Manaaki Whenua
Landcare Research

SedNetNZ modelling to assess sediment contributions from natural land cover areas and impacts of climate change in Taranaki

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Contents

Summary

Project and client

- Taranaki Regional Council (TRC) previously contracted Manaaki Whenua – Landcare Research (MWLR) to model mean annual suspended sediment loads under different land cover scenarios (Neverman et al. 2021).
- Reductions in mean annual suspended sediment load required to meet the National Policy Statement for Freshwater Management 2020 (NPS-FM (2020)) suspended fine sediment attribute states (visual clarity) were also modelled at selected water quality monitoring sites (Neverman et al. 2021), and the future attribute state estimated for the future soil conservation scenario consisting of fully implemented and mature Whole Farm Plans (WFPs).
- TRC subsequently requested MWLR estimate the impact of projected climate change on sediment loads at the selected water quality monitoring sites reported in Neverman et al. (2021) for the contemporary baseline and future soil conservation scenarios; and that they also estimate the contribution of natural land cover areas to modelled loads.
- The work on contributions from natural cover areas and climate change impacts was completed under Envirolink Medium advice grants 2305-TRC004 and 2308-TRC005, respectively.

Objectives

- Model the effects of climate change on erosion and suspended sediment loads for mid-century and late century for:
  - a the contemporary baseline scenario (2018 land cover and the extent and maturity of soil conservation works completed to date)
  - b the future soil conservation scenario (fully implemented and matured soil conservation works).
- Compare model results with and without the effect of climate change to assess the extent to which soil conservation measures mitigate projected impacts from climate change.
- Assess compliance with the NPS-FM (2020) for suspended fine sediment at selected water quality monitoring sites for the future soil conservation scenario under projected climate change.
- Estimate the contribution of natural cover areas to suspended sediment loads at selected water quality monitoring sites for the contemporary baseline and future soil conservation scenarios.
- Compare natural cover load contributions with the estimated load reductions required to achieve the NPS-FM (2020) attribute bands for suspended fine sediment reported in Neverman et al. (2021).

Methods

- The effect of projected climate change on region-wide erosion and suspended sediment loads was modelled for the contemporary baseline and future soil conservation scenarios using future rainfall and temperature estimates 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.
- Changes in sediment loads under projected climate change were assessed at selected water quality monitoring sites. The changes in load for the future soil conservation scenario were compared to the load reductions required to achieve the national bottom line (NBL) in the NPS-FM (2020), or improve the attribute state of the monitoring site, to assess potential future compliance with the NPS-FM (2020). Where monitoring sites are projected to degrade under future climate, load reductions required to maintain the baseline state are reported.
- Suspended sediment load contributions from natural cover areas were estimated at selected water quality monitoring sites for the contemporary baseline and future soil conservation scenarios described in Neverman et al. (2021). The land cover classes from the New Zealand Landcover Database (LCDBv5) were classified as natural or non-natural. The load derived from each class was accumulated downstream to monitoring sites, accounting for floodplain deposition and storage in lakes.

Results

- Climate change is projected to increase mean annual suspended sediment load delivered to the Taranaki coast by between 13% and 57% at mid-century, and 7% and 108% by late century, if no further reductions were achieved from soil conservation works under the contemporary scenario. This equates to an increase from the baseline 1.7 Mt/yr to 1.9–2.7 Mt/yr and 1.8–3.5 Mt/yr by mid-century and late century, respectively.
- Under the future soil conservation scenario, the load delivered to the Taranaki coast is projected to range from 1.6–2.3 Mt/yr by mid-century, and 1.6–3.0 Mt/yr by late century under projected climate change. This equates to a difference of -32% to -3% by mid-century and of -35% to +28% by late century, compared to the pre-mitigation baseline. It equates to a difference of -3% to +37% by mid- century and of -8% to +81% by late century, compared to the contemporary baseline.
- Six of the seven monitoring sites with a baseline state in band A are projected to remain in band A under projected climate change. The Waingongoro River at SH45 is estimated to improve in attribute state from band C to band A or B for lower greenhouse gas emission pathways. Four sites (29%) are projected to have declines in attribute band by mid-century, and five sites (35%) by late century.
- By late century, the Mangaoraka Stream at Corbett Rd, Pātea River at Barclay Rd Bridge, Pātea River at Skinner Rd Bridge, and Waiwhakaiho River at SH3 are projected to have lower sediment loads than their baseline state across all RCPs. Three sites (Mangaehu River at Raupuha Rd Bridge, Waingongoro River at Eltham Rd Bridge, and

Waingongoro River at SH45) require additional reductions in load to maintain their baseline state for RCPs 4.5, 6.0, and 8.5.

- Waiokura pumphouse, Whenuakura River at Nicholson Rd, and Waitara River at Autawa Rd are projected to have increases in load across all climate projections by late century and therefore require further reductions to achieve the NBL.
- Natural cover areas contribute less than 1%–56% of contemporary suspended sediment loads, and less than 1%–60% of future soil conservation scenario sediment loads under baseline climate conditions. At the monitoring sites, 44%–100% of contemporary suspended sediment loads are derived from non-natural cover areas. This suggests the load reductions required at most sites (except the Whenuakura River at Nicholson Rd) to improve their attribute state are less than the load coming from non-natural cover areas, where mitigations may be feasible. Proportional load contributions from natural and non-natural land covers are comparable under baseline climate and projected climate change.

Conclusions and recommendations

- Continued investment in soil conservation works for erosion mitigation will be required to reduce potentially significant impacts of climate change on suspended sediment loads by late century.
- Compared to the pre-mitigation baseline, fully implemented and mature soil conservation works may offset the effects of climate change at late century for greenhouse gas pathways up to RCP6.0 for the total load delivered to the coast across Taranaki. Soil conservation works may offset the impacts of climate change at 50% of monitoring sites across all climate projections by late century.
- Due to the extent of soil conservation works assumed to be implemented by 2018, additional conservation works from the contemporary baseline appear to have less impact, but do still offset climate change under some projections.
- It is likely the capacity for sediment load reductions in the future has been underestimated due to an overestimation of the extent and maturity of soil conservation works implemented in the contemporary baseline scenario. This modelling could be improved with regional data on the extent to which soil conservation works outlined in WFPs have been completed, and their level of maturity.
- The availability of regional LiDAR and S-Map data will enable better representation of erosion processes within SedNetNZ. Future work could update SedNetNZ using these data. Future load estimates may be updated when downscaled CMIP6 projections become available for New Zealand.

1 Introduction

Taranaki Regional Council (TRC) previously contracted Manaaki Whenua – Landcare Research (MWLR) to model mean annual suspended sediment loads under different land cover scenarios (Neverman et al. 2021). This included a) an initial baseline using 1996 land cover without specific representation of soil conservation works, representing a pre-mitigation state; b) a contemporary baseline using 2018 land cover and erosion mitigations implemented to date; c) a future soil conservation scenario consisting of fully implemented and matured best practice soil conservation works. Reductions in mean annual suspended sediment load required to meet the National Policy Statement for Freshwater Management 2020 (NPS-FM 2020) (Ministry for the Environment 2022) suspended fine sediment attribute states (visual clarity) were also modelled at selected water quality monitoring sites (Neverman et al. 2021); future attribute state was estimated for the future soil conservation scenario.

Subsequently, TRC requested MWLR estimate the impact of projected climate change at the selected water quality monitoring sites reported in Neverman et al. (2021) for the contemporary baseline and future soil conservation scenarios; and estimate the contribution of natural land cover areas to suspended sediment loads.

2 Background

Neverman et al. (2021) estimated there had been a 29% reduction in suspended sediment loads delivered to the Taranaki coast since soil conservation works were first implemented in 1996, and that a total reduction of 40% may be achievable once all soil conservation works have been fully implemented and matured. However, this analysis did not consider the potential effects of climate change on erosion and suspended sediment loads.

Since the completion of the previous work in the Taranaki region (Neverman et al. 2021), SedNetNZ has been updated to include the capability to model changes in erosion and sediment loads under projected climate change (Smith et al. 2022; Vale et al. 2022). SedNetNZ models the effect of climate change on erosion processes individually before combining the loads to route through the stream network. This allows erosion processes to respond in different directions and with different magnitudes depending on the response of their primary hydro-climatic driver to future climate. Spatial variation in the net effect of climate change on erosion is therefore reflected in catchment loads (Neverman et al. 2023).

3 Objectives

- Model the effects of climate change on erosion and suspended sediment loads at mid-century and late century for:
  a. the contemporary baseline scenario (2018 land cover and the extent and maturity of soil conservation works completed to date)

b the future soil conservation scenario (fully implemented and matured soil conservation works).

- Compare model results with and without the effect of climate change to assess the extent to which soil conservation measures mitigate projected climate change impacts on soil erosion and suspended sediment loads.
- Assess compliance with the NPS-FM (2020) for suspended fine sediment at selected water quality monitoring sites for the future soil conservation scenario under projected climate change.
- Estimate the contribution of natural cover areas to suspended sediment loads at selected water quality monitoring sites for the contemporary baseline and future soil conservation scenarios.
- Compare natural cover load contributions with the estimated load reductions required to achieve the NPS-FM (2020) attribute bands for suspended fine sediment reported in Neverman et al. (2021).

4 Methods

The SedNetNZ model and land cover scenarios are described in Neverman et al. (2021). The same SedNetNZ model configuration was used for the contemporary baseline and future soil conservation scenarios but with additional functions to model the effects of climate change, and a spatial ruleset to determine the location of natural cover areas. These additions are described below.

4.1 Impacts of climate change

We modelled the effect of projected climate change on erosion and suspended sediment loads following Vale et al. (2022), Smith et al. (2022), and Neverman et al. (2023). Erosion and suspended sediment loads were modelled for mid-century (the 2031–2050 period, represented by 2040), and late century (the 2080–2100 period, represented by 2090) using climate outputs from CMIP5 (Coupled Model Inter-comparison Project) global climate models (GCMs) coupled with the New Zealand Regional Climate Model (NZRCM) (Sood 2014) for downscaling and bias correction (Ministry for the Environment 2018). The downscaled projections are referred to as regional climate models (RCMs). Downscaled CMIP6 projections are not yet available for New Zealand. Shrestha et al. (2013) and Eekhout & de Vente (2022) recommend using multiple GCMs to account for model uncertainty. We used outputs from six GCMs (BCC-CSM1.1, CESM1-CAM5, GFDL-CM3, GISS-E2-R, HadGEM2-ES, and NorESM1-M), chosen for their performance, availability of data, and difference in parent global models to represent the range of model sensitivity (Collins et al. 2018; Ministry for the Environment 2018).

To account for the uncertainty in future CO_2 concentrations, four scenarios (representative concentration pathways, or RCPs (van Vuuren et al. 2011)) from the IPCC's fifth assessment report (IPCC 2013) were used to drive each RCM. The RCPs represent different radiative forcing based on greenhouse gas trajectories (Table 1; Ministry for the Environment 2018). The RCPs represent total radiative forcing of 2.6 W/m^2 (a mitigation pathway), 4.5 W/m^2

and 6.0 W/m^2 (stabilisation pathways), and 8.5 W/m^2 (continual increase scenario), referred to as RCP2.6, RCP4.5, RCP6.0, and RCP8.5, respectively. Variations in the RCPs become more evident after mid-century (Figure 1). Each RCM-RCP pair is referred to as a 'climate projection'.

Table 1. Representative concentration pathways and their descriptions

Representative concentration pathway (RCP)	Description
2.6	Mitigation scenario, requiring removal of CO_2 from the atmosphere
4.5	Intermediate scenario where CO_2 concentrations stabilise
6.0	Intermediate scenario where CO_2 concentrations stabilise
8.5	Continual increase in CO_2 concentrations (representing a worst-case scenario)

Source: Based on Ministry for the Environment 2018.

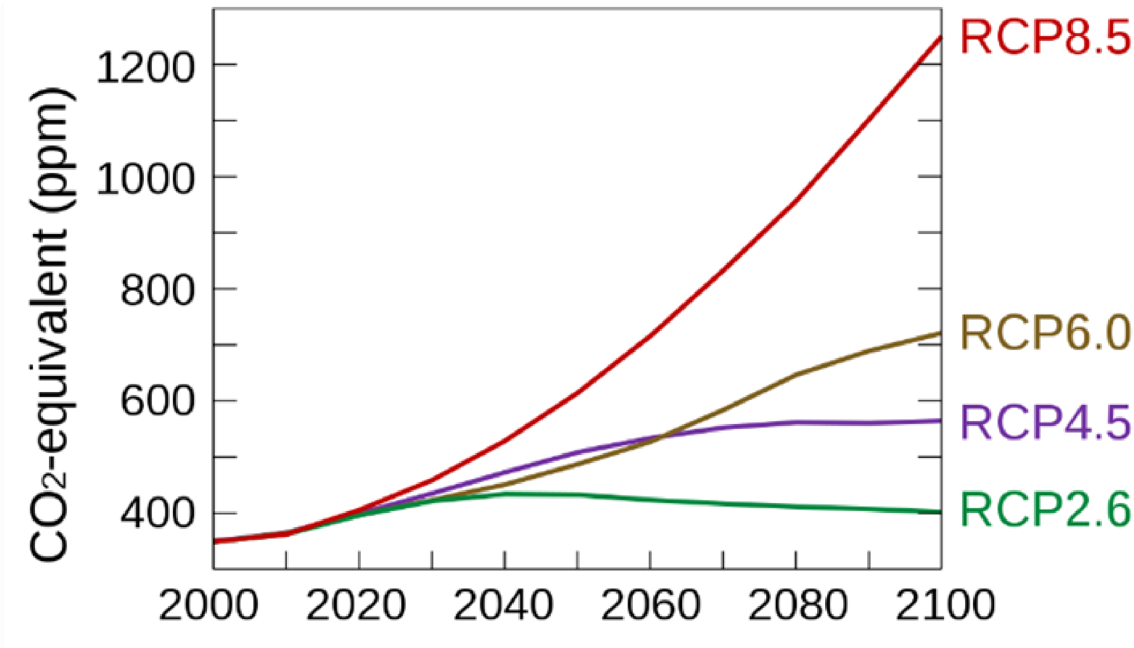

Figure 1. CO_2-equivalent concentration pathways through time, referred to as representative concentration pathways (RCPs), based on the IPCC's fifth assessment report (IPCC 2013).

The effect of climate change on erosion processes is represented in SedNetNZ using different hydro-climatic variables to drive changes in individual erosion processes following Neverman et al. (2023). In the hillslope domain, changes in surficial erosion are modelled for each climate projection using the estimated change in mean annual rainfall to directly adjust P in the NZUSLE (see Equation 1 in Neverman et al. 2021). In New Zealand's soft-rock hill country sediment loads are dominated by mass movement erosion, usually in the form of storm-triggered shallow landslides (Page et al. 1994; Trustrum et al. 1999; Basher 2013). Mass movement erosion (shallow landslides, gullies, and earthflows) is therefore assumed to change as a function of changes in storm rainfall depth resulting from changes in the magnitude and frequency of landslide-triggering storm events, following the relationship between total storm rainfall and landslide density identified by Reid and Page (2003). Carey-Smith et al. (2018) recommend using a uniform augmentation factor based on change in temperature to estimate future storm rainfall for New Zealand. We therefore calculate future storm rainfall as:

$$R' = R(1 + \Delta T\ AF) \tag{1}$$

where R' is future rainfall (mm), R is historical rainfall (mm), ΔT is future change in temperature relative to baseline (°C), and AF is the augmentation factor. AF is derived from the estimated change in rainfall depth per 1°C increase in temperature for a 30-year average recurrence interval rainfall event of 48 hours duration, which is assumed to represent the dominant landslide-triggering event (Basher et al. 2020; Neverman et al. 2023), giving a value of 0.073 for AF (Ministry for the Environment 2018). Rain gauges with complete records for the last 50 years were selected from CliFlo (NIWA 2021) and used to represent historic rainfall. At each gauge, Equation 1 was used to calculate R' under a range of temperature increases.

Storm events were identified in the baseline and future rainfall records as consecutive days where rainfall exceeded a breakpoint of 10 mm/day. The storms were considered landslide producing events if >150 mm of rain fell in a 48-hour period during the event (Basher et al. 2020; Neverman et al. 2023). The density of shallow landslides produced in each rainfall record was estimated using the relationship between total storm rainfall and shallow landslide density identified by Reid and Page (2003):

$$LD = mP_s + b \tag{2}$$

where LD is the density of shallow landslides (n landslides/km^2), P_s is the total rainfall for the storm event (mm), m is the slope of the linear relationship between LD and P_s, set to 0.72 (Basher et al. 2020; Neverman et al. 2023), and b is the y-intercept of the relationship, calculated by solving for b under the assumption LD = 0 when $P_s \leq 150$ mm:

$$0 = 150m + b$$

$$b = -136.8 \tag{3}$$

Linear models were developed for the relationship between LD and ΔT at each rain gauge location:

$$LD' = a\Delta T + LD \tag{4}$$

where LD' is the future landslide density (n landslides/km^2), a is the slope of the linear relationship between ΔT and LD', and therefore the absolute change in landslide density per 1°C of temperature change; and LD is the landslide density for the baseline rainfall record, R.

The mass movement change factor, CF, was then determined at each rain gauge as the proportional increase in landslide density per 1°C of temperature change, calculated as:

$$CF = \frac{a}{LD} \tag{5}$$

CF was interpolated spatially using Sibson's (1981) natural neighbours interpolation.

Future rates of mass movement, MM', were calculated by augmenting the baseline mass movement rate, MM, by CF and the change in temperate, ΔT, such that:

$$MM' = MM(1 + CF\Delta T) \quad (6)$$

where MM represents the hillslope mass movement dominated processes, EL, EE, and EG, from Equations 8, 9, 10 in Neverman et al. (2021).

The effect of climate change on bank erosion was based on estimated changes in mean annual flood (MAF) for each climate projection per stream segment. Linear relationships between bank migration rates and discharge or stream power have been illustrated by empirical and modelling studies (Richard et al. 2005; Larsen et al. 2006; Nicoll & Hickin 2010; Hooke 2012, 2015). Mean annual flood has been used previously as a spatial predictor of bank erosion in New Zealand (Dymond et al. 2016; Smith et al. 2019; Neverman et al. 2023).

Future net suspended sediment loads from bank erosion (t/yr) for the jth stream segment under climate change (B_j') were estimated as

$$B_j' = B_j \Delta MAF_j \quad (7)$$

where B_j is the baseline net suspended sediment load from bank erosion (equation 11, Neverman et al. 2021) and ΔMAF_j is a dimensionless change factor based on the change in MAF between the baseline and future climate projections. This relationship assumes channel resistance and geometry remain constant (Neverman et al. 2023).

Future changes in MAF were estimated from hydrological modelling that simulated flows over successive 20-year periods for each RCM (Collins et al. 2018; Collins 2020) and computed proportional changes in future MAF relative to a historical baseline period (1986–2005). These predicted proportional changes in future MAF were available as the median across the six RCMs for each RCP but not for individual RCMs (Neverman et al. 2023). We therefore use these median values for each RCP.

Future mean annual suspended sediment loads were computed for mid-century (2031–2050, represented by 2040) and late century (2080–2100, represented by 2090) for each RCM and RCP. Projected changes in sediment loads for each RCP at mid-century and late century are reported as the upper, lower, and median across the six RCMs for each water quality monitoring site.

4.1.1 NPS-FM 2020 compliance at selected water quality monitoring sites

Future compliance with the NPS-FM (2020) suspended fine sediment bands ('attribute states') at selected water quality monitoring sites was assessed by comparing the projected change in sediment load with the estimated change in load required to achieve a different band. We use the approach developed by Hicks et al. (2019) to estimate the proportional change in sediment load required to change the band from the baseline state. 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 same approach was used in Neverman et al. (2021). As suspended sediment loads may increase under future climate conditions, with a decrease in visual clarity, we extended the work of Neverman et al. (2021) to also calculate the increase in suspended sediment load required for the attribute state to decline at each monitoring site.

Following Hicks et al. (2019) and Ministry for the Environment (2022), the proportional change in sediment load required to achieve a target visual clarity is a function of the ratio between the baseline visual clarity and the target visual clarity:

$$P_v = (V_o/V_b)^{1/a} - 1 \tag{8}$$

where P_v is the minimum proportional change in mean annual suspended sediment load required to achieve the target visual clarity, V_o is the target median visual clarity (measured in metres (m)), and V_b is the baseline median visual clarity (in m). We followed the recommendation of Ministry for the Environment (2022) and assumed a takes the national average reported by Hicks et al. (2019) of -0.76. To assess the minimum proportional change in sediment load required to improve the attribute band, we used the lower bound visual clarity for each band (Table 2) for V_o; the upper bound was used to assess the minimum change in load required for a decline in state from a higher band.

We also report the load reductions required under future climate to improve the attribute state from baseline. For sites with projected increases in load under future climate, and therefore a degraded visual clarity state, we report the reduction in future load required to return the site to 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).

The numeric attribute states for suspended fine sediment are determined by the 'sediment class' associated with each River Environment Classification v2 (RECv2) digital river network segment (Table 2), as defined in Appendix 2C of the NPS-FM (2020). The sediment class of a given segment is determined by the climate, topography, and geology classification (as defined in the REC) of upstream segments predominately contributing flow to a given segment. Neverman et al. (2021) used the layer denoting suspended sediment class for the RECv2 digital stream network produced by Hicks & Shankar (2020)[1] to identify the sediment class of each monitoring site. The dominant suspended sediment class at monitoring sites in Taranaki is class 1, with a median visual clarity at the national bottom line (NBL) of 1.34 m (Table 2). The proportional change in mean annual suspended sediment load required to achieve the target visual clarity, P_v, was then applied to the

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

contemporary mean annual sediment load to calculate the absolute change in load required to achieve the target attribute state.

Table 2. Attribute bands and associated numeric attribute states for suspended fine sediment, reproduced from the NPS-FM (2020). Note the use of visual clarity (m) as the attribute unit

Value (and component)	Ecosystem health (Water quality)			
Freshwater body type	Rivers			
Attribute unit	Visual clarity (metres)			
Attribute band and description	**Numeric attribute state by suspended sediment class**			
	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	**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 minimum record length for grading a site is the median of 5 years of at least monthly samples (at least 60 samples).

Councils may monitor turbidity and convert the measures to visual clarity.

See Appendix 2C Tables 23 and 26 for the definition of suspended sediment classes and their composition.

The following are examples of **naturally occurring processes** relevant for suspended sediment:

- naturally highly coloured brown-water streams
- glacial flour affected streams and rivers
- selected lake-fed REC classes (particularly warm climate classes) where low visual clarity may reflect autochthonous phytoplankton production.

4.2 Contributions from natural cover areas

The 2018 land cover from the New Zealand Landcover Database (LCDB) version 5 (Newsome et al. 2008) was used for both the contemporary baseline and future soil conservation scenarios in Neverman et al. (2021). It was also used to classify areas of natural land cover in the present report. Table 3 lists the LCDB 2018 cover classes present in Taranaki, and whether they are classified as natural or non-natural cover. As this analysis aimed to identify the proportion of the sediment load that would not typically be reduced by erosion mitigation measures the natural cover classification includes areas of native woody vegetation, natural bare ground, and other land cover classes not routinely targeted for erosion mitigation.

The LCDB has a minimum mapping unit of 1 ha, thus natural or non-natural cover areas of <1 ha could not be classified in this analysis. For instance, areas of woody vegetation established on pastoral or cropland as part of Whole Farm Plans (WFPs) for erosion control that were <1 ha have not been included as natural cover. The spatial extent of natural and non-natural cover is illustrated in Figure 2.

Table 3. The LCDBv5 2018 land cover classes present in Taranaki, and their classification as natural cover for this analysis

Class name	LCDB Class code	Natural cover
Built-up Area (settlement)	1	No
Urban Parkland/Open Space	2	No
Transport Infrastructure	5	No
Surface Mine or Dump	6	No
Sand or Gravel	10	Yes
Landslide	12	Yes
Alpine Grass/Herbfield	15	Yes
Gravel or Rock	16	Yes
Lake or Pond	20	Yes
River (water)	21	Yes
Estuarine Open Water	22	Yes
Short-rotation Cropland	30	No
Orchards, Vineyards or Other Perennial Crops	33	No
High Producing Exotic Grassland	40	No
Low Producing Grassland	41	No
Tall Tussock Grassland	43	Yes
Herbaceous Freshwater Vegetation	45	Yes
Herbaceous Saline Vegetation	46	Yes
Flaxland	47	Yes
Fernland	50	Yes
Gorse and/or Broom	51	Yes
Manuka and/or Kanuka	52	Yes
Broadleaved Indigenous Hardwoods	54	Yes
Sub Alpine Shrubland	55	Yes
Mixed Exotic Shrubland	56	Yes
Matagouri or Grey Scrub	58	Yes
Forest - Harvested	64	No
Deciduous Hardwoods	68	Yes
Indigenous Forest	69	Yes
Exotic Forest	71	No

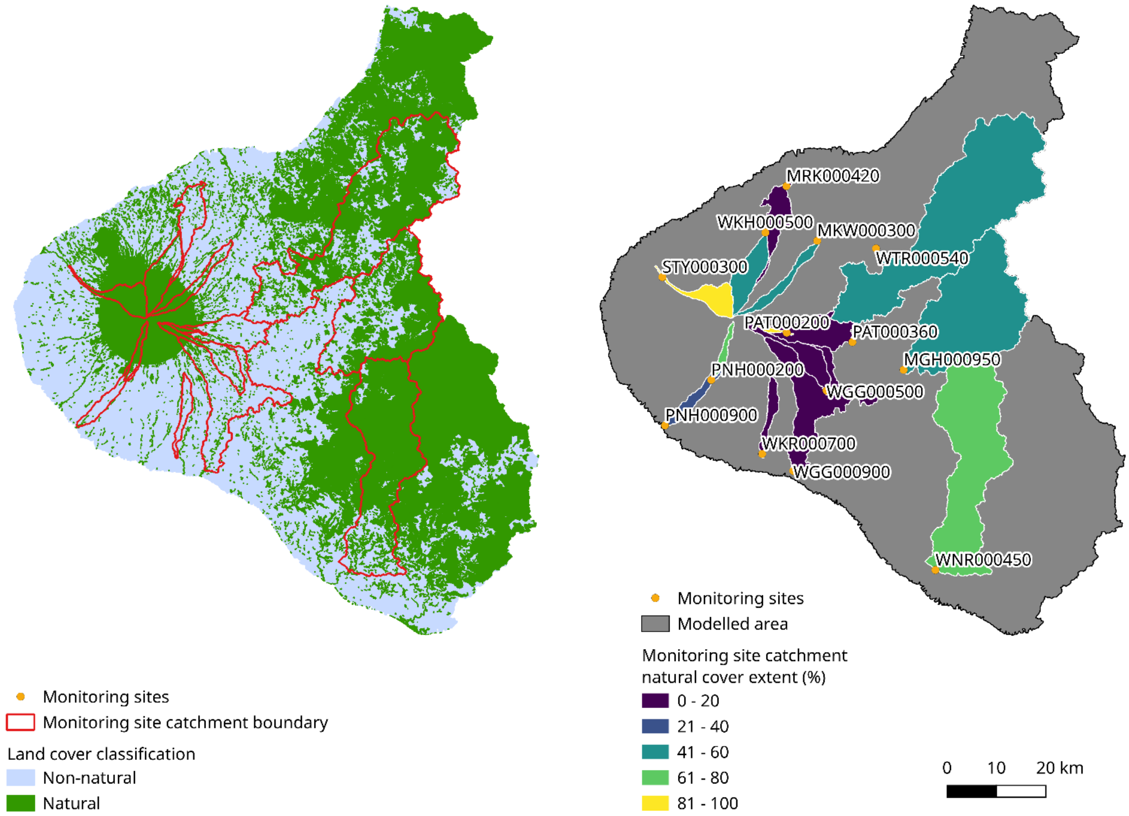

Figure 2. Extent of natural cover in Taranaki (left), and the proportion of upstream catchment area under natural cover at each monitoring site (right).

The mean annual suspended sediment load from hillslope erosion processes in natural and non-natural cover areas was calculated for each RECv2 watershed and routed through the RECv2 digital stream network, which accounted for floodplain deposition and lake trapping using the same procedure as Neverman et al. (2021).

As bank erosion was modelled at the reach scale (an individual RECv2 segment), it was not possible to apportion load from bank erosion to natural and non-natural cover areas at the sub-reach scale. We conservatively apportioned bank erosion to natural cover only for those RECv2 segments where 100% of the riparian buffer was natural cover in the LCDB. This was calculated by applying a 15 m buffer to the RECv2 stream network and intersecting with the land cover layer.

5 Results

5.1 Effects of climate change on suspended sediment loads

Changes in suspended sediment load under future scenarios are the product of both changes in land cover and changes in hydro-climatic drivers. To distinguish the impacts of climate change from the impacts of soil conservation works we compare a) loads under projected climate change with loads for baseline climate conditions using the same land cover, and b) loads for the future soil conservation scenario adjusted for climate change with both the pre-mitigation and contemporary sediment load baselines.

Comparing sediment loads with and without the impact of climate change for contemporary land cover provides an assessment of climate impacts independent from the effects of changes in land cover. Mean annual suspended sediment loads for this scenario are presented for the Taranaki region in Table 4, and for the selected water quality monitoring sites in Table 5 and Table 6. To visualise the spatial pattern in erosion rates, we present the sediment yield ($t/km^2/yr$) for selected RCMs in Figure 3. Sediment yield was calculated as the sum of sediment loads from all erosion processes present within each RECv2 watershed divided by the watershed area. This does not account for downstream storage of sediment in lakes and on floodplains.

For the Taranaki region, the mean annual suspended sediment load delivered to the coast under contemporary land cover is projected to increase from the baseline 1.7 Mt/yr to 1.9–2.7 Mt/yr and 1.8–3.5 Mt/yr by mid-century and late century, respectively, across the range of RCPs (Table 4). These changes correspond to increases of 13%–57% and 7%–108% (Table 4) compared to the baseline sediment load by mid-century and late century, respectively.

The 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 (Figure 1). A smaller increase in load is projected by late century (median 20%) compared to mid-century (median 22%) under the mitigation pathway represented by RCP2.6 (Table 4). RCP4.5 and RCP6.0 are stabilisation pathways, and RCP8.5 represents a pathway with very high greenhouse gas emissions that results in the largest projected increases in sediment load (Table 4). Suspended sediment loads are expected to increase from RCP2.6 to RCP8.5 at mid-century and late century, with more pronounced differences between each RCP observed at late century relative to the mid-century projections.

Table 4. Net suspended sediment loads delivered to the coast for the Taranaki region under baseline climate conditions (from Neverman at al. 2021) and projected climate change at mid-century and late century for the contemporary land cover

RCP	Mid-century			Late century		
	Selected RCMs[1]	Load (Mt/yr)	Diff[2] (%)	Selected RCMs[1]	Load (Mt/yr)	Diff[2] (%)
	Baseline	1.68	-	Baseline	1.68	-
2.6	Min [NorESM1-M]	1.90	13	Min [GISS-EL-R]	1.80	7
	Median	2.06	22	Median	2.03	20
	Max [HadGEM2-ES]	2.22	32	Max [CESM1-CAM5]	2.23	32
4.5	Min [GISS-E2-R]	2.06	23	Min [GISS-E2-R]	2.08	24
	Median	2.22	32	Median	2.34	39
	Max [HadGEM2-ES]	2.42	44	Max [CESM1-CAM5]	2.62	56
6.0	Min [NorESM1-M]	2.04	21	Min [NorESM1-M]	2.36	40
	Median	2.2	30	Median	2.71	61
	Max [HadGEM2-ES]	2.48	47	Max [HadGEM2-ES]	2.92	73
8.5	Min [GISS-EL-R]	2.31	37	Min [GISS-EL-R]	2.86	70
	Median	2.40	42	Median	3.26	94
	Max [HadGEM2-ES]	2.65	57	Max [GFDL-CM3]	3.51	108

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

[2] 'Diff refers to the percentage difference between the sediment load under climate change compared to the contemporary baseline load.

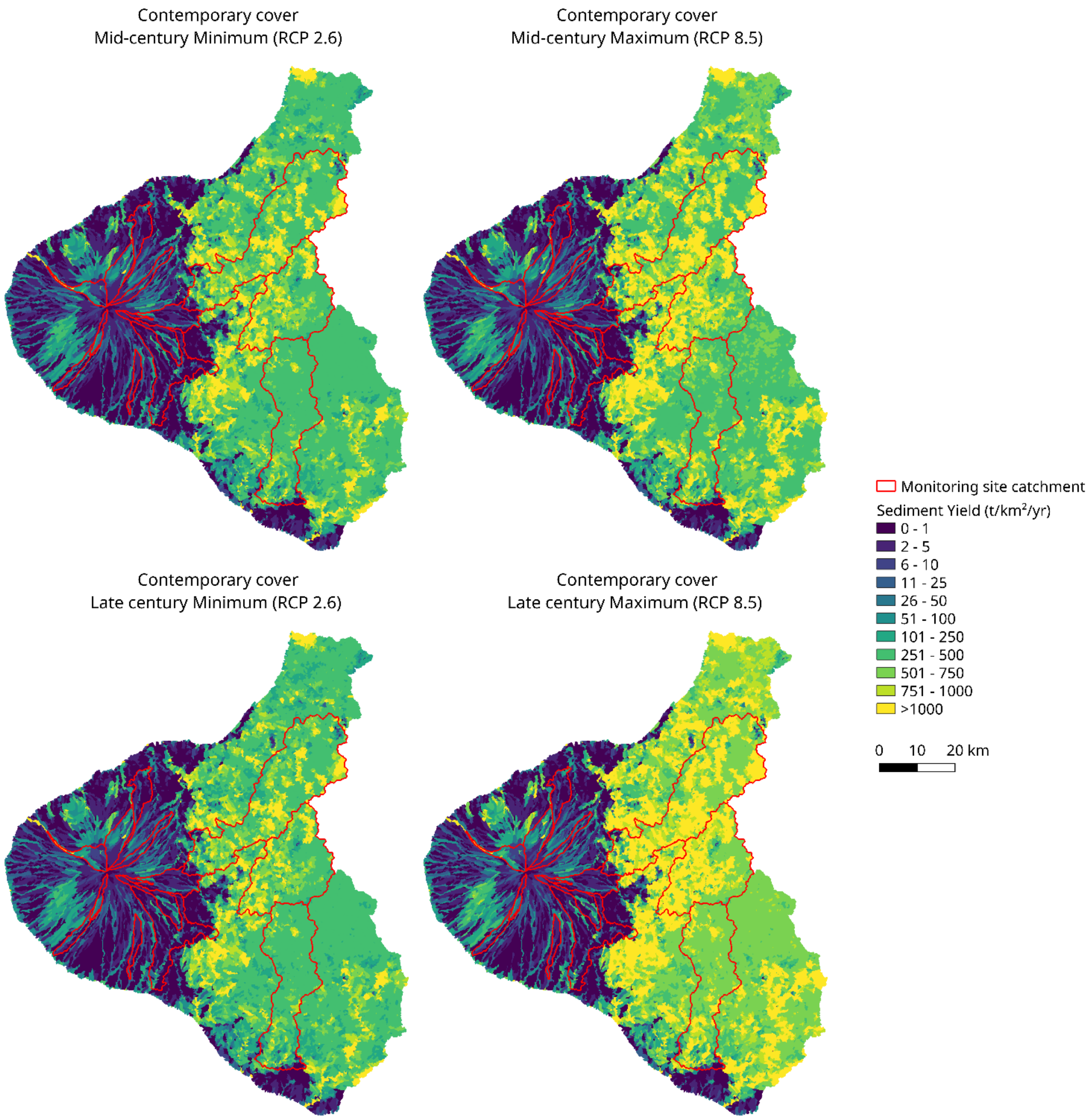

Figure 3. Modelled suspended sediment yield (t/km^2/yr) for each RECv2 watershed for selected RCMs across the Taranaki region under contemporary land cover.

Across the water quality monitoring sites the proportional changes in load under contemporary land cover ranged from -48% to +65% by mid-century (Table 5) and -48% to +123% (Table 6) by late century, compared to the baseline sediment load. The monitoring sites show similar patterns to the regional loads, where loads were typically lower for late century than mid-century under the mitigation pathway (RCP2.6), and the range in projected loads were greatest by late century due to divergence between the RCPs.

The hill-country water quality monitoring sites (Waitara River at Autawa Rd, Mangaehu River at Raupuha Rd Bridge, and Waitara River at Autawa Rd) exhibited the greatest range in response across the climate projections, with loads projected to increase between 8 to 123% by late century. These sites also experience the largest projected increases in load. In contrast, the Pātea River at Barclay Rd Bridge, Pātea River at Skinner Rd Bridge, and

Mangaoraka Stream at Corbett Rd (ring plain sites) exhibit load decreases under all climate projections. The largest proportional reductions in load occur at the Pātea River at Skinner Rd Bridge.

This contrast in response arises from differences in the erosion processes which dominate hill-country and ring plain catchments, and the directions of change in their hydro-climatic drivers. Hill-country catchments are dominated by shallow landslide erosion, which is projected to increase due to more frequent and higher magnitude storm rainfall under future climate. In ring plain catchments, changes in rainfall, evapotranspiration, and snowpack will drive changes in surficial erosion as well as streamflow which affects bank erosion. These erosion processes dominate fine suspended sediment loads in ring plain catchments. These hydro-climatic drivers have opposing trajectories across catchments and climate projections, leading to diverse responses in sediment loads for ring plain catchments.

Table 5. Net suspended sediment loads at monitoring sites for baseline climate (from Neverman at al. 2021) and projected climate change at mid-century for the contemporary land cover scenario

Time period	RCP	Site name	Mangaehu River at Raupuha Rd Bridge		Maketawa Stream at Tarata Rd		Mangaoraka Stream at Corbett Rd		Pātea River at Barclay Rd Bridge		Pātea River at Skinner Rd Bridge		Punehu Stream at Wiremu Rd		Punehu Stream at SH45		Hangatahua (Stony) River at Mangatete Rd		Waingongoro River at Eltham Rd Bridge		Waingongoro River at SH45		Waiwhakaiho River at SH3		Waiokura pumphouse		Whenuakura River at Nicholson Rd		Waitara River at Autawa Rd	
		Site code	MGH000950		MKW000300		MRK000420		PAT000200		PAT000360		PNH000200		PNH000900		STY000300		WGG000500		WGG000900		WKH000500		WKR000700		WNR000450		WTR000540	
			Load (kt/yr)	Diff[1] (%)	Load (kt/yr)	Diff (%)	Load (kt/yr)	Diff (%)	Load (kt/yr)	Diff (%)	Load (kt/yr)	Diff (%)	Load (kt/yr)	Diff (%)	Load (kt/yr)	Diff (%)	Load (kt/yr)	Diff (%)	Load (kt/yr)	Diff (%)	Load (kt/yr)	Diff (%)	Load (kt/yr)	Diff (%)	Load (kt/yr)	Diff (%)	Load (kt/yr)	Diff (%)	Load (kt/yr)	Diff (%)
Baseline			231	-	0.67	-	0.76	-	0.15	-	2.0	-	0.56	-	0.99	-	8.3	-	1.9	-	9.1	-	3.7	-	0.10	-	144	-	346	-
Mid-century	2.6	Min	262	13	0.72	7	0.53	-31	0.11	-30	1.1	-48	0.75	34	1.3	34	10	21	1.8	-7	7.3	-21	4.0	11	0.11	13	164	13	397	15
		Median	285	23	0.72	8	0.54	-29	0.11	-29	1.1	-48	0.76	35	1.3	35	10	22	1.9	-1	7.8	-15	4.1	13	0.11	13	177	23	433	25
		Max	307	33	0.73	9	0.56	-27	0.11	-29	1.1	-47	0.77	36	1.3	36	10	23	2.1	8	8.4	-8	4.3	17	0.11	14	193	33	468	35
	4.5	Min	287	24	0.73	9	0.56	-26	0.11	-28	1.1	-47	0.69	23	1.2	23	10	22	1.9	1	7.8	-15	4.2	14	0.11	10	179	24	438	27
		Median	312	35	0.74	10	0.57	-25	0.11	-28	1.1	-47	0.69	24	1.2	23	10	23	2.1	7	8.3	-9	4.3	16	0.11	10	193	34	474	37
		Max	338	46	0.74	11	0.59	-22	0.11	-28	1.1	-47	0.70	25	1.2	25	10	24	2.2	16	8.9	-2	4.4	20	0.11	11	211	46	520	51
	6.0	Min	284	23	0.75	12	0.55	-28	0.11	-25	1.1	-44	0.74	31	1.3	31	10	22	1.9	-1	7.7	-15	4.1	12	0.12	17	174	21	435	26
		Median	307	33	0.76	14	0.57	-25	0.11	-25	1.1	-44	0.74	32	1.3	32	10	23	2.0	7	8.3	-9	4.2	15	0.12	18	190	32	468	35
		Max	346	50	0.77	15	0.60	-22	0.12	-24	1.1	-44	0.75	34	1.3	34	10	25	2.3	18	9.1	1	4.4	20	0.12	20	215	49	533	54
	8.5	Min	323	40	0.76	14	0.58	-24	0.11	-27	1.1	-46	0.72	28	1.3	28	11	30	2.1	10	8.5	-6	4.4	20	0.11	14	198	37	495	43
		Median	337	46	0.77	14	0.59	-22	0.11	-27	1.1	-46	0.72	29	1.3	28	11	31	2.2	14	8.8	-3	4.4	21	0.11	14	207	43	515	49
		Max	371	60	0.78	16	0.61	-19	0.11	-26	1.1	-45	0.73	31	1.3	30	11	32	2.4	25	9.7	6	4.6	26	0.11	15	229	59	572	65

[1] 'Diff' refers to the percentage difference between the sediment load under baseline and future climate.

Table 6. Net suspended sediment loads at monitoring sites for baseline conditions (from Neverman at al. 2021) and projected climate change at late century for the contemporary land cover scenario

Time period	RCP	Site name	Mangaehu River at Raupuha Rd Bridge		Maketawa Stream at Tarata Rd		Mangaoraka Stream at Corbett Rd		Pātea River at Barclay Rd Bridge		Pātea River at Skinner Rd Bridge		Punehu Stream at Wiremu Rd		Punehu Stream at SH45		Hangatahua (Stony) River at Mangatete Rd		Waingongoro River at Eltham Rd Bridge		Waingongoro River at SH45		Waiwhakaiho River at SH3		Waiokura pumphouse		Whenuakura River at Nicholson Rd		Waitara River at Autawa Rd	
		Site code	MGH000950		MKW000300		MRK000420		PAT000200		PAT000360		PNH000200		PNH000900		STY000300		WGG000500		WGG000900		WKH000500		WKR000700		WNR000450		WTR000540	
			Load (kt/yr)	Diff[1] (%)	Load (kt/yr)	Diff (%)	Load (kt/yr)	Diff (%)	Load (kt/yr)	Diff (%)	Load (kt/yr)	Diff (%)	Load (kt/yr)	Diff (%)	Load (kt/yr)	Diff (%)	Load (kt/yr)	Diff (%)	Load (kt/yr)	Diff (%)	Load (kt/yr)	Diff (%)	Load (kt/yr)	Diff (%)	Load (kt/yr)	Diff (%)	Load (kt/yr)	Diff (%)	Load (kt/yr)	Diff (%)
Baseline			231	-	0.67	-	0.76	-	0.15	-	2.0	-	0.56	-	0.99	-	8.3	-	1.9	-	9.1	-	3.7	-	0.10	-	144	-	346	-
Late century	2.6	Min	249	8	0.70	4	0.50	-35	0.11	-30	1.0	-48	0.70	24	1.2	24	9.8	17	1.7	-10	7.0	-23	3.9	8	0.11	14	156	8	375	9
		Median	281	22	0.70	5	0.52	-32	0.11	-30	1.0	-48	0.71	26	1.2	26	9.9	19	1.9	-1	7.7	-15	4.1	12	0.11	14	176	22	427	24
		Max	312	35	0.71	6	0.54	-29	0.11	-30	1.0	-48	0.71	27	1.3	27	10	21	2.1	8	8.3	-9	4.2	16	0.11	14	193	34	478	38
	4.5	Min	291	26	0.72	8	0.54	-29	0.11	-28	1.1	-47	0.76	35	1.3	35	9.8	18	2.0	2	7.9	-13	4.1	11	0.11	11	181	25	443	28
		Median	328	42	0.73	9	0.57	-25	0.11	-28	1.1	-46	0.77	37	1.3	36	10	19	2.2	12	8.7	-5	4.2	16	0.11	12	202	40	504	46
		Max	368	59	0.74	11	0.60	-22	0.11	-28	1.1	-46	0.78	38	1.4	38	10	21	2.4	24	9.6	5	4.4	21	0.11	13	228	58	566	64
	6.0	Min	332	43	0.73	9	0.59	-23	0.11	-25	1.1	-44	0.78	40	1.4	39	11	30	2.1	12	8.7	-4	4.3	18	0.12	17	202	40	509	47
		Median	382	65	0.75	11	0.62	-19	0.12	-25	1.1	-44	0.80	42	1.4	42	11	32	2.4	26	9.8	7	4.6	24	0.12	18	236	63	587	70
		Max	407	76	0.76	13	0.65	-15	0.12	-24	1.1	-44	0.80	43	1.4	43	11	34	2.6	35	10	14	4.7	29	0.12	19	251	74	632	83
	8.5	Min	401	73	0.78	16	0.66	-13	0.11	-28	1.1	-46	0.86	53	1.5	52	12	39	2.5	32	10	12	4.8	32	0.12	17	246	70	621	80
		Median	459	98	0.79	19	0.70	-8	0.11	-28	1.1	-46	0.87	55	1.5	55	12	42	2.8	48	11	25	5.1	39	0.12	18	281	95	714	107
		Max	494	114	0.80	20	0.73	-5	0.11	-28	1.1	-46	0.88	57	1.5	56	12	44	3.0	58	12	33	5.3	44	0.12	19	302	109	770	123

[1] 'Diff' refers to the percentage difference between the sediment load under baseline and future climate.

Table 7 and Table 8 present the mean annual suspended sediment load delivered to the coast across the Taranaki region under projected climate change for the future soil conservation scenario and compare these loads to the pre-mitigation and contemporary baseline sediment loads from Neverman et al. (2021). The mean annual suspended sediment load delivered to the coast is projected to range from 1.6–2.3 Mt/yr by mid-century and 1.6–3.0 Mt/yr by late century across the range of RCPs. Compared to the contemporary baseline of 1.7 Mt/yr, these changes correspond to differences of -3% to +37% (Table 7) and -8% to +81% (Table 8) by mid-century and late century, respectively. Compared to the pre-mitigation baseline of 2.4 Mt/yr, these changes correspond to differences of -32% to -3% by mid-century (Table 7) and -35% to +28% by late century (Table 8). Sediment yields ($t/km^2/yr$) are presented for selected RCMs in Figure 4.

These results indicate that fully implemented and mature soil conservation works may offset the impacts of climate change under all modelled greenhouse gas pathways (represented by the RCPs) if they were to be fully implemented and mature by mid-century, compared to the pre-mitigation baseline. By late century, fully implemented and mature soil conservation works may offset the effects of climate change for greenhouse gas pathways up to RCP6.0. Under RCP8.5 regional loads may increase by between 4% and 28% compared to the pre-mitigation baseline loads. This is significantly less than the >70% increase in load expected from the effects of projected climate change without further reductions from conservation measures between baseline and late century under RCP8.5 (Table 4), demonstrating the benefit of soil conservation works.

Table 7. Comparison of net suspended sediment loads delivered to the coast for the Taranaki region under projected climate change for the future soil conservation scenario at mid-century with the pre-mitigation and contemporary baselines (from Neverman at al. 2021)

Time period	RCP	Selected RCMs[1]	Initial (pre-mitigation) baseline compared to future soil conservation works		Contemporary baseline compared to future soil conservation works	
			Load (Mt/yr)	Diff[3] (%)	Load (Mt/yr)	Diff (%)
Baseline[2]			2.38	-	1.68	-
Mid-century	2.6	Min [NorESM1-M]	1.63	-32	1.63	-3
		Median	1.77	-26	1.77	5
		Max [HadGEM2-ES]	1.92	-20	1.92	14
	4.5	Min [GISS-E2-R]	1.78	-25	1.78	6
		Median	1.92	-19	1.92	14
		Max [HadGEM2-ES]	2.10	-12	2.10	25
	6.0	Min [NorESM1-M]	1.75	-26	1.75	4
		Median	1.90	-20	1.90	13
		Max [HadGEM2-ES]	2.15	-10	2.15	28
	8.5	Min [GISS-EL-R]	1.99	-16	1.99	18
		Median	2.07	-13	2.07	23
		Max [HadGEM2-ES]	2.30	-3	2.30	37

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

[2] 'Baseline' refers to the baseline climate state with either the pre-mitigation land cover or the contemporary land cover. The future loads are modelled for the future soil conservation scenario with the effects of climate change.

[3] 'Diff' refers to the percentage difference between the baseline and future sediment load.

Table 8. Comparison of net suspended sediment loads delivered to the coast for the Taranaki region under projected climate change for the future soil conservation scenario at late century with the pre-mitigation and contemporary baselines (from Neverman at al. 2021)

Time period	RCP	Selected RCMs[1]	Initial (pre-mitigation) baseline compared to future soil conservation works		Contemporary baseline compared to future soil conservation works	
			Load (Mt/yr)	Diff[3] (%)	Load (Mt/yr)	Diff (%)
Baseline[2]			2.38	-	1.68	-
Late century	2.6	Min [NorESM1-M]	1.55	-35	1.55	-8
		Median	1.75	-27	1.75	4
		Max [HadGEM2-ES]	1.93	-19	1.93	15
	4.5	Min [GISS-E2-R]	1.80	-24	1.80	8
		Median	2.03	-15	2.03	20
		Max [HadGEM2-ES]	2.28	-4	2.28	35
	6.0	Min [NorESM1-M]	2.04	-14	2.04	21
		Median	2.36	-1	2.36	40
		Max [HadGEM2-ES]	2.54	6	2.54	51
	8.5	Min [GISS-EL-R]	2.49	4	2.49	37
		Median	2.84	19	2.84	54
		Max [HadGEM2-ES]	3.06	28	3.06	81

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

[2] 'Baseline' refers to the baseline climate state with either the pre-mitigation land cover or the contemporary land cover. The future loads are modelled for the future soil conservation scenario with the effects of climate change.

[3] 'Diff' refers to the percentage difference between the baseline and future sediment load.

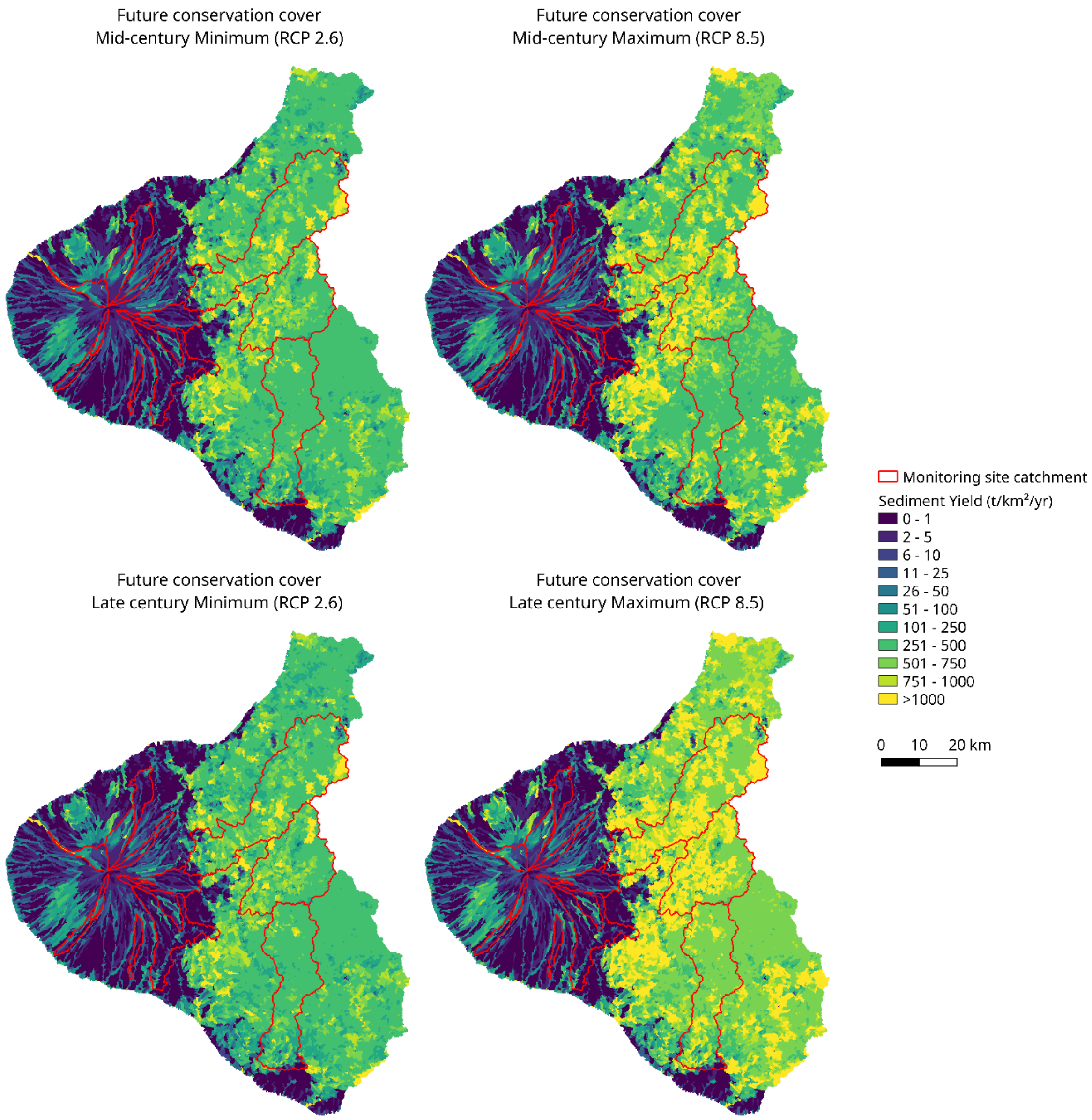

Figure 4. Modelled suspended sediment yield (t/km^2/yr) for each RECv2 watershed for selected RCMs across the Taranaki region under the future soil conservation scenario.

Across the selected water quality monitoring sites, proportional changes in load between the pre-mitigation baseline and the future soil conservation scenario with the effects of climate change ranged from -69% to +24% (Table 9) by mid-century, and -69% to +47% (Table 10) by late century. Comparing the future soil conservation scenario with the effects of climate change to the contemporary baseline (Table 11 and Table 13), changes in load ranged from -58% to +42% by mid-century and -59% to 98% by late century.

Loads at monitoring sites were typically lower for late century than mid-century under the mitigation pathway (RCP2.6), and the range in projected loads was greatest by late century due to greater divergence between the RCPs.

Similar to results which only consider the impacts of climate change (Table 5 and Table 6), the hill-country monitoring sites (Waitara River at Autawa Rd, Mangaehu River at Raupuha Rd Bridge, and Whenuakura River at Nicholson Rd) exhibited the greatest range in potential load changes by late century when the impact of future soil conservation works were included. The range in load changes by late century was less for these sites when future soil conservation loads were compared to the pre-mitigation baseline (Table 10) as opposed to the contemporary baseline. In addition, Waingongoro River at Eltham Rd Bridge and Waingongoro River at SH45 had similar ranges in load changes by late century when compared to the pre-mitigation scenario.

The Pātea River at Barclay Rd Bridge, Pātea River at Skinner Rd Bridge, and Mangaoraka Stream at Corbett Rd (ring plain sites) exhibited decreases in load under all climate change projections for the future soil conservation scenario when compared to both the contemporary and pre-mitigation baselines. In addition, the Maketawa Stream at Tarata Rd, Punehu Stream at SH45, Waingongoro River at SH45, and Waiokura pumphouse also exhibited decreases in load under all climate projections for the future soil conservation scenario when compared to the pre-mitigation baseline.

These results highlight the significant benefit of soil conservation works implemented since 1996, which offset the impacts of climate change at seven monitoring sites (50%) across all projections by late century, and reduce the range in impacts across the RCPs in hill-country catchments. Under the stabilisation pathways (RCP4.5 and RCP6.0), soil conservation works offset the impacts of climate change at 8 to 13 sites (57% to 93%), depending on the RCM.

Table 9. Net suspended sediment loads at selected water quality monitoring sites under projected climate change for the future soil conservation scenario at mid-century, compared with the pre-mitigation baseline loads (from Neverman at al. 2021)

Time period	RCP	Site name	Mangaehu River at Raupuha Rd Bridge		Maketawa Stream at Tarata Rd		Mangaoraka Stream at Corbett Rd		Pātea River at Barclay Rd Bridge		Pātea River at Skinner Rd Bridge		Punehu Stream at Wiremu Rd		Punehu Stream at SH45		Hangatahua (Stony) River at Mangatete Rd		Waingongoro River at Eltham Rd Bridge		Waingongoro River at SH45		Waiwhakaiho River at SH3		Waiokura pumphouse		Whenuakura River at Nicholson Rd		Waitara River at Autawa Rd	
		Site code	MGH000950		MKW000300		MRK000420		PAT000200		PAT000360		PNH000200		PNH000900		STY000300		WGG000500		WGG000900		WKH000500		WKR000700		WNR000450		WTR000540	
			Load	Diff[1]	Load	Diff	Load	Diff	Load	Diff	Load	Diff	Load	Diff	Load	Diff	Load	Diff	Load	Diff	Load	Diff	Load	Diff	Load	Diff	Load	Diff	Load	Diff
			(kt/yr)	(%)	(kt/yr)	(%)	(kt/yr)	(%)	(kt/yr)	(%)	(kt/yr)	(%)	(kt/yr)	(%)	(kt/yr)	(%)	(kt/yr)	(%)	(kt/yr)	(%)	(kt/yr)	(%)	(kt/yr)	(%)	(kt/yr)	(%)	(kt/yr)	(%)	(kt/yr)	(%)
Baseline			370	-	1.2	-	1.1	-	0.17	-	2.7	-	0.74	-	1.7	-	8.9	-	2.2	-	13	-	4.3	-	0.13	-	194	-	539	-
Mid-century	2.6	Min	223	-40	0.69	-43	0.48	-54	0.11	-38	0.84	-69	0.73	-1	1.3	-25	10	13	1.8	-18	7.0	-47	3.8	-12	0.10	-20	154	-21	339	-37
		Median	244	-34	0.70	-43	0.50	-53	0.11	-38	0.84	-69	0.74	-1	1.3	-24	10	14	1.9	-12	7.4	-44	3.9	-9	0.10	-20	167	-14	370	-31
		Max	263	-29	0.71	-42	0.52	-51	0.11	-38	0.84	-69	0.75	1	1.3	-23	10	15	2.1	-5	8.0	-39	4.0	-6	0.10	-19	181	-7	400	-26
	4.5	Min	246	-33	0.70	-43	0.51	-52	0.11	-37	0.84	-69	0.67	-9	1.2	-31	10	14	1.9	-11	7.5	-43	3.9	-9	0.10	-22	169	-13	375	-31
		Median	267	-28	0.71	-42	0.53	-50	0.11	-37	0.85	-69	0.68	-9	1.2	-30	10	15	2.0	-5	8.0	-40	4.0	-7	0.10	-22	182	-6	406	-25
		Max	290	-22	0.72	-41	0.55	-48	0.11	-37	0.85	-68	0.68	-8	1.2	-30	10	16	2.2	2	8.6	-35	4.2	-4	0.10	-21	198	2	446	-17
	6.0	Min	244	-34	0.73	-41	0.51	-52	0.11	-34	0.89	-67	0.72	-3	1.3	-26	10	15	1.9	-12	7.4	-44	3.9	-11	0.11	-17	164	-16	372	-31
		Median	263	-29	0.73	-40	0.52	-51	0.11	-34	0.89	-67	0.72	-2	1.3	-26	10	16	2.0	-6	8.0	-40	4.0	-8	0.11	-17	179	-8	400	-26
		Max	297	-20	0.74	-39	0.55	-48	0.12	-33	0.90	-67	0.73	-1	1.3	-25	10	17	2.3	4	8.8	-34	4.2	-4	0.11	-15	202	4	457	-15
	8.5	Min	277	-25	0.74	-40	0.54	-49	0.11	-35	0.87	-68	0.70	-5	1.2	-28	11	22	2.1	-3	8.2	-38	4.1	-4	0.10	-20	187	-4	424	-21
		Median	289	-22	0.74	-40	0.55	-49	0.11	-35	0.87	-67	0.70	-5	1.2	-28	11	22	2.2	1	8.5	-36	4.2	-3	0.10	-19	195	1	441	-18
		Max	319	-14	0.75	-39	0.57	-46	0.11	-35	0.88	-67	0.71	-4	1.3	-26	11	24	2.4	11	9.3	-30	4.4	1	0.10	-18	216	11	490	-9

[1] 'Diff' refers to the percentage difference between the baseline and future sediment load.

Table 10. Net suspended sediment loads at monitoring sites under projected climate change for the future soil conservation scenario at late century, compared with the pre-mitigation baseline loads (from Neverman at al. 2021)

Time period	RCP	Site name	Mangaehu River at Raupuha Rd Bridge		Maketawa Stream at Tarata Rd		Mangaoraka Stream at Corbett Rd		Pātea River at Barclay Rd Bridge		Pātea River at Skinner Rd Bridge		Punehu Stream at Wiremu Rd		Punehu Stream at SH45		Hangatahua (Stony) River at Mangatete Rd		Waingongoro River at Eltham Rd Bridge		Waingongoro River at SH45		Waiwhakaiho River at SH3		Waiokura pumphouse		Whenuakura River at Nicholson Rd		Waitara River at Autawa Rd	
		Site code	MGH000950		MKW000300		MRK000420		PAT000200		PAT000360		PNH000200		PNH000900		STY000300		WGG000500		WGG000900		WKH000500		WKR000700		WNR000450		WTR000540	
			Load (kt/yr)	Diff[1] (%)	Load (kt/yr)	Diff (%)	Load (kt/yr)	Diff (%)	Load (kt/yr)	Diff (%)	Load (kt/yr)	Diff (%)	Load (kt/yr)	Diff (%)	Load (kt/yr)	Diff (%)	Load (kt/yr)	Diff (%)	Load (kt/yr)	Diff (%)	Load (kt/yr)	Diff (%)	Load (kt/yr)	Diff (%)	Load (kt/yr)	Diff (%)	Load (kt/yr)	Diff (%)	Load (kt/yr)	Diff (%)
Baseline			370	-	1.2	-	1.1	-	0.17	-	2.7	-	0.74	-	1.7	-	8.9	-	2.2	-	13	-	4.3	-	0.13	-	194	-	539	-
Late century	2.6	Min	213	-42	0.67	-45	0.46	-57	0.11	-38	0.83	-69	0.68	-8	1.2	-30	9.8	10	1.7	-21	6.7	-49	3.7	-14	0.10	-19	147	-24	320	-41
		Median	241	-35	0.68	-45	0.48	-55	0.11	-38	0.84	-69	0.69	-7	1.2	-29	9.9	12	1.9	-12	7.4	-44	3.9	-11	0.10	-19	166	-14	365	-32
		Max	267	-28	0.69	-44	0.50	-52	0.11	-38	0.84	-69	0.70	-6	1.2	-28	10	13	2.1	-5	8	-39	4.0	-7	0.10	-19	182	-6	409	-24
	4.5	Min	249	-33	0.70	-43	0.50	-53	0.11	-37	0.86	-68	0.74	-1	1.3	-24	9.8	10	1.9	-10	7.6	-43	3.8	-11	0.10	-21	170	-12	379	-30
		Median	281	-24	0.71	-42	0.53	-50	0.11	-37	0.86	-68	0.75	1	1.3	-23	9.9	12	2.1	-1	8.4	-37	4.0	-7	0.10	-21	190	-2	432	-20
		Max	316	-14	0.72	-42	0.56	-48	0.11	-36	0.86	-68	0.76	2	1.3	-22	10	14	2.4	10	9.2	-30	4.2	-3	0.10	-20	215	11	486	-10
	6.0	Min	284	-23	0.71	-42	0.54	-49	0.11	-34	0.89	-67	0.76	3	1.3	-21	11	22	2.1	-1	8.4	-37	4.1	-5	0.11	-17	191	-2	436	-19
		Median	328	-11	0.72	-41	0.57	-46	0.12	-33	0.89	-67	0.78	5	1.4	-20	11	24	2.4	11	9.4	-29	4.3	1	0.11	-16	222	15	503	-7
		Max	350	-5	0.73	-40	0.60	-43	0.12	-33	0.90	-66	0.78	6	1.4	-19	11	26	2.6	20	10	-24	4.5	4	0.11	-15	237	22	543	1
	8.5	Min	345	-7	0.75	-39	0.61	-42	0.11	-36	0.86	-68	0.84	13	1.5	-14	12	31	2.5	17	9.9	-26	4.6	6	0.11	-17	232	20	533	-1
		Median	395	7	0.77	-37	0.65	-39	0.11	-36	0.87	-68	0.85	15	1.5	-13	12	33	2.8	31	11	-17	4.8	12	0.11	-16	265	37	614	14
		Max	426	15	0.78	-36	0.68	-36	0.11	-36	0.87	-68	0.86	16	1.5	-12	12	35	3.0	40	12	-11	5.0	16	0.11	-16	285	47	662	23

[1] 'Diff' refers to the percentage difference between the baseline and future sediment load.

Table 11. Net suspended sediment loads at monitoring sites under projected climate change for the future soil conservation scenario at mid-century, compared with the contemporary baseline loads (from Neverman at al. 2021)

Time period	RCP	Site name	Mangaehu River at Raupuha Rd Bridge		Maketawa Stream at Tarata Rd		Mangaoraka Stream at Corbett Rd		Pātea River at Barclay Rd Bridge		Pātea River at Skinner Rd Bridge		Punehu Stream at Wiremu Rd		Punehu Stream at SH45		Hangatahua (Stony) River at Mangatete Rd		Waingongoro River at Eltham Rd Bridge		Waingongoro River at SH45		Waiwhakaiho River at SH3		Waiokura pumphouse		Whenuakura River at Nicholson Rd		Waitara River at Autawa Rd	
		Site code	MGH000950		MKW000300		MRK000420		PAT000200		PAT000360		PNH000200		PNH000900		STY000300		WGG000500		WGG000900		WKH000500		WKR000700		WNR000450		WTR000540	
			Load (kt/yr)	Diff[1] (%)	Load (kt/yr)	Diff (%)	Load (kt/yr)	Diff (%)	Load (kt/yr)	Diff (%)	Load (kt/yr)	Diff (%)	Load (kt/yr)	Diff (%)	Load (kt/yr)	Diff (%)	Load (kt/yr)	Diff (%)	Load (kt/yr)	Diff (%)	Load (kt/yr)	Diff (%)	Load (kt/yr)	Diff (%)	Load (kt/yr)	Diff (%)	Load (kt/yr)	Diff (%)	Load (kt/yr)	Diff (%)
Baseline			231	-	0.67	-	0.76	-	0.15	-	2.0	-	0.56	-	0.99	-	8.3	-	1.9	-	9.1	-	3.7	-	0.10	-	144	-	346	-
Mid-century	2.6	Min	223	-3	0.69	3	0.48	-36	0.11	-30	0.84	-58	0.73	31	1.3	30	10	20	1.8	-7	7.0	-24	3.8	4	0.10	3	154	6	339	-2
		Median	244	5	0.70	4	0.50	-34	0.11	-29	0.84	-58	0.74	32	1.3	31	10	21	1.9	-1	7.4	-18	3.9	7	0.10	3	167	15	370	7
		Max	263	14	0.71	6	0.52	-32	0.11	-29	0.84	-58	0.75	33	1.3	33	10	23	2.1	7	8.0	-12	4.0	10	0.10	4	181	26	400	16
	4.5	Min	246	7	0.7	5	0.51	-32	0.11	-28	0.84	-58	0.67	20	1.2	19	10	22	1.9	1	7.5	-18	3.9	7	0.10	-1	169	17	375	8
		Median	267	16	0.71	6	0.53	-31	0.11	-28	0.85	-58	0.68	21	1.2	20	10	23	2.0	7	8.0	-12	4.0	10	0.10	1	182	26	406	18
		Max	290	25	0.72	7	0.55	-28	0.11	-28	0.85	-58	0.68	22	1.2	22	10	24	2.2	15	8.6	-6	4.2	14	0.10	1	198	37	446	29
	6.0	Min	244	5	0.73	8	0.51	-33	0.11	-25	0.89	-56	0.72	28	1.3	28	10	22	1.9	-1	7.4	-19	3.9	5	0.11	7	164	13	372	8
		Median	263	14	0.73	10	0.52	-31	0.11	-25	0.89	-56	0.72	29	1.3	29	10	23	2.0	6	8.0	-13	4.0	8	0.11	7	179	24	400	16
		Max	297	29	0.74	11	0.55	-27	0.12	-24	0.90	-55	0.73	31	1.3	30	10	25	2.3	18	8.8	-4	4.2	14	0.11	10	202	40	457	32
	8.5	Min	277	20	0.74	10	0.54	-29	0.11	-27	0.87	-57	0.70	25	1.2	25	11	30	2.1	10	8.2	-10	4.1	13	0.10	3	187	29	424	23
		Median	289	25	0.74	10	0.55	-28	0.11	-27	0.87	-56	0.70	26	1.2	25	11	30	2.2	14	8.5	-7	4.2	14	0.10	4	195	35	441	28
		Max	319	38	0.75	12	0.57	-25	0.11	-26	0.88	-56	0.71	27	1.3	27	11	32	2.4	25	9.3	2	4.4	19	0.10	5	216	49	490	42

[1] 'Diff' refers to the percentage difference between the baseline and future sediment load.

Table 12. Net suspended sediment loads at monitoring sites under projected climate change for the future soil conservation scenario at late century, compared with the contemporary baseline loads (from Neverman at al. 2021)

Time period	RCP	Site name	Mangaehu River at Raupuha Rd Bridge		Maketawa Stream at Tarata Rd		Mangaoraka Stream at Corbett Rd		Pātea River at Barclay Rd Bridge		Pātea River at Skinner Rd Bridge		Punehu Stream at Wiremu Rd		Punehu Stream at SH45		Hangatahua (Stony) River at Mangatete Rd		Waingongoro River at Eltham Rd Bridge		Waingongoro River at SH45		Waiwhakaiho River at SH3		Waiokura pumphouse		Whenuakura River at Nicholson Rd		Waitara River at Autawa Rd	
		Site code	MGH000950		MKW000300		MRK000420		PAT000200		PAT000360		PNH000200		PNH000900		STY000300		WGG000500		WGG000900		WKH000500		WKR000700		WNR000450		WTR000540	
			Load (kt/yr)	Diff[1] (%)	Load (kt/yr)	Diff (%)	Load (kt/yr)	Diff (%)	Load (kt/yr)	Diff (%)	Load (kt/yr)	Diff (%)	Load (kt/yr)	Diff (%)	Load (kt/yr)	Diff (%)	Load (kt/yr)	Diff (%)	Load (kt/yr)	Diff (%)	Load (kt/yr)	Diff (%)	Load (kt/yr)	Diff (%)	Load (kt/yr)	Diff (%)	Load (kt/yr)	Diff (%)	Load (kt/yr)	Diff (%)
Baseline			231	-	0.67	-	0.76	-	0.15	-	2.0	-	0.56	-	0.99	-	8.3	-	1.9	-	9.1	-	3.7	-	0.10	-	144	-	346	-
Late century	2.6	Min	213	-8	0.67	1	0.46	-40	0.11	-30	0.83	-59	0.68	21	1.2	21	9.8	17	1.7	-11	6.7	-26	3.7	1	0.10	3	147	2	320	-7
		Median	241	4	0.68	2	0.48	-37	0.11	-30	0.84	-58	0.69	23	1.2	22	9.9	19	1.9	-1	7.4	-18	3.9	6	0.10	4	166	15	365	6
		Max	267	16	0.69	3	0.50	-34	0.11	-30	0.84	-58	0.70	24	1.2	24	10	20	2.1	7	8	-12	4.0	10	0.10	4	182	26	409	19
	4.5	Min	249	8	0.70	4	0.50	-34	0.11	-28	0.86	-57	0.74	32	1.3	31	9.8	18	1.9	2	7.6	-17	3.8	5	0.10	1	170	18	379	10
		Median	281	22	0.71	5	0.53	-31	0.11	-28	0.86	-57	0.75	33	1.3	33	9.9	19	2.1	12	8.4	-8	4.0	10	0.10	2	190	32	432	25
		Max	316	37	0.72	7	0.56	-27	0.11	-28	0.86	-57	0.76	35	1.3	35	10	21	2.4	24	9.2	1	4.2	15	0.10	3	215	49	486	41
	6.0	Min	284	23	0.71	6	0.54	-29	0.11	-25	0.89	-56	0.76	36	1.3	36	11	30	2.1	11	8.4	-8	4.1	12	0.11	6	191	32	436	26
		Median	328	42	0.72	8	0.57	-25	0.12	-25	0.89	-55	0.78	38	1.4	38	11	32	2.4	26	9.4	3	4.3	18	0.11	7	222	54	503	46
		Max	350	51	0.73	9	0.60	-21	0.12	-24	0.90	-55	0.78	40	1.4	40	11	34	2.6	35	10	10	4.5	23	0.11	9	237	64	543	57
	8.5	Min	345	49	0.75	13	0.61	-19	0.11	-28	0.86	-57	0.84	49	1.5	49	12	39	2.5	32	9.9	8	4.6	25	0.11	7	232	61	533	54
		Median	395	71	0.77	15	0.65	-14	0.11	-28	0.87	-57	0.85	51	1.5	51	12	42	2.8	48	11	21	4.8	32	0.11	8	265	84	614	78
		Max	426	84	0.78	16	0.68	-11	0.11	-28	0.87	-57	0.86	53	1.5	52	12	43	3.0	58	12	29	5.0	37	0.11	8	285	98	662	92

[1] 'Diff' refers to the percentage difference between the baseline and future sediment load.

5.2 NPS-FM 2020 compliance under projected climate change

Compliance with the NPS-FM (2020) at the selected water quality monitoring sites is assessed against the change in contemporary baseline loads required to achieve a target attribute state. Table 13 presents the proportional and absolute reductions in load required for improvement in attribute state. Based on the change in load between the contemporary baseline and the future soil conservation scenario with the effects of climate change, the future attribute states are presented in Table 14 and Table 15.

Under the contemporary baseline, 7 of the 14 monitoring sites achieve band A (highest achievable state), 2 achieve band B, 2 achieve band C, and 3 do not achieve the national bottom line (NBL) (Neverman et al. 2021). Of the seven sites below band A for the baseline state, only the Mangaehu is predicted to see an improvement in attribute state with additional implementation and maturity of soil conservation works without the effects of climate change (Neverman et al. 2021).

With the effects of climate change, 6 of the 7 sites achieving band A at baseline state remain in band A for all projections by mid-century (Table 15) and late century (Table 14 and Table 15), with the exception of the Hangatahua (Stony) River at Mangatete Rd under the maximum RCP 8.5 projection (Figure 5). The Waingongoro River at SH45 is projected to improve from band C to band B by mid-century for some projections between RCPs 2.6 to 6.0, and by late century under RCPs 2.6 and 4.5. Under the minimum RCP2.6 this site is projected to achieve band A by late century.

Four sites (29%) (Mangaehu River at Raupuha Rd Bridge, Punehu Stream at Wiremu Rd, Punehu Stream at SH45, Waingongoro River at Eltham Rd Bridge) representing three catchments are projected to have declines in attribute band by mid-century. An additional seven sites (50%) are projected to have increases in load under one or more RCPs which would result in a decline in visual clarity without crossing a band threshold. As the NPS-FM (2020) does not allow for deterioration below the baseline state (Ministry for the Environment, 2022), these sites would require load reductions to return to baseline visual clarity.

Five sites (36%) (Mangaehu River at Raupuha Rd Bridge, Punehu Stream at Wiremu Rd, Punehu Stream at SH45, Waingongoro River at Eltham Rd Bridge, and Waingongoro River at SH45) representing three catchments are projected to decline in band by late century under more than one RCP. The Hangatahua (Stony) River at Mangatete Rd is projected to decline for the maximum RCP8.5 projection. An additional five sites (36%) are expected to remain in their baseline band but have degraded visual clarity, requiring a reduction in load to return to baseline state.

Table 13. Proportional and absolute changes from contemporary baseline sediment load required for the attribute band to improve at selected water quality monitoring sites (Neverman et al. 2021). A negative value indicates a reduction in load is required to achieve an increase in visual clarity, while '-' indicates the attribute band has already been achieved

Site Code	Location	Required proportional change in load (%)[1]			Required absolute change in load (kt/yr)[2]		
		NBL	B band	A band	NBL	B band	A band
MGH000950	Mangaehu River at Raupuha Rd Bridge	-	-11	-28	-	-24.4	-64.8
MKW000300	Maketawa Stream at Tarata Rd	-	-	-	-	-	-
MRK000420	Mangaoraka Stream at Corbett Rd	-	-	-	-	-	-
PAT000200	Pātea River at Barclay Rd Bridge	-	-	-	-	-	-
PAT000360	Pātea River at Skinner Rd Bridge	-	-	-	-	-	-
PNH000200	Punehu Stream at Wiremu Rd	-	-	-6	-	-	-0.033
PNH000900	Punehu Stream at SH45	-	-	-13	-	-	-0.129
STY000300	Hangatahua (Stony) River at Mangatete Rd	-	-	-	-	-	-
WGG000500	Waingongoro River at Eltham Rd Bridge	-	-	-	-	-	-
WGG000900	Waingongoro River at SH45	-	-11	-26	-	-0.994	-2.35
WKH000500	Waiwhakaiho River at SH3	-	-	-	-	-	-
WKR000700	Waiokura pumphouse	-60	-67	-72	-0.060	-0.067	-0.072
WNR000450	Whenuakura River at Nicholson Rd	-57	-68	-75	-82.6	-98.1	-109
WTR000540	Waitara River at Autawa Rd	-43	-57	-67	-147	-197	-232

[1] For sites with a baseline state below the national bottom line (NBL), C band will be achieved if the decrease in load is greater than that required for the NBL and less than that required for B band.

[2] Note: absolute reductions required were incorrectly reported in Table 7 of Neverman et al. (2021), although proportional reductions were correctly reported. This did not affect subsequent analysis in Neverman et al. (2021).

Table 14. Proportional change in suspended sediment loads at selected water quality monitoring sites between the contemporary baseline and future loads under projected climate change with future soil conservation works at mid-century, and the associated attribute state

Time period	RCP	Site name	Mangaehu River at Raupuha Rd Bridge		Maketawa Stream at Tarata Rd		Mangaoraka Stream at Corbett Rd		Pātea River at Barclay Rd Bridge		Pātea River at Skinner Rd Bridge		Punehu Stream at Wiremu Rd		Punehu Stream at SH45		Hangatahua (Stony) River at Mangatete Rd		Waingongoro River at Eltham Rd Bridge		Waingongoro River at SH45		Waiwhakaiho River at SH3		Waiokura pumphouse		Whenuakura River at Nicholson Rd		Waitara River at Autawa Rd	
		Site code	MGH000950		MKW000300		MRK000420		PAT000200		PAT000360		PNH000200		PNH000900		STY000300		WGG000500		WGG000900		WKH000500		WKR000700		WNR000450		WTR000540	
			Diff[1] (%)	State	Diff (%)	State	Diff (%)	State	Diff (%)	State	Diff (%)	State	Diff (%)	State	Diff (%)	State	Diff (%)	State	Diff (%)	State	Diff (%)	State	Diff (%)	State	Diff (%)	State	Diff (%)	State	Diff (%)	State
Baseline			-	C	-	A	-	A	-	A	-	A	-	B	-	B	-	A	-	A	-	C	-	A	-	D	-	D	-	D
Mid-century	2.6	Min	-3	C	3	A	-36	A	-30	A	-58	A	31	C	30	D	20	A	-7	A	-24	B	4	A	3	D	6	D	-2	D
		Median	5	C	4	A	-34	A	-29	A	-58	A	32	C	31	D	21	A	-1	A	-18	B	7	A	3	D	15	D	7	D
		Max	14	D	6	A	-32	A	-29	A	-58	A	33	C	33	D	23	A	7	B	-12	B	10	A	4	D	26	D	16	D
	4.5	Min	7	C	5	A	-32	A	-28	A	-58	A	20	C	19	C	22	A	1	A	-18	B	7	A	-1	D	17	D	8	D
		Median	16	D	6	A	-31	A	-28	A	-58	A	21	C	20	C	23	A	7	B	-12	B	10	A	1	D	26	D	18	D
		Max	25	D	7	A	-28	A	-28	A	-58	A	22	C	22	C	24	A	15	B	-6	C	14	A	1	D	37	D	29	D
	6.0	Min	5	C	8	A	-33	A	-25	A	-56	A	28	C	28	D	22	A	-1	A	-19	B	5	A	7	D	13	D	8	D
		Median	14	D	10	A	-31	A	-25	A	-56	A	29	C	29	D	23	A	6	B	-13	B	8	A	7	D	24	D	16	D
		Max	29	D	11	A	-27	A	-24	A	-55	A	31	C	30	D	25	A	18	B	-4	C	14	A	10	D	40	D	32	D
	8.5	Min	20	D	10	A	-29	A	-27	A	-57	A	25	C	25	C	30	A	10	B	-10	C	13	A	3	D	29	D	23	D
		Median	25	D	10	A	-28	A	-27	A	-56	A	26	C	25	C	30	A	14	B	-7	C	14	A	4	D	35	D	28	D
		Max	38	D	12	A	-25	A	-26	A	-56	A	27	C	27	D	32	A	25	C	2	C	19	A	5	D	49	D	42	D

[1] 'Diff' refers to the percentage difference between the baseline and future sediment load.

Table 15. Proportional change in suspended sediment loads at selected water quality monitoring sites between the contemporary baseline and future loads under projected climate change with future soil conservation works at late century, and the associated attribute state

Time period	RCP	Site name	Mangaehu River at Raupuha Rd Bridge		Maketawa Stream at Tarata Rd		Mangaoraka Stream at Corbett Rd		Pātea River at Barclay Rd Bridge		Pātea River at Skinner Rd Bridge		Punehu Stream at Wiremu Rd		Punehu Stream at SH45		Hangatahua (Stony) River at Mangatete Rd		Waingongoro River at Eltham Rd Bridge		Waingongoro River at SH45		Waiwhakaiho River at SH3		Waiokura pumphouse		Whenuakura River at Nicholson Rd		Waitara River at Autawa Rd	
		Site code	MGH000950		MKW000300		MRK000420		PAT000200		PAT000360		PNH000200		PNH000900		STY000300		WGG000500		WGG000900		WKH000500		WKR000700		WNR000450		WTR000540	
			Diff[1] (%)	State	Diff (%)	State	Diff (%)	State	Diff (%)	State	Diff (%)	State	Diff (%)	State	Diff (%)	State	Diff (%)	State	Diff (%)	State	Diff (%)	State	Diff (%)	State	Diff (%)	State	Diff (%)	State	Diff (%)	State
Baseline			-	C	-	A	-	A	-	A	-	A	-	B	-	B	-	A	-	A	-	C	-	A	-	D	-	D	-	D
Late century	2.6	Min	-8	C	1	A	-40	A	-30	A	-59	A	21	C	21	C	17	A	-11	A	-26	A	1	A	3	D	2	D	-7	D
		Median	4	C	2	A	-37	A	-30	A	-58	A	23	C	22	C	19	A	-1	A	-18	B	6	A	4	D	15	D	6	D
		Max	16	D	3	A	-34	A	-30	A	-58	A	24	C	24	C	20	A	7	B	-12	B	10	A	4	D	26	D	19	D
	4.5	Min	8	C	4	A	-34	A	-28	A	-57	A	32	C	31	D	18	A	2	B	-17	B	5	A	1	D	18	D	10	D
		Median	22	D	5	A	-31	A	-28	A	-57	A	33	C	33	D	19	A	12	B	-8	C	10	A	2	D	32	D	25	D
		Max	37	D	7	A	-27	A	-28	A	-57	A	35	C	35	D	21	A	24	C	1	C	15	A	3	D	49	D	41	D
	6.0	Min	23	D	6	A	-29	A	-25	A	-56	A	36	C	36	D	30	A	11	B	-8	C	12	A	6	D	32	D	26	D
		Median	42	D	8	A	-25	A	-25	A	-55	A	38	D	38	D	32	A	26	C	3	C	18	A	7	D	54	D	46	D
		Max	51	D	9	A	-21	A	-24	A	-55	A	40	D	40	D	34	A	35	C	10	D	23	A	9	D	64	D	57	D
	8.5	Min	49	D	13	A	-19	A	-28	A	-57	A	49	D	49	D	39	A	32	C	8	D	25	A	7	D	61	D	54	D
		Median	71	D	15	A	-14	A	-28	A	-57	A	51	D	51	D	42	A	48	D	21	D	32	A	8	D	84	D	78	D
		Max	84	D	16	A	-11	A	-28	A	-57	A	53	D	52	D	43	B	58	D	29	D	37	A	8	D	98	D	92	D

[1] 'Diff' refers to the percentage difference between the baseline and future sediment load.

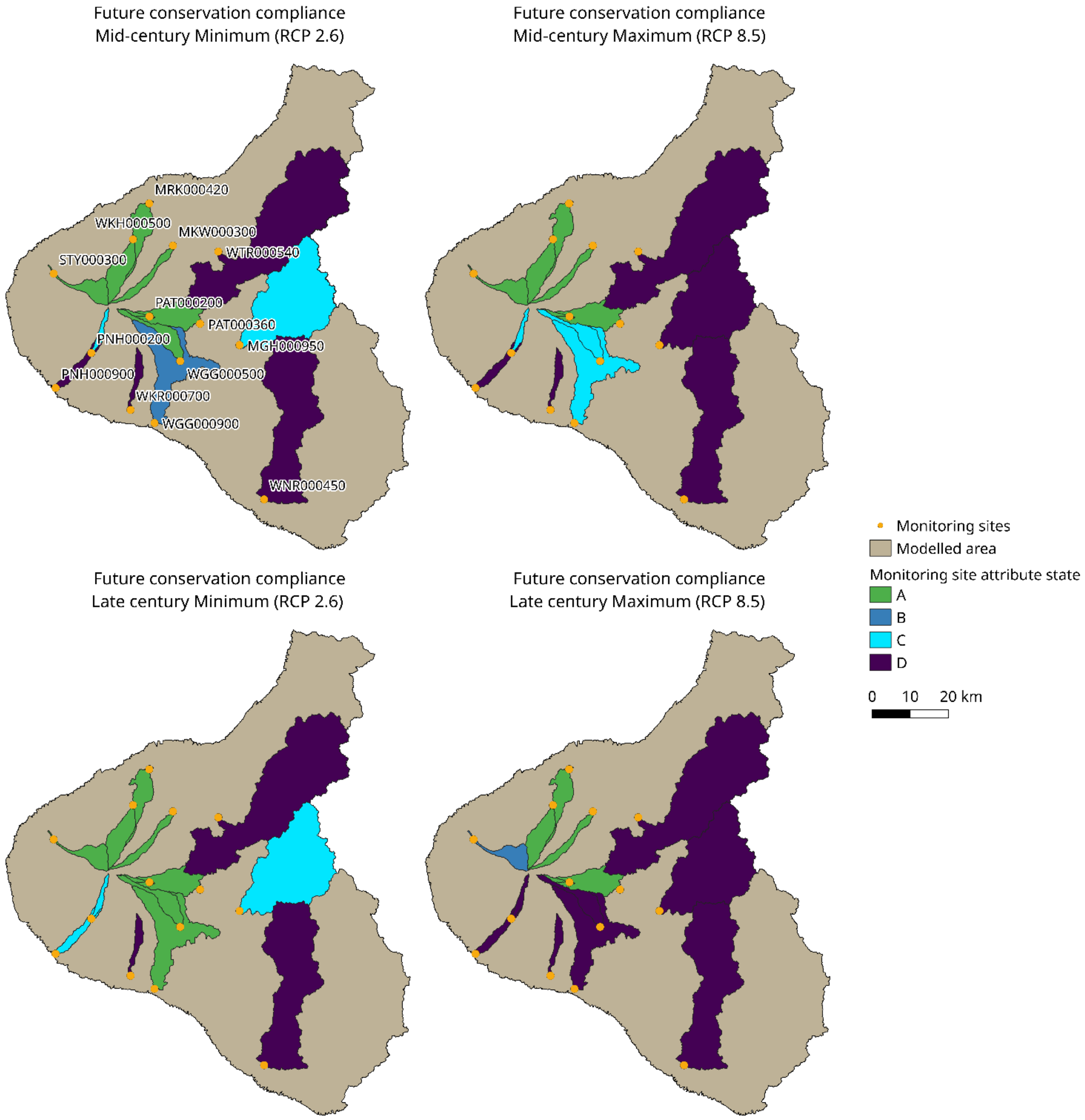

Figure 5. Range in compliance across the 14 selected water quality monitoring sites under the future soil conservation scenario for selected RCMs at mid-century and late century. Note: the attribute state only applies to the RECv2 segment of the monitoring site; it may not apply to upstream segments. Catchment polygons are used for display purposes only.

The load reductions required to achieve an improvement in attribute band under projected climate change with future soil conservation works by mid- and late century are provided in Table 16 and Table 17. As the NPS-FM (2020) does not allow for deterioration below the baseline state (Ministry for the Environment 2022), we also report the reduction required to maintain baseline state (baseline median visual clarity) where a site is projected to degrade. The required reductions apply to the future load.

Under projected climate change with future soil conservation works by mid-century the Mangaoraka Stream at Corbett Rd, Pātea River at Barclay Rd Bridge, and Pātea River at Skinner Rd Bridge are projected to have improved above their baseline visual clarity across all projections and already achieve A band so require no further load reductions (Table 16). Waingongoro River at SH45 also requires no further reduction to maintain baseline state under all projections except for the maximum RCP8.5 (Table 16), but may require further reductions to achieve a higher attribute band.

Waiokura pumphouse, Whenuakura River at Nicholson Rd, and Waitara River at Autawa Rd have a baseline state below the NBL and therefore require reductions to improve their state to at least the NBL. These sites are projected to have increases in load across all RCPs by mid-century compared to the contemporary baseline and therefore require further reductions to achieve the NBL. The remaining seven sites require further load reductions at mid-century to maintain their baseline visual clarity.

By late century, Mangaoraka Stream at Corbett Rd, Pātea River at Barclay Rd Bridge, Pātea River at Skinner Rd Bridge, and Waiwhakaiho River at SH3 are projected to improve above their baseline visual clarity across all projections and require no further reduction (Table 17). The Mangaehu River at Raupuha Rd Bridge, Waingongoro River at Eltham Rd Bridge, and Waingongoro River at SH45 also improve under lower greenhouse gas emissions, but require further reductions in load to maintain their baseline state for RCPs 4.5, 6.0, and 8.5.

Waiokura pumphouse, Whenuakura River at Nicholson Rd, and Waitara River at Autawa Rd are projected to have increases in load across all RCPs by late century and therefore require further reductions to achieve the NBL. The remaining four sites require further load reductions at late century to maintain their baseline state.

Table 16. Proportional changes in mean annual suspended sediment load required to maintain or improve the baseline attribute state at selected water quality monitoring sites under projected climate change with future soil conservation works by mid-century. Negative values indicate a reduction in load is required. "-" indicates no further load reduction required to achieve the target, or the target is below baseline state and thus non-compliant with the NPS-FM (2020). "Base" refers to the baseline visual clarity

		Site name	Mangaehu River at Raupuha Rd Bridge				Maketawa Stream at Tarata Rd				Mangaoraka Stream at Corbett Rd				Pātea River at Barclay Rd Bridge				Pātea River at Skinner Rd Bridge				Punehu Stream at Wiremu Rd				Punehu Stream at SH45			
		Site code	MGH000950				MKW000300				MRK000420				PAT000200				PAT000360				PNH000200				PNH000900			
Baseline State			C				A				A				A				A				B				B			
Time period	RCP	Target	Base	NBL	B	A	Base	NBL	B	A	Base	NBL	B	A	Base	NBL	B	A	Base	NBL	B	A	Base	NBL	B	A	Base	NBL	B	A
Mid-century	2.6	Min	-	-	-7	-25	-3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-24	-	-	-28	-23	-	-	-33
		Median	-5	-	-15	-32	-4	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-24	-	-	-29	-24	-	-	-34
		Max	-12	-	-21	-37	-5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-25	-	-	-29	-25	-	-	-35
	4.5	Min	-6	-	-16	-32	-5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-16	-	-	-21	-16	-	-	-27
		Median	-14	-	-23	-38	-6	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-17	-	-	-22	-17	-	-	-28
		Max	-20	-	-29	-43	-7	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-18	-	-	-23	-18	-	-	-29
	6.0	Min	-5	-	-15	-32	-8	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-22	-	-	-26	-22	-	-	-32
		Median	-12	-	-21	-37	-9	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-23	-	-	-27	-22	-	-	-32
		Max	-22	-	-30	-44	-10	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-24	-	-	-28	-23	-	-	-33
	8.5	Min	-17	-	-25	-40	-9	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-20	-	-	-25	-20	-	-	-30
		Median	-20	-	-28	-42	-9	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-20	-	-	-25	-20	-	-	-31
		Max	-27	-	-35	-48	-11	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-21	-	-	-26	-21	-	-	-32

Table 16 (continued)

		Site name	Hangatahua (Stony) River at Mangatete Rd				Waingongoro River at Eltham Rd Bridge				Waingongoro River at SH45				Waiwhakaiho River at SH3				Waiokura pumphouse				Whenuakura River at Nicholson Rd				Waitara River at Autawa Rd			
		Site code	**STY000300**				**WGG000500**				**WGG000900**				**WKH000500**				**WKR000700**				**WNR000450**				**WTR000540**			
Baseline State			**A**				**A**				**C**				**A**				**D**				**D**				**D**			
Time period	**RCP**	**Target**	**Base**	**NBL**	**B**	**A**	**Base**	**NBL**	**B**	**A**	**Base**	**NBL**	**B**	**A**	**Base**	**NBL**	**B**	**A**	**Base**	**NBL**	**B**	**A**	**Base**	**NBL**	**B**	**A**	**Base**	**NBL**	**B**	**A**
Mid-century	2.6	Min	-17	-	-	-	-	-	-	-	-	-	-	-3	-4	-	-	-	-	-61	-68	-73	-	-60	-70	-77	-	-41	-56	-66
		Median	-18	-	-	-	-	-	-	-	-	-	-	-9	-6	-	-	-	-	-61	-68	-73	-	-63	-72	-79	-	-46	-60	-69
		Max	-19	-	-	-	-7	-	-	-	-	-	-	-16	-9	-	-	-	-	-61	-68	-73	-	-66	-74	-80	-	-50	-63	-72
	4.5	Min	-18	-	-	-	-1	-	-	-	-	-	-	-10	-7	-	-	-	-	-60	-67	-72	-	-63	-73	-79	-	-47	-60	-70
		Median	-18	-	-	-	-6	-	-	-	-	-	-	-15	-9	-	-	-	-	-60	-67	-72	-	-66	-75	-80	-	-51	-63	-72
		Max	-19	-	-	-	-13	-	-	-	-	-	-5	-21	-12	-	-	-	-	-60	-67	-73	-	-69	-77	-82	-	-56	-67	-74
	6.0	Min	-18	-	-	-	-	-	-	-	-	-	-	-9	-5	-	-	-	-	-62	-69	-74	-	-62	-72	-78	-	-47	-60	-69
		Median	-19	-	-	-	-6	-	-	-	-	-	-	-15	-8	-	-	-	-	-63	-69	-74	-	-66	-74	-80	-	-50	-63	-72
		Max	-20	-	-	-	-15	-	-	-	-	-	-8	-23	-12	-	-	-	-	-63	-70	-75	-	-69	-77	-82	-	-57	-67	-75
	8.5	Min	-23	-	-	-	-9	-	-	-	-	-	-1	-18	-12	-	-	-	-	-61	-68	-73	-	-67	-75	-81	-	-53	-65	-73
		Median	-23	-	-	-	-12	-	-	-	-	-	-4	-20	-12	-	-	-	-	-61	-68	-73	-	-68	-76	-82	-	-55	-66	-74
		Max	-24	-	-	-	-20	-	-	-	-2	-	-13	-27	-16	-	-	-	-	-62	-68	-74	-	-71	-79	-84	-	-60	-70	-77

Table 17. Proportional changes in mean annual suspended sediment load required to maintain or improve the baseline attribute state at water quality monitoring sites under projected climate change with future soil conservation works for late century. Negative values indicate a reduction in load is required. "-" indicates no further load reduction required to achieve the target, or the target is below baseline state and thus non-compliant with the NPS-FM (2020). "Base" refers to the baseline visual clarity

		Site name	Mangaehu River at Raupuha Rd Bridge				Maketawa Stream at Tarata Rd				Mangaoraka Stream at Corbett Rd				Pātea River at Barclay Rd Bridge				Pātea River at Skinner Rd Bridge				Punehu Stream at Wiremu Rd				Punehu Stream at SH45			
		Site code	MGH000950				MKW000300				MRK000420				PAT000200				PAT000360				PNH000200				PNH000900			
Baseline State			C				A				A				A				A				B				B			
Time period	RCP	Target	Base	NBL	B	A	Base	NBL	B	A	Base	NBL	B	A	Base	NBL	B	A	Base	NBL	B	A	Base	NBL	B	A	Base	NBL	B	A
Late century	2.6	Min	-		-3	-22	-1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-18	-	-	-22	-17	-	-	-28
		Median	-4		-14	-31	-2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-19	-	-	-23	-18	-	-	-29
		Max	-13		-23	-38	-3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-19	-	-	-24	-19	-	-	-30
	4.5	Min	-7		-17	-33	-4	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-24	-	-	-29	-24	-	-	-34
		Median	-18		-26	-41	-5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-25	-	-	-29	-25	-	-	-35
		Max	-27		-35	-47	-6	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-26	-	-	-30	-26	-	-	-35
	6.0	Min	-19		-27	-41	-5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-27	-	-	-31	-26	-	-	-36
		Median	-30		-37	-49	-7	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-28	-	-	-32	-28	-	-	-37
		Max	-34		-41	-52	-8	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-28	-	-	-33	-28	-	-	-38
	8.5	Min	-33		-40	-52	-11	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-33	-	-	-37	-33	-	-	-42
		Median	-41		-48	-58	-13	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-34	-	-	-38	-34	-	-	-42
		Max	-46		-51	-61	-14	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-35	-	-	-38	-34	-	-	-43

Table 17 (continued)

		Site name	Hangatahua (Stony) River at Mangatete Rd				Waingongoro River at Eltham Rd Bridge				Waingongoro River at SH45				Waiwhakaiho River at SH3				Waiokura pumphouse				Whenuakura River at Nicholson Rd				Waitara River at Autawa Rd			
		Site code	**STY000300**				**WGG000500**				**WGG000900**				**WKH000500**				**WKR000700**				**WNR000450**				**WTR000540**			
Baseline State			**A**				**A**				**C**				**A**				**D**				**D**				**D**			
Time period	**RCP**	**Target**	**Base**	**NBL**	**B**	**A**	**Base**	**NBL**	**B**	**A**	**Base**	**NBL**	**B**	**A**	**Base**	**NBL**	**B**	**A**	**Base**	**NBL**	**B**	**A**	**Base**	**NBL**	**B**	**A**	**Base**	**NBL**	**B**	**A**
Late century	2.6	Min	-15	-	-	-	-	-	-	-	-		-	-	-	-	-	-1	-	-61	-68	-73	-	-58	-69	-76	-	-38	-54	-64
		Median	-16	-	-	-	-	-	-	-	-		-	-9	-	-	-	-5	-	-61	-68	-73	-	-63	-72	-79	-	-46	-59	-69
		Max	-17	-	-	-	-7	-	-	-	-		-	-16	-	-	-	-9	-	-61	-68	-73	-	-66	-75	-80	-	-52	-64	-72
	4.5	Min	-15	-	-	-	-2	-	-	-	-		-	-11	-	-	-	-5	-	-60	-67	-73	-	-64	-73	-79	-	-48	-61	-70
		Median	-16	-	-	-	-11	-	-	-	-		-3	-19	-	-	-	-9	-	-60	-67	-73	-	-68	-76	-81	-	-54	-66	-74
		Max	-18	-	-	-	-19	-	-	-	-1		-12	-26	-	-	-	-13	-	-61	-68	-73	-	-71	-78	-83	-	-59	-69	-77
	6.0	Min	-23	-	-	-	-10	-	-	-	-		-3	-19	-	-	-	-11	-	-62	-69	-74	-	-68	-76	-81	-	-54	-66	-74
		Median	-24	-	-	-	-20	-	-	-	-3		-14	-28	-	-	-	-15	-	-63	-69	-74	-	-72	-79	-84	-	-61	-71	-77
		Max	-25	-	-	-	-26	-	-	-	-9		-19	-33	-	-	-	-19	-	-63	-69	-75	-	-74	-80	-85	-	-63	-73	-79
	8.5	Min	-28	-	-	-	-24	-	-	-	-7		-17	-31	-	-	-	-20	-	-62	-69	-74	-	-73	-80	-85	-	-63	-72	-79
		Median	-29	-	-	-	-32	-	-	-	-17		-26	-39	-	-	-	-24	-	-63	-69	-74	-	-77	-83	-87	-	-68	-76	-81
		Max	-30	-	-	-	-37	-	-	-	-22		-31	-42	-	-	-	-27	-	-63	-69	-74	-	-78	-84	-88	-	-70	-78	-83

5.3 Sediment load contributions from natural cover areas

Table 18 summarises the proportion of land under natural cover within the selected water quality monitoring site catchments, and the proportion of the total suspended sediment load coming from natural cover areas for the contemporary baseline and future soil conservation scenarios under contemporary climate from Neverman et al. (2021). Natural cover extents range from <1% to 93% of catchment areas, which is constant for all land cover and climate scenarios.

Natural cover areas contribute <1% to 56% of contemporary suspended sediment loads, and <1% to 60% of future soil conservation scenario sediment loads under baseline climate conditions. Under the future soil conservation scenario, the suspended sediment load from non-natural cover areas and the total load decrease, while the absolute load from natural cover areas remains unchanged. This produces an increase in the proportion of total load from natural cover areas while the absolute load contribution remains the same.

Variation between catchments in the proportion of suspended sediment load from natural cover areas generally reflects variation in the extent of natural cover. The Hangatahua (Stony) River at Mangatete Rd, Punehu Stream at Wiremu Rd, and Pātea River at Barclay Rd Bridge show relatively low suspended sediment load contributions from natural cover (2%–37%) compared with the extent of natural cover in their catchments (29%–93%). These catchments primarily drain the flanks of Mt Taranaki within the national park. The sediment from these steep natural areas is likely to include a substantial coarse sediment component that typically does not travel in suspension and is not represented by SedNetNZ, which models fine suspended sediment. This is supported by the relatively high baseline visual clarity states at these sites, as coarse sediment has little impact on visual clarity (Davies-Colley & Smith 2001).

Contemporary attribute state and mean annual sediment loads at the selected water quality monitoring sites are reported in Table 19, along with the proportion of load from non-natural cover areas, and reductions in load required to achieve NPS-FM (2020) attribute states. Across the monitoring sites, 44%–100% of contemporary suspended sediment loads are derived from non-natural cover areas. The results suggest that at most sites (except the Whenuakura River at Nicholson Rd) the load reductions required to improve the site attribute state are less than the load coming from non-natural cover areas, where mitigations may be feasible.

Table 20 and Table 21 summarise the proportion of the total suspended sediment load derived from non-natural cover areas for the future soil conservation scenario under projected climate change. Contributions from natural and non-natural land cover are similar as under baseline climate, with 39%–100% of suspended sediment loads derived from non-natural cover areas under projected climate change by both mid-century and late century. Five sites (36%) (Mangaehu River at Raupuha Rd Bridge, Maketawa Stream at Tarata Rd, Waiwhakaiho River at SH3, Whenuakura River at Nicholson Rd, and Waitara River at Autawa Rd) have decreases of ≥5 percentage points in the proportion of load from non-natural cover areas under projected climate change compared to baseline climate (Table 21).

Table 18. Summary of the upstream catchment area under natural cover, and the load proportions from natural cover areas for selected water quality monitoring sites for the contemporary baseline and future soil conservation scenarios under baseline climate from Neverman et al. (2021)

Site Code	Location	Upstream catchment area under natural cover (%)	Load from natural cover* - both scenarios (t/yr)	Contemporary baseline		Future soil conservation	
				Total load (t/yr)	Proportion from natural cover (%)	Total load (t/yr)	Proportion from natural cover (%)
MGH000950	Mangaehu River at Raupuha Rd Bridge	46	52,000	231,000	22	196,000	26
MKW000300	Maketawa Stream at Tarata Rd	44	110	670	17	640	18
MRK000420	Mangaoraka Stream at Corbett Rd	4	6	760	<1	660	<1
PAT000200	Pātea River at Barclay Rd Bridge	85	12	150	8	150	8
PAT000360	Pātea River at Skinner Rd Bridge	11	14	2,000	<1	1,600	<1
PNH000200	Punehu Stream at Wiremu Rd	78	16	560	3	550	3
PNH000900	Punehu Stream at SH45	29	17	990	2	960	2
STY000300	Hangatahua (Stony) River at Mangatete Rd	93	3,100	8,300	37	8,300	37
WGG000500	Waingongoro River at Eltham Rd Bridge	18	43	1,900	2	1,900	2
WGG000900	Waingongoro River at SH45	7	64	9,100	<1	8,500	<1
WKH000500	Waiwhakaiho River at SH3	59	990	3,700	27	3,400	29
WKR000700	Waiokura pumphouse	<1	<1	100	<1	91	<1
WNR000450	Whenuakura River at Nicholson Rd	71	81,000	144,000	56	135,000	60
WTR000540	Waitara River at Autawa Rd	51	80,000	346,000	23	293,000	27

Table 19. Summary of the baseline attribute state and mean annual suspended sediment load from non-natural cover for the contemporary baseline, as well as load reductions required to achieve NPS-FM (2020) attribute states, and load reduction achieved relative to the contemporary baseline under the future soil conservation scenario at the selected water quality monitoring sites

Site Code	Location	Contemporary attribute band	Contemporary total load (t/yr)	Contemporary load from non–natural cover		Load reduction required to achieve attribute state (t/yr)			Load reduction achieved by future soil conservation scenario (t/yr)
				Absolute (t/yr)	Proportion of total (%)	NBL	B band	A band	
MGH000950	Mangaehu River at Raupuha Rd Bridge	C	231,000	180,000	78	0	24,000	65,000	36,000
MKW000300	Maketawa Stream at Tarata Rd	A	670	560	83	0	0	0	25
MRK000420	Mangaoraka Stream at Corbett Rd	A	760	750	99	0	0	0	97
PAT000200	Pātea River at Barclay Rd Bridge	A	150	140	92	0	0	0	0
PAT000360	Pātea River at Skinner Rd Bridge	A	2,000	2,000	99	0	0	0	400
PNH000200	Punehu Stream at Wiremu Rd	B	560	550	97	0	0	33	14
PNH000900	Punehu Stream at SH45	B	990	970	98	0	0	130	25
STY000300	Hangatahua (Stony) River at Mangatete Rd	A	8,300	5,300	63	0	0	0	17
WGG000500	Waingongoro River at Eltham Rd Bridge	A	1,900	1,900	98	0	0	0	29
WGG000900	Waingongoro River at SH45	C	9,100	9,100	99	0	990	2,300	660
WKH000500	Waiwhakaiho River at SH3	A	3,700	2,700	73	0	0	0	220
WKR000700	Waiokura pumphouse	D	100	100	100	60	67	72	9
WNR000450	Whenuakura River at Nicholson Rd	D	144,000	63,000	44	83,000	98,000	109,000	8,900
WTR000540	Waitara River at Autawa Rd	D	346,000	265,000	77	147,000	197,000	232,000	53,000

Table 20. Proportion of monitoring site catchment total load derived from non-natural cover areas under the future soil conservation scenario with the effects of climate change at mid-century compared to the contemporary baseline. 'Prop' is the proportion (%) of the total load derived from non-natural cover areas

Time period	RCP	Site name	Mangaehu River at Raupuha Rd Bridge		Maketawa Stream at Tarata Rd		Mangaoraka Stream at Corbett Rd		Pātea River at Barclay Rd Bridge		Pātea River at Skinner Rd Bridge		Punehu Stream at Wiremu Rd		Punehu Stream at SH45		Hangatahua (Stony) River at Mangatete Rd		Waingongoro River at Eltham Rd Bridge		Waingongoro River at SH45		Waiwhakaiho River at SH3		Waiokura pumphouse		Whenuakura River at Nicholson Rd		Waitara River at Autawa Rd	
		Site code	MGH000950		MKW000300		MRK000420		PAT000200		PAT000360		PNH000200		PNH000900		STY000300		WGG000500		WGG000900		WKH000500		WKR000700		WNR000450		WTR000540	
			Load (kt/yr)	Prop (%)	Load (kt/yr)	Prop (%)	Load (kt/yr)	Prop (%)	Load (kt/yr)	Prop (%)	Load (kt/yr)	Prop (%)	Load (kt/yr)	Prop (%)	Load (kt/yr)	Prop (%)	Load (kt/yr)	Prop (%)	Load (kt/yr)	Prop (%)	Load (kt/yr)	Prop (%)	Load (kt/yr)	Prop (%)	Load (kt/yr)	Prop (%)	Load (kt/yr)	Prop (%)	Load (kt/yr)	Prop (%)
Baseline			180	78	0.56	83	0.75	99	0.14	92	2.0	99	0.55	97	0.97	98	5.3	63	1.9	98	9.1	99	2.7	73	0.10	100	63	44	265	77
Mid-century	2.6	Min	164	73	0.57	82	0.48	99	0.10	91	0.83	99	0.72	98	1.3	98	6.5	64	1.7	98	6.9	99	2.7	71	0.10	100	61	40	245	72
		Median	179	73	0.57	81	0.49	99	0.10	91	0.83	99	0.72	97	1.3	98	6.5	64	1.9	98	7.4	99	2.8	71	0.10	100	66	40	267	72
		Max	193	73	0.57	80	0.51	99	0.10	90	0.83	99	0.73	97	1.3	98	6.5	63	2.0	98	8	99	2.8	70	0.10	100	72	40	288	72
	4.5	Min	181	73	0.57	81	0.51	99	0.10	91	0.83	99	0.65	97	1.2	98	6.5	64	1.9	98	7.4	99	2.8	70	0.10	100	67	40	270	72
		Median	196	73	0.57	80	0.52	99	0.10	91	0.84	99	0.66	97	1.2	98	6.5	63	2.0	98	7.9	99	2.8	70	0.10	100	72	40	293	72
		Max	213	73	0.57	79	0.54	99	0.10	90	0.84	99	0.66	97	1.2	98	6.5	62	2.2	98	8.5	99	2.9	69	0.10	100	79	40	321	72
	6.0	Min	179	73	0.59	82	0.50	99	0.10	91	0.88	99	0.70	97	1.2	98	6.5	64	1.8	98	7.3	99	2.7	70	0.11	100	65	40	268	72
		Median	193	73	0.59	81	0.52	99	0.10	91	0.88	99	0.70	97	1.2	98	6.5	63	2.0	98	7.9	99	2.7	69	0.11	100	71	40	288	72
		Max	218	73	0.59	80	0.54	99	0.10	90	0.89	99	0.71	97	1.3	98	6.5	62	2.2	98	8.7	99	2.8	68	0.11	100	80	40	328	72
	8.5	Min	203	73	0.59	80	0.53	99	0.10	91	0.86	99	0.68	97	1.2	98	6.9	64	2.1	98	8.1	99	2.9	70	0.10	100	74	39	305	72
		Median	212	73	0.59	80	0.54	99	0.10	90	0.86	99	0.68	97	1.2	98	6.9	63	2.1	98	8.4	99	2.9	69	0.10	100	77	39	318	72
		Max	234	73	0.59	79	0.56	99	0.10	90	0.87	99	0.69	97	1.2	98	6.9	62	2.3	98	9.2	99	3.0	68	0.10	100	85	40	352	72

Table 21. Proportion of monitoring site catchment total load derived from non-natural cover areas under the future soil conservation scenario with the effects of climate change at late century compared to the contemporary baseline. 'Prop' is the proportion (%) of the total load derived from non-natural cover areas

Time period	RCP	Site name	Mangaehu River at Raupuha Rd Bridge		Maketawa Stream at Tarata Rd		Mangaoraka Stream at Corbett Rd		Pātea River at Barclay Rd Bridge		Pātea River at Skinner Rd Bridge		Punehu Stream at Wiremu Rd		Punehu Stream at SH45		Hangatahua (Stony) River at Mangatete Rd		Waingongoro River at Eltham Rd Bridge		Waingongoro River at SH45		Waiwhakaiho River at SH3		Waiokura pumphouse		Whenuakura River at Nicholson Rd		Waitara River at Autawa Rd	
		Site code	MGH000950		MKW000300		MRK000420		PAT000200		PAT000360		PNH000200		PNH000900		STY000300		WGG000500		WGG000900		WKH000500		WKR000700		WNR000450		WTR000540	
			Load (kt/yr)	Prop (%)	Load (kt/yr)	Prop (%)	Load (kt/yr)	Prop (%)	Load (kt/yr)	Prop (%)	Load (kt/yr)	Prop (%)	Load (kt/yr)	Prop (%)	Load (kt/yr)	Prop (%)	Load (kt/yr)	Prop (%)	Load (kt/yr)	Prop (%)	Load (kt/yr)	Prop (%)	Load (kt/yr)	Prop (%)	Load (kt/yr)	Prop (%)	Load (kt/yr)	Prop (%)	Load (kt/yr)	Prop (%)
Baseline			180	78	0.56	83	0.75	99	0.14	92	2.0	99	0.55	97	0.97	98	5.3	63	1.9	98	9.1	99	2.7	73	0.10	100	63	44	265	77
Late century	2.6	Min	156	73	0.55	82	0.45	99	0.10	91	0.82	99	0.66	97	1.2	98	6.3	64	1.7	98	6.7	99	2.7	72	0.10	100	59	40	232	72
		Median	177	73	0.55	81	0.47	99	0.10	91	0.82	99	0.67	97	1.2	98	6.3	63	1.9	98	7.4	99	2.7	70	0.10	100	66	40	264	72
		Max	196	73	0.55	80	0.50	99	0.10	90	0.83	99	0.68	97	1.2	98	6.3	63	2.0	98	8.0	99	2.8	69	0.10	100	72	40	295	72
	4.5	Min	183	73	0.56	81	0.49	99	0.10	91	0.85	99	0.72	97	1.3	98	6.2	63	1.9	98	7.5	99	2.7	70	0.10	100	67	40	273	72
		Median	206	73	0.56	80	0.52	99	0.10	90	0.85	99	0.73	97	1.3	98	6.2	62	2.1	98	8.3	99	2.7	68	0.10	100	75	40	311	72
		Max	232	73	0.56	78	0.55	98	0.10	90	0.85	99	0.74	97	1.3	98	6.2	61	2.3	98	9.1	99	2.8	67	0.10	100	85	40	349	72
	6.0	Min	208	73	0.56	80	0.53	99	0.10	91	0.88	99	0.74	97	1.3	98	6.9	63	2.1	98	8.3	99	2.8	69	0.11	100	75	39	314	72
		Median	240	73	0.56	78	0.56	99	0.10	90	0.88	99	0.75	97	1.3	98	6.9	62	2.4	98	9.3	99	2.9	67	0.11	100	88	40	362	72
		Max	256	73	0.56	77	0.59	98	0.10	90	0.89	99	0.76	97	1.4	98	6.9	61	2.5	98	10	99	3.0	66	0.11	100	94	40	389	72
	8.5	Min	252	73	0.59	78	0.60	99	0.10	90	0.85	99	0.81	97	1.4	98	7.2	62	2.5	98	9.8	99	3.1	68	0.11	100	91	39	383	72
		Median	289	73	0.59	76	0.64	98	0.10	90	0.86	99	0.82	97	1.5	98	7.2	61	2.8	98	11	99	3.2	66	0.11	100	105	39	440	72
		Max	311	73	0.59	75	0.67	98	0.10	89	0.86	99	0.83	97	1.5	98	7.2	60	3.0	98	12	99	3.3	65	0.11	100	112	39	474	72

6 Model Limitations

6.1 Climate change projections

Variations between Global Climate Models (GCMs), greenhouse gas emission trajectories (RCPs), and how climate change affects erosion processes, contribute to a high degree of uncertainty in projected changes in suspended sediment loads. This range of variations means there can be considerable difference between our lowest and highest projections, especially by late century. We attempt to account for the range of uncertainty by presenting results from climate projections derived from six GCMs and four RCPs, which were selected to represent the range of uncertainties (Collins et al. 2018; Ministry for the Environment 2018; Collins 2020).

Simplifications and assumptions are required to relate changes in hydro-climatic drivers to changes in erosion processes and sediment loads. For example, the prediction of future mass movement erosion on hillslopes assumes that all mass movement processes increase proportionately with shallow landslides, and will be driven by changes in storm rainfall. As shallow landslide erosion is the dominant mass movement process in Taranaki (Basher 2013) we expect the model outputs to have a low sensitivity to this assumption. Rainfall events exceeding 150 mm in a 48-hour period have been assumed to represent the triggering threshold for shallow landslides, with an average recurrence interval (ARI) of 30 years. This uniform triggering threshold has been used to estimate future changes in landslide density, and erosion from other mass movement processes, but this threshold may vary for different terrains, land covers, and mass movement processes (e.g. Reid & Page 2003; Basher et al. 2020).

Basher et al. (2020) noted that only a few studies have addressed the potential impacts of climate change on erosion in New Zealand, and most of these consisted of general statements about likely trends rather than quantifying change. For instance, Crozier (2010) reviewed the basis for assessing the impact of climate change on landslides and found that although there is a strong theoretical basis for increased landslide activity in response to predicted climate change, there is a high level of uncertainty resulting from the uncertainty inherent in downscaling GCMs spatially and temporally. Due to the high uncertainty, the results of the climate change projections should be interpreted as indicative of trends rather than absolute values (Basher et al. 2020).

6.2 Achievement of NPS-FM (2020) attribute states

There are several areas which contribute to uncertainty in estimating the change in suspended sediment load required to achieve target median visual clarity.

We estimated the proportional changes in sediment load required to achieve target visual clarity states using empirical models relating changes in visual clarity to changes in suspended sediment fitted to a national dataset (including sites from Taranaki, see Hicks et al. 2019), as recommended by Ministry for the Environment (2022). This should result in the models being fit to a wide range of catchment variables and therefore representing the variability across Taranaki. 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 given site is primarily affected by suspended sediment and does not account for the potential influence of other matter, such as tannins or waste discharges, on visual clarity.

We also assumed 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, land use, or climate may alter the relationship between flow and suspended sediment concentration due to changes in either catchment hydrology or sediment supply dynamics. As data are not presently available to model the effects of these changes on the relationship between suspended sediment concentration and flow, we assume the associated relationships remain constant across the mitigation and climate scenarios.

Current state median visual clarity was derived from monthly fixed-interval sampling. Fixed-interval sampling likely results in visual clarity predominantly being measured at or near baseflow, when most of the suspended sediment load may be derived from within-channel sources (e.g. remobilisation from channel bed or from bank erosion). In contrast, the modelled mean annual suspended sediment loads also capture storm event-driven erosion and sediment loads, with shallow landslide erosion being a dominant sediment source in hill country areas of Taranaki over multi-decadal timescales. Hence, the link between reductions in storm-generated sediment loads and increases in visual clarity at generally low flows may depend in part on a reduction in the storage and subsequent remobilisation of storm-derived fine sediment in the channel network. The present modelling assumes that the relationship between erosion, storage, and transport remain constant across scenarios.

One of the key limitations of the analysis presented in this report is the assumption that WFPs are fully implemented in their first year (Neverman et al. 2021). This assumption likely results in underestimation of the capacity for load reductions under future scenarios where WFPs have not been fully implemented in their first year. This could result in an underestimation in the achievable attribute state at monitoring sites under future climate projections for catchments where a significant number of WFPs have not been implemented as extensively as assumed. Information on the extent of soil conservation works implemented on farms through time, and the associated proportion of the WFP completed, would allow us to better constrain this model parameter.

7 Conclusions and recommendations

- Fully implemented and mature soil conservation works may offset the effects of climate change at late century on the total sediment load delivered to the coast across Taranaki for greenhouse gas pathways up to RCP6.0 when compared to the pre-mitigation baseline.
- Soil conservation works implemented since 1996 may offset the impacts of climate change on sediment loads at 50% of monitoring sites by late century. Under the stabilisation pathways (RCP4.5 and RCP6.0), soil conservation works offset the impacts of climate change at 57% to 93% of monitoring sites.
- Due to the extent of soil conservation works assumed to be implemented by 2018, future soil conservation works appear to have less impact when compared to the 2018 contemporary baseline.
- The Waingongoro River at SH45 is projected to improve in attribute state under lower greenhouse gas emissions. Four sites (29%) are projected to have declines in attribute band by mid-century, and five sites (35%) by late century.
- By late century, four sites are projected to have lower sediment loads than their baseline state across all projections. The Mangaehu River at Raupuha Rd Bridge, Waingongoro River at Eltham Rd Bridge, and Waingongoro River at SH45 tend to require additional reductions in load to maintain their baseline state for RCPs 4.5, 6.0, and 8.5.
- The Waiokura pumphouse, Whenuakura River at Nicholson Rd, and Waitara River at Autawa Rd are projected to require further reductions to achieve the NBL.
- Between 44% and 100% of contemporary suspended sediment loads are derived from non-natural cover areas at the selected water quality monitoring sites. This suggests the load reductions required to improve their attribute state are less than the load coming from non-natural cover areas, where mitigations may be feasible. Contributions from non-natural land cover are similar under projected climate change.
- Information on the extent of soil conservation works implemented on farms through time, and the associated proportion of the WFP completed, would allow better representation of the effectiveness of conservation measures implemented to date and the potential reductions achievable in future. This would improve the estimation of future compliance with the NPS-FM (2020).
- Future applications of SedNetNZ in the Taranaki region may incorporate regional LiDAR data to better represent erosion processes. This could be supported by capturing data on erosion processes, such as building a database of storm-driven shallow landslides for use in modelling landslide susceptibility at higher resolution (e.g. Smith et al. 2021), or through improved representation of the channel network and riparian vegetation using LiDAR. This would enable better calibration of the erosion process components for future applications of SedNetNZ in the Taranaki region.
- Climate impacts may be updated when downscaled CMIP6 projections become available for New Zealand.

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