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Effects of climate change and erosion mitigation on suspended sediment loads and visual clarity in the Wairoa catchment, Hawke's Bay

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Effects of climate change and erosion mitigation on suspended sediment loads and visual clarity in the Wairoa catchment, Hawke's Bay

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Summary

Project

- The Wairoa River is significant to the iwi and hapū of Te Rohe o Te Wairoa. An important threat to the health of the river is from sediment entering the water.
- The Wairoa Tripartite (Wairoa District Council, Tātau Tātau o Te Wairoa, Hawke's Bay Regional Council) and the Whitiwhiti Ora project (part of the Our Land and Water National Science Challenge) have formed a partnership to jointly guide the direction and delivery of a project focused on understanding cultural values related to the river and the impact of sediment on these values.

Objectives

- The objective of the present report is to model erosion and suspended sediment loads in the Wairoa catchment under a 'best-efforts' erosion mitigation scenario and assess reductions required to meet National Policy Statement for Freshwater Management 2020 (NPS-FM) fine suspended sediment attribute bands for visual clarity at State of Environment (SOE) sites. This will be assessed under contemporary and future climate scenarios. This information will inform work assessing sediment impacts on the river's cultural values.

Methods

- A best-efforts erosion mitigation scenario was developed and modelled using SedNetNZ. This scenario comprises full scrub reversion on Land Use Capability (LUC) 7e and 8e pastoral land, space planting of trees on LUC 4e, 5e, and 6e pastoral land, and fencing and woody-revegetation of riparian areas along streams of River Environment Classification version 2 (RECv2) order 3 and above.
- The effects of future climate change were modelled for the best-efforts erosion mitigation scenario using rainfall and temperature grids from six regionally downscaled climate models and four greenhouse gas trajectories (representative concentration pathways, RCPs) at mid-century and late century to adjust modelled erosion process rates under climate change and estimate future suspended sediment loads.
- Baseline visual clarity was determined from SOE visual clarity data. Proportional reductions required to meet visual clarity targets for suspended fine sediment attribute bands were assessed for the SOE sites (*n* = 7) under contemporary and future climate change scenarios for recent baseline conditions and the best-efforts mitigation scenario.

Results

- The modelled mean annual suspended sediment load delivered to the coast for the best-efforts mitigation scenario amounts to 1.0 Mt/yr under contemporary climatic conditions, which corresponds to a 60% reduction from 2.5 Mt/yr under recent baseline conditions.
- The best-efforts scenario reduced sediment loads under climate change by 51%–57% by mid-century and 43%–58% by late century, relative to the recent baseline.
- The SOE sites 'Mangaaruhe at Mangaaruhe Station' and 'Mangapoike River at Suspension Bridge' achieve a baseline attribute state of band A and require no further reductions. The remaining five sites are classed as band D (below national bottom line, NBL) and require proportional load reductions ranging from 38%–70% to achieve NBL under baseline conditions.
- Under the best-efforts mitigation scenario with contemporary climate, two sites, 'Waiau River at Otoi' and 'Wairoa River at Railway Br.', were not able to achieve NBL and require further proportional reductions of 48% and 26%, respectively.
- Under the baseline scenario with future climate change, 'Mangaaruhe at Mangaaruhe Station' and 'Mangapoike River at Suspension' require load reductions of 10%–31% and 8%–45% to maintain baseline visual clarity by mid-century and late century, respectively, across the range of RCPs. Under the best-efforts scenario these sites achieve band A.
- The remaining sites under the baseline scenario require proportional load reductions of 45%–79% and 43%–83% to achieve NBL by mid-century and late century, respectively, across the range of RCPs. Under best-efforts mitigation the required reductions decrease to 0%–56% and 0%–59% to achieve NBL by mid-century and late century, respectively, across the range of RCPs.

Conclusions

- Suspended sediment loads in the Wairoa catchment are significantly reduced under a best-efforts mitigation scenario. The widespread application of erosion mitigation measures is projected to more than offset potential future increases in suspended sediment loads due to climate change.
- Under baseline conditions, two SOE sites achieve band A attribute state while the remaining five sites are at band D and will require significant load reductions to achieve NBL.
- The best-efforts erosion mitigation scenario with contemporary climatic conditions results in five SOE sites achieving NBL, whereas under future climate change three sites are likely to achieve NBL at mid-century and late century across all RCPs.

1 Introduction

The Wairoa River is significant to the iwi and hapū of Te Rohe o Te Wairoa, and is valued ecologically as well as for recreation and mahinga kai. Excess sediment entering the water is an important threat to the health and mauri of the river.

The Wairoa Tripartite (Wairoa District Council, Tātau Tātau o Te Wairoa, Hawke's Bay Regional Council) and the Whitiwhiti Ora project (part of the Our Land and Water National Science Challenge) have formed a partnership to jointly guide the direction and delivery of a project focused on the river, particularly the impact of sediment on this taonga. The Wairoa project aims to:

- understand the values of the local hapū with respect to the river, with a focus on mahinga kai and sites of cultural significance
- assess how sediment affects these values
- inform targeting of sediment sources via intervention scenarios to reduce the impacts of sediment on these values.

This report is intended to be read in conjunction with the preceding report '*Climate change impacts on suspended sediment loads in the Wairoa catchment, Hawke's Bay*' by Smith et al. (2022) which provides a comprehensive background and description of the SedNetNZ model.

Smith et al. (2022) used existing SedNetNZ model results for erosion processes (including the updated bank erosion loads) in combination with an updated algorithm for lake and floodplain sediment storage to estimate mean annual suspended sediment loads for the baseline scenario, represented by contemporary land cover and climatic conditions. This was then combined with projected changes in climate to estimate potential impacts of suspended sediment loads in the Wairoa catchment by mid- and late century.

In the present report, we build on initial baseline modelling by Smith et al. (2022) to quantitatively assess the impact of a 'best-efforts' mitigation scenario on the spatial patterns in erosion and suspended sediment loads across the Wairoa catchment. These loads are compared with previously modelled baseline sediment loads under contemporary and future climate change conditions. This model-based approach allows us to better understand the extent to which interventions mitigate the impact future climate change may have on the amount of sediment entering the river and reaching the coast.

We also determine baseline visual clarity for State of Environment (SOE) sites and assess the suspended sediment load reductions required to meet each suspended fine sediment attribute band based on National Policy Statement for Freshwater Management 2020 (NPS-FM).

2 Methods

The following section describes the approach used to model the best-efforts erosion mitigation scenario and the load reductions required to achieve NPS-FM (2020) suspended fine sediment attribute bands and the national bottom line (NBL) for visual clarity.

SedNetNZ includes representation of surficial erosion, shallow landslide erosion, earthflow erosion, gully erosion, bank erosion, floodplain deposition and river network routing. A full description of the erosion processes in the model is given in Smith et al. (2022). The previous report also describes climate change impacts on erosion processes and sediment loads, as well as the climate models and representative concentration pathways (RCPs) used for future projections.

2.1 Best-efforts erosion mitigation scenario

A best-efforts erosion mitigation scenario was developed in consultation with the Wairoa Tripartite. This scenario involves natural reversion on the most erodible pastoral land and re-vegetating riparian areas. It also includes space-planting of trees (poplars/willows) across remaining pastoral hill country areas, which retains functional pastoral land (Dominati et al. 2014). Spatial application of erosion mitigation was based on the New Zealand Land Resource Inventory (NZLRI) Land Use Capability (LUC) (Landcare Research NZ Ltd 2010). The NZLRI LUC Class is the broadest grouping of land capability classification reflecting the physical limitations of the land (erodibility (e), wetness (w), soil (s), climate (c)) (Figure 1). There are 8 classes increasing in limitations and decreasing in versatility from LUC Class 1 to LUC Class 8 (Lynn et al. 2009). The spatial ruleset for the erosion mitigation scenario therefore included:

- full scrub reversion on LUC 7e and 8e pastoral land
- space-planting on LUC 4e, 5e, and 6e pastoral land
- fencing and woody re-vegetation of riparian areas on stream orders 3 and above.

2.1.1 Full scrub reversion and space planting

Full scrub reversion and space-planting were applied as a best-efforts erosion mitigation. LUC classes 7e and 8e were considered the appropriate level for full scrub reversion. LUC classes 4e, 5e and 6e, representing remaining hill country, were considered appropriate for space-planting of trees for erosion control (there was no LUC 5e class land in the Wairoa catchment).

Pastoral land was based on Land Cover Database (LCDB) v4.1 (Landcare Research NZ Ltd. 2015) to reflect 'High Producing Exotic Grassland' and 'Low Producing Exotic Grassland'' classes. This recognizes pasture is the most likely landcover for full scrub reversion and excludes landcover already under woody cover (e.g. forestry, native vegetation). Figure 2 shows the areas treated with scrub reversion and space-planting resulting from the above ruleset.

A 90% reduction in sediment load was applied to areas with scrub reversion (Phillips et al. 1990; Hicks 1992; Dymond et al. 2016; Neverman et al. 2021b, Vale et al. 2022), while a 70% reduction was applied to areas with space-planted trees based on published data from Hawley and Dymond (1988) and Dymond et al. (2010).

Increasing limitations to use ↓

LUC Class	Arable cropping suitability†	Pastoral grazing suitability	Production forestry suitability	General suitability
1	High	High	High	Multiple use land
2	↓	↓	↓	
3				
4	Low			
5	Unsuitable			Pastoral or forestry land
6				
7		Low	Low	
8		Unsuitable	Unsuitable	Conservation land

Decreasing versatility of use ↓

Figure 1. Increasing limitations to use and decreasing versatility of use from LUC Class 1 to LUC Class 8 (reproduced from Lynn et al. 2009). † Includes vegetable cropping.

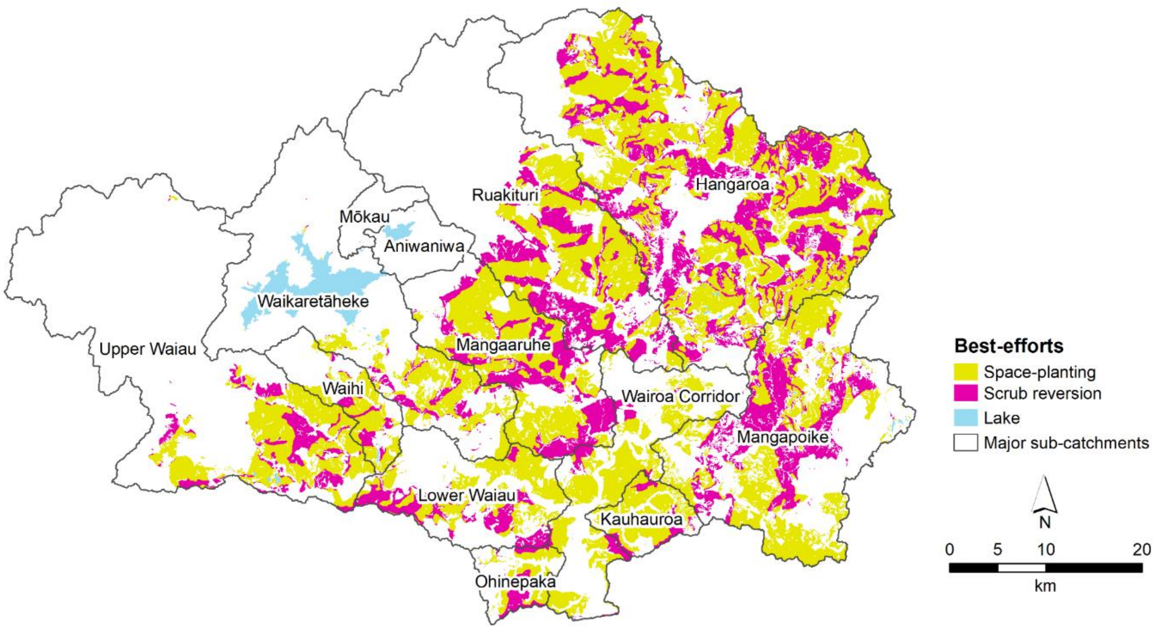

Figure 2. Best-efforts erosion mitigation scenario showing areas designated for full scrub reversion and space-planting in the Wairoa catchment.

2.1.2 Fencing and woody re-vegetation of riparian areas

The reduction in net suspended sediment load from bank erosion due to fencing and stock exclusion (B_{F_j}) is computed as:

$$B_{F_j} = B_j \times (1 - 0.8FR_j) \quad (1)$$

where B_j is the net suspended sediment load from bank erosion without the effect of fences and FR_j is the fraction of stream segment (j) fenced. A reduction of 80% in net suspended sediment load from bank erosion may be attributable to riparian fencing and stock exclusion (Dymond et al. 2016). This reflects the effects of reduced stock trampling and foraging on banks (Trimble 1994) as well as the potential for riparian woody vegetation to become better established in the absence of livestock over the longer-term. The estimated 80% reduction assumes the riparian area is no longer grazed and sufficient time has elapsed for banks to recover from previous trampling impacts and for woody vegetation to become established, resulting in increased bank stabilisation.

Reductions in bank erosion from fencing and woody-re-vegetation were applied to pastoral land based on LCDB for streams classified as River Environment Classification version 2 (RECv2) stream order 3 and above. A reduction to bank erosion was also modelled for all RECv2 stream orders where full scrub reversion would result in woody revegetation of the riparian areas. Therefore, the overall reduction to bank erosion for each RECv2 segment reflects the estimated proportion of each RECv2 segment experiencing riparian re-vegetation from fencing and/or full scrub reversion.

Figure 3 shows the spatial pattern of riparian fencing and full scrub reversion based on these criteria.

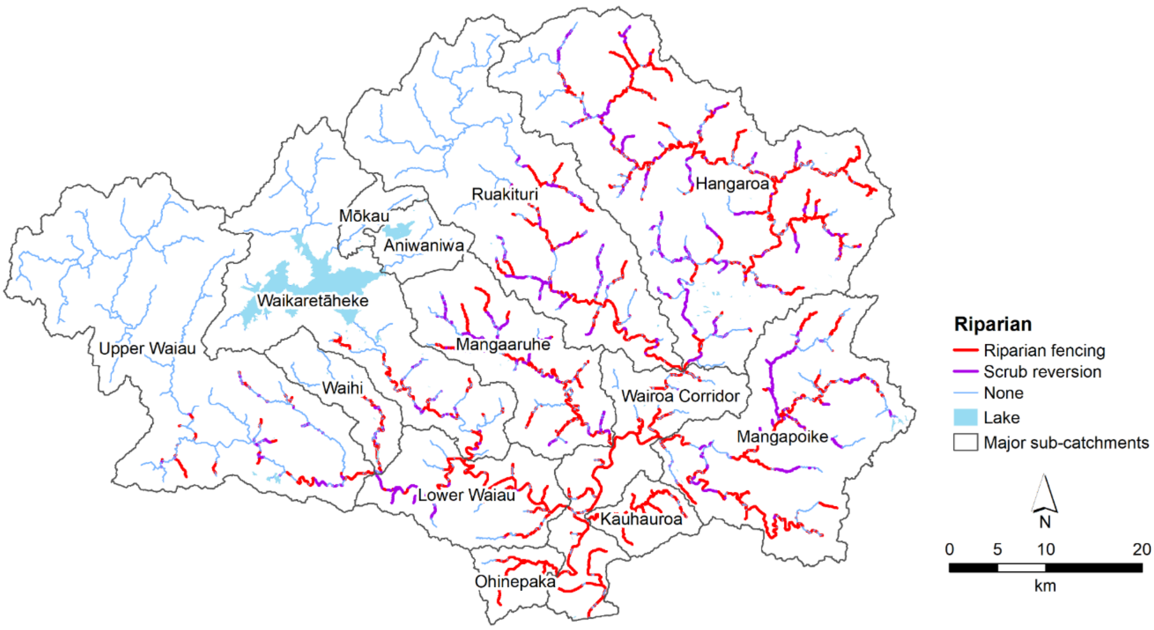

Figure 3. Best-efforts mitigation scenario showing RECv2 segments designated for riparian fencing and scrub reversion in the Wairoa catchment.

2.2 Reductions for NPS-FM visual clarity attribute bands

The reductions in suspended sediment load required to meet NPS-FM (2020) suspended fine sediment objectives were estimated following approaches using SedNetNZ from Neverman et al. 2021a, 2021b; Neverman and Smith (2022); Vale et al. (2022); Neverman et al. (2023). These approaches employ a national-scale empirical model relating reductions in average annual suspended sediment load to changes in median visual clarity developed by Hicks et al. (2019). The approach of Hicks et al. (2019) is recommended by the Ministry for the Environment in their guidance for implementing the NPS-FM (2020) sediment requirements (Ministry for the Environment 2022), and directly informed development of the suspended fine sediment attribute for the NPS-FM (2020) (Hicks & Shankar 2020).

The attribute state thresholds (see Table 1) were based on NPS-FM (2020) and the national sediment class map[1] developed for the NPS-FM by Hicks and Shankar (2020).

The proportional reduction in suspended sediment load required to achieve each attribute state was calculated as a function of the difference between the baseline and minimum numeric attribute state for each band:

$$PR_v = 1 - (V_o/V_b)^{1/a} \tag{2}$$

where PR_v is the minimum proportional reduction in load required to achieve the attribute state; V_o is the minimum visual clarity for each band; V_b is the baseline median visual clarity, and assumed a to take the national average reported by Hicks et al. (2019) as –0.76, as recommended by the Ministry for the Environment (2022).

[1] Available from the MfE data portal at https://data.mfe.govt.nz/layer/103687-hydrological-modelling-tosupport-proposed-sediment-attribute-impact-testing-2020/

Table 1. Attribute bands and numeric attribute states for suspended fine sediment. Reproduced from Table 8 in the NPS-FM (2020)

Attribute band and description	Numeric attribute state by suspended sediment class (visual clarity (m))			
	1	2	3	4
A Minimal impact of suspended sediment on instream biota. Ecological communities are similar to those observed in natural reference conditions.	≥1.78	≥0.93	≥2.95	≥1.38
B Low to moderate impact of suspended sediment on instream biota. Abundance of sensitive fish species may be reduced.	<1.78 and ≥1.55	<0.93 and ≥0.76	<2.95 and ≥2.57	<1.38 and ≥1.17
C Moderate to high impact of suspended sediment on instream biota. Sensitive fish species may be lost.	<1.55 and >1.34	<0.76 and >0.61	<2.57 and >2.22	<1.17 and >0.98
National bottom line (NBL)	1.34	0.61	2.22	0.98
D High impact of suspended sediment on instream biota. Ecological communities are significantly altered, and sensitive fish and macroinvertebrate species are lost or at high risk of being lost.	<1.34	<0.61	<2.22	<0.98

The baseline attribute state was determined using the median visual clarity for each SOE site supplied by NIWA (Figure 4). Median visual clarity requires monthly observations over a minimum record length of 5 years (60 samples) and not all sites meet this requirement. Caution is needed when interpreting those sites with less data available. An additional site 'Wairoa River D/S Wastewater Discharge' was excluded from the analysis due to its location close to the river mouth and the strong tidal/saline influence, which is not considered in the suspended fine sediment attribute. 'Wairoa River at Railway Br.', located further upstream, was included despite some tidal influence as it is the only site available to represent the Wairoa catchment as a whole (Figure 4).

Where the baseline visual clarity already achieves NBL, band B or band A, the required reductions for those bands under modelled climate change represent the reductions required to maintain the baseline visual clarity state. This reflects the NPS-FM (2020) policy which requires attribute targets to be set at or above the baseline state and therefore does not allow for deterioration below baseline visual clarity (Ministry for the Environment, 2022).

Table 2. Summary information for SOE sites[a] with estimated visual clarity (CLAR, m) based on black disc measurements in the Wairoa catchment

Site	nzsegment	Suspended sediment class	CLAR (median)	n^b
Hangaroa River at Doneraille Park	8143530	1	0.93	133
Mangaaruhe at Mangaaruhe Station	8155795	2	0.99	22
Mangapoike River at Suspension Bridge	8155822	2	0.95	107
Ruakituri River at Sports Ground	8149195	1	0.83	133
Waiau River at Otoi	8159305	1	0.67	115
Wairoa River at Marumaru	8155540	1	0.71	22
Wairoa River at Railway Br.	8165291	1	0.53	52

[a] nzsegments were corrected for several SOE sites to ensure the appropriate nzsegment and sediment class.

[b] *n* is the number of observations

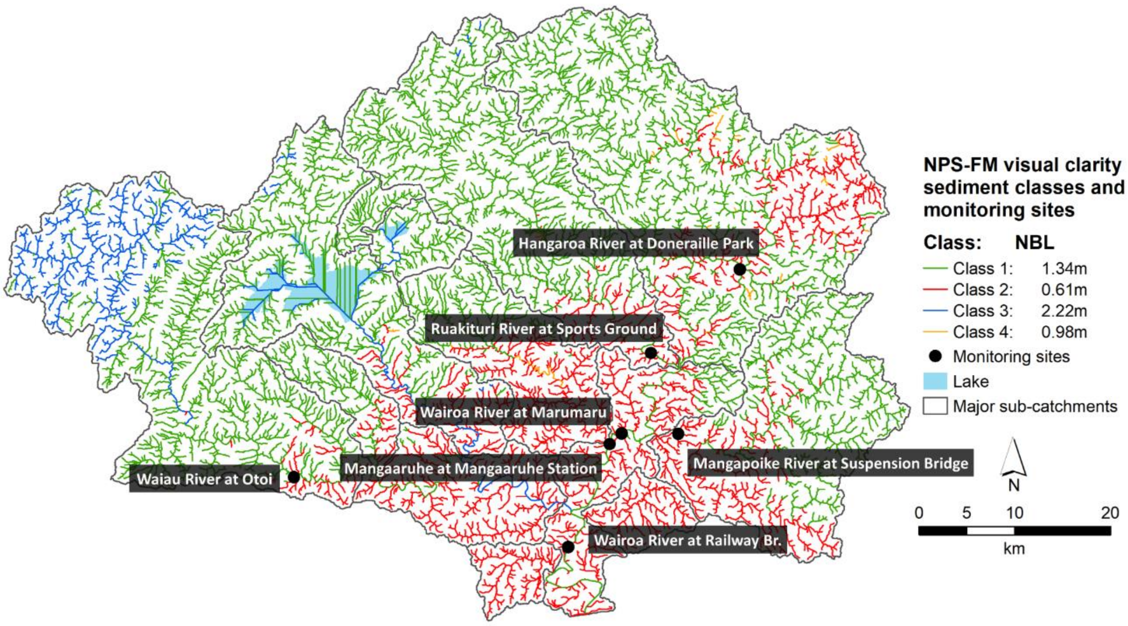

Figure 4. NPS-FM (2020) visual clarity suspended sediment classes and locations of the SOE monitoring sites in the Wairoa catchment.

3 Results

3.1 Best-efforts suspended sediment loads

The modelled mean annual suspended sediment load for the Wairoa catchment reaching the coast amounts to 1.0 Mt/yr under the best-efforts mitigation scenario and contemporary climatic conditions (Table 3). This load is significantly lower (60%) than the recent baseline modelled load of 2.5 Mt/yr under contemporary land cover (Smith et al. 2022).

Major sub-catchment suspended sediment loads include 0.23, 0.30, and 0.17 Mt/yr from the Hangaroa, Waiau, and Mangapoike tributaries, respectively, for the best-efforts scenario (Table 3). This compares to the baseline suspended sediment loads of 0.70, 0.60, and 0.41 Mt/yr from the Hangaroa, Waiau, and Mangapoike tributaries, respectively (Smith et al. 2022). Mean annual net suspended sediment loads are shown with major sub-catchment boundaries in Figure 5. These are net suspended sediment loads that accumulate downstream while accounting for losses of sediment into long-term storage in lakes and on floodplains.

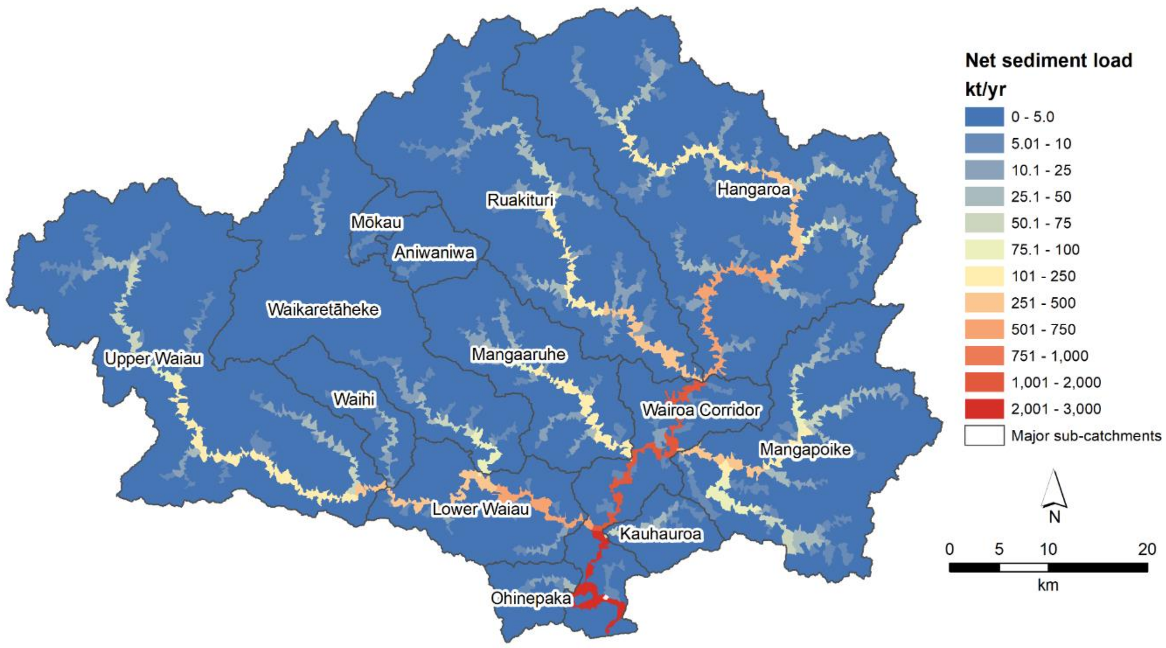

Figure 5. Modelled best-efforts mean annual net suspended sediment load (kt/yr) for each RECv2 sub-catchment across the Wairoa catchment, with the boundaries of major tributaries shown. Net sediment load accounts for lake sediment trapping and floodplain deposition.

Suspended sediment load can be expressed as a sediment yield per RECv2 sub-catchment. Figure 6 shows the spatial pattern in mean annual suspended sediment yield (t/km^2/yr) for each RECv2 sub-catchment. The largest sediment yields typically occur in areas of pastoral hill country on erodible, soft-rock terrain as well as along sections of eroding river channel. Lower sediment yields occur in areas with woody vegetation cover or low slope (Smith et al. 2022). In a few cases, high yields (t/km^2/yr) occur in sub-catchments despite having relatively low erosion (t/yr) due to their very small areas (< 0.05 km^2).

The relative proportion each erosion process contributes to the total erosion changes under the best-efforts mitigation scenario compared to the baseline scenario under contemporary climatic conditions. Total erosion refers to the sum of sediment loads from all erosion processes and does not account for losses of sediment to storage in lakes or on floodplains. Shallow landslide erosion still makes the largest contribution to total erosion on average over a multi-decadal timescale (Figure 7), however the relative proportion is reduced from 71% to 53% for the whole Wairoa catchment. Surficial (41%) and bank (5%) remain the next largest contributors. Among the major sub-catchments, the estimated long-term average contribution of landslides to total erosion varies between 38% and 75%, while surficial erosion ranges between 20% and 62%.

Table 3. Net suspended sediment loads for the whole Wairoa catchment and major sub-catchments for baseline (Smith et al. 2022) and best-efforts scenarios under contemporary climatic conditions

Scenario	Wairoa catchment[a]		Aniwaniwa		Hangaroa		Kauhauroa		Mangaaruhe		Mangapoike		Mōkau		Ohinepaka		Ruakituri		Upper Waiau		Waiau[b]		Waihi		Waikaretāheke	
	Load (kt/yr)	Diff[c] (%)	Load (kt/yr)	Diff[c] (%)	Load (kt/yr)	Diff[c] (%)	Load (kt/yr)	Diff[c] (%)	Load (kt/yr)	Diff[c] (%)	Load (kt/yr)	Diff[c] (%)	Load (kt/yr)	Diff[c] (%)	Load (kt/yr)	Diff[c] (%)	Load (kt/yr)	Diff[c] (%)	Load (kt/yr)	Diff[c] (%)	Load (kt/yr)	Diff[c] (%)	Load (kt/yr)	Diff[c] (%)	Load (kt/yr)	Diff[c] (%)
Baseline	2,540	-	6.8	-	701	-	55	-	236	-	409	-	7.4	-	35	-	376	-	299	-	602	-	23	-	99	-
Best-efforts	1,002	-60	6.8	-0	226	-68	19	-65	75	-68	172	-58	7.4	-0	11	-68	161	-57	189	-37	302	-50	10	-57	45	-55

[a] 'Wairoa catchment' refers to the whole catchment draining to the coast and includes net sediment contributions from the 'Wairoa corridor' sub-catchment shown in Figures 5–7.

[b] Suspended sediment loads reported for the Waiau include net contributions from its sub-catchments (i.e. upper Waiau, lower Waiau, Waihi, Waikaretāheke, Mōkau, Aniwaniwa).

[c] 'Diff' refers to the percentage difference between the sediment load under best-efforts compared to the baseline load.

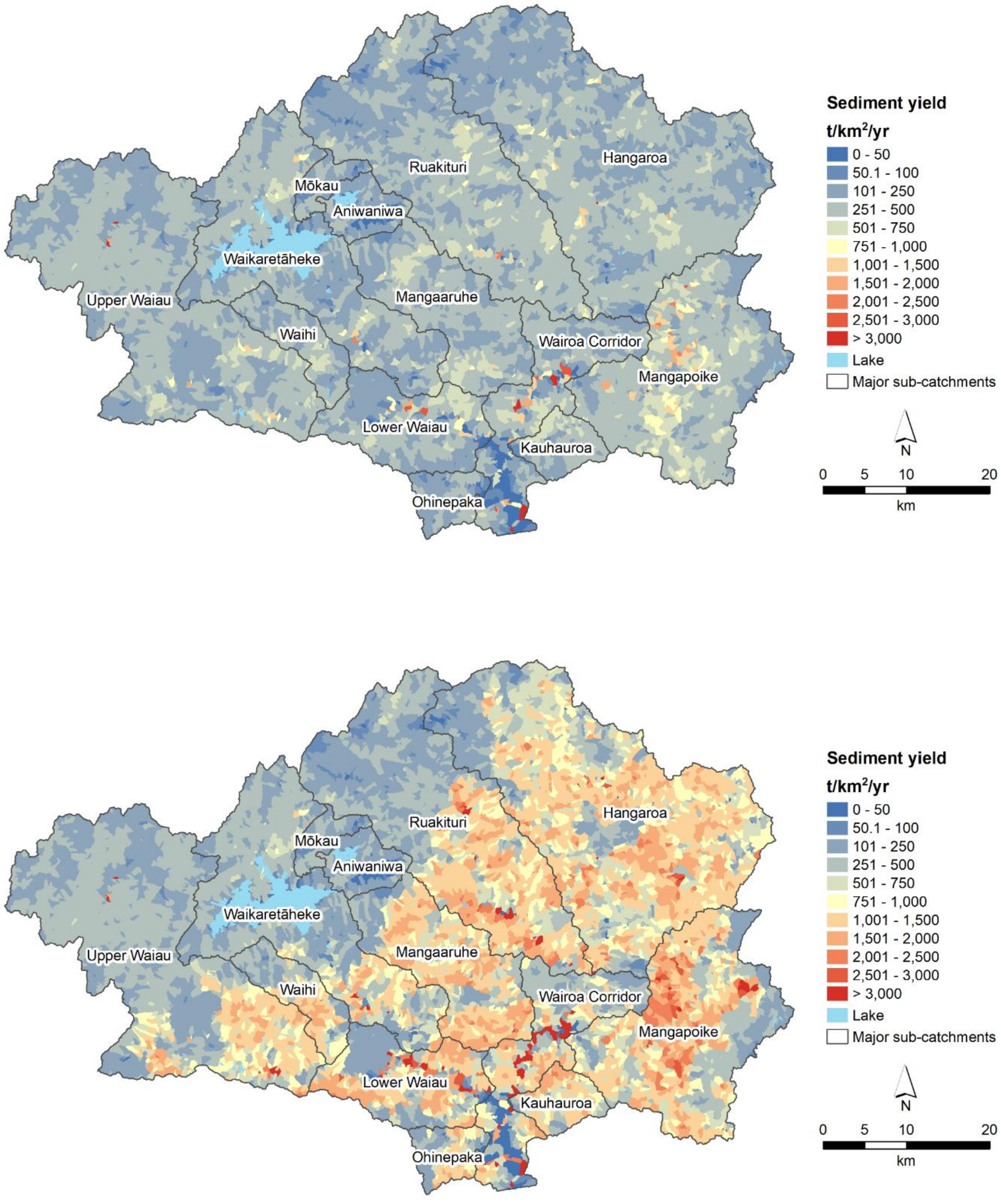

Figure 6. Modelled best-efforts mitigation scenario (top) and baseline (Smith et al. 2022) (bottom) suspended sediment yield (t/km^2/yr) for each RECv2 sub-catchment in the Wairoa catchment.

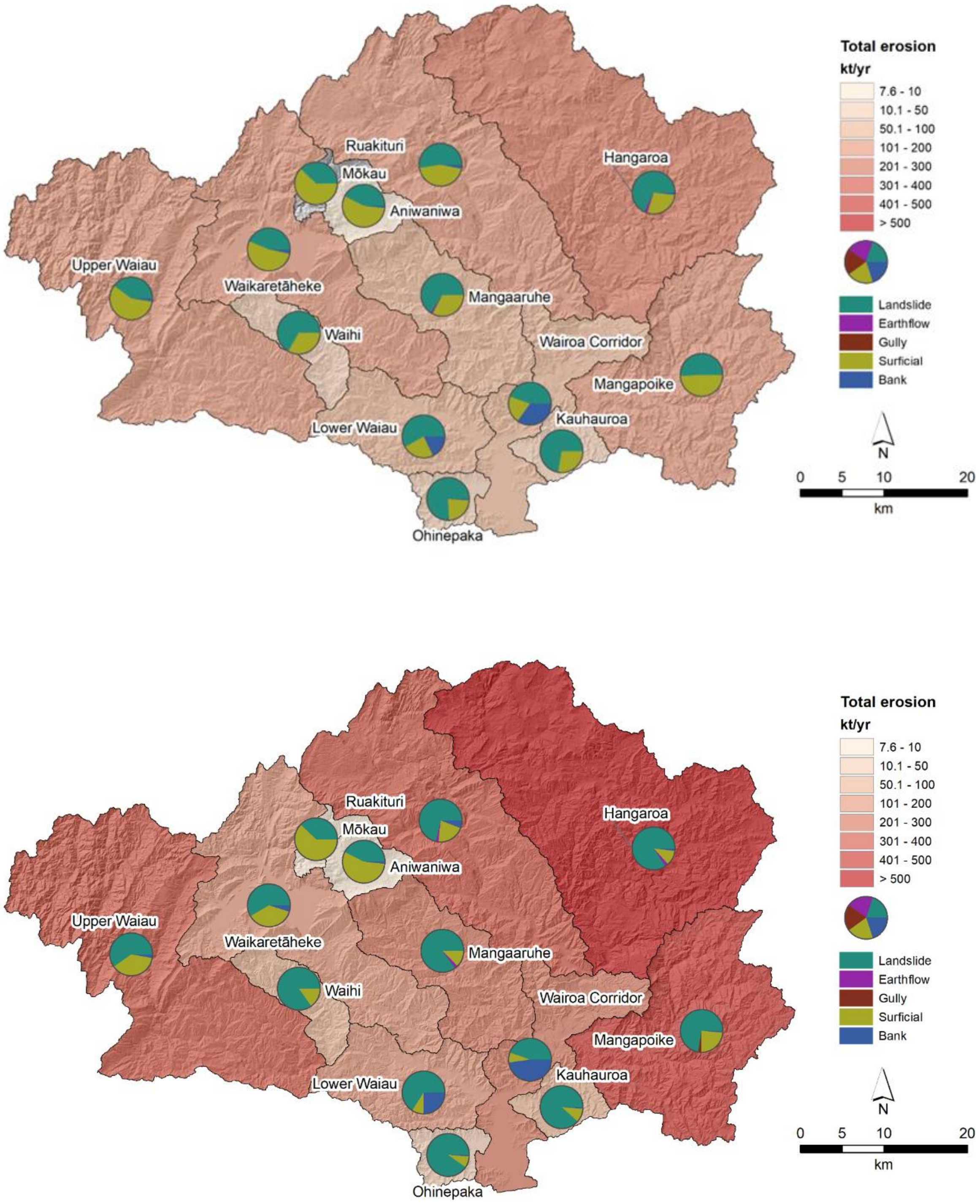

Figure 7. Modelled best-efforts mitigation scenario (top) and baseline (Smith et al. 2022) (bottom) total erosion (kt/yr) and erosion process load contributions for major sub-catchments in the Wairoa catchment. Total erosion represents the sum of sediment loads from all erosion processes and does not account for losses of sediment to storage in lakes or on floodplains.

3.2 Climate change impacts on suspended sediment loads

The modelled climate change projections produce a wide range of predicted changes in suspended sediment loads. This reflects the variability between climate models and the diverging climate trajectories represented by each RCP (Smith et al. 2022). RCP2.6 represents a mitigation pathway resulting in the lowest sediment load increases, with late century loads lower than mid-century in many cases. Both RCP4.5 and RCP6.0 are stabilisation pathways, while RCP8.5 represents a pathway with very high greenhouse gas concentrations that results in the largest projected increases in sediment load.

For the Wairoa catchment, the mean annual suspended sediment load delivered to the coast is projected to increase from 2.5Mt/yr to 2.8–3.5 Mt/yr and 2.7–4.3 Mt/yr by mid-century and late century, respectively, across the range of RCPs without intervention (Smith et al. 2022). These changes correspond to increases of 10%–37% and 7%–69% compared to the contemporary baseline sediment load by mid-century and late century, respectively. In contrast, the best-efforts scenario is predicted to reduce sediment loads under climate change by 51%–57% (Table 4) and 43–58% (Table 5) by mid- and late century, respectively, relative to the contemporary baseline. These results suggest the widespread application of erosion mitigation measures may more than offset potential increases in suspended sediment load due to climate change.

Figure 8 shows the difference between the lower and upper projected increases in sediment yields by comparing RCP2.6 (minimum) versus RCP8.5 (maximum) at mid- and late century for both the baseline and best-efforts scenarios. This figure spatially highlights the contrast between significant increases in sediment yield under baseline versus the widespread reductions achieved under the best-efforts scenario for mid- and late century.

As with the baseline scenario (Smith et al., 2022), major sub-catchments show significant variation in the projected sediment loads for the best-efforts scenario at mid- (Table 4) and late (Table 5) century. The implementation of best-effort erosion mitigation reverses the previously projected sediment load increases for major sub-catchments currently dominated by pasture (Smith et al. 2022). This outcome reflects the widespread extent of mitigation measures applied in these sub-catchments.

Those sub-catchments that are predominantly forested (i.e. Aniwaniwa and Mōkau) previously exhibited the smallest proportional increases in suspended sediment loads with climate change (Smith et al. 2022). Under the best-efforts scenario, these sub-catchments now show the largest proportional increases in load compared to the contemporary baseline because they have minimal areas to mitigate. Nonetheless, the Aniwaniwa and Mōkau sub-catchments continue to exhibit the lowest sediment yields (t/km^2/yr) compared to the other major sub-catchments, demonstrating the comparative resilience of forested versus pasture areas to climate change impacts on sediment loads.

Table 4. Net suspended sediment loads for the whole Wairoa catchment and major sub-catchments under the best-efforts scenario and projected climate change at mid-century

Time period	RCP	Selected RCMs[a]	Wairoa catchment[b]		Aniwaniwa[c]		Hangaroa		Kauhauroa		Mangaaruhe		Mangapoike		Mōkau[c]		Ohinepaka		Ruakituri		Upper Waiau		Waiau[d]		Waihi		Waikaretāheke	
			Load (kt/yr)	Diff[e] (%)	Load (kt/yr)	Diff[e] (%)	Load (kt/yr)	Diff[e] (%)	Load (kt/yr)	Diff[e] (%)	Load (kt/yr)	Diff[e] (%)	Load (kt/yr)	Diff[e] (%)	Load (kt/yr)	Diff[e] (%)	Load (kt/yr)	Diff[e] (%)	Load (kt/yr)	Diff[e] (%)	Load (kt/yr)	Diff[e] (%)	Load (kt/yr)	Diff[e] (%)	Load (kt/yr)	Diff[e] (%)	Load (kt/yr)	Diff[e] (%)
Recent		Baseline	2,540	-	6.8	-	701	-	55	-	236	-	409	-	7.4	-	35	-	376	-	299	-	602	-	23	-	99	-
		Best-efforts	1,002	-60	6.8	0	226	-68	19	-65	75	-68	172	-58	7.4	0	11	-68	161	-57	189	-37	302	-50	10	-57	45	-55
Mid-century	2.6	Min [GISS-E2-R]	1,091	-57	7.4	9	249	-64	21	-61	82	-65	189	-54	8.0	9	13	-64	176	-53	206	-31	330	-45	11	-52	50	-50
		Median	1,086	-57	7.2	6	256	-63	22	-61	83	-65	181	-56	7.8	6	13	-63	177	-53	197	-34	322	-47	11	-52	50	-49
		Max [HadGEM2-ES]	1,129	-55	7.4	9	267	-62	23	-59	87	-63	187	-54	8.2	11	14	-61	182	-52	208	-31	338	-44	12	-49	52	-47
	4.5	Min [GISS-E2-R]	1,172	-54	8.0	18	270	-62	23	-59	89	-62	203	-50	8.8	19	13	-61	190	-50	223	-26	354	-41	12	-48	53	-47
		Median	1,188	-53	8.0	17	276	-61	24	-57	90	-62	209	-49	8.7	18	14	-60	192	-49	220	-27	352	-42	12	-48	53	-46
		Max [HadGEM2-ES]	1,173	-54	7.6	12	280	-60	24	-57	91	-61	195	-52	8.3	13	14	-59	188	-50	213	-29	349	-42	12	-46	54	-45
	6.0	Min [NorESM1-M]	1,148	-55	7.7	13	267	-62	22	-59	85	-64	206	-50	8.4	14	13	-63	186	-50	211	-30	337	-44	11	-51	51	-49
		Median	1,130	-55	7.4	9	267	-62	23	-59	87	-63	191	-53	8.1	10	13	-62	182	-52	205	-32	334	-45	12	-50	51	-48
		Max [HadGEM2-ES]	1,186	-53	7.7	13	285	-59	24	-56	92	-61	196	-52	8.4	15	14	-58	191	-49	214	-29	351	-42	12	-46	55	-44
	8.5	Min [BCC-CSM1.1]	1,159	-54	7.7	13	277	-61	23	-58	90	-62	193	-53	8.4	14	14	-61	190	-49	208	-30	340	-44	12	-48	53	-46
		Median	1,209	-52	8.1	18	286	-59	24	-56	93	-61	203	-50	8.8	20	14	-59	197	-48	220	-27	357	-41	12	-46	55	-44
		Max [HadGEM2-ES]	1,244	-51	8.1	19	302	-57	26	-53	98	-58	198	-52	8.8	20	15	-56	201	-46	224	-25	369	-39	13	-42	58	-41

[a] RCMs were selected for inclusion in the table based on minimum, median, and maximum total erosion across the whole Wairoa catchment. The median is represented by the mid-point between the middle two RCMs.

[b] 'Wairoa catchment' refers to the whole catchment draining to the coast and includes net sediment contributions from the 'Wairoa corridor' sub-catchment shown in Figures 5–7.

[c] The selected RCMs do not consistently equate to the equivalent min/median/max values for Aniwaniwa and Mōkau due to relative differences in total erosion between RCMs at sub-catchment versus catchment scales. For consistency, we present sediment load results for the selected RCMs across all sub-catchments, which allows comparison between sub-catchments for the same RCM.

[d] Suspended sediment loads reported for the Waiau include net contributions from its sub-catchments (i.e. upper Waiau, lower Waiau, Waihi, Waikaretāheke, Mōkau, Aniwaniwa).

[e] 'Diff' refers to the percentage difference between the best-efforts sediment load and best-efforts sediment load under climate change compared to the recent baseline load.

Table 5. Net suspended sediment loads for the whole Wairoa catchment and major sub-catchments under the best-efforts scenario and projected climate change at late century

Time period	RCP	Selected RCMs[a]	Wairoa catchment[b] Load (kt/yr)	Wairoa catchment[b] Diff[e] (%)	Aniwaniwa[c] Load (kt/yr)	Aniwaniwa[c] Diff[e] (%)	Hangaroa Load (kt/yr)	Hangaroa Diff[e] (%)	Kauhauroa Load (kt/yr)	Kauhauroa Diff[e] (%)	Mangaaruhe Load (kt/yr)	Mangaaruhe Diff[e] (%)	Mangapoike Load (kt/yr)	Mangapoike Diff[e] (%)	Mōkau[c] Load (kt/yr)	Mōkau[c] Diff[e] (%)	Ohinepaka Load (kt/yr)	Ohinepaka Diff[e] (%)	Ruakituri Load (kt/yr)	Ruakituri Diff[e] (%)	Upper Waiau[3] Load (kt/yr)	Upper Waiau[3] Diff[e] (%)	Waiau[d] Load (kt/yr)	Waiau[d] Diff[e] (%)	Waihi Load (kt/yr)	Waihi Diff[e] (%)	Waikaretāheke Load (kt/yr)	Waikaretāheke Diff[e] (%)
Recent		Baseline	2,540	-	6.8	-	701	-	55	-	236	-	409	-	7.4	-	35	-	376	-	299	-	602	-	23	-	99	-
		Best-efforts	1,002	-60	6.8	0	226	-68	19	-65	75	-68	172	-58	7.4	0	11	-68	161	-57	189	-37	302	-50	10	-57	45	-55
Late century	2.6	Min [GISS-E2-R]	1,083	-57	7.6	11	244	-65	21	-62	82	-65	186	-55	8.2	12	12	-65	174	-54	213	-29	336	-44	11	-52	50	-50
		Median	1,063	-58	7.2	5	249	-64	21	-62	82	-65	174	-57	7.8	7	13	-64	174	-54	198	-34	320	-47	11	-52	49	-50
		Max [CESM1-CAM5]	1,171	-54	7.7	13	276	-61	24	-57	90	-62	201	-51	8.3	12	14	-60	188	-50	213	-29	345	-43	12	-48	53	-46
	4.5	Min [GISS-E2-R]	1,145	-55	7.7	12	268	-62	23	-59	87	-63	200	-51	8.3	13	13	-62	185	-51	213	-29	341	-43	12	-50	52	-48
		Median	1,178	-54	7.7	13	280	-60	24	-57	91	-62	202	-51	8.4	14	14	-60	191	-49	210	-30	344	-43	12	-48	54	-46
		Max [CESM1-CAM5]	1,264	-50	8.2	21	305	-56	26	-54	99	-58	211	-48	8.7	19	15	-56	202	-46	229	-24	374	-38	13	-42	59	-41
	6.0	Min [NorESM1-M]	1,201	-53	7.7	14	288	-59	24	-56	92	-61	208	-49	8.4	14	14	-59	195	-48	210	-30	344	-43	12	-48	54	-46
		Median	1,249	-51	8.1	18	301	-57	25	-54	97	-59	207	-49	8.8	19	15	-57	201	-47	223	-26	366	-39	13	-43	58	-41
		Max [HadGEM2-ES]	1,336	-47	8.6	27	324	-54	27	-51	103	-56	221	-46	9.4	28	16	-53	213	-43	243	-19	397	-34	14	-38	62	-37
	8.5	Min [GISS-E2-R]	1,374	-46	9.0	32	333	-53	28	-49	107	-55	230	-44	9.8	33	17	-52	222	-41	248	-17	404	-33	14	-37	63	-36
		Median	1,407	-45	8.9	31	352	-50	29	-47	111	-53	227	-44	9.7	32	18	-49	228	-39	244	-19	406	-33	15	-35	66	-34
		Max [GFDL-CM3]	1,455	-43	9.0	32	371	-47	31	-44	117	-50	230	-44	9.8	33	19	-46	237	-37	244	-19	414	-31	16	-32	69	-30

[a] RCMs were selected for inclusion in the table based on minimum, median, and maximum total erosion across the whole Wairoa catchment. The median is represented by the mid-point between the middle two RCMs.

[b] 'Wairoa catchment' refer to the whole catchment draining to the coast and includes net sediment contributions from the 'Wairoa corridor' sub-catchment shown in Figures 5–7.

[c] The selected RCMs do not consistently equate to the equivalent min/median/max values for Aniwaniwa, Mōkau and upper Waiau due to relative differences in total erosion between RCMs at sub-catchment versus catchment scales. For consistency, we present sediment load results for the selected RCMs across all sub-catchments, which allows comparison between sub-catchments for the same RCM.

[d] Suspended sediment loads reported for the Waiau include net contributions from its sub-catchments (i.e. upper Waiau, lower Waiau, Waihi, Waikaretāheke, Mōkau, Aniwaniwa).

[e] 'Diff' refers to the percentage difference between the best-efforts sediment load and best-efforts sediment load under climate change compared to the recent baseline load.

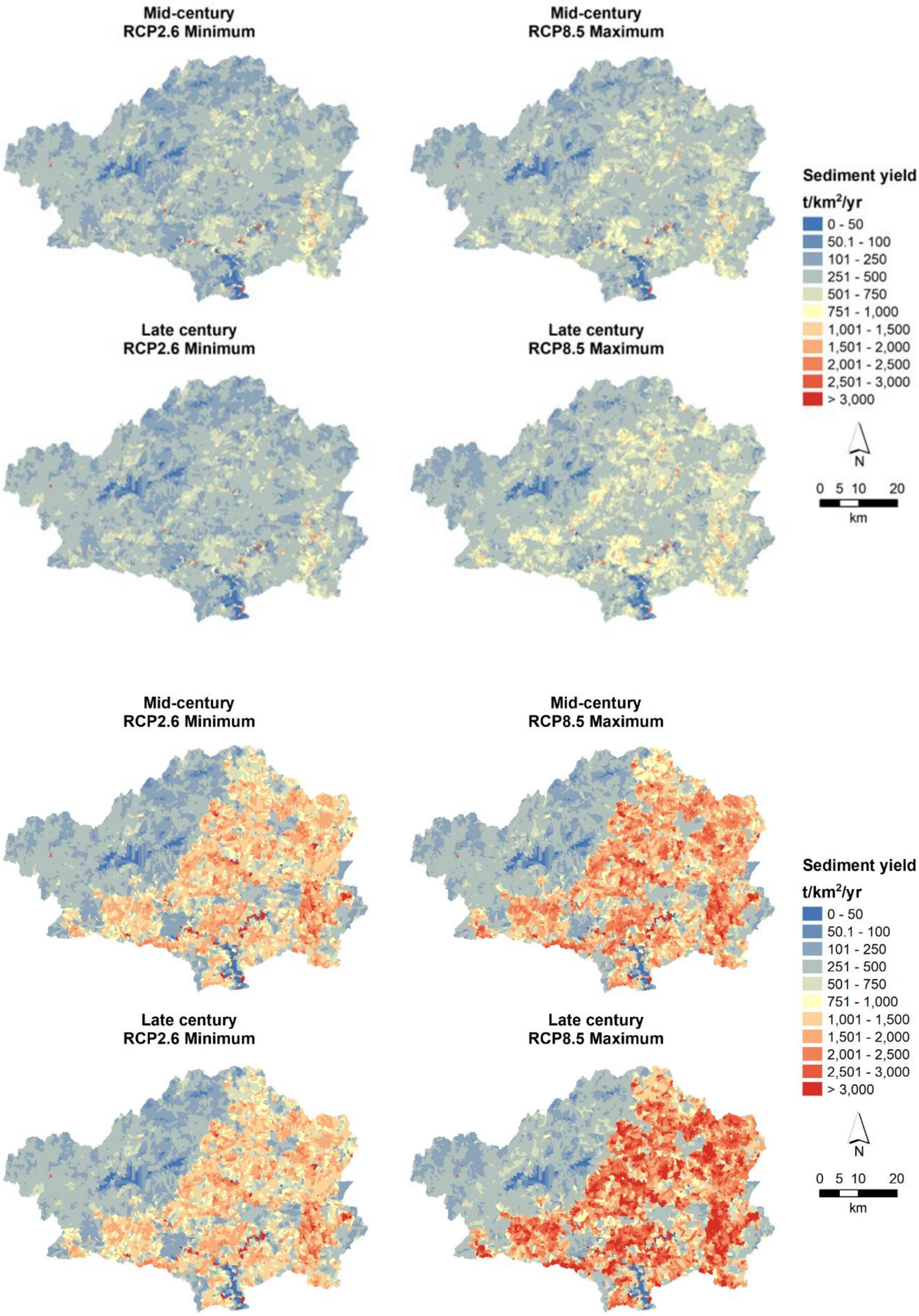

Figure 8. Modelled best-efforts (top) and baseline (Smith et al. 2022) (bottom) suspended sediment yields (t/km^2/yr) for each RECv2 sub-catchment for selected climate change scenarios across the Wairoa catchment.

3.3 Load reductions for NPS-FM visual clarity attribute bands

Baseline and best-efforts mitigation scenarios under contemporary climate conditions

Suspended sediment load reductions required to achieve NPS-FM 2020 suspended fine sediment attribute bands were modelled as proportional reductions for seven SOE sites across the Wairoa catchment for both the baseline and best-effort mitigation scenarios.

Baseline attribute states for each SOE site were determined using the median measured visual clarity provided by NIWA (Table 6). Of the seven sites, two sites, 'Mangaaruhe at Mangaaruhe Station' and 'Mangapoike River at Suspension Bridge' have a band A baseline state, while the remaining five have a band D state (i.e. below NBL) (Table 6). The suspended sediment class assigned to each site based on the national map developed by Hicks and Shankar (2020) has an important effect on the baseline attribute state and visual clarity thresholds required to achieve each attribute band. 'Mangaaruhe at Mangaaruhe Station' and 'Mangapoike River at Suspension Bridge' are both sediment class 2, while the five remaining sites achieving band D are sediment class 1. Under baseline conditions, 'Mangaaruhe at Mangaaruhe Station' and 'Mangapoike River at Suspension Bridge' sites require no further reductions under baseline conditions. The remaining sites achieving band D require proportional reductions ranging from 8%–70%, 49%–76%, and 57%–80% to achieve NBL, band B, and band A, respectively.

Under the best-efforts mitigation scenario, two sites, 'Waiau River at Otoi' and 'Wairoa River at Railway Br.', were not able to achieve NBL and require proportional load reductions of 48% and 26%, respectively. 'Mangaaruhe at Mangaaruhe Station' and 'Mangapoike River at Suspension Bridge' and one additional site, 'Hangaroa River at Doneraille Park', achieve band A under the best-efforts mitigation scenario. The remaining sites require proportional reductions of 15%–64% to achieve band A under the best-efforts mitigation scenario.

The 'Wairoa River at Railway Br.' site, which is most closely related to the end-of-catchment load, has the lowest baseline visual clarity, and requires a 70% reduction to achieve NBL under the baseline conditions which decreases to a 26% reduction under the best-efforts mitigation scenario. This site experiences tidal influence which may affect the visual clarity measurements.

Table 6. SOE site information for the Wairoa catchment and proportional reductions (%) in suspended sediment load required to achieve NPS-FM (2020) suspended fine sediment attribute bands for visual clarity at each site under baseline and best-efforts mitigation scenarios for contemporary climatic conditions ("-" indicates no further reduction in load is required)

Site Name			**Hangaroa River at Doneraille Park**	**Mangaaruhe at Mangaaruhe Station**	**Mangapoike River at Suspension Bridge**	**Ruakituri River at Sports Ground**	**Waiau River at Otoi**	**Wairoa River at Marumaru**	**Wairoa River at Railway Br.**
nzsegment			8143530	8155795	8155822	8149195	8159305	8155540	8165291
Sediment Class			1	2	2	1	1	1	1
Visual clarity (CLAR, m)			0.93	0.99	0.95	0.83	0.67	0.71	0.53
Baseline attribute state			D	A	A	D	D	D	D
Proportional reduction to achieve NBL or band	NBL	Baseline	38	-	-	47	60	57	70
		Best-efforts	-	-	-	-	48	-	26
	Band B	Baseline	49	-	-	56	67	64	76
		Best-efforts	-	-	-	-	57	6	39
	Band A	Baseline	57	-	-	63	72	70	80
		Best-efforts	-	-	-	15	64	21	49

Baseline and best-efforts mitigation scenarios under future climate change

The proportional suspended sediment load reductions required to achieve NBL are provided for each SOE site across the modelled climate change projections for the baseline and best-efforts mitigation scenarios in Tables 7 and 8, respectively. Proportional suspended sediment load reductions required to achieve band B and band A under future climate change are shown in Appendix A. Where the baseline visual clarity already achieved NBL, band B or band A thresholds, the proportional reductions under modelled climate change represent the reductions required to maintain the baseline visual clarity state. This reflects the NPS-FM (2020) policy which requires attribute targets to be set at or above the baseline state and, therefore, does not allow for deterioration below baseline visual clarity (Ministry for the Environment 2022).

Under the baseline scenario with future climate change, 'Mangaaruhe at Mangaaruhe Station' and 'Mangapoike River at Suspension Bridge' require 10%–31% and 8%–45% sediment load reductions to maintain baseline visual clarity by mid-century and late century, across the range of RCPs (Table 7; Appendix A: Table A1, Table A2). The remaining sites, require proportional reductions ranging from 45%–79% and 43%–83% for NBL (Table 7), 55%–82% and 53%–86% for band B (Appendix A: Table A1), and 62%–85% and 61%–88% for band A (Appendix A: Table A2), by mid-century and late century, respectively, across all RCPs.

Under the best-efforts mitigation scenario with future climate change, proportional load reductions required to achieve NBL, band B, and band A remain at 0% for 'Mangaaruhe at Mangaaruhe Station' and 'Mangapoike River at Suspension Bridge' by mid- and late century, across the range of RCPs (Table 8, Appendix A: Tables A3 and A4). The remaining sites require proportional reductions ranging from 0–56% and 0–59%, for NBL (Table 8), 0–63% and 0–66% for band B (Appendix A: Table A3), and 0–69% and 0–72% for band A (Appendix A: Table A4), by mid-century and late century, respectively. 'Hangaroa River at Doneraille Park', 'Ruakituri River at Sports Ground', and 'Wairoa River at Marumaru' show the largest improvement under best-practice mitigation and either achieve or are close to achieving NBL for the range of RCPs. 'Hangaroa River at Doneraille Park' was able to achieve band A by mid-century and late century.

Table 7. Proportional reductions (%) in suspended sediment load required to achieve NBL (or maintain baseline state) at Wairoa SOE sites under the baseline scenario and projected climate change at mid- and late century ("-" indicates no further load reduction required to achieve NBL)

NBL	Time period	RCP	Selected RCMs	Hangaroa River at Doneraille Park	Mangaaruhe at Mangaaruhe Station	Mangapoike River at Suspension Bridge	Ruakituri River at Sports Ground	Waiau River at Otoi	Wairoa River at Marumaru	Wairoa River at Railway Br.
Baseline	Mid-century	2.6	Min [GISS-E2-R]	45	10	10	52	63	61	73
			Median	48	15	12	54	63	63	74
			Max [HadGEM2-ES]	51	21	16	56	65	64	76
		4.5	Min [GISS-E2-R]	49	17	17	56	66	64	75
			Median	51	19	19	57	66	65	76
			Max [HadGEM2-ES]	54	25	20	58	66	66	77
		6.0	Min [NorESM1-M]	48	14	16	55	65	63	74
			Median	51	19	16	56	64	64	75
			Max [HadGEM2-ES]	55	26	21	59	66	67	77
		8.5	Min [BCC-CSM1.1]	53	22	18	58	65	66	76
			Median	54	24	22	59	67	67	77
			Max [HadGEM2-ES]	58	31	25	62	68	69	79
	Late century	2.6	Min [GISS-E2-R]	43	8	8	51	64	60	73
			Median	47	14	9	53	63	61	74
			Max [CESM1-CAM5]	52	21	18	57	65	65	76
		4.5	Min [GISS-E2-R]	49	16	16	55	65	64	75
			Median	53	23	21	58	65	66	76
			Max [CESM1-CAM5]	57	30	26	61	68	69	78
		6.0	Min [NorESM1-M]	54	23	22	59	65	67	77
			Median	58	30	26	61	68	69	78
			Max [HadGEM2-ES]	61	35	31	64	70	71	80
		8.5	Min [GISS-E2-R]	61	36	33	65	71	71	80
			Median	65	41	36	67	71	73	81
			Max [GFDL-CM3]	67	45	39	69	72	75	83

Table 8. Proportional reductions (%) in suspended sediment load required to achieve NBL (or maintain baseline state) at Wairoa SOE sites under the best-efforts mitigation scenario and projected climate change at mid- and late century ("-" indicates no further load reduction required to achieve NBL)

NBL	Time period	RCP	Selected RCMs	Hangaroa River at Doneraille Park	Mangaaruhe at Mangaaruhe Station	Mangapoike River at Suspension Bridge	Ruakituri River at Sports Ground	Waiau River at Otoi	Wairoa River at Marumaru	Wairoa River at Railway Br.
Best-efforts	Mid-century	2.6	Min [GISS-E2-R]	-	-	-	-	52	-	32
			Median	-	-	-	-	49	-	32
			Max [HadGEM2-ES]	-	-	-	-	52	-	34
		4.5	Min [GISS-E2-R]	-	-	-	-	56	3	37
			Median	-	-	-	-	55	5	38
			Max [HadGEM2-ES]	-	-	-	-	53	3	37
		6.0	Min [NorESM1-M]	-	-	-	-	53	2	36
			Median	-	-	-	-	51	-	34
			Max [HadGEM2-ES]	-	-	-	-	53	4	38
		8.5	Min [BCC-CSM1.1]	-	-	-	-	52	3	36
			Median	-	-	-	-	54	6	39
			Max [HadGEM2-ES]	-	-	-	1	55	8	40
	Late century	2.6	Min [GISS-E2-R]	-	-	-	-	54	-	32
			Median	-	-	-	-	50	-	30
			Max [CESM1-CAM5]	-	-	-	-	53	4	37
		4.5	Min [GISS-E2-R]	-	-	-	-	53	1	35
			Median	-	-	-	-	52	4	37
			Max [CESM1-CAM5]	-	-	-	2	56	10	41
		6.0	Min [NorESM1-M]	-	-	-	-	52	7	38
			Median	-	-	-	1	54	9	41
			Max [HadGEM2-ES]	-	-	-	6	58	15	45
		8.5	Min [GISS-E2-R]	-	-	-	10	59	18	46
			Median	-	-	-	13	58	20	47
			Max [GFDL-CM3]	-	-	-	16	57	23	49

3.4 Model limitations

An evaluation of the SedNetNZ model, erosion process representation, and climate change projections was provided in Smith et al. (2022). A summary of limitations related to the best-efforts mitigation scenario and sediment load reductions required to achieve the NPS-FM (2020) attribute bands is given below.

Best-efforts mitigation

Significant uncertainty exists regarding the effectiveness of the erosion mitigations represented in the best-efforts scenario. The effectiveness for each erosion mitigation uses values from previous SedNetNZ modelling, which are based on best available information from literature. More data on the effectiveness of different types of erosion mitigation are needed to improve the prediction of sediment load reduction, especially if values can be derived from local data.

The best-efforts scenario also assumes mitigation measures are fully implemented and fully matured, and that this has been achieved by mid-century and late century. In practice, this is unlikely to allow sufficient time for full implementation and maturation of tree plantings, given the time required to complete this type of work and for trees to grow. Thus, the best-efforts scenario should be viewed as testing the limits of what sediment load reductions may be achievable rather than a projection of the rate at which mitigations may be completed.

Reductions required to meet visual clarity attribute bands

Proportional reductions in mean annual suspended sediment load required to achieve the visual clarity objectives were estimated using an empirical model relating improvements in clarity to reductions in sediment load (Hicks et al. 2019), as recommended by Ministry for the Environment (2022). This model was fitted to a national data set that should include a wide range of catchment variables and represent the variability across the Wairoa catchment. However, this may lead to under- or over-estimation of required reductions at any one site due to local variability in the relationship between suspended sediment concentration and visual clarity. This variability arises due to variations in sediment characteristics between sites, such as differences in the proportion of fine-grained clay minerals which dominate light attenuation by sediments (Davies-Colley & Smith 2001). This relationship assumes visual clarity at any site is primarily affected by the suspended sediment concentration and does not account for the potential influence of other matter, such as tannins or waste discharges. Additionally, visual clarity thresholds are based on the sediment class assigned to the RECv2 segment. This can lead to abrupt changes in target thresholds between adjacent RECv2 segments.

The model also assumes the relationship between suspended sediment concentration and flow remains consistent at a site. Warrick (2015) and Hicks et al. (2016) illustrated that changes in sediment load may not affect the shape of the relationship between suspended sediment concentration and flow, particularly when catchment hydrology is unaltered. However, changes in catchment land cover or climate may affect the relationship between flow and suspended sediment concentration due to changes in catchment hydrology

(Hicks et al. 2019). As data are not presently available to model the effects of these changes on the relationship between suspended sediment concentration and flow, we assume that the relationship remains constant.

4 Conclusions

Suspended sediment loads across the Wairoa catchment were significantly reduced under a best-efforts mitigation scenario. The modelled mean annual suspended sediment load delivered to the coast under the best-efforts scenario amounted to 1.0 Mt/yr, which corresponds to a 60% reduction in load from 2.5 Mt/yr for recent baseline conditions. Under climate change, the best-efforts scenario is projected to reduce sediment loads by 51%–57% and 43%–58% by mid-century and late century, respectively, relative to the recent baseline. The widespread application of erosion mitigation measures more than offsets potential future increases in suspended sediment load due to climate change.

The SOE sites 'Mangaaruhe at Mangaaruhe Station' and 'Mangapoike River at Suspension Bridge' achieve a baseline attribute state of band A and require no further reductions. The remaining sites are classed as band D and require proportional load reductions ranging 38%–70% to achieve NBL under baseline conditions. Under the best-efforts mitigation scenario, two sites – 'Waiau River at Otoi' and 'Wairoa River at Railway Br.'– were not able to achieve NBL and require further proportional reductions of 48% and 26%, respectively.

Under the baseline scenario with future climate change, 'Mangaaruhe at Mangaaruhe Station' and 'Mangapoike River at Suspension' require load reductions of 10%–31% and 8%–45% to maintain baseline visual clarity by mid-century and late century, across the range of RCPs. Under the best-efforts scenario these sites achieve band A. The remaining sites under the baseline scenario require proportional load reductions of 45%–79% and 43%–83% to achieve NBL by mid-century and late century, respectively, across the range of RCPs. Under best-efforts mitigation, the required reductions decrease to 0%–56% and 0%–59% to achieve NBL by mid-century and late century, respectively, across the range of RCPs.

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Appendix A – Proportional reductions (%) in suspended sediment load required to achieve band B and band A (or maintain baseline state) for suspended fine sediment under projected climate change at mid-century and late-century

Table A1. Proportional reductions (%) in suspended sediment load required to achieve band B (or maintain baseline state) at Wairoa SOE sites under the 'baseline' scenario and projected climate changes at mid- and late century ("-" indicates no further load reduction required to achieve band B)

Band B	Time period	RCP	Selected RCMs	Hangaroa River at Doneraille Park	Mangaaruhe at Mangaaruhe Station	Mangapoike River at Suspension Bridge	Ruakituri River at Sports Ground	Waiau River at Otoi	Wairoa River at Marumaru	Wairoa River at Railway Br.
Baseline	Mid-century	2.6	Min [GISS-E2-R]	55	10	10	60	70	68	78
			Median	57	15	12	62	69	69	79
			Max [HadGEM2-ES]	60	21	16	64	71	71	80
		4.5	Min [GISS-E2-R]	58	17	17	63	72	70	79
			Median	59	19	19	64	72	71	80
			Max [HadGEM2-ES]	62	25	20	66	72	72	81
		6.0	Min [NorESM1-M]	57	14	16	62	71	70	79
			Median	59	19	16	64	70	70	80
			Max [HadGEM2-ES]	63	26	21	66	72	73	81
		8.5	Min [BCC-CSM1.1]	61	22	18	65	71	72	80
			Median	62	24	22	66	72	72	81
			Max [HadGEM2-ES]	65	31	25	68	74	74	82
	Late century	2.6	Min [GISS-E2-R]	53	8	8	59	70	67	77
			Median	56	14	9	61	69	68	78
			Max [CESM1-CAM5]	60	21	18	64	71	71	80
		4.5	Min [GISS-E2-R]	58	16	16	63	71	70	79
			Median	61	23	21	65	71	72	81
			Max [CESM1-CAM5]	65	30	26	68	74	74	82
		6.0	Min [NorESM1-M]	62	23	22	66	71	72	81
			Median	65	30	26	68	73	74	82
			Max [HadGEM2-ES]	68	35	31	70	76	76	83
		8.5	Min [GISS-E2-R]	68	36	33	71	76	76	84
			Median	71	41	36	73	76	78	85
			Max [GFDL-CM3]	73	45	39	75	77	79	86

Table A2. Proportional reductions (%) in suspended sediment load required to achieve band A (or maintain baseline state) at Wairoa SOE sites under the 'baseline' scenario and projected climate changes at mid- and late century ("-" indicates no further load reduction required to achieve band A)

Band A	Time period	RCP	Selected RCMs	Hangaroa River at Doneraille Park	Mangaaruhe at Mangaaruhe Station	Mangapoike River at Suspension Bridge	Ruakituri River at Sports Ground	Waiau River at Otoi	Wairoa River at Marumaru	Wairoa River at Railway Br.
Baseline	Mid-century	2.6	Min [GISS-E2-R]	62	10	10	67	75	73	82
			Median	64	15	12	68	74	74	82
			Max [HadGEM2-ES]	66	21	16	70	76	75	83
		4.5	Min [GISS-E2-R]	65	17	17	69	77	75	83
			Median	66	19	19	70	77	76	83
			Max [HadGEM2-ES]	68	25	20	71	77	77	84
		6.0	Min [NorESM1-M]	64	14	16	69	76	75	82
			Median	66	19	16	70	75	75	83
			Max [HadGEM2-ES]	69	26	21	72	77	77	84
		8.5	Min [BCC-CSM1.1]	68	22	18	71	76	76	84
			Median	68	24	22	72	77	77	84
			Max [HadGEM2-ES]	71	31	25	74	78	79	85
	Late century	2.6	Min [GISS-E2-R]	61	8	8	66	75	72	81
			Median	63	14	9	68	74	73	82
			Max [CESM1-CAM5]	67	21	18	70	76	76	83
		4.5	Min [GISS-E2-R]	65	16	16	69	76	75	83
			Median	68	23	21	71	76	77	84
			Max [CESM1-CAM5]	71	30	26	73	78	78	85
		6.0	Min [NorESM1-M]	68	23	22	72	76	77	84
			Median	71	30	26	73	78	78	85
			Max [HadGEM2-ES]	73	35	31	75	80	80	86
		8.5	Min [GISS-E2-R]	73	36	33	76	80	80	86
			Median	76	41	36	77	80	82	87
			Max [GFDL-CM3]	77	45	39	79	80	83	88

Table A3. Proportional reductions (%) in suspended sediment load required to achieve band B (or maintain baseline state) at Wairoa SOE sites under the 'best-efforts' mitigation scenario and projected climate changes at mid- and late century ("-" indicates no further load reduction required to achieve band B)

Band B	Time period	RCP	Selected RCMs	Hangaroa River at Doneraille Park	Mangaaruhe at Mangaaruhe Station	Mangapoike River at Suspension Bridge	Ruakituri River at Sports Ground	Waiau River at Otoi	Wairoa River at Marumaru	Wairoa River at Railway Br.
Best-efforts	Mid-century	2.6	Min [GISS-E2-R]	-	-	-	6	60	14	44
			Median	-	-	-	7	58	14	44
			Max [HadGEM2-ES]	-	-	-	10	60	17	46
		4.5	Min [GISS-E2-R]	-	-	-	14	63	20	48
			Median	-	-	-	15	63	22	49
			Max [HadGEM2-ES]	-	-	-	13	61	20	48
		6.0	Min [NorESM1-M]	-	-	-	12	61	19	47
			Median	-	-	-	10	60	17	46
			Max [HadGEM2-ES]	-	-	-	14	61	21	48
		8.5	Min [BCC-CSM1.1]	-	-	-	14	60	20	47
			Median	-	-	-	17	62	23	49
			Max [HadGEM2-ES]	-	-	-	18	63	24	51
	Late century	2.6	Min [GISS-E2-R]	-	-	-	6	62	12	44
			Median	-	-	-	6	58	11	42
			Max [CESM1-CAM5]	-	-	-	13	61	20	48
		4.5	Min [GISS-E2-R]	-	-	-	11	61	19	47
			Median	-	-	-	14	60	21	48
			Max [CESM1-CAM5]	-	-	-	19	64	26	52
		6.0	Min [NorESM1-M]	-	-	-	16	60	23	49
			Median	-	-	-	18	62	25	51
			Max [HadGEM2-ES]	-	-	-	23	66	30	54
		8.5	Min [GISS-E2-R]	-	-	-	26	66	32	56
			Median	-	-	-	28	65	34	57
			Max [GFDL-CM3]	4	-	-	31	65	37	58

Table A4. Proportional reductions (%) in suspended sediment load required to achieve band A (or maintain baseline state) at Wairoa SOE sites under the 'best-efforts' mitigation scenario and projected climate changes at mid- and late century ("-" indicates no further load reduction required to achieve band A)

Band A	Time period	RCP	Selected RCMs	Hangaroa River at Doneraille Park	Mangaaruhe at Mangaaruhe Station	Mangapoike River at Suspension Bridge	Ruakituri River at Sports Ground	Waiau River at Otoi	Wairoa River at Marumaru	Wairoa River at Railway Br.
Best-effort	Mid-century	2.6	Min [GISS-E2-R]	-	-	-	22	67	28	53
			Median	-	-	-	22	65	28	53
			Max [HadGEM2-ES]	-	-	-	25	67	30	55
		4.5	Min [GISS-E2-R]	-	-	-	28	69	33	57
			Median	-	-	-	29	69	35	57
			Max [HadGEM2-ES]	-	-	-	27	67	33	57
		6.0	Min [NorESM1-M]	-	-	-	27	68	33	56
			Median	-	-	-	25	66	31	55
			Max [HadGEM2-ES]	-	-	-	28	67	34	57
		8.5	Min [BCC-CSM1.1]	-	-	-	28	67	33	56
			Median	-	-	-	30	69	36	58
			Max [HadGEM2-ES]	1	-	-	32	69	37	59
	Late century	2.6	Min [GISS-E2-R]	-	-	-	21	68	27	53
			Median	-	-	-	21	65	26	52
			Max [CESM1-CAM5]	-	-	-	27	68	34	56
		4.5	Min [GISS-E2-R]	-	-	-	26	68	32	56
			Median	-	-	-	28	67	34	57
			Max [CESM1-CAM5]	2	-	-	32	70	38	60
		6.0	Min [NorESM1-M]	-	-	-	30	67	36	58
			Median	<1	-	-	32	69	38	59
			Max [HadGEM2-ES]	8	-	-	36	71	42	62
		8.5	Min [GISS-E2-R]	10	-	-	38	72	44	63
			Median	15	-	-	40	71	45	64
			Max [GFDL-CM3]	20	-	-	42	71	47	65