reviewed studies, government reports, and case studies relevant to the selected nature-based solutions. The review focused on understanding the mechanisms by which the short-listed nature-based solutions influence groundwater recharge and river baseflows, with particular attention to hydrogeological conditions similar to those in the study area. Key findings were synthesised to inform the conceptual

[1] Hereafter, the term "baseflow" will refer to groundwater contributions to river flow under low-flow conditions, as the modelling was based on groundwater levels observed during summer.

impact assessment and feasibility considerations for nature-based solutions implementation in the catchment.

3.2 Comparative modelling assessment

The selected nature-based solutions were assessed via a high-level, steady-state comparative groundwater modelling assessment with base model results compared against the nature-based solutions shortlist scenarios and associated variations. The assessment was conducted using MODFLOW 6, a widely used numerical groundwater flow simulation code developed by the U.S. Geological Survey (USGS)[2]. The model was configured and executed within ModelMuse[3], a graphical user interface (GUI) for MODFLOW.

The base model was developed to represent average hydrogeological conditions (steady-state) in summer (December to February) within the study area (see Figure Appendix A.2), incorporating available data on groundwater levels, aquifer properties, and recharge sources. The model was structured using a discretised finite-difference grid, with Boundary Conditions set to reflect average river-aquifer interactions and regional groundwater flow dynamics during summer months. The base model was used as a template for all other scenarios, with adjustments made according to the conditions being represented.

To evaluate the impact of nature-based solutions, the base model was systematically modified to create seven scenario models, each reflecting a variation in one of the three selected nature-based solutions implementation. Changes in model parameters included variations in recharge rates, river parameters, and introduction of new boundary conditions depending on the expected influence of each nature-based solutions approach (e.g., reafforestation, storage, or channel realignment effects).

Following model execution, outputs such as water balance components (e.g., recharge, discharge, and storage changes) and groundwater head contours and changes were extracted and compared across scenarios. The analysis focused on identifying the relative effects of each nature-based solution on groundwater recharge and river baseflow, providing a comparative, qualitative assessment of their feasibility and potential hydrological benefits. The limitations of the numerical modelling assessment are discussed in Section 8.

4 Relevant details of literature review

4.1 External nature-based solutions meta-review article

A meta-review article[4] was selected, providing a comprehensive analysis of existing scientific literature on the hydrological impacts of nature-based solutions at the catchment scale. The review highlights the context-dependent and often variable outcomes of nature-based solutions interventions (see Figure 4.1 below). Relevant to this assessment, the review explores afforestation, reafforestation, wetlands and other distributed storage systems (such as micro-reservoirs, infiltration trenches and others). The review does not comment on river realignment nature-based solutions.

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[2] USGS, “MODFLOW 6: USGS Modular Hydrologic Model,” 2024, https://doi.org/10.5066/F76Q1VQV.

[3] R.B. Winston, “ModelMuse Version 5.3.1: U.S. Geological Survey Software Release, 17 September 2024,” 2024, https://doi.org/10.5066/P14CDRIK.

[4] Morgane Lalonde et al., “Scientific Evidence of the Hydrological Impacts of Nature-Based Solutions at the Catchment Scale,” *WIREs Water* 11, no. 5 (2024): e1744, https://doi.org/10.1002/wat2.1744.

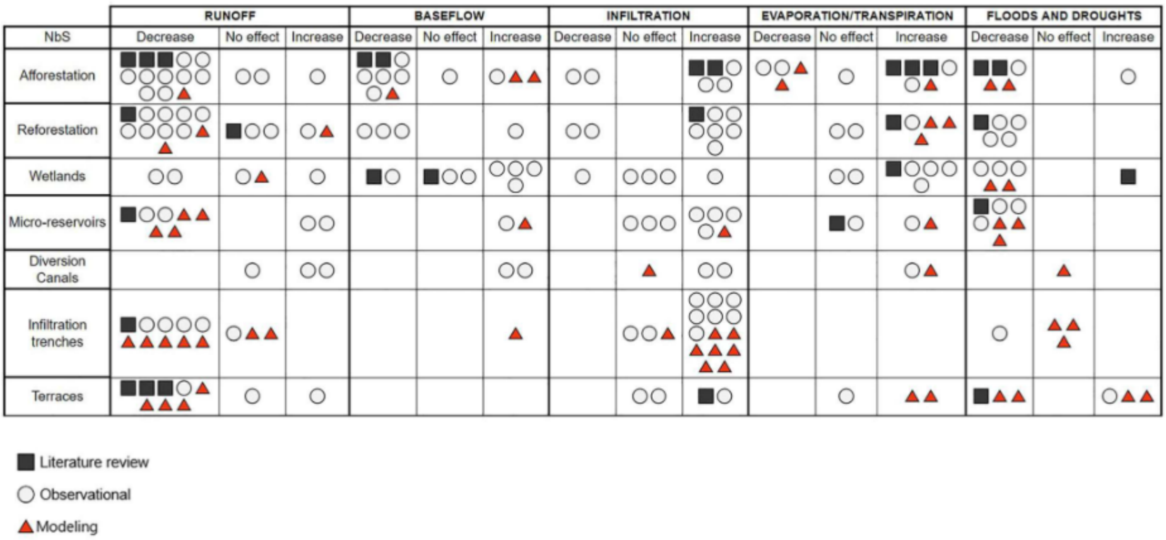

Figure 4.1: Number of studies reporting effect of seven different types of nature-based solutions on main hydrological processes.

The authors indicate that wetland nature-based solutions have controversial and complex impacts on groundwater recharge and baseflow. While some studies suggest wetlands can buffer baseflow in specific contexts, these effects are not consistently observed, and the impact on infiltration appears primarily driven by soil parameters. Overall, the effect of wetlands on groundwater recharge is not universally positive, and knowledge regarding their influence on droughts is limited. Micro-reservoirs (dry, grassed detention basins - e.g., swales) are mostly reported to increase the infiltrated volume of water, although sometimes no impact is observed. Permeable micro-reservoirs can increase baseflow. However, their impact on evaporation and transpiration is not well-studied, with some studies showing no significant changes and others reporting increases.

Infiltration trenches (trenches constructed on hillslopes parallel to contour lines) are found to have a reduction effect on runoff. While a global review suggests a potential increase in infiltration due to decreased runoff, the capacity of infiltration trenches to increase infiltration remains highly uncertain and site dependent. Few studies have included the effect of infiltration trenches on baseflow, with one study reporting only a slight increase in the mid–late rainy season.

For the re/afforestation nature-based solutions, the review generally finds an increase in total infiltrated water and infiltration rates across various degraded and agricultural lands. While most studies report a decrease in surface runoff, particularly in drier climates and with mature forests, afforestation in mountainous catchments has been linked to a decrease in baseflow. The impact of reforestation on groundwater recharge in mountain regions remains a knowledge gap, and some evidence suggests it could even increase drought severity in certain catchments. In summary, re/afforestation tends to enhance infiltration and reduce runoff, but its effect on baseflow and groundwater recharge is more nuanced and can be negative depending on the environment.

4.2 Previous investigation of the Upper Valley catchment[5]

This report, prepared by Gyopari and McAlister (2010) for Greater Wellington provides a detailed overview of the hydrogeological characteristics of the Upper Valley catchment of the Wairarapa Valley. This overview has been used to inform the conceptual hydrogeology used in this assessment.

[5] M C Gyopari et al., "Wairarapa Valley Groundwater Resource Investigation: Upper Valley Catchment Hydrogeology and Modelling," November 2010.

The Upper Valley catchment, covering approximately 160 km^2, is situated largely to the northeast of the Waingawa River and is centred on the town of Masterton, thereby including the Waipoua catchment. The dominant land use is agriculture, primarily sheep and beef farming, with significant groundwater abstraction for irrigation occurring on the intensively farmed Te Ore Ore plain.

The groundwater environment is dynamic and complex, consisting of a heterogeneous succession of late Quaternary and Holocene unconsolidated sediments. This aquifer system has been shaped by geological structures such as the Masterton, Mokonui, and Wairarapa faults (see Figure 5.1), which have dislocated and folded the sediment sequence, creating features like the Te Ore Ore basin.

Four broad hydrostratigraphic units have been identified:

- Unit A: Tararua-sourced alluvial fan gravels (Q2+) forming poor to moderate aquifers;
- Unit B: Q1 Holocene alluvium along modern river channels, generally a high-yielding aquifer hydraulically connected to surface water;
- Unit C: Q2+ Tararua-sourced basin-fill alluvium within the Te Ore Ore basin; and
- Unit D: Q2+ eastern hill-sourced basin fill alluvium, also within the Te Ore Ore basin.

A key characteristic of the Upper Valley catchment is the strong interdependence between surface water and groundwater. The river systems, including the Ruamāhanga, Waingawa, and Waipoua rivers, exhibit complex patterns of flow gain and loss with respect to the underlying shallow aquifers. Figure 4.2 denotes a pattern of reasonably predictable river losses and gains when flows at Mikimiki are less than approximately 700 L/s. The gauging stations shown along the x-axis of the figure are arranged in order of their position in the Waipoua catchment, from the highest elevation (most upstream) on the left to the lowest elevation (most downstream) on the right. The initial losses to groundwater downstream of Mikimiki are attributed to faulting and subsequent gains between Akura and Railway Crescent are attributed to groundwater inputs. Drying of reaches in the mid-catchment (Youngs to Akura) has been observed when flows at Mikimiki are less than 200L/s.

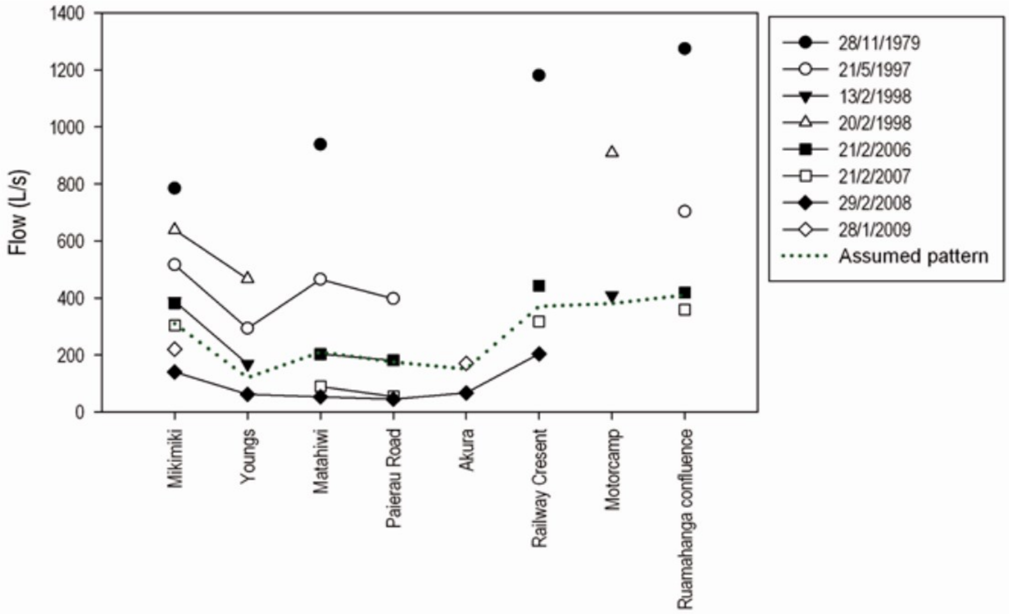

Figure 4.2: Concurrent flow gauging results for the Waipoua River (adapted from unpublished material[6] from Greater Wellington).

6 "Waipoua River FMU_Low flow description extract for T&T_Jan 2025"; attached to email correspondence from Mike Thompson on 17 Feb 2025.

Rainfall recharge and riverbed leakage are both important sources of recharge to the groundwater system. Numerous springs are present in the low-lying areas, particularly around the Masterton Fault, which appears to impede groundwater flow.

The groundwater head distribution indicates that the Upper Valley groundwater environment behaves as a hydraulic continuum, with groundwater flow patterns reflecting the close interaction between rivers and adjacent shallow aquifers. The report notes that the Masterton and Mokonui faults act as internal, low permeability flow barriers, disrupting or impeding groundwater flow.

Regarding nature-based solutions interventions in the Upper Valley, the report mentions the presence of an extensive network of gravity-fed water races (like the Opaki and Te Ore Ore water races) that divert water from the main rivers. These were constructed in the early 20th century and are used primarily for stock water supply and limited irrigation. The report suggests that these water races probably contribute to some groundwater recharge in more permeable fan areas and receive spring discharges in low-lying areas. However, the report does not explicitly discuss modern nature-based solutions interventions like wetland restoration, engineered storage devices, reforestation for hydrological purposes, or river widening/realignment within the Upper Valley catchment.

5 Base model configuration

5.1 Data and input preparation

Prior to configuration of the base model, the following acquisition and pre-processing of inputs was conducted:

- **Interpolation of Groundwater Levels:** Groundwater level data from Greater Wellington was processed and interpolated to generate average summer (Dec – Feb) groundwater contours. Average summer groundwater levels were used to reflect 'low groundwater conditions' that are typically observed during drier months. These contours provided a reference for model calibration and boundary condition definition;
- **Note**: While the broader feasibility study considers flood risk potential, this model specifically represents average summer hydrological conditions. This model provides a foundation for understanding the groundwater dynamics considered. Transient analyses and extensions of this model will likely provide improved understanding of seasonal variations in the water balance and enhanced characterisation of hydrological responses during extreme events, such as the 1 % AEP flood event;
- **Recharge Estimation**: Recharge rates were derived using virtual climate station network data[7] and select groundwater level records. The estimation process utilised the PASTAS hydrological modelling package in Python, testing a range of paired assessments with both linear and non-linear solvers. The final recharge value of 444 mm/year was adopted as it resulted in an appropriate R^2 value, indicating a reasonable statistical fit between observed and modelled groundwater trends. This value corresponds to the non-linear solution for the data from the Zyzalo (T26-0239) borehole and VCSN 28803. See Figure Appendix A.1 for more information; and
- **Sky-TEM[8] data**: SkyTEM data was requested as part of the initial data request, but Greater Wellington informed us the data was not yet available[9].

7 NIWA, "Virtual Climate Station Network (VCSN) Data Technical Description," accessed March 14, 2025, https://niwa.co.nz/climate-and-weather/virtual-climate-station-network-vcsn-data-technical-description.
8 Aerial electromagnetic technology for geophysical surveying (https://skytem.com/; accessed 29 March 2025).
9 Private email correspondence with Ella Boam of Greater Wellington (20 Dec 2024).

5.2 Model extent and grid discretisation

The model domain was restricted to the lower half of the Waipoua catchment to leverage the highest density of groundwater level and river data (see Figure Appendix A.2). The grid resolution was set to 250 m, balancing computational efficiency with spatial detail. To enhance accuracy and allow for river realignment in critical hydrological zones, a three-tier local refinement was applied around river polylines.

5.3 Conceptual hydrogeology

The hydrogeological framework, including spatial extent and depth profiles, was adapted from previous work conducted for Greater Wellington[10] (see Figure 5.1). The hydraulic conductivity (Kx) values assigned to the three model layers were:

- Layer 1 (alluvium materials; see Figure Appendix A.3): 2.5×10^{-4} m/s (default), with refined values for floodplain areas:
  - Upper floodplain: 5×10^{-4} m/s; and
  - Lower floodplain: 2×10^{-3} m/s.
- Layer 2 (older sediments): 1×10^{-5} m/s; and
- Layer 3 (Greywacke basement): 1×10^{-8} m/s.

Vertical and horizontal hydraulic conductivity relationships were set as follows:

- $K_y = K_x$ (isotropic in horizontal plane); and
- $K_z = K_x / 10$ (anisotropic vertical conductivity).

Hydraulic conductivity values were initially set to 1×10^{-4}, 1×10^{-5} and 1×10^{-8} m/s respectively for the three model layers, corresponding to the conceptual hydrogeology where shallower layers exhibit higher hydraulic conductivity. The final values listed above were derived during the calibration process described in Section 5.5 below.

[10] Gyopari et al., "Wairarapa Valley Groundwater Resource Investigation: Upper Valley Catchment Hydrogeology and Modelling."

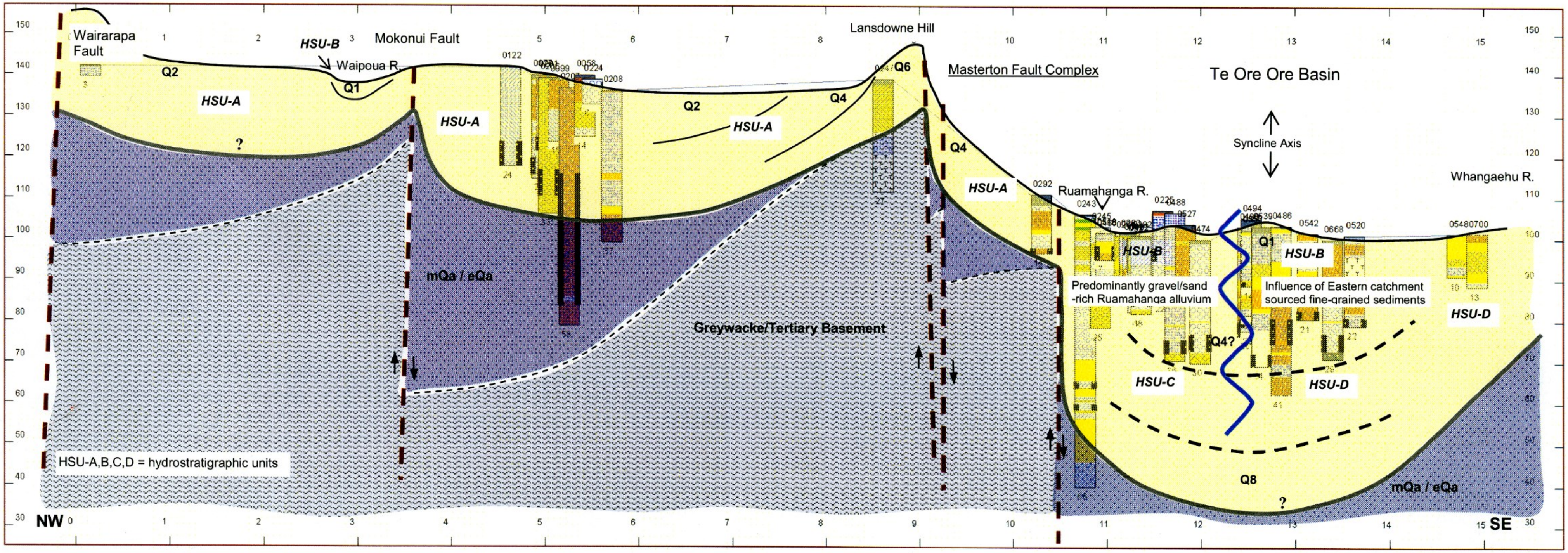

Figure 5.1: Upper valley conceptual hydrogeological cross-section[11]; Q1: Holocene aged gravel/sand, Q2-Q8: late Quaternary aged alluvium, mQa/eQa: middle Quaternary aged alluvial/swamp. Location relative to the extent of the present model domain/study area is shown in Figure Appendix A.2.

[11] Gyopari et al., "Wairarapa Valley Groundwater Resource Investigation: Upper Valley Catchment Hydrogeology and Modelling," 127.

5.4 Boundary Conditions

Key Boundary Conditions (BC) included river representation, drains, and recharge distribution:

- **River BC**: A 5 m buffered polygon was used to define significant river segments in the catchment (Waipoua River and Wakamoekau Creek):
  - River stage was set to match interpolated observed groundwater levels in the base model. This reflects the observation of very low flows and/or dry reaches within the Waipoua river during summer months;
  - Bed level was inferred as 1 m below interpolated observed groundwater levels. This offset was applied consistently across river features; and
  - Conductance was calculated as vertical hydraulic conductivity (Kz) multiplied by intersected river area within each model cell.
- **Drain BC**: A drain boundary condition was assigned along the southeastern model edge to simulate groundwater discharge:
  - Drain elevation was set at 96 m, based on the interpolated observed groundwater level in this region; and
  - Conductance was fixed at 0.001 m^2/s.
- **Recharge BC**: Recharge was applied in three zones based on catchment subdivision (upper, middle, and lower; see Figure Appendix A.4), with values reflecting relative differences in mean annual rainfall:
  - Middle catchment recharge rate was set to the PASTAS-derived value of 444 mm/year; and
  - Upper and lower catchments were scaled by factors of 1.2 and 0.75, respectively.

5.5 Calibration process

Manual calibration of hydraulic conductivity across hydrogeological units was conducted to achieve two key objectives:

1. Minimising discrepancies between modelled groundwater heads and interpolated groundwater contours (summer average); and
2. Maintaining model water balance in approximate alignment with the steady-state water balance reported in a previous groundwater investigation in this area[12], ensuring proportional equivalency of key budget components.

The calibration process involved iterative adjustments to hydraulic conductivity values, guided by:

- The conceptual hydrogeology of the catchment;
- Observed hydraulic gradients; and
- General hydraulic principles to ensure realistic groundwater flow behaviour.

6 Scenario configuration

Key parameters of base model and scenarios are described in Table 6.1 below.

[12] Gyopari et al., "Wairarapa Valley Groundwater Resource Investigation: Upper Valley Catchment Hydrogeology and Modelling," 52.

Table 6.1: MODFLOW simulation scenarios

Model version name	Simulation description	Configuration/modifications[13]
Base	Simplified groundwater model of the Waipoua river catchment.	Described in detail in Section 5.
Reafforestation NbS1_v1	Broad native reforestation across the catchment. Vegetation changes affect river flows and rainfall recharge.	0.7 multiplier applied to recharge rate and river stage reduced by 30 %.
Reafforestation NbS1_v2	Broad native reforestation across the catchment. Vegetation changes affect recharge only.	0.7 multiplier applied to recharge rate.
Reafforestation NbS1_v3	Native reforestation in areas primarily north of the model extent. Vegetation changes affect river flows only.	River stage reduced by 30 %.
Storage NbS2 v1	5 % coverage of floodplain with small-scale retention systems. Wetland water level is consistent with groundwater level.	Configure an additional 54 wetland cells across the floodplain area using the RIV package14 which required fewer parameters than the LAK package. Wetland cell stage set to base model groundwater level.
Storage NbS2 v2	5 % coverage of floodplain with small-scale retention systems. Wetland water level is 0.5 m lower than groundwater level.	Configure as NbS2 v1, but reduce wetland cell stage by 0.5 m.
Channel realignment NbS3 v1	Restore river to wider floodplain area Suggested bed level increases incorporated.	Apply suggested bed level changes and buffer distances to reaches as discussed with T+T's geomorphologist undertaking the geomorphic assessment in parallel.[15] Adjust river stage values for reaches to maintain constant cross-sectional area. Refer to Table 6.2 for more information.
Channel realignment NbS3 v2	Restore river to wider floodplain area Suggested bed level increases ignored.	Configure as NbS3 v1, but do not include bed level changes.

6.1 Reafforestation Scenarios (NbS1)

The reafforestation scenario explores the hydrological impacts of land retirement and native forest revegetation on hillslopes in the catchment. This scenario is designed to simulate the effects of land use change on groundwater recharge and river stage using empirical relationships reported in the literature. These relationships indicate that afforestation typically leads to a reduction in groundwater recharge due to increased evapotranspiration and altered soil water retention properties. Similarly, changes in vegetation can affect surface water hydrology, potentially leading to reductions in river stage.

[13] Note: further detail on scenario configuration provided in Sections 6.1, 6.2 and 6.3.

[14] Mary P. Anderson, William W. Woessner, and R. J. Hunt, *Applied Groundwater Modeling: Simulation of Flow and Advective Transport*, Second edition (London; San Diego, CA: Academic Press, 2015), 283.

[15] Tonkin + Taylor (2025). Waipoua Geomorphic Assessment: Stage 2 - Nature-based solutions. The purpose was to understand the effectiveness of the shortlisted nature-based solutions at reducing flood risk near Masterton and mapping where each nature-based solution is most likely to have the greatest impact within the catchment, based on geomorphic character, behaviour, and sensitivity.

To implement this scenario, modifications were made to key hydrological parameters in the MODFLOW 6 model relative to the base case. The primary adjustments involved:

- **Recharge rate reduction** to reflect the lower infiltration rates associated with forest cover; and
- **River stage reduction** to account for potential decreases in surface water levels due to changes in upstream catchment hydrology.

It is important to note that this scenario does not account for any geomorphological changes resulting from reforestation, such as alterations in stream morphology or sediment transport. The simulation focuses solely on hydrological impacts based on the assumed land use transformation.

To examine the effects of reforestation at different spatial scales and configurations, three variations (v1, v2, and v3) were developed. Each variation applies different adjustments to recharge and river stage to represent distinct reforestation strategies across the catchment.

6.1.1 Broad catchment wide reafforestation – recharge and river stage reduction (NbS1 v1)

In the v1 scenario, both recharge rate and river stage are reduced across the catchment. This represents a widespread afforestation effort, where native forest cover is expanded throughout the entire catchment area. The changes in recharge and river stage were applied proportionally across all relevant zones, based on empirical reductions reported in similar studies. This version provides insights into the cumulative hydrological effects of large-scale land retirement and reforestation efforts.

6.1.2 Lower catchment afforestation - recharge reduction only (NbS1 v2)

The v2 scenario focuses on afforestation primarily in the lower catchment, where native forest establishment is expected to have the most significant effect on groundwater recharge. In this version, only the recharge rate is reduced, while river stage remains unchanged. This approach represents a targeted reforestation strategy where forest expansion is concentrated in lower-elevation areas, influencing groundwater infiltration but not directly affecting river stage dynamics.

6.1.3 Upper catchment reafforestation - river stage reduction only (NbS1 v3)

The v3 scenario simulates afforestation concentrated in the upper catchment, closely aligned with the suggested locations for re/afforestation efforts. In this version, only river stage is reduced, while recharge remains unchanged. This represents a scenario where land retirement and native forest revegetation primarily influence surface water dynamics, potentially altering baseflow contributions and streamflow characteristics. The model assumes that hydrological changes in this region predominantly affect river discharge rather than direct infiltration into groundwater.

6.2 Storage scenarios (NbS2)

The scenario involves the creation and reestablishment of small-scale distributed retention storage systems, such as wetlands, retention basins, and infiltration trenches, within the catchment. Wetlands were simulated by defining 54 new river cells (equates to 5 % coverage of the floodplain area within the model extent; this figure was agreed with the project team), distributed randomly across an area defined by the floodplain extent minus a 250 m buffer from the river polyline. The river stage for the wetland cells was set using the steady-state groundwater level data set computed in the base model. For NbS2 v1 the stage was set to the steady-state groundwater head in the wetland cells and in NbS2 v2 these values were reduced by 0.5 m relative to v1 (accounting for potential for transpiration and open water evaporation). In both v1 and v2, the rate of recharge was set to zero in wetland cells to account for losses to evaporation/evapotranspiration. The effect of these losses was assumed to be a 0.5 m reduction in water level in the wetland in v2.

6.2.1 Base storage simulation (NbS2 v1)

In the NbS2 v1 scenario, the river stage for the newly defined wetland cells was set to match the steady-state groundwater level from the base model. This assumes that the retention areas function in equilibrium with the surrounding groundwater system, providing storage without significantly altering surface water-groundwater exchange dynamics. Recharge in these cells was set to zero to account for losses due to evaporation and evapotranspiration, to reflect that some of these storage elements will have significant revegetation associated with them.

6.2.2 Lowered wetland stage (NbS2 v2)

The NbS2-v2 scenario introduced a variation in wetland water levels by reducing the water level by 0.5 m relative to v1. This adjustment represents potential water level change due to the loss of rainfall recharge that may lower the surface water elevation in retention areas, as well as greater water losses representing a situation where the groundwater surface is exposed in large areas of wetland with associated wetland vegetation. As in v1, recharge was set to zero in these wetland cells.

6.3 Channel realignment scenarios (NbS3)

The NbS3 scenario assesses the hydrological effects of increasing overall channel realignment width and adjusting the bed level, providing more space for the river. This intervention is intended to enhance connectivity between the river and its surrounding landscape, potentially altering groundwater-surface water interactions and improving flow resilience. The adjustments in river width and bed level were defined based on input from the T+T fluvial geomorphology team, ensuring that the modifications aligned with plausible natural river processes and expected morphological responses.

To implement these changes in MODFLOW 6, river stage values were adjusted proportionally to maintain a consistent cross-sectional area after widening. Conductance values were modified based on vertical hydraulic conductivity and the area of the polygon intersected by each model cell. The original 5 m buffered river polygon from the base model was retained for local refinement, ensuring that grid discretisation remained consistent.

Table 6.2 presents the specific buffer radii and bed level adjustments applied to each river reach. The NbS3 scenario is represented by two variations (v1 and v2), which differ in the magnitude of bed level adjustments and stage modifications.

Table 6.2: Buffer radii and bed level applied to river for NbS3 scenarios

Reach	Buffer radius (m)	v1 bed level (m; relative to interpolated groundwater level)	v2 bed level (m; relative to interpolated groundwater level)	v1 stage (m; relative to interpolated groundwater level)	v2 stage (m; relative to interpolated groundwater level)
3 (top)	10	-0.60 (increase of 0.4)	-1.00	0.10	-0.30
2 (middle)	20	-0.30 (increase of 0.7)	-1.00	0.27	-0.43

Reach	Buffer radius (m)	v1 bed level (m; relative to interpolated groundwater level)	v2 bed level (m; relative to interpolated groundwater level)	v1 stage (m; relative to interpolated groundwater level)	v2 stage (m; relative to interpolated groundwater level)
1 (lower)	7.5	-0.50 (increase of 0.5)	-1.00	0.29	-0.21
Wakamoekau	0	-1.00 (no change)	-1.00	0.15	0.15

Note: Buffer radius of 5 m applied to all river reaches in base model; buffer values in this table are in addition to the base model river width.

6.3.1 Moderate bed level increase (NbS3 v1)

In the NbS3 v1 scenario, river width was increased, and bed levels were adjusted. These adjustments raise bed levels relative to the base model, reflecting a scenario where channel modifications include both widening and longer-term aggradation resulting from it. River stage values were scaled accordingly to maintain the channel cross-sectional area after these modifications. This resulted in water levels in the main Waipoua river that sit slightly above the groundwater level.

6.3.2 No bed level changes (NbS3 v2)

The NbS3 v2 scenario maintains the base model bed level of -1 m below the interpolated groundwater surface, ensuring that only river widening is applied without vertical adjustments. This scenario isolates the impact of increased channel width while keeping bed levels constant, providing a contrast to v1 and helping to assess the relative influence of depth versus width modifications on groundwater-surface water interactions. River stage values were modified in line with the adjusted width but without further changes to elevation. The lower water levels in this scenario resulted in water levels slightly below the groundwater level.

7 Results and discussion

The following sections comprise the comparative analysis of the base model and scenarios. The primary outputs from the numerical modelling process are presented in Table 7.1 and Appendix A.

7.1 Base model

Notable aspect of the base model results include:

- Steady-state water balance of 3.8 m^3/s in and out of the model;
- Water enters the model from surface recharge (i.e. a proportion of rainfall) and enters and leaves the model via river leakage. Water leaves the model via groundwater flow at the southeastern edge of the model. Flows into and out of the river are approximately equal; and
- The base model groundwater level contours (Figure Appendix A.6) approximately match the interpolated summer groundwater levels (Figure Appendix A.5) across the model extent. However, base model groundwater levels drop towards the north-western quadrant of the model (this trend is not as strongly emphasised in the interpolated data).

7.2 Reafforestation (NbS1)

7.2.1 Broad/lower catchment afforestation (NbS1 v1 and v2)

Results from versions 1 and 2 of the NbS1 model provided the following insights:

- The recharge reduction may not be representative of the final proposed afforestation scheme as reafforestation may be limited to land at and to the north of the model extent; and
- The decline in groundwater level as a result of rainfall recharge changes is most noticeable in the northwest corner of the model, distant from the Waipoua River. The maximum water level decline of ~4 m occurs in the northwestern part of the model. Areas of the model furthest from river show the greatest water level decline. Observed drawdown decreases with proximity to the river, which may provide a source of water to groundwater in addition to rainfall recharge (see Figure Appendix A.7 and Figure Appendix A.8).

7.2.2 Upper catchment reafforestation (NbS1 v3)

Results from NbS1 version 3 were distinct from versions 1 and 2, with the following insights:

- There is a 4 % reduction in the water budget under this scenario. The reduced input from the river (-8 %) results in similar decreases in river baseflow (-4 %) and groundwater flows across the southeastern model edge (-4 %); and
- On average, the groundwater decline is 0.4-0.5 m across the catchment, reaching a maximum at the upstream ends of the Waipoua river and Wakamoekau Creek.

7.2.3 Further comments on NbS1 results

The model scenario NbS1 v3 most accurately reflects the afforestation locations proposed by the project team, i.e. upstream of the model and accordingly rainfall recharge remains unchanged within the model extent.

The cause of observed groundwater decline around the upstream end of the river reaches (see Figure Appendix A.9) is not clear, however may be a result of the abrupt change in recharge and river water level at the upstream model boundary i.e. is an model artifice and can be ignored.

There is good literature support for reduction in groundwater levels under land use change from pasture to forest (this assessment supports these observations). In the literature (refer Section 4.1), the reduction in peak flood flows is well observed in paired catchments[16] for different types of flood events, while the effect on river baseflow is harder to confirm. While there is an overall reduction in mean catchment flows, the effect on river baseflow is contradictory. The meta-review suggests baseflow decreases and that droughts decrease – the measurement of each may need further definition.

7.3 Storage (NbS2)

7.3.1 Base storage simulation (NbS2 v1)

Results from version 1 of the NbS2 model provide the following insights:

- Very minimal changes observed in water balance and groundwater levels (see Figure Appendix A.10); and
- For modelling, the wetland stage was set to modelled groundwater levels from the base model, meaning no significant changes were expected.

[16] The paired catchment approach a method used in hydrology to study the impact different activities on water systems. This approach involves comparing two catchments that are similar in all aspects except for the activity e.g. reafforestation, being studied. This method helps to isolate and understand the specific effects of an activity on water quantity and quality.

7.3.2 Lowered wetland stage (NbS2 v2)

Results from version 2 of the NbS2 model provide the following insights:

- Slight increase in total water balance – this is due to increased flows from the wetland cells to groundwater;
- There is a slight decrease in groundwater flow across the southeastern model extent in this scenario; and
- Groundwater levels are reduced by up to 0.4 m around wetland cells (see Figure Appendix A.11)

7.3.3 Further comments on NbS2 results

The catchment hydrogeology (Gyopari, 2006) indicates that faulting in the lower catchment results in increased groundwater levels and baseflow upstream (north) of the Masterton and Mokonui faults due to decreased thickness of the upper aquifer unit. River baseflow is increased in these areas where the river stage is lower than adjacent groundwater levels. This water level difference causes water to flow from the shallow aquifer to the river through the sides and base of the riverbed. River baseflow may also increase in areas where water races (e.g., the Opaki water race) discharge to the river channel.

Construction of wetlands suggests potential changes to flows in this system in two distinct ways, depending on connectivity with groundwater:

- Where wetlands intercept groundwater in the shallow aquifer, groundwater contributions to river flows may be reduced as wetlands may intercept horizontal flow and increase losses from groundwater to evaporation and evapotranspiration; and
- Where wetlands do not intercept groundwater, recharge may be increased due to collection of stormwater surface runoff or diversion of streamflow and potential for infiltration (i.e. swale-type behaviour). Note that numerical groundwater modelling carried out in this evaluation did not account for this type of surface water/groundwater interaction as there was no additional source of water in the model and these inflows would be episodic

Selection of locations for constructed wetlands should consider the following:

- If baseflow reduction is desired, wetlands may be constructed in areas near rivers where the depth to groundwater is relatively shallow (e.g., within the wider river channel below terraces) and where rivers are gaining (e.g., north of the Masterton or Mokonui faults); and
- If the goal is to enhance recharge to shallow groundwater, wetlands should be constructed in permeable areas where the groundwater depth is below the proposed excavation depth. However, this does impact the feasibility of maintaining permanent water in them and it may prove more practical to implement these as dry infiltration basins. When feasible for construction, terraced areas with significant rainfall may offer the greatest potential for reducing surface runoff and improving groundwater infiltration.

A better understanding of required excavation depths for potential wetlands may be obtained by generating cross-sections across fault lines within the model extent and examining the depth to groundwater.

As noted previously, simulation of the wetlands that are used to intercept surface water runoff and increased aquifer infiltration was not conducted as part of the modelling assessment. A wetland or infiltration area that receives stored surface water or runoff is similar to the concept of managed aquifer recharge (MAR). MAR typically requires a source of clean water to provide aquifer infiltration (recharge) e.g. from surface water and/or by collecting (damming) rainfall runoff.

Modelling MAR via wetlands would use a suitable boundary condition e.g. constant head. This approach would help to estimate the volume of water that may be required to support MAR. However, in the absence of a source of water for MAR it would exaggerate the contribution of wetlands to groundwater for the assessment described here. This type of assessment would require transient modelling to match the inflows available to wetlands, which would vary seasonally. Overall, the modelled influence of wetlands on shallow groundwater suggests that these systems are unlikely to significantly increase the annual catchment yield.

7.4 Channel realignment (NbS3)

7.4.1 Moderate bed level increase (NbS3 v1)

Results from version 1 of the NbS3 model provide the following insights:

- The river geomorphology changes (i.e. long-term bed level and width increases) make a comparison difficult as there are significant changes in the water budget. This long-term bed level increase means that more water may enter groundwater from the river as the scenario river stage is above the base model river stage. This means that baseflow is likely to be reduced compared with the base case model if increased river flows cannot be maintained from catchment inputs upstream of the model;
- Flow from the river to the groundwater system is expected to increase with the increase in riverbed level;
- In the absence of upstream catchment treatments that increase river baseflow into the model, groundwater flow increases out of the southeastern edge of the model in this scenario (see Figure Appendix A.12), with a reduction in baseflow; and
- However, if the baseflow into the northern edge of the model can be increased and maintained (e.g. by insertion of wetlands; refer Figure 4.1) then it is reasonable to expect that there may be increase in both groundwater flow and river flow at the southeastern edge of the model.

7.4.2 No bed level changes (NbS3 v2)

Results from version 2 of the NbS3 model provide the following insights:

- In this scenario there is an overall increase in leakage from the river to the groundwater system. This is consistent with an increase in leakage from the river under the proposed new river realignment which has increased riverbed surface area. Increases in modelled groundwater levels associated with river changes are observed in model outputs within the northern model extent;
- There is also an increase in river baseflow which corresponds to the lowered river stage relative to the local groundwater level. These effects are focussed within the southern half of the model extent;
- There is a decrease in in groundwater flow through the southeastern edge of the model. This suggests that there is a decrease in river baseflow at the southeastern edge of the model consistent with the decrease in groundwater levels and flows generally in this location; and
- Ultimately, the effects associated with changes to the river compete and the net effect is an increase in the total water balance with reduced flows across the south-eastern model boundary. Increases in modelled shallow groundwater levels are the greatest near the northern model boundary and generally decrease to the south (see Figure Appendix A.13).

7.5 Results summary

- All scenarios show decreased groundwater flows (with the exception of NbS2 v1 and NbS3 v1) through the south-eastern border of the model (i.e. refer to the drain component as shown in Table 7.1). This result indicates that groundwater levels (and flows) at Masterton will generally be reduced by the majority of nature-based solutions scenarios considered. The differences shown by the results for NbS2 v1 and NbS3 v1 are described further below;
- For NbS2 v1 there is no change from the base model;
- For NbS3 v1 there is an apparent increase in groundwater flow through the southeastern edge of the model together with an apparent increase in water balance. A pro-rated water balance (i.e. matching the base model) confirms that there will be an increase in groundwater flow from the model. However, considering the increase in bed level there is likely to be a decrease in river baseflow;
- Overall, there is generally a decrease in baseflow in the Waipoua River for all nature-based solutions scenarios considered, however the NbS3 results indicate how baseflows and groundwater levels have a higher chance of increasing;
- However, consideration of NbS3 v1 confirms that if a suitable out-of-catchment water supply was available (or if baseflows could be increased by removal of groundwater takes or reafforestation) together with suitable infiltration methods then groundwater levels and river baseflow may be increased; and
- The NbS3 scenarios (i.e. river realignment) show the most promise for shallow groundwater recharge, and potentially baseflow increases.
- Broadly speaking the more suitable locations for nature-based solutions treatments in the Waipoua River catchment are assessed as:
  - Reafforestation (NbS1):
    - This location has been advised as land that is less suitable for pastoral, arable, or horticultural farming. This land is primarily located adjacent to the Tararua Ranges upstream of the groundwater modelling extent.
  - Storage (NbS2):
    - If baseflow reduction is desired, distributed storage structures (e.g., wetlands may be constructed in areas near rivers where the depth to groundwater is relatively shallow (e.g., within the wider river channel below terraces) and where rivers are gaining (e.g., north of the Masterton or Mokonui faults); and
    - If the goal is to enhance recharge to shallow groundwater, distributed storage structures (e.g., infiltration basins) should be constructed in permeable areas where the groundwater depth is below the proposed excavation depth. When feasible for construction, terraced areas with significant rainfall may offer the greatest potential for reducing surface runoff and improving groundwater infiltration.
  - Channel realignment (NbS3):
    - As per the geomorphological assessment, river realignment treatment would be best located between Mikimiki and Masterton. Within this part of the catchment, and with the introduction of an additional water source, the assessment indicates that increases in baseflows and groundwater levels would be expected. However as works progress monitoring should be carried out to ensure estimated effects are delivered.

Table 7.1: Water balance summary

Budget component (Flows into model)	Base model	NbS1 v1	NbS1 v2	NbS1 v3	NbS2 v1	NbS2 v2	NbS3 v1	NbS3 v2
Scenario description	-	Reafforestation (river level and recharge reduced by 30 %)	Reafforestation (recharge reduced by 30 %)	Reafforestation (river level reduced by 30 %)	Distributed storage (no recharge in wetland cells)	Distributed storage (no recharge, stage set to – 0.5 m)	Channel realignment (with bed level increases)	Channel realignment (no bed level increases)
River	(2.12)	-3 % (2.04)	+11 % (2.36)	-15 % (1.8)	+1 % (2.16)	+9 % (2.32)	+60 % (3.4)	+19 % (2.54)
Recharge	(1.69)	-30 % (1.18)	-30 % (1.18)	no change	-2 % (1.65)	-2 % (1.65)	no change	no change
Total	(3.81)	-15 % (3.22)	-7 % (3.54)	-8 % (3.49)	no change	+4 % (3.97)	+33 % (5.09)	+10 % (4.22)
Budget component (Flows out of model)	**Base model**	**NbS1 v1**	**NbS1 v2**	**NbS1 v3**	**NbS2 v1**	**NbS2 v2**	**NbS3 v1**	**NbS3 v2**
Drain	(1.47)	-27 % (1.07)	-1 % (1.45)	-26 % (1.09)	no change	-3 % (1.42)	+55 % (2.29)	-13 % (1.28)
River	(2.33)	-7 % (2.15)	-10 % (2.08)	+2 % (2.4)	no change	+9 % (2.55)	+19 % (2.8)	+26 % (2.95)
Total	(3.81)	-15 % (3.22)	-7 % (3.54)	-8 % (3.49)	no change	+4 % (3.97)	+33 % (5.09)	+10 % (4.22)
Comment	-	Reduced inflows (both groundwater recharge and river flows) as water is intercepted by trees in the upper catchment. Outflows are correspondingly reduced (both groundwater and river flow).	Inflows reduced overall (decrease in groundwater recharge and slight increase in river flow) due to interception of water by trees in lower catchment. Outflows are reduced, reflecting reduced inflows.	Inflows reduced (river flow only) due to interception of water by trees in the upper catchment. Outflows reduced overall (decreased drain flow and marginally increased river flows) due to reduced inflows.	Only marginal changes observed as wetland stage is equal to shallow groundwater. Groundwater recharge inflow is slightly reduced because water is intercepted by wetlands.	Inflows increase marginally due to wetland inflows. Groundwater recharge inflow is slightly reduced because water is intercepted by wetlands. Outflow across the southern border of the model are marginally reduced.	Inflows increase significantly (river contribution to groundwater increase; groundwater recharge unchanged) due to raised river levels. Outflows increased corresponding to increased inputs from River.	Similar to NbS3 v1 but increase in inflows is less pronounced as bed levels were not increased. Outflows correspondingly increase.

Note: Unbracketed values reflect % change relative to the base model. Bracketed values are absolute flows with units of m^3/s. Drain represents outflow from the model boundary.

8 Limitations

While the numerical groundwater model developed for this study provides valuable insights into regional groundwater dynamics, several limitations should be acknowledged. These limitations stem from the scale of the study, simplifications in model development, and data constraints. Key issues that may affect the interpretation and applicability of the model results are outlined below.

8.1 Scale issues

A significant challenge in this study arises from the scale of the model compared to the scales of existing literature and observations. Many studies referenced in this work focus on smaller catchments where hydrological responses can be more readily observed and interpreted. However, when transitioning to a larger catchment-scale model, the effects identified in small-scale studies become more difficult to replicate and observe.

Consequently, while small-scale studies provide valuable insights, their findings may not always be directly transferable to a regional scale and vice a versa.

8.2 Modelling limitations

Several modelling constraints influenced the accuracy and scope of the groundwater simulation results.

8.2.1 Steady-state assumptions

The model was developed under steady-state conditions, meaning that groundwater flow conditions were assumed to be in equilibrium over time. While this approach is useful for understanding general flow patterns and long-term groundwater conditions, it does not capture transient/episodic variations caused by seasonal recharge fluctuations, pumping dynamics, or climate variability. A transient analysis would provide a more realistic representation of groundwater flow over time, but implementing such an approach would require coupling MODFLOW 6 with additional time-series datasets and calibration efforts, which were beyond the scope of this study.

8.2.2 Lack of detailed data incorporation

Due to scope limitations, several detailed datasets and analyses that could improve model accuracy were not incorporated. These simplifications may impact the precision of the model outputs in specific areas.

- **Reafforestation representation**
  - In reafforestation scenarios, only effects on groundwater recharge were considered; and
  - Other potential impacts such as altered stream morphology and/or sediment transport were not considered.
- **River representation**
  - The model does not incorporate detailed river stage and bed level data; and
  - Instead of performing a detailed hydrological analysis to delineate river networks based on topography and flow accumulation, a polyline dataset from LINZ was used to represent river channels. This approach simplifies river geometry and may not fully capture the hydrological complexity of the system.

- **Aquifer properties and delineation**
  - The model uses generic aquifer property values. While these values are reasonable approximations, they introduce uncertainty in predicting groundwater behaviour; and
  - The spatial delineation of aquifer units was also simplified, potentially affecting the accuracy of hydraulic conductivity distributions and groundwater flow patterns.
- **Omission of Opaki Water Race**
  - The Opaki water race, which could influence local groundwater recharge and surface water interactions, was not included in the model. This omission may impact localised water balance estimates, particularly in areas influenced by these artificial water conveyance systems.
- **Simulation of Wetlands**
  - Wetlands were simulated using the MODFLOW River Package, which provides a simplified representation of groundwater-surface water exchanges. However, wetlands have unique hydrological characteristics, including variable water levels, evapotranspiration, and bidirectional interactions with groundwater. Using the River Package to represent wetlands may misrepresent some of these critical processes, leading to inaccuracies in simulating their hydrological function.

8.3 Implications of model limitations

These limitations should be considered when interpreting the model results. While the model provides a useful approximation of regional groundwater flow, some localised and detailed hydrological interactions may not be fully represented due to data and scope constraints. In particular, the Waipoua River – which is characterised by very low summer flows and intermittent drying reaches – may be especially sensitive to even small hydrological changes resulting from nature-based solutions interventions. These sensitivities could lead to either beneficial or adverse impacts, underscoring the importance of further targeted investigation. Future improvements could include:

- Incorporating transient modelling to capture temporal variations (including impact of flood events on groundwater recharge and river flow);
- Enhancing river-aquifer interaction representation using more detailed hydrological data;
- Refining aquifer property distributions with site-specific field data;
- Explicitly modelling wetlands with a more appropriate numerical approach, such as coupling with a surface water model; and
- Undertaking monitoring and finer-scale dynamic modelling (for example focussing on key areas such as seasonally dry reaches of the Waipoua river) if specific nature-based solutions are to progress beyond the conceptual stage.

Despite these limitations, the MODFLOW 6 model provides a valuable foundation for understanding groundwater dynamics in the study area. However, caution should be exercised when applying the results for detailed water management decisions at finer spatial and temporal scales.

9 References/bibliography

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10 Applicability

This report has been prepared for the exclusive use of our client Greater Wellington Regional Council, with respect to the particular brief given to us and it may not be relied upon in other contexts or for any other purpose, or by any person other than our client, without our prior written agreement.

Tonkin & Taylor Ltd
Environmental and Engineering Consultants

Report prepared by:

....

Colter Carson
Environmental Consultant

Authorised for Tonkin & Taylor Ltd by:

....

Bryn Quilter
Project Director

Technical review by:

....

Tony Reynolds
Environmental Consultant

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Appendix A Figures

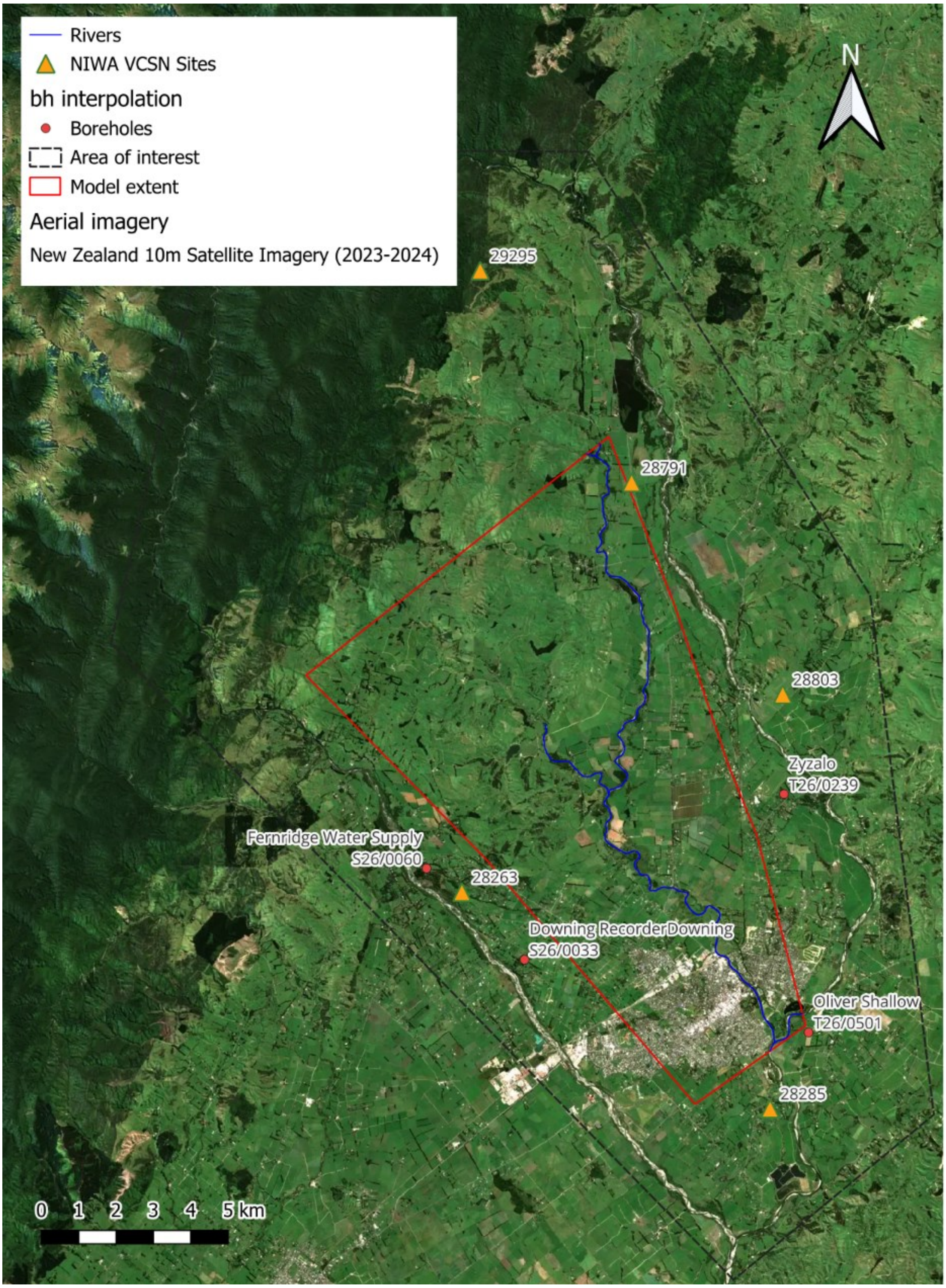


Figure Appendix A.1: PASTAS recharge estimation input overview.

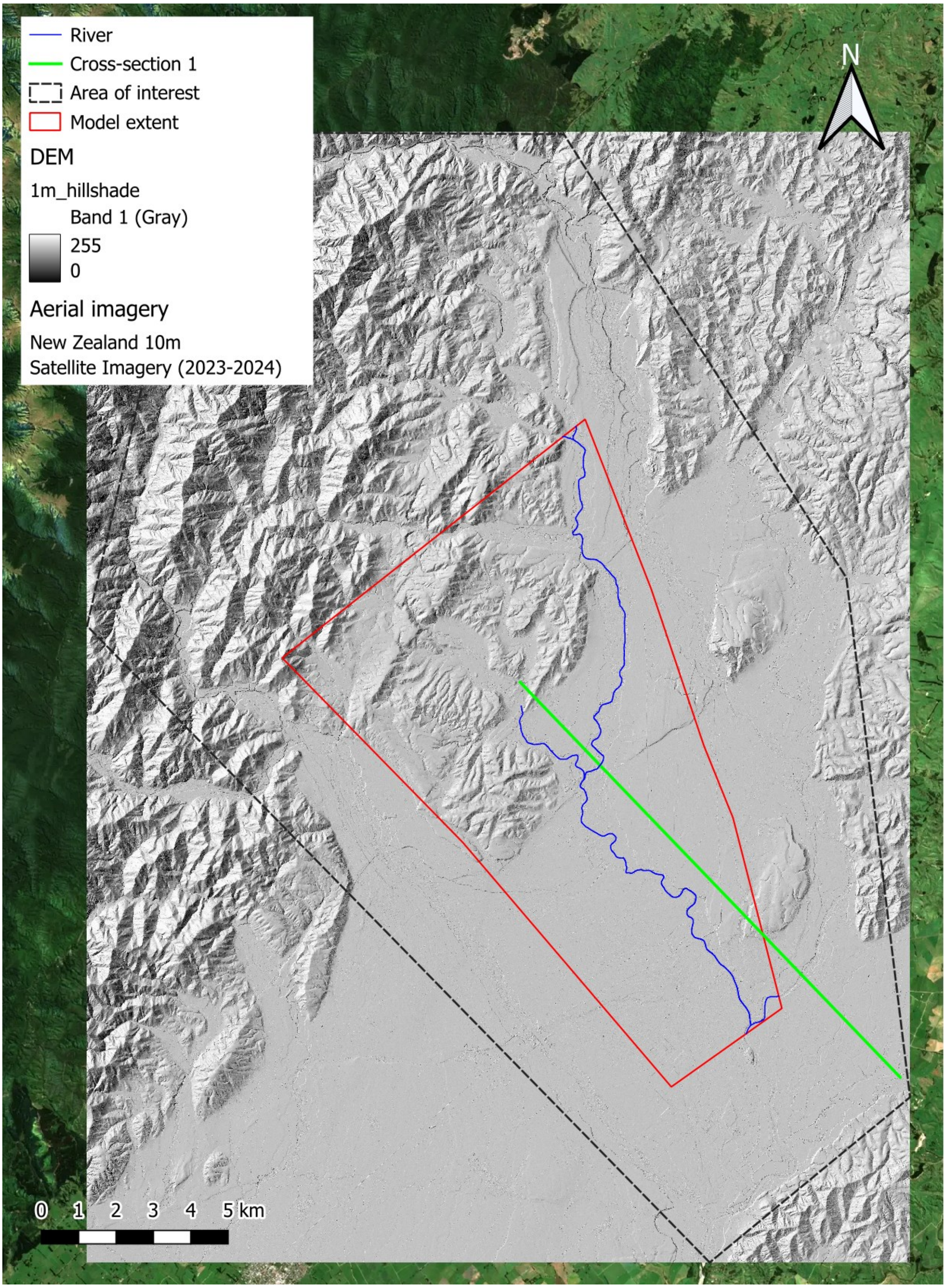


Figure Appendix A.2: Model overview figure.

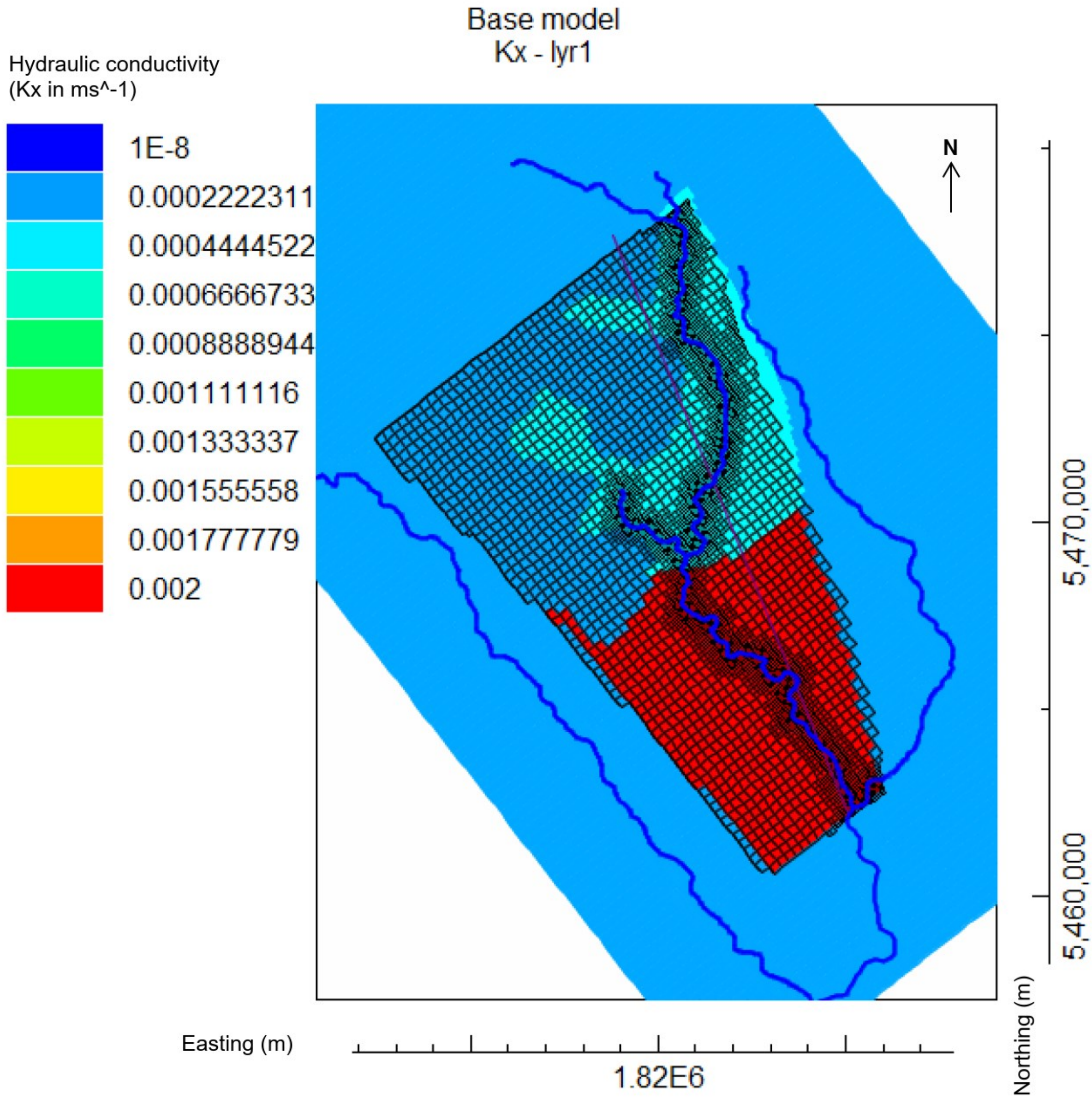


Figure Appendix A.3: Hydraulic conductivity in layer 1.

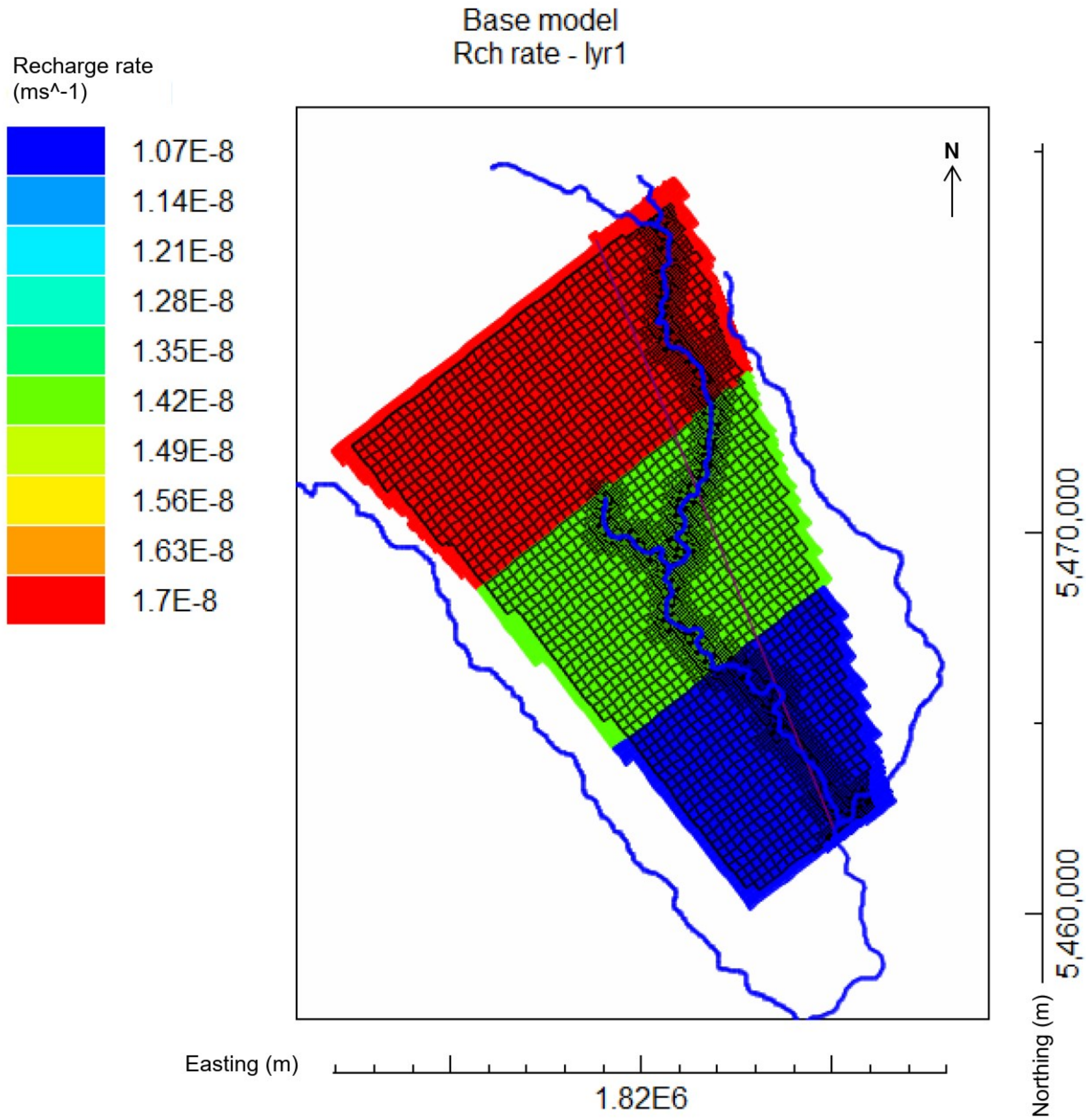


Figure Appendix A.4: Rainfall recharge rate in layer 1.

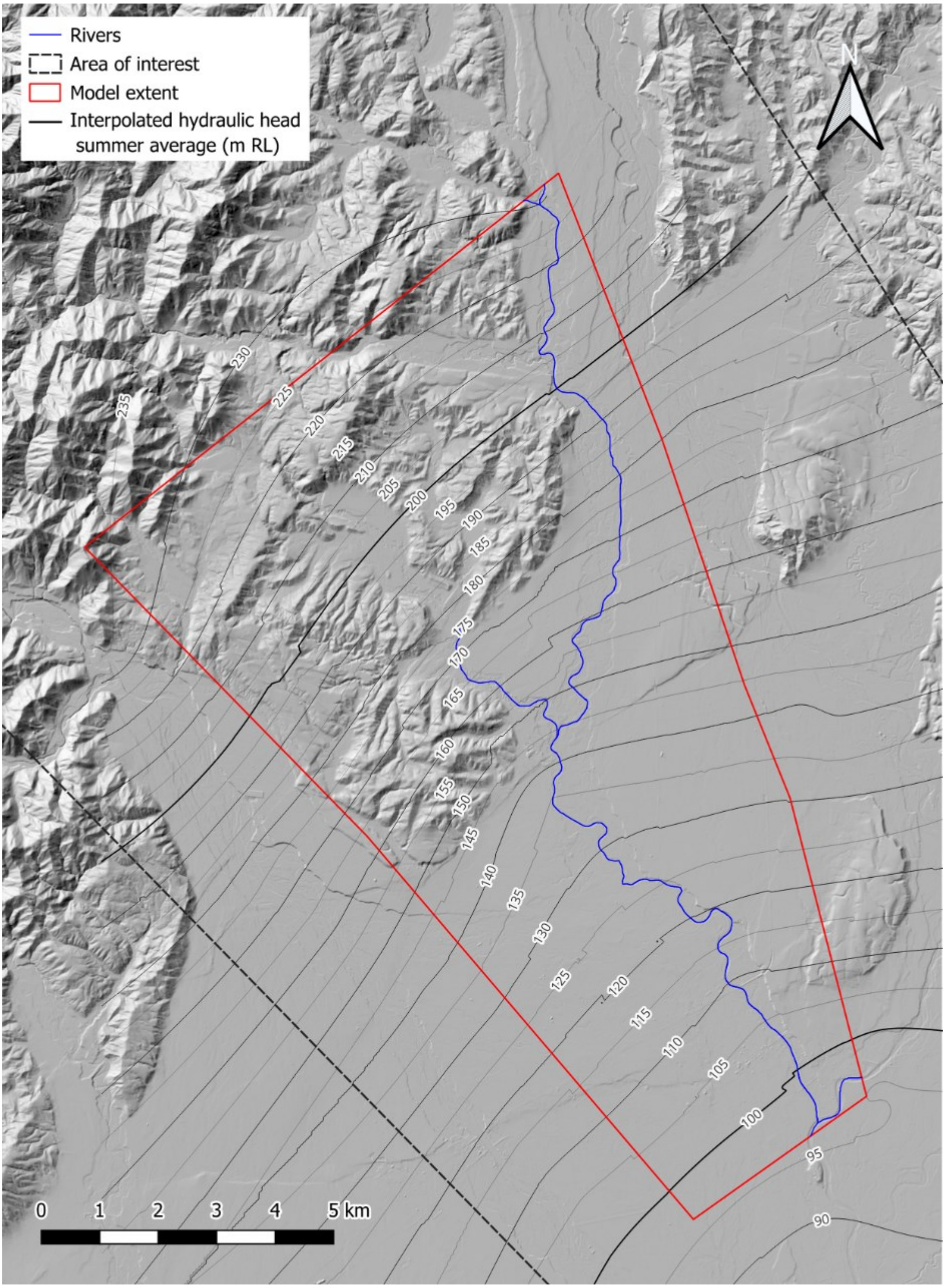


Figure Appendix A.5: Interpolated average summer groundwater levels.

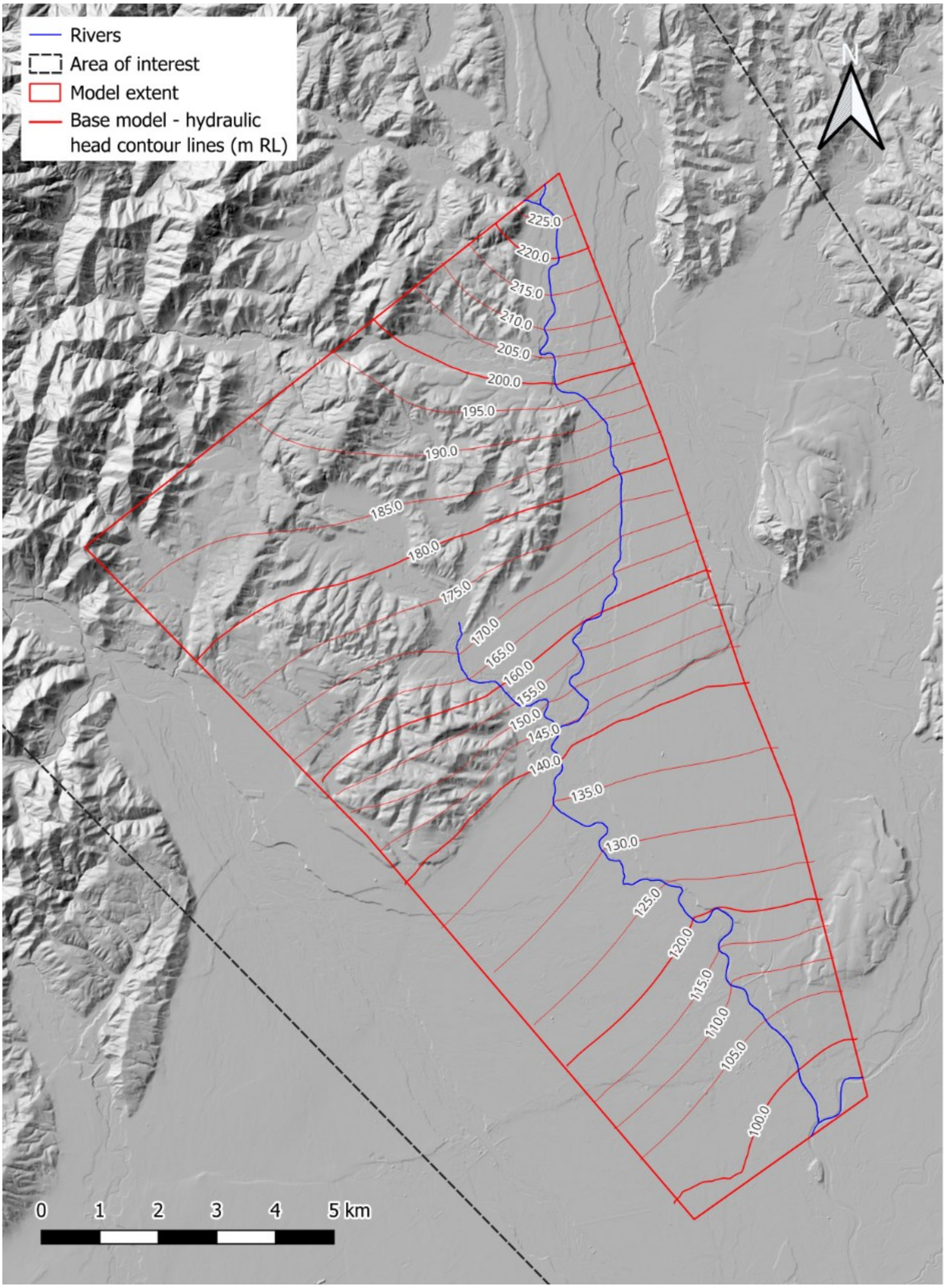


Figure Appendix A.6: Base model groundwater contours.

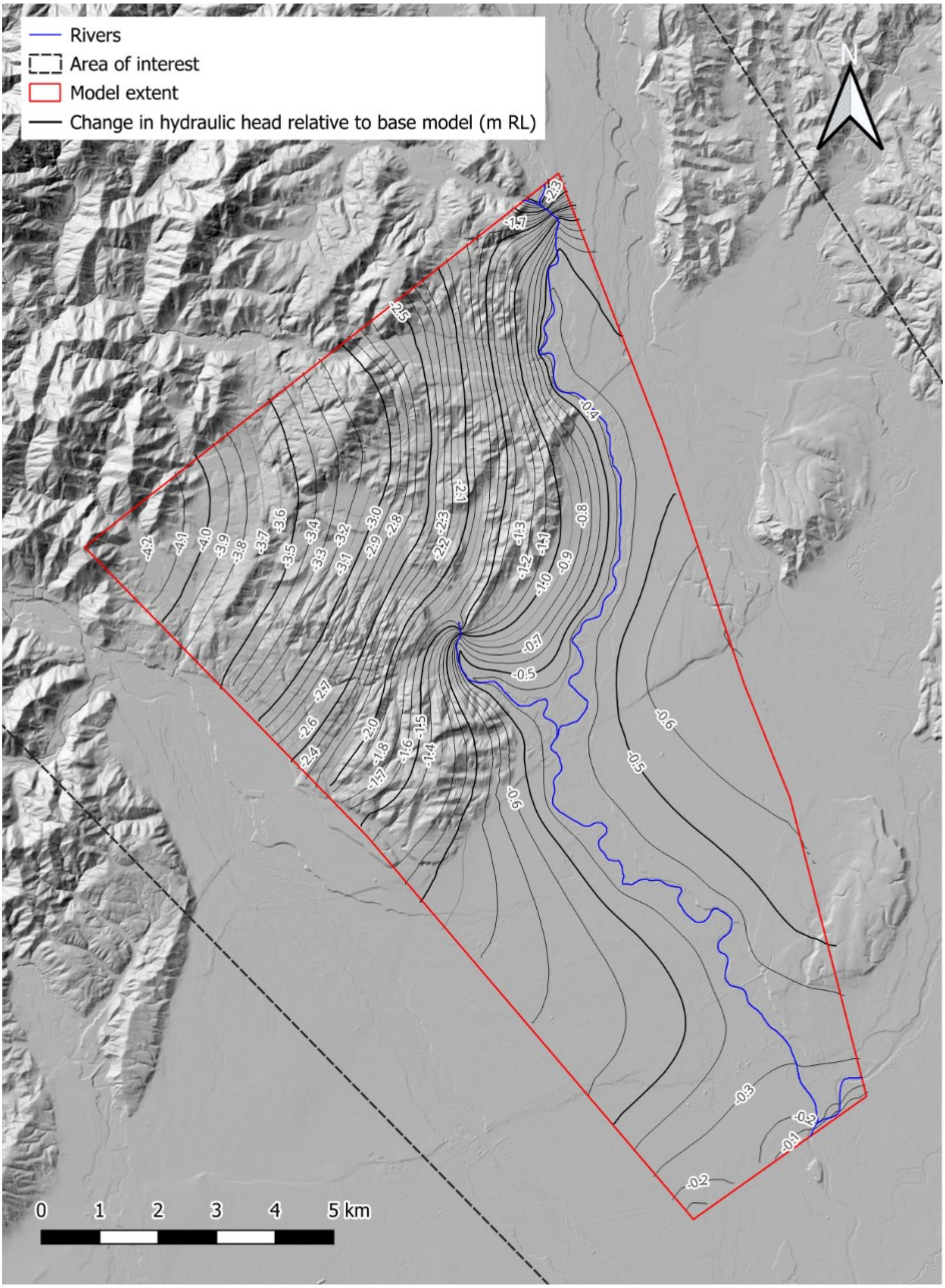


Figure Appendix A.7: NbS1 v1 - change in hydraulic head.

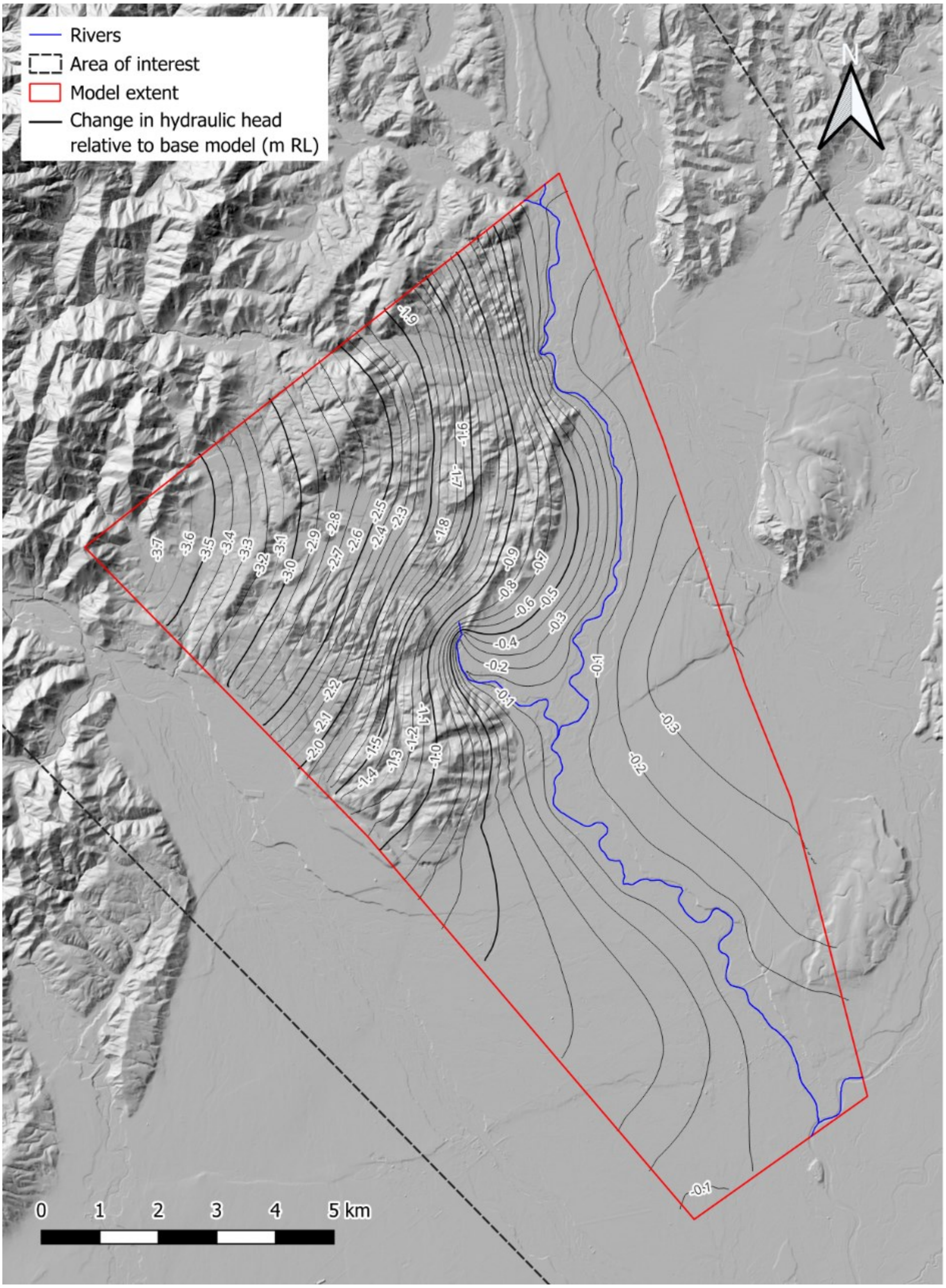


Figure Appendix A.8: NbS1 v2 - change in hydraulic head.

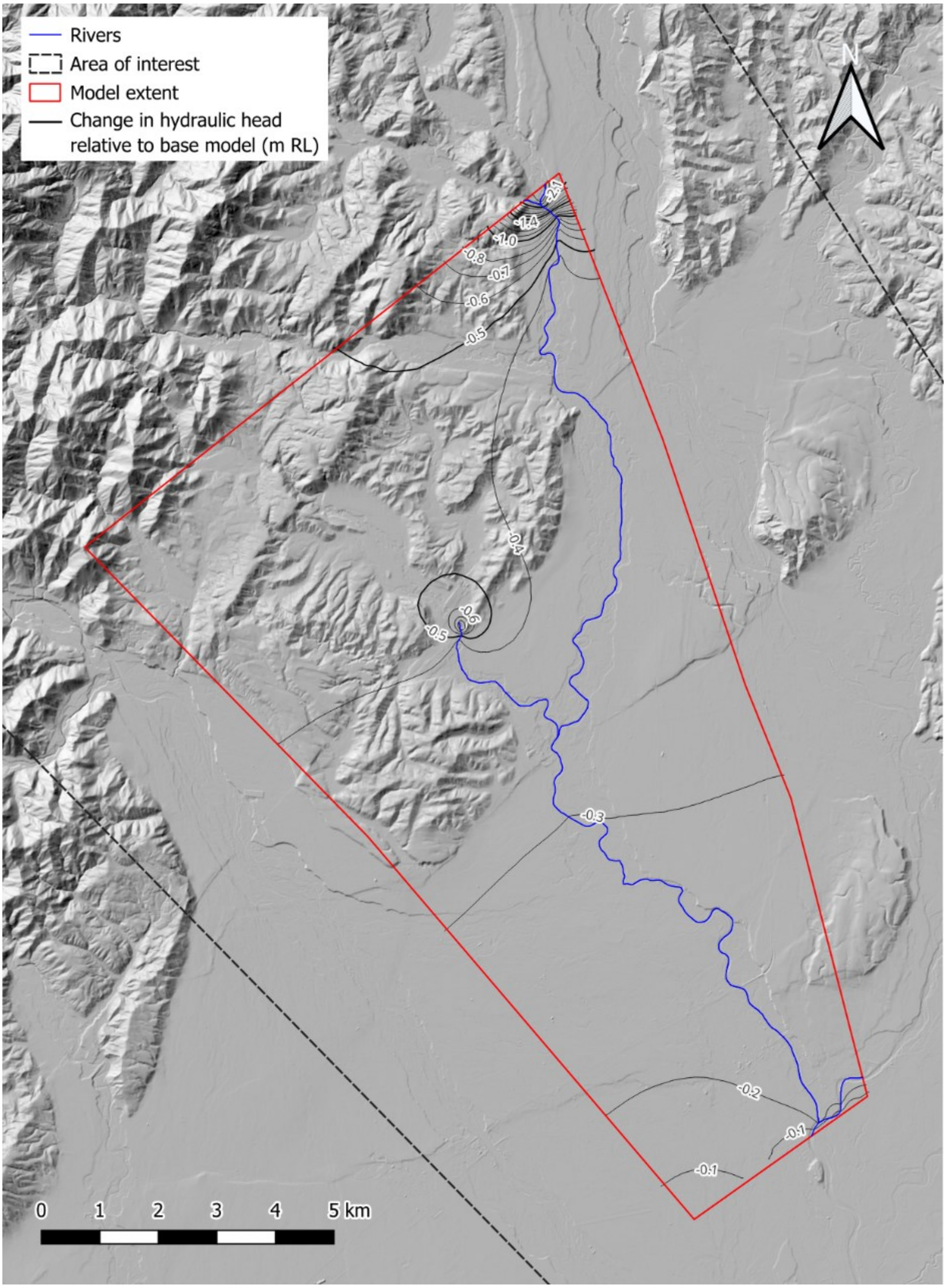


Figure Appendix A.9: NbS1 v3 - change in hydraulic head.

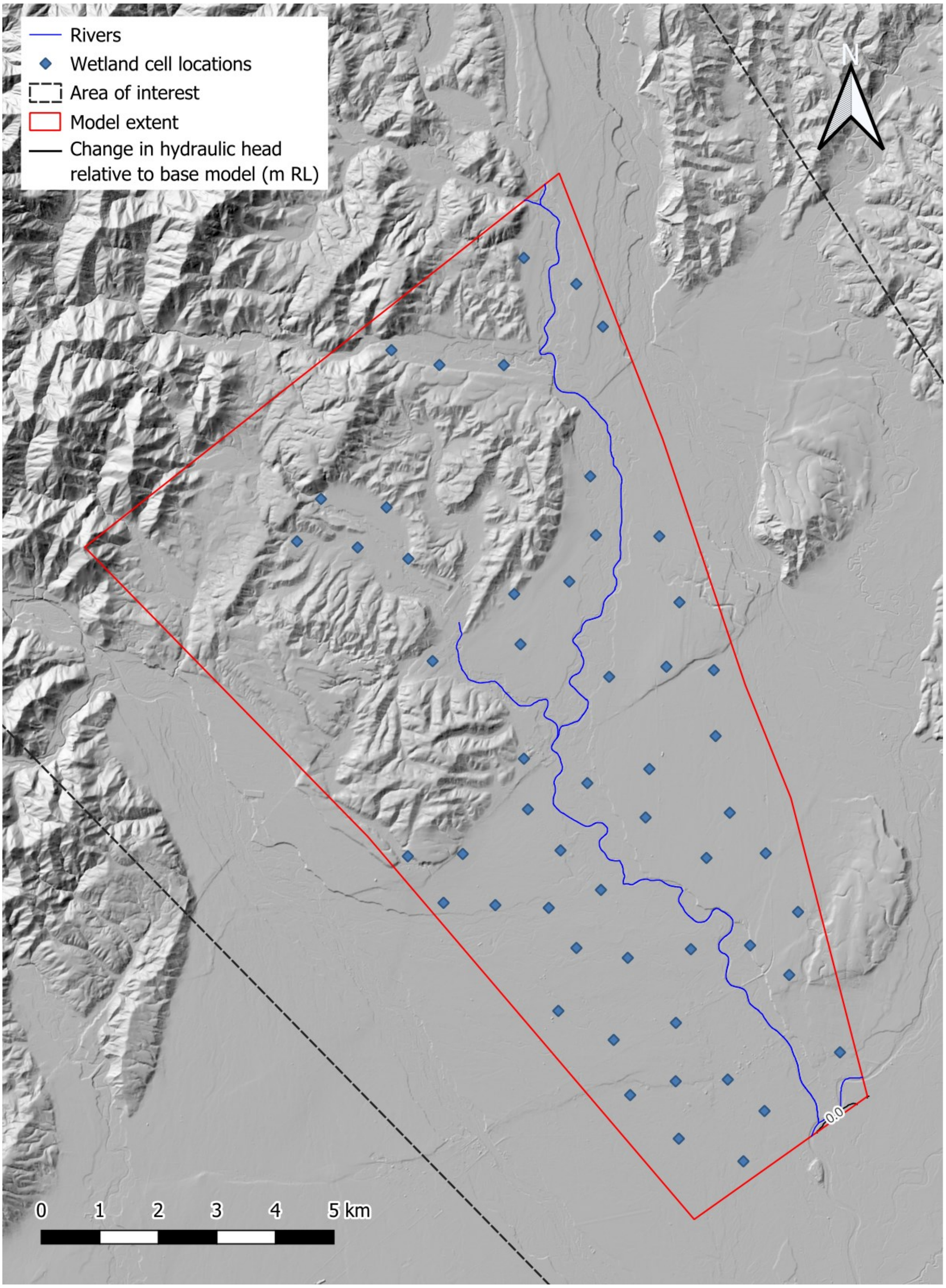


Figure Appendix A.10: NbS2 v1 - change (nil) in hydraulic head.

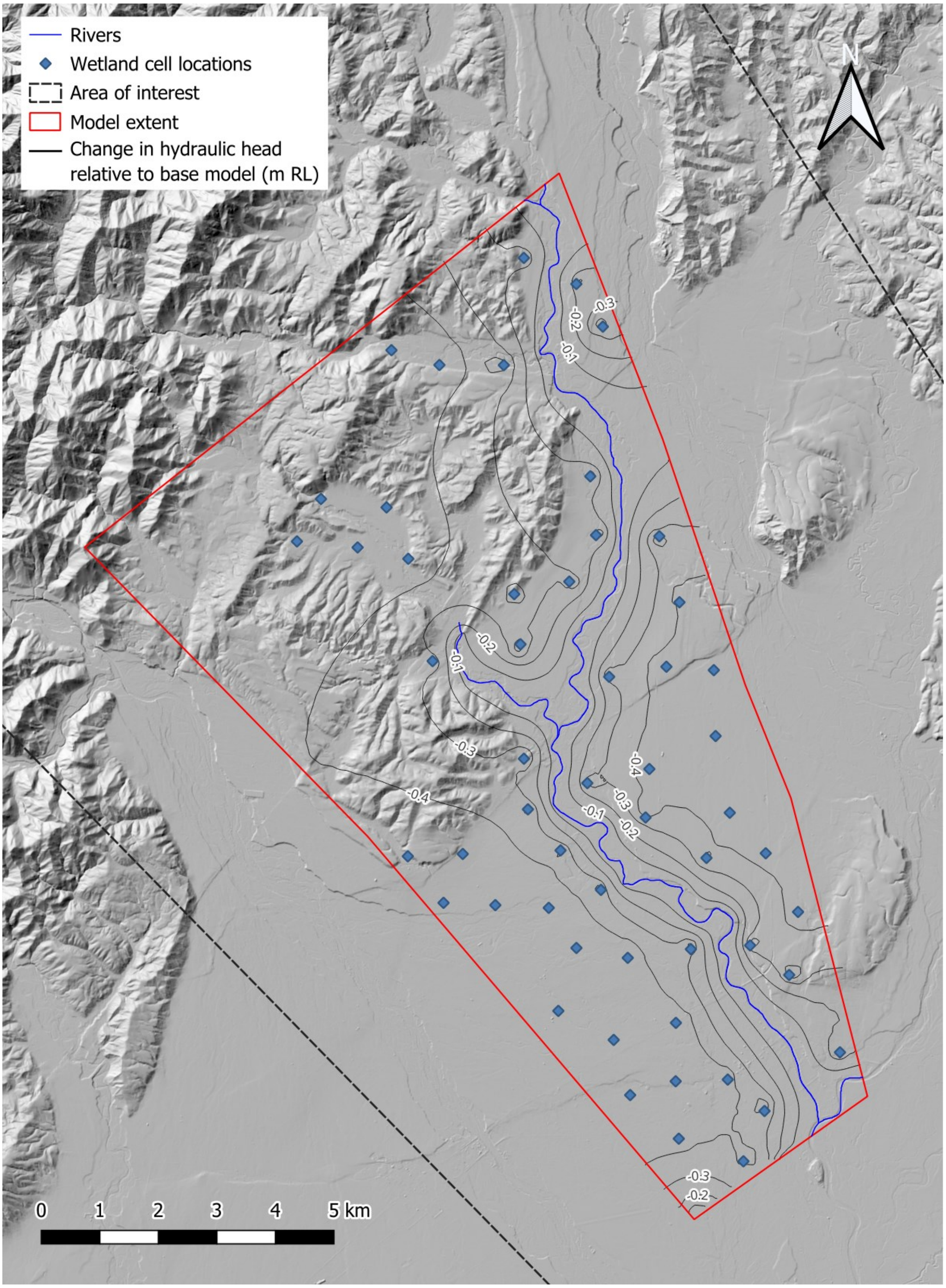


Figure Appendix A.11: : NbS2 v2 - change in hydraulic head.

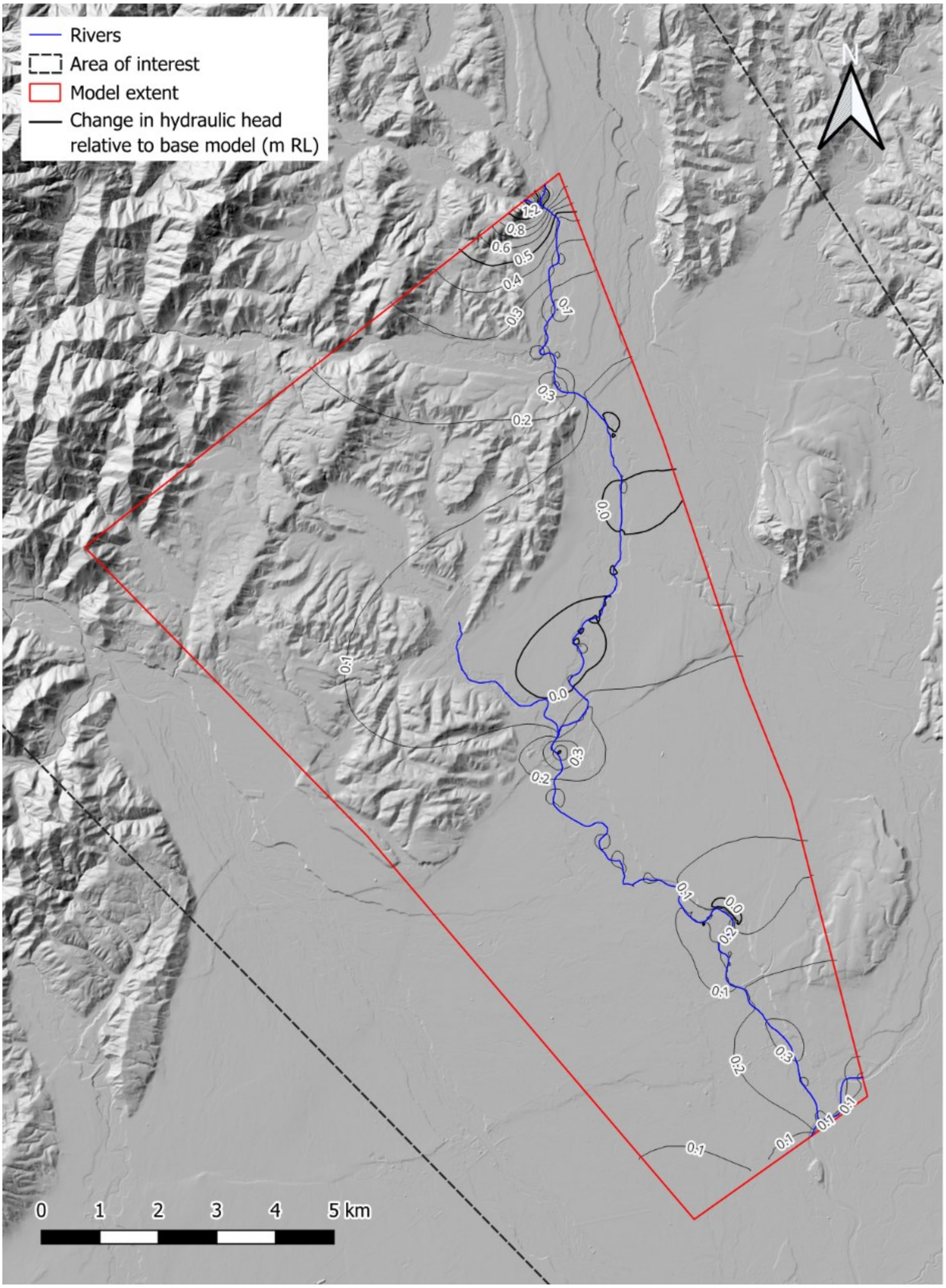


Figure Appendix A.12: NbS3 v1 - change in hydraulic head.

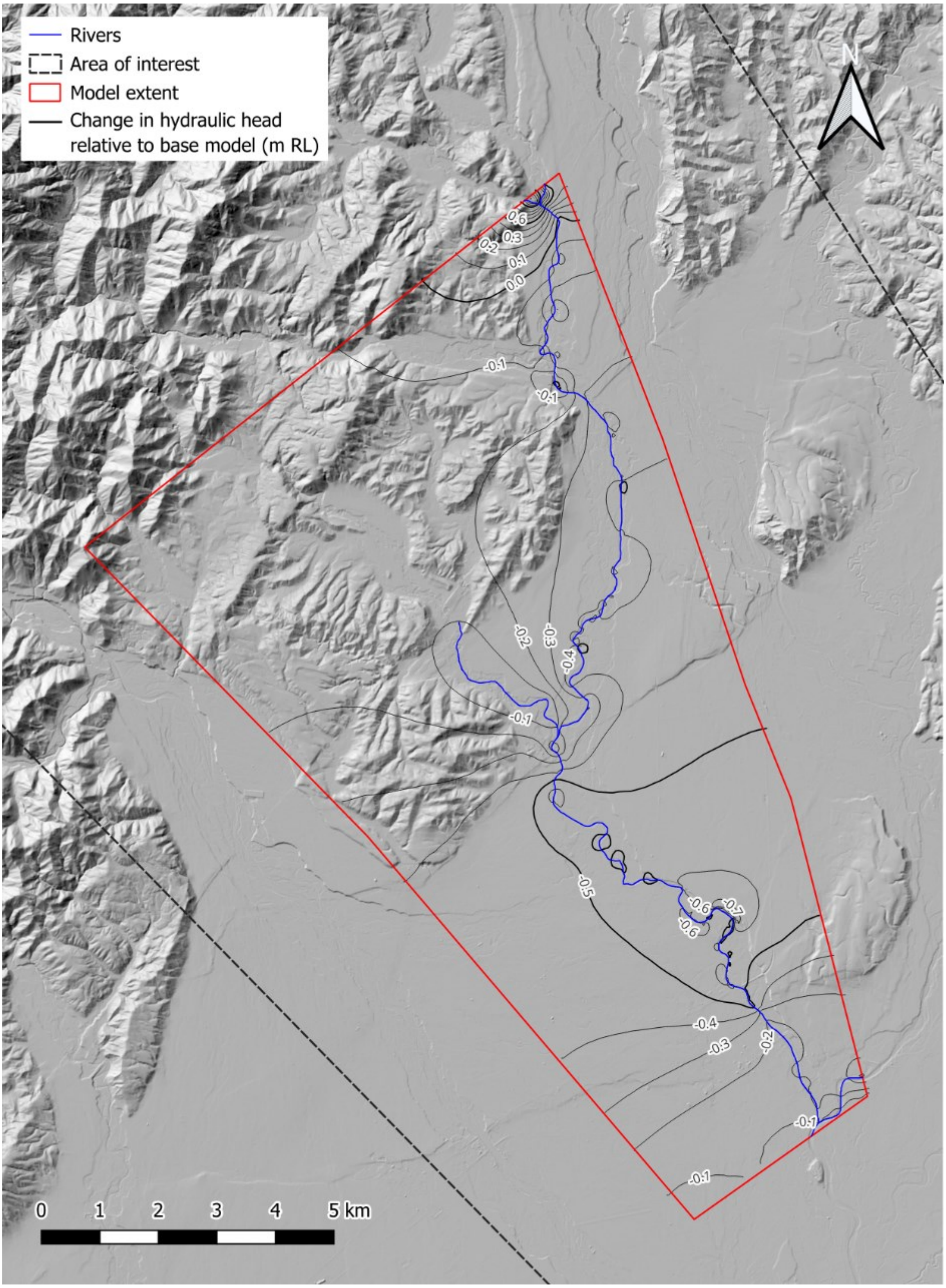


Figure Appendix A.13: NbS3 v2 - change in hydraulic head.

Appendix G. Indigenous vegetation report

Waipoua Indigenous Vegetation for Flood Risk Management

MIHI WHAKATAU

Ki ngā atua tēnā koutou. Ki ā Ranginui rāua ko Papatūānuku tēnā kōrua. Ki a Tangaroa rātou ko Hinemoana, ko Waitī, ko Waipoua tēnā koutou. He mihi nui ki te mana tiaki ō te whenua ki a Rangitāne ō Wairarapa me Ngāti Kahungunu hoki.

He mihi nui ki ngā tumuaki me ngā kaimahi o Te Pane Matua Taiao mō tēnei kōwhiringa.

We thank Greater Wellington Regional Council for the opportunity to present the findings of this important mahi and for the recognition you give to the whakapapa of Waipoua Awa and the significance of this place for Mana Whenua and the wider community. We recognise Rangitāne ō Wairarapa and Ngāti Kahungunu ki Wairarapa as mana tiaki ō te whenua me wai hoki ki konei, here in this landscape.

KAUPAPA CONTEXT

The scope of this mahi is to investigate wetland types and other natural ecosystems (plantings of all types) found in the Waipoua catchment and recommend a list of appropriate indigenous plants to restore the whenua, flora, and fauna and to help mitigate the effects of flooding using an Indigenous approach.

Greater Wellington Regional Council have engaged our team to support a feasibility study for nature-based solutions to address the flood risk for the Waipoua awa catchment. Nature-based solutions are defined as 'actions to protect, conserve, restore, sustainable use and manage natural or modified terrestrial, freshwater, coastal and marine ecosystems, which address social, economic and environmental challenges effectively and adaptively, while simultaneously providing human well-being, ecosystem services and resilience and biodiversity benefits'. (United Nations Environment Assembly 2022).

Our scope is to recommend an appropriate selection of indigenous plant species and locations to help mitigate the effects of flooding within the Waipoua catchment. We will do this holistically, through a kaupapa founded on a Te Ao Māori approach, we will look at the catchment as a whole. Our approach will be to look and understand the connections within the taiao, of whenua and wai, of ngākau and wai and between people and place. We will look at the influences of past, present and future. We will look at balance in all aspects.

Nature based solutions are being adopted at a local, national and global scale. Te Mana o Te Taiao, Aotearoa New Zealand Biodiversity Strategy (2020) sets out a clear understanding of what nature-based solutions are and how they contribute to the connection between people and place. Mātauranga is a common term used to describe Māori knowledge systems and ways of being. Indigenous peoples have been practicing nature based solutions as a way of life. Indigenous practice in caring for the taiao is similar to the practice of nature-based solutions. Therefore it will be most common for Māori, for Indigenous peoples to advise on holistic best practice solutions that put the taiao, the environment at the forefront.

EXISTING & CURRENT CONTEXT

The Waipoua Awa is one of many significant awa within the Wairarapa takiwā. The Ruamahanga awa is the largest and most prominent, flowing through the length of Wairarapa, before reaching Lake Ōnoke. The Waipoua Awa originating from the Tararua Ranges is a tributary of the Ruamahanga awa.

The Wairarapa takiwā is located in the south eastern part of Te Ika a Māui, North Island in Aotearoa (Figure 1). Wairarapa is known for its beautiful landscapes and unique townships. The urban context is shaped by the main townships of Masterton, Carterton, Greytown, Featherston and Martinborough. Masterton is the largest township and wraps urban context around the lower reaches of the Waipoua awa.

Several active fault lines are also responsible for the shaping of the Wairarapa takiwā with activity and studies of geological features having connections within the Waipoua catchment. These have influence on present day and the future planning of best practice solutions for the whenua and our uri.

Historically, the Wairarapa region was rich with extensive wetlands that played a crucial role in the local ecosystem. These wetlands, including areas around Lake Wairarapa and Lake Ōnoke, located downstream of the Waipoua Awa, were vital for maintaining water quality, providing habitat for diverse species, and supporting cultural practice. Before colonisation and the large-scale settlement of people, wetlands covered significant portions of the landscape, acting as natural water filters and flood mitigators. They were home to a variety of native plants and fauna, including important food sources like tuna and inanga. However, over the past century, more than 90% of wetlands in Aotearoa, have been drained or altered and less than 3% of orginal wetland extents remain in the Wellington region due to agricultural and urban development (Greater Wellington, 2024). This loss has had profound impacts on biodiversity, water quality, and the ability to manage flood risks effectively.

In recent years, there has been a concerted effort to restore and protect the remaining wetlands in the Wairarapa region. Projects like the Wairarapa Moana Wetlands Project aim to rehabilitate these critical ecosystems by reintroducing indigenous vegetation, controlling invasive species, managing livestock access and improving water management practices. The Wairarapa Moana Wetlands, which include Lake Wairarapa and surrounding areas, are now recognised as wetlands of international significance under the Ramsar Convention. These efforts not only help to restore ecological balance but also support cultural heritage by preserving sites of importance to local iwi, such as Ngāti Kahungunu ki Wairarapa. Local practices and projects such as this can have significance, show progress and enable 'how to' for reintroducing indigenous vegetation for flood mitigation to the Waipoua awa catchment.

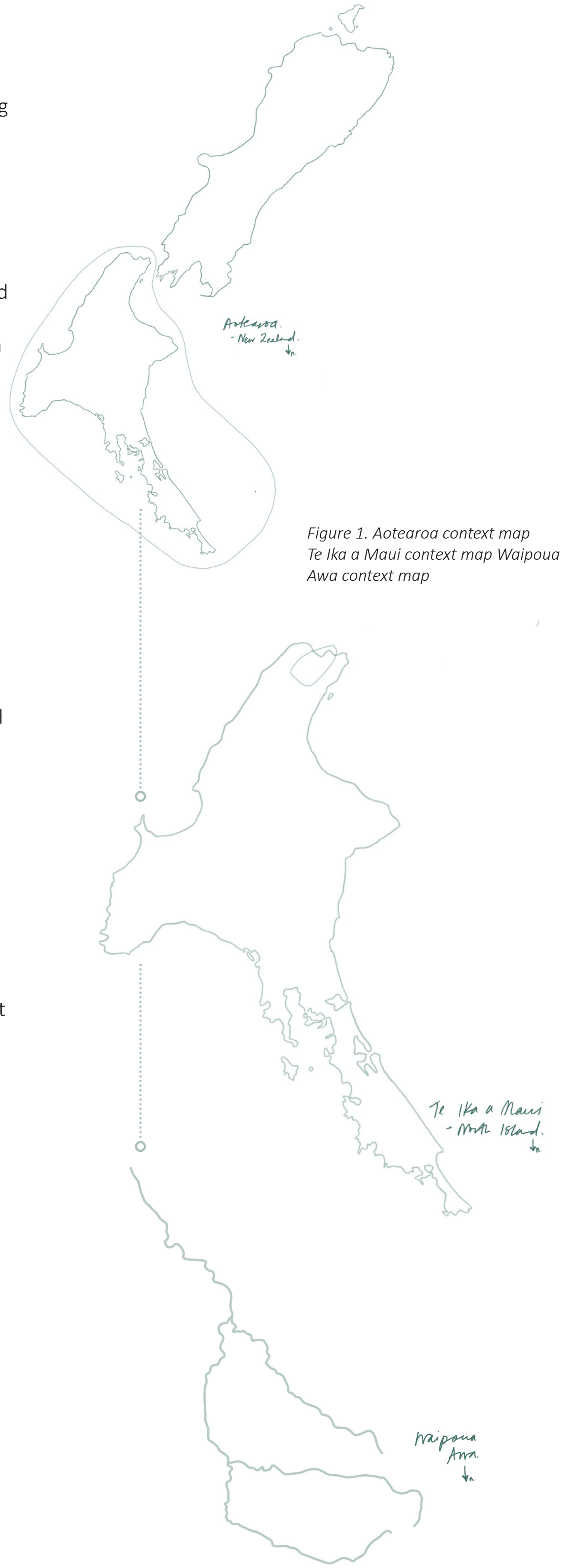


Figure 1. Aotearoa context map Te Ika a Maui context map Waipoua Awa context map

CONNECTION TO TAIAO

Through our connections to the taiao, to the environment, we must set out the importance of the elements that support this mahi. What is the importance of wai, of whenua, of ngākau?

Te Mana o te Wai and Te Mana o te Whenua are fundamental concepts in te ao Māori that emphasize the intrinsic value and interconnectedness of water and land, respectively.

Te Mana o te Wai translates to “the mana of the water” and underscores the importance of protecting the health and well-being of freshwater bodies. This concept is central to the National Policy Statement for Freshwater Management (2020) in Aotearoa, which prioritizes the life-supporting capacity of water. It involves a hierarchy of obligations: first, ensuring the health and well-being of water bodies and freshwater ecosystems; second, meeting the health needs of people (such as drinking water); and third, enabling the social, economic, and cultural well-being of communities. Te Mana o te Wai integrates Māori values such as kaitiakitanga, manaakitanga, and mana whakahaere, ensuring that water management practices respect and uphold the relationship between tangata whenua and their waterways.

As a people we have an inherent connection to water. Our waters visible and invisible in our taiao across the motu are close to each of the wāhi we are connected to. Our waters are tangible and intangible in our atua, in atua wāhine, in atua tāne, expressing themselves and all their attributes, true expression of energy, of wairua, of life and of mauri. In the movement of our atua whether it be still or turbulent, and in all forms we find comfort and emotion, we see transparency yet such depths of knowledge, learnings and layering of whakapapa and of story.

Over 50% of our tinana is water. Our wellbeing sits in the movement, sits in the humbling respect of wai, sits in the life that wai restores and revitalizes all that we are, sits in so many aspects that it becomes hand in hand. Without wai we are ‘wai mate’.

Ko te wai ora ngā mea katoa, water is the life giver of all things.

To understand the shifting patterns of wai, through all aspects, through the processes of rain through to ground water movements we must understand the holistic nature of wai. Look to the emerging patterns within the catchment and ask what stories are the whenua and the awa trying to tell us? Is it that the awa when in flood takes the path of least resistance and we find that path to be places of historic wetland and or water courses? The landscape tells a story and we need to begin to understand the patterns, connections and whakapapa to help, heal, restore and live as one.

When considering mātauranga Māori and restoring indigenous vegetation for the health and well-being of wai, we need to consider all processes including the movement of wai both horizontally and vertically.

The Waipoua Awa as a body of wai, weaves through the landscape, ki uta ki tai, from ngā maunga, the ranges through to connect with the Ruamahanga Awa and out to the moana, through Lake Wairarapa and Lake Ōnoke. The Waipoua awa sustains all forms of life, is a place of home, refugee, habitat, movement, recreation, joy and creation. There are many aspects of the Waipoua that keep the ecosystems of Wairarapa balanced. The movement of the Waipoua both vertically and horizontally in flood are part of that balance. For as long as we have been occupying this space there are evident natural forces that are beyond our control.

Figure 2 depicts the connections between people and place. Taiao sits central to all. Taiao is connected to whenua, to wai and to whakapapa. Without each of these connections we would lose he tangata, the people, mauri, the life, kōrero tuku iho, our taonga, our stories and our culture. We need balance, tuakana/teina relationships and a connection and understanding of ngā atua to support connection to whenua and to wai. Whakapapa is our strength. Our connections to ngākau all sit within each aspect of these connections and are central to supporting taiao.

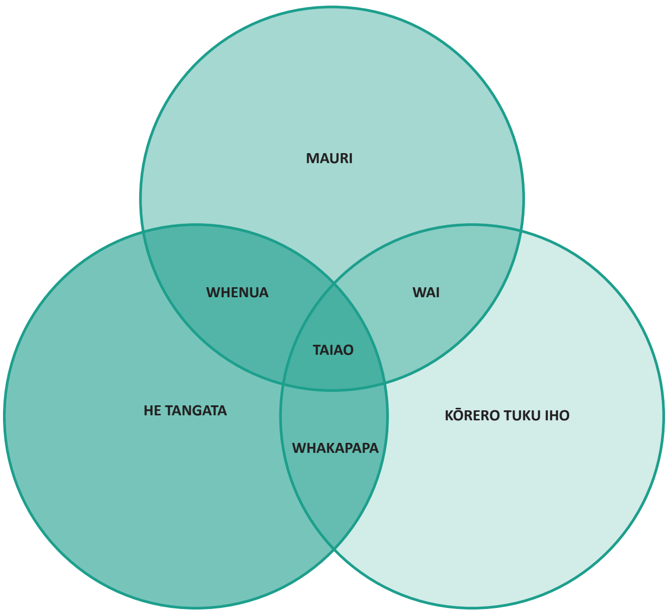
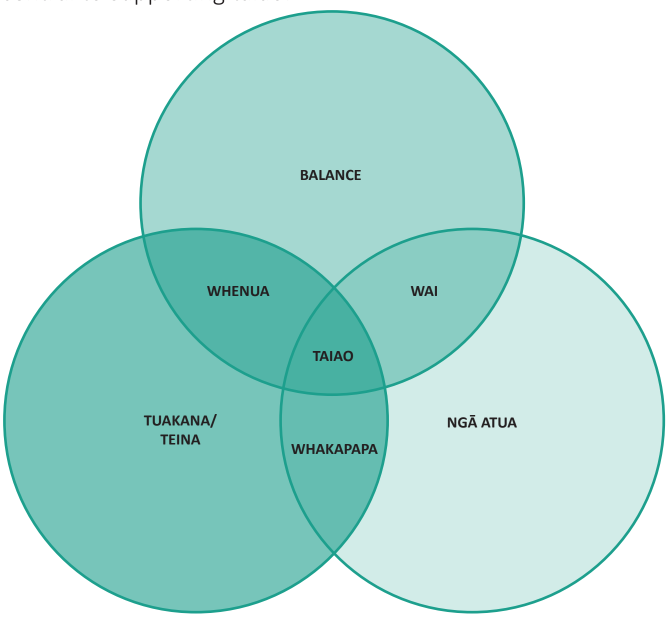


Figure 2: Taiao connections through whakapapa, whenua and wai



Taiao connections through balance, tuakana/teina and ngā atua

CONNECTION TO TAIAO

We create solutions to try to control wai and to control the movements of wai for our own benefits. Waipoua awa will inevitably create and take the path that it wishes to take and we should create solutions to work with the awa and not against. We should, not create boundaries and not control natural flow and course for our benefit but, create solutions that benefit the taiao and the awa. When the awa and the landscapes have room to breathe, we as a people and our urban bounds should also be able to breathe. It is a matter of finding the correct balance.

Te Mana o te Whenua translates to "the mana of the land" and reflects the deep connection and responsibility that Māori have towards the land. This concept emphasizes the need to maintain the health and vitality of the land to support the well-being of all living things. It involves practices that promote sustainable land use, protect natural resources, and restore ecosystems. Te Mana o te Whenua is about recognizing the land's inherent value and ensuring that it is managed in a way that respects mauri and supports the cultural, spiritual, and economic needs of present and future generations. This concept also aligns with principles of kaitiakitanga, where tangata whenua act as kaiawhina or carers of the whenua, ensuring protection and sustainable use is practised.

Te Mana o te Wai and Te Mana o te Whenua provide a holistic framework for environmental awhi that acknowledges and uplifts the interconnectedness of water, land, and people. They guide practices that respect taiao.

The ngāhere, the forests, plants, vegetation all hold an important role in ensuring our waters are healthy, re-charged and sustainable. They play a part in the collective ecosystem, adding to the balance of taiao. Without one you cannot have the other. No part of the taiao stands individually but is part of a collective system. We cannot appreciate one piece without thinking of the whole. This mahi is centered around solutions involving the placement of indigenous vegetation. Like wai, like whenua, our plants all have healing properties and work hard as part of the wider ecosystem. The immence workings of each plant species and each root system gives life to the whenua, gives life to soil and to wai.

In bringing together solutions that connect people to place, to educate and to understand, the use of storytelling through this mahi, through the use of native plants as a mitigation solution to reduce the effects of flooding is a powerful tool to weave cultural heritage and cultural knowledge with people and the natural world. Each plant carries its own unique stories and significance, often passed down through generations. For example, plants like harakeke and kawakawa are not only valued for their practical uses but also for their spiritual and symbolic meanings. Harakeke, used in weaving, symbolizes family and community, with its strong outer leaves protecting the tender inner shoots, much like elders protect the young. This also represents how we can plant in clusters through whānau planting systems within the Waipoua awa catchment. Kawakawa, known for its medicinal properties, is often associated with healing and well-being. By sharing these stories, we can foster a deeper appreciation for native plants and their roles in our ecosystems, the connection our plants have to people and also how they heal and are a support system for the whenua and for wai. This storytelling helps preserve traditional knowledge, promotes environmental stewardship, and strengthens connections between the people of this place and te taiao.

IMPACTS FROM THE REMOVAL OF INDIGENOUS VEGETATION

Across Aotearoa only 35% of original native forests remain with 65% being lost primarily due to the change in land use for forestry, farming and urban development. (Ministry for Environment and Stats NZ, 2024) In the landscape we see the remnants of wetlands, bogs, swamps and marshlands. Around 90% of all native wetlands have been drained due to change in land use for forestry, farming and urban development (Ministry for the Environment and Stats NZ, 2024). This scale of loss has detrimental effects on the wider ecosystem and natures way of being. If we look at the taiao as a living body it makes it easier to understand and acknowledge our responsibilities as a people to care, maintain and uphold best outcomes as uri, as descendants.

An important example of natural systems that are key to a healthy Aotearoa ecosystem, are our wetlands. Wetlands act as natural filtration systems within their catchments, flushing, circulating, filtering and holding wai along river catchments much like the way in which kidneys work. When we drain wetlands and or remove kidneys we are removing a vital part of an interconnected system. This removes the ability to flush, hold, circulate, and filter water and allows more toxins and pollutants to enter the wider system. Wetlands naturally can hold and store wai in small flood events slowly releasing the wai back into the catchment over time. This ability depends on the size of the catchment and wetland systems present in the landscape. It has been proven that wetland drainage leads to significant environmental impacts, including the increase of flood risk, issues with water quality and the loss of habitat for native species.

The removal of native vegetation has significant impacts. One of the most immediate effects is soil erosion. Without the root systems of native plants to hold the soil in place, it becomes more susceptible to being washed or blown away by rain and wind. This erosion can lead to the loss of fertile soil and soil that can hold and absorb water. Additionally, the absence of vegetation may result in increasing sedimentation in waterways, which can degrade water quality, increase water runoff, increases the risk of flooding and drought. Another major impact is the loss of biodiversity. Native vegetation provides habitat and food for a wide range of species, from insects and birds to mammals, fish, amphibians and reptiles. When indigenous plants are removed, the populations of native fauna that depend on them for habitat may de line, be displaced or perish, leading to a decline in local indigenous biodiversity. This loss of vegetation also fragments ecosystems, making it difficult for species to migrate, find mates, and maintain genetic diversity.

Fragmentation of landscapes as a result of de-forestation and manipulated watercourses results in overall loss in biodiversity, mauri, and connection. A whole system and holistic approach is lost due to a narrow mindset focused on changing land use for economic benefit. Unfortunately, this mindset is strong not only locally in the Wairarapa but at a national and global scale. Removing native vegetation to make way for agricultural use is the biggest land use change globally.

Wai will naturally sit in spaces of existing water flow paths. Where historic wetlands once were thriving, where there are historic springs and aquifers, whether it be in an urban or rural settings, wai knows where home is through whakapapa. There are large areas of indigenous vegetation removal within Waipoua awa catchment, where historic wetlands, swamp and marshlands have been drained. These areas also correlate with mapped areas where less than 10% indigenous vegetation cover remains in the catchment (Singers and Rogers, 2014). These spaces we see are the areas that are taken up by flood waters during significant events.

DATA MAPPING

To approach this feasibility study from a Te Ao Māori perspective, we wanted to take a holistic approach which includes comparing and contrasting the data, including historic and current data sets. It was also crucial that these datasets came from reputable sources including; Greater Wellington Regional Council, Ministry for the Environment, Manaaki Whenua Landcare Research and Tonkin and Taylor so that our findings can be as accurate as possible.

We chose to compare data that told a story of the whenua both past and present, including, understanding where our people may have settled, what vegetation existed for them for use for hunting and fishing as well as providing food source and material to gather food; vegetation that existed for traditional healing practices, for traditional cultural practices, ceremony and certain taonga species. Vegetation that existed that may have been used for domestic uses and for all things that allowed our Indigenous peoples to thrive. This data was overlaid with data for soil types, soil drainage, water bodies, aquifers and flood modelling. The combination of the datasets told the story we needed to understand in order to provide a strategy for indigenous vegetation that will support the reduction of flooding impacts as a nature-based solution.

By analyzing the historic vegetation data, we can see the types of ecosystems that may have existed, informing placement for future indigenous vegetation. Specifically, Manaaki Whenua Landcare Research and the Singers and Rogers (2014) layers, both come together, producing a story that gives insight into the pre-human landscape of the Waipoua awa catchment. Similarly by introducing and overlaying numerous data sets, visiting and being present in the whenua, talking with people who reside and are of uri, we were able to see a 'big picture' view of the current state of the environment and make recommendations based on what the data, whenua and people relaid.

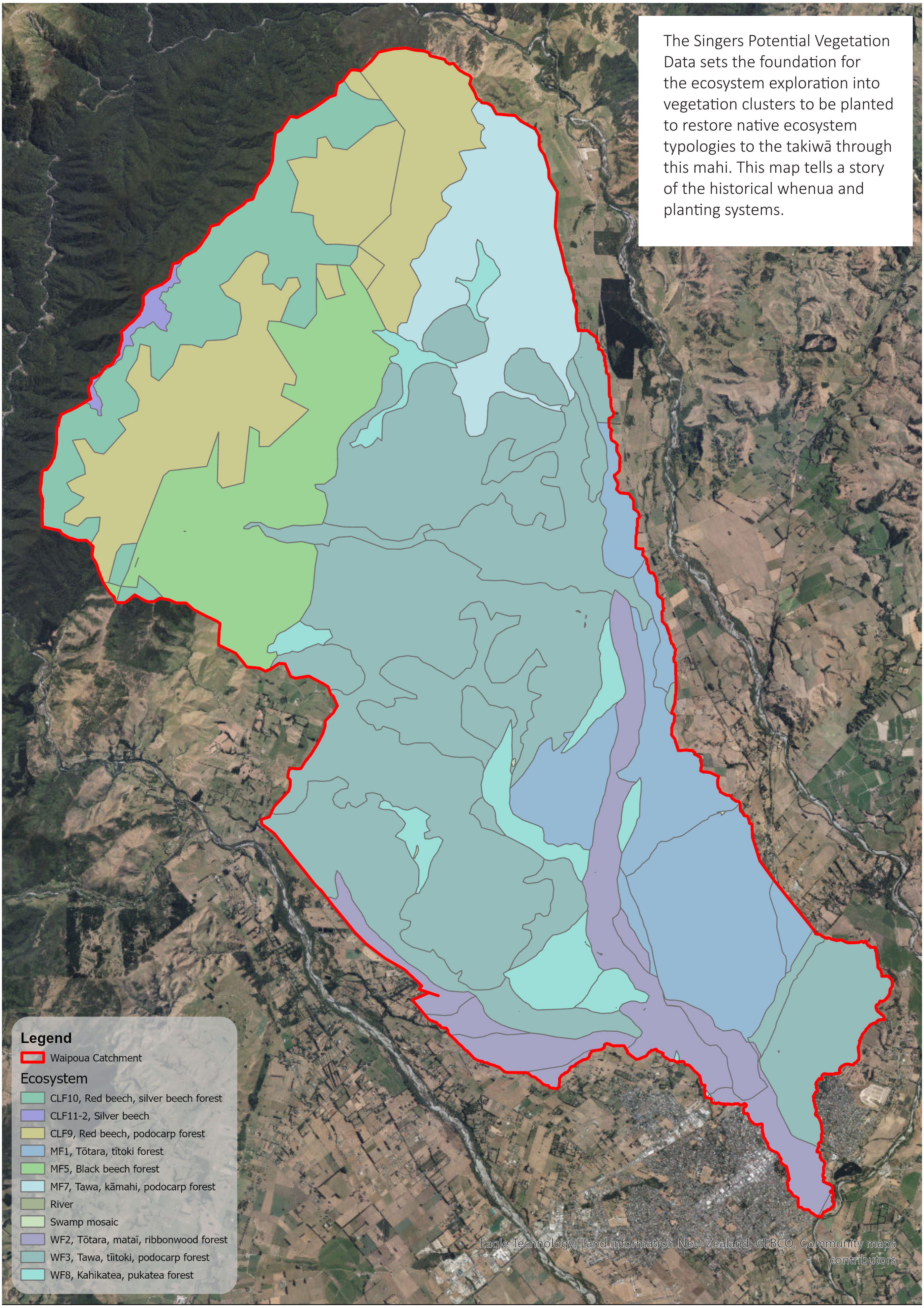
The ecosystems within the Wellington Region and their 'Natural Extent' are mapped and explained in the 2018 report 'Forest Ecosystems of the Wellington Region' (Singers et al., 2018). The maps in this report also detail some of the data and findings from the 'Forest Ecosystems of the Wellington Region' through Singers and Rogers (2014). We will build on these ecosystem types in our recommendations.

There are several ecosystem types within the Waipoua awa catchment. These are; CLF10- Red beech/silver beech forest, CLF11-2- Silver beech, CLF9 - Red beech, podocarp forest, MF1- Tōtara, Tītoki forest, MF5- Black beech forest, MF7- Tawa, Kāmahi, Podocarp forest, WF2- Tōtara, Mataī, Ribbonwood forest, WF3- Tawa, Tītoki, Podocarp forest and the WF8- Kahikatea, Pukatea forest.

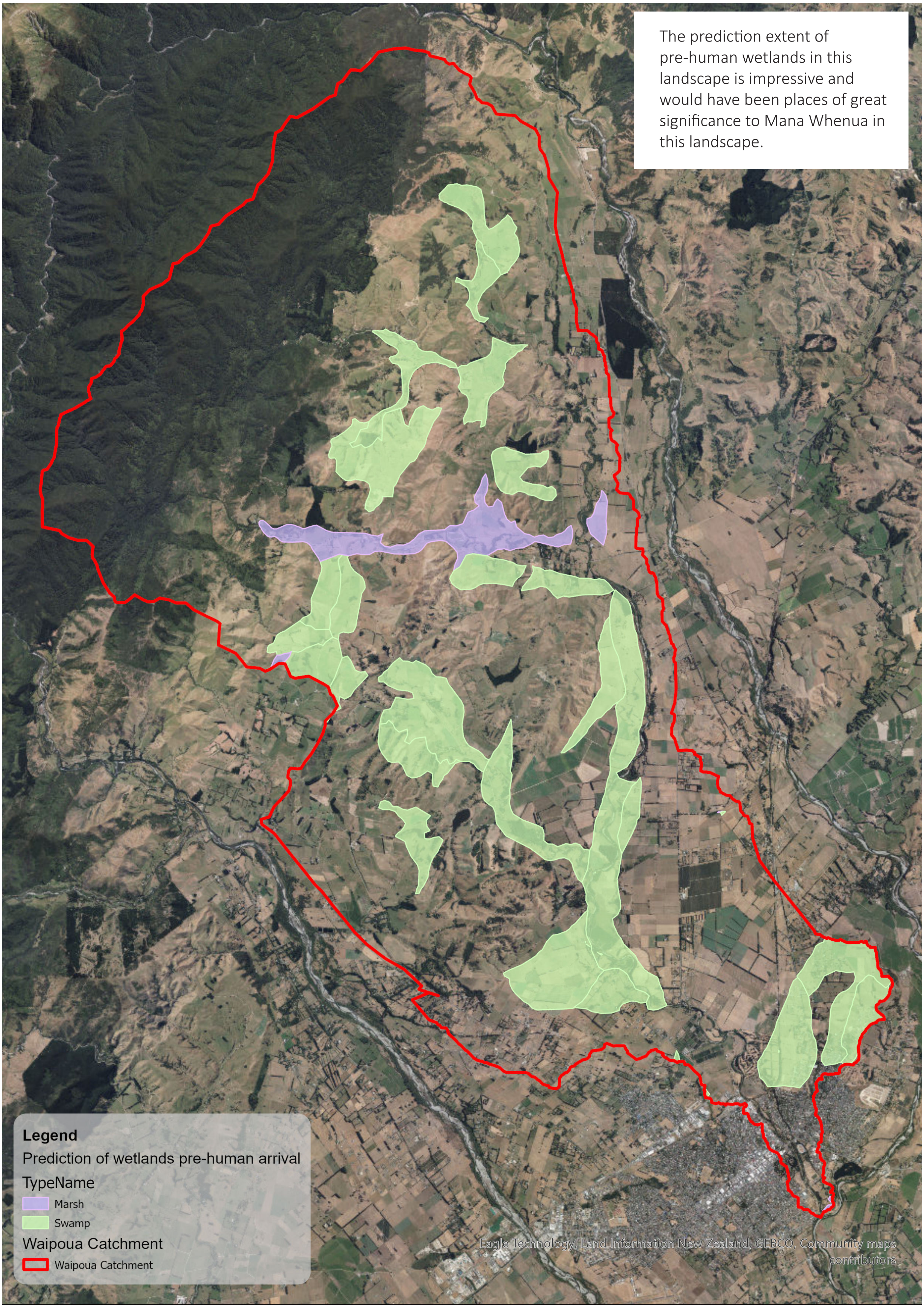
We put focus on MF1, WF2,3 and 8 all being listed by Singers et al (2018) as regionally Critically Endangered ecosystems with less than 10% remaining due to fragmentation, grazing, drainage and weeds. Ecosystem MF7 is listed as Endangered, with less than 30% remaining and ecosystem MF5 is listed as Vulnerable with less than 50% remaining, due to pests and animal intervention.

The ngāhere who whakapapa and thrive in these ecosystems are important in the establishment of healthy landscapes, biodiversity and the overall holistic approach to supporting flood mitigation and the breathing of wai.

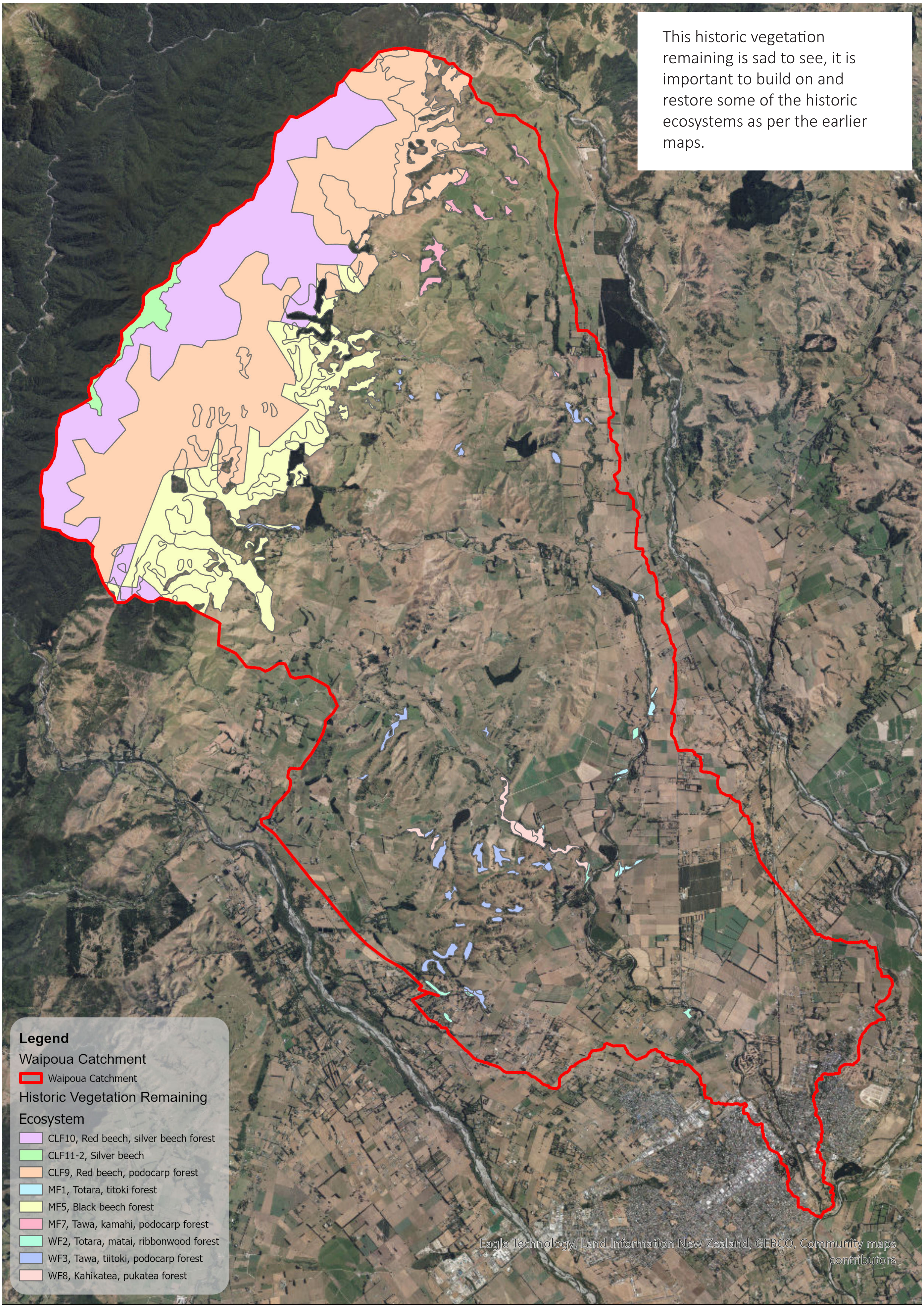
The Singers Potential Vegetation Data sets the foundation for the ecosystem exploration into vegetation clusters to be planted to restore native ecosystem typologies to the takiwā through this mahi. This map tells a story of the historical whenua and planting systems.



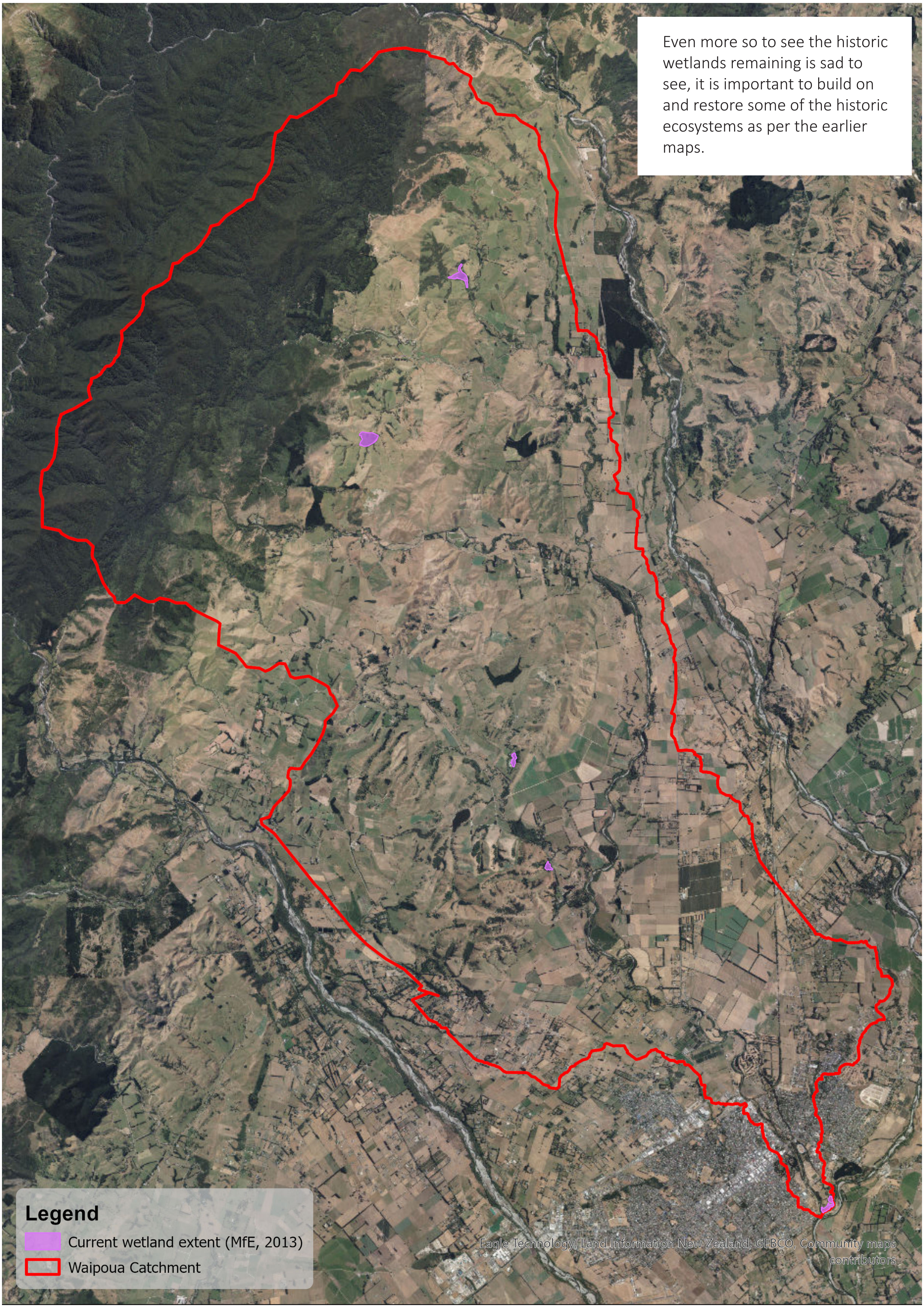
Map 0.1. Singers Potential Vegetation 2014. Greater Wellington Regional Council Waipoua Catchment



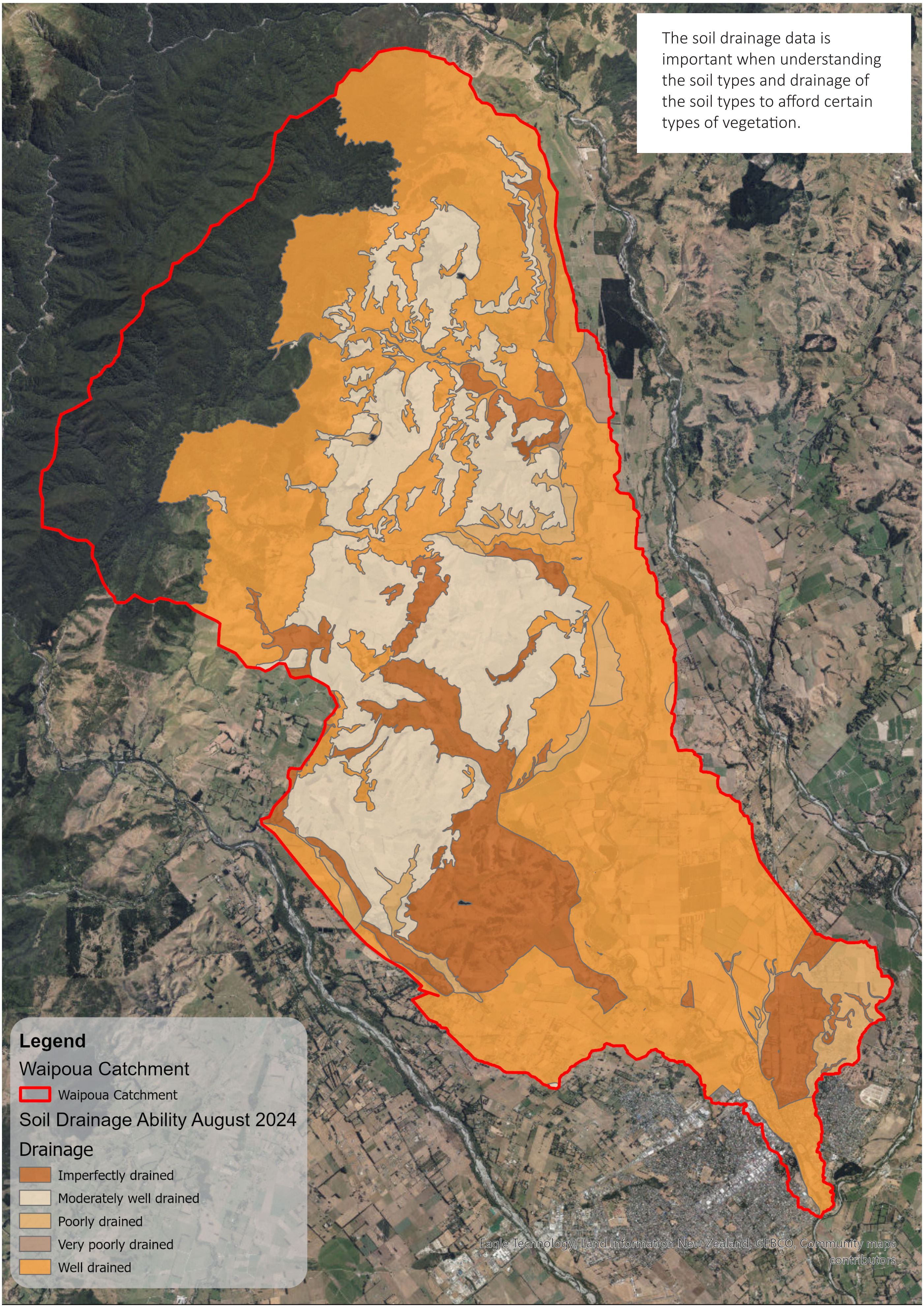
Map 0.2 Prediction of wetlands pre-human arrival. Ministry for the Environment via MfE Data Service Waipoua Catchment



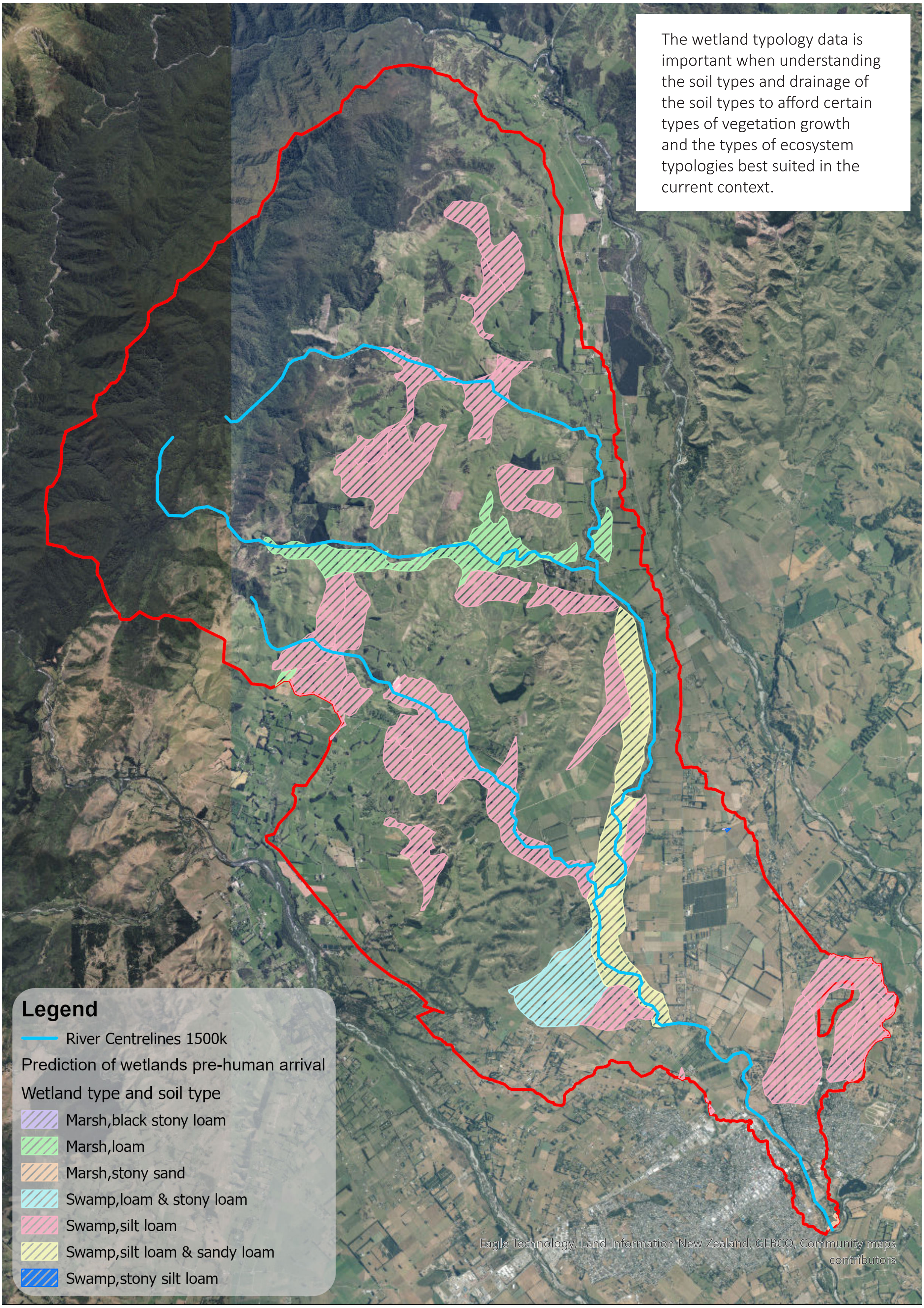
Map 0.3 Historic vegetation remaining. Greater Wellington Regional Council Waipoua Catchment



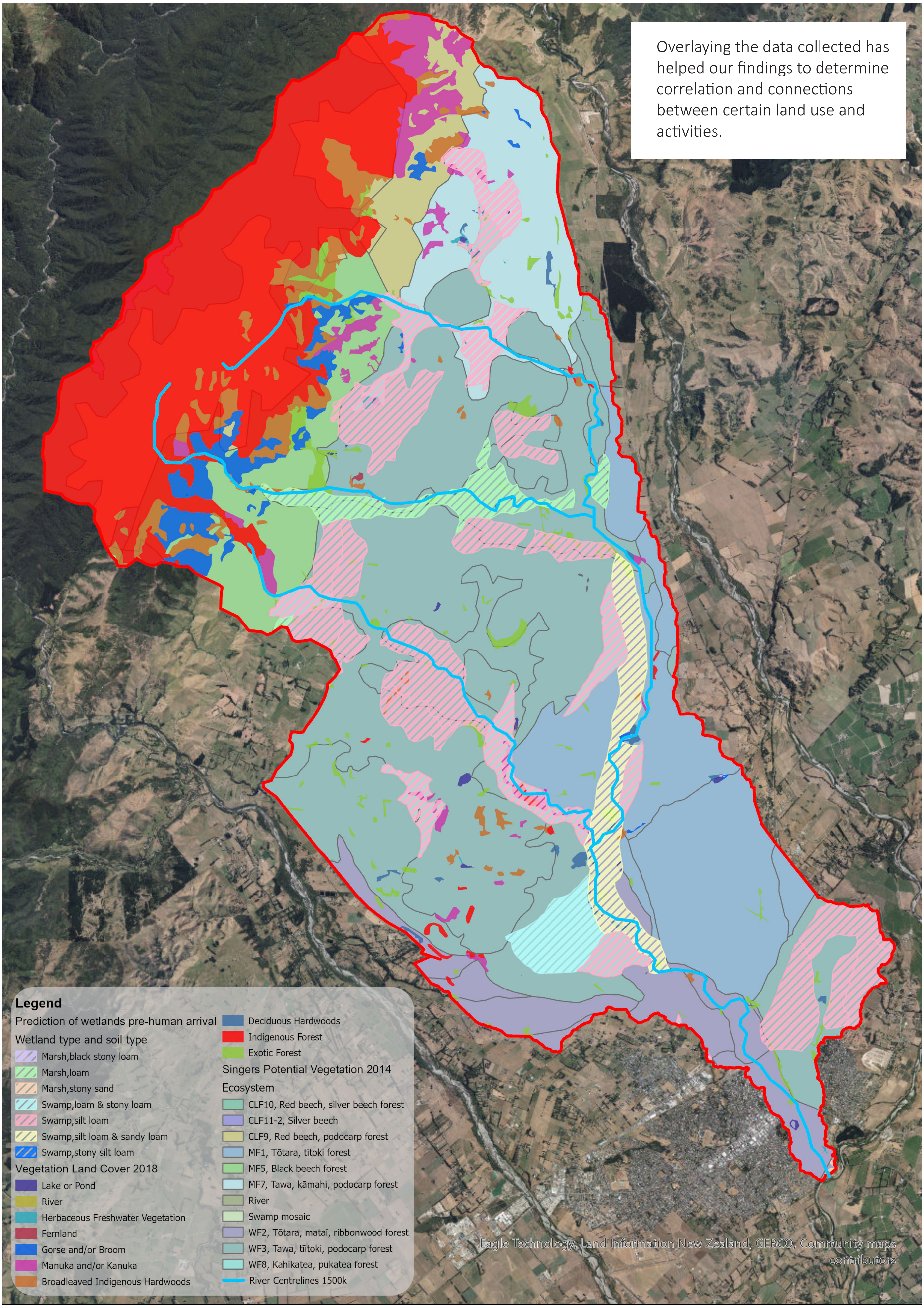
Map 0.4 Current wetland extent. Ministry for the Environment via MfE Data Service Waipoua Catchment



Map 0.5 S-map soil drainage ability 2024. LRIS Portal. Manaaki Whenua Waipoua Catchment

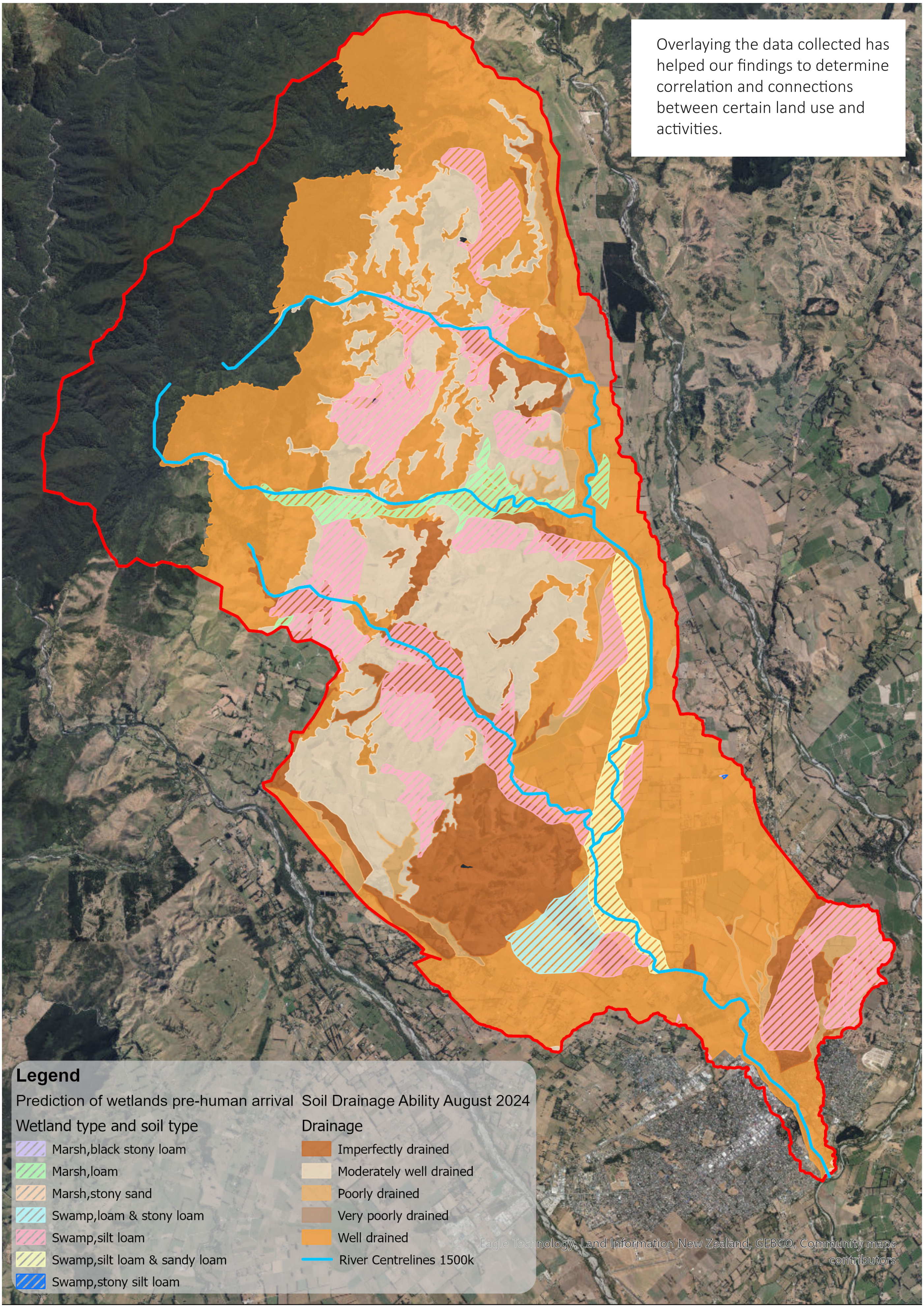


Map 0.6 Prediction of wetlands pre-human arrival by wetland type and soil. Ministry for the Environment via MfE Data Service Waipoua Catchment



Map 0.7 Maps 0.1, 0.2 and 0.7 overlaid

Overlaying the data collected has helped our findings to determine correlation and connections between certain land use and activities.



Map 0.8 Maps 0.6 and 0.7 overlaid

FINDINGS

Each map tells a story with the connection we have to the whenua, to wai, to taiao and to the ngākau. For example the maps on potential vegetation cover prior to human intervention (Maps 0.1) shows how as a peoples we may have settled and or moved through the landscape based on the types of vegetation. The maps also highlight the pre-human and present forms of wetlands (Maps 0.2, 0.4). Wetlands were spaces of refuge, were spiritual spaces that provided inspiration and a deep connection to whenua, and were spaces for our people that provided resources, kai, mauri and rongoā. They were places of multi-faceted healing. The mapped pre-human wetlands (Map 0.2) indicates where our people would have found refuge, how they understood the landscape where wai fluctuated and where safe whenua was for kāinga. The present existence of wetlands (Map 0.4), soil drainage (Map 0.5) and existing vegetation cover (Map 0.3) tells the story of disconnect from the whenua and the ways in which we have stripped the whenua of such important natural healing, and of mauri.

From the data mapping we have made the connection between past, present and the story the land is telling. The Waipoua awa has moved and shifted over a vast period and has fluctuated in flood and in dry spells (as shown in Maps 0.2 and 0.5). There are engineered solutions that have contained parts of the awa and places of deflection to direct the movement and the course of the awa in a preferred direction. The removal of indigenous vegetation, drained wetlands, lost springs and aquifers, all contribute to the wider context of the Waipoua awa, noted through the data, painting a picture common to the Aotearoa landscape. The data, mapping and stories of this place all have contributed to the solutions we are recommending with regards to introducing indigenous vegetation to the catchment.

Through our findings we are able to identify general locations for indigenous plantings. The most important and influential sites have been documented as feasible and priority and will be planted first. The flood and erosion risk to the rural and urban footprint within the Waipoua catchment holds the immediate priority. Restoration and intervention to the upper and middle reaches of the catchment will have positive impact on the lower urban context.

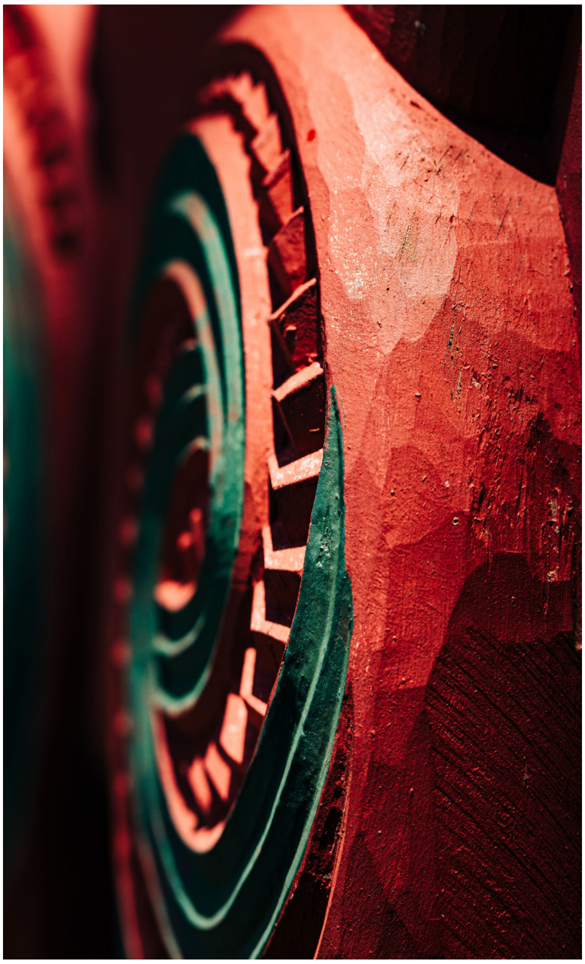
The removal of indigenous vegetation and the removal of critical wetland and natural infrastructure has had effects on the whole of the catchment. Planting indigenous species that aren't viable and feasible in the current context will not result in successful restoration. We advise to introduce indigenous vegetation through planting immediate priority areas first followed by lower priority areas, through whānau planting and planting in context to support current and future systems.

Aspirations to restore and protect indigenous vegetation within the wider catchement will, in future enhance te mauri o te wai me te mauri o te taiao, in turn supporting and mitigating the impact and effects of flooding.

The types of whānau planting will need also support other aspects of nature-based solutions for example, indigenous vegetation can be planted to support re-afforestation, small scale distributed retention storage and in places allow room for the river to breath.

The climate in the region and soil types also means that planting needs to be specific and adaptable to dry and wet spells, and be suitable for dry soils, for wet soils and spaces in between.

Findings show that the immediate priority for indigenous planting should occur on existing and pre-historic patterns close to the river corridor. This will build on and support existing patches of indigenous, exotic, Mānuka, broadleaf, and hardwood forests. These generally sit within swamp, silt, loam, stony and sandy soils. These areas are locally poorly drained sites within a wider context of well drained soils. The plant selections reflect these findings and the mapped locations are high level and provide room for growth and succession.



INDIGENOUS VEGETATION AS A SOLUTION

Specific plants are often used for traditional Māori healing and medicinal practices. Although commonly used to treat and heal personal or human illness, rongoā can be healing for the whenua and the wai due to the profound healing and restorative properties that indigenous plants hold. The use of indigenous plants in healing reinforces the connection between people and whenua. Rongoā, emphasizes the interconnectedness of all living things and the importance of maintaining balance within the taiao. Indigenous plants can enhance the health of whenua and wai through natural processes, stabilising soil and enabling water filtration, helping to maintain the integrity of water bodies, reducing sedimentation and giving back mauri to the whenua. The natural filtration processes carried out by indigenous plants natural to riparian and wetland ecosystems, ensure that all types of water bodies remain clean and healthy, supporting both human and ecological well-being.

Indigenous vegetation plays a crucial role in flood mitigation through the natural properties of native plants and the relationship between native plants and wai. Indigenous plants natural to riparian and wetland ecosystems can often have deep root systems that enhance soil structure, increase the ability of the whenua to absorb and retain water, reducing surface water runoff. Additionally, appropriate indigenous vegetation can filter and trap sediments and pollutants, filtering and preventing them from entering important waterways, preventing poor water quality and exacerbating flood conditions. As water percolates through the whenua, the roots of indigenous plants can act as natural filters, trapping sediments and absorbing pollutants such as heavy metals, pesticides, and excess nutrients. This filtration process helps maintain the quality of groundwater and surface water. In addition to the filtering capabilities of indigenous plants, they contribute to nutrient cycling within the ecosystem. By restoring and preserving indigenous plant communities, we can bring back and live alongside resilient landscapes, that not only mitigate the impacts of flood waters but also support biodiversity and improve overall ecosystem health.

The presence of indigenous plants supports a healthy soil microbiome, which is crucial for nutrient avalibility and soil fertility. When native plants shed their leaves, flowers, and other organic materials, these materials decompose and release essential nutrients back into the soil. This decomposition process is facilitated by soil microorganisms, which break down organic matter into simpler compounds that plants can readily absorb. By promoting the growth of indigenous plants, we acknowledge and restore natural processes that maintain healthy ecosystems, support biodiversity, and enhance the mauri of the taiao.

Indigenous plants can also play a role in recharging aquifers through their natural processes. When it rains, water infiltrates the soil and is absorbed by plant roots. This water then moves downward through the soil layers, a process known as percolation. The roots of native plants, natural to riparian and wetland ecosystems, which often extend deep into the ground, enhance this percolation by creating channels that allow water to penetrate deeper into the soil. Additionally, plants help maintain soil structure and prevent erosion, ensuring that more water can seep into the ground rather than running off the surface. As the water moves through the soil, it eventually reaches the aquifer, replenishing groundwater levels and ensuring a sustainable supply of water. This natural recharge process is crucial for maintaining healthy aquifers and supporting water availability for ecosystems.

Restoring indigenous plants that are native to the Waipoua and Wairarapa context, will provide habitat and food for local flora and fauna, supporting a diverse range of species and promoting ecological balance.

Indigenous plants play a crucial role in restoring biodiversity, ecosystems, and providing habitat for a wide range of species. By reintroducing indigenous vegetation, we can begin to recreate the natural habitats that many local native fauna species depend on for survival. These plants are adapted to the local climate and soil conditions, making them more resilient and better suited to support native wildlife. For example, native trees and shrubs provide food and shelter for birds, insects, reptiles and mammals, creating a balanced and thriving ecosystem. The presence of native plants can attract pollinators like bees and butterflies, which are essential for the reproduction of many plant species and the overall health of the ecosystem.

In addition to supporting wildlife, native plants help restore ecosystem functions that have been disrupted by human activities. They improve soil health by enhancing its structure and fertility through their root systems and the organic matter they contribute. This, in turn, supports a diverse community of soil organisms that play a key role in nutrient cycling and decomposition. Indigenous plants contribute to the resilience of ecosystems by promoting genetic diversity and reducing the spread of invasive species. Invasive plants often out compete native species, leading to a loss of biodiversity and ecosystem degradation. By planting native species, we can create more stable and resilient ecosystems that are better able to withstand environmental stresses such as climate change, pests, and diseases. This not only benefits the plants and animals that rely on these habitats but also enhances the ecosystem services that our peoples depend on.

Additionally, by restoring and reintroducing indigenous vegetation, we can rehabilitate degraded areas, enhance the overall water quality, mitigate future flood risk, while creating sustainable landscapes that benefit both the taiao and our urban and rural landscapes. Preserving and restoring indigenous vegetation, we not only protect the ecological health of the whenua and the wai but also acknowledge and perpetuate taonga species and mātauranga of indigenous communities.

The species selected are suitable for the context of the Waipoua catchment they have been selected based on data provided by Greater Wellington Regional Council. The descriptions and images for each species is referenced to online source; *The New Zealand Plant Conservation Network, Rōpū hononga Koiora Taiao ki Aotearoa* and *Ngā Rauropi Whakaoranga.*

CLF9 - Red Beech, Podocarp Forest

The species have been selected based on ecosystem typology information fit for purpose. Location and whānau cluster planting will be based on ecosystem typologies. Not all species listed in the Plant Lists are easily available for restoration planting, but are listed for completeness.

Fuscospora fusca
Tawhai raunui

- Tall forest tree upto 30m tall
- Common in lowland to montane forest

Pteraphylla racemosa
Kāmahi

- Common dye species, domestic uses and used for rongoā
- Tree to small shrub
- Coastal to sub-alpine
- A widespread and common tree of disturbed habitats in coastal and lowland montane forest

Lophozonia menziesii
Silver beech

- Commonly used for dyes and fishing and hunting
- Common forest canopy tree with silvery bark
- Lowland to montane forest or as shrub in subalpine scrub
- Not threatened

Dacrydium cupressinum
Rimu

- Common rongoā species, used for hunting and fishing, construction of whare, as a dye and for kai
- Dioecious conifer
- 35m tall
- Lowland to montane forest, occasionally ascending to subalpine scrub
- Not threated as a forest type

Prumnopitys taxifolia
Mataī

- Common rongoā species, kai, used for domestic uses, as a material source and as a fragrant source
- Dioecious conifer upto 25m tall
- Lowland forest, often in drier climates where it can dominate alluvial soils which are waterlogged in winter and dry in summer

Podocarpus totara var. totara
Tōtara

- Common rongoā species, used for kai, domestic uses and as a material source
- Robust dioecious conifer up to 30m tall
- Widespread and at times abundant tree of lowland forest

Kunzea ericoides
Kānuka

- Common rongoā species, used for domestic uses, as a material source and as a fragrant source
- Trees upto 18m
- Found in coastal to lowland shrubland, regenerating forest and forest margins

Leptospermum scoparium
Mānuka

- Common rongoā species, used for kai, scent, domestic uses and as a material source
- Common small prickly shrub or small tree with flaky bark and more or less hairy new growth and bearing masses of oval pointed leaves and white or pinkish read-centred flowers

Pectinopitys ferruginea
Miro

- Common rongoā species, used for kai, dyes, scent, domestic uses and as a material source Common canopy tree with a tall dark single trunk
- Stout tree upto 25m tall
- Common tree of lowland to montane forest

Nestegis cunninghamii
Black maire

- Common domestic, material and traditional uses
- Large tree bearing pairs of dark green wavy leaves
- Widespread in coastal to montane forest
- Often prominent in riparian Podocarp forest
- Not threatened

Elaeocarpus dentatus
Hīnau

- Common rongoā species, material uses, as a dye, as a kai source and for domestic practices
- Canopy tree upto 20m tall
- Common tree of mainly coastal and lowland forest though occasionally extending into montane

Dacrycarpus dacrydioides
Kahikatea, white pine

- Common rongoā species, used for kai, dyes, domestic uses and as a material source This conifer is the tallest indigenous plant in Aotearoa growing up to 65m
- Found in lowland forest, on frequently flooded or poorly drained soils

CLF9 - Red Beech, Podocarp Forest

The species have been selected based on ecosystem typology information fit for purpose. Location and whānau cluster planting will be based on ecosystem typologies. Not all species listed in the Plant Lists are easily available for restoration planting, but are listed for completeness.

Blechnum penna-marina
Alpine hard fern

- Rongoā uses
- Creeping rhizome
- Coastal to alpine in open forest, subalpine scrub, grassland, alpine herbfield, turf and in moss field on the shaded sites of rock outcrops
- Not threatened

Lycopodiella fastigiatum
Alpine clubmoss

- Rhizome mostly buried, creeping, bearing scattered, oppressed scale-leave
- Coastal alpine in frost flats, subalpine and geothermal scrub, alpine herbfield, grassland and peat bogs
- Not threatened

Lycopodiella lateralis

- Coastal to montane in peat bogs, gumland and other open, poorly drained shrublands
- Not threatened
- Facultative wetland, usually is a hydrophyte but occasionally found in uplands

Polystichum vestitum
Pūniu

- Rhizome, sometimes forming a trunk up to 0.9m tall
- Coastal to alpine
- Not threatened

Lepidosperma australe
Square sedge

- Stout, rush-like sedge
- Coastal to alpine, usually in open ground, seral vegetation or peat bogs
- Colonising seasonally dry, or well drained substrates as well as permanently wet substrates such as peat
- Not threatened

Adenochilus gracilis

- Gracile, terrestrial, rhizomatous, perennial herb without tubers
- Found in the northern part of its range usually montane otherwise widespread in lowland to alpine habitats
- Not threatened

Ophioglossum coriaceum
Adder's tongue

- Rhizome
- Coastal to alpine
- Throughout in mostly open or sparsely vegetated habitats including sand swales and dune systems
- Not threatened

CLF10 - Red Beech/Silver Beech Forest

The species have been selected based on ecosystem typology information fit for purpose. Location and whānau cluster planting will be based on ecosystem typologies. The Red Beech/Silver Beech Forest ecosystem is found in the upper catchments on typically free-draining soils. Not all species listed in the Plant Lists are easily available for restoration planting, but are listed for completeness.

Pteraphylla racemosa
Kāmahi

- Common dye species, domestic uses and used for rongoā
- Tree to small shrub
- Coastal to sub-alpine
- A widespread and common tree of disturbed habitats in coastal and lowland montane forest

Podocarpus totara var. totara
Tōtara

- Common rongoā species, used for kai, domestic uses and as a material source
- Robust dioecious conifer up to 30m tall
- Widespread and at times abundant tree of lowland forest

Lophozonia menziesii
Silver beech

- Commonly used for dyes and fishing and hunting
- Common forest canopy tree with silvery bark
- Lowland to montane forest or as shrub in subalpine scrub
- Not threatened

Kunzea ericoides
Kānuka

- Common rongoā species, used for domestic uses, as a material source and as a fragrant source
- Trees upto 18m
- Found in coastal to lowland shrubland, regenerating forest and forest margins

Phyllocladus alpinus
Mountain toatoa

- Commonly used for dyes
- Monoecious shrub or tree up to 6m tall
- Mostly sub-alpine to low alpine forests

Leptospermum scoparium
Mānuka

- Common rongoā species, used for kai, scent, domestic uses and as a material source
- Common small prickly shrub or small tree with flaky bark and more or less hairy new growth and bearing masses of oval pointed leaves and white or pinkish read-centered flowers

Pseudopanax colensoi
Mountain five finger

- Small much-branched tree
- Montane to low alpine forest and scrub

Pseudopanax crassifolius
Horoeka

- Small tree with distinctive draped thick long narrow toothed juvenile leaves
- Bushy topped tree to 15m tall
- Lowland to montane forest
- Not threatened

Griselinia littoralis
Kāpuka

- Common rongoā species
- Bushy tree with a rough dark trunk bearing thick glossy green rounded leaves
- Not threatened

Aristotelia serrata
Makomako

- Used for kai, fishing and hunting
- Common rongoā species
- Dioecious tree to 10m tall
- Much branched small tree with thin heart-shaped sharply toothed leaves
- Often forming dense thickets following disturbance

Carpodetus serratus
Putaputawētā

- Small tree up to 10m tall
- Coastal to montane
- Found in moist broadleaf forest, locally common in beech forest
- A frequent component of secondary forest
- Found on streamsides and forest margins

Ixerba brexioides
Tawari

- Used for kai and as a dye
- Bushy tree bearing narrow thick serrated green leaves
- Common in montane forest

CLF10 - Red Beech/Silver Beech Forest

The species have been selected based on ecosystem typology information fit for purpose. Location and whānau cluster planting will be based on ecosystem typologies. The Red Beech/Silver Beech Forest ecosystem is found in the upper catchments on typically free-draining soils. Not all species listed in the Plant Lists are easily available for restoration planting, but are listed for completeness.

Fuscospora fusca
Tawhai raunui

- Tall forest tree upto 30m tall
- Common in lowland to montane forest

Adenochilus gracilis

- Gracile, terrestrial, rhizomatous, perennial herb without tubers
- Found in the northern part of its range usually montane otherwise widespread in lowland to alpine habitats
- Not threatened

Blechnum penna-marina
Alpine hard fern

- Rongoā uses
- Creeping rhizome
- Coastal to alpine in open forest, subalpine scrub, grassland, alpine herbfield, turf and in moss field on the shaded sites of rock outcrops
- Not threatened

Ophioglossum coriaceum
Adder's tongue

- Rhizome
- Coastal to alpine
- Throughout in mostly open or sparsely vegetated habitats including sand swales and dune systems
- Not threatened

Lycopodiella fastigiatum
Alpine clubmoss

- Rhizome mostly buried, creeping, bearing scattered, oppressed scale-leave
- Coastal alpine in frost flats, subalpine and geothermal scrub, alpine herbfield, grassland and peat bogs
- Not threatened

Lycopodiella lateralis

- Coastal to montane in peat bogs, gumland and other open, poorly drained shrublands
- Not threatened
- Facultative wetland, usually is a hydrophyte but occasionally found in uplands

Polystichum vestitum
Pūniu

- Rhizome, sometimes forming a trunk up to 0.9m tall
- Coastal to alpine
- Not threatened

Lepidosperma australe
Square sedge

- Stout, rush-like sedge
- Coastal to alpine, usually in open ground, seral vegetation or peat bogs
- Colonising seasonally dry, or well drained substrates as well as permanently wet substrates such as peat
- Not threatened

CLF11-2 - Silver Beech Forest

The species have been selected based on ecosystem typology information fit for purpose. Location and whānau cluster planting will be based on ecosystem typologies. Not all species listed in the Plant Lists are easily available for restoration planting, but are listed for completeness.

Pteraphylla racemosa
Kāmahi

- Common dye species, domestic uses and used for rongoā
- Tree to small shrub
- Coastal to sub-alpine
- A widespread and common tree of disturbed habitats in coastal and lowland montane forest

Fuchsia excorticata
Kōtukutuku

- Common dye species, domestic uses and used for rongoā and kai source
- Spreading small tree with thin flaky orange bark
- Facultative upland, occasionally is a hydrophyte but usually occurs in uplands

Dacrydium cupressinum
Rimu

- Common rongoā species, used for hunting and fishing, construction of whare, as a dye and for kai
- Dioecious conifer
- 35m tall
- Lowland to montane forest, occasionally ascending to subalpine scrub
- Not threated as a forest type

Olearia virgata

- Small tree with many thin often interlacing square twigs
- North threatened
- Facultative, commonly occurs as either a hydrophyte or non-hydrophyte

Pectinopitys ferruginea
Miro

- Common rongoā species, used for kai, dyes, scent, domestic uses and as a material source Common canopy tree with a tall dark single trunk
- Stout tree upto 25m tall
- Common tree of lowland to montane forest

Asplenium oblongifolium
Huruhuruwhenua

- Used for traditional cultural practices and as a kai source
- Rhizome
- Coastal to montane
- Occupying a diverse range of habitats from coastal cliffs and rock stacks to deep forest where it may be epiphyte or grow on the ground
- Not threatened

Lophozonia menziesii
Silver beech

- Commonly used for dyes and fishing and hunting
- Common forest canopy tree with silvery bark
- Lowland to montane forest or as shrub in subalpine scrub
- Not threatened

Blechnum penna-marina
Alpine hard fern

- Rongoā uses
- Creeping rhizome
- Coastal to alpine in open forest, subalpine scrub, grassland, alpine herbfield, turf and in moss field on the shaded sites of rock outcrops
- Not threatened

Phyllocladus alpinus
Mountain toatoa

- Commonly used for dyes
- Monoecious shrub or tree up to 6m tall
- Mostly sub-alpine to low alpine forests

Huperzia australiana
Fir clubmoss

- Terrestrial tufted plants
- Coastal to alpine, in scrub, herbfield and peat bogs
- Not threatened
- Facultative wetland, usually is a hydrophyte but occasionally found in uplands

Pseudopanax colensoi
Mountain five finger

- Small much-branched tree
- Montane to low alpine forest and scrub

Gleichenia dicarpa
Tangle fern

- Rhizome
- Coastal to subalpine in poorly drained soils, clay pans and pakihi and peat bogs. In lowland peat bogs often forming dense masses
- Not threatened

CLF11-2 - Silver Beech Forest

The species have been selected based on ecosystem typology information fit for purpose. Location and whānau cluster planting will be based on ecosystem typologies. Not all species listed in the Plant Lists are easily available for restoration planting, but are listed for completeness.

Histiopteris incisa
Water fern

- Rongoā uses
- Terrestrial often summer green fern
- Coastal to subalpine. Usually in open sites. Histiopteris is typically a primary coloniser of disturbed ground such as in clearings caused by tree falls or in forest that has been seriously damaged by

Adenochilus gracilis

- Gracile, terrestrial, rhizomatous, perennial herb without tubers
- Found in the northern part of its range usually montane otherwise widespread in lowland to alpine habitats
- Not threatened

Lycopodiella fastigiatum
Alpine clubmoss

- Rhizome mostly buried, creeping, bearing scattered, oppressed scale-leave
- Coastal alpine in frost flats, subalpine and geothermal scrub, alpine herbfield, grassland and peat bogs
- Not threatened

Polystichum vestitum
Pūniu

- Rhizome, sometimes forming a trunk up to 0.9m tall
- Coastal to alpine
- Not threatened

Lycopodiella lateralis

- Coastal to montane in peat bogs, gumland and other open, poorly drained shrublands
- Not threatened
- Facultative wetland, usually is a hydrophyte but occasionally found in uplands

Ophioglossum coriaceum
Adder's tongue

- Rhizome
- Coastal to alpine
- Throughout in mostly open or sparsely vegetated habitats including sand swales and dune systems
- Not threatened

Lepidosperma australe
Square sedge

- Stout, rush-like sedge
- Coastal to alpine, usually in open ground, seral vegetation or peat bogs
- Colonising seasonally dry, or well drained substrates as well as permanently wet substrates such as peat
- Not threatened

MF1 - Tōtara, Tītoki Forest

The species have been selected based on ecosystem typology information fit for purpose. Location and whānau cluster planting will be based on ecosystem typologies. The Tōtara, Tītoki Forest ecosystem primarily occurs in hill slopes and older alluvial terraces. Not all species listed in the Plant Lists are easily available for restoration planting, but are listed for completeness.

Plagianthus regius
Mānatu

- Tall tree with soft jagged pointed leaves
- Coastal to lower montane
- Often prominent tree in lowland alluvial forest
- Not threatened

Hoheria angustifolia
Narrow-leaved houhere

- Tall soft-wooded grey-trunked tree bearing masses of narrow sharply-toothed leaves and small clusters of white flowers
- A common mostly lowland forest species frequenting alluvial forest where it may at times be dominant
- Not threatened

Sophora microphylla
Kōwhai

- Common rongoā species, used for kai, dyes, domestic uses and as a material source
- Tree upto 25m tall, usually a single trunk
- This is a species of mainly riparian forest
- Not threatened

Alectryon excelsus
Tītoki

- Common rongoā species, used for kai, scent, domestic uses and as a material source
- Small tree with spreading branches and a dark fluted trunk
- Often favouring well drained, fertile alluvial soils along river banks and associated terraces

Knightia excelsa
Rewarewa

- Common rongoā species, material uses, traditional ceremonial uses, as a kai source and for domestic practices
- Tall cylindrical tree upto 30m tall
- A common tree of coastal, lowland and lower montane shrubland

Elaeocarpus dentatus
Hīnau

- Common rongoā species, material uses, as a dye, as a kai source and for domestic practices
- Canopy tree upto 20m tall
- Common tree of mainly coastal and lowland forest though occasionally extending into montane

Podocarpus totara var. totara
Tōtara

- Common rongoā species, used for kai, domestic uses and as a material source
- Robust dioecious conifer up to 30m tall
- Widespread and at times abundant tree of lowland forest

Nestegis cunninghamii
Black maire

- Common domestic, material and traditional uses
- Large tree bearing pairs of dark green wavy leaves
- Widespread in coastal to montane forest
- Often prominent in riparian Podocarp forest
- Not threatened

Prumnopitys taxifolia
Mataī

- Common rongoā species, kai, used for domestic uses, as a material source and as a fragrant source
- Dioecious conifer upto 25m tall
- Lowland forest, often in drier climates where it can dominate alluvial soils which are waterlogged in winter and dry in summer

Pittosporum eugenioides
Tarata

- Has domestic, scent and rongoā uses
- Tree bearing light green wavy-edge oval leaves
- Gynodioecious tree up to 12m tall
- Common tree of regeneration and mature forest in coastal to montane situations

Teucrium parvifolium
Teucridium

- Rare shrub to 2m tall with yellowish wide-angled square branches bearing pairs of small rounded soft leaves and small white flowers inhabiting drier areas
- Found along fertile stream sides and river terraces in lowland dry forest and podocarp-hardwood forest

Myoporum laetum
Ngaio

- Common rongoā species and as a kai source
- Spreading tree upto 10m tall
- Decumbent shrub, shrub or small tree
- Coastal to lowland forest, sometimes well inland

MF1 - Tōtara, Tītoki Forest

The species have been selected based on ecosystem typology information fit for purpose. Location and whānau cluster planting will be based on ecosystem typologies. The Tōtara, Tītoki Forest ecosystem primarily occurs in hill slopes and older alluvial terraces. Not all species listed in the Plant Lists are easily available for restoration planting, but are listed for completeness.

Coprosma wallii

- Bushy dark green shrub to small tree.
- Occupies a range of habitats from seasonally flooded alluvial forest prone to cold winter riparian forests

Coprosma rhamnoides

- Common small bushy shrub with very wide-angled branches bearing clusters of small paired leaves
- Not threatened

Carmichaelia australis
Mākaka

- Common small tree with many flattened green twigs clustered at the top of grey-brown branches
- Coastal to montane, on river terraces, stream banks, among tussock grassland, on the edge and margins of dense bush, forest and in swamps

Coprosma rigida

- Bushy large shrub
- Not threatened
- Facultative, commonly occurs as either a hydrophyte or non-hydrophyte

Coprosma crassifolia

- Shrub with wide-angled reddish branches and pairs of small thick round or oval glossy leaves that are white underneath
- Coastal rocky and sandy lowland to montane shrubland and forest up to 600mm
- Not threatened

Melicytus micranthus
Swamp Mahoe

- Common rongoā species, used for scent
- Zig-zagging shrub
- Lowland forest, scrub and forest margins
- Not threatened

Coprosma dumosa

- A bushy, small leaved shrub
- Lowland to montane shrubland, scrub and forest. More likely to descend in altitude towards its southern extent
- Not threatened
- Facultative, commonly occurs as either a hydrophyte or non-hydrophyte

Coprosma propinqua
Mingimingi

- Very common bushy shrub
- Not threatened
- Facultative, commonly occurs as either a hydrophyte or non-hydrophyte

Pittosporum obcordatum
Heart-leaved kohuhu

- Common rongoā species
- Small, usually single-trunked columnar tree 5-8m tall.
- A species of primarily eastern lowland alluvial forest
- Threatened, primarily threatened by loss of habitat

MF5 - Black Beech Forest

The species have been selected based on ecosystem typology information fit for purpose. Location and whānau cluster planting will be based on ecosystem typologies. Not all species listed in the Plant Lists are easily available for restoration planting, but are listed for completeness.

Dacrycarpus dacrydioides
Kahikatea, white pine

- Common rongoā species, used for kai, dyes, domestic uses and as a material source This conifer is the tallest indigenous plant in Aotearoa growing up to 65m
- Found in lowland forest, on frequently flooded or poorly drained soils

Dacrydium cupressinum
Rimu

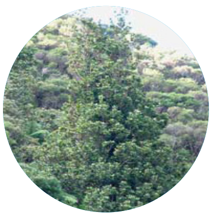
- Common rongoā species, used for hunting and fishing, construction of whare, as a dye and for kai
- Dioecious conifer
- 35m tall
- Lowland to montane forest, occasionally ascending to subalpine scrub
- Not threated as a forest type

Prumnopitys taxifolia
Mataī

- Common rongoā species, kai, used for domestic uses, as a material source and as a fragrant source
- Dioecious conifer upto 25m tall
- Lowland forest, often in drier climates where it can dominate alluvial soils which are waterlogged in winter and dry in summer

Podocarpus totara var. totara
Tōtara

- Common rongoā species, used for kai, domestic uses and as a material source
- Robust dioecious conifer up to 30m tall
- Widespread and at times abundant tree of lowland forest



Knightia excelsa
Rewarewa

- Common rongoā species, material uses, traditional ceremonial uses, as a kai source and for domestic practices
- Tall cylindrical tree upto 30m tall
- A common tree of coastal, lowland and lower montane shrubland

Elaeocarpus dentatus
Hīnau

- Common rongoā species, material uses, as a dye, as a kai source and for domestic practices
- Canopy tree upto 20m tall
- Common tree of mainly coastal and lowland forest though occasionally extending into montane

Elaeocarpus hookerianus
Pōkākā

- Common rongoā species, used for kai, dyes, domestic uses and as a material source Small tree with distinct small narrow glossy olive-green and brown wavy leaves
- Common tree of lowland to montane forests Not threatened

Nestegis cunninghamii
Black maire

- Common domestic, material and traditional uses
- Large tree bearing pairs of dark green wavy leaves
- Widespread in coastal to montane forest
- Often prominent in riparian Podocarp forest
- Not threatened

Carpodetus serratus
Putaputawētā

- Small tree up to 10m tall
- Coastal to montane
- Found in moist broadleaf forest, locally common in beech forest
- A frequent component of secondary forest
- Found on streamsides and forest margins

Lycopodiella fastigiatum
Alpine clubmoss

- Rhizome mostly buried, creeping, bearing scattered, oppressed scale-leave
- Coastal alpine in frost flats, subalpine and geothermal scrub, alpine herbfield, grassland and peat bogs
- Not threatened

Poa cita
Silver tussock

- Used as a fibre source, for rongoā and has domestic uses
- Dense light green-yellow, shiny tussock
- Lowland to subalpine
- Grassland, grazed open pasture, open scrub and forest, coastal cliffs, on relatively fertile soil

Carex edura
Hooksedge

- Montane to alpine. A species of open forest, scrub, tussock grassland, herbfield, mires, bogs and river beds
- Not threatened
- Facultative, commonly occurs as either a hydrophyte or non-hydrophyte

MF5 - Black Beech Forest

The species have been selected based on ecosystem typology information fit for purpose. Location and whānau cluster planting will be based on ecosystem typologies. Not all species listed in the Plant Lists are easily available for restoration planting, but are listed for completeness.

Carex comans
Sedge

- Used for fibre and traditional cultural practice
- Tufts very dense
- Coastal to subalpine
- Usually in free draining soils either in the open or under scrub or tall forest
- It often naturalises in urban areas
- Not threatened

Adenochilus gracilis

- Gracile, terrestrial, rhizomatous, perennial herb without tubers
- Found in the northern part of its range usually montane otherwise widespread in lowland to alpine habitats
- Not threatened

Prasophyllum colensoi
Leek orchid

- Coastal to alpine in wetlands, gumland and subalpine scrub, successional forest, tussock grassland, herb and fellfield
- Not threatened

Celmisia gracilenta
Pekapeka

- Common mountain daisy
- Herb
- Not threatened

Epilobium nerteroides

- Loosely matted creeping perennial herb
- Coastal to subalpine
- Found in riparian sites within forests and dense scrub growing on moss and liverwort encrusted rocks along watercourses
- Not threatened

Ophioglossum coriaceum
Adder's tongue

- Rhizome
- Coastal to alpine
- Throughout in mostly open or sparsely vegetated habitats including sand swales and dune systems
- Not threatened

Viola lyallii
Haaka

- An abundant species of coastal, lowland and montane to subalpine wetlands, swamps, bogs and mires
- Also found in wet places within riparian forest
- Most common in lowland to montane wetlands
- Not threatened

MF7 - Tawa, Kāmahi, Podocarp Forest

The species have been selected based on ecosystem typology information fit for purpose. Location and whānau cluster planting will be based on ecosystem typologies. The Tawa, Kamahi, Podocarp Forest ecosystem includes species that are generally found in hill country and mountain ranges. Not all species listed in the Plant Lists are easily available for restoration planting, but are listed for completeness.

Dacrycarpus dacrydioides
Kahikatea, white pine

- Common rongoā species, used for kai, dyes, domestic uses and as a material source This conifer is the tallest indigenous plant in Aotearoa growing up to 65m
- Found in lowland forest, on frequently flooded or poorly drained soils

Beilschmiedia tawa
Tawa

- Common rongoā species, used for kai, scent, domestic uses and as a material source Common canopy tree with a tall dark single trunk
- Major canopy dominant in the lowland and lower montane forests of the North Island and northern South Island

Dacrydium cupressinum
Rimu

- Common rongoā species, used for hunting and fishing, construction of whare, as a dye and for kai
- Dioecious conifer
- 35m tall
- Lowland to montane forest, occasionally ascending to subalpine scrub
- Not threated as a forest type

Prumnopitys taxifolia
Mataī

- Common rongoā species, kai, used for domestic uses, as a material source and as a fragrant source
- Dioecious conifer upto 25m tall
- Lowland forest, often in drier climates where it can dominate alluvial soils which are waterlogged in winter and dry in summer

Podocarpus totara var. totara
Tōtara

- Common rongoā species, used for kai, domestic uses and as a material source
- Robust dioecious conifer up to 30m tall
- Widespread and at times abundant tree of lowland forest

Pteraphylla racemosa
Kāmahi

- Common dye species, domestic uses and used for rongoā
- Tree to small shrub
- Coastal to sub-alpine
- A widespread and common tree of disturbed habitats in coastal and lowland montane forest

Pectinopitys ferruginea
Miro

- Common rongoā species, used for kai, dyes, scent, domestic uses and as a material source Common canopy tree with a tall dark single trunk
- Stout tree upto 25m tall
- Common tree of lowland to montane forest

Kunzea ericoides
Kānuka

- Common rongoā species, used for domestic uses, as a material source and as a fragrant source
- Trees upto 18m
- Found in coastal to lowland shrubland, regenerating forest and forest margins

Coprosma wallii

- Bushy dark green shrub to small tree.
- Occupies a range of habitats from seasonally flooded alluvial forest prone to cold winter riparian forests

Carmichaelia australis
Mākaka

- Common small tree with many flattened green twigs clustered at the top of grey-brown branches
- Coastal to montane, on river terraces, stream banks, among tussock grassland, on the edge and margins of dense bush, forest and in swamps

Coprosma crassifolia

- Shrub with wide-angled reddish branches and pairs of small thick round or oval glossy leaves that are white underneath
- Coastal rocky and sandy lowland to montane shrubland and forest up to 600mm
- Not threatened

Coprosma dumosa

- A bushy, small leaved shrub
- Lowland to montane shrubland, scrub and forest. More likely to descend in altitude towards its southern extent
- Not threatened
- Facultative, commonly occurs as either a hydrophyte or non-hydrophyte

MF7 - Tawa, Kāmahi, Podocarp Forest

The species have been selected based on ecosystem typology information fit for purpose. Location and whānau cluster planting will be based on ecosystem typologies. The Tawa, Kamahi, Podocarp Forest ecosystem includes species that are generally found in hill country and mountain ranges. Not all species listed in the Plant Lists are easily available for restoration planting, but are listed for completeness.

Coprosma propinqua
Mingimingi

- Very common bushy shrub
- Not threatened
- Facultative, commonly occurs as either a hydrophyte or non-hydrophyte

Pittosporum obcordatum
Heart-leaved kohuhu

- Common rongoā species
- Small, usually single-trunked columnar tree 5-8m tall.
- A species of primarily eastern lowland alluvial forest
- Threatened, primarily threatened by loss of habitat

Coprosma rhamnoides

- Common small bushy shrub with very wide-angled branches bearing clusters of small paired leaves
- Not threatened

Coprosma rigida

- Bushy large shrub
- Not threatened
- Facultative, commonly occurs as either a hydrophyte or non-hydrophyte

Melicytus micranthus
Swamp Mahoe

- Common rongoā species, used for scent
- Zig-zagging shrub
- Lowland forest, scrub and forest margins
- Not threatened

WF2 - Tōtara, Mataī, Ribbonwood Forest

The species have been selected based on ecosystem typology information fit for purpose. Location and whānau cluster planting will be based on ecosystem typologies. The Tōtara, Mataī, Ribbonwood Forest ecosystem includes species most abundant to the Wairarapa Plains on alluvial terraces with free draining stony soils. Not all species listed in the Plant Lists are easily available for restoration planting, but are listed for completeness.

Dacrycarpus dacrydioides
Kahikatea, white pine

- Common rongoā species, used for kai, dyes, domestic uses and as a material source
  This conifer is the tallest indigenous plant in Aotearoa growing up to 65m
- Found in lowland forest, on frequently flooded or poorly drained soils

Sophora microphylla
Kōwhai

- Common rongoā species, used for kai, dyes, domestic uses and as a material source
- Tree upto 25m tall, usually a single trunk
- This is a species of mainly riparian forest
- Not threatened

Alectryon excelsus
Tītoki

- Common rongoā species, used for kai, scent, domestic uses and as a material source
- Small tree with spreading branches and a dark fluted trunk
- Often favouring well drained, fertile alluvial soils along river banks and associated terraces

Cordyline australis
Ti kōuka, cabbage tree

- Common rongoā species, used for kai, domestic uses and as a material source
  Common palm-like tree
- Widespread and common from coastal to montane forest. Most commonly encountered on alluvial terraces within riparian forest
- Not threatened

Melicytus ramiflorus
Māhoe

- Common rongoā species, used for hunting and fishing, construction of whare, as a dye and for kai
- Common small tree with pale trunk and think light green toothed leaves
- Abundant small tree of coastal, lowland and lower montane forests throughout

Plagianthus regius
Mānatu

- Tall tree with soft jagged pointed leaves
- Coastal to lower montane
- Often prominent tree in lowland alluvial forest
- Not threatened

Lophozonia menziesii
Silver beech

- Commonly used for dyes and fishing and hunting
- Common forest canopy tree with silvery bark
- Lowland to montane forest or as shrub in subalpine scrub
- Not threatened

Podocarpus totara var. totara
Tōtara

- Common rongoā species, used for kai, domestic uses and as a material source
- Robust dioecious conifer up to 30m tall
- Widespread and at times abundant tree of lowland forest

Kunzea ericoides
Kānuka

- Common rongoā species, used for domestic uses, as a material source and as a fragrant source
- Trees upto 18m
- Found in coastal to lowland shrubland, regenerating forest and forest margins

Prumnopitys taxifolia
Mataī

- Common rongoā species, kai, used for domestic uses, as a material source and as a fragrant source
- Dioecious conifer upto 25m tall
- Lowland forest, often in drier climates where it can dominate alluvial soils which are waterlogged in winter and dry in summer

Pennantia corymbosa
Kaikōmako

- Common domestic uses
- Dense tangled shrub
- Not threatened

Notelaea neolanceolata
White maire

- Common domestic uses
- Stout gynodioecious spreading tree upto 20m tall
- Widespread in coastal to montane forest, can be locally common in riparian forest

WF2 - Tōtara, Mataī, Ribbonwood Forest

The species have been selected based on ecosystem typology information fit for purpose. Location and whānau cluster planting will be based on ecosystem typologies. The Tōtara, Mataī, Ribbonwood Forest ecosystem includes species most abundant to the Wairarapa Plains on alluvial terraces with free draining stony soils. Not all species listed in the Plant Lists are easily available for restoration planting, but are listed for completeness.

Coprosma wallii

- Bushy dark green shrub to small tree.
- Occupies a range of habitats from seasonally flooded alluvial forest prone to cold winter riparian forests

Lophomyrtus obcordata
Rōhutu

- Common rongoā species
- Bushy shrub with a corded smooth trunk
- Coastal to montane in forest through mostly found in coastal and lowland forested habitats
- At risk, declining due to myrtle rust

Myrsine australis
Māpou

- Common rongoā species with traditional and material uses
- Common tall bushy shrub with bright red twigs bearing wavy yellow-green leaves
- Common tree of regenerating and mature forest in coastal to montane situations

Myrsine salicina
Toro

- Small upright tree bearing long narrow smooth leaves
- Coastal to montane in forests
- On occasion Toro may form a major part of forest canopy along stream sides
- Not threatened

Carmichaelia australis
Mākaka

- Common small tree with many flattened green twigs clustered at the top of grey-brown branches
- Coastal to montane, on river terraces, stream banks, among tussock grassland, on the edge and margins of dense bush, forest and in swamps

Corokia cotoneaster
Korokia

- Common rongoā species
- Common variable shrub with zig-zag thin grey twigs bearing clusters of small leaves
- Much-branched shrub up to 3m or more tall
- Lowland shrubland, river-flats and rocky places
- Not threatened

Coprosma crassifolia

- Shrub with wide-angled reddish branches and pairs of small thick round or oval glossy leaves that are white underneath
- Coastal rocky and sandy lowland to montane shrubland and forest up to 600mm
- Not threatened

Coprosma perpusilla

- Dwarf low-growing sprawling shrub
- Not threatened
- Facultative, commonly occurs as either a hydrophyte or non-hydrophyte

Coprosma propinqua
Mingimingi

- Very common bushy shrub
- Not threatened
- Facultative, commonly occurs as either a hydrophyte or non-hydrophyte

Coprosma rhamnoides

- Common small bushy shrub with very wide-angled branches bearing clusters of small paired leaves
- Not threatened

Coprosma rigida

- Bushy large shrub
- Not threatened
- Facultative, commonly occurs as either a hydrophyte or non-hydrophyte

Coprosma rotundifolia

- Large bushy shrub
- Lowland to montane. Usually in riparian forest and shrubland, especially on alluvial soils
- Not threatened
- Facultative, commonly occurs as either a hydrophyte or non-hydrophyte

WF2 - Tōtara, Mataī, Ribbonwood Forest

The species have been selected based on ecosystem typology information fit for purpose. Location and whānau cluster planting will be based on ecosystem typologies. The Tōtara, Mataī, Ribbonwood Forest ecosystem includes species most abundant to the Wairarapa Plains on alluvial terraces with free draining stony soils. Not all species listed in the Plant Lists are easily available for restoration planting, but are listed for completeness.

Pentachondra pumila

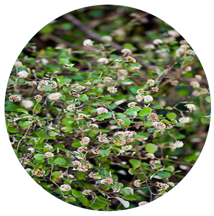
- Very low growing patches to 0.5m wide with many very small hard blue-green leaves.
- Not threatened
- Facultative, commonly occurs as either a hydrophyte or non-hydrophyte

Coprosma virescens

- Rare orangeish or olive green bushy shrub with tangled wide-angled branches bearing pairs of small pointed oval leaves on flattened leaf stalk
- Lowland to lower montane
- On well drained to poorly draining fertile soils
- At risk, declining

Pittosporum obcordatum
Heart-leaved kohuhu

- Common rongoā species
- Small, usually single-trunked columnar tree 5-8m tall.
- A species of primarily eastern lowland alluvial forest
- Threatened, primarily threatened by loss of habitat



Helichrysum lanceolatum
Niniao

- Common untidy much-branched small-leaved shrub
- Not threatened

Teucrium parvifolium
Teucridium

- Rare shrub to 2m tall with yellowish wide-angled square branches bearing pairs of small rounded soft leaves and small white flowers inhabiting drier areas
- Found along fertile stream sides and river terraces in lowland dry forest and podocarp-hardwood forest

Leptospermum scoparium
Mānuka

- Common rongoā species, used for kai, scent, domestic uses and as a material source
- Common small prickly shrub or small tree with flaky bark and more or less hairy new growth and bearing masses of oval pointed leaves and white or pinkish read-centred flowers

Veronica salicifolia
Koromiko

- Common rongoā species. Also traditional used for cultural practice, for kai and domestic use
- Narrow pointed leaves
- Occurs from sea-level to close to the tree line
- Mostly in open sites and in forest

Melicytus micranthus
Swamp Mahoe

- Common rongoā species, used for scent
- Zig-zagging shrub
- Lowland forest, scrub and forest margins
- Not threatened

Neomyrtus pedunculata
Rōhutu

- Common rongoā species, common species for kai
- Wide-angled shrub with long pale twigs that are square in cross-section bearing small pale green oval leaves
- Coastal to montane forest and shrubland
- Not threatened

Corunastylis nuda

- A species of mainly lowland to montane areas, favouring open shrublands including pakihi sites
- Threatened - nationally vulnerable
- Naturally uncommon

Olearia virgata

- Small tree with many thin often interlacing square twigs
- North threatened
- Facultative, commonly occurs as either a hydrophyte or non-hydrophyte

Microtis oligantha
Small onion orchid

- Found in damp places, in tussock grassland, on lake, tarn, river and wetland margins
- Coastal to subalpine
- Not threatened

WF2 - Tōtara, Mataī, Ribbonwood Forest

The species have been selected based on ecosystem typology information fit for purpose. Location and whānau cluster planting will be based on ecosystem typologies. The Tōtara, Mataī, Ribbonwood Forest ecosystem includes species most abundant to the Wairarapa Plains on alluvial terraces with free draining stony soils. Not all species listed in the Plant Lists are easily available for restoration planting, but are listed for completeness.

Pellaea rotundifolia
Button Fern

- Native fern
- Not threatened

Poa cita
Silver tussock

- Used as a fibre source, for rongoā and has domestic uses
- Dense light green-yellow, shiny tussock
- Lowland to subalpine
- Grassland, grazed open pasture, open scrub and forest, coastal cliffs, on relatively fertile soil

Polystichum vestitum
Pūniu

- Rhizome, sometimes forming a trunk up to 0.9m tall
- Coastal to alpine
- Not threatened

Austroderia fulvida
Kakaho

- Used as a food source, for hunting and fishing, domestic uses, scent and as a material source
- Coastal to montane robust tussock
- Common alongside streams, lake margins, in damp spots and within forest clearings

Ophioglossum coriaceum
Adder's Tongue

- Rhizome
- Coastal to alpine. Throughout in mostly open or sparsely vegetated habitats including sand swales and dunes systems, grassland, forest clearings, lake, pond and river margins, peat bogs, fellfield, river flats, tuft associations.

Austroderia toetoe
Toetoe

- Used as a food source, for hunting and fishing, domestic uses, scent and as a material source Stout, tussock-forming grass up to 4m tall when in flower
- Common in freshwater swamps and wet places from sea level to lower montane habitats

Histiopteris incisa
Water fern

- Rongoā uses
- Terrestrial often summer green fern
- Coastal to subalpine. Usually in open sites. Histiopteris is typically a primary coloniser of disturbed ground such as in clearings caused by tree falls or in forest that has been seriously damaged by

Deyeuxia quadriseta

- At risk, declining
- Facultative, commonly occurs as either a hydrophyte or non-hydrophyte

Blechnum novae-zelandiae
Kiokio

- Used as a kai source and for traditional cultural practices
- Short-creeping rhizome
- Coastal to montane. One of the most widespread, abundant and easily recognisable ferns in Aotearoa
Not threatened

Hierochloe redolens
Kāretu

- Common domestic, rongoā and scent uses
- Large scented grass with broad leaves
- In tussock grassland
- Facultative, commonly occurs as either a hydrophyte or non-hydrophyte
- Florets are water and wind dispersed

Lindsaea linearis

- Terrestrial, tufted fern
- Short to long creeping rhizome
- Coastal to lower montane. Usually in open ground, on clay pans, under light scrub and on the margins of bogs and swamps
- Not threatened

Phormium tenax
Harakeke, flax

- Used as a food source, rongoā, fibre, for hunting and fishing, domestic uses, dye, traditional cultural practices, and as a material source
- Common from lowland and coastal areas to montane forest, usually but not exclusively, in wetlands and in open ground along riversides

WF2 - Tōtara, Mataī, Ribbonwood Forest

The species have been selected based on ecosystem typology information fit for purpose. Location and whānau cluster planting will be based on ecosystem typologies. The Tōtara, Mataī, Ribbonwood Forest ecosystem includes species most abundant to the Wairarapa Plains on alluvial terraces with free draining stony soils. Not all species listed in the Plant Lists are easily available for restoration planting, but are listed for completeness.

Carex comans
Sedge

- Used for fibre and traditional cultural practice
- Tufts very dense
- Coastal to subalpine
- Usually in free draining soils either in the open or under scrub or tall forest
- It often naturalises in urban areas
- Not threatened

Carex dipsacea
Teasel sedge

- Coastal to subalpine. Favouring wetlands this species usually grows along rivers, lakes and ponds within sand dunes, tall forest, shrubland and tussock grassland
- Not threatened

Carex dissita
Forest sedge

- Lowland to montane. Usually in riparian forest, where it may be abundant along stream sides
- Not threatened

Carex edura
Hooksedge

- Montane to alpine. A species of open forest, scrub, tussock grassland, herbfield, mires, bogs and river beds
- Not threatened
- Facultative, commonly occurs as either a hydrophyte or non-hydrophyte

Carex lambertiana
Forest sedge

- Coastal to montane
- Usually in relatively open but shaded sites within tall forest or in riparian forest along riversides and on river terraces
- Not threatened

Carex testacea
Speckled sedge

- Densely tufted sedge
- Coastal to montane
- In sand dunes, coastal forest and scrub, dense forest or short tussock grassland
- Not threatened

Calystegia sepium subsp.: Roseata
Pink bindweed

- Summer-green, rhizomatous vine
- A weedy species of coastal and lowland successional habitats, which very rarely extends to montane forest. Often found along the margins of wetlands
Not threatened

Clematis paniculata
Puawananga

- Food, domestic and species used for rongoā
- Robust high-climbing evergreen woody vine
- Coastal to montane in shrubland or tall forest
- Not threatened

Metrosideros albiflora
White rātā

- Common material source and used for rongoā Woody long climbing vine
- Coastal to montane in forest
- Not threatened

Parsonsia heterophylla
New Zealand Jasmine

- Used for hunting and fishing
- Climbing vine
- Not threatened

Rubus australis
Swamp lawyer

- Kai source, used for hunting and fishing, rongoā, material source and traditional cultural practices
- Prickly vine
- Coastal to montane
- Usually in forest but also found in scrub, and often on the margins of, or within wetland

Rubus schmidelioides
Tātarāmoa, bush lawyer, white-leaved lawyer

- Prickly scrambling vine
- Coastal to montane in scrub and forest
- Not threatened

WF2 - Tōtara, Mataī, Ribbonwood Forest

The species have been selected based on ecosystem typology information fit for purpose. Location and whānau cluster planting will be based on ecosystem typologies. The Tōtara, Mataī, Ribbonwood Forest ecosystem includes species most abundant to the Wairarapa Plains on alluvial terraces with free draining stony soils. Not all species listed in the Plant Lists are easily available for restoration planting, but are listed for completeness.

Thelymitra formosa
Sun orchid

- Very stout, robust orchid
- Mainly found in lowland to montane wetlands, scrub and open forest
- At risk
- Naturally uncommon

Thelymitra ixioides
Spotted sun orchid

- Terrestrial, tuberous, glabrous perennial herb
- Coastal to montane
- At risk
- Naturally uncommon

Oxalis magellanica

- Rhizomatous or stoloniferous perennial herb
- Coastal to montane where it is mainly confined to indigenous forested habitats, though sometimes extending into the alpine zone
- Not threatened

Viola lyallii
Haaka

- An abundant species of coastal, lowland and montane to subalpine wetlands, swamps, bogs and mires
- Also found in wet places within riparian forest
- Most common in lowland to montane wetlands
- Not threatened

Epilobium hirtigerum

- Robust perennial
- Coastal, lowland to montane
- A short-lived species of open ground, seepages on cliff faces, sparsely-vegetated wetland margins, braided riverbeds, lake edge and swamps

Epilobium nerteroides

- Loosely matted creeping perennial herb
- Coastal to subalpine
- Found in riparian sites within forests and dense scrub growing on moss and liverwort encrusted rocks along watercourses
- Not threatened

WF3 - Tawa, Tītoki, Podocarp Forest

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Dacrycarpus dacrydioides
Kahikatea, white pine

- Common rongoā species, used for kai, dyes, domestic uses and as a material source This conifer is the tallest indigenous plant in Aotearoa growing up to 65m
- Found in lowland forest, on frequently flooded or poorly drained soils

Laurelia novae-zelandia
Pukatea

- Common rongoā species, used for hunting and fishing and as a material source
- Tall tree with a fluted base bearing pairs of oval glossy dark green toothed leaves inhabiting wetter sites
- Lowland semi-swamp forest and gully forest
- Not threatened

Beilschmiedia tawa
Tawa

- Common rongoā species, used for kai, scent, domestic uses and as a material source Common canopy tree with a tall dark single trunk
- Major canopy dominant in the lowland and lower montane forests of the North Island and northern South Island

Dacrydium cupressinum
Rimu

- Common rongoā species, used for hunting and fishing, construction of whare, as a dye and for kai
- Dioecious conifer
- 35m tall
- Lowland to montane forest, occasionally ascending to subalpine scrub
- Not threated as a forest type

Alectryon excelsus
Tītoki

- Common rongoā species, used for kai, scent, domestic uses and as a material source
- Small tree with spreading branches and a dark fluted trunk
- Often favouring well drained, fertile alluvial soils along river banks and associated terraces

Knightia excelsa
Rewarewa

- Common rongoā species, material uses, traditional ceremonial uses, as a kai source and for domestic practices
- Tall cylindrical tree upto 30m tall
- A common tree of coastal, lowland and lower montane shrubland

Prumnopitys taxifolia
Mataī

- Common rongoā species, kai, used for domestic uses, as a material source and as a fragrant source
- Dioecious conifer upto 25m tall
- Lowland forest, often in drier climates where it can dominate alluvial soils which are waterlogged in winter and dry in summer

Elaeocarpus dentatus
Hīnau

- Common rongoā species, material uses, as a dye, as a kai source and for domestic practices
- Canopy tree upto 20m tall
- Common tree of mainly coastal and lowland forest though occasionally extending into montane

Podocarpus totara var. totara
Tōtara

- Common rongoā species, used for kai, domestic uses and as a material source
- Robust dioecious conifer up to 30m tall
- Widespread and at times abundant tree of lowland forest

Coprosma pedicellata

- Bushy shrub with wide angled branches bearing abundant clusters of pairs of small oval leaves
- Very tolerant of water logging and plants may be found growing within water
- Extremely vulnerable to habitat loss
- Facultative wetland

Lophozonia menziesii
Silver beech

- Commonly used for dyes and fishing and hunting
- Common forest canopy tree with silvery bark
- Lowland to montane forest or as shrub in subalpine scrub
- Not threatened

Huperzia australiana
Fir clubmoss

- Terrestrial tufted plants
- Coastal to alpine, in scrub, herbfield and peat bogs
- Not threatened
- Facultative wetland, usually is a hydrophyte but occasionally found in uplands

WF3 - Tawa, Tītoki, Podocarp Forest

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Amphibromus fluitans
Kakaho

- Weakly tufted, semi aquatic grass
- Coastal to montane in moderately fertile, seasonally dry wetlands or along the edges of shallow lakes and lagoons
- At risk, declining - Habitat loss through wetland drainage, stock grazing and competition from weeds

Austroderia toetoe
Toetoe

- Used as a food source, for hunting and fishing, domestic uses, scent and as a material source Stout, tussock-forming grass up to 4m tall when in flower
- Common in freshwater swamps and wet places from sea level to lower montane habitats

Deschampsia cespitosa
Tufted hair grass

- Yellow-green tussock
- Wetlands and lake margins. Coastal to subalpine damp grass or sedge swards near lakes, rivers and swamps. Also found in estuarine margin communities
- At risk, declining, very palatable to farm and feral stock

Lachnagrostis filiformis
Wind grass

- Grass, usually slender, upright, tufted, glaucous green, light green to yellow green, annual or short-lived perennial grass up to 700mm tall
- Coastal to subalpine. Common around lakes and fringing ponds, streams and on wetland margins

Phormium tenax
Harakeke, flax

- Used as a food source, rongoā, fibre, for hunting and fishing, domestic uses, dye, traditional cultural practices, and as a material source
- Common from lowland and coastal areas to montane forest, usually but not exclusively, in wetlands and in open ground along riversides

Juncus australis
leafless rush, wīwī

- Used for hunting and fishing, material uses and as a source of rongoā
- Coastal to lower montane usually in damp pasture and swampy ground. Rarely within shrubland and open forest. Often on poorly drained clay soils

Juncus planifolius
Grass-leaved rush

- Tufted, grass-like perennial herb of rather variable stature
- Coastal to montane in open, moist ground. Often found on fresh exposed damp clay, or along track sides or on the margins of drains
- Not threatened

Abrotanella caespitosa

- Mat forming herb
- Montane to subalpine
- Often common but inconspicuous in bogs and permanently wet hollows
- Not threatened

Carex cirrhosa
Curly sedge

- Tufted sedge forming dense tussocks
- Lake, pond and tarn margins, preferring low marginal turf in sites subjected to seasonal inundation
- Threatened, nationally endangered

Carex geminata
Cutty grass

- Coastal to lower montane in freshwater wetlands, along river and stream banks, lake margins and in damp seepages, pond margins and clearings within forest
- Not threatened
- Facultative wetland, usually is a hydrophyte but occasionally found in uplands

Carex lessoniana
Cutty grass

- Coastal to lowland. Usually on the margins of peat swamps, or in very wet alluvial forest
- Not threatened
- Facultative wetland, usually is a hydrophyte but occasionally found in uplands

Isolepis reticularis

- Rather delicate, finely tufted, drooping plants
- Coastal to montane
- Favouring riparian habitats in lowland forest
- Not threatened

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Schoenus apogan

- Densely tufted sedge
- Coastal to montane
- Prefers open, seasonally damp or poorly drained ground
- Not threatened

Schoenus maschalinus
Dwarf bog rush

- Small flaccid, tufted or widely spreading sedge
- Coastal to alpine
- In damp poorly drained soils in a wide range of habitats from dense forest to river margins, lake sides to alpine seepages and turfs

Rubus australis
Swamp lawyer

- Kai source, used for hunting and fishing, rongoā, material source and traditional cultural practices
- Prickly vine
- Coastal to montane
- Usually in forest but also found in scrub, and often on the margins of, or within wetland

Calystegia sepium subsp. Roseata
Pink bindweed

- Summer-green, rhizomatous vine
- A weedy species of coastal and lowland successional habitats, which very rarely extends to montane forest. Often found along the margins of wetlands
- Not threatened

Clematis paniculata
Puawananga

- Food, domestic and species used for rongoā
- Robust high-climbing evergreen woody vine
- Coastal to montane in shrubland or tall forest
- Not threatened

Corybas macranthus

- Terrestrial, tuberousm spring to summer green perennial forming dense colonies
- Lowland to subalpine, usually in damp shaded to well-lit seepages, or in shaded sites under tall forest
- Not threatened

Thelymitra pulchella
Striped sun orchid

- Common food source
- Terrestrial, tuberous, glabrous perennial herb
- Widespread from coastal to montane areas
- Not threatened

Callitriche muelleri

- Short-lived perennial to annual herb forming matted patches
- Coastal to montane in damp, muddy ground or in shallow seasonal pools, along lake and stream sides
- Often in dense forest
- Not threatened

Celmisia graminifolia

- Tufted herb with simple or sparingly branched stock
- Found in coastal forest where it mostly grows on steep-sided, shaded or exposed, sparsely vegetated slopes, rock outcrops, cliff faces and rock tors.
- A naturally uncommon, narrow range endemic

Centipeda minima
Sneezeweed

- Rongoā species
- Aromatic, usually prostrate, annual, bright green, spreading herb
- Found in wet or partially dried out lake, pond and stream margins
- At risk
- Naturally uncommon

Centipeda aotearoana
New Zealand Sneezewort

- Annual to short-lived perennial prostrate herb
- Found in open damp ground, lake, tarn and river margins, ephemeral wetlands and drains
- Not threatened

Cotula coronopifolia
Yellow buttons

- Vascular herb
- Not threatened
- Facultative wetland, usually is a hydrophyte but occasionally found in uplands

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Leptinella maniototo

- Perennial or annual herb
- Found in lowland to upper montane
- Growing around lake, slow flowing stream, tarn and kettlehole margins
- At risk, declining

Lobelia anceps

- Native vascular herb
- Not threatened

Euchiton polylepis

- Stoloniferous perennial daisy
- Lowland to subalpine in damp places, especially stream sides and damp hollows in grassland, cliffs and rocky laces
- At risk, declining

Ranunculus membranifolius

- Perennial herb
- Found in damp places in the forest and scrub

Crassula ruamahanga

- Perennial herb
- Found at sea level to lowland
- An opportunistic species which can be expected to occur in any suitably damp, open habitats
- At risk, naturally uncommon

Viola lyallii
Haaka

- An abundant species of coastal, lowland and montane to subalpine wetlands, swamps, bogs and mires
- Also found in wet places within riparian forest
- Most common in lowland to montane wetlands
- Not threatened

Epilobium hirtigerum

- Robust perennial
- Coastal, lowland to montane
- A short-lived species of open ground, seepages on cliff faces, sparsely-vegetated wetland margins, braided riverbeds, lake edge and swamps

Coprosma wallii

- Bushy dark green shrub to small tree.
- Occupies a range of habitats from seasonally flooded alluvial forest prone to cold winter riparian forests

Epilobium komarovianum

- Creeping perennial herb
- A species of open, flushes, seepages, and places where water seasonally ponds
- Not threatened

Euchiton limosus

- Native vascular herb
- Not threatened

WF8 - Kahikatea, Pukatea Forest

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Syzygium maire
Swamp maire

- Common rongoā species, used for kai and dye
- Tree with pale bark
- Mostly found in coastal and lowland riparian forest in water logged ground, on the margins of swamps and streamsides
- At risk, declining, nationally critical

Deschampsia cespitosa
Tufted hair grass

- Yellow-green tussock
- Wetlands and lake margins. Coastal to subalpine damp grass or sedge swards near lakes, rivers and swamps. Also found in estuarine margin communities
- At risk, declining, very palatable to farm and feral stock

Amphibromus fluitans
Kakaho

- Weakly tufted, semi aquatic grass
- Coastal to montane in moderately fertile, seasonally dry wetlands or along the edges of shallow lakes and lagoons
- At risk, declining - Habitat loss through wetland drainage, stock grazing and competition from weeds

Lachnagrostis filiformis
Wind grass

- Grass, usually slender, upright, tufted, glaucous green, light green to yellow green, annual or short-lived perennial grass up to 700mm tall
- Coastal to subalpine. Common around lakes and fringing ponds, streams and on wetland margins

Anemanthele lessoniana
Gossamer grass

- Tufted shortly rhizomatous perennial
- Sea level to montane forest, forest margins, scrub and on cliff faces and associated talus
- At risk, declining

Phormium tenax
Harakeke, flax

- Used as a food source, rongoā, fibre, for hunting and fishing, domestic uses, dye, traditional cultural practices, and as a material source
- Common from lowland and coastal areas to montane forest, usually but not exclusively, in wetlands and in open ground along riversides

Astelia linearis var. Novae zelandiae

- Not threatened
- Obligate wetland, almost always is a hydrophyte, rarely in uplands

Rytidosperma pulchrum

- Vascular grass
- At risk, naturally uncommon
- Obligate wetland, almost always is a hydrophyte, rarely in uplands

Astelia grandis
Swamp astelia

- Not threatened
- Obligate wetland, almost always is a hydrophyte, rarely in uplands

Sparganium subglobosum
Mārū, burr-reed

- Glabrous, summer-green, rhizomatous, perennial herb of aquatic or fertile swamps
- Coastal to lowland
- Usually an emergent in shallow water, often on the margins of ponds, lakes and slow flowing streams. Not threatened
- Obligate wetland

Austroderia toetoe
Toetoe

- Used as a food source, for hunting and fishing, domestic uses, scent and as a material source Stout, tussock-forming grass up to 4m tall when in flower
- Common in freshwater swamps and wet places from sea level to lower montane habitats

Rytidosperma nigiricans

- Grass, endemic to the North Island, Tararua and Rimutaka Ranges.
- Not threatened
- Facultative wetland, usually is a hydrophyte, but occasionally found in uplands

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Juncus distegua

- Small, dark green to re-green, wiry, tightly packed clumps
- Widespread but generally local in its occurrences. Coastal to upper montane. Often fringing swamps
- Not threatened
- Facultative wetland, usually is a hydrophyte but occasionally found in uplands

Huperzia australiana
Fir clubmoss

- Terrestrial tufted plants
- Coastal to alpine, in scrub, herbfield and peat bogs
- Not threatened
- Facultative wetland, usually is a hydrophyte but occasionally found in uplands

Rytidosperma nudum

- Diminutive, diffuse tufted grass
- Subalpine to alpine in flushes and bogs
- At risk, naturally uncommon
- A very local endemic, rarely collected
- Obligate wetland, almost always is a hydrophyte, rarely in uplands

Juncus planifolius
Grass-leaved rush

- Tufted, grass-like perennial herb of rather variable stature
- Coastal to montane in open, moist ground. Often found on fresh exposed damp clay, or along track sides or on the margins of drains
- Not threatened

Azolla rubra
Kārearea

- Rongoā uses
- Aquatic, floating, usually forming ovate to ovoid patches on the surface of water bodies
- Coastal to lower montane. An aquatic plant, frequenting shallow water bodies, shallow eutrophic water bodies but it can also establish in more acidic wetland systems

Juncus pusillus
Dwarf rush

- Perennial forming widely creeping tufted patches arising from an ascending rhizome 0.5mm diameter
- Open, swampy ground, in cushion bogs and alongside tarn, lake and river margins. Coastal to alpine
- At risk, naturally uncommon

Blechnum minus
Swamp kiokio

- Creeping rhizome
- Coastal to lower montane in swampy ground within swamp forest, wetlands and along the margins of freshwater lakes, streams and rivers
- Not threatened

Juncus sarophorus
Broom rush

- Densely tufted, tussock forming, dull blue-green perennial herb
- Coastal to lowland in damp, open ground. Often in pasture or on the margins of coastal wetlands and along river flats
- Not threatened

Gleichenia dicarpa
Tangle fern

- Rhizome
- Coastal to subalpine in poorly drained soils, clay pans and pakihi and peat bogs. In lowland peat bogs often forming dense masses
- Not threatened

Juncus antarcticus

- Bright green tufted perennial
- A local species of wetlands, bogs mires and muddy ground
- Not threatened
- Obligate wetland
- Almost always is a hydrophyte, rarely in uplands

Gleichenia alpina
Alpine tangle fern

- Rhizome
- Lowland to alpine. In peat bogs, on the margins of tarns and in poor drained fellfield
- Not threatened
- Facultative wetland, usually is a hydrophyte but occasionally found in uplands.

Juncus australis
leafless rush, wīwī

- Used for hunting and fishing, material uses and as a source of rongoā
- Coastal to lower montane usually in damp pasture and swampy ground. Rarely within shrubland and open forest. Often on poorly drained clay soils

WF8 - Kahikatea, Pukatea Forest

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Coprosma tenuicaulis
Hukihuki, swamp coprosma

- Erect bushy shrub with long thin twigs bearing pairs of thin rounded leaves on short flattened leaf stalks inhabiting wetland sites.
- Lowland in swamps and boggy ground, poorly drained shrubland and riparian forest
- Not threatened
- Facultative wetland

Abrotanella caespitosa

- Mat forming herb
- Montane to subalpine
- Often common but inconspicuous in bogs and permanently wet hollows
- Not threatened

Carex cirrhosa
Curly sedge

- Tufted sedge forming dense tussocks
- Lake, pond and tarn margins, preferring low marginal turf in sites subjected to seasonal inundation
- Threatened, nationally endangered

Carex diandra
Sedge

- Loosely tufted, non-tussock-forming edge
- Coastal to subalpine in open, moderately fertile to mid oligotrophic wetlands developed on river flats, within forest or in short or tall-tussock grasslands
- Not threatened

Carex echinata
Star sedge

- Sedge
- Coastal to alpine. Common in wetlands such as bogs and mires or on stream banks and around tarn margins
- Not threatened
- Obligate wetland, almost always is a hydrophyte, rarely in uplands

Carex gaudichaudiana
Gaudichaud's sedge

- Sedge
- Lowland to alpine in wetlands, bogs and mires, along river flats, in seepages, around the margins of lakes, ponds and tarns
- Not threatened

Carex geminata
Cutty grass

- Coastal to lower montane in freshwater wetlands, along river and stream banks, lake margins and in damp seepages, pond margins and clearings within forest
- Not threatened
- Facultative wetland, usually is a hydrophyte but occasionally found in uplands

Juncus edgariae
Wīwī

- Used for hunting and fishing, material uses and as a source of rongoā
- Easily the most common indigenous species. Usually in open shrubland, fringing wetlands and in seasonally damp sites
- Not threatened

Juncus pauciflorus

- Used for hunting and fishing, material uses and as a source of rongoā Coastal to lowland in damp ground and hollows under light scrub, in pasture, on swamp margins, in dune swales under scrub or within coastal forest
- Threatened, nationally vulnerable and uncommon

Juncus pallidus
Giant rush, leafless rush

- Very robust, tall perennial forming dense patches up to 2m tall
- Coastal to lowland. Often in pastures where it can be as major weed. Usually in damp swampy hollows, on the margins of wetlands and lakes, in open shrubland on damp ground

Androstoma empetrifolia
Bog mingimingi

- Low growing sprawling reddish shrub
- Coastal to alpine. A species of open shrubland, tussock grassland, peat bogs and other poor drained sites
- Not a threatened species
- Facultative wetland species, usually is hydrophyte but occasionally found in uplands

Coprosma pedicellata

- Bushy shrub with wide angled branches bearing abundant clusters of pairs of small oval leaves
- Very tolerant of water logging and plants may be found growing within water
- Extremely vulnerable to habitat loss
- Facultative wetland

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Isolepis aucklandica

- Widely creeping, bright green, leafy, rhizomatous sedge
- Coastal to alpine
- Mostly montane
- Not threatened
- Obligate wetland, almost always is a hydrophyte, rarely in uplands

Isolepis basilaris
Pygmy clubrush

- Densely tufted plant
- Coastal, lowland to upland habitats
- At risk, naturally uncommon
- Domestic and feral cattle, sheep, horses and pigs are the serious threats through browse, trampling and facilitating the spread of weeds

Isolepis distigmatosa

- Coastal to montane in fresh water wetlands
- Often forming a floating sud around lake, pond and stream margins
- Not threatened

Isolepis inundata

- Coastal to montane in fresh water wetlands
- Often forming a floating sud around lake, pond and stream margins
- Not threatened
- Obligate wetland, almost always is a hydrophyte, rarely in uplands

Isolepis reticularis

- Rather delicate, finely tufted, drooping plants
- Coastal to montane
- Favouring riparian habitats in lowland forest
- Not threatened

Isolepis prolifera

- Coastal to lower montane
- Mostly in open freshwater wetland systems
- Sometimes an aggressive weed in farm dams
- Often invading poorly drained pasture
- Highly palatable to livestock
- Not threatened

Machaerina juncea

- Tufted, rush-like rhizomatous perennial
- Coastal to lower montane. Locally common in damp sites in gum land, swamps, salt marshes and also along margins and river estuaries
- Not threatened

Carex lessoniana
Cutty grass

- Coastal to lowland. Usually on the margins of peat swamps, or in very wet alluvial forest
- Not threatened
- Facultative wetland, usually is a hydrophyte but occasionally found in uplands

Carex maorica
Māori sedge

- Light green to yellow-green tufted sedge
- Coastal to lowland in freshwater wetlands, under willow in gully systems, along river and stream banks, lake margins, and in damp seepages, pond margins and clearings within forest
- Not threatened

Eleocharis acuta
Sharp spike-sedge

- Terrestrial or semi-aquatic sedge
- Coastal to montane. Common in open to partially shaded permanently damp ground. Usually in swamps and on stream, river, pond and lake margins
- Not threatened

Eleocharis gracilis
Slender spike-sedge

- Terrestrial or semi-aquatic sedge
- Coastal to subalpine
- A species of usually open situations on permanently damp ground such as lake, pond, tarn, stream and river sides and wetlands
- Not threatened

Eleocharis pusilla

- Emergent or aquatic diminutive, sedge forming tufts
- Usually found on the margins of and submerged within lakes, tarns and slow flowing rivers and streams
- Not threatened but not very common

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- Coastal to montane
- Mostly in standing water, growing in brackish or freshwater systems such as lakes, ponds, lagoons, river and stream margins
- Not threatened

Schoenoplectus tabernaemontani
Kuta, lake sedge

- Common food source
- Terrestrial, tuberous, glabrous perennial herb
- Widespread from coastal to montane areas
- Not threatened

Thelymitra pulchella
Striped sun orchid

- Densely tufted sedge
- Coastal to montane
- Prefers open, seasonally damp or poorly drained ground
- Not threatened

Schoenus apogan

- Glaucous to bright-green, rhizomatous sedge
- Coastal to montane in most freshwater wetland. More rarely on the margins of lakes, tarns and slow-flowing streams
- Not threatened
- Obligate wetland, almost always a hydrophyte

Machaerina rubiginosa

- Small flaccid, tufted or widely spreading sedge
- Coastal to alpine
- In damp poorly drained soils in a wide range of habitats from dense forest to river margins, lake sides to alpine seepages and turfs

Schoenus maschalinus
Dwarf bog rush

- Stout, leafy sedge
- Coastal to montane
- Not threatened
- Obligate wetland, almost always is a hydrophyte, rarely uplands

Machaerina sinclairii

- Kai source, used for hunting and fishing, rongoā, material source and traditional cultural practices
- Prickly vine
- Coastal to montane
- Usually in forest but also found in scrub, and often on the margins of, or within wetland

Rubus australis
Swamp lawyer

- Grass-green, reed-like tufted sedge
- Coastal to subalpine
- Usually on peat in bogs, around tarns and slow flowing peaty streams
- Not threatened

Machaerina tenax

- Coastal to montane
- Mostly in acidic, often restiad-dominated peat bogs
- Not threatened

Thelymitra cyanea
Swamp/striped sun orchid

- Swarding to densely tufted sedge dark green to yellow green rush-like sedge
- Coastal to montane mostly in moderately acid to extremely acidic peat bogs
- Not threatened

Machaerina teretifolia

- Coastal, lowland to subalpine
- A plant of bogs, fens and swamps, ranging from acidic to eutrophic
- Threatened
- Nationally critical due to drainage of habitat and invasion by weeds

Pterostylis micromega

- Terrestrial, tuberousm spring to summer green perennial forming dense colonies
- Lowland to subalpine, usually in damp shaded to well-lit seepages, or in shaded sites under tall forest
- Not threatened

Corybas macranthus

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Centipeda elatinoides
Sneezeweed

- Rongoā species
- Prostrate annual to perennial herb
- Coastal to lowland
- Usually on recently exposed muddy ground on seasonally inundated sites, shallow lake and lake margins, ephemeral ponds, river and stream banks

Epilobium chionanthum

- Loosely clumped perennial herb
- Found in swamps and wet swards of grasses or sedges
- At risk - due to draining wetlands and the spread of invasive species

Centipeda minima
Sneezeweed

- Rongoā species
- Aromatic, usually prostrate, annual, bright green, spreading herb
- Found in wet or partially dried out lake, pond and stream margins
- At risk
- Naturally uncommon

Callitriche muelleri

- Short-lived perennial to annual herb forming matted patches
- Coastal to montane in damp, muddy ground or in shallow seasonal pools, along lake and stream sides
- Often in dense forest
- Not threatened

Cotula coronopifolia
Yellow buttons

- Vascular herb
- Not threatened
- Facultative wetland, usually is a hydrophyte but occasionally found in uplands

Callitriche petriei

- Widely creeping perennial
- Coastal to alpine in damp muddy ground, lake, pond and tarn turf, in damp temporary pools, puddles and soaks within forest and scrub. Sometimes found permanently submerged
- Not threatened

Crassula ruamahanga

- Perennial herb
- Found at sea level to lowland
- An opportunistic species which can be expected to occur in any suitably damp, open habitats
- At risk, naturally uncommon

Celmisia graminifolia

- Tufted herb with simple or sparingly branched stock
- Found in coastal forest where it mostly grows on steep-sided, shaded or exposed, sparsely vegetated slopes, rock outcrops, cliff faces and rock tors.
- A naturally uncommon, narrow range endemic

Drosera binata
Forked sundew

- Found coastal to subalpine in bogs and poorly drained pasture overlying acid soils
- More common in coastal to lowland situations
- Not threatened

Centella uniflora
Centella

- Rongoā species
- Herb
- Not threatened
- Facultative wetland, usually is a hydrophyte but occasionally found uplands

Drosera spathulata
Sundew

- A species of open, acidic, poorly drained ground
- Not threatened
- Vascular herb

Centipeda aotearoana
New Zealand Sneezewort

- Annual to short-lived perennial prostrate herb
- Found in open damp ground, lake, tarn and river margins, ephemeral wetlands and drains
- Not threatened

WF8 - Kahikatea, Pukatea Forest

The species have been selected based on ecosystem typology information fit for purpose. Location and whānau cluster planting will be based on ecosystem typologies. The Kahikatea, Pukatea Forest ecosystem includes species that are aquatic, swamp, marsh, wetland and suited to water margins. Not all species listed in the Plant Lists are easily available for restoration planting, but are listed for completeness.

Hydrocotyle pterocarpa

- Native vascular herb
- Not threatened

Epilobium komarovianum

- Creeping perennial herb
- A species of open, flushes, seepages, and places where water seasonally ponds
- Not threatened

Hypericum pusillum

- Native vascular herb
- Perennial or annual non-rhizomatous herb
- Coastal to subalpine, on river and stream banks, lake and tarn margins, swamps and bogs, open areas in forest and damp hollows among tussocks
- Not threatened

Euchiton limosus

- Native vascular herb
- Not threatened

Leptinella maniototo

- Perennial or annual herb
- Found in lowland to upper montane
- Growing around lake, slow flowing stream, tarn and kettlehole margins
- At risk, declining

Gratiola sexdentata

- Terrestrial to semi-aquatic glabrous spreading perennial herb
- Found in lake, pond, tarn and on river margins
- Not threatened

Lobelia carens

- Creeping prostrate herb
- Found in lowland to subalpine
- A species of the margins of lakes, tarn and ephemeral wetlands

Hydrocotyle hydrophila

- Native vascular herb
- Not threatened

Montia fontanca subsp. Fontana

- Native vascular herb
- Not threatened

Lobelia anceps

- Native vascular herb
- Not threatened

Potamogeton suboblongus
Rērēwai, mud pondweed

- Food source
- Aquatic, submerged or floating herb
- Coastal to subalpine, being mostly found in upper montane and subalpine areas
- Not threatened

Euchiton polylepis

- Stoloniferous perennial daisy
- Lowland to subalpine in damp places, especially stream sides and damp hollows in grassland, cliffs and rocky laces
- At risk, declining

WF8 - Kahikatea, Pukatea Forest

The species have been selected based on ecosystem typology information fit for purpose. Location and whānau cluster planting will be based on ecosystem typologies. The Kahikatea, Pukatea Forest ecosystem includes species that are aquatic, swamp, marsh, wetland and suited to water margins. Not all species listed in the Plant Lists are easily available for restoration planting, but are listed for completeness.

Ranunculus amphitrichus
Waoriki

- Rongoā species
- Perennial herb
- Coastal to montane
- Often partially submerged in shallow water , wet grassland and lake, pond or tarn marginal turf communities
- Not threatened

Sphagnum falcatulum
Sphagnum

- Rongoā species
- Native non-vascular moss

Ranunculus macropus
Swamp buttercup

- Semi aquatic herb
- Coastal to lowland, usually found in raupō dominated wetlands where it grows in still moderately deep to deep water
- At risk, threatened by wetland drainage, modifications and the spread of weeds

Epilobium insulare

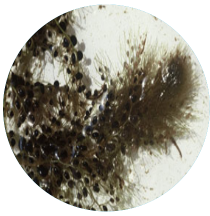
- Loosely matted perennial herb
- Found in open marshy places, bogs, and about lake margins
- At risk, declining

Stylidium subulatum

- Native
- Vascular
- Not threatened

Typha orientalis
Raupō

- Used as a food source, rongoā, for hunting and fishing, domestic uses, and as a material source
- Stout simmer green, rhizomatous, colonial, usually emergent perennial herb up to 3m tall
- Coastal to lowland in fertile wetlands, on the margins of ponds, lakes, slow flowing streams and rivers
- Not threatened, obligate wetland, rarely in uplands



Utricularia australis
Yellow bladderwort

- Wholly submerged, floating carnivorous aquatic plant
- Found coastal to lowland
- Peat lakes, peaty pools and slow-moving streams draining peat bogs
- Often found floating near or amongst spikerush
- Threatened by other aquatic weeds and drainage

Sphagnum australe
Sphagnum

- Rongoā species
- Native non-vascular moss

Alectryon excelsus
Tītoki

- Common rongoā species, used for kai, scent, domestic uses and as a material source
- Small tree with spreading branches and a dark fluted trunk
- Often favouring well drained, fertile alluvial soils along river banks and associated terraces

Sphagnum cristatum
Sphagnum

- Rongoā species
- Native non-vascular moss

Beilschmiedia tawa
Tawa

- Common rongoā species, used for kai, scent, domestic uses and as a material source
Common canopy tree with a tall dark single trunk
- Major canopy dominant in the lowland and lower montane forests of the North Island and northern South Island

WF8 - Kahikatea, Pukatea Forest

The species have been selected based on ecosystem typology information fit for purpose. Location and whānau cluster planting will be based on ecosystem typologies. The Kahikatea, Pukatea Forest ecosystem includes species that are aquatic, swamp, marsh, wetland and suited to water margins. Not all species listed in the Plant Lists are easily available for restoration planting, but are listed for completeness.

Dacrycarpus dacrydioides
Kahikatea, white pine

- Common rongoā species, used for kai, dyes, domestic uses and as a material source This conifer is the tallest indigenous plant in Aotearoa growing up to 65m
- Found in lowland forest, on frequently flooded or poorly drained soils

Sophora microphylla
Kōwhai

- Common rongoā species, used for kai, dyes, domestic uses and as a material source
- Tree upto 25m tall, usually a single trunk
- This is a species of mainly riparian forest
- Not threatened

Laurelia novae-zelandia
Pukatea

- Common rongoā species, used for hunting and fishing and as a material source
- Tall tree with a fluted base bearing pairs of oval glossy dark green toothed leaves inhabiting wetter sites
- Lowland semi-swamp forest and gully forest
- Not threatened

Coprosma wallii

- Bushy dark green shrub to small tree.
- Occupies a range of habitats from seasonally flooded alluvial forest prone to cold winter riparian forests

Dacrydium cupressinum
Rimu

- Common rongoā species, used for hunting and fishing, construction of whare, as a dye and for kai
- Dioecious conifer
- 35m tall
- Lowland to montane forest, occasionally ascending to subalpine scrub
- Not threated as a forest type

Melicytus ramiflorus
Māhoe

- Common rongoā species, used for hunting and fishing, construction of whare, as a dye and for kai
- Common small tree with pale trunk and think light green toothed leaves
- Abundant small tree of coastal, lowland and lower montane forests throughout

Plagianthus regius
Mānatu

- Tall tree with soft jagged pointed leaves
- Coastal to lower montane
- Often prominent tree in lowland alluvial forest
- Not threatened

Elaeocarpus hookerianus
Pōkākā

- Common rongoā species, used for kai, dyes, domestic uses and as a material source Small tree with distinct small narrow glossy olive-green and brown wavy leaves
- Common tree of lowland to montane forests Not threatened

PLANTING TYPOLOGIES

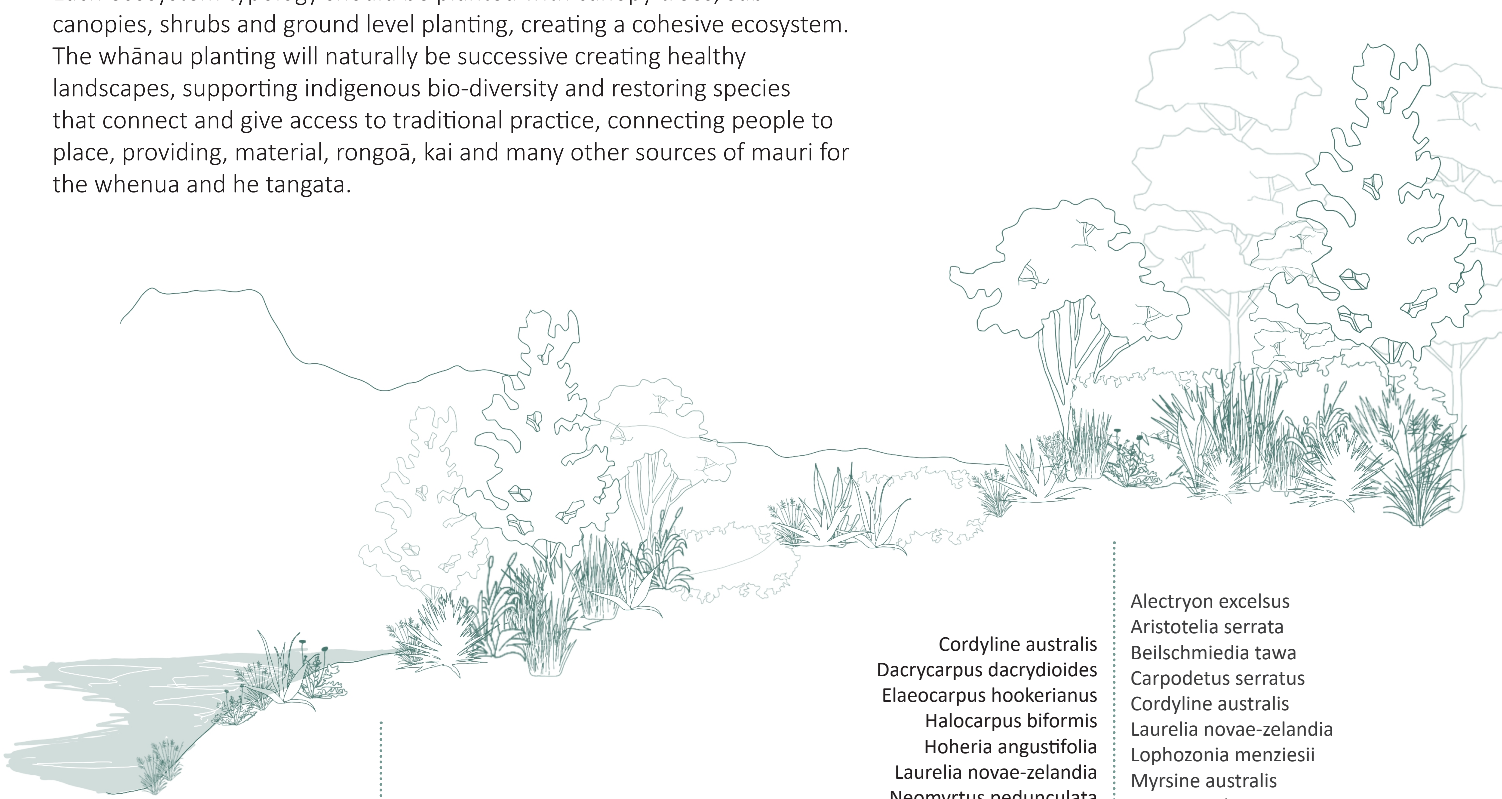
We have collated a series of sections that give more detail to general planting typologies for the context of the Waipoua catchment. These set out the habitat for Indigenous vegetation and their suitability to landscape type. The plant species listed below are plants taken from the above selections that are of priority to the context.

Whānau cluster planting should be done to mimic natural ecosystems. Each ecosystem as set out above is suited to site conditions from coastal to alpine forests. The ngāhere is most likely to thrive in systems where it would have naturally occurred, uplifting, restoring and supporting the takiwā.

Each ecosystem typology should be planted with canopy trees, sub-canopies, shrubs and ground level planting, creating a cohesive ecosystem. The whānau planting will naturally be successive creating healthy landscapes, supporting indigenous bio-diversity and restoring species that connect and give access to traditional practice, connecting people to place, providing, material, rongoā, kai and many other sources of mauri for the whenua and he tangata.

The ngāhere in their whānau clusters will enable wider support in each catchment zone for various measures of mitigation toward rising horizontal and vertical wai that inundates the takiwā.

This practice is commonly used in riparian planting, kai plantings, plantings in restoring native vegetation to the whenua where support and succession is needed.



Dacrycarpus dacrydioides
Syzyglium maire

Astelia linearis var. Novae zelandiae
Typha orientalis
Juncus antarcticus

Juncus pusillus

Carex diandra
Carex echinata
Carex secta
Carex sinclarii
Eleocharis acuta
Eleocharis gracilus
Isolepis prolifera
Machaerina rubiginosa
Schoenoplectus tabernaemontani

Sphagnum australe
Sphagnum cristatum

Androstoma empetrifolia
Coprosma tenuicaulis

Blechnum minus
Gleichenia alpina
Gleichenia dicarpa

Austroderia toetoe
Phormium tenax

Juncus australis
Juncus caespiticius
Juncus edgariae
Juncus novae-zelandiae
Juncus sarophorus

Abrotanella caespitosa
Carex geminata
Carex lessoniana
Carex virgata
Cyperus ustulatus
Machaerina tenax
Machaerina teretifolia
Schoenus maschalinus

Cordyline australis
Dacrycarpus dacrydioides
Elaeocarpus hookerianus
Halocarpus biformis
Hoheria angustifolia
Laurelia novae-zelandia
Neomyrtus pedunculata

Coprosma propinqua var. propinqua
Leptospermum scoparium
Olearia virgata
Pentachondra pumila

Lycopodiella lateralis

Austroderia fulvida
Phormium tenax

Carex solandri
Colobanthus apetalus
Gahnia xanthocarpa
Lepidosperma australe

Calystegia sepium subsp. Roseata
Rubus australis

Alectryon excelsus
Aristotelia serrata
Beilschmiedia tawa
Carpodetus serratus
Cordyline australis
Laurelia novae-zelandia
Lophozonia menziesii
Myrsine australis
Myrsine salicina
Nestegis cunninghamii
Pittosporum eugenioides
Plagianthus regius
Podocarpus totara var. totara
Pseudopanax crassifolius

Coprosma propinqua
Coprosma rhamnoides
Coprosma rigida
Coprosma virescens
Coprosma crassifolia
Corokia cotonesta
Hebe stricta
Helichrysum lanceolatum
Carmichaelia australis
Teucridium parvifolium

Fuchsia perscandens
Clematis forsteri
Parsonsia capsularis

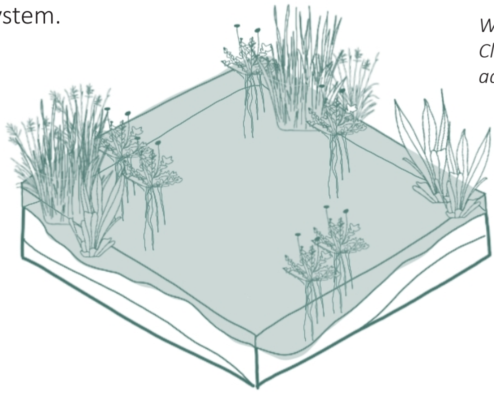
Pellaea rotundifolia
Cyathea dealbata
Polystichum oculatum

Carex testacea
Carex comans
Poa cita

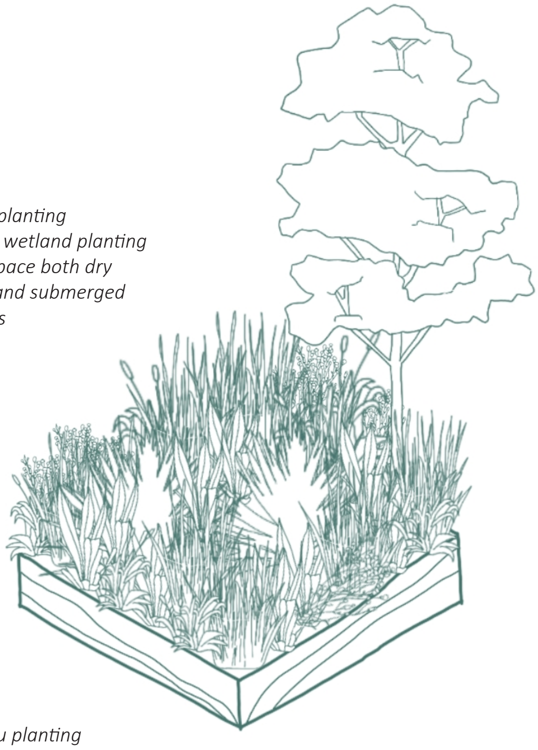
WHĀNAU CLUSTER PLANTING

Implementing any planting for flood mitigation in the Waipoua catchment and or for any other measures should be done within specific typologies where the planting is suited to the soil type, ecosystem type, context conditions and is native. An important aspect to the implementation of this planting is the succession of the planting. Like a whānau, like a family unit there are the central pou, the grandparents who are the heart of the whānau, as much as they are the strength of the whānau they also need protecting, they sit in the middle and are succeeded by their children and grandchildren creating a strong whānau cluster, each person, each ngākau with purpose. Each person, each ngākau given the opportunity to grow and give back. They way in which the planting will succeed is if all planting is whānau clustered ensuring the success and growth of each individual and the collection so the planted rōpū can give back and be purposeful and contribute to the wider ecosystem.

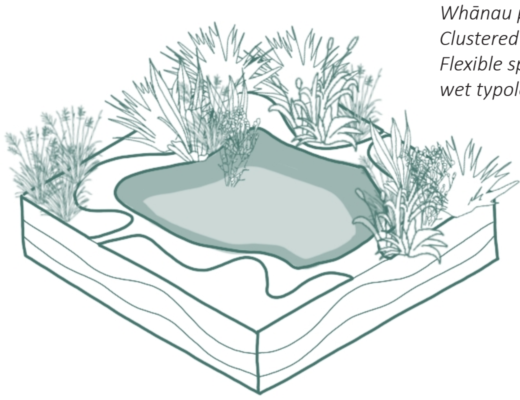
Whānau planting
Clustered submerged and aquatic planting



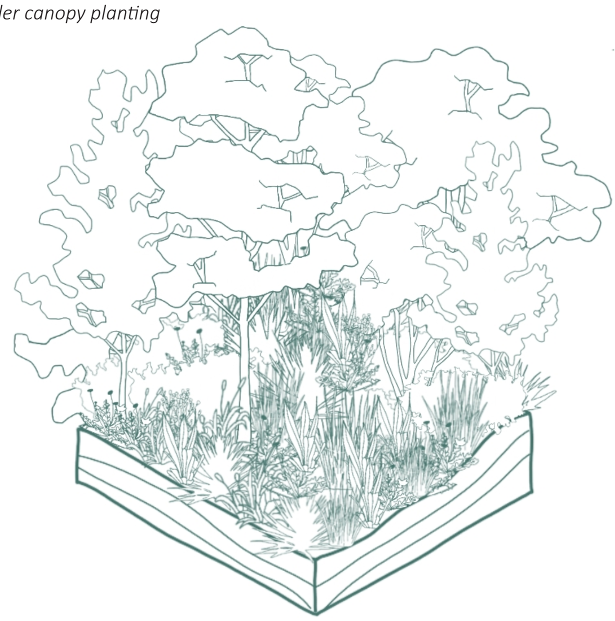
Whānau planting
Clustered wetland planting
Flexible space both dry and wet and submerged typologies



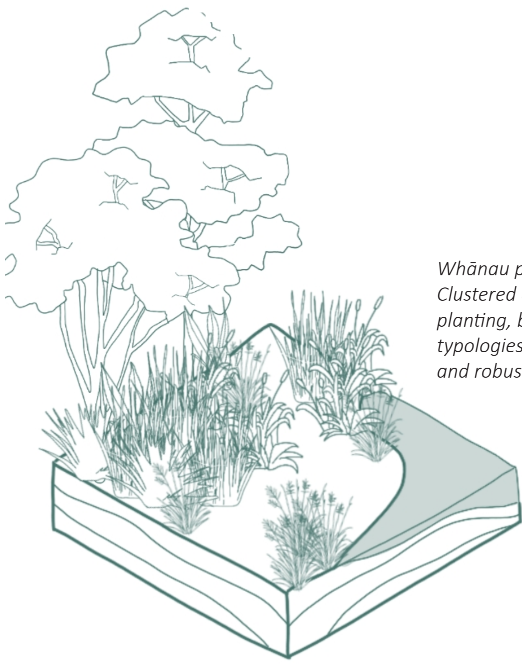
Whānau planting
Clustered detention planting
Flexible space both dry and wet typologies



Whānau planting
Clustered forestation planting, forest canopy and under canopy planting



Whānau planting
Clustered awa corridor planting, both wet and dry typologies, low maintenance and robust planting.



A WAY FORWARD

The following maps set out a way forward. The series depicts areas that have been overlaid with the existing data research, highlighting where Indigenous vegetation would be best placed to support flood mitigation.

Priority zone one (Map 1.0) focuses on the river margins within the extent to which immediate flooding will occur. Priority one also includes areas for planting within patterns of wetland systems that may have existed pre-human arrival. The priority mapping has been determined through the overlaying of data mapping, kōrero tuku iho and through reading the patterns within the whenua.

Priority zone two (Map 2.0) builds on zone one pushing further into the wider landscape, this will include the retirement of pasture and grazing allow space for vegetation to support healthy soil stabilisation, the growth of native biodiversity and the restoration of various ecosystems to the region.

Priority zone three (Map 3.0) looks to major retirement of the current landscape. This builds on priority zones one and two with all three zones supporting nature-based solutions mitigating flood impacts to the Waipoua awa catchment.

The location is at a large scale and further investigations will need to be undertaken at a smaller scale when implementation is confirmed. In addition to these maps, indigenous vegetation and the species listed will complement and support other nature-based solution strategies. The mapping shows immediate and high priority needs closest to the river corridor, with succession and future thinking to the retirement of wider sections of whenua for Indigenous vegetation. The restoration of the whenua and the restoration of te mauri o te whenua, te mauri o te wai is paramount.

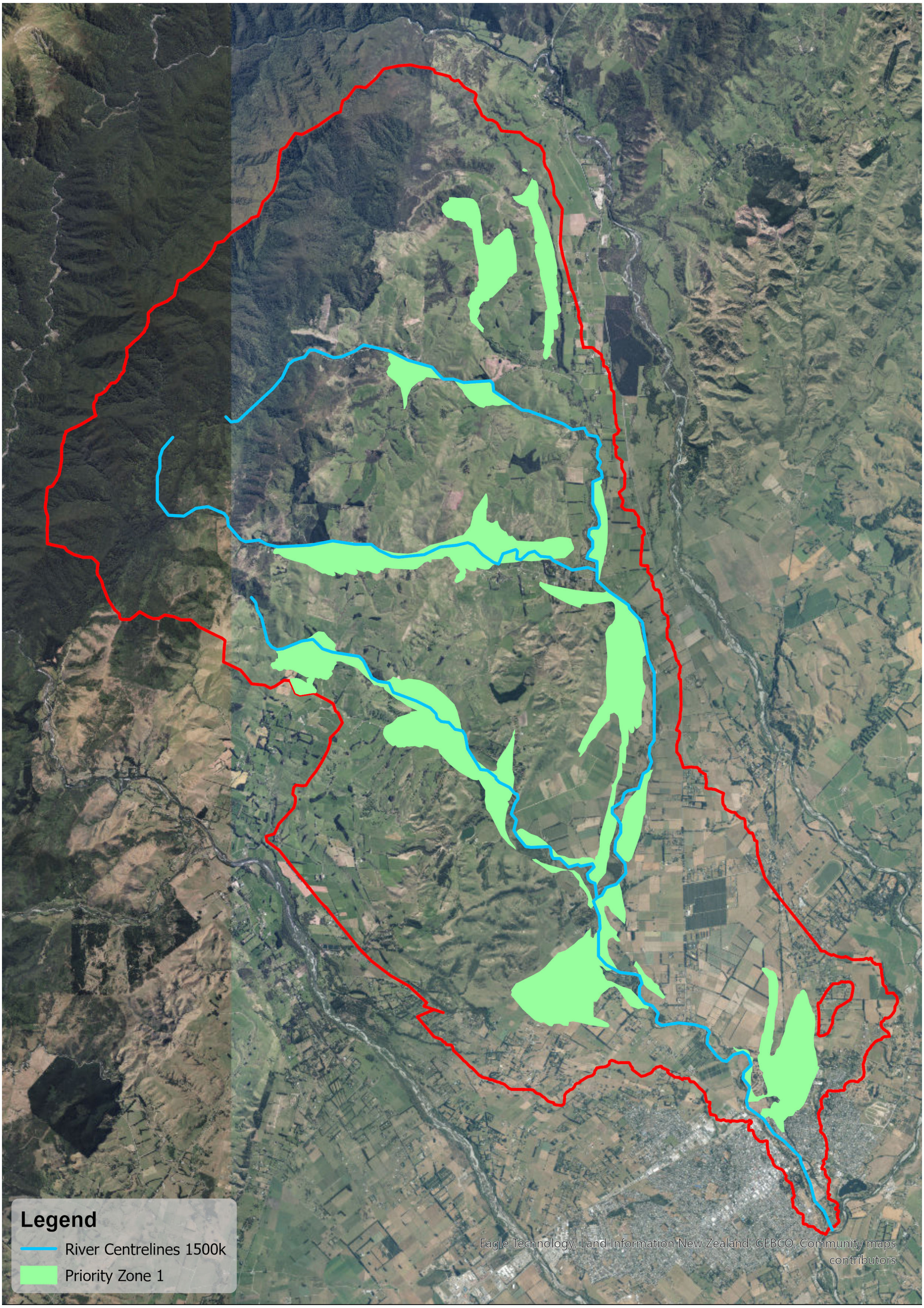
Restoring various ecosystem typologies to the takiwā will not only support the basis of this mahi through nature-based solutions and flood mitigation but will also restore connections to whenua, bringing people and place together. Access to indigenous plantings will enhance local biodiversity, soil and whenua health as well as the health and well-being of the people. Indigenous ngāhere have benefits beyond single stage solutions for the benefit of our urban environments included connected holistic properties that restores mauri to all.

Forests in Aotearoa follow a lifecycle which involves the replacement of one group of plants by another over time (succession). Following the removal of native vegetation (by natural means such as fire, landslide and flood, or by humans) the first plants to grow are pioneer species such as bracken fern, mānuka, kanuka, tree tutu, makomako, kōwhai, toetoe, and koromiko. The dense cover of mature pioneer plants forms a nursery for seedlings of native herbs, shrubs and trees (e.g. kāmahi, mahoe, ribbonwood, maire, māpou) which are shade tolerant. Once the first generation forest plants overtop the pioneer plants and form a low canopy, the pioneer plants reach the end of their life span and are unable to survive in the shady conditions. Second generation forest plants such as conifers and podocarps (e.g. rewarewa, miro, rimu, totara, matai, kahikatea, beech) grow up beneath the first generation low canopy and eventually form a mature, perpetuating canopy which can last for thousands of years. During a succession, plant height increases, soil builds up, soil nutrients increase, and the assemblage of plant species present changes from short-lived, shade-intolerant species to long-lived, shade-tolerant species. The forest succession must be considered when creating a planting plan for any given location, with pioneer species planted initially, first generation forest species next, and mature forest species planted several years to decades after initial planting of a site. (Maggy Wassilieff, Forest succession and regeneration)

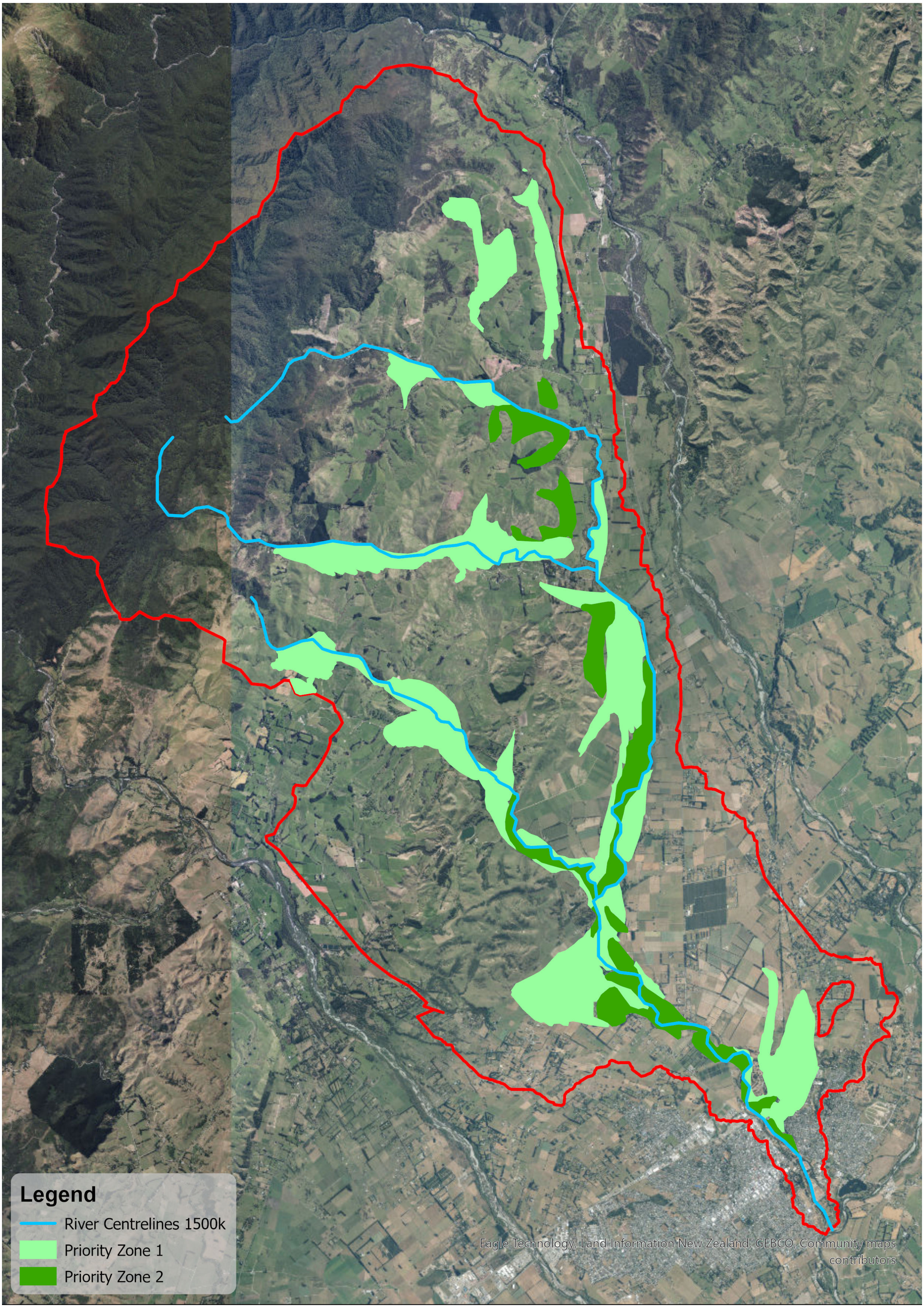
CONCLUSION

In summary, this mahi has sought to investigate wetland types and other natural ecosystems found in the Waipoua awa catchment, and recommend a list of appropriate indigenous plants to restore the whenua, flora, fauna and to help mitigate the effects of flooding. We did so founded on a Te Ao Māori, Indigenous approach, by working through a range of data maps, talking with local Iwi representatives and understanding the stories the whenua is reflecting. The findings from this mahi have resulted in the collection of a range of Indigenous plant species that cover various typologies and how and where they can support flood mitigation strategies uncovered in the nature based solutions investigations. The mahi in this report, although holistic in nature needs further investigation at a detailed scale to determine the typologies for specific locations. It will also be important to continue to work alongside Mana Whenua to identify taonga species and aspirations for the plantings and for the whenua.

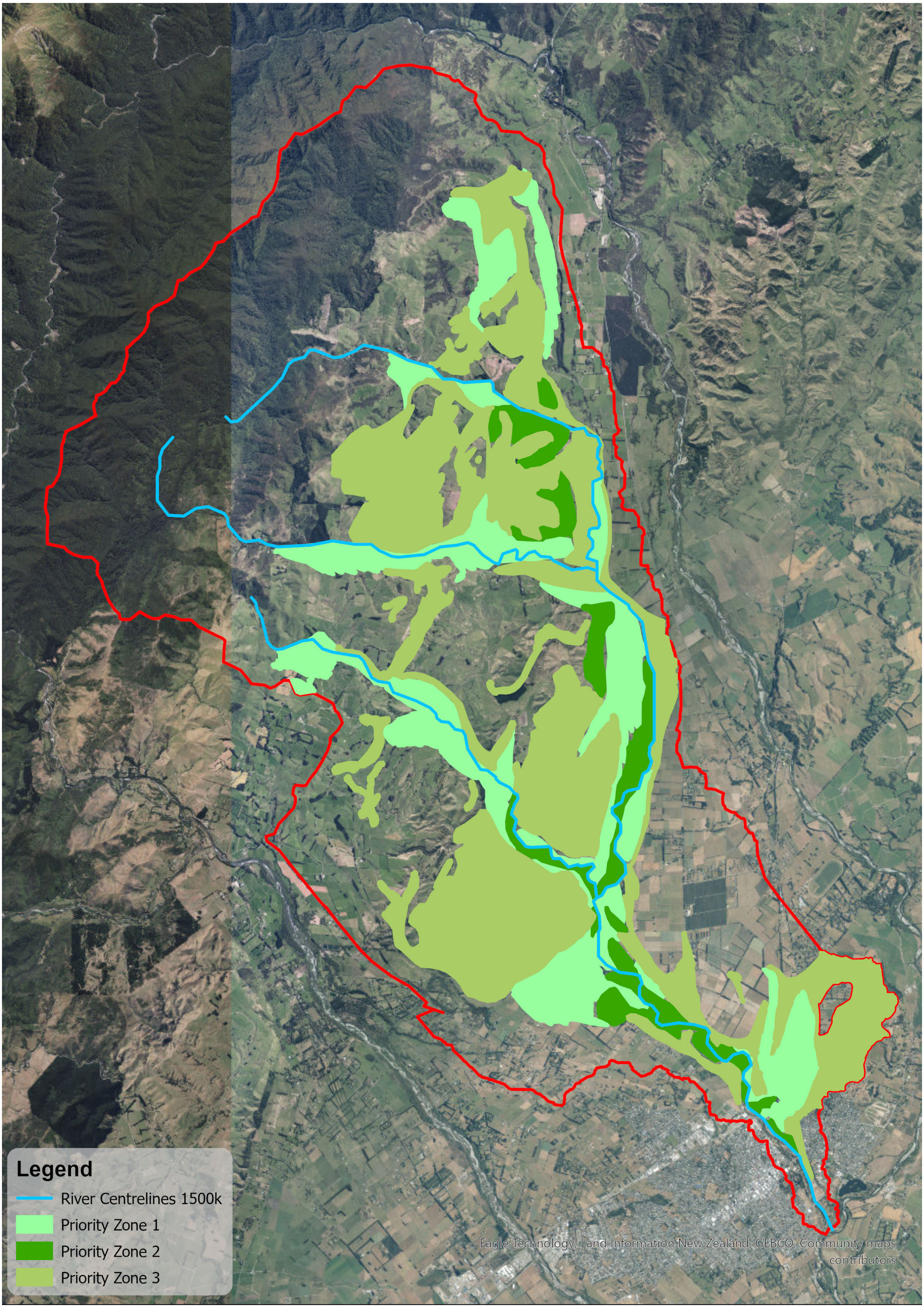
It is intended that this mahi will help support funders and government agencies to better understand from an Indigenous perspective the connections, relationships and impacts amongst people, whenua, wai and taiao. While this mahi was able to shed some light on an Indigenous perspective to Indigenous vegetation for flood mitigation, it is not without limitations. Although the findings analysed the data through existing and pre-human GIS mapping as well as collective plant species data from across the region and kōrero tuku iho, the results need to be considered with caution. However we are confident that the mahi detailed in this report is inline with prior research and whaakaro and expands on the limited evidence available on the topic.



Map 1.0: Waipoua Catchment - Strategy 01, priority zones for Indigenous vegetation to support flood mitigation



Map 2.0: Waipoua Catchment - Strategy 02, successive zones building on Strategy 01 for Indigenous vegetation to support flood mitigation



Map 3.0: Waipoua Catchment - Strategy 03, future retirement of land for Indigenous vegetation to support flood mitigation and te mauri o te taiao, te mauri o te whenua, te mauri o te wai

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Appendix H. Cost estimates - detailed table

Waipoua Nature Based Solutions

Estimate Summary

Scope of Work	NBS 1 retirement and afforestation	NBS 2 floodplain re-engagement - no planting - low estimate	NBS 2 floodplain re-engagement - no planting - high estimate	NBS 2 floodplain re-engagement - full planting - low estimate	NBS 2 floodplain re-engagement - full planting - high estimate	NBS 3 distributed storage - low estimate	NBS 3 distributed storage - high estimate	NBS 4 room for river
Summary								
Land Acquisition								
Land Purchase	15,327,000	1,005,000	2,520,000	5,025,000	5,025,000	720,000	2,730,000	6,465,000
Nominal allowance for additional land procurement costs	2,299,100	150,800	378,000	753,800	753,800	108,000	409,500	969,800
Acquisition Sub-Total	**17,626,100**	**1,155,800**	**2,898,000**	**5,778,800**	**5,778,800**	**828,000**	**3,139,500**	**7,434,800**
Physical Works								
Clearance		2,204,800	2,204,800	2,204,800	2,204,800			
Earthworks		34,499,200	60,586,500	34,499,200	60,586,500			
Fencing		4,409,500	4,409,500	1,587,400	1,587,400			
Retention Pond / Bund						104,850,000	178,290,000	
Planting	71,015,100			12,386,625	12,386,625			
Wetland Vegetation							3,694,100	
Riparian Planting								1,833,900
Willow Removal								511,600
Construction Sub-Total	**71,015,100**	**41,113,500**	**67,200,800**	**50,678,025**	**76,765,325**	**104,850,000**	**181,984,100**	**2,345,500**
Other Costs								
Environmental controls / mitigations (2% of construction sub-total)	1,421,000	823,000	1,345,000	1,014,000	1,536,000	2,097,000	3,640,000	47,000
Concept, developed and detailed design costs (12% of construction sub-total)	8,522,000	4,934,000	8,065,000	6,082,000	9,212,000	12,582,000	21,839,000	282,000
MSQA / Construction supervision costs (6% on construction sub-total)	4,261,000	2,467,000	4,033,000	3,041,000	4,606,000	6,291,000	10,920,000	141,000
Other Costs Sub-Total	**14,204,000**	**8,224,000**	**13,443,000**	**10,137,000**	**15,354,000**	**20,970,000**	**36,399,000**	**470,000**
Total	**102,845,200**	**50,493,300**	**83,541,800**	**66,593,825**	**97,898,125**	**126,648,000**	**221,522,600**	**10,250,300**
Contingency								
Nominal contingency percentage	*20%*	*20%*	*20%*	*20%*	*20%*	*20%*	*20%*	*40%*
Contingency allocation	20,570,000	10,099,000	16,709,000	13,319,000	19,580,000	25,330,000	44,305,000	4,101,000
Total incl. nominal contingency allowance	**123,415,200**	**60,592,300**	**100,250,800**	**79,912,825**	**117,478,125**	**151,978,000**	**265,827,600**	**14,351,300**

Clarifications:

- All physical works have been built-up from first principles based upon nominal productivities per day for the likely labour, plant and material operations.
- All percentage mark-ups for environmental compliance, erosion and sediment control, traffic management and preliminary and general costs are nominal, and will be subject to change as the design proceeds.
- We have included a nominal 15% allowance for additional land procurement costs
- The following items are specifically excluded from this high level optioneering estimate:

** Costs related to consenting, legal fees, other fees and any other costs not specifically stated are excluded from the estimate.*
** Costs relating to testing and remediation of contaminated soil.*
** Costs relating to ecological and cultural mitigation and monitoring.*
** Cost escalation past Q2 2025.*

					Net		Mark-Up			Gross	
Level	Item	Bill description	Qty	Unit	Rate	Amount	On-site OH	Off-site OH &P	Risk	Rate	Amount
1		**WAIPOUA - NATURE BASED SOLITIONS**					12.50%	15%	2%		
2	1	**NBS 1 retirement and afforestation**									
3	1.1	**NB Solution 1 - Afforestation - Land Purchase and Planting**									
4	1.1.1	**Land Purchase**									
	1.1.1.1	Land purchase of 40% of 4,257ha, per hectare cost is deemed to include access	1,703	/ha	9,000.00	15,327,000.00				9,000.00	15,327,000.00
4	1.1.2	**Planting**									
	1.1.2.1	Establishment and planting costs per hectare including allowance establishing access, fencing and 3 year maintenance	1,703	/ha	41,700.00	71,015,100.00				41,700.00	71,015,100.00
2	2	**NBS 2 floodplain re-engagement - no planting - low estimate**									
3	2.1	**NB Solution 2 - Floodplain re-engagement - disposal of excavated material within 5 min. travel time**									
4	2.1.1	**Land Purchase**									
	2.1.1.1	Land purchase	67	/ha	15,000.00	1,005,000.00				15,000.00	1,005,000.00
4	**NEW**	**Clearance**									
	NEW	General site clearance	335	/ha	5,000.00	1,675,000.00	209,375.00	282,656.25	37,687.50	6,581.49	2,204,800.00
4	2.1.2	**Earthworks**									
	2.1.2.1	Flood plain lowering, including free of charge disposal within 5 mins travel distance	500,000	/m3	25.95	12,975,343.90	1,621,917.99	2,189,589.28	291,945.24	34.16	17,078,800.00
	2.1.2.2	Spillway lowering, including free of charge disposal within 5 mins travel distance	500,000	/m3	25.95	12,975,343.90	1,621,917.99	2,189,589.28	291,945.24	34.16	17,078,800.00
	2.1.2.3	Erosion and sediment control based upon 1% of earthworks value	1	/sum	259,506.89	259,506.89	32,438.36	43,791.79	5,838.91	341,600.00	341,600.00
4	**NEW**	**Fencing**									
	NEW	Re-establish fencing, access tracks	335	/ha	10,000.00	3,350,000.00	418,750.00	565,312.50	75,375.00	13,162.69	4,409,500.00
4	2.1.3	**Planting**									
	2.1.3.1	Establishment and planting costs per hectare including allowance establishing access, fencing and maintenance provision	0	/ha	36,975.00	0.00				#DIV/0!	0.00
3	2.2	**NBS 2 floodplain re-engagement - no planting - high estimate**									
4	2.2.1	**Land Purchase**									
	2.2.1.1	Land purchase	168	/ha	15,000.00	2,520,000.00				15,000.00	2,520,000.00
4	**NEW**	**Clearance**									
	NEW	General site clearance	335	/ha	5,000.00	1,675,000.00	209,375.00	282,656.25	37,687.50	6,581.49	2,204,800.00
4	2.2.2	**Earthworks**									
	2.2.2.1	Flood plain lowering, including free of charge disposal within 30 mins travel distance	500,000	/m3	45.57	22,786,881.25	2,848,360.16	3,845,286.21	512,704.83	59.99	29,993,300.00
	2.2.2.2	Spillway lowering, including free of charge disposal within 30 mins travel distance	500,000	/m3	45.57	22,786,881.25	2,848,360.16	3,845,286.21	512,704.83	59.99	29,993,300.00
	2.2.2.3	Erosion and sediment control based upon 1% of earthworks value	1	/sum	455,737.64	455,737.64	56,967.21	76,905.73	10,254.10	599,900.00	599,900.00
4	**NEW**	**Fencing**									
	NEW	Re-establish fencing, access tracks	335	/ha	10,000.00	3,350,000.00	418,750.00	565,312.50	75,375.00	13,162.69	4,409,500.00
4	2.2.3	**Planting**									
	2.2.3.1	Establishment and planting costs per hectare including allowance establishing access, fencing and maintenance provision	0	/ha	36,975.00	0.00				#DIV/0!	0.00
2	2	**NBS 2 floodplain re-engagement - full planting - low estimate**									
3	2.1	**NB Solution 2 - Floodplain re-engagement - disposal of excavated material within 5 min. travel time**									
4	2.1.1	**Land Purchase**									
	2.1.1.1	Land purchase	335	/ha	15,000.00	5,025,000.00				15,000.00	5,025,000.00
4	**NEW**	**Clearance**									
	NEW	General site clearance	335	/ha	5,000.00	1,675,000.00	209,375.00	282,656.25	37,687.50	6,581.49	2,204,800.00
4	2.1.2	**Earthworks**									
	2.1.2.1	Flood plain lowering, including free of charge disposal within 5 mins travel distance	500,000	/m3	25.95	12,975,343.90	1,621,917.99	2,189,589.28	291,945.24	34.16	17,078,800.00
	2.1.2.2	Spillway lowering, including free of charge disposal within 5 mins travel distance	500,000	/m3	25.95	12,975,343.90	1,621,917.99	2,189,589.28	291,945.24	34.16	17,078,800.00
	2.1.2.3	Erosion and sediment control based upon 1% of earthworks value	1	/sum	259,506.89	259,506.89	32,438.36	43,791.79	5,838.91	341,600.00	341,600.00
4	**NEW**	**Fencing**									
	NEW	Re-establish fencing	335	/ha	3,600.00	1,206,000.00	150,750.00	203,512.50	27,135.00	4,738.51	1,587,400.00
4	2.1.3	**Planting**									
	2.1.3.1	Establishment and planting costs per hectare including allowance establishing access, fencing and maintenance provision	335	/ha	36,975.00	12,386,625.00				36,975.00	12,386,625.00
3	2.2	**NBS 2 floodplain re-engagement - full planting - high estimate**									
4	2.2.1	**Land Purchase**									
	2.2.1.1	Land purchase	335	/ha	15,000.00	5,025,000.00				15,000.00	5,025,000.00
4	**NEW**	**Clearance**									
	NEW	General site clearance	335	/ha	5,000.00	1,675,000.00	209,375.00	282,656.25	37,687.50	6,581.49	2,204,800.00
4	2.2.2	**Earthworks**									
	2.2.2.1	Flood plain lowering, including free of charge disposal within 30 mins travel distance	500,000	/m3	45.57	22,786,881.25	2,848,360.16	3,845,286.21	512,704.83	59.99	29,993,300.00
	2.2.2.2	Spillway lowering, including free of charge disposal within 30 mins travel distance	500,000	/m3	45.57	22,786,881.25	2,848,360.16	3,845,286.21	512,704.83	59.99	29,993,300.00
	2.2.2.3	Erosion and sediment control based upon 1% of earthworks value	1	/sum	455,737.64	455,737.64	56,967.21	76,905.73	10,254.10	599,900.00	599,900.00
4	**NEW**	**Fencing**									
	NEW	Re-establish fencing	335	/ha	3,600.00	1,206,000.00	150,750.00	203,512.50	27,135.00	4,738.51	1,587,400.00

4	**2.2.3**	**Planting**									
	2.2.3.1	Establishment and planting costs per hectare including allowance establishing access, fencing and maintenance provision	335	/ha	36,975.00	12,386,625.00				36,975.00	12,386,625.00
2	**3**	**NBS 3 distributed storage - low estimate**									
3	**3.1**	**NBS Solution 3 - Small scale, distributed retention storage - cut to fill**									
4	**3.1.1**	**Land Purchase**									
	3.1.1.1	Land purchase, per hectare cost is deemed to include access and fencing provision	24	/ha	30,000.00	720,000.00				30,000.00	720,000.00
4	**3.1.2**	**Retention pond / bund**									
c		**Refer to 'RetentionPondPricing' tab for information**									
		Construct retention pond measured complete	1,800,000	/m3	58.25	104,850,000.00				58.25	104,850,000.00
4	**3.1.3**	**Wetland vegetation**									
	3.1.3.1	Establishment of wetland planting including an allowance for fencing and maintenance provision	0	/ha	61,568.00	0.00				#DIV/0!	0.00
3	**3.1**	**NBS 3 distributed storage - high estimate**									
4	**3.1.1**	**Land Purchase**									
	3.1.2	Land purchase, per hectare cost is deemed to include access	91	/ha	30,000.00	2,730,000.00				30,000.00	2,730,000.00
4	**3.1.2**	**Retention pond / bund**									
c		**Refer to 'RetentionPondPricing' tab for information**									
c		**Earthworks**									
	3.1.3	Construct retention pond measured complete	1,800,000	/m3	99.05	178,290,000.00				99.05	178,290,000.00
4	**3.1.3**	**Wetland vegetation**									
	3.1.4	Establishment of wetland planting including an allowance for fencing and maintenance provision	60	/ha	61,568.00	3,694,080.00				61,568.33	3,694,100.00
2	**4**	**NBS 4 room for river**									
3	**4.1**	**NBS Solution 4 - Channel realignment/reconnection and room for the river**									
4	**4.1.1**	**Land Purchase**									
	4.1.1.1	Land purchase, per hectare cost is deemed to include access	431	/ha	15,000.00	6,465,000.00				15,000.00	6,465,000.00
4	**4.1.2**	**Riparian Planting**									
	4.1.3	Establishment and planting costs per hectare for native riparian vegetation including allowance establishing access, fencing and maintenance provision	28	/ha	66,083.00	1,833,803.25				66,086.49	1,833,900.00
4	**4.1.3**	**Willow Removal**									
	4.1.4	Removal of existing willow and scrub from river bank	37,000	/m	10.50	388,648.00	48,581.00	65,584.35	8,744.58	13.83	511,600.00