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Application of SedNetNZ in the Waikato region to support NPS-FM 2020 implementation

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Contract Report: LC4432

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Summary

Project and client

- Waikato Regional Council (WRC) contracted Manaaki Whenua – Landcare Research to model erosion and suspended sediment loads across the region using SedNetNZ for a range of erosion mitigation and climate change scenarios.
- The project was undertaken to support implementation of the 2020 National Policy Statement for Freshwater Management (NPS-FM 2020).
- The present report updates and replaces previous SedNetNZ modelling completed in the Waikato Region on a catchment or water management zone basis. The project applied an updated version of the SedNetNZ model that contains improvements to the model's components, including representation of riverbank and surficial erosion, floodplain sedimentation, and lake sediment trapping.

Objectives

The project has three objectives:

1 to model region-wide mean annual suspended sediment loads to provide:

   - a contemporary baseline (2022) using recent land cover and erosion mitigations completed to date
   - past land cover and riparian fencing, based on the WRC regional riparian survey, matched to the nearest Land Cover Database (LCDB) mapping year
   - future erosion mitigation scenarios based on a targeted approach that ranks watersheds draining to individual stream segments by sediment load, and applies mitigation works sequentially to pastoral land based on its Land Use Capability (LUC) class; future riparian fencing was applied to watersheds according to the requirements of the stock exclusion regulations (2020).

2 to model the effect of future climate change projections on region-wide erosion and suspended sediment loads at mid- (2040) and late (2090) century for the baseline land cover and mitigations to date, and each of the future erosion mitigation scenarios.

3 to assess the load reductions required to meet NPS-FM 2020 attribute bands and the national bottom line (NBL) for suspended fine sediment (visual clarity) for the baseline and future mitigation scenarios, with and without the effects of climate change.

Methods

- The updated SedNetNZ model was applied to the Waikato Region to estimate mean annual suspended sediment loads across the River Environment Classification v2 (REC2) digital stream network.
- The contemporary baseline simulation uses recent land cover (LCDBv5, 2018), erosion mitigations completed to date, and the estimated regional riparian fencing extent based on the 2017 WRC regional riparian survey. The baseline includes an assessment of model sensitivity to variations in the spatial arrangement of winter-forage cropping based on regional mapping of forage crops in 2021 and 2022.

- The backward-looking scenarios use the WRC regional riparian survey data for 2002, 2007, 2012, and 2017 (referred to as B2002–B2017) and the nearest past land-cover maps from LCDB, as well as available river management and soil conservation data.
- Future erosion mitigation scenarios were applied to watersheds separately, ranked by sediment loads from pastoral areas on (a) LUC class 7e and 8e land, and (b) LUC class 6e land. These scenarios apply targeted mitigations to 20, 30, 40, 50, and 100% (referred to as M20–M100) of (a) LUC class 7e and 8e (afforested with natives or exotics) and (b) LUC class 6e (space-planted trees) pastoral land by sequentially selecting from load-ranked watersheds. Riparian fencing was applied across all mitigation scenarios.
- The effect of future climate change on erosion and suspended sediment loads for the contemporary baseline and future mitigation scenarios was modelled following a similar approach to that described by Basher et al. (2020) and Neverman et al. (2023). This involved the use of rainfall and temperature grids from six regionally downscaled climate models (RCMs) and four representative concentration pathway (RCP) climate trajectories at mid- and late century to modify projected future erosion process rates under climate change. The M100 mitigation scenario was only modelled at late century in recognition of the longer timeframe required to plausibly achieve this level of erosion mitigation across the region.
- Proportional and absolute load reductions required to meet NPS-FM 2020 attribute bands and the NBL for state of the environment (SOE) monitoring sites were assessed for contemporary and future mitigation scenarios.

Results

- The contemporary baseline region-wide total erosion was estimated as 2.32 Mt yr^{-1}. The highest sediment yields occur in the earthflow and shallow landslide-prone terrains. This is mostly restricted to the steeper hill country in the West Coast and Waipā catchment management zones (CMZs), as well as in areas where there are gullies, particularly in the Upper Waikato and Lake Taupō CMZs. West Coast has the highest total erosion (808 kt yr^{-1}), followed by Waipā and Upper Waikato (322 kt yr^{-1} and 304 kt yr^{-1}), while Central Waikato has the lowest (24.8 kt yr^{-1}).
- The backward-looking scenarios showed that region-wide total erosion decreased by 4.1% (98.7 kt yr^{-1}) from 2,423 kt yr^{-1} to 2,324 kt yr^{-1} between the B2002 and B2017 survey years. This is due to increased riparian fencing modelled throughout the region. However in Upper Waikato erosion increased due to changes in land cover from woody cover to pasture.
- Comparison of sediment loads between the two winter-forage years (WF2021 and WF2022) showed a minor region-wide change of −0.03% (−0.619 kt yr^{-1}). The largest difference occurred in Waihou–Piako (–0.54 kt yr^{-1}, −0.23%).
- Under the future mitigation scenarios, region-wide total erosion was estimated to decrease 13% to 2.01 Mt yr^{-1} for the M20 scenario, 27% to 1.69 Mt yr^{-1} under the M50 scenario, and 41% to 1.38 Mt yr^{-1} for the M100 scenario. Most of the sediment load reduction occurs in the West Coast, Upper Waikato, and Waipā CMZs, representing approximately 70% of the region-wide load reduction.
- Of the 105 SOE monitoring sites, 59 (56%) require load reductions to achieve the NBL given the contemporary baseline. In addition, 64 sites (61%) and 77 sites (73%) require

reductions to achieve B band and A band, respectively. The number of SOE sites requiring further reductions to achieve the NBL decreases to 55 sites (52%) under the M20 mitigation scenario, 44 sites (42%) under the M50 scenario, and 28 sites (27%) under the M100 scenario under contemporary climate.

- Under the projected impact of future climate change, total erosion across all RCPs is estimated at 2.6–3.6 Mt yr^{-1} and 2.5–4.9 Mt yr^{-1} for mid- and late century, respectively, for the contemporary baseline land cover and erosion mitigations. This represents an increase of 14% to 57% for mid-century and 7% to 110% for late century, compared to loads modelled without the impacts of climate change.
- Under the M20 mitigation scenario, total erosion with the effects of climate change across all RCPs is estimated to between 2.3–3.1 Mt yr^{-1} and 2.2–4.1 Mt yr^{-1} for mid- and late century. This represents a change of −7% to +26% and −12% to +68% for mid- and late century, compared to contemporary baseline loads modelled without the impacts of climate change.
- Total erosion is estimated to be between 1.9–2.5 Mt yr^{-1} and 1.8–3.3 Mt yr^{-1} for mid- and late century under the M50 scenario, and 1.4–2.4 Mt yr^{-1} for late century under the M100 scenario. This represents a change ranging from −23% to +1% and −27% to +33% for mid- and late century under the M50 scenario, and −41% to −1% for late century under the M100 scenario, compared to contemporary baseline loads modelled without the impacts of climate change.
- Under contemporary land cover and erosion mitigations with the effects of future climate change, 88–94% and 86–95% of the SOE sites require sediment load reductions to maintain baseline visual clarity at mid- and late century, respectively. This decreases to 13–79% and 10–95% of sites at mid- and late century under M50, and 7–50% under M100 at late century, requiring further reductions to maintain baseline visual clarity.
- Under the contemporary baseline with the effects of future climate change, 59–70% and 58–77% of SOE sites require load reductions to achieve NBL at mid- and late century. This decreases to 48–60% and 49–69% of sites at mid- and late century under the M50 scenario, and 27–54% of sites at late century under the M100 scenario.

Conclusions and recommendations

- Region-wide total erosion is estimated at 2.32 Mt yr^{-1}, with the highest sediment yields primarily found in areas prone to earthflows, shallow landslides, and gullies in the West Coast, Waipā, and Upper Waikato CMZs.
- Estimated changes in riparian fencing since 2002 produced a minor, region-wide decrease in modelled mean annual sediment load (4.1%) between 2002 and 2017, although changes in land cover from woody cover to pasture increased erosion during this time, partly offsetting reductions in load related to fencing.
- Potential modelled future erosion mitigations produced significant reductions in total erosion, with decreases of up to 41% under the most ambitious scenario (M100). These reductions are predominantly expected in the West Coast, Upper Waikato, and Waipā CMZs, areas that currently make a substantial contribution (c. 1.43 Mt yr^{-1} or 62%) to the overall sediment load.
- Climate change is anticipated to exacerbate erosion and increase suspended sediment loads by late century under contemporary land cover and erosion mitigations. However,

the implementation of additional erosion mitigation (M20, M50, M100) can substantially offset these increases, demonstrating the potential effectiveness of targeted erosion control measures in negating the worst impacts of climate change on sediment loads.

- To meet NPS-FM 2020 visual clarity limits, 56% of the 105 SOE sites across the Waikato region require sediment load reductions to achieve the NBL. This decreases to 27% of sites under the M100 erosion mitigation scenario for contemporary climate.
- Under climate change, the number of SOE sites requiring reductions to achieve the NBL increases, and most SOE sites require reductions to at least maintain baseline visual clarity with the implementation of the most ambitious erosion mitigations (M100) by late century.
- Continued investment in erosion mitigations is necessary to limit the potential impacts of climate change on suspended sediment loads by late century.
- Improvements in model predictions could be made with further acquisition of comprehensive data on the effectiveness of erosion control measures, particularly region-specific data. Additionally, use of region-wide LiDAR-derived terrain data would enable improved representation of the stream network and erosion processes at higher spatial resolutions.

1 Introduction

Waikato Regional Council (WRC) contracted Manaaki Whenua – Landcare Research to model erosion and suspended sediment loads across the region using SedNetNZ for a range of erosion mitigation and climate change scenarios. The project was undertaken to support implementation of the 2020 National Policy Statement for Freshwater Management (NPS-FM 2020).

The scope of the work carried out for WRC involved:

- modelling region-wide suspended sediment loads for a contemporary baseline to represent recent land cover and completed erosion mitigations
- modelling backward-looking scenarios to represent past land cover and riparian fencing estimates for 2002, 2007, 2012, and 2017 based on the regional riparian survey years
- modelling region-wide suspended sediment loads under future erosion mitigation scenarios
- assessing the load reductions required to achieve NPS-FM 2020 attribute states for suspended fine sediment (visual clarity) at state of the environment (SOE) monitoring sites
- comparing reductions in modelled suspended sediment loads under future erosion mitigation relative to the contemporary baseline
- modelling suspended sediment loads under future climate change scenarios and assessing the load reductions required to achieve NPS-FM 2020 attribute states.

2 Background

2.1 SedNetNZ

The SedNetNZ sediment budget model was developed to represent the range of erosion processes that occur in New Zealand. These include shallow landslide, earthflow, gully, and surficial erosion (Dymond et al. 2016), as well as streambank erosion using a recently improved bank erosion model (Smith, Spiekermann et al. 2019). Model outputs for these erosion processes are combined with losses due to floodplain deposition and lake sediment trapping to estimate mean annual suspended sediment loads at the River Environment Classification v2 (REC2) watershed level.

While conceptually similar to the Australian SedNet model (Wilkinson et al. 2009), SedNetNZ differs in its specific representation of erosion processes that predominantly occur in New Zealand, particularly mass movement processes (shallow landslide, earthflow) that are not included in the Australian SedNet model, and also through its parameterisation using erosion process data from New Zealand (e.g. Betts, Basher et al. 2017).

SedNetNZ modelling was previously completed for the Waikato Region on a catchment or water management zone basis. Palmer et al. (2013) undertook analysis of the Waipā catchment using a combination of SedNetNZ, the New Zealand Empirical Erosion Model (NZeem®), and the Highly Erodible Land (HEL) model to identify high-risk areas of hillslope sediment generation and stream bank erosion. In this case, SedNetNZ was used only to estimate streambank erosion. We also assessed the extent to which riparian fencing might reduce suspended sediment loads from bank erosion.

A further application of SedNetNZ was conducted by Palmer et al. (2015) for both the Waipā and Waikato catchments (Lower, Central, and Upper Waikato, but excluding Lake Taupō). In this application, a wider range of erosion processes (e.g. shallow landslides, earthflows, gullies, surficial and streambank erosion) were represented by SedNetNZ, and subsequently the Waipā catchment was remodelled. Also, alignment of the sediment budgets with the REC2 watershed boundaries was required. SedNetNZ was subsequently applied to the remaining Waikato regions in 2017: Western Waikato, Coromandel, Waihou–Piako, and Lake Taupō (Betts, Spiekermann et al. 2017).

Since the completion of the previous work in the Waikato Region, SedNetNZ has undergone several significant updates. These include the development of an improved bank erosion model (Smith, Herzig et al. 2019; Smith et al. 2020), which replaced the previous model of bank erosion in SedNetNZ (Dymond et al. 2016). The improved bank erosion model now includes spatial representation of additional factors that may influence bank migration rates, such as the extent of riparian woody vegetation, channel sinuosity, and bank erodibility (Smith, Herzig et al. 2019).

The surficial erosion component of SedNetNZ now includes improved representation of surface-runoff-contributing areas (Smith, Spiekermann et al. 2019), and the use of a constant value for soil erodibility has been replaced with a variable soil erodibility term based on soil mapping data (Neverman et al. 2021). Lake sediment trapping is now represented as part of the stream network routing algorithm (Neverman et al. 2021), while the floodplain deposition algorithm has been refined to better represent spatial patterns in floodplain deposition based on upstream loads rather than averaging the load deposited on floodplains across major catchments (Vale et al. 2021).

Additional components have also been coupled to the SedNetNZ model to expand the model's functionality. These include components representing the effects of climate change on erosion process rates (Basher et al. 2020; Manderson et al. 2015; Neverman et al. 2023; Vale et al. 2021; Vale et al. 2022; Vale & Smith 2023); and the impact of changes in suspended sediment load on visual clarity, which forms the attribute unit for the suspended fine sediment attribute in the NPS-FM 2020 (Ministry for the Environment 2022a) (e.g. Vale et al. 2022; Vale & Smith 2023; Neverman et al. 2022).

3 Objectives

The project has three objectives:

1. to model region-wide mean annual suspended sediment loads to provide:
   - a contemporary baseline (2022) using recent land cover (LCDBv5, 2018) and completed erosion mitigations, including the estimated regional riparian fencing extent based on the 2017 WRC riparian survey (the baseline includes an assessment of model sensitivity to variations in the spatial arrangement of winter-forage cropping based on regional mapping of forage crops in 2021 and 2022)
   - past land cover and riparian fencing, based on the regional riparian survey (i.e. 2002, 2007, 2012, and 2017 survey years) matched to the nearest LCDB mapping year, and including river management and soil conservation works where these data are available
   - future erosion mitigation scenarios based on a targeted approach that separately ranks watersheds draining to individual stream segments by sediment loads from pastoral areas on (a) LUC class 7e and 8e land and (b) LUC class 6e land; these scenarios apply targeted mitigations to 20, 30, 40, 50, and 100% of (a) LUC class 7e and 8e (afforested with natives or exotics) and (b) LUC class 6e (space-planted trees) pastoral land by sequentially selecting from load-ranked watersheds; riparian fencing is applied across all future mitigation scenarios
2. to model the effect of future climate change projections on region-wide erosion and suspended sediment loads at mid (2040) and late (2090) century for the baseline land cover and mitigations to date, and each of the mitigation scenarios
3. to assess the load reductions required to meet NPS-FM 2020 attribute bands and the NBL for suspended fine sediment (visual clarity) for the baseline and mitigation scenarios, with and without the effects of climate change.

4 Methods

This section provides a description of the methods used in the application of SedNetNZ in the Waikato Region. It outlines (1) the SedNetNZ model components, (2) model simulations for the land cover and erosion mitigation scenarios and climate change projections, and (3) the method for estimating the sediment load reductions required to achieve NPS-FM 2020 visual clarity attribute bands.

4.1 SedNetNZ model description

4.1.1 Surficial erosion

Surficial erosion processes in SedNetNZ (Dymond et al. 2016) are represented by the New Zealand Universal Soil Loss Equation (NZUSLE; Dymond et al. 2010) model:

$$ES = aP^2KLSC \quad (1)$$

where ES denotes surficial erosion in t km^{-2} yr^{-1}; a is a constant (t km^{-2} yr^{-1} mm^{-2}) calibrated against measurements (Dymond et al. 2010) with a value of 1.2 × 10^{-3}; P is mean annual rainfall (mm); K is the soil erodibility factor (dimensionless); L is the slope length factor; S is the slope steepness factor; and C represents the impact of vegetation cover (dimensionless) (1.0 for bare ground, 0.01 for pasture, and 0.005 for forest and scrub).

We use a revised representation of surficial erosion processes as part of the SedNetNZ model, following Smith, Herzig et al. (2019), which replaces the slope length and slope steepness factors. The uniform slope length factor (L) of the NZUSLE (Dymond et al. 2010) is replaced with a factor that better represents the effect of topography on the size of convergent upslope areas contributing overland flow and surficial erosion, as described by Desmet and Govers (1996):

$$L = \frac{\left(A + D^2\right)^{m+1} - A^{m+1}}{D^{m+2} \times x^m \times 22.13^m} \quad (2)$$

where L is the slope length factor for a given raster cell (pixel), A is the upstream catchment area (m^2) at the cell inlet, D is the raster cell width (m), m is the slope length exponent, and x = sin a+cos a, with α being the slope aspect.

The slope length exponent, m, is calculated based on the rill to inter-rill ratio, β, and the slope gradient, θ (Foster et al. 1977 and McCool et al. 1989, cited in Renard 1997):

$$\beta = \frac{\sin\theta / 0.896}{3 \times (\sin\theta)^{0.8} + 0.56} \quad (3)$$

$$m = \frac{\beta}{1 + \beta} \quad (4)$$

We also apply a revised slope factor, S, which is calculated according to a threshold in slope gradient sp (%) (Renard 1997):

$$S = \begin{cases} 10.8 \times \sin\theta + 0.03 & with\ sp < 9\% \\ 16.8 \times \sin\theta - 0.5 & with\ sp \geq 9\% \end{cases} \quad (5)$$

Furthermore, we apply a revised, spatially variable K factor in the NZUSLE developed in Neverman et al. 2021 to better represent the spatial variability of soil erodibility, utilising the Fundamental Soil Layers (FSL) to represent soil parameters. We adapted the K factor equations in Wang et al. 2001 and Yang et al. 2018 to the NZUSLE:

$$K = \frac{2.1(12 - OM)M^{1.14}10^{-4} + 3.25(SS - 2) + 2.5(PP - 3)}{7.59 \times 10} \quad (6)$$

where OM is the soil organic matter content, M is the particle size parameter, SS is the soil structure code, and PP is the soil profile permeability code. We use six PP classes, adapted from Rosewell & Loch 2002. The soil structure code was set at SS = 2 because the FSL has insufficient data on soil structure to relate to the SS classes used for calculating K. We found the magnitude of K was not sensitive to the choice of SS class value. M is calculated as a function of the proportion of silt and clay:

$$M = Silt(100 - Clay) \quad (7)$$

where $Silt$ and $Clay$ are the percentage of silt and clay in the soil, respectively.

$Silt$ was limited to a range of 15–70%, and OM was capped at 4% to fit the nomograph of Wischmeier et al. (1971) used to derive equation 6 for organic soils. Where there was no FSL information available to calculate a spatially varying K factor, a uniform value of 0.25 was used (Dymond et al. 2010).

4.1.2 Shallow landslide erosion

Shallow landslides are considered the most common form of erosion in New Zealand hill country (Eyles 1983). Typical landslides are seldom greater than 2 m deep, and individual failures are usually of small areal extent (50–100 m^2) (Smith et al. 2021). They usually have a debris tail of deposited sediment below their source, which often reaches a stream (in approximately half of debris tails; see Dymond et al. 1999). Landslide occurrence is highly correlated with slope angle, with most failures occurring on slopes steeper than 26 degrees, but landslides can occur on slopes as low as 15 degrees (De Rose 2013; Smith et al. 2021).

The expected mass of soil lost to landslide erosion per square kilometre per year, and the connection with a stream, is given by EL:

$$EL = \rho \, SDR \, d_l f(s) \quad (8)$$

where ρ is the bulk density of soil (t m^{-3}), SDR is the sediment delivery ratio, d_l is the mean depth of landslide failure (m), and $f(s)$ is the expected area of landslide scars per square kilometre per year at slope angle s (m^2 km^{-2} yr^{-1}).

Landslide erosion is estimated for those Erosion Terrains[1] (see Dymond et al. 2010) identified as being susceptible to landslide erosion; ρ is set to 1.5 t m^{-3} (Dymond et al. 2016); SDR values are typically 0.5 (Dymond et al. 2016), but vary from 0.1 to 1.0 depending on the specific Erosion Terrain calibrated for the region; d_l is set to 1 m (Betts et al. 2017; Page et al. 1994; Reid & Page 2003; Phillips et al. 2021); and $f(s)$ is determined from previous calibration of SedNetNZ in Manawatū (Dymond et al. 2016; Betts, Basher et al. 2017). Permanent forest cover is estimated to reduce shallow landslide erosion by 90% compared with pasture (Basher 2013; Dymond et al. 2016; Phillips et al. 2020; Smith et al. 2023), while an 80% reduction is applied under exotic plantation forest (Vale et al. 2021). The lower reduction estimated for plantation versus permanent forest recognises the effectiveness of forest cover for reducing shallow landslides (Marden 2012; Smith et al. 2023) for much of the rotation while acknowledging the period spanning several years between harvest and canopy closure of the replanted crop during which there is an increase in susceptibility to shallow landslide erosion (Phillips et al. 2018; 2020).

[1] An Erosion Terrain is a land type with a unique combination of erosion processes and rates leading to characteristic sediment generation and yields. Erosion Terrains were derived from New Zealand Land Resource Inventory data and are based on combinations of rock type/parent material, topography, rainfall, and erosion process type and severity. Erosion Terrain coefficients are listed in Dymond et al. 2010.

4.1.3 Earthflow erosion

Slow-moving earthflows (c. 1 m per year) are common in Erosion Terrains underlain by crushed mudstone and argillite (Dymond et al. 2010). The delivery of sediment to streams is via the undercutting of earthflow toes. The mass of soil delivered to streams by earthflows in t km^{-2} yr^{-1} is denoted by EE and is estimated as:

$$EE = \rho \, d_e \, v \, ED \quad (9)$$

where ρ is the bulk density of soil (t m^{-3}), d_e is the mean depth of earthflows (m), v is the mean speed of earthflows (m yr^{-1}), and ED is the mean length of stream intersecting earthflow toes in a square kilometre (m km^{-2}). Here ρ is set to 1.5 t m^{3} (Dymond et al. 2016), d_e is set to 3 m (based on field observation; Dymond et al. 2016), and v is set to 0.1 m yr^{-1} (average from published data; Guy 1977; Zhang et al. 1991; Marden et al. 2008, 2014). The default ED is set to 1,024 m km^{-2} (from digitising stream lengths on scanned aerial photographs; Dymond et al. 2016), except for an isolated area in the upper Waipā, which was set to 256 m km^{-2} as part of the model calibration.

4.1.4 Gully erosion

Gullies commonly initiate at channel heads, usually because of excessive surface or subsurface water flow. Once initiated, a gully can continue to expand over long time periods (decades). The mass of soil delivered to streams by gullies, in t km^{-2} yr^{-1}, is denoted by EG and is estimated by:

$$EG = \frac{\rho \, A_g \, GD}{T} \quad (10)$$

where ρ is the bulk density of soil (t m^{-3}), A_g is the mean cross-sectional area of gullies (m^{2}), GD is the length of gullies in a square kilometre (km km^{-2}), and T is the time since gully initiation (yr).

Following Dymond et al. (2016), ρ was set to 1.5 t m^{-3}; A_g was set to 900 m^{2} (from field observations); the default GD was set to 220 m (from digitising gully lengths on scanned aerial photographs); and T was set to 120 yr. As part of the model calibration from suspended sediment load data, GD was reduced to 110 m, particularly for the gully features in the terrace and low fans around Lake Taupō.

4.1.5 Bank erosion

SedNetNZ represents bank erosion at the reach scale, where the river network is divided into stream links based on the River Environment Classification v2 (REC2). The total mass of material eroded from riverbanks each year is a function of bank height, reach length, and bank migration rate (Dymond et al. 2016):

$$B_j = \rho M_j H_j L_j \quad (11)$$

where B_j is the total eroded mass for the jth stream link (t yr^{-1}), ρ is the bulk density of the bank material (t m^{-3}), M_j is the bank migration rate (m yr^{-1}), H_j is the mean bank height (m), and L_j is the length (m) of the jth stream link. Bank height is derived from a relationship with mean annual discharge, and bulk density is estimated at 1.5 t m^{-3} (Dymond et al. 2016).

The predicted mass of material eroded from riverbanks represents the gross contribution of sediment supplied to the river channel per year. This does not account for redeposition and storage of eroded bank material on banks or within the channel bed, or the lateral accretion of material on bars with channel migration. Hence, net bank erosion in SedNetNZ is estimated as one-fifth of gross bank erosion based on reach-scale sediment budget results comparing bank erosion and accretion (De Rose & Basher 2011). Overbank vertical accretion of fine sediment on floodplains beyond the active channel is represented separately (Dymond et al. 2016).

Bank migration rate (M_j) in equation 12 is represented as a function of six factors, as follows:

$$M_j = SP_j Sn_j T_j V_j \left(1 - PR_j\right)\left(1 - PW_j\right) \quad (12)$$

where M_j is the bank migration rate (m yr^{-1}) of the jth stream link; SP_j is the stream power of the mean annual flood for the jth stream link; Sn_j is the channel sinuosity rate factor of the jth link; T_j is the soil texture-based erodibility factor of the jth link; V_j is the valley confinement factor of the jth link; PR_j is the proportion of riparian woody vegetation of the jth link; and PW_j is the fraction of bank protection works for the jth link (Smith, Spiekermann et al. 2019).

Stream power (SP_j) for the mean annual flood (MAF_j, m^3 s^{-1}) is estimated for each stream link by the product of mean annual flood and channel slope (S_j). MAF is estimated from a fitted power relationship ($MAF = aq^b$) with mean annual discharge (q, m^3 s^{-1}) using data from long-term river flow gauging within the catchment or region of interest:

$$SP_j = MAF_j S_j = a{q_j}^b S_j \quad (13)$$

Various studies report increasing bank migration rates with increasing bankfull discharge and stream power (Hooke 1979; Nanson & Hickin 1986; Walker & Rutherfurd 1999; Alber & Piégay 2017). While MAF has been shown to relate to bank erosion rates (Dymond et al. 2016), other factors, such as channel sinuosity (Nanson & Hickin 1983), the cohesiveness of bank materials (Julian & Torres 2006), valley confinement (Hall et al. 2007), and riparian woody vegetation (Abernethy & Rutherfurd 2000), are also important, resulting in high levels of spatial variability in bank erosion.

We use the log-normal probability density function to represent the relationship between channel sinuosity and migration rate, which we term the sinuosity rate factor. This function allows us to represent the positive skew observed in the relationship between channel sinuosity and migration rate (Crosato 2009). The dimensionless channel sinuosity rate factor (Sn_j) is calculated as:

$$Sn_j = \frac{1}{\left(Sinu_j - 1\right)\sigma\sqrt{2\pi}}\, e^{\left(-\frac{\left(\ln\left(Sinu_j - 1\right) - \mu\right)^2}{2\sigma^2}\right)} \quad (14)$$

where $Sinu_j$ is the sinuosity of the jth stream link of the REC2 network, and μ and σ are the mean and standard deviation parameters that determine the location and scale of the distribution. The μ and σ parameters are fitted using measurements of reach-scale bank migration rates.

The texture of bank material influences bank migration rates (Hickin & Nanson 1984; Julian & Torres 2006; Wynn & Mostaghimi 2006). Our approach is based on an empirical relationship between percentage silt + clay content (SC) and soil critical shear stress (τ_c) derived by Julian and Torres (2006) using data from Dunn 1959, as follows:

$$\tau_c = 0.1 + 0.1779SC + 0.0028SC^2 - 0.0000234SC^3 \quad (15)$$

SC is obtained from spatial data on soil textural classes compiled from the Fundamental Soil Layers (FSL) (Newsome et al. 2008), which provide national coverage. The soil texture-based erodibility factor (T_j) is represented by a power function to characterise the relationship between τ_c and bank erodibility for the jth stream link:

$$T_j = c{\tau_{c,j}}^{-d} \quad (16)$$

where the c and d parameters are fitted using available bank migration rate data. The choice of a power function is based on experimental (Arulanandan et al. 1980) and field (Hanson & Simon 2001; Julian & Torres 2006) observations of the relationship between stream bank or bed critical shear stress and erodibility.

Floodplain extent and the level of valley confinement are factors that may limit lateral bank migration (Hall et al. 2007; De Rose & Basher 2011). The presence of steep valley sides and/or exposure of bedrock influence spatial patterns of erosion and deposition (Fryirs et al. 2016). Here we adapt the Australian SedNet model approach to estimate a valley confinement factor (V_j) by using the mean slope (SB_j) in degrees of a buffer zone either side of the jth stream link:

$$V_j = \left(1 - e^{\left(-15/SB_j\right)}\right)^{11} \quad (17)$$

Woody riparian vegetation typically increases bank stability via the effects of root reinforcement and root cohesion (Abernethy & Rutherfurd 2000; Hubble et al. 2010; Polvi et al. 2014; Konsoer et al. 2016). Woody vegetation can also increase roughness and flow resistance, thereby reducing the boundary shear stress acting on the bank surface (Thorne 1990).

In addition, woody vegetation has hydrological effects on bank stability. For example, woody vegetation was found to be more effective than grass cover in lowering soil water content due to increased canopy interception and evapotranspiration, thus improving bank stability (Simon & Collison 2002).

We represent the effect of riparian woody vegetation (PR_j) in reducing bank migration rates at the reach scale. Bank migration rates are reduced in proportion to the extent of woody riparian vegetation along the j^{th} stream link (equation 12). Stream links with complete and mature riparian woody vegetation cover are assumed to erode at 0.05 of the migration rate with no woody cover (De Rose et al. 2003). Spatial information on woody vegetation is obtained from satellite imagery and intersected with the Land Information New Zealand (LINZ) digital stream network obtained from 1:50,000 topographic mapping. The mapped stream network was used in preference to the 15 m channel network derived from the digital elevation model (DEM) because it tends to exhibit better planform accuracy, which should improve the spatial correspondence between channel position and riparian woody vegetation.

In some cases the LINZ stream network provides poor representation of channel width for wider reaches with exposed gravel. To address this issue, the spatial union of the LINZ river polygons with LCDB v5 'river' and 'gravel and rock' land-cover classes was used to produce revised river polygons. Mapped gravel and rock areas located beyond the extent of the channel network were removed. The revised stream network layer improved alignment between channel banks and mapped woody vegetation when quantifying the reach-scale extent of riparian woody vegetation cover. The proportion of riparian woody vegetation is computed from the intersection of the revised stream network with a 15 m buffer and a classified map of 2002 woody vegetation cover (called EcoSat Woody) derived from Landsat TM at 15 m resolution (Dymond & Shepherd 2004).

We also include representation of channel protection works (PW_j) that are designed to reduce bank erosion (e.g. rock riprap, willow edge protection), as well as stopbanks employed for flood protection, where such data are available. We assume that over the multi-decadal model time scale, erosion mitigation would ultimately be targeted to where migrating riverbanks approach stopbanks, or that such interventions have already been implemented to protect stopbank integrity.

The proportional length of bank erosion mitigation measures (PEC_j) and stopbanks (PSB_j) is summed to give the proportion of channel works (PW_j) for the jth stream link. PEC_j is computed as the length of erosion mitigation measures within a stream link relative to the total length of that link. This assumes erosion mitigation measures are targeted to the eroding bank side. Stopbanks may be located on either side of the channel, irrespective of the direction of bank migration. Therefore, PSB_j is computed as the length of stopbanks in a link relative to twice the link length.

Inputs to the bank erosion model component of SedNetNZ were obtained from national-scale spatial data sets comprising the REC2 and LINZ stream networks, 15 m DEM, FSL for soil data, and EcoSat Woody for 2002 woody vegetation cover. LCDB v5 (Landcare Research NZ Ltd 2020) was not used, despite being more recent, because it has a minimum mapping unit of 10,000 m^2 versus 225 m^2 for EcoSat. This makes LCDB less suitable for characterising the narrow corridors of woody vegetation often found along channel banks in otherwise predominantly pastoral areas. However, to capture more broadscale changes in woody vegetation cover associated with changes in the extent of exotic forestry, we used the repeated LCDB mapping from 2001, 2008, 2012 and 2018. These mapping years are comparable to the regional riparian survey years (2002, 2007, 2012, 2017), which allowed us to identify areas of forestry-to-pasture or pasture-to-forestry conversion and incorporate this spatial information into model simulations for each riparian survey year.

Mean annual discharge estimated for each link in the REC2 stream network is based on an empirical water balance model (Woods et al. 2006) used in the CLUES water quality model (Elliott et al. 2016). Mean annual flood statistics for 46 gauging stations where records exceed 10 years were supplied by WRC. The resulting set of river gauging stations had a mean record length of 38 years (range 13-70 years). These data were used to fit relationships between mean annual discharge and mean annual flood for use in calculating stream power for each REC2 link in the stream network.

MAF was best predicted by grouping the gauging site data to represent three zones spanning (a) Coromandel, Kauaeranga, Kirikiri, Puriri, Hikutaia, Komata, and Ohinemuri catchments ($MAF = 84q^{0.76}, R^2 = 0.72, n = 8$); (b) Ōraka Stream and the upper Waikato catchments spanning the Taupō Gates to Lake Karapiro and Lake Taupō freshwater management units, but excluding the Tongariro River catchment ($MAF = 5.2q, R^2 = 0.98, n = 3$); and (c) the remainder of the region ($MAF = 26q^{0.61}, R^2 = 0.97, n = 35$). WRC also provided spatial data on stopbanks and channel protection works that have been included in the model simulations.

We used a data set comprising available measured bank migration rates from the Manawatū and Kaipara catchments to calibrate the bank erosion model (Spiekermann et al. 2017; Smith, Spiekermann et al. 2019). Calibration of the bank migration model was performed by minimising the mean square error between predicted and observed data by optimising parameter values for the sinuosity (μ and σ) and bank soil texture (c and d) factors in equations 14 and 16, respectively. This produced reasonable agreement (R^2 = 0.74 relative to the 1:1 line and root mean square error = 0.54 based on model calibration) between measured and observed rates of bank migration (Figure 1).

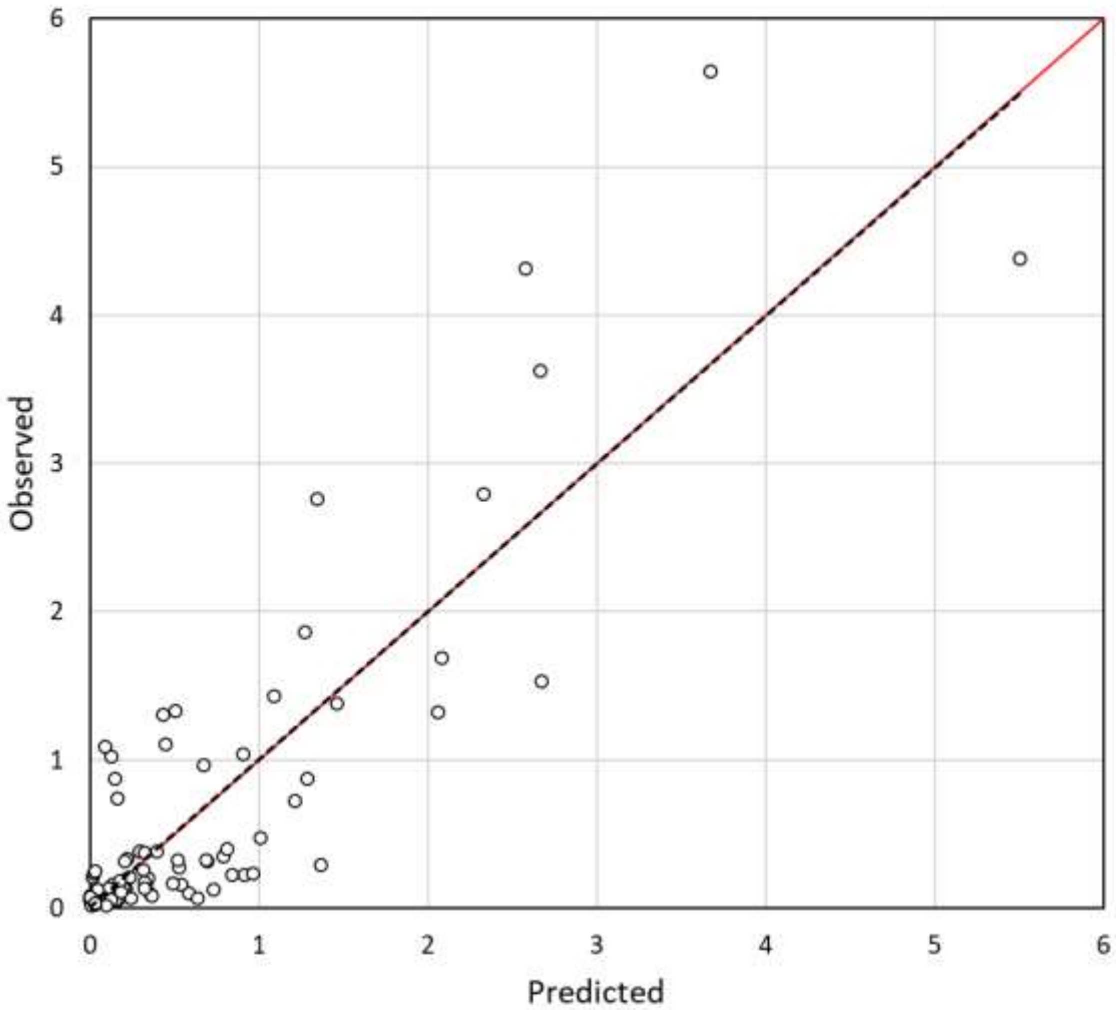

Figure 1. Plot comparing predicted versus observed bank migration rates (m yr^{-1}) based on calibrated parameter values for the sinuosity and erodibility factors. Fitted regression line (black dashed) and the 1:1 line (red) are also shown.

4.1.6 Sediment routing

SedNetNZ accounts for the deposition of sediment in lakes and on floodplains as the sediment is transported through the channel network. To account for sediment trapping through lakes, we apply a revised SedNetNZ sediment routing algorithm. The revised routing algorithm applies a lake-specific sediment passing factor (SPF) to the net routed sediment load at the end of an REC2 sub-catchment draining to a lake. SPF was calculated using an adaptation of Gill's (1979) approximation of Brune's (1953) trap efficiency (the inverse of passing factor) curve for medium sediment:

$$SPF = 1 - \frac{V/I}{1.02(V/I)+0.012} \quad (18)$$

where V is the lake volume and I is the annual inflow to the lake. This is similar to the approach of Hicks, Semadeni-Davies et al. (2019).

The mass of sediment deposited on the floodplain in a given reach is calculated as:

$$F_i = pS_t \frac{L_i accS_i^2}{\sum L_i accS_i^2} \quad (19)$$

where F_i is the total floodplain deposition (t yr^{-1}) in the ith sub-catchment; p is the proportion of the sediment load generated by hillslope erosion per lake or sea-draining catchment that is deposited on floodplains in the catchment, set to 5% based on previous SedNetNZ parameterisation carried out in Manawatū (Dymond et al. 2016); S_t is the total sediment (t yr^{-1}) generated by hillslope erosion per lake or sea-draining catchment; L_i is the reach length (m) on floodplain in the ith sub-catchment; and $accS_i$ is the total accumulated (upstream) sediment from hillslope erosion (t yr^{-1}) in the ith sub-catchment.

4.2 Model simulations

4.2.1 Scenario overview

Contemporary baseline

The contemporary baseline (C2022) represents recent land cover (LCDB v5, 2018) and erosion mitigations completed to date based on available river management and soil conservation works spatial data. The 2017 riparian survey year was used to represent the extent of riparian fencing at the REC2 stream segment level, expressed as a proportion of the stream segment. Winter-forage crop maps for 2021 and 2022 (referred to as WF2021 and WF2022) were burned into LCDB v5 and used to assess the sensitivity in sediment loads to changes in the number and spatial arrangement of winter-forage paddocks in 2021 and 2022.

Backward-looking scenarios

The backward-looking scenarios represent past land cover and riparian fencing for 2002, 2007, 2012, and 2017 based on the WRC regional riparian survey years. Land cover was represented by the LCDB mapping year with the closest match to the survey year. Available data on WRC river management and soil conservation works completed by each year were also included. These scenarios are referred to as B2002, B2007, B2012, and B2017.

Future erosion mitigation

The future erosion mitigation scenarios use a 'ranked-watershed' approach to represent the targeted implementation of erosion mitigation works in REC2 watersheds.

REC2 watersheds across the region were separately ranked from highest to lowest based on the contemporary baseline sediment load (t yr^{-1}) coming from pastoral areas on (a) LUC class 7e and 8e land and (b) LUC class 6e land. The load-ranked watersheds for LUC class 7e and 8e were then used to sequentially target mitigations to 20, 30, 40, 50, and 100% of pastoral land on LUC class 7e and 8e land for afforestation with natives or exotics. The ranked watersheds for LUC class 6e were targeted for space-planted trees on 20, 30, 40, 50, and 100% of pastoral LUC class 6e land. These scenarios combining targeted afforestation and space-planting are referred to as M20, M30, M40, M50, and M100.

These future mitigations scenarios also represent current regulations for riparian stock-exclusion fencing (refer Resource Management (Stock Exclusion) Regulations 2020), where full implementation of riparian fencing requirements is expected to be completed by 2025. Therefore, the same level of future riparian fencing was applied across all scenarios (M20–M100) based on the regulations. Where the level of fencing required by regulation is less than the estimated contemporary riparian fencing extent based on the 2017 riparian survey, the 2017 estimates were retained.

Climate change scenarios

Climate change scenarios were applied in combination with the contemporary baseline land cover and mitigations as well as the future erosion mitigation scenarios. For the future mitigation scenarios, it was envisaged that it may be plausible to afforest or space-plant between 20 and 50% of pastoral LUC class 7e/8e and LUC class 6e land, respectively, by mid-century, while the 100% afforested or space-planted scenario was only considered plausible by late century.

Six global climate models (GCMs) were used to characterise regional-scale projections of changes in New Zealand climate (temperature and precipitation) to 2040 (2031–2050) and 2090 (2081–2100) in combination with representative concentration pathways (RCPs 2.6, 4.5, 6.0, and 8.5) based on the IPCC’s Fifth Assessment Report (Ministry for the Environment 2018). The approach for modelling climate change impacts on erosion rates is fully described in section 4.2.3.

4.2.2 Estimating sediment load reductions from mitigation works

Reduction in hillslope erosion from mitigation works

The reduction in sediment load from hillslope erosion processes is determined by the change in land cover related to the mitigation work in each scenario. The total reduction is determined by the effectiveness and maturity of each type of erosion mitigation. Effectiveness represents the capacity of the erosion mitigation to reduce sediment load once fully mature and is specific to each mitigation, while the maturity represents the proportion of time passed relative to the age at which a mitigation may be considered fully mature and thus fully effective. Maturity rates are outlined in Table 1 based on values used in previous work (e.g. Manderson et al. 2011; McIvor et al. 2011; Basher et al. 2018).

Past, present, and future erosion mitigation works, and the related changes to land cover, are represented in the model. Spatial data on the past and present erosion mitigation works were provided by WRC in the form of soil conservation data for the region. This provided information on the spatial extent, type, and year of implementation of soil conservation works. The types of soil conservation work were matched to the erosion mitigation types represented in the model Table 1), and the year of implementation and rate of maturity were used to determine the maturity of the works for the year associated with each scenario. The spatial extent of land cover and mitigation associated with future mitigation scenarios are shown in Figure 2.

Conversion to permanent woody cover has an effectiveness value of 90% for mass movement erosion based on published data (Phillips et al 2020; Dymond et al. 2006; Page et al. 1999; Pain & Stephens 1990; Bergin et al. 1993, 1995; Phillips et al. 1990; Marden & Rowan 1993; Marden et al 1991). Space-planted trees and gully tree planting have a value of 70% based on data from Hawley and Dymond (1988) repeated in Dymond et al. (2010), and consistent with Douglas et al. (2009, 2013); McIvor et al. (2015), although various studies report varying effectiveness (see Model limitations). The effectiveness of afforestation and bush retirement in reducing surficial erosion (Table 1) was derived from the change in C in equation 1 based on the conversion of pasture to forest/scrub. Space-planted trees and gully tree planting do not typically achieve canopy closure, and therefore reductions from these mitigations were not applied to surficial erosion. Riparian retirement was applied to mitigate bank erosion with a reduction of 80% attributable to riparian fencing and stock exclusion (Dymond et al. 2016; Phillips et al 2020), although we recognize that published studies report a range of effectiveness values for various erosion mitigations (see Model limitations).

Table 1. Summary of maturity and effectiveness of the erosion mitigation works on pasture used in the modelling, after Basher et al. 2018

Erosion mitigation	Years to fully mature	Annual maturity rate	Effectiveness	Soil conservation asset type from WRC data
Conversion to woody cover (afforestation/ bush retirement)	10	10%	90% (mass movement) 50% (surficial)	'Indigenous Retirement', 'Protection Production Plantings'
Space-planted trees	15	6.66%	70% (mass movement)	'Space Planting'
Riparian retirement	2	50%	80% (bank erosion)	'Riparian Retirement', 'Stream Bank Erosion Control Plantings'

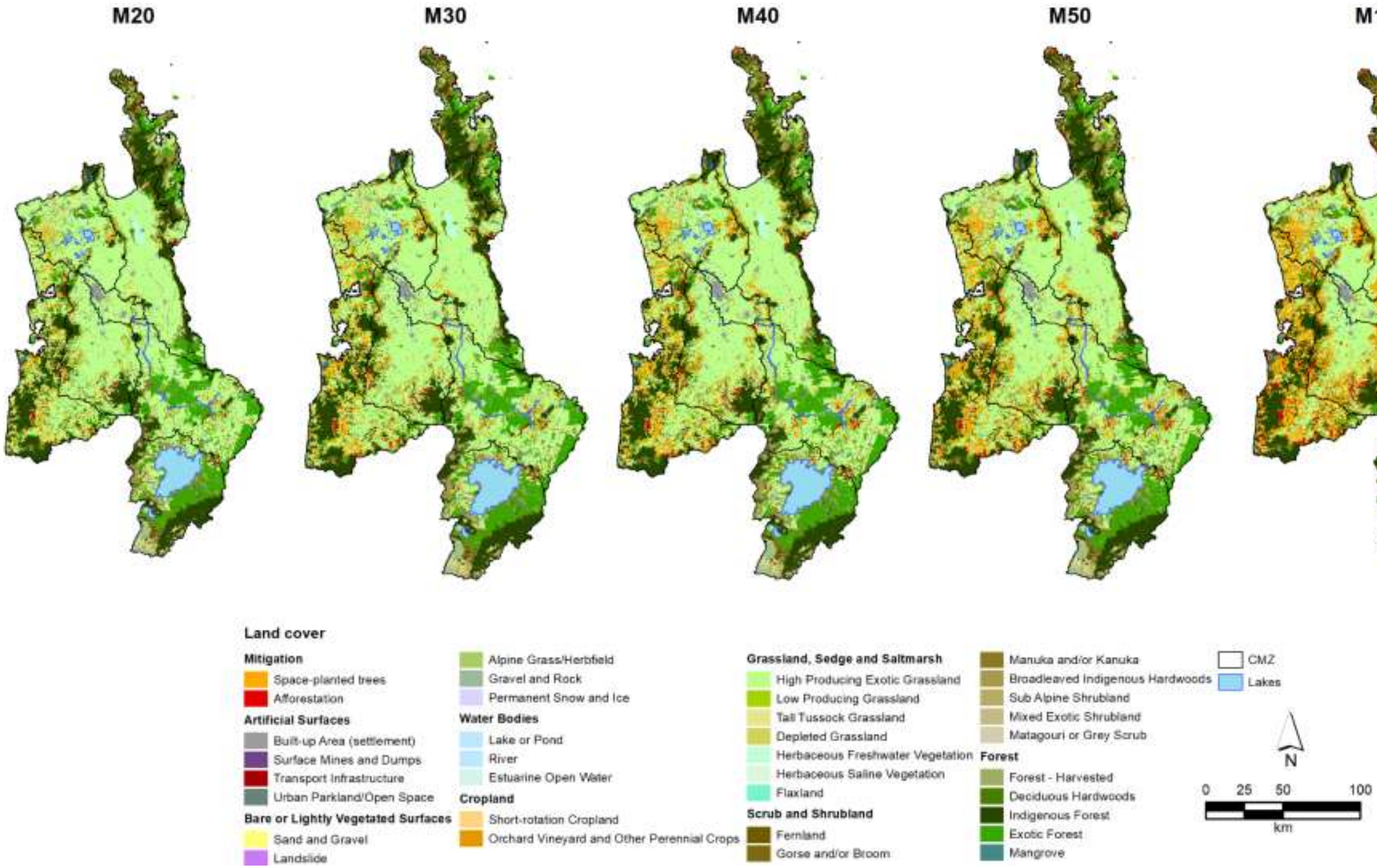

Figure 2. Erosion mitigation scenarios showing spatial extent of mitigation works and land cover (LCDBv5, 2018).

Reduction in hillslope sediment delivery to streams from surficial erosion

A sediment passing factor, the inverse of trapping efficiency, was calculated for the riparian buffer of the jth stream segment (PF_{F_j}) following Zhang et al. (2010):

$$PF_{F_j} = 1 - \frac{k(1 - e^{-bw})}{100} \quad (20)$$

where k and b are fitted parameters equal to 90.9 and 0.446, respectively (Zhang et al. 2010), and w is the buffer width. A mean buffer width for each REC2 segment was estimated based on the proportion of land class and the corresponding buffer width intersecting with the segment. The mean buffer width was determined using data from the WRC regional riparian survey (described below) for the backward-looking scenario with contemporary climate. Riparian fencing applied to the future scenarios based on the Resource Management (Stock Exclusion) Regulations 2020 applied a 3 m buffer width for wide streams intersecting with low-slope land, and 2 m for wide streams intersecting with high-slope land.

Wide streams are 'Accord streams', defined by the Sustainable Dairying Water Accord (Dairy Environment Leadership Group 2013) as being wider than 1 m, deeper than 30 cm, and having a permanent flow. The width of the streams was estimated using mean annual flow data for each REC2 segment (Booker & Hicks 2013; Semadeni-Davies & Elliott 2016; Whitehead & Booker 2020). Low-slope land is defined by the 'Stock exclusion low slope land 2022' layer (Ministry for the Environment 2022b).

The reduction in suspended sediment load from surficial erosion due to fencing and stock exclusion from riparian retirement in a reach (S_{F_j}) is a function of the proportion of the reach fenced (FR_j) and the buffer passing factor:

$$S_{F_j} = ES_j \times \left(1 - FR_j PF_{F_j}\right) \quad (21)$$

where ES_j is the load from surficial erosion for the j^{th} reach per REC2 watershed.

Reduction in bank erosion

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

$$B_{F_j} = B_j \times \left(1 - 0.8FR_j\right) \quad (22)$$

where B_j is the net suspended sediment load from bank erosion without the effect of fences reducing erosion. A reduction of 80% in net suspended sediment load from bank erosion may be attributable to riparian fencing and stock exclusion (Dymond et al. 2016; Phillips et al. 2020). This reflects the effect of reduced stock trampling and foraging on banks (Trimble 1994), as well as the potential for riparian woody vegetation to become better established in the absence of livestock over the longer term. The estimated 80% reduction assumes the buffer strip is no longer grazed and sufficient time has elapsed for banks to recover from previous trampling impacts, and for woody vegetation to become established and increase bank stability.

Riparian fencing estimates

The proportion of riparian fencing across Waikato was estimated based on survey data provided by WRC from four region-wide riparian surveys (2002, 2007, 2012, and 2017) (Figure 3). These surveys were established to track changes in the extent of fencing and vegetation on selected sites on pastoral land across Waikato (Norris et al. 2020).

The original (2002) regional riparian characteristics survey employed a stratified random sampling design to evenly represent land use, stream order and management zone across the region. The sites initially represented a 1 km long stretch of waterway whereby both banks were evaluated for a range of parameters, including fencing and buffer width, in each survey. From the 2017 survey the length of the reach surveyed at each site was reduced to 500 m. The number of sites surveyed also varied each year.

The site data were processed to derive the proportion of fencing at each site for each survey year. These proportions were then summarised according to stream order (1–8) and land use/farm type (i.e. drystock or dairy) to enable the application of fencing proportions onto the REC2 digital stream network according to the spatial criteria (Table 2). The criteria reflect the main variables informing the survey design (e.g. land use and stream order) and factors influencing the spatial variation in riparian fencing extent while maintaining a sufficient sample size per stream order and farm type ($n \geq 7$, except for one 2017 sample; most sample sizes were ≥10 and ≤60). The criteria also align with Resource Management (Stock Exclusion) Regulations 2020.

Table 2. Summary of estimated fencing proportions based on WRC riparian surveys

Stream order	Farm type	Survey year				Mean buffer width (m)
		2002	2007	2012	2017	
1	Dairy	42%	55%	72%	91%	3.3
	$Drystock_{narrow}$	25%	36%	39%	39%	5.3
	$Drystock_{wide}$	22%	36%	43%	43%	5.0
2	Dairy	51%	55%	71%	92%	3.8
	$Drystock_{narrow}$	36%	58%	63%	63%	7.4
	$Drystock_{wide}$	47%	54%	56%	56%	5.7
3	Dairy	37%	50%	62%	89%	5.7
	Drystock	27%	37%	47%	48%	5.5
4	Dairy	43%	44%	70%	93%	5.2
	Drystock	18%	31%	48%	62%	6.4
5	Dairy	37%	44%	69%	85%	5.0
	Drystock	30%	48%	52%	62%	6.2
≥6	Dairy	46%	48%	73%	95%	5.8
	Drystock	20%	47%	54%	57%	5.7

The designation of 'narrow' or 'wide' was based on the 'Accord stream' definition from the Sustainable Dairying Water Accord (Dairy Environment Leadership Group 2013).

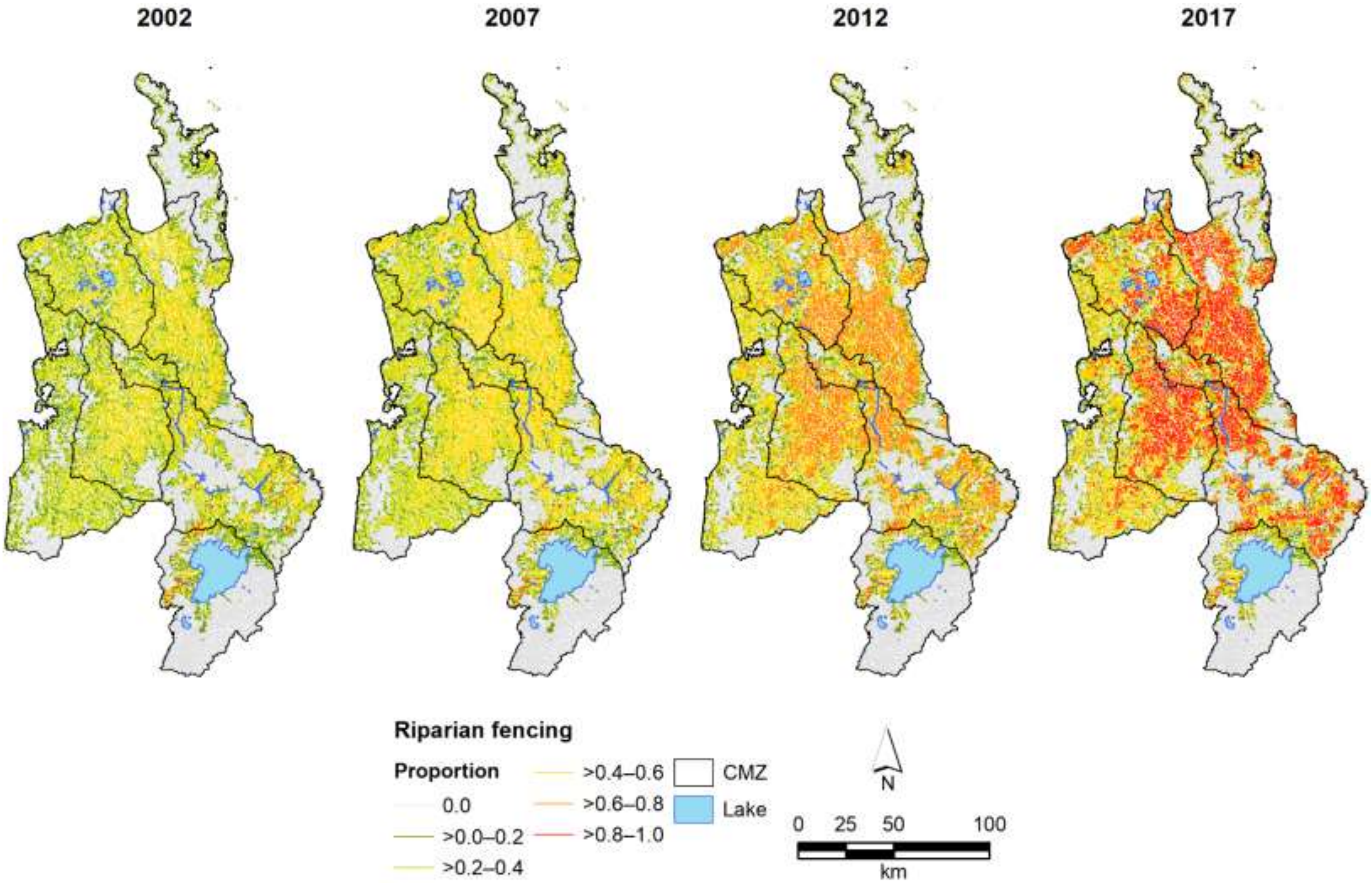

Figure 3. Estimated proportions of riparian fencing for 2002, 2007, 2012, and 2017 for the REC2 digital stream network, derived from WRC regional riparian surveys.

Land use associated with the digital stream network segments was determined using AgriBase™ in combination with LCDB v5 to mask out areas that are associated with AgriBase™ farms but that would not generally be considered for riparian fencing (e.g. woody cover). The designation of a stream segment as 'narrow' or 'wide' was determined from the 'Accord stream' definition by the Sustainable Dairying Water Accord (Dairy Environment Leadership Group 2013). This definition was used to further summarise and apply fencing proportions for first- and second-order streams on drystock farms to provide a distinction between narrow and wide streams.

Accord (wide) streams are freshwater waterways that are wider than 1 m, deeper than 30 cm, and have a permanent flow. The width of the streams was estimated using mean annual flow data for each REC2 segment (Booker & Hicks 2013; Semadeni-Davies & Elliott 2016; Whitehead & Booker 2020).

According to the Resource Management (Stock Exclusion) Regulations 2020, full implementation of riparian fencing is expected to be completed by 2025. To represent this in the modelling, we assumed that all wide streams intersecting with drystock and dairy land uses (based on AgriBase™) within 'low slope land' (defined by Ministry for the Environment 2022b), as well as all wide streams intersecting with dairy land use across all slopes, will be fenced for the future mitigation scenarios.

Winter-forage cropping

Winter-forage paddock spatial data for 2021 and 2022 were provided by WRC. To incorporate the impact of winter-forage grazing on surficial erosion, a modified C factor was used in winter-forage paddocks (C_{WF}) to represent the temporal variability in cover. Where forage cropping occurs, it is assumed the average paddock has vegetation cover with a C factor equivalent to pasture for 9 months of the year and bare ground for 3 months of the year, as a result of the sowing and grazing cycles. C_{WF} is therefore calculated as:

$$C_{WF} = 0.75\mathrm{C}_p + 0.25\mathrm{C}_B \tag{23}$$

where C_p is the C factor for pasture and C_B is the C factor for bare ground. This gives a C factor of 0.2575 for winter-forage cropping. This C factor produces a c. 25-fold increase in erosion relative to pasture, which is a similar order of magnitude increase reported by other models (Donovan 2022) and empirical studies (Monaghan et al. 2017).

4.2.3 Climate change projections

The effects of future climate change on erosion and suspended sediment loads were modelled following the approach of Basher et al. (2020). Six CMIP5 (Coupled Model Inter-comparison Project Phase 5) global climate models (GCMs) (BCC-CSM1.1, CESM1-CAM5, GFDL-CM3, GISS-E2-R, HadGEM2-ES, and NorESM1-M) were coupled with the New Zealand Regional Climate Model (RCM, Sood 2014) by the Ministry for the Environment (2018) to characterise future temperature and precipitation to 2100 on a 5 km grid. Four forcing scenarios from the Intergovernmental Panel on Climate Change's Fifth Assessment Report (IPCC 2013), known as representative concentration pathways (RCPs), are used to drive the models, and represent different radiative forcing based on greenhouse gas trajectories

(Ministry for the Environment 2018). The RCP pathways 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} (very high greenhouse gas concentrations), referred to as RCP2.6, RCP4.5, RCP6.0, and RCP8.5, respectively. Variations in the climate change scenarios become more evident after 2035 due to divergence in the radiative forcing pathways (RCPs) (Basher et al. 2020).

The effect of climate change on erosion processes is represented in SedNetNZ using different climatic variables to drive changes in different erosion processes. In the hillslope domain, surficial erosion is modelled for each climate scenario using the estimated change in mean annual rainfall from the RCM models to directly adjust P in Equation 1 (Basher et al. 2020). Mass movement erosion is assumed to change as a function of changing storminess (i.e. a change in storm total rainfall resulting from changes in frequency and magnitude of storm events) across the region. This change in storminess is used to derive a proportional change in the density of shallow landsliding that occurs under each climate scenario. This is used to represent a factor of change, CF, in all hillslope mass-movement-dominated erosion processes, following Manderson et al. (2015), Basher et al. (2020), and Neverman et al. (2023).

The change in storminess under each climate scenario is calculated by adjusting historical rainfall records (CliFlo; NIWA 2021) by an augmentation factor based on predicted changes in storm rainfall as a result of the change in temperature:

$$R' = R(1 + \Delta T\, AF) \tag{24}$$

where R' is future rainfall, R is historical rainfall, ΔT is future absolute change in temperature relative to baseline, and AF is the augmentation factor. AF is derived from the estimated change in rainfall depth per 1°C increase in temperature calculated by Ministry for the Environment (2018) for a 30 yr annual recurrence interval (ARI) 48 h duration rainfall event. This is assumed to represent the dominant landslide-triggering event (Basher et al. 2020), giving a value of 0.073. Rain gauges with complete records for the last 50 yr across the region were selected from CliFlo (NIWA 2021) and used to represent historical rainfall. At each gauge, equation 24 was used to calculate R' under temperature changes up to 3°C.

Storm events were then identified in the baseline and future rainfall records as consecutive days where rainfall exceeded 10 mm per day. The storms were considered landslide-producing events if >150 mm of rain fell in a 48 h period during the event. The total rainfall for the storm event was used to estimate the density of shallow landslides produced in each rainfall record for baseline and climate scenarios using the relationship between storm total rainfall and shallow landslide density identified by Reid and Page (2003):

$$LD = mR_s + b \tag{25}$$

where LD is the density of shallow landslides per square kilometre, R_S is the total rainfall for the storm event, m is the slope of the linear relationship between LD and R_s (set to 0.72; Basher et al. 2020), and b is the y-intercept of the relationship, calculated by solving for b under the assumption LD = 0 when R_s ≤ 150 mm:

$$0 = 150m + b \tag{26}$$

$$b = -136.8 \tag{27}$$

Linear models were developed for the relationship between LD and ΔT at each rain gauge location and can be used to estimate the future landslide density given a change in temperature:

$$LD' = a\Delta T + LD \quad (28)$$

where LD' is the future landslide density; 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 change factor, CF, is then calculated at each rain gauge as the proportional increase in landslide density per 1°C of temperature change, calculated as:

$$CF = \frac{a}{LD} \quad (29)$$

CF was then interpolated spatially using Sibson's (1981) natural neighbours interpolation. Gauges from across the North Island were included in the interpolation.

Future rates of mass movement, MM', are then calculated by augmenting the baseline mass movement rate, MM, by CF and the change in temperature, ΔT, at the i^{th} pixel of the 5 km temperature change grids for each climate scenario, such that:

$$MM' = MM(1 + CF\Delta T_i) \quad (30)$$

where MM represents the hillslope mass movement-dominated processes, EL, EE, and EG, from equations 8 to 10.

The effect of climate change on bank erosion is based on estimated changes in MAF_j for each climate scenario, per stream segment. MAF has been previously used as a spatial predictor of streambank erosion (Dymond et al. 2016; Smith, Herzig et al. 2019).

National projections of MAF under future climate change were produced by NIWA in the Phase 1 Deep South Challenge-funded project *Climate impacts on the national water cycle*. These outputs were made available for use in the present work via a data access agreement with NIWA. Future changes in MAF were estimated based on TopNet hydrological modelling that simulated flows over successive 20 yr periods for each RCM and RCP (Collins et al. 2018) and computed proportional changes in future MAF relative to a historical baseline period (1986–2005). The data were only available as the median predicted proportional change in MAF across the six RCMs for each RCP, but not for individual RCMs. We therefore use these median values with each RCM.

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

$$B_j' = B_j \Delta MAF_j \quad (31)$$

where B_j is the baseline net suspended sediment load from bank erosion (equation 11) and ΔMAF_j is a dimensionless change factor based on the change in MAF between the baseline and future climate scenarios (RCPs).

Climate change effects on erosion and suspended sediment loads are reported for the upper (max), lower (min), and median (med) projected changes from the RCM ensemble for mid- and late century.

4.3 Reductions for NPS-FM visual clarity attribute bands

To assess the improvement in attribute state under future scenarios, we use the approach developed by Hicks, Haddadchi et al. (2019) to estimate the proportional change in mean annual suspended sediment load required to achieve an improved attribute state. This approach is recommended by the Ministry for the Environment in their guidance for implementing the NPS-FM 2020 sediment requirements (Ministry for the Environment 2022a), and directly informed development of the suspended fine sediment attribute for the NPS-FM 2020 (see Hicks & Shankar 2020).

Suspended sediment loads may increase under future climate conditions, decreasing visual clarity, so we estimate the attribute band associated with the increase in sediment load. For segments with projected increases in load under future scenarios, and therefore degraded visual clarity, we report the reduction in the future scenario load required to return the segment to the baseline visual clarity, following Neverman & Smith. 2023. This reflects the NPS-FM 2020 policy, which requires target attribute states to be set at or above the baseline and therefore does not allow for deterioration below baseline visual clarity (Ministry for the Environment 2022a).

Following Hicks, Haddadchi et al. 2019 and Ministry for the Environment 2022a, the proportional change in mean annual suspended sediment load required to achieve a target attribute state is calculated as a function of the ratio between the current state visual clarity (visual clarity for each scenario) and the target visual clarity using equation 32 at each segment of the River Environment Classification v2.4 (REC2) digital stream network:

$$PR_v = 1 - (V_o/V_b)^{1/a} \quad (32)$$

where PR_v is the minimum proportional change in mean annual suspended sediment load required to achieve the target visual clarity, V_o is the target visual clarity for each attribute band (Table 3), and V_b is the current state median visual clarity. We follow the recommendation of the Ministry for the Environment (2022a) and assume a in equation 32 takes the national average reported by Hicks, Haddadchi et al. (2019) of –0.76.

The baseline attribute state was determined using the median visual clarity calculated from the most recent 60 visual clarity observations for each SOE site provided by WRC (Table 4; Figure 4). Median visual clarity requires monthly observations over a minimum record length of 5 yr (60 samples) and not all sites meet this requirement. Sites with close to 60 (≥50) observations were also included.

To assess the minimum proportional change in suspended sediment load required to improve the attribute band, we used the lower-bound visual clarity for each band (Table 3) 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.

The attribute band thresholds for suspended fine sediment are determined by the 'sediment class' associated with each REC2 segment (Table 3; Figure 4). The sediment class of a given segment is determined by the climate, topography, and geological classification (as defined in the REC2) of upstream segments predominantly contributing flow to a given segment. This can produce abrupt changes in sediment class between adjoining REC2 segments. We use the layer denoting suspended sediment class for the REC2 digital stream network produced by Hicks and Shankar (2020)[2] to identify the sediment class of the segment associated with each SOE monitoring site.

Table 3. Attribute bands and numerical attribute states for suspended fine sediment

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

Source: Reproduced from Table 8 in the NPS-FM 2020.

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

Table 4. Summary details for SOE monitoring sites with estimated median visual clarity (CLAR, m) based on black disc measurements

CMZ	Site name	Site	nzsegment	Date range	n	Sediment class	Median CLAR	Base state
Central Waikato (10)	Karapiro Stm at Hickey Rd Bridge – Cambridge	230_5	3070130	Oct-2017 - Apr-2023	60	1	0.84	D
	Kirikiriroa Stm at Tauhara Dr	253_4	3061405	Feb-2018 - Mar-2023	60	2	0.39	D
	Mangakotukutuku Stm (Rukuhia) at Peacockes Rd	398_1	3064979	Mar-2018 - May-2023	60	2	0.45	D
	Mangaone Stm (Waikato) at Annebrooke Rd Br	417_7	3064673	Nov-2017 - May-2023	60	2	0.79	B
	Mangaonua Stm at Hoeka Rd	421_10	3063144	Mar-2018 - May-2023	60	2	0.83	B
	Mangaonua Stm at Te Miro Rd (a.k.a Waitakaruru Stm)	421_16	3065476	Mar-2018 - May-2023	60	2	1.11	A
	Mangawhero Stm (Cambridge) at Cambridge-Ohaupo Rd	488_1	3069532	Dec-2017 - Apr-2023	60	2	0.22	D
	Waikato River at Horotiu Br	1131_69	3059280	Apr-2018 - May-2023	60	3	1.41	D
	Waikato River at Narrows Boat Ramp	1131_328	3066645	Apr-2018 - May-2023	60	3	1.64	D
	Waitawhiriwhiri Stm at Edgecumbe Street	1236_2	3062685	Jan-2018 - Mar-2023	60	2	0.33	D
Coromandel (4)	Tapu River at Tapu-Coroglen Rd	954_5	3040973	Jan-2018 - May-2023	60	1	4.49	A
	Waiau River at E309 Rd Ford	1105_3	3037259	Dec-2017 - May-2023	60	1	2.31	A
	Waiwawa River at SH25 Coroglen	1257_3	3039645	Feb-2018 - May-2023	60	1	2.95	A
	Wharekawa River at SH25	1312_3	3044647	Jul-2017 - May-2023	60	1	2.26	A
Lake Taupō (6)	Hinemaiaia River at SH1	171_5	3149003	Feb-2018 - May-2023	60	1	2.09	A
	Kuratau River at SH41 Moerangi	282_4	3150837	Feb-2018 - May-2023	60	1	2.25	A
	Mapara Stm (Lake Taupō) at Off Mapara Rd (Whakaipo Res) T1	504_2	3136377	Feb-2018 - May-2023	60	1	1.17	D
	Tauranga-Taupo River at 20 metres U/S SH1 Bridge	971_5	3153026	Feb-2018 - May-2023	60	1	2.13	A
	Waihaha River at SH32	1106_4	3136644	Dec-2017 - Apr-2023	60	1	2.74	A
	Waitahanui River at Blake Rd	1226_1	3144485	Dec-2017 - May-2023	60	1	2.54	A

CMZ	Site name	Site	nzsegment	Date range	n	Sediment class	Median CLAR	Base state
Lower Waikato (18)	Awaroa River (Waiuku) at Otaua Rd Br opp Moseley Rd	41_9	3048412	Oct-2016 - Sep-2022	60	1	0.45	D
	Awaroa Stm (Rotowaro) at Sansons Br @ Rotowaro-Huntly Rd	39_11	3056003	Mar-2018 - May-2023	60	2	1.30	A
	Komakorau Stm at Henry Rd	258_4	3056992	Jan-2018 - May-2023	60	2	0.14	D
	Mangatangi River at SH2 Maramarua	453_6	3046991	Jan-2017 - Apr-2023	60	2	0.47	D
	Mangatawhiri River at Lyons Rd at Buckingham Br	459_6	3045657	Aug-2017 - Apr-2023	60	2	1.30	A
	Mangawara Stm at Rutherford Rd Br	481_7	3055409	Mar-2018 - May-2023	60	2	0.20	D
	Northern Outlet Canal at DownStream of Control Gates	3021_3	3051398	Sep-2018 - May-2023	51	3	0.09	D
	Ohaeroa Stm at SH22 Br	612_9	3048723	Sep-2016 - Sep-2022	60	2	0.83	B
	Opuatia Stm at Ponganui Rd	665_5	3050086	Jun-2017 - Jan-2023	60	2	0.51	D
	Waerenga Stm at Taniwha Rd	1098_1	3050816	Dec-2017 - May-2023	60	2	0.73	C
	Waikato River at Huntly–Tainui Br	1131_77	3055438	Apr-2018 - May-2023	60	3	0.91	D
	Waikato River at Mercer Br	1131_91	3047923	Jun-2018 - May-2023	57	3	0.64	D
	Waikato River at Rangiriri Br	1131_117	3052038	Sep-2018 - May-2023	54	3	0.89	D
	Waikato River at Tuakau Br	1131_133	3048245	Feb-2018 - May-2023	60	3	0.68	D
	Whakapipi Stm at SH22 Br	1282_8	3047194	Dec-2017 - May-2023	60	1	1.33	D
	Whangamarino River at Island Block Rd	1293_7	3048671	Sep-2017 - May-2023	60	3	0.16	D
	Whangamarino River at Jefferies Rd Br	1293_9	3049660	Oct-2017 - Apr-2023	60	2	0.27	D
	Whangape Stm at Rangiriri-Glen Murray Rd	1302_1	3052363	Oct-2017 - Apr-2023	60	3	0.12	D
Upper Waikato (18)	Kawaunui Stm at SH5 Br	240_5	3110340	Jan-2018 - May-2023	60	1	1.11	D
	Little Waipa Stm at Arapuni–Putaruru Rd	335_1	3081097	Nov-2017 - May-2023	60	1	1.54	C
	Mangaharakeke Stm (Atiamuri) at SH30 (Off Jct SH1)	359_1	3106095	Jul-2017 - May-2023	60	1	1.02	D
	Mangakara Stm (Reporoa) at SH5	380_2	3116290	Jun-2017 - May-2023	60	1	0.72	D

CMZ	Site name	Site	nzsegment	Date range	n	Sediment class	Median CLAR	Base state
Upper Waikato (18) (cont.)	Mangakino Stm (Whakamaru) at Sandel Rd	388_1	3115030	Sep-2017 - Jun-2023	60	1	1.68	B
	Mangamingi Stm (Tokoroa) at Paraonui Rd Br	407_1	3091783	Feb-2018 - May-2023	60	1	0.75	D
	Otamakokore Stm at Hossack Rd	683_4	3103240	Feb-2018 - May-2023	60	1	1.20	D
	Pokaiwhenua Stm at Puketurua	786_2	3081022	Feb-2018 - May-2023	60	1	1.08	D
	Pueto Stm at Broadlands Rd Br	802_1	3129762	Oct-2017 - May-2023	60	1	1.56	B
	Tahunaatara Stm at Ohakuri Rd	934_1	3105500	Nov-2017 - May-2023	60	1	1.15	D
	Waikato River at Karapiro Tailrace	1131_79	3071503	Sep-2018 - May-2023	55	3	1.73	D
	Waikato River at Lake Ohakuri Boat Ramp	1131_82	3111846	Mar-2018 - May-2023	60	3	2.50	C
	Waikato River at Ohaaki Br	1131_105	3123400	Mar-2018 - May-2023	60	3	5.05	A
	Waikato River at Waipapa Tailrace	1131_143	3099935	Mar-2018 - May-2023	60	3	2.08	D
	Waikato River at Whakamaru Tailrace	1131_147	3112254	Feb-2018 - May-2023	60	3	2.30	C
	Waiotapu Stm at Campbell Rd Br	1186_2	3109925	Feb-2018 - May-2023	60	1	1.07	D
	Waipapa Stm (Mokai) at Tirohanga Rd Br	1202_7	3112958	Feb-2018 - May-2023	60	1	1.14	D
	Whakauru Stm at U/S SH1 Br	1287_7	3093674	Feb-2018 - May-2023	60	1	0.41	D
Waihou–Piako (18)	Hikutaia River at Old Maratoto Rd	169_2	3048567	Feb-2018 - May-2023	60	1	2.51	A
	Kauaeranga River at Smiths Cableway Recorder	234_11	3044978	Jan-2018 - May-2023	60	1	3.84	A
	Mangawhero Stm (Kaihere) at Mangawara Rd	489_2	3051409	Oct-2017 - May-2023	60	2	0.87	B
	Ohinemuri River at Karangahake	619_16	3051925	Jan-2018 - May-2023	60	1	3.05	A
	Ohinemuri River at Queens Head	619_19	3051991	Oct-2017 - Apr-2023	60	1	3.70	A
	Ohinemuri River at SH25 Br	619_20	3050858	Dec-2017 - May-2023	60	1	3.05	A
	Oraka Stm at Lake Rd	669_6	3071941	Jan-2018 - May-2023	60	1	0.91	D
	Piako River at Kiwitahi	749_10	3059826	Feb-2018 - Apr-2023	60	1	1.75	B

CMZ	Site name	Site	nzsegment	Date range	n	Sediment class	Median CLAR	Base state
Waihou–Piako (18) (cont.)	Piako River at Paeroa-Tahuna Rd Br	749_15	3054261	Dec-2017 - Apr-2023	60	2	0.79	B
	Piakonui Stm at Piakonui Rd	753_4	3066020	Mar-2018 - May-2023	60	1	1.13	D
	Waihou River at Okauia	1122_18	3064061	Nov-2017 - Apr-2023	60	1	1.06	D
	Waihou River at Te Aroha	1122_34	3055227	Mar-2018 - May-2023	60	2	0.95	A
	Waihou River at Whites Rd	1122_41	3078605	Jan-2018 - May-2023	60	1	4.73	A
	Waiomou Stm at Matamata-Tauranga Rd	1174_4	3067934	Feb-2018 - Apr-2023	60	1	1.25	D
	Waitakaruru River (Hauraki Plains) at Coxhead Rd Br	1230_1	3047683	May-2017 - Apr-2023	60	2	1.00	A
	Waitekauri River at U/S Ohinemuri conflu	1239_32	3051680	Dec-2017 - May-2023	60	1	3.76	A
	Waitoa River at Landsdowne Rd Br	1249_15	3062720	Feb-2018 - Apr-2023	60	1	1.40	C
	Waitoa River at Mellon Rd Recorder	1249_18	3054693	Jan-2018 - Apr-2023	60	2	0.88	B
Waipā (17)	Firewood Creek at Waingaro Road Bridge	124_8	3058597	Sep-2018 - May-2023	54	2	0.86	B
	Kaniwhaniwha Stm at Wright Rd	222_16	3068190	Jun-2016 - Dec-2022	60	1	0.74	D
	Mangaohoi Stm at South Branch Maru Rd	411_9	3079677	Apr-2018 - Jun-2023	60	1	1.32	D
	Mangaokewa Stm at Lawrence Street Br	414_6	3103339	Jan-2018 - May-2023	60	1	0.89	D
	Mangapiko Stm (Pirongia/Te Awamutu) at Bowman Rd	438_3	3074894	Aug-2017 - Apr-2023	60	1	0.58	D
	Mangapu River at Otorohanga	443_3	3091562	Oct-2015 - Aug-2022	60	1	0.58	D
	Mangatutu Stm (Waikeria) at Walker Rd Br	476_7	3083539	Apr-2018 - Jun-2023	60	1	1.26	D
	Mangauika Stm at Te Awamutu Borough W/S Intake	477_10	3077698	Dec-2017 - May-2023	60	1	3.20	A
	Ohote Stm at Whatawhata/Horotiu Rd	624_5	3062320	Mar-2018 - May-2023	60	2	0.45	D
	Puniu River at Bartons Corner Rd Br	818_2	3078623	Apr-2012 - Jun-2023	60	1	0.90	D
	Puniu River at Wharepapa Rd Bridge	818_40	3087956	Sep-2018 - Jun-2023	54	1	1.28	D
	Waipa River at Mangaokewa Rd	1191_5	3114412	Nov-2017 - May-2023	60	1	1.80	A

CMZ	Site name	Site	nzsegment	Date range	n	Sediment class	Median CLAR	Base state
Waipā (17) (cont.)	Waipa River at Ngaruawahia Br	1191_6	3057910	Sep-2018 - May-2023	50	1	0.60	D
	Waipa River at Pukehoua Bridge on Baffin Road	1191_2	3075687	Mar-2017 - Nov-2022	60	1	0.64	D
	Waipa River at SH3 Otorohanga	1191_12	3091406	Jan-2018 - May-2023	60	1	1.00	D
	Waitomo Stm at SH31 Otorohanga	1253_5	3090304	Jun-2017 - Apr-2023	60	1	0.50	D
	Waitomo Stm at Tumutumu Rd	1253_7	3096865	Dec-2017 - May-2023	60	1	1.00	D
West Coast (14)	Awakino River at Gribbon Rd	33_6	3123054	Feb-2018 - May-2023	60	3	1.97	D
	Awakino River at SH3 Awakau Rd Junction	33_9	3131731	Aug-2017 - May-2023	60	2	1.26	A
	Manganui River at off Manganui Rd	410_4	3130367	Aug-2017 - May-2023	60	2	1.21	A
	Mangaotaki River at SH3 Br	428_3	3119483	Nov-2017 - May-2023	60	1	0.98	D
	Marokopa River at Speedies Rd (off Te Anga Rd)	513_3	3095966	Oct-2017 - May-2023	60	1	0.99	D
	Mokau River at Awakau Rd	556_2	3133651	Apr-2017 - Dec-2022	60	2	0.53	D
	Mokau River at Mangaokewa Rd (off SH30)	556_5	3115276	May-2010 - May-2023	60	1	1.10	D
	Mokau River at Totoro Rd Recorder	556_9	3123396	May-2017 - Apr-2023	60	1	1.00	D
	Mokauiti Stm at Three Way Point - Aria	557_5	3122377	Jan-2018 - May-2023	60	2	0.77	B
	Ohautira Stm at Waingaro Te Uku Rd	616_1	3061831	Sep-2017 - Feb-2023	60	2	1.04	A
	Oparau River at Langdon Rd (off Okupata Rd)	658_1	3078902	Nov-2017 - May-2023	60	2	1.40	A
	Tawarau River at off Speedies Rd	976_1	3096753	Dec-2017 - May-2023	60	1	1.07	D
	Waingaro River (Pukemiro) at Ruakiwi Rd off SH22	1167_4	3060386	Jul-2017 - Mar-2023	60	2	0.89	B
	Waitetuna River at Te Uku-Waingaro Rd	1247_2	3064930	Sep-2017 - Feb-2023	60	2	0.92	B

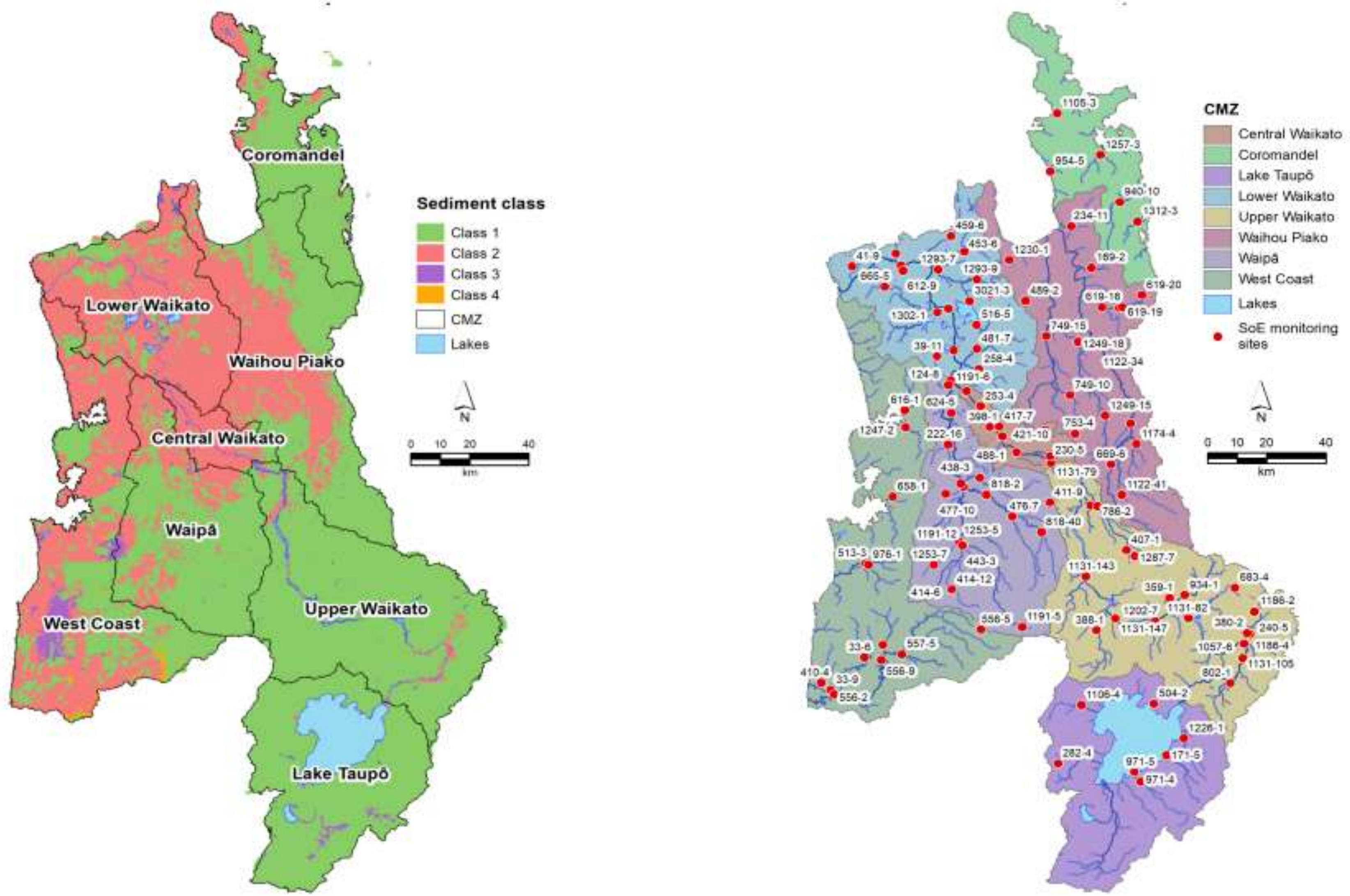

Figure 4. NPS-FM 2020 suspended sediment classes (left) across Waikato, and the location of SOE monitoring sites (right).

5 Results

5.1 Suspended sediment loads under contemporary climate

Mean annual suspended sediment loads are provided in two forms:

- 'total erosion', which may be expressed as the total suspended sediment load (t yr^{-1}) or yield (t km^{-2} yr^{-1}) produced from all erosion processes in each REC2 watershed.
- 'total net load', which represents the net suspended sediment load (t yr^{-1}) routed through the stream network to the coast, accounting for lake trapping and floodplain deposition.

These modelled loads do not include climate change impacts, which are described in section 5.3.

5.1.1 Contemporary baseline (C2022)

Total erosion loads for contemporary baseline scenario, summarised by CMZ and region wide, are presented in Table 5. Mean annual suspended sediment yield (t km^{-2} yr^{-1}) and net sediment load (kt yr^{-1}) are shown for the contemporary baseline (C2022) in Figure 5.

Table 5. Total erosion and total net load for contemporary baseline (C2022), summarised by each CMZ, Waikato Region, and selected rivers

	Contemporary baseline (C2022)			
CMZ	**Total erosion (kt yr^{-1})**	**Total net load delivered to coast (kt yr^{-1})**	**River**	**Total net load delivered to coast or downstream CMZ (kt yr^{-1})**
Central Waikato	24.8	-	Waikato River	42.0
Coromandel	182	177	Waiwawa River	17.7
			Tairua River	21.6
Lake Taupō	219	-	Waikato River	4.1
			Tongariro River	66.9
Lower Waikato*	221	501	Waikato River	501
Upper Waikato	304	-	Waikato River	17.1
Waihou–Piako	239	227	Waihou River	147
			Piako River	48.0
Waipā	322	-	Waipā River	312
West Coast	808	764	Awakino River	86.1
			Mōkau River	286
Waikato Region	**2,319**	**1,668**		

* Suspended sediment loads reported for Lower Waikato include net contributions from its sub-catchments (i.e. Lake Taupō, Upper Waikato, Central Waikato, Waipā).

The contemporary baseline region-wide total erosion was estimated as 2.32 Mt yr^{-1}. The highest sediment yields occur in the earthflow and shallow landslide-prone terrains. This is mostly restricted to the hill country in the West Coast and Waipā CMZs, as well as terrain affected by gullies, particularly in the Upper Waikato and Lake Taupō CMZs (Figure 5). Approximately 1.67 Mt yr^{-1} of sediment is delivered to the coast, accounting for losses to floodplain deposition and lake trapping. West Coast has the highest total erosion (808 kt yr^{-1}), followed by Waipā and Upper Waikato (322 kt yr^{-1} and 304 kt yr^{-1}), while Central Waikato has the lowest (24.8 kt yr^{-1}).

The proportion of each erosion process contributing to total erosion load varies across the CMZs, which reflects the erosion terrains within each CMZ (Table 6). Sediment load from shallow landslide erosion represented the dominant contribution (53%) across the region. However, the shallow landslide contribution across the CMZs varied from 17% in Lake Taupō to 64% in Lower Waikato and Waipā. Surficial erosion represented the second most dominant process at 22% of the total erosion load. Bank erosion represented an 11% contribution across the region, varying from 7% in West Coast to 25% in the Lake Taupō CMZ. Earthflow and gully erosion represented a relatively minor region-wide sediment load of 7% and 6%, respectively, but they are significant in specific CMZs. Earthflows constitute up to 14% of sediment load in West Coast and Lower Waikato, while gully erosion contributes 27% in Lake Taupō and 20% in Upper Waikato.

Table 6. Proportion of erosion load contribution by each erosion process for contemporary baseline (2022)

CMZ	Proportion erosion process contribution (%)				
	Shallow landslide erosion	**Earthflow erosion**	**Gully erosion**	**Surficial erosion**	**Bank erosion**
Central Waikato	58%	-	15%	9%	18%
Coromandel	54%	-	-	34%	12%
Lake Taupō	17%	-	27%	31%	25%
Lower Waikato	64%	14%	<1%	7%	15%
Upper Waikato	62%	-	20%	12%	6%
Waihou–Piako	60%	-	-	25%	15%
Waipā	64%	2%	2%	21%	11%
West Coast	51%	16%	<1%	26%	7%
Waikato Region	**53%**	**7%**	**6%**	**22%**	**11%**

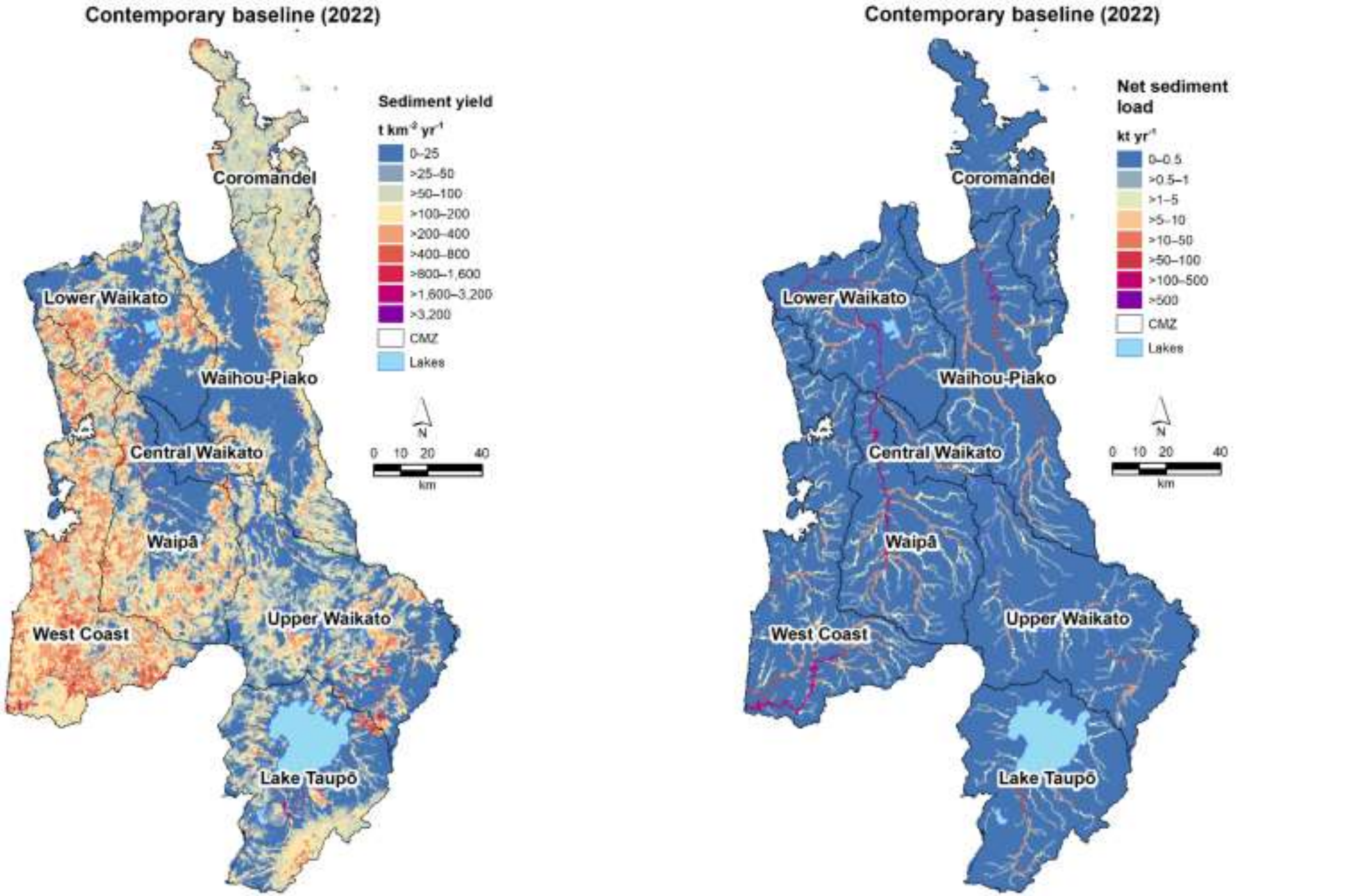

Figure 5. Mean annual suspended sediment yield (t km^{-2} yr^{-1}) (left) and mean annual net suspended sediment load (kt yr^{-1}) for the contemporary baseline (2022).

Winter-forage crops

Total erosion loads for the contemporary baseline sensitivity analysis of WF2021 and WF2022 winter-forage crop scenarios are presented in Table 7. The table summarises erosion loads and the area of winter-forage cropping by CMZ, as well as difference between the two years.

The difference between sediment loads for the two modelled winter-forage years is small, with a region-wide change in total sediment load of −0.619 kt yr^{-1}, or −0.03% from WF2021 to WF2022. This small difference reflects the typical location of winter-forage paddocks in mostly low-slope areas and their small total area in the Waikato region.

The largest change occurs in the Waihou–Piako CMZ, with a difference of −0.54 kt yr^{-1} or −0.23%, while the smallest change occurs in Coromandel with a difference of −0.002 kt yr^{-1} or −0.001%.

Table 7. Total erosion for the contemporary baseline comparing winter-forage cropping for WF2021 and WF2022, summarised for each CMZ and the Waikato Region

CMZ	Total erosion (kt yr^{-1})			Area (km^2)		
	WF2021	WF2022	Difference per yr, %	WF2021	WF2022	Difference km^2, %
Central Waikato	24.84	24.82	−0.021 −0.08%	1.41	0.56	−0.86 −154.2%
Coromandel	181.92	181.91	−0.002 −0.001%	0.04	0.05	0.002 4.2%
Lake Taupō	218.71	218.73	0.022 0.01%	4.09	4.65	0.57 12.2%
Lower Waikato	220.88	220.88	−0.009 −0.004%	3.21	1.97	−1.24 −62.9%
Upper Waikato	303.83	303.95	0.124 0.04%	16.51	18.51	2.00 10.8%
Waihou–Piako	239.43	238.89	−0.540 −0.23%	8.68	4.00	−4.68 −116.8%
Waipā	321.84	321.76	−0.074 −0.02%	11.01	8.41	−2.60 −30.9%
West Coast	807.88	807.76	−0.119 −0.01%	2.43	2.20	−0.23 −10.5%
Waikato Region	**2,319.32**	**2,318.70**	**−0.619 −0.03%**	**47.38**	**40.34**	**−7.04 −17.4%**

WF2021 and WF2022 refer to winter-forage paddock spatial data for 2021 and 2022 years

5.1.2 Backward-looking scenarios

Total erosion loads for the backward-looking scenarios (B2002, B2007, B2012 and B2017), based on the WRC riparian fencing survey years, and summarised by CMZ and region-wide, are provided in Table 8 and Figure A1.1. Region-wide total erosion decreases from B2002 to B2017 following the modelled increase in riparian fencing throughout the region. In B2002 total erosion is estimated as 2,423 kt yr^{-1}, decreasing to 2,324 kt yr^{-1} by B2017. This equates to a decrease of 98.7 kt yr^{-1} or 4.1%, and represents a mean annual decrease of 6.8 kt yr^{-1} (0.27%) for the period 2002 to 2017.

Across the CMZs the decrease in total erosion between B2002 and B2017 ranges from 3.5% to 8.5%, except for Upper Waikato, which shows an increase of 9.4%. This increase occurs due to changes to land cover in Upper Waikato. Despite increasing riparian fencing in areas of pasture, significant areas of woody cover (exotic forest) were converted to pasture, resulting in a predicted increase in erosion from these areas. A small increase in erosion also occurs in the Lake Taupō CMZ between B2002 and B2007 due to changes in land cover from woody cover to pasture.

Table 8. Total erosion for B2002, B2007, B2012, and B2017 scenarios related to the riparian survey years, summarised by CMZ and for the whole region

CMZ	Total erosion (kt yr^{-1})				Difference from 2002 (kt yr^{-1}, %)			Mean annual change (kt yr^{-1}, %)
	B2002	B2007	B2012	B2017	B2007	B2012	B2017	
Central Waikato	26.5	26.0	25.5	25.0	−0.4 −1.7%	−0.9 −3.6%	−1.5 −5.6%	−0.10 −0.37%
Coromandel	191.4	187.3	185.1	182.7	−4.1 −2.1%	−6.3 −3.3%	−8.7 −4.6%	−0.58 −0.30%
Lake Taupō	226.6	226.7	221.4	218.6	0.1 0.1%	−5.1 −2.3%	−8.0 −3.5%	−0.53 −0.24%
Lower Waikato	233.7	231.2	226.3	222.2	−2.4 −1.0%	−7.4 −3.2%	−11.5 −4.9%	−0.77 −0.33%
Upper Waikato	278.8	287.9	304.3	304.9	9.1 3.3%	25.5 9.1%	26.1 9.4%	1.74 0.63%
Waihou–Piako	259.7	256.9	248.1	239.2	−2.8 −1.1%	−11.6 −4.5%	−20.4 −7.9%	−1.36 −0.52%
Waipā	353.1	344.6	331.8	323.0	−8.5 −2.4%	−21.3 −6.0%	−30.1 −8.5%	−2.00 −0.57%
West Coast	853.3	834.5	817.1	808.7	−18.9 −2.2%	−36.2 −4.2%	−44.7 −5.2%	−2.98 −0.35%
Waikato Region	**2,423**	**2,395**	**2,359**	**2,324**	**−27.9** **−1.2%**	**−63.3** **−2.6%**	**−98.7** **−4.1%**	**−6.58** **−0.27%**

5.1.3 Future erosion mitigation

The future erosion mitigation scenarios use the 'ranked-watershed' approach to represent the implementation of erosion mitigation works on 20 to 100% (scenarios M20 to M100) of pastoral LUC class 6e, 7e, and 8e land. Total erosion loads, summarised by CMZ and region-wide, are presented in Table 9 and Figure A1.2. Mean annual suspended sediment yields (t km^{-2} yr^{-1}) are provided in Figure 6.

Under contemporary climate, the region-wide total erosion is estimated to decrease by 13.1% from 2.32 Mt yr^{-1} to 2.01 Mt yr^{-1} for the M20 scenario relative to the contemporary baseline. Further erosion mitigation works result in a 27% reduction to 1.69 Mt yr^{-1} in the M50 scenario, and a 41% reduction to 1.38 Mt yr^{-1} for the M100 scenario. Most of the load reduction occurs in the West Coast, Upper Waikato, and Waipā CMZs, representing c. 70% of the total region-wide load reduction.

The sediment load reductions achieved in each CMZ reflect the spatial extent of LUC class 6e, 7e, and 8e land available for mitigation with each successive scenario (M20 to M100). For example, for the M20 to M50 scenarios, the largest proportional reductions occur in the West Coast (17.9 to 32.9%), but Upper Waikato shows the greatest proportional reduction (52%) under the M100 scenario. West Coast shows the largest absolute load reductions for all scenarios due to the significantly greater sediment load in this CMZ. In contrast, lower sediment load reductions were achieved in the Lake Taupō, Coromandel, and Waihou–Piako CMZs, showing load reductions ranging from 3.4 to 7.4% under the M20 scenario and 19.2 to 34.5% under the M100 scenario.

Table 9. Total erosion (kt yr^{-1}) modelled for future erosion mitigation scenarios, summarised by CMZ and for the whole region

CMZ (C2022: kt yr^{-1})	Mitigation scenarios (kt yr^{-1})					Difference from contemporary baseline (C2022) (kt yr^{-1}, %)				
	M20	M30	M40	M50	M100	M20	M30	M40	M50	M100
Central Waikato (24.8)	21.9	20.0	18.3	16.8	12.4	−2.9 −11.8%	−4.8 −19.4%	−6.5 −26.3%	−8.1 −32.5%	−12.5 −50.2%
Coromandel (182)	176	172	167	162	141	−6.2 −3.4%	−9.7 −5.3%	−14.5 −8.0%	−19.9 −10.9%	−40.6 −22.3%
Lake Taupō (219)	203	200	198	196	177	−16.2 −7.4%	−18.7 −8.5%	−21.2 −9.7%	−22.9 −10.5%	−42.0 −19.2%
Lower Waikato (221)	189	175	161	149	113	−31.9 −14.4%	−45.5 −20.6%	−59.4 −26.9%	−71.6 −32.4%	−108.2 −49.0%
Upper Waikato (304)	260	240	222	205	146	−44.0 −14.5%	−64.1 −21.1%	−81.9 −26.9%	−99.0 −32.6%	−157.6 −51.8%
Waihou–Piako (239)	220	211	201	191	156	−18.4 −7.7%	−28.2 −11.8%	−38.3 −16.0%	−47.8 −20.0%	−82.4 −34.5%
Waipā (322)	281	263	246	230	176	−40.8 −12.7%	−58.6 −18.2%	−75.7 −23.5%	−91.7 −28.5%	−146.0 −45.4%
West Coast (808)	663	617	577	542	454	−144.3 −17.9%	−190.8 −23.6%	−230.6 −28.5%	−266.1 −32.9%	−353.5 −43.8%
Waikato Region (2,319)	**2,014**	**1,898**	**1,791**	**1,692**	**1,376**	**−304.8 −13.1%**	**−420.4 −18.1%**	**−528.1 −22.8%**	**−627.0 −27.0%**	**−942.9 −40.7%**

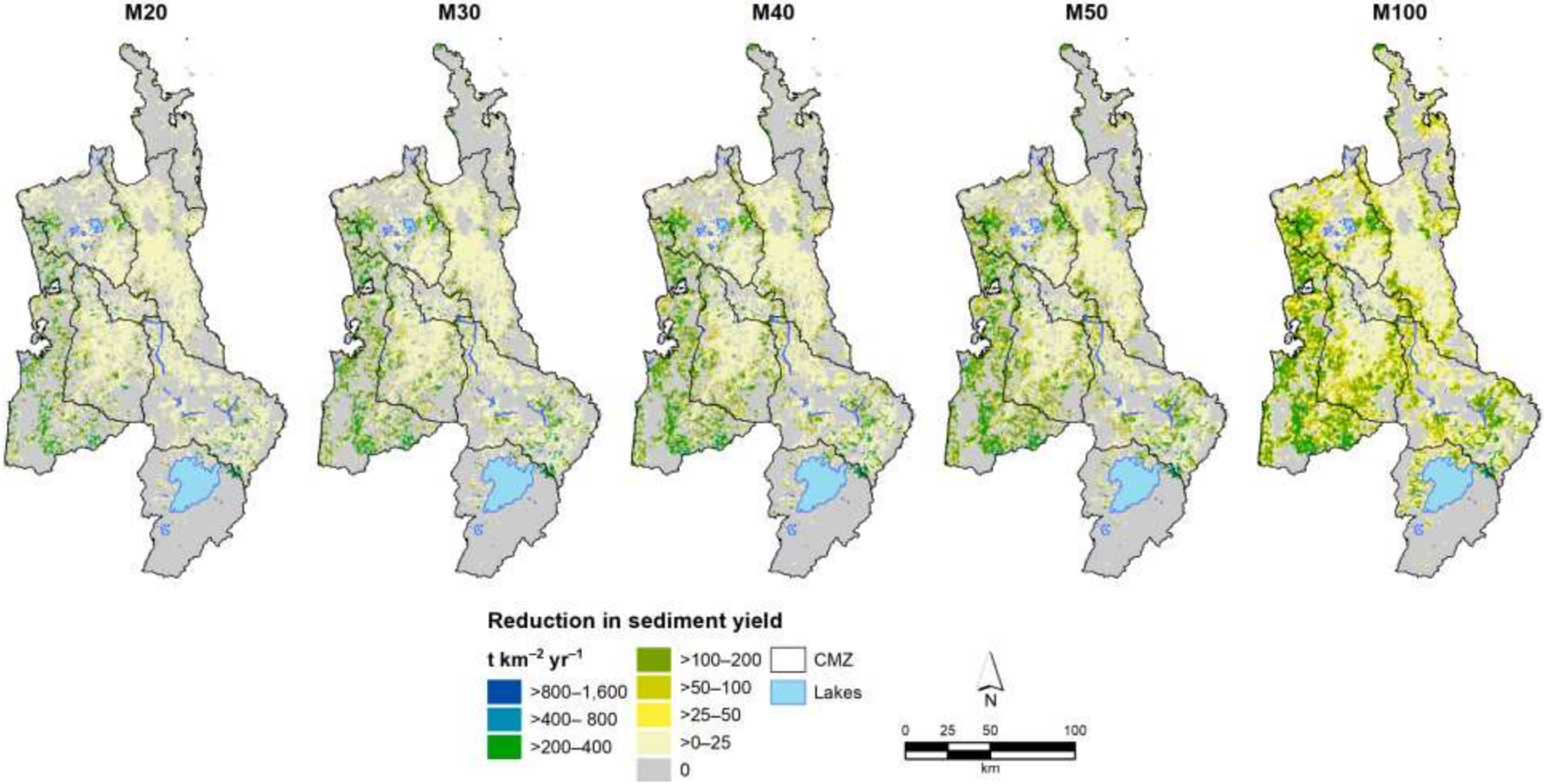

Figure 6. Reduction in mean annual suspended sediment yield (t km^{-2} yr^{-1}) relative to contemporary baseline (2022) modelled for future erosion mitigation scenarios (M20, M30, M40, M50, and M100).

5.2 Sediment load reductions required to meet NPS-FM visual clarity attribute bands under contemporary climate

Suspended sediment load reductions required to achieve the NPS-FM 2020 suspended fine sediment attribute bands were modelled to determine proportional reductions for 105 SOE sites across the Waikato Region for both the contemporary baseline (C2022) and mitigation scenarios.

Baseline attribute states for each SOE site were determined using the median measured visual clarity based on data provided by WRC (see section 4.3). A summary of sites requiring reductions to achieve the NPS-FM attribute bands and the NBL, by CMZ and the Waikato Region, is provided in Table 10. Proportional reductions in sediment load required at each SOE site are provided in Table 11.

Of the 105 sites, 59 (56%) require reductions to achieve the NBL (C band) under the contemporary baseline, 64 sites (61%) require reductions to achieve the B band, and 77 sites (73%) require reductions to achieve the A band. Across the CMZs, Coromandel (zero sites, 0%) and Lake Taupō (one site, 17%) have the lowest number of sites requiring reductions to achieve the NBL (highest compliance), while Waipā (14 sites, 82%), Lower Waikato (14 sites, 78%), and Central Waikato (7 sites, 70%) have the highest number of sites requiring reductions to achieve the NBL.

The number of SOE sites requiring further reductions to achieve the NBL decreases to 52% (55 sites) under the M20 scenario, 42% (44 sites) under the M50 scenario, and 27% (28 sites) under the M100 scenario. The Upper Waikato and Waipā CMZs have the largest decreases in the proportion of sites requiring further reductions to achieve the NBL under the M100 scenario, decreasing from 12 sites (67%) to 3 sites (17%) for Upper Waikato, and from 14 sites (82%) to 7 sites (41%) for Waipā.

The reductions required for each attribute band and the NBL are provided for individual SOE monitoring sites in Table 11, but there are too many to comment on in detail here. The increasing erosion mitigation works represented in the mitigation scenarios generally decrease the reductions required to achieve each attribute band and the NBL. The scale of the reduction varies spatially and depends on the extent of erosion mitigation works applied in the upstream areas contributing sediment load. At some SOE sites there may be no decrease in reductions required for a given scenario due to there being no erosion mitigation works in that part of the catchment.

Table 10. Summary of Waikato SOE monitoring sites (by number and % of sites) requiring reductions to achieve the NPS-FM (2020) attribute bands, summarised by CMZ and for the whole region.

CMZ (sites)	Contemporary baseline (C2022)			Mitigation scenarios M20			M30			M40			M50			M100		
	C (NBL)	B	A	C (NBL)	B	A	C (NBL)	B	A	C (NBL)	B	A	C (NBL)	B	A	C (NBL)	B	A
Central Waikato 10	7 70%	7 70%	9 90%	7 70%	7 70%	8 80%	7 70%	7 70%	8 80%	7 70%	7 70%	8 80%	7 70%	7 70%	8 80%	4 40%	5 50%	8 80%
Coromandel 4	- 0%	- 0%	- 0%	- 0%	- 0%	- 0%	- 0%	- 0%	- 0%	- 0%	- 0%	- 0%	- 0%	- 0%	- 0%	- 0%	- 0%	- 0%
Lake Taupō 6	1 17%	1 17%	1 17%	1 17%	1 17%	1 17%	1 17%	1 17%	1 17%	1 17%	1 17%	1 17%	1 17%	1 17%	1 17%	- 0%	- 0%	- 0%
Lower Waikato 18	14 78%	15 83%	16 89%	14 78%	14 78%	16 89%	13 72%	14 78%	15 83%	12 67%	14 78%	15 83%	12 67%	14 78%	15 83%	11 61%	11 61%	12 67%
Upper Waikato 18	12 67%	15 83%	17 94%	11 61%	12 67%	15 83%	11 61%	11 61%	15 83%	8 44%	11 61%	15 83%	6 33%	11 61%	13 72%	3 17%	4 22%	6 33%
Waihou–Piako 18	4 22%	5 28%	9 50%	4 22%	5 28%	8 44%	3 17%	5 28%	6 33%	3 17%	4 22%	6 33%	3 17%	4 22%	4 22%	1 6%	2 11%	4 22%
Waipā 17	14 82%	14 82%	15 88%	12 71%	14 82%	15 88%	12 71%	14 82%	15 88%	12 71%	13 76%	14 82%	12 71%	13 76%	14 82%	7 41%	10 59%	13 76%
West Coast 14	7 50%	7 50%	10 71%	6 43%	7 50%	7 50%	6 43%	7 50%	7 50%	5 36%	7 50%	7 50%	3 21%	7 50%	7 50%	2 14%	4 29%	7 50%
Waikato Region 105	**59 56%**	**64 61%**	**77 73%**	**55 52%**	**60 57%**	**70 67%**	**53 50%**	**59 56%**	**67 64%**	**48 46%**	**57 54%**	**66 63%**	**44 42%**	**57 54%**	**62 59%**	**28 27%**	**36 34%**	**50 48%**

Table 11. Proportional reductions (%) in suspended sediment load required to achieve attribute bands and the NBL at SOE monitoring sites under the contemporary baseline and future mitigation scenarios

CMZ	Site name	Site	nzsegment	Base state	Contemporary baseline (C2022)			Mitigation scenarios: M20			M30			M40			M50			M100		
					C (NBL) %	B %	A %	C (NBL) %	B %	A %	C (NBL) %	B %	A %	C (NBL) %	B %	A %	C (NBL) %	B %	A %	C (NBL) %	B %	A %
Central Waikato (10)	Karapiro Stm at Hickey Rd Bridge – Cambridge	230_5	3070130	D	46	56	63	43	53	61	38	49	57	31	43	52	21	35	45	-	-	14
	Kirikiriroa Stm at Tauhara Dr	253_4	3061405	D	44	58	68	43	57	67	43	57	67	43	57	67	43	57	67	43	57	67
	Mangakotukutuku Stm (Rukuhia) at Peacockes Rd	398_1	3064979	D	33	50	62	20	40	54	20	40	54	20	40	54	20	40	54	19	39	53
	Mangaone Stm (Waikato) at Annebrooke Rd Br	417_7	3064673	B	-	-	19	-	-	15	-	-	15	-	-	15	-	-	15	-	-	11
	Mangaonua Stm at Hoeka Rd	421_10	3063144	B	-	-	15	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Mangaonua Stm at Te Miro Rd (a.k.a Waitakaruru Stm)	421_16	3065476	A	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Mangawhero Stm (Cambridge) at Cambridge-Ohaupo Rd	488_1	3069532	D	74	80	85	65	74	80	60	70	77	47	61	70	41	56	66	18	39	53
	Waikato River at Horotiu Br	1131_69	3059280	D	45	55	62	39	50	58	34	46	55	29	42	51	23	37	47	-	13	27
	Waikato River at Narrows Boat Ramp	1131_328	3066645	D	33	45	54	26	39	49	19	33	45	13	29	40	6	22	35	-	-	10
	Waitawhiriwhiri Stm at Edgecumbe Street	1236_2	3062685	D	55	67	74	53	65	73	53	65	73	53	65	73	53	65	73	53	65	73
Coromandel (4)	Tapu River at Tapu-Coroglen Rd	954_5	3040973	A	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Waiau River at E309 Rd Ford	1105_3	3037259	A	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Waiwawa River at SH25 Coroglen	1257_3	3039645	A	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Wharekawa River at SH25	1312_3	3044647	A	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

CMZ	Site name	Site	nzsegment	Base state	Contemporary baseline (C2022)			Mitigation scenarios															
								M20			M30			M40			M50			M100			
					C (NBL) %	B %	A %	C (NBL) %	B %	A %	C (NBL) %	B %	A %	C (NBL) %	B %	A %	C (NBL) %	B %	A %	C (NBL) %	B %	A %	
Lake Taupō (6)	Hinemaiaia River at SH1	171_5	3149003	A	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
	Kuratau River at SH41 Moerangi	282_4	3150837	A	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
	Mapara Stm (Lake Taupō) at Off Mapara Rd (Whakaipo Res) T1	504_2	3136377	D	16	31	42	16	31	42	16	31	42	16	31	42	2	19	33	-	-	-	
	Tauranga-Taupo River at 20 metres U/S SH1 Bridge	971_5	3153026	A	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
	Waihaha River at SH32	1106_4	3136644	A	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
	Waitahanui River at Blake Rd	1226_1	3144485	A	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
Lower Waikato (18)	Awaroa River (Waiuku) at Otaua Rd Br opp Moseley Rd	41_9	3048412	D	76	80	84	75	79	83	75	79	83	75	79	83	75	79	83	70	75	79	
	Awaroa Stm (Rotowaro) at Sansons Br @ Rotowaro-Huntly Rd	39_11	3056003	A	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
	Komakorau Stm at Henry Rd	258_4	3056992	D	86	89	92	83	87	90	83	87	90	83	87	90	83	87	90	83	87	90	
	Mangatangi River at SH2 Maramarua	453_6	3046991	D	29	47	59	24	43	56	21	41	55	17	38	52	9	32	48	-	-	23	
	Mangatawhiri River at Lyons Rd at Buckingham Br	459_6	3045657	A	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
	Mangawara Stm at Rutherford Rd Br	481_7	3055409	D	77	83	87	74	81	85	72	79	84	69	77	82	66	74	80	50	63	72	
	Northern Outlet Canal at DownStream of Control Gates	3021_3	3051398	D	99	99	99	98	98	99	98	98	99	98	98	98	97	98	98	96	97	97	
	Ohaeroa Stm at SH22 Br	612_9	3048723	B	-	-	14	-	-	13	-	-	13	-	-	7	-	-	1	-	-	-	

CMZ	Site name	Site	nzsegment	Base state	Contemporary baseline (C2022)			Mitigation scenarios M20			M30			M40			M50			M100		
					C (NBL) %	B %	A %	C (NBL) %	B %	A %	C (NBL) %	B %	A %	C (NBL) %	B %	A %	C (NBL) %	B %	A %	C (NBL) %	B %	A %
Lower Waikato (18) (cont.)	Opuatia Stm at Ponganui Rd	665_5	3050086	D	21	41	55	2	26	44	-	20	39	-	14	34	-	1	24	-	-	-
	Waerenga Stm at Taniwha Rd	1098_1	3050816	C	-	5	27	-	-	9	-	-	-	-	-	-	-	-	-	-	-	-
	Waikato River at Huntly–Tainui Br	1131_77	3055438	D	69	75	79	65	71	76	63	69	74	60	67	72	57	65	70	43	53	61
	Waikato River at Mercer Br	1131_91	3047923	D	80	84	87	77	81	85	76	80	83	74	79	82	72	77	81	63	70	75
	Waikato River at Rangiriri Br	1131_117	3052038	D	70	75	79	66	72	76	63	70	75	61	68	73	58	65	71	45	55	62
	Waikato River at Tuakau Br	1131_133	3048245	D	79	83	86	76	80	84	74	79	82	72	77	81	70	76	80	61	68	73
	Whakapipi Stm at SH22 Br	1282_8	3047194	D	1	19	32	1	18	32	1	18	32	-	15	29	-	6	22	-	-	-
	Whangamarino River at Island Block Rd	1293_7	3048671	D	97	97	98	96	97	97	96	96	97	95	96	97	95	96	96	93	94	95
	Whangamarino River at Jefferies Rd Br	1293_9	3049660	D	66	74	80	57	68	75	49	62	71	40	55	66	31	48	60	7	30	47
	Whangape Stm at Rangiriri-Glen Murray Rd	1302_1	3052363	D	98	98	99	97	98	98	97	98	98	97	97	98	96	97	98	95	96	97
Upper Waikato (18)	Kawaunui Stm at SH5 Br	240_5	3110340	D	22	36	47	20	34	45	1	18	32	-	3	20	-	3	20	-	-	-
	Little Waipa Stm at Arapuni–Putaruru Rd	335_1	3081097	C	-	1	18	-	-	11	-	-	8	-	-	8	-	-	7	-	-	-
	Mangaharakeke Stm (Atiamuri) at SH30 (Off Jct SH1)	359_1	3106095	D	31	43	52	24	37	47	20	34	45	18	32	43	15	30	42	10	25	38
	Mangakara Stm (Reporoa) at SH5	380_2	3116290	D	56	64	70	44	54	62	37	48	57	26	39	49	16	31	42	-	-	4
	Mangakino Stm (Whakamaru) at Sandel Rd	388_1	3115030	B	-	-	7	-	-	7	-	-	2	-	-	<1	-	-	-	-	-	-

CMZ	Site name	Site	nzsegment	Base state	Contemporary baseline (C2022) C (NBL) %	Contemporary baseline (C2022) B %	Contemporary baseline (C2022) A %	M20 C (NBL) %	M20 B %	M20 A %	M30 C (NBL) %	M30 B %	M30 A %	M40 C (NBL) %	M40 B %	M40 A %	M50 C (NBL) %	M50 B %	M50 A %	M100 C (NBL) %	M100 B %	M100 A %
								Mitigation scenarios														
Upper Waikato (18) (cont.)	Mangamingi Stm (Tokoroa) at Paraonui Rd Br	407_1	3091783	D	53	62	68	50	58	65	49	58	65	44	53	61	41	51	59	20	34	45
	Otamakokore Stm at Hossack Rd	683_4	3103240	D	14	29	40	-	5	20	-	-	14	-	-	14	-	-	8	-	-	-
	Pokaiwhenua Stm at Puketurua	786_2	3081022	D	25	38	48	21	35	46	18	32	44	15	30	42	11	27	39	-	5	21
	Pueto Stm at Broadlands Rd Br	802_1	3129762	B	-	-	16	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Tahunaatara Stm at Ohakuri Rd	934_1	3105500	D	19	33	44	11	26	39	6	22	35	-	14	29	-	10	25	-	-	-
	Waikato River at Karapiro Tailrace	1131_79	3071503	D	28	41	50	22	36	47	17	32	43	13	28	40	7	23	36	-	-	9
	Waikato River at Lake Ohakuri Boat Ramp	1131_82	3111846	C	-	4	20	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Waikato River at Ohaaki Br	1131_105	3123400	A	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Waikato River at Waipapa Tailrace	1131_143	3099935	D	8	24	37	5	22	35	1	19	32	-	15	29	-	10	25	-	-	-
	Waikato River at Whakamaru Tailrace	1131_147	3112254	C	-	14	28	-	-	15	-	-	9	-	-	4	-	-	-	-	-	-
	Waiotapu Stm at Campbell Rd Br	1186_2	3109925	D	26	39	49	13	28	40	11	26	38	3	20	33	-	9	24	-	-	-
	Waipapa Stm (Mokai) at Tirohanga Rd Br	1202_7	3112958	D	19	33	44	9	25	37	2	19	32	<1	18	31	-	9	24	-	-	-
	Whakauru Stm at U/S SH1 Br	1287_7	3093674	D	79	83	86	78	82	85	78	82	85	76	80	83	75	79	83	66	72	76
Waihou–Piako (18)	Hikutaia River at Old Maratoto Rd	169_2	3048567	A	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Kauaeranga River at Smiths Cableway Recorder	234_11	3044978	A	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Mangawhero Stm (Kaihere) at Mangawara Rd	489_2	3051409	B	-	-	8	-	-	8	-	-	8	-	-	8	-	-	-	-	-	-

CMZ	Site name	Site	nzsegment	Base state	Contemporary baseline (C2022)			Mitigation scenarios														
								M20			M30			M40			M50			M100		
					C (NBL) %	B %	A %	C (NBL) %	B %	A %	C (NBL) %	B %	A %	C (NBL) %	B %	A %	C (NBL) %	B %	A %	C (NBL) %	B %	A %
Waihou–Piako (18) (cont.)	Ohinemuri River at Karangahake	619_16	3051925	A	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Ohinemuri River at Queens Head	619_19	3051991	A	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Ohinemuri River at SH25 Br	619_20	3050858	A	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Oraka Stm at Lake Rd	669_6	3071941	D	40	51	59	38	49	57	35	46	55	32	44	53	29	41	51	10	26	38
	Piako River at Kiwitahi	749_10	3059826	B	-	-	3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Piako River at Paeroa-Tahuna Rd Br	749_15	3054261	B	-	-	20	-	-	5	-	-	-	-	-	-	-	-	-	-	-	-
	Piakonui Stm at Piakonui Rd	753_4	3066020	D	20	34	45	20	34	45	20	34	45	12	27	39	5	22	35	-	-	5
	Waihou River at Okauia	1122_18	3064061	D	27	39	49	22	36	47	19	33	44	15	30	42	12	27	39	-	8	23
	Waihou River at Te Aroha	1122_34	3055227	A	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Waihou River at Whites Rd	1122_41	3078605	A	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Waiomou Stm at Matamata-Tauranga Rd	1174_4	3067934	D	9	25	38	3	20	33	-	16	30	-	11	26	-	8	23	-	-	4
	Waitakaruru River (Hauraki Plains) at Coxhead Rd Br	1230_1	3047683	A	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Waitekauri River at U/S Ohinemuri conflu	1239_32	3051680	A	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Waitoa River at Landsdowne Rd Br	1249_15	3062720	C	-	13	27	-	7	23	-	3	19	-	-	10	-	-	-	-	-	-
	Waitoa River at Mellon Rd Recorder	1249_18	3054693	B	-	-	7	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-

CMZ	Site name	Site	nzsegment	Base state	Contemporary baseline (C2022)			Mitigation scenarios: M20			M30			M40			M50			M100		
					C (NBL) %	B %	A %	C (NBL) %	B %	A %	C (NBL) %	B %	A %	C (NBL) %	B %	A %	C (NBL) %	B %	A %	C (NBL) %	B %	A %
Waipā (17)	Firewood Creek at Waingaro Road Bridge	124_8	3058597	B	-	-	10	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Kaniwhaniwha Stm at Wright Rd	222_16	3068190	D	55	63	69	43	53	61	41	51	59	38	48	57	29	42	51	6	22	35
	Mangaohoi Stm at South Branch Maru Rd	411_9	3079677	D	2	19	33	2	19	33	2	19	33	2	19	33	2	19	33	-	-	17
	Mangaokewa Stm at Lawrence Street Br	414_6	3103339	D	42	52	60	35	46	55	30	42	52	22	36	47	17	31	43	-	9	24
	Mangapiko Stm (Pirongia/Te Awamutu) at Bowman Rd	438_3	3074894	D	67	73	77	60	67	73	56	64	70	52	60	67	46	55	63	28	40	50
	Mangapu River at Otorohanga	443_3	3091562	D	67	73	77	63	70	75	61	68	73	58	66	71	56	63	70	39	50	58
	Mangatutu Stm (Waikeria) at Walker Rd Br	476_7	3083539	D	8	24	37	-	17	31	-	13	28	-	11	26	-	7	23	-	-	5
	Mangauika Stm at Te Awamutu Borough W/S Intake	477_10	3077698	A	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Ohote Stm at Whatawhata/Horotiu Rd	624_5	3062320	D	33	50	62	28	46	58	28	46	58	28	46	58	28	46	58	28	46	58
	Puniu River at Bartons Corner Rd Br	818_2	3078623	D	41	51	59	35	46	55	30	42	52	24	37	48	18	32	44	-	-	15
	Puniu River at Wharepapa Rd Bridge	818_40	3087956	D	6	22	35	-	15	29	-	5	21	-	-	9	-	-	1	-	-	-
	Waipā River at Mangaokewa Rd	1191_5	3114412	A	-	-	-	-	-	1	-	-	1	-	-	-	-	-	-	-	-	-
	Waipa River at Ngaruawahia Br	1191_6	3057910	D	65	71	76	60	67	73	58	65	71	55	63	69	51	60	67	37	48	56

CMZ	Site name	Site	nzsegment	Base state	Contemporary baseline (C2022)			Mitigation scenarios M20			M30			M40			M50			M100		
					C (NBL) %	B %	A %	C (NBL) %	B %	A %	C (NBL) %	B %	A %	C (NBL) %	B %	A %	C (NBL) %	B %	A %	C (NBL) %	B %	A %
Waipā (17) (cont.)	Waipa River at Pukehoua Bridge on Baffin Road	1191_2	3075687	D	62	69	74	57	65	71	54	62	69	51	60	66	48	57	64	31	43	52
	Waipa River at SH3 Otorohanga	1191_12	3091406	D	32	44	53	24	37	47	17	32	43	12	27	39	5	22	35	-	2	19
	Waitomo Stm at SH31 Otorohanga	1253_5	3090304	D	73	77	81	71	76	80	70	75	79	68	74	78	65	71	76	55	63	69
	Waitomo Stm at Tumutumu Rd	1253_7	3096865	D	32	44	53	24	38	48	24	37	47	21	35	46	17	31	43	-	11	26
West Coast (14)	Awakino River at Gribbon Rd	33_6	3123054	D	15	30	41	10	26	38	9	25	37	8	24	37	7	23	36	3	20	33
	Awakino River at SH3 Awakau Rd Junction	33_9	3131731	A	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Manganui River at off Manganui Rd	410_4	3130367	A	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Mangaotaki River at SH3 Br	428_3	3119483	D	34	45	54	15	30	42	8	24	37	-	17	31	-	9	24	-	-	8
	Marokopa River at Speedies Rd (off Te Anga Rd)	513_3	3095966	D	33	45	54	21	35	46	19	33	44	15	30	42	11	27	39	<1	18	31
	Mokau River at Awakau Rd	556_2	3133651	D	17	38	52	-	23	41	-	17	36	-	11	31	-	4	26	-	-	11
	Mokau River at Mangaokewa Rd (off SH30)	556_5	3115276	D	23	37	47	17	31	43	17	31	43	14	29	41	4	21	34	-	11	26
	Mokau River at Totoro Rd Recorder	556_9	3123396	D	32	44	53	15	30	42	8	24	37	<1	18	31	-	10	25	-	-	5
	Mokauiti Stm at Three Way Point – Aria	557_5	3122377	B	-	-	23	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Ohautira Stm at Waingaro Te Uku Rd	616_1	3061831	A	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

CMZ	Site name	Site	nzsegment	Base state	Contemporary baseline (C2022)			Mitigation scenarios														
								M20			M30			M40			M50			M100		
					C (NBL) %	B %	A %	C (NBL) %	B %	A %	C (NBL) %	B %	A %	C (NBL) %	B %	A %	C (NBL) %	B %	A %	C (NBL) %	B %	A %
West Coast (14) (cont.)	Oparau River at Langdon Rd (off Okupata Rd)	658_1	3078902	A	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Tawarau River at off Speedies Rd	976_1	3096753	D	26	39	49	11	27	39	8	24	37	3	20	33	-	15	29	-	6	22
	Waingaro River (Pukemiro) at Ruakiwi Rd off SH22	1167_4	3060386	B	-	-	6	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Waitetuna River at Te Uku-Waingaro Rd	1247_2	3064930	B	-	-	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

"-" indicates no further load reduction required to achieve NBL; NBL refers to 'national bottom line' for suspended fine sediment in the NPS-FM 2020 (Ministry for the Environment 2020).

5.3 Impact of climate change

5.3.1 Suspended sediment loads

Suspended sediment loads under projected climate change were modelled for land cover and erosion mitigations corresponding to the contemporary baseline (C2022). The results are reported as the minimum, median, and maximum based on the six RCMs for each RCP at mid- (2040) and late (2090) century.

The modelled climate change projections resulted in a wide range of predicted changes to sediment loads. This reflects the variability between each of the climate models and the diverging climate trajectories represented by each RCP. RCP2.6 represents a greenhouse gas mitigation pathway resulting in the lowest sediment load increases, with late century being lower than mid-century. RCP4.5 and RCP6.0 are stabilisation pathways, and RCP8.5 represents a worst-case scenario with very high greenhouse gas concentrations that result in large predicted increases in sediment load. Therefore, total erosion is expected to increase between RCP2.6 to RCP8.5 at mid- and late century, with more pronounced differences between each RCP observed at late century due to the range in greenhouse gas trajectories represented across the RCPs.

Region-wide total erosion loads under climate change are summarised in Table 12 and shown in Figure 7 and Figure 8. Total erosion loads for each climate change scenario, summarised by CMZ and region-wide, are provided in Appendix A2, Tables A2.1 and A2.2. Projected mean annual suspended sediment yields are shown for the minimum RCP2.6 and maximum RCP8.5 at mid- and late century in Figure 9.

Under the contemporary baseline (C2022) land cover and mitigations, total erosion across all RCPs amounts to 2.6–3.6 Mt yr^{-1} and 2.5–4.9 Mt yr^{-1} for mid- and late century, respectively. This represents an increase of 14–57% and 7–110% for mid- and late century, compared to loads modelled without the impacts of climate change.

The projected impact of climate change on total erosion varies between CMZs. Coromandel and Lake Taupō show the smallest change (increase or reduction) in erosion at both mid- and late century. In contrast, Upper Waikato and West Coast show the largest increase in erosion (Table 12). These patterns reflect areas with already higher sediment yields and the impact of climate change on mass-movement erosion processes compared to low sediment yielding areas, where minor changes are observed. For example, significant increases in sediment loads are observed in the West Coast and Waipā hill country, compared to lowland areas in the Waihou–Piako and Central Waikato CMZs (Figure 9).

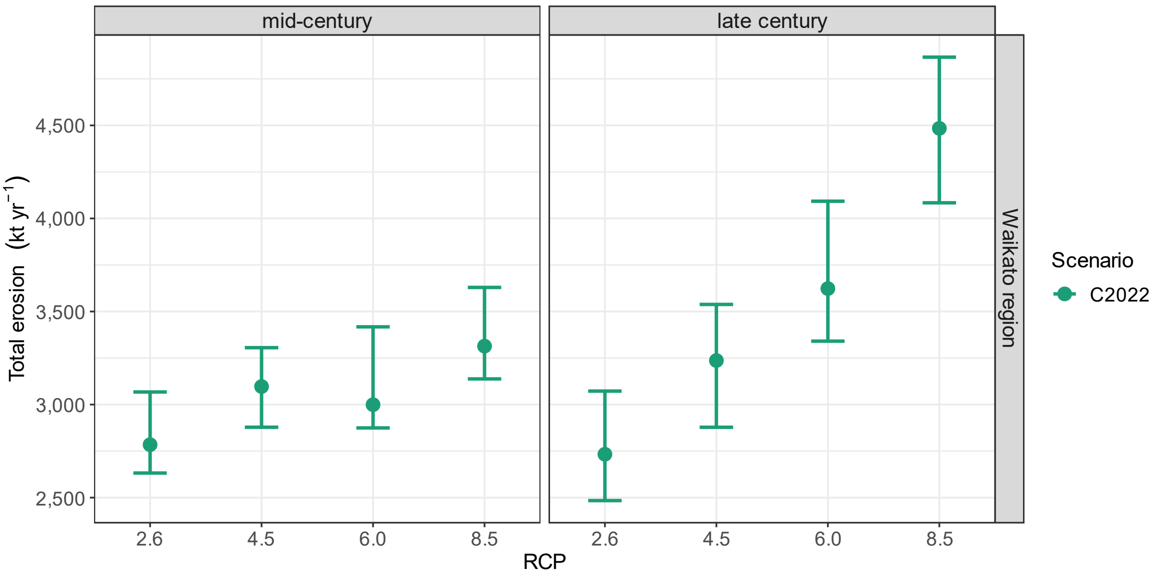

Figure 7. Range of total erosion loads modelled for the contemporary baseline (C2022) under projected climate change, summarised at mid- and late century, represented by minimum, median, and maximum results for each RCP scenario.

Table 12. Summary of the range of total erosion loads modelled for the contemporary baseline under projected climate change for the Waikato Region at mid- and late century, summarised across the selected RCMs and all four RCPs.

CMZ (C2022: kt yr^{-1})	Total erosion (kt yr^{-1})		Difference from baseline load without climate change (kt yr^{-1}, %)	
	Mid-century	Late century	Mid-century	Late century
Central Waikato 24.8	26.1–38.6	24.7–52.5	1.3–13.8 5–56%	−0.1–27.7 0–112%
Coromandel 182	208–242	197–303	25.8–60.1 14–33%	15–121 8–67%
Lake Taupō 219	221–292	214–377	2.2–73.1 1–33%	−5.1–158 −2–72%
Lower Waikato 221	240–334	225–443	19.1–113 9–51%	4.1–222 2–100%
Upper Waikato 304	353–525	334–728	48.7–221 16–73%	30.4–424 10–140%
Waihou–Piako 239	264–350	253–463	25.2–111 11–47%	14.3–224 6–94%
Waipā 322	363–512	342–687	41.5–190 13–59%	20.4–365 6–113%
West Coast 808	957–1339	894–1813	149–532 18–66%	86.3–1,006 11–124%
Waikato region 2,318	**2,632–3,629**	**2,484–4,867**	**314–1,311 14–57%**	**165–2,548 7–110%**

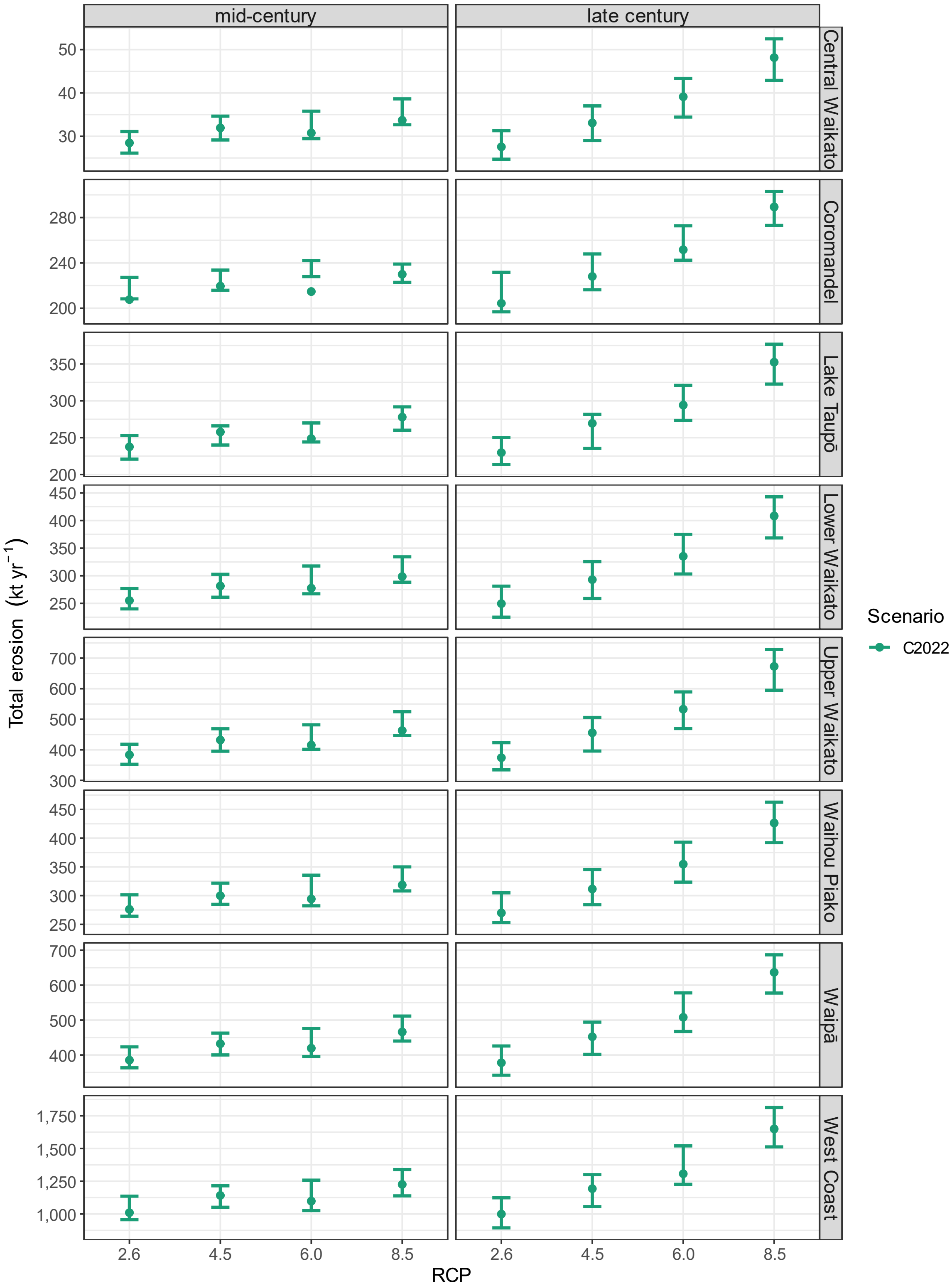

Figure 8. Range of total erosion loads modelled for the contemporary baseline (C2022) under projected climate change, summarised by CMZ at mid- and late century, and represented by minimum, median, and maximum results for each RCP scenario. Note the difference in y-axis scales.

Note: The selected RCMs do not consistently equate to the equivalent min/med/max values for Coromandel due to relative differences in total erosion between RCMs at catchment/CMZ versus regional scales. For consistency, we present sediment load results for the selected RCMs across all CMZs, which allows comparison between catchments for the same RCM.

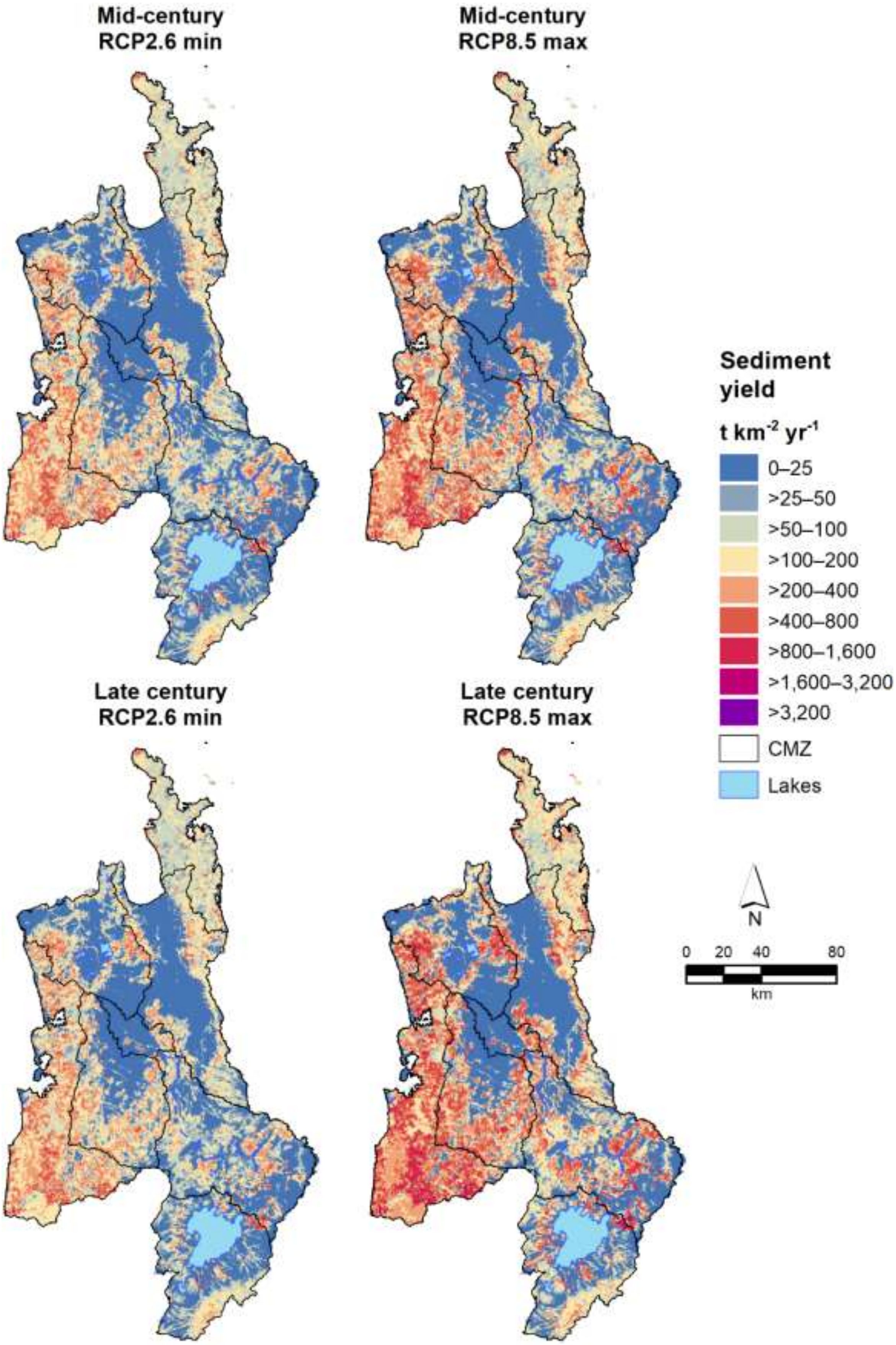

Figure 9. Mean annual suspended sediment yield under projected climate change at mid- and late century, represented by RCP2.6 minimum and RCP8.5 maximum, for land cover and erosion mitigations under the contemporary baseline (C2022).

5.3.2 Future erosion mitigation

Suspended sediment loads under projected climate change were modelled for the future mitigation scenarios. The results are reported as the minimum, median and maximum based on the six regional climate models (RCMs) for each RCP at mid- (2040) and late (2090) century.

Region-wide total erosion loads under climate change are summarised in Table 13 and Table 14 and shown in Figure 10 and Figure 11. Total erosion loads for each climate change scenario summarised by CMZ and region-wide are provided in Appendix A2, Tables A2.1 and A2.2. Projected mean annual suspended sediment yields are shown for the minimum RCP2.6 and maximum RCP8.5 at mid- and late century in Figure 12 and Figure 13.

Total erosion across all RCPs is estimated as 2.3–3.1 Mt yr^{-1} and 2.2–4.1 Mt yr^{-1} for mid- and late century under the M20 scenario. This represents between −7% to +26% and −12% to +68% for mid- and late century, compared to contemporary baseline loads modelled without the impacts of climate change. Total erosion under the M50 scenario is estimated as between 1.9–2.5 Mt yr^{-1} and 1.8–3.3 Mt yr^{-1} for mid- and late century, respectively. This represents a change in total erosion between −23% to +1% and −27% to +33% for mid- and late century under the M50 scenario.

Total erosion decreases further under the M100 scenario to 1.4–2.4 Mt yr^{-1} for late century. This represents a change in total erosion between −41% and −1% for late century under the M100 scenario compared to contemporary baseline loads modelled without the impacts of climate change. The extent of erosion mitigation required under M100 did not seem plausible by mid-century, so only results for late century are presented here.

Across the CMZs, changes to sediment loads range from −10% to +40% and −17 to +94% at mid- and late century under the M20 scenario. The small decreases are associated with the RCP2.6 minimums in Central Waikato and Lake Taupō. The larger increases are associated with RCP8.5 maximums in Upper Waikato.

Under the M50 scenario larger decreases are observed in the RCP2.6 minimum and smaller increases in the RCP8.5 maximum, with changes to sediment loads ranging from −36% to +15% and −39% to +46% at mid- and late century. These further decrease to −59% to +17% by late century under the M100 scenario. The larger decreases occur in Central Waikato, Lower Waikato, and Upper Waikato, while the smaller decrease or larger increase occurs in Coromandel and Lake Taupō.

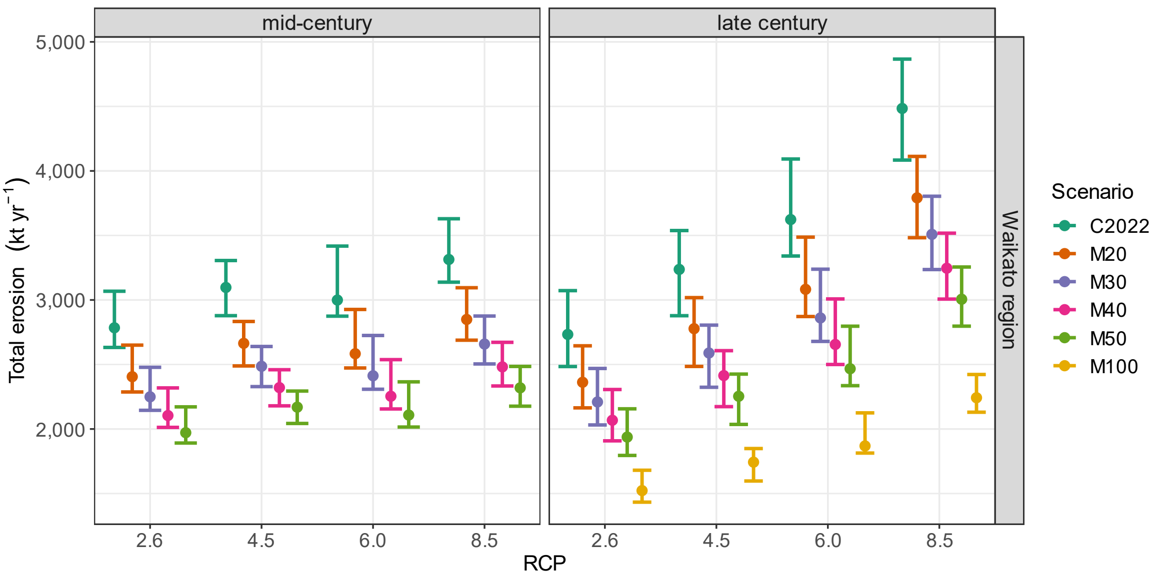

Figure 10. Range of total erosion loads modelled for future mitigation scenarios under projected climate change, summarised at mid- and late century, and represented by minimum, median, and maximum results for each RCP scenario.

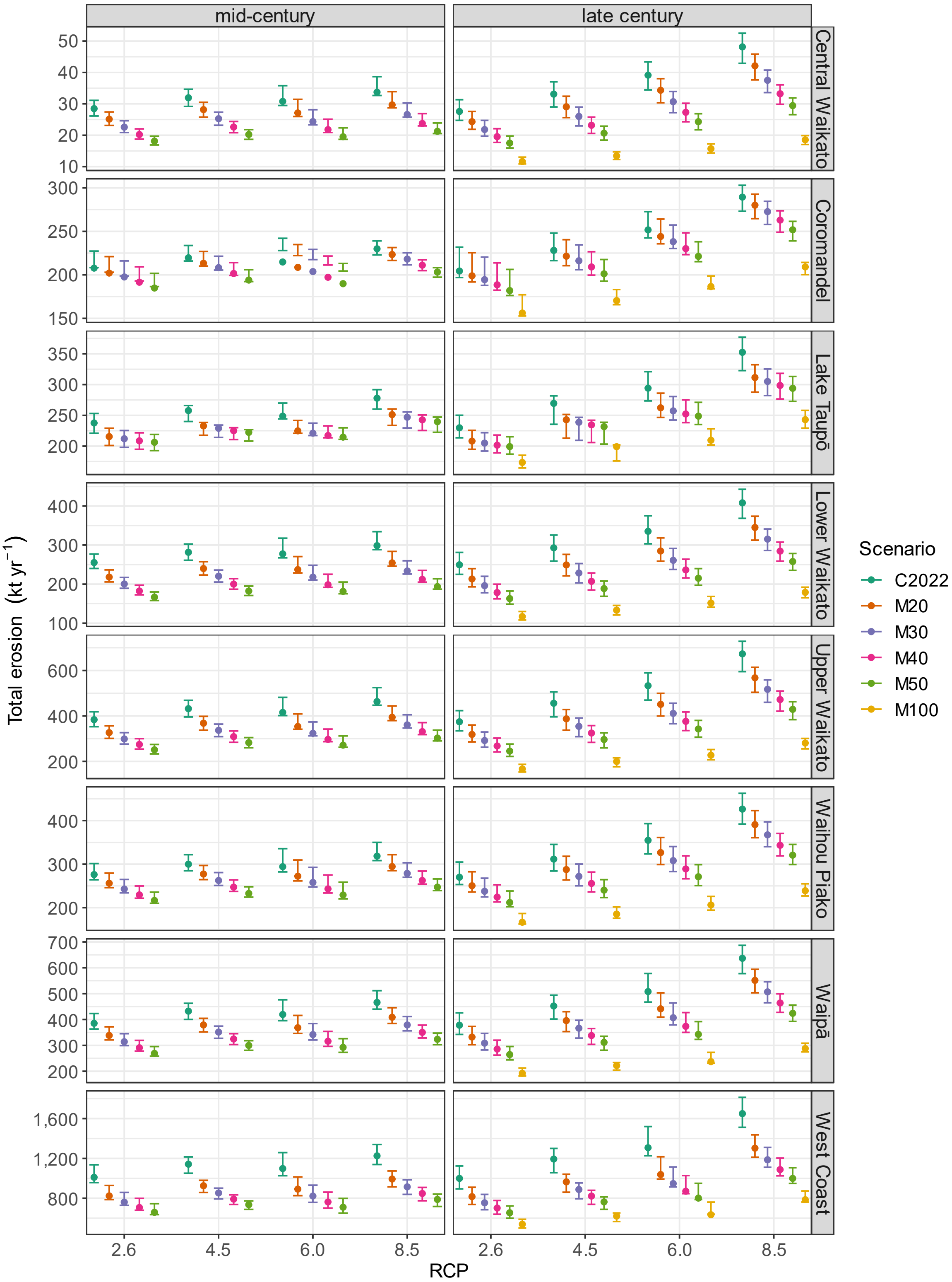

Figure 11. Range of total erosion loads modelled for future mitigation scenarios under projected climate change, summarised by CMZ at mid- and late century, and represented by minimum, median, and maximum results for each RCP scenario.

Note: The selected RCMs do not consistently equate to the equivalent min/med/max values for Coromandel due to relative differences in total erosion between RCMs at catchment/CMZ versus regional scales. For consistency, we present sediment load results for the selected RCMs across CMZs, which allows comparison between catchments for the same RCM.

Table 13. Summary of the range of total erosion by CMZ and whole region at mid-century for each erosion mitigation scenario with the future effects of climate change summarised across the selected RCMs and all four RCPs

	CMZ (C2022: kt yr^{-1})	Mitigation scenarios (kt yr^{-1})				Difference from contemporary baseline (kt yr^{-1}, %)			
		M20	M30	M40	M50	M20	M30	M40	M50
Mid-century	**Central Waikato 24.8**	23.1–33.9	20.9–30.2	18.8–26.9	16.9–23.9	−3.3–7.5 −13–28%	−5.5–3.8 −21–14%	−7.6–<1 −29–2%	−9.5–−2.5 −36–−9%
	Coromandel 182	202–235	198–229	192–222	185–213	16.3–49.1 9–26%	11.9–43.5 6–23%	5.8–35.9 3–19%	−0.9–27.4 <1–15%
	Lake Taupō 219	201–260	198–256	195–251	193–247	−19.4–39.9 −9–18%	−22.5–35 −10–16%	−25.6–30.1 −12–14%	−27.8–26.6 −13–12%
	Lower Waikato 221	206–284	189–260	173–235	158–214	−22.5–55.7 −10–24%	−38.8–31.7 −17–14%	−55.5–7 −24–3%	−70.1–−14.4 −31–−6%
	Upper Waikato 304	301–444	276–405	254–371	233–338	−15.2–128 −5–40%	−40.1–88.7 −13–28%	−62.2–54.2 −20–17%	−83.3–21 −26–7%
	Waihou–Piako 239	246–322	234–303	222–284	210–266	−8.4–67.3 −3–26%	−20.4–48.7 −8–19%	−32.6–29.6 −13–12%	−44.3–11.6 −17–5%
	Waipā 322	321–446	299–411	278–378	258–348	−32–92.6 −9–26%	−53.9–58.4 −15–17%	−75–25.3 −21–7%	−94.7–−5.5 −27–−2%
	West Coast 808	786–1074	729–985	679–909	636–841	−78.3–210 −9–24%	−136–121 −16–14%	−185–44.6 −21–5%	−229–−23.3 −26–−3%
	Waikato Region 2,318	**2,287–3,095**	**2,145–2,875**	**2,013–2,672**	**1,891–2,485**	**−162–646 −7–26%**	**−304–427 −12–17%**	**−436–223 −18–9%**	**−558–36.2 −23–1%**

Table 14. Summary of the range of total erosion by CMZ and whole region at late century for each erosion mitigation scenario, with the future effects of climate change summarised across the selected RCMs and all four RCPs

	CMZ (C2022: kt yr^{-1})	Mitigation scenarios (kt yr^{-1})					Difference from contemporary baseline (kt yr^{-1}, %)				
		M20	M30	M40	M50	M100	M20	M30	M40	M50	M100
Late century	**Central Waikato** **24.8**	21.9–45.8	19.7–40.8	17.7–36.1	16–31.9	10.8–19.9	−4.5–19.4 −17–73%	−6.7–14.4 −25–55%	−8.7–9.7 −33–37%	−10.4–5.5 −39–21%	−15.6–−6.5 −59–−25%
	Coromandel **182**	192–293	188–285	182–274	176–262	153–214	6.1–107 3–58%	2.1–98.8 1–53%	−3.4–88 −2–47%	−9.4–75.8 −5–41%	−33–28.6 −18–15%
	Lake Taupō **219**	195–332	192–325	189–318	187–313	165–258	−25.6–112 −12–51%	−28.5–105 −13–48%	−31.5–97.7 −14–44%	−33.5–92.7 −15–42%	−56–37.6 −25–17%
	Lower Waikato **221**	193–374	178–341	162–308	149–278	108–192	−35–146 −15–64%	−50.2–113 −22–50%	−65.7–79.5 −29–35%	−79.4–50.3 −35–22%	−120–−35.9 −53–−16%
	Upper Waikato **304**	286–614	262–559	242–510	222–463	153–301	−30.6–297 −10–94%	−54.1–242 −17–76%	−74.9–193 −24–61%	−94.8–146 −30–46%	−163–−15.4 −52–−5%
	Waihou–Piako **239**	236–423	225–397	213–371	202–345	162–255	−18.3–169 −7–66%	−29.6–143 −12–56%	−41.2–116 −16–46%	−52.2–90.9 −21–36%	−92–<1 −36–<1%
	Waipā **322**	303–594	282–546	262–499	244–456	181–308	−50.4–241 −14–68%	−70.9–193 −20–55%	−90.6–146 −26–41%	−109–103 −31–29%	−172–−44.6 −49–−13%
	West Coast **808**	738–1,437	685–1,310	640–1,203	599–1,107	500–874	−127–572 −15–66%	−179.5–446 −21–52%	−225–338 −26–39%	−265–242 −31–28%	−364–9.3 −42–1%
	Waikato Region 2,318	**2,164–4,112**	**2,032–3,804**	**1,908–3,518**	**1,795–3,256**	**1,433–2,422**	**−285–1,664** **−12–68%**	**−417–1,355** **−17–55%**	**−541–1,069** **−22–44%**	**−654–807** **−27–33%**	**−1,016–−26.4** **−41–−1%**

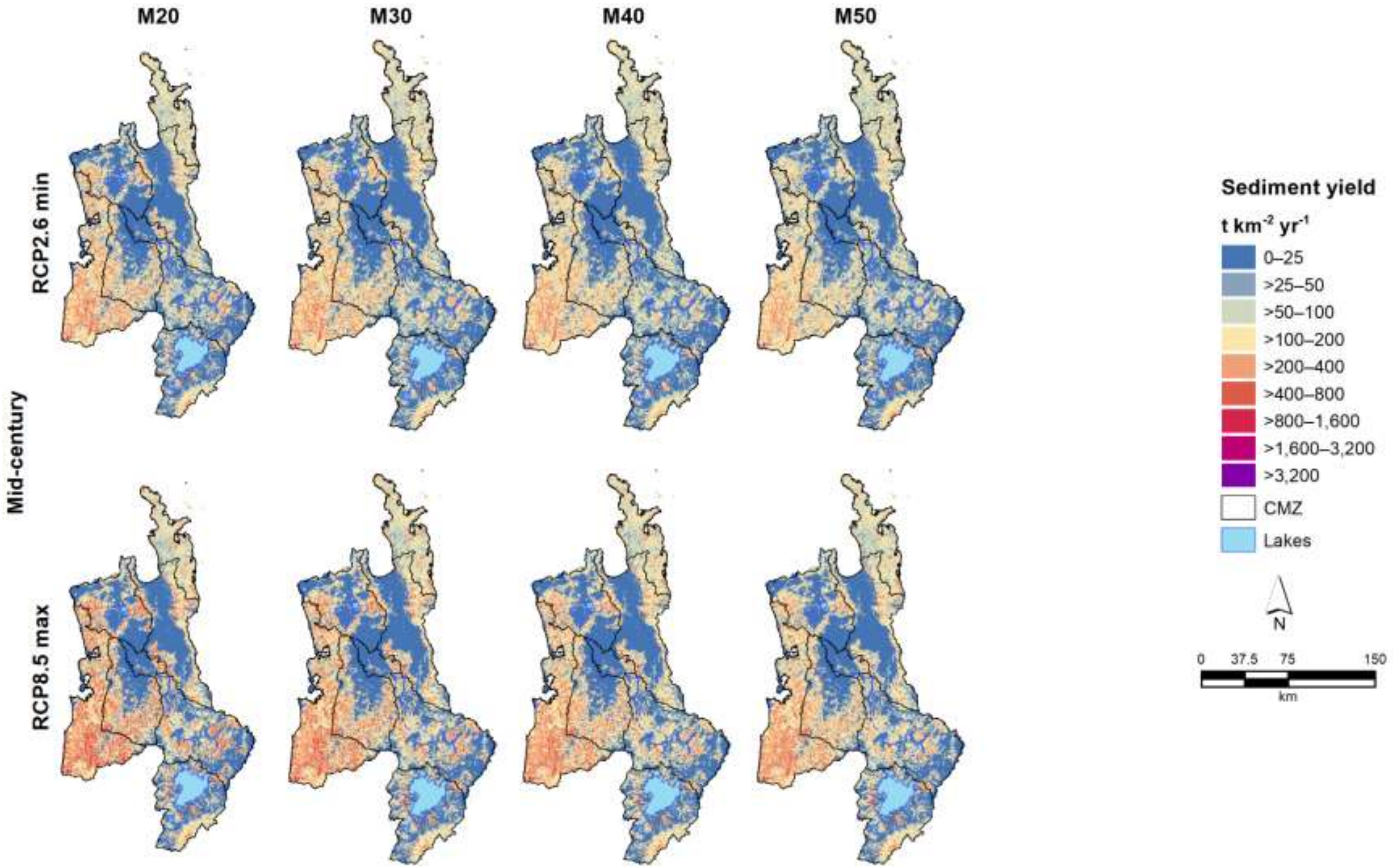

Figure 12. Mean annual suspended sediment yield under projected climate change at mid-century, represented by RCP2.6 minimum and RCP8.5 maximum, for future erosion mitigation scenarios.

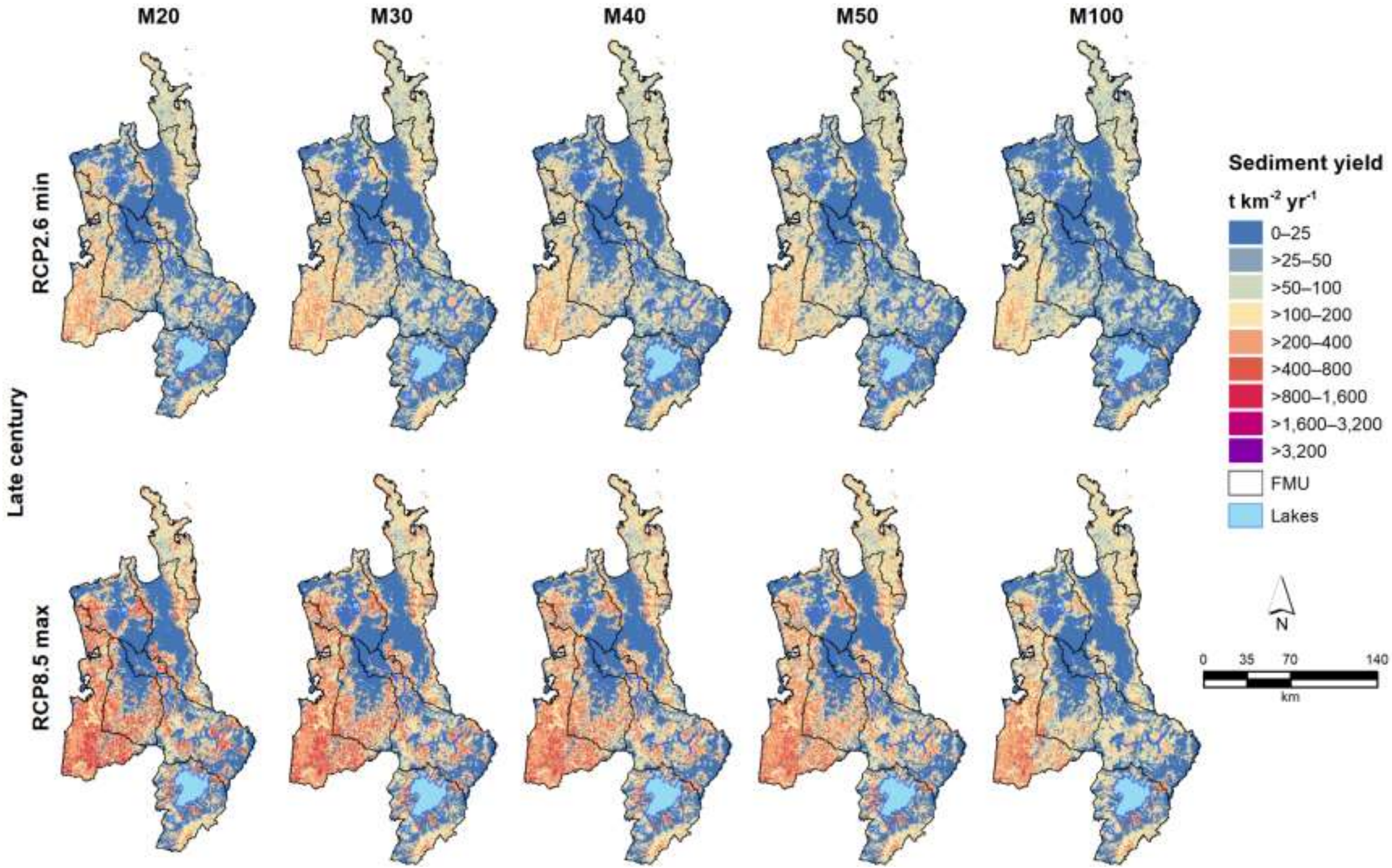

Figure 13. Mean annual suspended sediment yield under projected climate change at late century, represented by RCP2.6 minimum and RCP8.5 maximum, for future erosion mitigation scenarios.

5.3.3 Reductions in suspended sediment load required to meet NPS-FM visual clarity attribute bands under climate change

Suspended sediment load reductions required to achieve NPS-FM 2020 suspended fine sediment attribute bands were modelled as proportional reductions for 105 SOE sites across the Waikato region for both the contemporary baseline (C2022) and future mitigation under the future effects of climate change. These are summarised in Table 15 and Table 16, and a comprehensive table of reductions required for individual SOE sites is provided in Appendix A3, Tables A3.1 and A3.2.

The NPS-FM 2020 requires target attribute states to be set at or above the baseline state, so it does not allow for deterioration below baseline visual clarity (Ministry for the Environment 2022a). We also summarise the SOE sites requiring further reductions at mid- and late century to return the site to the visual clarity under contemporary baseline state (Table 15Table 15 and Table 16), which represents baseline visual clarity, along with the reductions required to achieve NPS-FM 2020 attribute bands and the NBL.

Most sites require reductions to maintain baseline visual clarity due to a widespread increase in sediment loads under future climate change. Under the contemporary baseline scenario with the effects of future climate change, 88–94% and 86–95% of the SOE sites at mid- and late-century require reductions to maintain baseline visual clarity. This decreases to 13–79% and 10–95% of sites at mid- and late century under M50, and 7–50% at late century under the M100 scenario.

The number of SOE sites requiring reductions to achieve the NBL range from 59 to 70% and 58 to 77% at mid- and late century under the contemporary baseline scenario with the effects of future climate change. With increasing erosion mitigations under M50, the number of sites requiring further reduction decreases to 48–60% and 49–69% at mid- and late century, and to 27–54% at late century under M100.

Across the CMZs, the highest proportion of SOE sites requiring further reductions to achieve the NBL thresholds under the contemporary baseline scenario with future effects of climate change occur in Waipā, Upper Waikato, and Lower Waikato, ranging from 78 to 94% and 72 to 94% at mid- and late century. Under M50 the number of SOE sites decreases to 56–83% and 56–89% at mid- and late century, and to 11–76% at late century under the M100 scenario.

The proportion of SOE sites requiring further reductions to achieve the NBL under the future effects of climate change for the contemporary baseline is relatively low in Coromandel, Lake Taupō, and Waihou–Piako, and ranges from 0 to 50% and 0 to 61% at mid- and late century. Under the M50 scenario this decreases to 0–28% and 0–50% at mid- and late century for these CMZs, and to 0–22% at late century under the M100 scenario.

The spatial variation across the CMZs reflects variations in the dominant erosion processes and the projected direction of change in their hydro-climatic drivers. For example, catchments with extensive hill country are dominated by shallow landslide erosion, which is projected to increase in the future due to more frequent and higher-magnitude storm rainfall under projected climate change, particularly for higher greenhouse gas concentration scenarios (RCPs). Changes in rainfall and evapotranspiration will drive changes in surficial erosion as well as streamflow, which affects bank erosion. Their hydro-climatic drivers are projected to have opposing trajectories across catchments and climate projections, leading to diverse responses in sediment loads. In some cases, this will lead to decreases in loads.

Table 15. Summary of Waikato SOE monitoring sites under projected climate change at mid-century requiring reductions to achieve NPS-FM 2020 attribute bands and the NBL, and to maintain baseline visually clarity, summarised across the selected RCMs and all four RCPs (Continues horizontally over next page)

	CMZ (sites)	Contemporary baseline				Mitigation scenarios							
		C2022				M20				M30			
		Base	C (NBL)	B	A	Base	C (NBL)	B	A	Base	C (NBL)	B	A
Mid-century	**Central Waikato (10)**	6–6 60–60%	7–8 70–80%	8–9 80–90%	8–9 80–90%	2–6 20–60%	7–8 70–80%	7–8 70–80%	8–9 80–90%	1–6 10–60%	7–7 70–70%	7–8 70–80%	8–9 80–90%
	Coromandel (4)	4–4 100–100%	0–0 0–0%	0–0 0–0%	0–1 0–25%	4–4 100–100%	0–0 0–0%	0–0 0–0%	0–1 0–25%	4–4 100–100%	0–0 0–0%	0–0 0–0%	0–1 0–25%
	Lake Taupō (6)	5–6 83–100%	1–1 17–17%	1–1 17–17%	1–4 17–67%	5–6 83–100%	1–1 17–17%	1–1 17–17%	1–4 17–67%	5–6 83–100%	1–1 17–17%	1–1 17–17%	1–4 17–67%
	Lower Waikato (18)	16–17 89–94%	14–15 78–83%	15–16 83–89%	16–17 89–94%	6–17 33–94%	14–15 78–83%	15–16 83–89%	16–16 89–89%	5–17 28–94%	14–14 78–78%	14–16 78–89%	16–16 89–89%
	Upper Waikato (18)	15–18 83–100%	14–17 78–94%	16–17 89–94%	17–17 94–94%	9–18 50–100%	12–16 67–89%	14–17 78–94%	16–17 89–94%	6–16 33–89%	11–15 61–83%	14–16 78–89%	15–17 83–94%
	Waihou–Piako (18)	18–18 100–100%	5–9 28–50%	7–11 39–61%	11–11 61–61%	18–18 100–100%	5–8 28–44%	5–10 28–56%	9–11 50–61%	13–18 72–100%	4–7 22–39%	5–9 28–50%	9–11 50–61%
	Waipā (17)	15–16 88–94%	14–16 82–94%	15–16 88–94%	16–16 94–94%	12–16 71–94%	14–15 82–88%	14–16 82–94%	16–16 94–94%	5–16 29–94%	14–15 82–88%	14–16 82–94%	16–16 94–94%
	West Coast (14)	13–14 93–100%	7–8 50–57%	8–10 57–71%	10–13 71–93%	4–14 29–100%	6–8 43–57%	7–10 50–71%	10–10 71–71%	1–14 7–100%	6–7 43–50%	7–10 50–71%	8–10 57–71%
	Waikato Region (105)	**92–99 88–94%**	**62–74 59–70%**	**70–80 67–76%**	**79–88 75–84%**	**60–99 57–94%**	**59–71 56–68%**	**63–78 60–74%**	**76–84 72–80%**	**40–97 38–92%**	**57–66 54–63%**	**62–76 59–72%**	**73–84 70–80%**

Table 15. Continued horizontally from previous page

	CMZ (sites)	M40 Base	M40 C (NBL)	M40 B	M40 A	M50 Base	M50 C (NBL)	M50 B	M50 A
		Mitigation scenarios							
		M40				**M50**			
		Base	**C (NBL)**	**B**	**A**	**Base**	**C (NBL)**	**B**	**A**
Mid-century	**Central Waikato (10)**	0–5 0–50%	7–7 70–70%	7–8 70–80%	7–9 70–90%	0–5 0–50%	7–7 70–70%	7–8 70–80%	7–8 70–80%
	Coromandel (4)	4–4 100–100%	0–0 0–0%	0–0 0–0%	0–1 0–25%	4–4 100–100%	0–0 0–0%	0–0 0–0%	0–0 0–0%
	Lake Taupō (6)	5–6 83–100%	1–1 17–17%	1–1 17–17%	1–4 17–67%	4–6 67–100%	1–1 17–17%	1–1 17–17%	1–4 17–67%
	Lower Waikato (18)	3–16 17–89%	14–14 78–78%	14–15 78–83%	15–16 83–89%	1–11 6–61%	12–14 67–78%	14–15 78–83%	15–16 83–89%
	Upper Waikato (18)	3–16 17–89%	10–15 56–83%	12–16 67–89%	15–16 83–89%	1–14 6–78%	10–15 56–83%	12–15 67–83%	15–16 83–89%
	Waihou–Piako (18)	6–17 33–94%	3–6 17–33%	5–9 28–50%	8–11 44–61%	3–17 17–94%	3–5 17–28%	4–9 22–50%	6–11 33–61%
	Waipā (17)	3–16 18–94%	13–14 76–82%	14–16 82–94%	14–16 82–94%	1–14 6–82%	12–14 71–82%	13–15 76–88%	14–16 82–94%
	West Coast (14)	1–14 7–100%	5–7 36–50%	7–8 50–57%	7–10 50–71%	0–12 0–86%	5–7 36–50%	7–7 50–50%	7–10 50–71%
	Waikato Region (105)	**25–94 24–90%**	**53–64 50–61%**	**60–73 57–70%**	**67–83 64–79%**	**14–83 13–79%**	**50–63 48–60%**	**58–70 55–67%**	**65–81 62–77%**

NBL refers to 'national bottom line' for suspended fine sediment in the NPS-FM 2020 (Ministry for the Environment 2020).

Table 16. Summary of Waikato SOE monitoring sites under projected climate change at late century requiring reductions to achieve NPS-FM 2020 attribute bands and the NBL, and to maintain baseline visually clarity, summarised across the selected RCMs and all four RCPs. (Continues horizontally over next page)

		Contemporary baseline				Mitigation scenarios							
	CMZ (sites)	C2022				M20				M30			
		Base	C (NBL)	B	A	Base	C (NBL)	B	A	Base	C (NBL)	B	A
Late century	**Central Waikato** **10**	6–7 60–70%	7–9 70–90%	7–9 70–90%	8–9 80–90%	1–7 10–70%	7–8 70–80%	7–9 70–90%	8–9 80–90%	0–7 0–70%	7–8 70–80%	7–9 70–90%	8–9 80–90%
	Coromandel **4**	4–4 100–100%	0–0 0–0%	0–1 0–25%	0–2 0–50%	4–4 100–100%	0–0 0–0%	0–1 0–25%	0–2 0–50%	4–4 100–100%	0–0 0–0%	0–1 0–25%	0–2 0–50%
	Lake Taupō **6**	4–6 67–100%	1–2 17–33%	1–4 17–67%	1–6 17–100%	4–6 67–100%	1–2 17–33%	1–4 17–67%	1–6 17–100%	4–6 67–100%	1–2 17–33%	1–4 17–67%	1–6 17–100%
	Lower Waikato **18**	16–17 89–94%	14–16 78–89%	15–17 83–94%	16–18 89–100%	4–17 22–94%	14–16 78–89%	14–16 78–89%	16–18 89–100%	3–17 17–94%	14–16 78–89%	14–16 78–89%	15–18 83–100%
	Upper Waikato **18**	14–18 78–100%	13–17 72–94%	15–17 83–94%	17–18 94–100%	6–18 33–100%	12–17 67–94%	13–17 72–94%	16–17 89–94%	2–18 11–100%	11–17 61–94%	13–17 72–94%	15–17 83–94%
	Waihou–Piako **18**	18–18 100–100%	5–11 28–61%	6–11 33–61%	10–12 56–67%	14–18 78–100%	4–10 22–56%	5–11 28–61%	9–11 50–61%	8–18 44–100%	4–9 22–50%	5–11 28–61%	9–11 50–61%
	Waipā **17**	15–16 88–94%	14–16 82–94%	14–16 82–94%	16–16 94–94%	6–16 35–94%	14–16 82–94%	14–16 82–94%	16–16 94–94%	3–16 18–94%	13–16 76–94%	14–16 82–94%	15–16 88–94%
	West Coast **14**	13–14 93–100%	7–10 50–71%	8–13 57–93%	10–14 71–100%	2–14 14–100%	7–10 50–71%	7–10 50–71%	9–13 64–93%	0–14 0–100%	6–9 43–64%	7–10 50–71%	8–13 57–93%
	Waikato Region **105**	**90–100** **86–95%**	**61–81** **58–77%**	**66–88** **63–84%**	**78–95** **74–90%**	**41–100** **39–95%**	**59–79** **56–75%**	**61–84** **58–80%**	**75–92** **71–88%**	**24–100** **23–95%**	**56–77** **53–73%**	**61–84** **58–80%**	**71–92** **68–88%**

Table 16. Continued horizontally from previous page

	CMZ (sites)	M40 Base	M40 C (NBL)	M40 B	M40 A	M50 Base	M50 C (NBL)	M50 B	M50 A	M100 Base	M100 C (NBL)	M100 B	M100 A
Late century	**Central Waikato 10**	0–7 0–70%	7–8 70–80%	7–9 70–90%	7–9 70–90%	0–7 0–70%	7–8 70–80%	7–9 70–90%	7–9 70–90%	0–1 0–10%	4–7 40–70%	6–7 60–70%	7–8 70–80%
	Coromandel 4	4–4 100–100%	0–0 0–0%	0–1 0–25%	0–2 0–50%	4–4 100–100%	0–0 0–0%	0–1 0–25%	0–2 0–50%	3–4 75–100%	0–0 0–0%	0–1 0–25%	0–2 0–50%
	Lake Taupō 6	4–6 67–100%	1–2 17–33%	1–4 17–67%	1–6 17–100%	3–6 50–100%	1–2 17–33%	1–4 17–67%	1–6 17–100%	3–5 50–83%	0–1 0–17%	0–4 0–67%	0–6 0–100%
	Lower Waikato 18	1–17 6–94%	12–15 67–83%	14–16 78–89%	15–18 83–100%	1–17 6–94%	12–15 67–83%	14–16 78–89%	15–17 83–94%	0–2 0–11%	11–13 61–72%	12–14 67–78%	13–15 72–83%
	Upper Waikato 18	1–18 6–100%	10–16 56–89%	12–17 67–94%	15–17 83–94%	0–18 0–100%	10–16 56–89%	12–17 67–94%	15–17 83–94%	0–9 0–50%	2–12 11–67%	4–14 22–78%	10–14 56–78%
	Waihou–Piako 18	5–18 28–100%	3–9 17–50%	5–11 28–61%	6–11 33–61%	2–18 11–100%	3–9 17–50%	4–11 22–61%	6–11 33–61%	1–13 6–72%	1–4 6–22%	2–5 11–28%	4–10 22–56%
	Waipā 17	1–16 6–94%	12–16 71–94%	14–16 82–94%	14–16 82–94%	1–16 6–94%	12–15 71–88%	13–16 76–94%	14–16 82–94%	0–7 0–41%	8–13 47–76%	12–15 71–88%	13–16 76–94%
	West Coast 14	0–14 0–100%	6–8 43–57%	7–10 50–71%	7–13 50–93%	0–14 0–100%	6–7 43–50%	7–10 50–71%	7–12 50–86%	0–12 0–86%	2–7 14–50%	4–7 29–50%	7–10 50–71%
	Waikato Region 105	**16–100 15–95%**	**51–74 49–70%**	**60–84 57–80%**	**65–92 62–88%**	**11–100 10–95%**	**51–72 49–69%**	**58–84 55–80%**	**65–90 62–86%**	**7–53 7–50%**	**28–57 27–54%**	**40–67 38–64%**	**54–81 51–77%**

NBL refers to 'national bottom line' for suspended fine sediment in the NPS-FM 2020 (Ministry for the Environment 2020).

5.4 Model evaluation and limitations

5.4.1 Model evaluation

SedNetNZ is designed to predict spatial patterns in erosion and suspended sediment load on a mean annual basis for periods spanning several decades. It is difficult to quantify a model's performance over such time scales other than through comparison with measurements of suspended sediment load, which has been the main form of SedNetNZ model evaluation (Basher et al. 2018). Often, longer-term suspended sediment load data are unavailable. However, various rivers have been monitored in the Waikato region and the resulting suspended sediment concentration (SSC) and discharge (Q) data have been used to estimate mean annual suspended sediment loads via SSC-Q rating curve methods (Hicks, Haddadchi et al. 2019).

We selected a subset of these estimates of mean annual suspended sediment load (obtained from Appendix D of Hicks, Haddadchi et al. 2019 and suspended sediment loads provided by WRC) to inform model calibration (Figure 14). The subset was restricted to sites where the monitoring period ends after 1 January 1995 and spans more than 10 years. This approach ensured sufficient data was available for model calibration while limiting the inclusion of sites where the estimated mean annual suspended sediment loads are based only on measurements from decades earlier that may hinder comparison with model results for more recent conditions.

Previously, Dymond et al. (2016) conducted a sensitivity analysis of model parameters and found uncertainty of approximately ±50% at the 95% confidence level. The greatest uncertainty arises from the landslide probability density function, landslide sediment delivery ratio (SDR), and gully density. The bank erosion component of SedNetNZ is calibrated separately, as described in section 4.1.5.

The relationship between mean annual suspended sediment loads estimated from SSC-Q rating curves and the calibrated model loads is shown in Figure 14. There is generally good agreement between available measured loads and the calibrated model, but agreement varies between catchments. Sediment loads predicted using the updated version of SedNetNZ applied in the present report are either similar to or improve on predictions using previous model versions when compared to SSQ-rating curve estimated loads in the Waikato Region (Table 17).

Palmer et al. (2015) compared modelled long-term mean annual suspended sediment loads with loads at seven river gauging sites. Revisiting this comparison, the absolute differences between SedNetNZ modelled loads in the present report and the estimated loads from the same river gauging stations have decreased at all but one site, compared to the values reported by Palmer et al. in 2015 (Table 17). A similar pattern is observed in comparison to the modelled loads at 11 sites, mostly in the Coromandel and Waihou–Piako CMZs reported by Betts, Spiekermann et al. (2017). Again, with the exception of one site, there is a reduction in the absolute difference between the updated SedNetNZ loads in the present report and loads estimated at gauged river sites compared to Betts, Spiekermann et al. 2017 (Table 17). It is important to note that sediment loads estimated from the river gauging sites used in the comparison and those from SedNetNZ often represent different time-periods and may not be directly comparable and therefore some difference is expected.

Evaluating modelled erosion process contributions to sediment loads is challenging as we lack data to apportion sediment loads from gauged sites to individual erosion processes averaged over multi-decadal timescales. Our modelling indicates that shallow landslide erosion represents the dominant contribution (53%) to suspended sediment loads across the region, followed by surficial erosion (22%) and bank erosion (11%). Although we do not have data to directly evaluate these estimates, several aspects provide a basis for confidence: These include:

- **Knowledge base**: Our modelling leverages a considerable body of erosion process knowledge, including a physical understanding of erosion processes, measurement data, and New Zealand-specific geospatial data.
- **Model validation**: There is reasonable agreement between modelled mean annual suspended sediment loads and load estimates from gauged sites.
- **Prevalence of mass movement**: Much of New Zealand is hilly or mountainous, making mass movement the most common type of erosion (Basher, 2013). Thus, it is not unexpected to see shallow landslides as the dominant source for the region given the extent of hilly terrain.

SedNetNZ models mean annual sediment loads over a multi-decadal period, accounting for high-magnitude rainfall events capable of triggering widespread erosion from mass movement processes such as shallow landslides. These episodic events can significantly contribute to the total sediment load over extended periods, even in CMZs with a comparatively low spatial extent of hill country. In years without such events, other erosion processes, such as surficial or bank erosion, may dominate. At a local watershed scale, the dominant erosion process will be more variable, particularly in lowland watersheds where streambank erosion can be a significant source of sediment.

We outline some specific limitations in terms of each modelling component below. Model outputs should be interpreted in the context of these limitations.

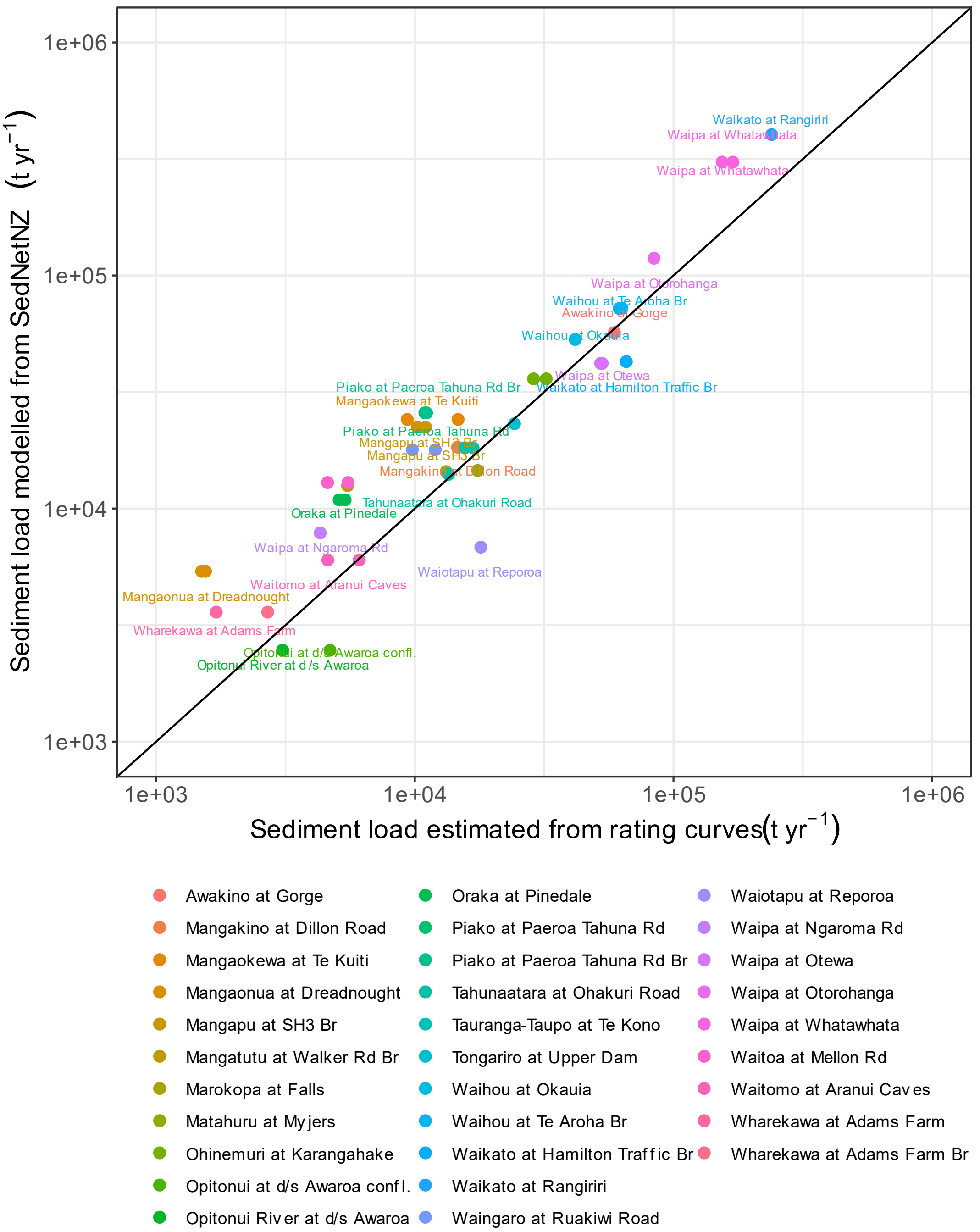

Figure 14. Mean annual suspended sediment loads estimated using SSC-Q rating curves versus modelled mean annual loads for selected river gauging stations in the Waikato Region.

Table 17. Comparison between modelled and SSC-Q rating curve estimated suspended sediment loads. For comparison, percentage differences between measured and modelled loads are reported for the updated version of SedNetNZ applied in the present report, as well as previous reports applying earlier versions of SedNetNZ in the region. The difference (Diff) is based on comparison to the loads from Hicks, Haddadchi et al. 2019 or WRC sediment load data when there is no load provided by Hicks, Haddadchi et al. 2019.

Site name (river at location)	nzsegment	CMZ	Catchment area (km^2)	Hicks, Haddadchi et al. 2019 (Appendix D) ($kt\ yr^{-1}$)	WRC sediment loads ($kt\ yr^{-1}$)	Palmer et al. 2015		Betts et al. 2017		Vale et al. 2024 – present report (C2022)	
						Sediment load ($kt\ yr^{-1}$)	Diff* ($kt\ yr^{-1}$, %)	Sediment load ($kt\ yr^{-1}$)	Diff* ($kt\ yr^{-1}$, %)	Sediment load ($kt\ yr^{-1}$)	Diff* ($kt\ yr^{-1}$, %)
Awakino at Gorge	3128195	West Coast	227.2	59.1	-	84.3	25.2 30%	-	-	54.1	−5 −9%
Mokau at Totoro Bridge	3123396	West Coast	156.9	166	-	40.8	−125 −306%	-	-	202.7	37 18%
Mangakino at Dillon Road	3111462	Upper Waikato	342.6	14.6	-	27.1	12.4 46%	-	-	18.7	4 22%
Pokaiwhenua at Puketurua	3081022	Upper Waikato	430.8	7.2	-	31.9	24.6 77%	-	-	17.5	10.2 58%
Waiotapu at Reporoa**	3114681	Upper Waikato	235.9	18.0	-	11.8	−6.2 −53%	-	-	6.7	−11.3 −170%
Waipa at Whatawhata	3063749	Waipā	2,863	170	154	438	268 61%	-	-	292.	122 42%
Tauranga-Taupo at Te Kono	3155812	Lake Taupō	196.7	15.6	16.8	36.4	20.8 57%	36.2	20.6 57%	18.2	2.6 14%
Opitonui River at d/s Awaroa	3036923	Coromandel	28.8	3.1	4.7	-	-	3.9	0.8 21%	2.5	−0.6 −25%
Tapu at Tapu-Coroglen	3040973	Coromandel	26.4	0.7	0.7	-	-	3.2	2.5 77%	2.0	1.3 64%
Wharekawa at Adams Farm	3044838	Coromandel	46.6	1.7	2.7	-	-	6.4	4.7 73%	3.6	1.9 52%

Site name (river at location)	nzsegment	CMZ	Catchment area (km^2)	Hicks, Haddadchi et al. 2019 (Appendix D) ($kt\ yr^{-1}$)	WRC sediment loads ($kt\ yr^{-1}$)	Palmer et al. 2015		Betts et al. 2017		Vale et al. 2024 – present report (C2022)	
						Sediment load ($kt\ yr^{-1}$)	Diff* ($kt\ yr^{-1}$, %)	Sediment load ($kt\ yr^{-1}$)	Diff* ($kt\ yr^{-1}$, %)	Sediment load ($kt\ yr^{-1}$)	Diff* ($kt\ yr^{-1}$, %)
Ohinemuri at Karangahake	3051925	Waihou–Piako	286.3	28.8	32.2	-	-	49.1	20.3 41%	33.6	4.8 14%
Piako at Paeroa Tahuna Rd	3054261	Waihou–Piako	538.8	10.9	11.1	-	-	39.5	28.6 72%	24.7	13.7 56%
Waitoa at Mellon Rd	3054693	Waihou–Piako	408.9	5.5	4.6	-	-	25.8	20.3 79%	12.1	6.6 55%
Waihou at Okauia	3064061	Waihou–Piako	806.2	41.7	-	-	-	139.8	98.1 70%	51.3	9.6 19%
Waihou at Te Aroha Br	3055227	Waihou–Piako	1,107	63.2	61.7	-	-	194.0	131 67%	68.2	5 7%
Oraka at Pinedale	3081726	Waihou–Piako	130.1	5.4	5.1	-	-	17.6	12.2 69%	10.8	5.4 50%
Waingaro at Ruakiwi Road	3060386	West Coast	118.5	9.8	12.0	-	-	23.0	13.2 57%	17.4	7.6 44%
Mangapu at SH3 Br	3095547	Waipā	150.4	10.2	11.0	-	-	-	-	21.7	11.4 53%
Mangatutu at Walker Rd Br	3083539	Waipā	121.5	4.1	5.5	-	-	-	-	12.1	8.0 66%
Waipā at Otewa	3097862	Waipā	319.4	53.0	52.3	-	-	-	-	40.7	-12.3 -30%
Waipā at Ōtorohanga	3090408	Waipā	918.7	-	84.1	-	-	-	-	114.1	30 26%
Waikato at Hamilton Traffic Br	3063520	Central Waikato	8,334	-	65.7	-	-	-	-	41.5	-24.2 -58%

Site name (river at location)	nzsegment	CMZ	Catchment area (km²)	Hicks, Haddadchi et al. 2019 (Appendix D) (kt yr⁻¹)	WRC sediment loads (kt yr⁻¹)	Palmer et al. 2015		Betts et al. 2017		Vale et al. 2024 – present report (C2022)	
						Sediment load (kt yr⁻¹)	Diff* (kt yr⁻¹, %)	Sediment load (kt yr⁻¹)	Diff* (kt yr⁻¹, %)	Sediment load (kt yr⁻¹)	Diff* (kt yr⁻¹, %)
Matahuru at Waiterimu Rd	3053073	Lower Waikato	105.3	5.4	7.6	-	-	-	-	15.6	10.2 66%
Waikato at Rangiriri	3052038	Lower Waikato	12,372	-	239.5	-	-	-	-	383.7	144.2 38%

*The 'Diff' comparison used Hicks, Haddadchi et al. 2019 rather than WRC sediment loads since it provided sediment load estimates for selected sites used in the previous reports. It is important to note that differences are expected since the sediment load estimates are not directly comparable due to differences between the monitoring period for the river gauging sites and the contemporary sediment loads modelled by SedNetNZ.

** Contemporary sediment loads modelled at 'Waiotapu at Reporoa' show a large proportional difference compared to estimated loads from Hicks, Haddadchi et al. 2019. This may be due to the difference between the time-periods each estimate represents, with sediment loads modelled using SedNetNZ reflecting contemporary landcover and recent erosion mitigation.

5.4.2 Model limitations

Limited empirical data presents an ongoing challenge in modelling erosion processes, particularly across New Zealand's diverse erosion terrains. This scarcity of data necessitates an approach to model parameterisation that draws from the available data in combination with expert judgment to inform the representation of erosion processes and mitigation effectiveness.

Erosion process representation

The main limitations in the surficial erosion component of SedNetNZ relate to the calculation of the C and K factors in the NZUSLE, and the availability of suitable input data. The updated model uses a spatially variable K factor instead of the uniform K factor applied in earlier NZUSLE modelling (e.g. Dymond et al. 2016). The further acquisition of higher-resolution soils data for the Waikato region, such as S-map, may improve estimates of surficial erosion.

Shallow landslides are initiated by storm events over a triggering threshold. This means the landslide load in any given year can vary significantly from the mean annual landslide load. This inter-annual variability in landslide occurrence is not represented in SedNetNZ. Instead, the storm-triggered shallow landslide contribution to the sediment load is averaged over a multi-decadal timescale. Calibration data from Manawatū (Dymond et al. 2016) were used to define the slope thresholds for landslide occurrence and density.

Landslide depth was approximated to a constant 1 m, however, actual depths can vary significantly. Phillips et al. (2021) reported typical depths of up to 2 m, while Page et al. (1994) observed scar depths ranging from 0.13 to 3.9 m, with an average of 0.89 m. Betts et al. (2017) reported depths in various materials, including weakly indurated sandstone (0.2–1.6 m; mean 0.69 ± 0.05 m), moderately indurated sandstone (0.3–1.4 m; mean 0.74 ± 0.05 m), and mudstone (0.3–3.0 m; mean 1.01 ± 0.07 m). Although informative, these data are limited, and we currently lack sufficient data to adequately represent this spatial variation in landslide depths within the model. While the model could benefit from development of a spatially varying landslide depth, Dymond et al. (2016) reported the greatest sensitivity in modelled catchment sediment loads relates to the landslide probability density function and landslide sediment delivery ratio (SDR).

Both earthflow and gully erosion are represented in SedNetNZ using a spatial averaging approach based on the estimated presence and spatial extent of these erosion features in the Erosion Terrains layer (Dymond et al. 2016). It is therefore possible that earthflow and gully erosion may be represented in sub-catchments that do not contain these features or may not be represented where they are present. Earthflows and gullies are not as spatially extensive as other erosion processes in the region. This limited extent allows for the use of aerial imagery to evaluate selected catchments, with adjustments made to the Erosion Terrain layers if there was no evidence of active gully erosion, alongside comparison of modelled sediment loads with load estimates derived from SSC-Q rating curves. Due to their limited spatial extent and the calibration process, uncertainties associated with the spatial extent of earthflows and gullies are unlikely to significantly impact overall patterns of erosion and sediment loads. Representation of earthflows and gullies in SedNetNZ would benefit from improved data to better reflect the spatial extent of these features as well as improved estimates of earthflow depths and movement rates across different erosion terrains.

Bank erosion prediction requires high-resolution spatial data on riparian woody vegetation. For this reason, riparian woody vegetation has been derived from 'EcoSat Woody' at 15 m resolution (Dymond & Shepherd 2004), because LCDB is less suitable for representing narrow strips of riparian vegetation due to its minimum mapping unit of 1 ha. Predictions of bank migration rates are therefore based on woody vegetation presence/absence in 2002. These estimates of riparian woody vegetation have been updated to reflect subsequent broad-scale land-cover changes (forestry-to-pasture conversions and vice versa) using LCDB, and are used in combination with estimates of riparian fencing extent based on data from the WRC riparian survey (2002–2017). It is assumed that riparian stock-exclusion fencing allows woody vegetation to establish and contribute to increased bank stability.

A further challenge relates to the spatial correspondence between mapped channel locations and woody vegetation, and changes in channel planform since mapping occurred. The future use of region-wide LiDAR data would enable improved spatial representation of riparian woody vegetation and spatial coherence with channel locations.

Mitigation effectiveness

The reduction in sediment load from hillslope erosion processes is determined by the change in land cover related to mitigation work in each scenario, referred to as effectiveness. The effectiveness values used in our modelling are based on simplifications of published data and assume full effectiveness of mitigations. However, a considerable range of effectiveness values for different erosion mitigations are reported in the literature and real-world effectiveness can vary significantly. A comprehensive summary of erosion mitigation effectiveness is provided by Phillips et al. (2020).

We used an effectiveness value of 90% for the reduction of mass movement erosion following the conversion from pasture to permanent woody cover. New Zealand studies have reported ranges between 35% and 91%, with most studies indicating a 70-90% reduction in landsliding under closed-canopy vegetation (such as indigenous forest, pines older than 8 years, or scrub) compared to pasture (e.g., DL Hicks 1989, 1990, 1991; Pain & Stephens 1990; Phillips et al. 1990; Marden et al. 1991; Marden & Rowan 1993; Bergin et al. 1993, 1995; Fransen & Brownlie 1995; Hancox & Wright 2005; Smith et al. 2023).

For the effectiveness of space-planted trees and gully tree planting, we adopted a value of 70% based on data from Hawley and Dymond (1988) but supported more broadly by published studies. Most empirical data on the performance of space-planted trees for erosion control are based on individual or small groups of trees rather than hillslope-scale performance. Reported values range from 22% to 95% in various New Zealand studies (Phillips et al., 2020). The large range reflects the high dependence on successful establishment of the trees and subsequent maintenance to ensure their survival and effectiveness (see Marden & Phillips 2013). When plantings are adequately spaced (10 m) and well maintained, published reductions in shallow landsliding range from 70-95% (e.g., Hawley & Dymond 1988; Douglas et al. 2009, 2013; McIvor et al. 2015).

Determining the most appropriate effectiveness value for reductions in stream bank erosion arising from riparian fencing and stock exclusion is challenging due to the limited studies available, with stream bank erosion one of the least understood erosion processes in New Zealand (Basher, 2013). Bank erosion varies with with stream order and scale (e.g. headwaters, lower reaches) and can occur through various processes, such as mass failure, stock trampling, and fluvial entrainment (Hughes, 2016), making the impact of riparian management on bank erosion highly variable. Our effectiveness value falls within the 30–90% range from published and unpublished sources (Phillips et al., 2020). These studies include:

- 30–90% bank erosion reductions (McKergow et al., 2007; using data from Line et al., 2000; McKergow et al., 2003; Meals & Hopkins, 2002; and Owens et al., 1996)
- 55–65% reduction in bank erosion depending on the type of planting and buffer width (based on unpublished data; Monaghan & Quinn, 2010)
- Reduction in actively eroding banks from 30% to 4%, 1–7 years after riparian buffers were established, resulting in an 85% reduction in catchment sediment load (Williamson et al., 1996).

Climate change projections

There is a high degree of uncertainty in the climate change projections and their impacts, arising from (a) differences between climate models, (b) divergent trajectories of future climate change depending on levels of greenhouse gas emissions, and (c) how these changes affect erosion processes.

The choice of climate model affects estimates due to the range of models (RCMs), while the divergence in potential climate futures is captured by the four RCPs and produces a large range in potential impacts. This range means there can be considerable difference between the lowest and highest projections, especially at late century, and spatial variation in relative change across the region.

Further uncertainty is introduced concerning the applicability of some assumptions for the whole region. For example, the adjustment for predicting the change in storm rainfall per 1°C temperature increase (+7.3%) assumes that landslides are triggered by an ARI30 48 h event. A uniform triggering threshold of 150 mm in 48 h has been used to estimate landslide density, but this threshold may vary for different terrains and different mass movement processes (e.g. Reid & Page 2003; Basher et al. 2020).

There is also a lack of information on the relationship between climate change and its impact on erosion processes in New Zealand. Basher et al. (2020) identified this knowledge gap, stating there had only been a few studies in New Zealand on the climate change impacts on erosion, 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 as a result of predicted climate change, there is a high level of uncertainty resulting from the error margins inherent in downscaling GCMs spatially and temporally. Due to the high uncertainty, the results of the climate change projections should, therefore, be interpreted as indicative of trends rather than absolute values (Basher et al. 2020).

Regional riparian fencing estimate

The estimation of riparian fencing coverage across Waikato was derived from survey data collated by WRC from four regional riparian surveys conducted in 2002, 2007, 2012, and 2017. Relying on these regional riparian surveys to estimate fencing extents introduces uncertainties, particularly when mapped onto the REC2 digital stream network. These uncertainties primarily stem from (1) limitations inherent in the survey data, including potential sample and observer biases and variability in data consistency across different years, and (2) challenges in ensuring the spatial representativeness of average fencing estimates and their alignment with the digital stream network.

The initial 2002 survey employed a stratified sampling approach, creating distinct sub-groups to capture a range of variables, including management zone, land-use type, and stream order. However, modifications to the survey methodology over subsequent surveys introduce a layer of uncertainty regarding whether observed changes in fencing extent reflect environmental changes or are due to adjustments to the method. For instance, the addition of new sites since 2002 was aimed at enhancing regional representativeness, though certain stratifications probably remain under-represented (Jones et al. 2016). Moreover, alterations in the number and selection of surveyed sites, notably the reduction of surveyed waterway length in 2017 from 1,000 to 500 m (offset by an increase in site numbers), affect year-to-year consistency, though previous analyses suggest the impact on precision is minimal (Jones et al. 2016; Norris et al. 2020).

A challenge arises in translating site-based fencing data to the region-wide digital stream network. Applying farm-type and stream-order-based average fencing proportions to represent regional patterns introduces potential inaccuracies at specific stream segments. Also, while site surveys can determine farm types at specific locations, mapping these onto the digital stream network using AgriBase™ farm classifications provides only a coarse approximation of land use over time, potentially missing more varied land uses within farm type classifications.

Accurately determining fencing proportions is also complicated by the precision of the digital stream network, particularly for lower-order streams. The digital network's sensitivity to the drainage area threshold for the initiation of first-order streams means its alignment with actual stream networks varies across terrains. As a result, within the digital network some first-order streams may be perennial, and others ephemeral or practically non-existent. This discrepancy probably introduces a bias in survey sites linked to first-order streams, favouring perennial streams, and challenges their representativeness across the digital network. We sought to partly address this by distinguishing between wide and narrow streams, based on 'Accord streams'.

Any overestimation of the contemporary riparian fencing extent limits the length of the remaining stream network available for further fencing and, consequently, the modelled future reduction in sediment load from additional riparian fencing. This limitation also affects the potential improvements in visual clarity and the ability to achieve NPS-FM 2020 attribute bands and the NBL. In contrast, where underestimation of the contemporary fencing extent occurs, it will lead to potential overestimation of the levels of load reduction and clarity improvement achieved with future fencing.

Reductions required to meet visual clarity attribute bands

Mean annual suspended sediment load reductions to achieve visual clarity and suspended fine sediment objectives were estimated using equations developed by Hicks, Haddadchi et al. (2019) from simplifications in the relationships reported by Dymond et al. (2017). A key assumption for calculating required load reductions to meet objectives is that the relationship between suspended sediment load and the flow frequency distribution remain constant at a site. In reality this relationship may change due to changes in catchment hydrology, leading to changes in the relationship between a given flow and suspended sediment load (Hicks, Haddadchi et al. 2019).

Because data are not presently available to predict these changes, we assume that the associated relationships remain constant. This assumption is particularly important when modelling changes in visual clarity under different scenarios, especially the climate change scenarios. Because these scenarios may significantly change the rainfall regime and land cover, both of which would result in changes in hydrology, the relationship between visual clarity and sediment load may differ at a given SOE site compared with the contemporary baseline (C2022).

We have estimated the required load reductions using empirical models fitted to a national data set. This should result in the models being fitted to a wide range of catchment variables and therefore representing the variability across Waikato, and sites from Waikato were used in the national data set (see Hicks, Haddadchi et al. 2019), but may lead to under- or overestimation of required reductions at any one location. Also, visual clarity thresholds are based on one of four sediment classes assigned to the REC2 segment. This can lead to abrupt changes in target thresholds for adjacent REC2 segments.

6 Conclusions and recommendations

- Total erosion for the Waikato region under the contemporary baseline land cover and erosion mitigations was estimated at 2.32 Mt yr^{-1}, with most erosion occurring in the West Coast, Waipā, and Upper Waikato CMZs. The predicted region-wide net suspended sediment load delivered to the coast is 1.67 Mt yr^{-1}.
- Comparison of sediment loads between the two winter-forage years showed minor region-wide change (−0.619 kt yr^{-1}, or −0.03%). This is due to the relatively small area of forage paddocks and their occurrence predominantly in low sediment yielding areas.
- The backward-looking scenarios showed that region-wide total erosion decreased by 4.1% (98.7 kt yr^{-1}) between B2002 and B2017 due to increased riparian fencing throughout the region, except in Upper Waikato, where erosion increased because of land-cover changes from woody cover to pasture.
- The future erosion mitigation scenarios used a sediment load ranking approach to target erodible pastoral land for afforestation or spaced tree planting. This resulted in a region-wide reduction in total erosion of 13.1% to 2.01 Mt yr^{-1} under the M20 scenario. This reduction increased further to a 27% reduction for M50 and a 41% for M100, primarily concentrated in the West Coast, Upper Waikato, and Waipā CMZs.

- To meet NPS-FM 2020 visual clarity standards, 56% of the 105 SOE selected sites across the Waikato region require sediment load reductions to achieve the NBL. This decreases to 42% and 27% of sites under the M50 and M100 mitigation scenarios. The largest decrease in sites requiring further reductions to achieve the NBL occur in the Upper Waikato and Waipā CMZs, highlighting the varying spatial impacts and effectiveness of erosion mitigation efforts.
- Climate change projections result in a range of predicted changes to suspended sediment loads but generally show a significant increase in loads across the Waikato region under contemporary land cover and erosion mitigations. Total erosion across all RCPs is estimated at 2.6–3.6 Mt yr^{-1} and 2.5–4.9 Mt yr^{-1} for mid- and late century. This represents an increase of 14–57% and 7–110% for mid- and late century, compared to loads modelled without the impacts of climate change.
- The impact of climate change on erosion varies across the CMZs, with minimal changes in low sediment-yielding areas like Coromandel and Lake Taupō, and larger increases in higher sediment-yielding areas such as Upper Waikato and West Coast, reflecting the susceptibility of different terrain to changes in erosion related to climate change.
- Under future erosion mitigation scenarios incorporating the effects of climate change, region-wide sediment loads are projected to change by −7% to +26% and −12% to +68% for mid- and late century under the M20 mitigation scenario. Larger reductions in loads (−41% to −1%) tend to occur by late century under the M100 scenario, demonstrating the potential to mostly mitigate climate-induced increases in erosion at the regional scale.
- The impact of erosion mitigation varies across CMZs, with changes to sediment loads ranging from −10% to +40% and from −17% to +94% at mid- and late century under the M20 scenario. These changes range from −59% to +17% by late century under the M100 scenario. The larger decreases occur in Central Waikato, Lower Waikato, and Upper Waikato, while the smaller decreases or increases in loads occur in Coromandel and Lake Taupō.
- Most SOE sites require reductions to maintain baseline visual clarity. Under the contemporary baseline land cover and erosion mitigations with the effects of future climate change, 88–94% and 86–95% of the SOE sites at mid- and late-century require reductions to maintain baseline visual clarity. This decreases to 7–50% at late century under the M100 scenario.
- The number of SOE sites requiring reductions to achieve the NBL range from 59% to 70% and 58% to 77% at mid- and late century under the contemporary baseline with the effects of future climate change. With erosion mitigations the number of sites requiring further reduction decreases to 27–54% by late century under M100.
- Continued investment in erosion mitigations is necessary to limit the potential impacts of climate change on suspended sediment loads by late century.
- Improvements in model predictions could be made by incorporating region-specific data on erosion control effectiveness and through use of region-wide LiDAR-derived terrain data to enable improved representation of the stream network as well as erosion processes at higher spatial resolutions.

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8 References

Abernethy B, Rutherfurd ID 2000. The effect of riparian tree roots on the mass-stability of riverbanks. Earth Surface Processes and Landforms 25(9): 921–937.

Alber A, Piégay H 2017. Characterizing and modelling river channel migration rates at a regional scale: case study of south-east France. Journal of Environmental Management 202: 479–493.

Arulanandan K, Gillogley E, Tully R 1980. Development of a quantitative method to predict critical shear stress and rate of erosion of natural undisturbed cohesive soils. USACE, Waterways Experiment Station Technical Report GL-80-5. Vicksburg, MS, USACE.

Basher L, Spiekermann R, Dymond J, Herzig A, Ausseil A-G 2018. SedNetNZ, SLUI and contaminant generation. Part1: Sediment and water clarity. Manaaki Whenua – Landcare Research contract report LC3135, prepared for Horizons Regional Council.

Basher L, Spiekermann R, Dymond J, Herzig A, Hayman E, Ausseil A-G 2020. Modelling the effect of land management interventions and climate change on sediment loads in the Manawatū–Whanganui region. New Zealand Journal of Marine and Freshwater Research 54(3): 490–511.

Basher LR 2013. Erosion processes and their control in New Zealand: Ecosystem services in New Zealand – conditions and trends 2013. Lincoln, Manaaki Whenua Press. Pp. 363–374.

Bergin DO, Kimberley MO, Marden M 1993. How soon does regenerating scrub control erosion? New Zealand Forestry (August): 38–40.

Bergin DR, Kimberley MO, Marden M 1995. Protective value of regenerating tea-tree stands on erosion-prone hill country, East Coast, North Island, New Zealand. New Zealand Journal of Forestry Science 25: 3–19.

Betts H, Basher L, Dymond J, Herzig A, Marden M, Phillips C 2017. Development of a landslide component for a sediment budget model. Environmental Modelling & Software 92: 28–39.

Betts H, Spiekermann R, Dymond J 2017. SedNetNZ modelling of sediment sources and loads from the Western Waikato, Coromandel, Waihou-Piako and Taupo Water Management Zones, Waikato Region. Manaaki Whenua – Landcare Research contract report LC2835, prepared for Waikato Regional Council

Booker D, Hicks M 2013. Estimating wetted width and fish habitat areas across New Zealand's rivers: wetted widths estimation. NIWA client report CHC2013-075. Prepared for Department of Conservation.

Brune GM 1953. Trap efficiency of reservoirs. Eos, Transactions American Geophysical Union 34(3): 407–418.

Collins D, Montgomery K, C. Zammit 2018. Hydrological projections for New Zealand rivers under climate change. NIWA Contract Report No. 2018193CH, prepared for Ministry for the Environment.

Crosato A 2009. Physical explanations of variations in river meander migration rates from model comparison. Earth Surface Processes and Landforms 34(15): 2078–2086.

Crozier MJ 2010. Deciphering the effect of climate change on landslide activity: a review. Geomorphology 124(3): 260–267.

Dairy Environment Leadership Group 2013. Sustainable Dairying: Water Accord: a commitment to New Zealand by the dairy sector. http://www.dairynz.co.nz/what-we-do/dairyindustry-strategy/

De Rose RC 2013. Slope control on the frequency distribution of shallow landslides and associated soil properties, North Island, New Zealand. Earth Surface Processes and Landforms 38(4): 356–371.

De Rose RC, Basher LR 2011. Strategy for the development of a New Zealand SedNet. Landcare Research Contract Report LC226, prepared for AgResearch and Ministry of Science and Innovation.

De Rose RC, Prosser IP, Weisse M, Hughes AO 2003. Patterns of erosion and sediment and nutrient transport in the Murray-Darling Basin. CSIRO Land and Water Technical Report 32/03.

Desmet P, Govers G 1996. A GIS procedure for automatically calculating the USLE LS factor on topographically complex landscape units. Journal of Soil and Water Conservation 51(5): 427–433.

Donovan M, 2022. Modelling soil loss from surface erosion at high-resolution to better understand sources and drivers across land uses and catchments: a national-scale assessment of Aotearoa, New Zealand. Environmental Modelling & Software 147: 105228. https://doi.org/10.1016/j.envsoft.2021.105228

Douglas GB, McIvor IR, Manderson AK, Koolaard JP, Todd M, Braaksma S, et al. 2013. Reducing shallow landslide occurrence in pastoral hill country using wide spaced trees. Land Degradation and Development 24: 103–114.

Douglas GB, McIvor IR, Manderson AK, Todd M, Braaksma S, Gray RAJ 2009. Effectiveness of space-planted trees for controlling soil slippage on pastoral hill country. In: Currie LD, Lindsay CL eds. Nutrient management in a rapidly changing world. Occasional Report No. 22. Palmerston North, Fertilizer and Lime Research Centre, Massey University.

Dunn IS 1959. Tractive resistance of cohesive channels. Journal of the Soil Mechanics and Foundations Division 85(3): 1–24.

Dymond J, Herzig A, Basher L, Betts HD, Marden M, Phillips CJ, et al. 2016. Development of a New Zealand SedNet model for assessment of catchment-wide soil-conservation works. Geomorphology 257: 85–93.

Dymond JR, Betts HD, Schierlitz CS 2010. An erosion model for evaluating regional land-use scenarios. Journal of Environmental Modelling Software 25(3): 289–298.

Dymond JR, Davies-Colley RJ, Hughes AO, Matthaei CD 2017. Predicting improved optical water quality in rivers resulting from soil conservation actions on land. Science of the Total Environment 603: 584–592.

Dymond JR, Jessen MR, Lovell LR 1999. Computer simulation of shallow landsliding in New Zealand hill country. International Journal of Applied Earth Observation and Geoinformation 1(2): 122–131.

Dymond JR, Shepherd JD 2004. The spatial distribution of indigenous forest and its composition in the Wellington region, New Zealand, from ETM+ satellite imagery. Remote Sensing of Environment 90: 116–125.

Dymond JR, Ausseil AG, Shepherd JD, Buettner L 2006. Validation of a region-wide model of landslide susceptibility in the Manawatu–Wanganui region of New Zealand. Geomorphology 74: 70–79.

Elliott AH, Semadeni-Davies AF, Shankar U, Zeldis JR, Wheeler DM, Plew DR, et al. 2016. A national-scale GIS-based system for modelling impacts of land use on water quality. Environmental Modelling & Software 86: 131–144.

Eyles GO 1983. The distribution and severity of present soil erosion in New Zealand. New Zealand Geographer 39(1): 12–28.

Fransen PJB, Brownlie RK 1995. Historical slip erosion in catchments under pasture and radiata pine forest, Hawke's Bay hill country. New Zealand Forestry 40(4): 29–33.

Foster GR, Meyer LD, Onstad CA 1977. A runoff erosivity factor and variable slope length exponents for soil loss estimates. Transactions of the ASAE 20(4): 683–687.

Fryirs KA, Wheaton JM, Brierley GJ 2016. An approach for measuring confinement and assessing the influence of valley setting on river forms and processes. Earth Surface Processes and Landforms 41(5): 701–710.

Gill MA 1979. Sedimentation and useful life of reservoirs. Journal of Hydrology 44(1): 89–95.

Guy GG 1977. Landslide investigations, Main North Line Railway, South Island, New Zealand. Unpublished MSc thesis, University of Canterbury. http://ir.canterbury.ac.nz/handle/10092/8095.

Hall JE, Holzer DM, Beechie TJ 2007. Predicting river floodplain and lateral channel migration for salmon habitat conservation 1. Journal of the American Water Resources Association 43(3): 786–797.

Hancox GT, Wright K 2005. Analysis of landsliding caused by the February 2004 rainstorms in the Wanganui–Manawatu hill country, southern North Island, New Zealand. Institute of Geological & Nuclear Sciences Science Report 2005/11. Wellington, GNS.

Hanson GJ, Simon A 2001. Erodibility of cohesive streambeds in the loess area of the midwestern USA. Hydrological Processes 15(1): 23–38.

Hawley JG, Dymond JR 1988. How much do trees reduce landsliding? Journal of Soil and Water Conservation 43(6): 495.

Hickin EJ, Nanson GC 1984. Lateral migration rates of river bends. Journal of Hydraulic Engineering 110(11): 1557–1567.

Hicks DM, Haddadchi A, Whitehead A, Shankar U 2019. Sediment load reductions to meet suspended and deposited sediment thresholds. NIWA Client Report 2019100CH, prepared for Ministry for the Environment.

Hicks DM, Semadeni-Davies A, Haddadchi A, Shankar U, Plew D 2019. Updated sediment load estimator for New Zealand. NIWA Client Report 2018341CH.

Hicks DM, Shankar U 2020. Sediment load reduction to meet visual clarity bottom lines. Memo prepared for Ministry for the Environment.

Hicks DL. Control of Soil Erosion on Farmland: A Summary of Erosion's Impact on New Zealand Agriculture, and Farm Management Practices Which Counteract it. MAF Policy, Ministry of Agriculture; 1995.

Hicks DL 1989. Storm damage to bush, pasture and forest: some evidence from Cyclone Bola. DSIR Land Resources Technical Record PN2. Palmerston North, DSIR.

Hicks DL 1990. Landslide damage to pasture, pine plantations, scrub and bush in Taranaki. DSIR Land Resources Technical Record 31. Lower Hutt, DSIR.

Hicks DL 1991. Erosion under pasture, pine plantations, scrub and indigenous forest: a comparison from Cyclone Bola. New Zealand Forestry 36(3): 21–22.

Thompson RC, Luckman PG. Performance of biological erosion control in New Zealand soft rock hill terrain. Agroforestry systems. 1993 Feb;21:191-211.

Hooke JM 1979. An analysis of the processes of river bank erosion. Journal of Hydrology 42(1): 39–62.

Hubble TCT, Docker BB, Rutherfurd ID 2010. The role of riparian trees in maintaining riverbank stability: a review of Australian experience and practice. Ecological Engineering 36(3): 292–304.

Hughes AO 2016. Riparian management and stream bank erosion in New Zealand. New Zealand Journal of Marine and Freshwater Research 50: doi:10.1080/00288330.2015.1116449

IPCC 2013. Climate change 2013: the physical science basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge, UK and New York, NY, Cambridge University Press, doi:10.1017/CBO9781107415324. p.

Jones H, Kimberley M, Hill R, Borman D 2016. Riparian characteristics of pastoral waterways in the Waikato region, 2002-2012. Waikato Regional Council Technical Report 2015/49. Hamilton, Waikato Regional Council.

Julian JP, Torres R 2006. Hydraulic erosion of cohesive riverbanks. Geomorphology 76(1): 193–206.

Konsoer KM, Rhoads BL, Langendoen EJ, Best JL, Ursic ME, Abad JD, Garcia MH 2016. Spatial variability in bank resistance to erosion on a large meandering, mixed bedrock-alluvial river. Geomorphology 252: 80–97.

Landcare Research NZ Ltd 2020. LCDB v5.0 – Land Cover Database version 5.0, Mainland New Zealand. Available from LRIS portal: https://lris.scinfo.org.nz/layer/104400-lcdb-v50-land-cover-database-version-50-mainland-new-zealand/.

Line, D.E.; Harman, W.A.; Jennings, G.D.; Thompson, E.J.; Osmond, D.L. (2000). Nonpoint-source pollutant load reductions associated with livestock exclusion. Journal of Environmental Quality 29: 1882-1890.

Manderson A, Dymond JR, Ausseil A-G 2015. Climate change impacts on water quality outcomes from the Sustainable Land Use Initiative (SLUI) Horizons Report No. 2015/EXT/1451.

Manderson A, Douglas G, Mackay A, Dymond JR 2011. SLUI Outcomes project: review of the SLUI database and development of a SLUI outcomes reporting framework. Report prepared for Horizons Regional Council by AgResearch.

Marden M 2012. Effectiveness of reforestation in erosion mitigation and implications for future sediment yields, East Coast catchments, New Zealand: a review. New Zealand Geographer 68: 24-35.

Marden M, Herzig A, Basher L 2014. Erosion process contribution to sediment yield before and after the establishment of exotic forest: Waipaoa catchment, New Zealand. Geomorphology 226: 162–174.

Marden M, Phillips CJ, Rowan D 2008. Recurrent displacement of a forested earthflow and implications for forest management, East Coast Region, New Zealand. IAHS publication 325: 491–501.

Marden M, Phillips CJ, Rowan D 1991. Declining soil loss with increasing age of plantation forests in the Uawa catchment, East Coast region. In: Henriques PR ed. Proceedings, International Conference on Sustainable Land Management, Napier, Hawke's Bay, New Zealand, 17–23 November 1991. Pp. 358–361.

Marden M, Rowan D 1993. Protective value of vegetation on Tertiary terrain before and during Cyclone Bola, East Coast, North Island, New Zealand. New Zealand Journal of Forestry Science 23: 255–263.

Marden M, Phillips CJ 2013. Survival and growth of poplar and willow pole plantings on East Coast hill country. Landcare Research Contract Report LC1622 for Plant and Food Research.

McCool DK, Foster GR, Mutchler CK, Meyer LD 1989. Revised slope length factor for the universal soil loss equation. Transactions of the ASAE 32(5): 1571–1576.

McIvor I, Douglas G, Dymond JR, Eyles G, Marden M 2011. Pastoral hillslope erosion in New Zealand and the role of poplar and willow trees in its reduction. In: Soil erosion issues in agriculture. Pp. 257–278. http://www.intechopen.com/articles/show/title/pastoral-hill-slope-erosion-in-new-zealand-and-the-role-of-poplar-and-willow-trees-in-its-reduction.

McIvor I, Clarke K, Douglas G 2015. Effectiveness of conservation trees in reducing erosion following a storm event. In: Currie LD, Burkitt LL eds. Proceedings, 28th Annual Fertiliser and Lime Research Centre Workshop 'Moving farm systems to improved attenuation'. Occasional Report 28. Palmerston North, Fertiliser and Lime Research Centre.

McKergow LA, Weaver DM, Prosser IP, Grayson RB, Reed AE. Before and after riparian management: sediment and nutrient exports from a small agricultural catchment, Western Australia. Journal of Hydrology. 2003 Jan 31;270(3-4):253-72.

McKergow LA, Tanner CC, Monaghan RM, Anderson G 2007. Stocktake of diffuse pollution attenuation tools for New Zealand pastoral farming systems. NIWA Client Report HAM2007-161 prepared for Pastoral 21 Research Consortium. Hamilton, National Institute of Water and Atmospheric Research.

Meals, D.W.; Hopkins, R.B. (2002). Phosphorus reductions following riparian restoration in two agricultural watersheds in Vermont, USA. Water Science and Technology 45(9): 51-60.

Ministry for the Environment 2018. Climate change projections for New Zealand: atmospheric projections based on simulations undertaken for the IPCC 5th Assessment. 2nd edn. Wellington, Ministry for the Environment.

Ministry for the Environment 2020. National Policy Statement for Freshwater Management 2020. Wellington, Ministry for the Environment.

Ministry for the Environment 2022a. Guidance for implementing the NPS-FM sediment requirements. Wellington, Ministry for the Environment.

Ministry for the Environment 2022b. Stock exclusion low slope land 2022. Retrieved from https://data.mfe.govt.nz/layer/111150-stock-exclusion-low-slope-land-2022/

Monaghan RM, Laurenson S, Dalley DE, Orchiston TS 2017. Grazing strategies for reducing contaminant losses to water from forage crop fields grazed by cattle during winter. New Zealand Journal of Agricultural Research 60: 333–348. https://doi.org/10.1080/00288233.2017.1345763.

Monaghan RM, Quinn J 2010. Appendix 9: Farms. National Institute of Water and Atmospheric Research (NIWA), Waikato River Independent Scoping Study. Hamilton, NIWA.

Nanson GC, Hickin EJ 1983. Channel migration and incision on the Beatton River. Journal of Hydraulic Engineering 109(3): 327–337.

Nanson GC, Hickin EJ 1986. A statistical analysis of bank erosion and channel migration in western Canada. Geological Society of America Bulletin 97(4): 497–504.

Neverman A, Smith HG, Herzig A, Basher LR 2021. Modelling baseline suspended sediment loads and load reductions required to achieve Draft Freshwater Objectives for Southland. Manaaki Whenua – Landcare Research Contract Report LC3749, prepared for Environment Southland.

Neverman A, Smith HG 2023. SedNetNZ modelling to assess sediment contributions from natural land cover areas and impacts of climate change in Taranaki. Manaaki Whenua - Landcare Research Contract Report LC4258 prepared for Taranaki Regional Council.

Neverman AJ, Donovan M, Smith HG, Ausseil AG, Zammit C 2023. Climate change impacts on erosion and suspended sediment loads in New Zealand. Geomorphology 427: 108607.

Newsome PFJ, Wilde RH, Willoughby EJ 2008. Land Resource Information System spatial data layers: data dictionary. Palmerston North, NZ, Landcare Research. http://digitallibrary.landcareresearch.co.nz/cdm/ref/collection/p20022coll14/id/67.

NIWA 2021. CliFlo: NIWA's National Climate Database on the Web. https://cliflo.niwa.co.nz/

Norris M, Jones H, Kimberley M, Borman D 2020. Riparian characteristics of pastoral waterways in the Waikato region, 2002-2017. Waikato Regional Council Technical Report 2020/12. Hamilton, Waikato Regional Council.

Owens, L.B.; Edwards, W.M.; Van Keuren, R.W. (1996). Sediment losses from a pastured watershed before and after fencing. Journal of Soil and Water Conservation 51(1): 90-94.

Page MJ, Trustrum NA, Dymond JR 1994. Sediment budget to assess the geomorphic effect of a cyclonic storm, New Zealand. Geomorphology 9(3): 169–188.

Page MJ, Reid LM, Lynn IH 1999. Sediment production from Cyclone Bola landslides, Waipaoa catchment. Journal of Hydrology (NZ) 38: 289–308.

Pain CF, Stephens PR 1990. Storm damage assessment using digitised aerial photographs: Eltham, New Zealand, 24–25 February 1986. New Zealand Geographer 46: 21–25.

Palmer D, Dymond J, Basher L 2013 Assessing erosion in the Waipa catchment using the New Zealand Empirical Erosion Model (NZeem®), Highly Erodible Land (HEL), and SedNetNZ models. Landcare Research contract report LC1685, prepared for Waikato Regional Council.

Palmer D, Dymond J, Herzig A, Betts H, Marden M, Basher L 2015. SedNetNZ modelling of the Waikato catchment. Landcare Research contract report LC2428, prepared for Waikato Regional Council.

Phillips C, Marden M, Basher LR 2018. Geomorphology and forest management in New Zealand's erodible steeplands: an overview. Geomorphology 307: 107-121.

Phillips C, Basher L, Spiekermann R 2020. Biophysical performance of erosion and sediment control techniques in New Zealand: a review. Landcare Research contract report LC3761 prepared for the Smarter Targeting of Erosion Control (STEC) MBIE research programme.

Phillips C, Hales T, Smith H, Basher L 2021. Shallow landslides and vegetation at the catchment scale: A perspective. Ecological Engineering, 173, p.106436.

Phillips CJ, Marden M, Pearce A 1990. Effectiveness of reforestation in prevention and control of landsliding during large cyclonic storms. Proceedings of the 19th World IUFRO Congress (Division 1, Vol. 1), Montreal, Canada, August 1990. Pp. 340–350.

Polvi LE, Wohl E, Merritt DM 2014. Modeling the functional influence of vegetation type on streambank cohesion. Earth Surface Processes and Landforms 39(9): 1245–1258.

Reid LM, Page MJ 2003. Magnitude and frequency of landsliding in a large New Zealand catchment. Geomorphology 49(1–2): 71–88.

Renard KG 1997. Predicting soil erosion by water: a guide to conservation planning with the Revised Universal Soil Loss Equation (RUSLE). Washington, DC, United States Government Printing.

Rosewell CJ, Loch RJ 2002. Estimation of the RUSLE soil erodibility factor. In: McKenzie N, Coughlan K, Cresswell H eds. Soil physical measurement and interpretation for land evaluation. Melbourne, Australia, CSIRO Publishing.

Semadeni-Davies A, Elliott S 2016. Modelling the effect of stock exclusion on *E. coli* in rivers and streams: national application. Technical Paper No. 2017/10, prepared for Ministry for Primary Industries by NIWA.

Sibson R 1981. A brief description of natural neighbor interpolation. In: Barnett V ed. Interpolating multivariate data. Chichester, UK, John Wiley. Pp. 21–36.

Simon A, Collison AJC 2002. Quantifying the mechanical and hydrologic effects of riparian vegetation on streambank stability. Earth Surface Processes and Landforms 27(5): 527–546.

Smith HG, Herzig A, Dymond JR, Basher LR 2019. Application of a revised SedNetNZ model to the Oreti and Aparima catchments, Southland. Manaaki Whenua – Landcare Research contract report LC3507, prepared for Our Land & Water National Science Challenge.

Smith HG, Spiekermann R, Dymond J, Basher L 2019. Predicting spatial patterns in riverbank erosion for catchment sediment budgets. New Zealand Journal of Marine and Freshwater Research 53(3): 338–362.

Smith HG, Spiekermann R, Betts H, Neverman AJ 2020. Application of a revised bank erosion model to update SedNetNZ results for Hawke's Bay. Manaaki Whenua – Landcare Research contract report LC3740, prepared for Hawke's Bay Regional Council.

Smith HG, Spiekermann R, Betts H, Neverman AJ 2021. Comparing methods of landslide data acquisition and susceptibility modelling: examples from New Zealand. Geomorphology 381: 107660.

Smith HG, Neverman AJ, Betts H, Spiekermann R 2023. The influence of spatial patterns in rainfall on shallow landslides. Geomorphology 437: 108795.

Sood A 2014. Improved bias corrected and downscaled regional climate model data for climate impact studies: validation and assessment for New Zealand. Retrieved from www.researchgate.net/publication/265510643_Improved_Bias_Corrected_and_Downscaled_Regional_Climate_Model_Data_for_Climate_Impact_Studies_Validation_and_Assessment_for_New_Zealand

Spiekermann R, Betts H, Dymond J, Basher L 2017. Volumetric measurement of river bank erosion from sequential historical aerial photography. Geomorphology 296: 193–208.

Thorne CR 1990. Effects of vegetation on riverbank erosion and stability. In: Thornes JB ed. Vegetation and erosion. Chichester, UK, John Wiley & Sons. Pp. 125–144.

Trimble SW 1994. Erosional effects of cattle on streambanks in Tennessee, U.S.A. Earth Surface Processes and Landforms 19(5): 451–464.

Vale SS, Smith HG, Neverman A, Herzig A 2021. Application of SedNetNZ with land management and climate change scenarios and temporal disaggregation in the Bay of Plenty Region. Manaaki Whenua – Landcare Research contract report LC4002, prepared for Bay of Plenty Regional Council.

Vale SS, Smith HG, Neverman A, Herzig A 2022. Application of SedNetNZ with SLUI erosion mitigation and climate change scenarios in the Horizons region to support NPS-FM

2020 implementation. Manaaki Whenua – Landcare Research contract report LC5033, prepared for Horizons Regional Council.

Vale SS, & Smith HG 2023. Application of SedNetNZ using updated erosion mitigations with climate change scenarios in the Horizons region to support NPS-FM 2020 implementation. Manaaki Whenua – Landcare Research contract report LC4295, prepared for Horizons Regional Council.

Walker M, Rutherfurd ID 1999. An approach to predicting rates of bend migration in meandering alluvial streams. In: Rutherfurd ID, Bartley R eds. Proceedings of the Second Australian Stream Management Conference, Melbourne, Australia. Cooperative Research Centre for Catchment Hydrology. Pp. 659–665.

Wang G, Gertner G, Liu X, Anderson A 2001. Uncertainty assessment of soil erodibility factor for revised universal soil loss equation. Catena 46(1): 1–14.

Whitehead AL, Booker DJ 2020. NZ river maps: an interactive online tool for mapping predicted freshwater variables across New Zealand. Christchurch, NIWA. https://shiny.niwa.co.nz/nzrivermaps/

Wilkinson SN, Prosser IP, Rustomji P, Read AMJEM, Software 2009. Modelling and testing spatially distributed sediment budgets to relate erosion processes to sediment yields. Environmental Modelling & Software 24(4): 489–501.

Williamson R, Smith C, Cooper A 1996. Watershed riparian management and its benefits to a eutrophic lake. Journal of Water Resources Planning and Management 122: 24–32.

Wischmeier WH, Johnson C, Cross B 1971. Soil erodibility nomograph for farmland and construction sites. Journal of Soil and Water Conservation 26(5): 189–193.

Woods R, Hendrikx J, Henderson R, Tait A 2006. Estimating mean flow of New Zealand rivers. Journal of Hydrology New Zealand 45(2): 95–109.

Wynn T, Mostaghimi S 2006. The effects of vegetation and soil type on streambank erosion, Southwestern Virginia, usa1. Journal of the American Water Resources Association 42(1): 69–82.

Yang X, Gray J, Chapman G, Zhu Q, Tulau M, McInnes-Clarke S 2018. Digital mapping of soil erodibility for water erosion in New South Wales, Australia. Soil Research 56(2): 158–170.

Zhang X, Liu X, Zhang M, Dahlgren RA, Eitzel M 2010. A Review of vegetated buffers and a meta-analysis of their mitigation efficacy in reducing nonpoint source pollution. Journal of Environmental Quality 39(1): 76–84.

Zhang X, Phillips C, Pearce A 1991. Surface movement in an earthflow complex, Raukumara Peninsula, New Zealand. Geomorphology 4(3): 261–272.

Appendix A1 –Backward-looking and future mitigation scenario figures

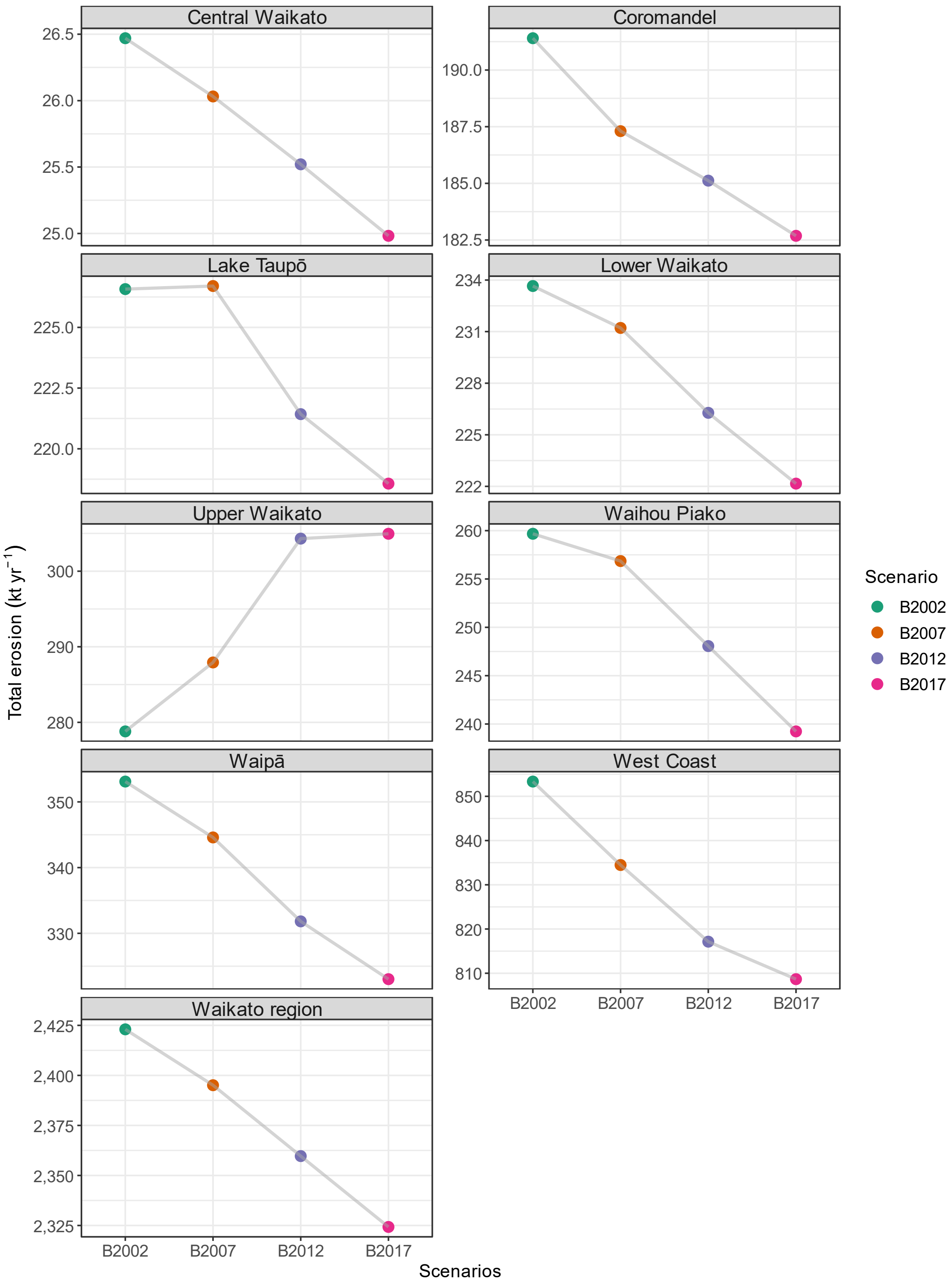

Figure A1.1. Total erosion (kt yr^{-1}) for B2002, B2007, B2012, and B2017 scenarios representing WRC riparian survey years summarised by CMZ and for the whole region.

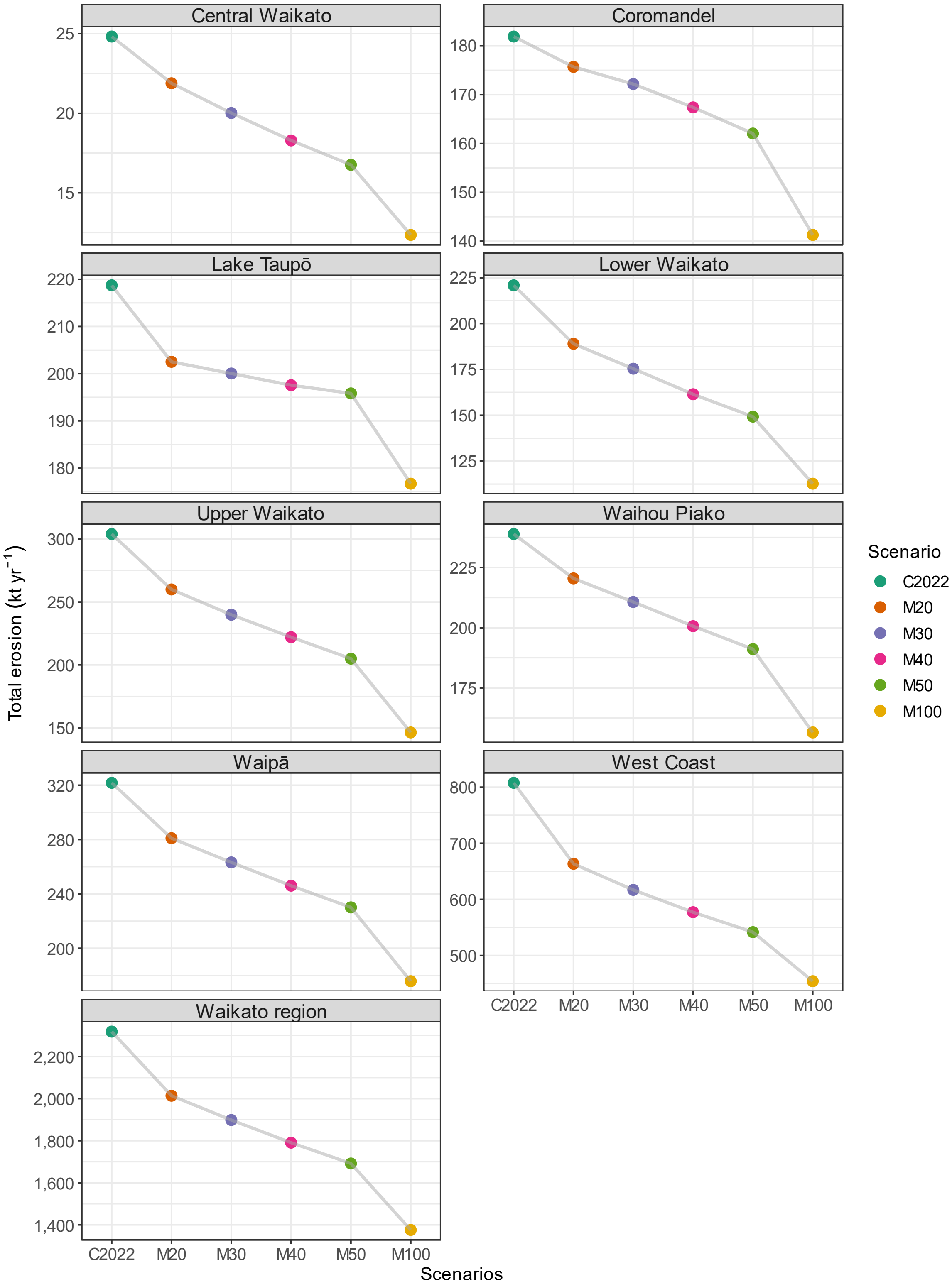

Figure A1.2. Total erosion (kt yr^{-1}) modelled for future mitigation scenarios, summarised by CMZ and for the whole region.

Appendix A2 – Total erosion by mid- and late century for each scenario under projected climate change

Table A2.1. Total erosion by mid-century for each climate change scenario, represented by minimum, median, and maximum selected climate models for each RCP, summarised for the CMZ and whole region

	CMZ	stat	Total erosion (kt yr^{-1})																			
			Contemporary baseline				Mitigation scenarios															
			C2022				M20				M430				M40				M50			
			RCP 2.6	RCP 4.5	RCP 6.0	RCP 8.5	RCP 2.6	RCP 4.5	RCP 6.0	RCP 8.5	RCP 2.6	RCP 4.5	RCP 6.0	RCP 8.5	RCP 2.6	RCP 4.5	RCP 6.0	RCP 8.5	RCP 2.6	RCP 4.5	RCP 6.0	RCP 8.5
Mid-century	Central Waikato	min	26	29	30	33	23	26	26	29	21	23	23	26	19	21	21	23	17	19	19	21
		med	29	32	31	34	25	28	27	30	23	25	24	27	20	23	22	24	18	20	20	21
		max	31	35	36	39	27	31	32	34	25	27	28	30	22	24	25	27	20	22	22	24
	Coromandel	min	208	216	228	223	203	210	222	217	199	205	218	212	193	199	211	205	187	192	204	197
		med	208	220	215	230	202	213	209	223	198	208	204	218	192	202	197	211	185	194	190	203
		max	227	234	242	239	221	227	235	231	216	221	229	225	209	214	222	217	202	206	213	208
	Lake Taupō	min	221	240	244	260	201	218	221	234	198	214	217	230	195	211	214	225	193	208	211	223
		med	238	258	249	278	216	233	225	251	212	229	221	247	209	225	217	243	206	222	215	240
		max	253	266	270	292	229	239	242	260	225	234	237	256	222	230	233	251	219	227	230	247
	Lower Waikato	min	240	261	267	288	206	223	229	246	189	205	211	226	173	187	192	205	158	171	175	187
		med	255	282	278	299	218	240	237	255	201	220	218	234	182	200	199	212	167	182	181	194
		max	277	303	318	334	236	258	271	284	217	236	248	260	197	214	225	235	180	195	205	214
	Upper Waikato	min	353	396	402	447	301	337	342	380	276	309	313	347	254	284	287	318	233	260	262	290
		med	384	432	416	463	327	368	354	394	299	337	324	361	275	309	297	331	251	283	272	303
		max	418	469	482	525	357	398	409	444	327	364	374	405	300	334	342	371	275	305	312	338
	Waihou–Piako	min	264	285	282	308	246	264	262	285	234	251	248	270	222	237	234	254	210	224	220	239
		med	276	300	294	319	256	277	272	295	243	262	258	279	230	247	243	263	217	233	229	247
		max	301	322	336	350	279	297	310	322	265	281	293	303	250	264	275	284	236	248	259	266
	Waipā	min	363	400	396	440	321	352	346	385	299	327	321	356	278	303	296	329	258	281	273	303
		med	385	432	420	466	338	379	368	409	314	351	342	379	291	325	316	350	269	300	292	323
		max	423	463	476	512	372	405	416	446	345	374	384	411	319	345	354	378	296	318	326	348
	West Coast	min	957	1,051	1,026	1,139	786	858	826	914	729	793	759	839	679	738	701	775	636	688	650	717
		med	1,010	1,142	1,098	1,226	824	926	892	993	761	853	822	915	707	791	763	848	659	735	710	788
		max	1,136	1,215	1,259	1,339	929	980	1,014	1,074	859	901	931	985	799	834	861	909	746	774	798	841
	Waikato Region	**min**	**2,632**	**2,878**	**2,875**	**3,138**	**2,287**	**2,489**	**2,473**	**2,688**	**2,145**	**2,329**	**2,308**	**2,504**	**2,013**	**2,180**	**2,155**	**2,333**	**1,891**	**2,043**	**2,015**	**2,177**
		med	**2,785**	**3,097**	**2,999**	**3,314**	**2,406**	**2,664**	**2,584**	**2,849**	**2,250**	**2,486**	**2,413**	**2,658**	**2,105**	**2,321**	**2,254**	**2,481**	**1,972**	**2,169**	**2,108**	**2,319**
		max	**3,068**	**3,306**	**3,418**	**3,629**	**2,650**	**2,833**	**2,927**	**3,095**	**2,478**	**2,640**	**2,725**	**2,875**	**2,319**	**2,459**	**2,538**	**2,672**	**2,172**	**2,294**	**2,366**	**2,485**

Table A2.2. Total erosion by late century for each climate change scenario, represented by minimum, median, and maximum selected climate models for each RCP, summarised for the CMZ and whole region

	CMZ	stat	Total erosion ($kt\ yr^{-1}$)																							
			Contemporary baseline				Mitigation scenarios																			
			C2022				M20				M430				M40				M50				M100			
			RCP 2.6	RCP 4.5	RCP 6.0	RCP 8.5	RCP 2.6	RCP 4.5	RCP 6.0	RCP 8.5	RCP 2.6	RCP 4.5	RCP 6.0	RCP 8.5	RCP 2.6	RCP 4.5	RCP 6.0	RCP 8.5	RCP 2.6	RCP 4.5	RCP 6.0	RCP 8.5	RCP 2.6	RCP 4.5	RCP 6.0	RCP 8.5
Late century	**Central Waikato**	**min**	25	29	35	43	22	26	30	38	20	23	27	34	18	21	24	30	16	18	22	27	11	12	14	17
		med	28	33	39	48	24	29	34	42	22	26	31	38	20	23	27	33	18	21	24	29	12	13	16	19
		max	31	37	43	53	28	32	38	46	25	29	34	41	22	26	30	36	20	23	27	32	13	15	17	20
	Coromandel	**min**	197	216	242	273	192	211	236	265	188	206	230	258	182	200	223	249	176	193	215	239	153	166	184	200
		med	204	228	252	289	199	221	244	280	194	216	238	273	189	209	230	263	182	201	221	252	156	170	187	209
		max	232	248	273	303	225	240	264	293	220	234	257	285	214	227	248	274	206	218	238	262	177	183	199	214
	Lake Taupō	**min**	214	236	274	323	195	213	247	288	192	209	242	282	189	206	238	277	187	203	235	273	165	176	202	229
		med	230	270	294	352	208	243	262	312	205	239	257	305	202	235	252	299	199	232	249	294	174	199	210	243
		max	250	282	321	377	226	252	286	332	222	247	281	325	218	242	275	318	215	239	271	313	185	202	228	258
	Lower Waikato	**min**	225	259	303	369	193	221	259	313	178	203	238	286	162	185	216	259	149	169	197	235	108	121	141	165
		med	250	293	335	408	213	249	285	345	196	228	261	315	178	207	236	285	163	189	215	258	117	133	152	179
		max	281	326	375	443	240	276	318	374	220	253	292	341	200	229	264	308	182	208	240	278	130	146	169	192
	Upper Waikato	**min**	334	396	470	595	286	337	400	504	262	309	366	460	242	284	336	421	222	259	307	384	153	177	207	255
		med	374	456	533	673	319	387	451	568	292	354	411	517	268	325	376	472	245	297	343	429	167	200	227	281
		max	423	506	590	728	360	428	500	614	330	391	456	559	302	358	417	510	276	326	380	463	187	216	252	301
	Waihou– Piako	**min**	253	284	324	392	236	264	299	361	225	250	283	340	213	236	266	319	202	223	251	299	162	176	194	227
		med	270	312	355	426	251	288	327	391	238	272	308	367	224	256	289	343	212	240	271	321	167	185	206	239
		max	305	345	393	463	283	318	361	423	268	300	341	397	253	282	319	371	238	264	299	345	187	202	226	255
	Waipā	**min**	342	402	467	578	303	353	409	503	282	328	379	465	262	304	350	427	244	281	323	393	181	204	231	275
		med	378	452	508	637	332	396	441	551	309	366	407	507	286	338	374	464	264	312	343	424	192	222	237	288
		max	426	494	578	687	373	430	503	594	346	397	464	546	320	365	427	499	296	335	392	456	213	234	273	308
	West Coast	**min**	894	1,056	1,227	1,512	738	861	992	1,212	685	795	914	1,111	640	739	846	1,025	599	689	786	948	500	566	640	762
		med	1,000	1,194	1,307	1,650	816	965	1,038	1,303	754	888	947	1,187	702	822	870	1,088	654	763	802	999	539	620	635	785
		max	1,124	1,300	1,520	1,813	910	1,041	1,216	1,437	839	954	1,114	1,310	777	880	1,028	1,203	723	813	950	1,107	589	652	761	874
	Waikato Region	**min**	**2,484**	**2,878**	**3,341**	**4,084**	**2,164**	**2,485**	**2,872**	**3,482**	**2,032**	**2,324**	**2,679**	**3,236**	**1,908**	**2,173**	**2,500**	**3,007**	**1,795**	**2,036**	**2,336**	**2,797**	**1,433**	**1,597**	**1,814**	**2,130**
		med	**2,733**	**3,237**	**3,623**	**4,484**	**2,362**	**2,778**	**3,082**	**3,792**	**2,210**	**2,589**	**2,861**	**3,508**	**2,068**	**2,414**	**2,655**	**3,246**	**1,938**	**2,254**	**2,467**	**3,006**	**1,523**	**1,743**	**1,869**	**2,242**
		max	**3,072**	**3,538**	**4,093**	**4,867**	**2,645**	**3,018**	**3,487**	**4,112**	**2,469**	**2,805**	**3,238**	**3,804**	**2,306**	**2,607**	**3,008**	**3,518**	**2,156**	**2,426**	**2,797**	**3,256**	**1,681**	**1,849**	**2,125**	**2,422**

Appendix A3 – Suspended sediment load reductions required to achieve attribute bands and the NBL, and to maintain the base state under projected climate change

Table A3.1. Proportional reductions (%) in suspended sediment load required to achieve attribute bands and the NBL, and to maintain the base state at SOE monitoring sites, under the contemporary baseline and future mitigation scenarios under project climate change at mid-century

CMZ	Site name	Site ID	Base state	Contemporary baseline				Mitigation scenarios															
				C2022				M20				M30				M40				M50			
				Base	C (NBL)	B	A	Base	C (NBL)	B	A	Base	C (NBL)	B	A	Base	C (NBL)	B	A	Base	C (NBL)	B	A
Central Waikato (10)	Karapiro Stm at Hickey Rd Bridge – Cambridge	230_5	D	14–43%	54–70%	62–75%	68–79%	11–41%	52–68%	60–74%	67–78%	2–34%	47–65%	57–71%	64–76%	0–26%	41–60%	51–67%	60–73%	0–14%	32–54%	44–62%	53–68%
	Kirikiriroa Stm at Tauhara Dr	253_4	D	0–0%	30–43%	47–58%	60–67%	0–0%	30–43%	47–58%	60–67%	0–0%	30–43%	47–58%	60–67%	0–0%	30–43%	47–58%	60–67%	0–0%	30–43%	47–58%	60–67%
	Mangakotukutuku Stm (Rukuhia) at Peacockes Rd	398_1	D	0–0%	5–17%	29–38%	45–52%	0–0%	5–17%	29–38%	45–52%	0–0%	5–17%	29–38%	45–52%	0–0%	5–17%	29–38%	45–52%	0–0%	5–17%	29–38%	45–52%
	Mangaone Stm (Waikato) at Annebrooke Rd Br	417_7	B	0–0%	0–0%	0–0%	0–0%	0–0%	0–0%	0–0%	0–0%	0–0%	0–0%	0–0%	0–0%	0–0%	0–0%	0–0%	0–0%	0–0%	0–0%	0–0%	0–0%
	Mangaonua Stm at Hoeka Rd	421_10	B	12–42%	0–14%	2–36%	25–51%	0–33%	0–<1%	0–25%	14–43%	0–30%	0–0%	0–22%	10–40%	0–21%	0–0%	0–12%	0–32%	0–14%	0–0%	0–5%	0–27%
	Mangaonua Stm at Te Miro Rd (a.k.a Waitakaruru Stm)	421_16	A	15–43%	0–0%	0–7%	0–29%	3–35%	0–0%	0–0%	0–18%	0–31%	0–0%	0–0%	0–13%	0–25%	0–0%	0–0%	0–6%	0–18%	0–0%	0–0%	0–0%
	Mangawhero Stm (Cambridge) at Cambridge-Ohaupo Rd	488_1	D	15–46%	78–86%	84–89%	87–92%	0–28%	71–81%	78–86%	83–89%	0–15%	66–78%	75–83%	80–87%	0–0%	55–71%	67–78%	74–83%	0–0%	50–67%	63–75%	71–81%
	Waikato River at Horotiu Br	1131_69	D	6–37%	49–65%	58–71%	65–76%	0–30%	43–62%	53–68%	61–74%	0–23%	38–58%	49–65%	57–71%	0–15%	33–53%	44–62%	54–68%	0–6%	26–48%	39–57%	49–64%
	Waikato River at Narrows Boat Ramp	1131_328	D	6–37%	37–58%	48–65%	57–71%	0–31%	31–53%	43–62%	53–68%	0–23%	24–48%	37–57%	48–64%	0–15%	18–43%	32–53%	43–61%	0–6%	9–37%	25–48%	37–56%
	Waitawhiriwhiri Stm at Edgecumbe Street	1236_2	D	0–0%	37–46%	53–59%	64–69%	0–0%	37–46%	53–59%	64–69%	0–0%	37–46%	53–59%	64–69%	0–0%	37–46%	53–59%	64–69%	0–0%	37–46%	53–59%	64–69%
Coromandel (4)	Tapu River at Tapu-Coroglen Rd	954_5	A	6–26%	0–0%	0–0%	0–0%	6–26%	0–0%	0–0%	0–0%	6–26%	0–0%	0–0%	0–0%	6–26%	0–0%	0–0%	0–0%	6–26%	0–0%	0–0%	0–0%
	Waiau River at E309 Rd Ford	1105_3	A	11–25%	0–0%	0–0%	0–0%	11–25%	0–0%	0–0%	0–0%	11–25%	0–0%	0–0%	0–0%	11–25%	0–0%	0–0%	0–0%	11–25%	0–0%	0–0%	0–0%
	Waiwawa River at SH25 Coroglen	1257_3	A	7–16%	0–0%	0–0%	0–0%	7–16%	0–0%	0–0%	0–0%	7–16%	0–0%	0–0%	0–0%	6–15%	0–0%	0–0%	0–0%	4–13%	0–0%	0–0%	0–0%
	Wharekawa River at SH25	1312_3	A	13–28%	0–0%	0–0%	0–1%	13–28%	0–0%	0–0%	0–1%	13–28%	0–0%	0–0%	0–1%	13–28%	0–0%	0–0%	0–1%	12–26%	0–0%	0–0%	0–0%
Lake Taupō (6)	Hinemaiaia River at SH1	171_5	A	<1–26%	0–0%	0–0%	0–8%	<1–26%	0–0%	0–0%	0–8%	<1–26%	0–0%	0–0%	0–8%	<1–26%	0–0%	0–0%	0–8%	<1–26%	0–0%	0–0%	0–8%
	Kuratau River at SH41 Moerangi	282_4	A	12–35%	0–0%	0–0%	0–11%	12–35%	0–0%	0–0%	0–11%	12–35%	0–0%	0–0%	0–11%	12–35%	0–0%	0–0%	0–11%	12–35%	0–0%	0–0%	0–11%
	Mapara Stm (Lake Taupō) at Off Mapara Rd (Whakaipo Res) T1	504_2	D	10–42%	25–52%	38–60%	48–67%	10–42%	25–52%	38–60%	48–67%	10–42%	25–52%	38–60%	48–67%	10–42%	25–52%	38–60%	48–67%	0–31%	11–42%	26–52%	39–60%
	Tauranga-Taupo River at 20 metres U/S SH1 Bridge	971_5	A	0–6%	0–0%	0–0%	0–0%	0–6%	0–0%	0–0%	0–0%	0–6%	0–0%	0–0%	0–0%	0–6%	0–0%	0–0%	0–0%	0–6%	0–0%	0–0%	0–0%
	Waihaha River at SH32	1106_4	A	11–33%	0–0%	0–0%	0–0%	11–33%	0–0%	0–0%	0–0%	11–33%	0–0%	0–0%	0–0%	11–33%	0–0%	0–0%	0–0%	11–33%	0–0%	0–0%	0–0%
	Waitahanui River at Blake Rd	1226_1	A	12–39%	0–0%	0–0%	0–2%	12–39%	0–0%	0–0%	0–2%	12–39%	0–0%	0–0%	0–2%	12–39%	0–0%	0–0%	0–2%	12–39%	0–0%	0–0%	0–2%
Lower Waikato (18)	Awaroa River (Waiuku) at Otaua Rd Br opp Moseley Rd	41_9	D	0–10%	74–79%	79–82%	82–85%	0–10%	74–79%	79–82%	82–85%	0–10%	74–79%	79–82%	82–85%	0–10%	74–79%	79–82%	82–85%	0–10%	74–79%	79–82%	82–85%
	Awaroa Stm (Rotowaro) at Sansons Br @ Rotowaro-Huntly Rd	39_11	A	14–37%	0–0%	0–0%	0–2%	5–30%	0–0%	0–0%	0–0%	3–28%	0–0%	0–0%	0–0%	0–16%	0–0%	0–0%	0–0%	0–6%	0–0%	0–0%	0–0%
	Komakorau Stm at Henry Rd	258_4	D	0–0%	79–82%	84–87%	88–90%	0–0%	79–82%	84–87%	88–90%	0–0%	79–82%	84–87%	88–90%	0–0%	79–82%	84–87%	88–90%	0–0%	79–82%	84–87%	88–90%
	Mangatangi River at SH2 Maramarua	453_6	D	12–35%	37–54%	53–65%	64–73%	6–30%	33–51%	50–63%	62–72%	3–28%	31–49%	48–62%	60–70%	0–24%	27–46%	46–59%	58–69%	0–16%	21–40%	41–55%	55–66%

CMZ	Site name	Site ID	Base state	Contemporary baseline				Mitigation scenarios															
				C2022				M20				M30				M40				M50			
				Base	C (NBL)	B	A	Base	C (NBL)	B	A	Base	C (NBL)	B	A	Base	C (NBL)	B	A	Base	C (NBL)	B	A
Lower Waikato (18) (cont.)	Mangatawhiri River at Lyons Rd at Buckingham Br	459_6	A	12–32%	0–0%	0–0%	0–0%	12–32%	0–0%	0–0%	0–0%	12–32%	0–0%	0–0%	0–0%	12–32%	0–0%	0–0%	0–0%	10–30%	0–0%	0–0%	0–0%
	Mangawara Stm at Rutherford Rd Br	481_7	D	14–43%	80–87%	85–90%	89–92%	5–36%	78–85%	84–89%	87–92%	0–31%	76–84%	82–88%	86–91%	0–21%	73–82%	80–86%	85–90%	0–11%	70–80%	78–85%	83–88%
	Northern Outlet Canal at DownStream of Control Gates	3021_3	D	13–41%	99–99%	99–99%	99–99%	0–25%	98–99%	99–99%	99–99%	0–14%	98–99%	99–99%	99–99%	0–3%	98–99%	98–99%	99–99%	0–0%	98–98%	98–99%	98–99%
	Ohaeroa Stm at SH22 Br	612_9	B	10–31%	0–0%	0–22%	22–40%	10–31%	0–0%	0–22%	22–40%	10–31%	0–0%	0–22%	22–40%	2–24%	0–0%	0–15%	16–35%	0–19%	0–0%	0–9%	10–30%
	Opuatia Stm at Ponganui Rd	665_5	D	15–39%	33–52%	50–64%	61–73%	0–25%	17–41%	38–56%	52–66%	0–18%	10–36%	33–52%	49–63%	0–11%	3–30%	27–48%	44–60%	0–0%	0–19%	16–39%	36–54%
	Waerenga Stm at Taniwha Rd	1098_1	C	17–45%	0–30%	21–48%	40–60%	0–31%	0–13%	2–35%	25–50%	0–11%	0–0%	0–15%	3–35%	0–0%	0–0%	0–0%	0–20%	0–0%	0–0%	0–0%	0–16%
	Waikato River at Huntly–Tainui Br	1131_77	D	11–37%	73–81%	77–84%	81–87%	0–28%	69–78%	75–82%	79–85%	0–22%	67–76%	73–80%	77–84%	0–15%	64–74%	70–79%	75–82%	0–7%	61–72%	68–77%	73–80%
	Waikato River at Mercer Br	1131_91	D	10–37%	82–88%	86–90%	88–91%	0–27%	80–86%	84–88%	86–90%	0–20%	78–84%	82–87%	85–89%	0–13%	77–83%	81–86%	84–88%	0–4%	75–81%	79–85%	83–87%
	Waikato River at Rangiriri Br	1131_117	D	10–37%	73–81%	78–84%	82–87%	0–28%	70–78%	75–82%	79–85%	0–22%	67–77%	73–81%	78–84%	0–15%	65–74%	71–79%	76–82%	0–7%	62–72%	69–77%	74–81%
	Waikato River at Tuakau Br	1131_133	D	10–36%	81–87%	85–89%	87–91%	0–27%	79–85%	82–87%	85–90%	0–20%	77–83%	81–86%	84–89%	0–13%	75–82%	79–85%	83–88%	0–5%	73–80%	78–84%	81–86%
	Whakapipi Stm at SH22 Br	1282_8	D	6–28%	7–29%	23–41%	36–51%	6–28%	7–29%	23–41%	36–51%	6–28%	7–29%	23–41%	36–51%	2–25%	3–26%	20–39%	33–49%	0–14%	0–15%	10–30%	25–42%
	Whangamarino River at Island Block Rd	1293_7	D	12–39%	97–98%	98–98%	98–99%	0–27%	97–98%	97–98%	98–98%	0–17%	96–97%	97–98%	97–98%	0–6%	96–97%	97–98%	97–98%	0–0%	95–97%	96–97%	97–98%
	Whangamarino River at Jefferies Rd Br	1293_9	D	14–43%	71–80%	78–85%	83–89%	0–30%	64–76%	73–82%	80–86%	0–17%	58–72%	68–79%	76–84%	0–1%	50–66%	63–75%	71–81%	0–0%	42–61%	57–71%	67–77%
	Whangape Stm at Rangiriri-Glen Murray Rd	1302_1	D	12–36%	98–99%	98–99%	99–99%	0–21%	98–98%	98–99%	98–99%	0–11%	97–98%	98–98%	98–99%	0–3%	97–98%	98–98%	98–99%	0–0%	97–98%	97–98%	98–98%
Upper Waikato (18)	Kawaunui Stm at SH5 Br	240_5	D	13–37%	32–51%	44–60%	53–67%	13–37%	32–51%	44–60%	53–67%	0–20%	15–38%	30–49%	42–57%	0–2%	0–24%	16–37%	30–48%	0–2%	0–24%	16–37%	30–48%
	Little Waipa Stm at Arapuni–Putaruru Rd	335_1	C	0–34%	0–21%	0–35%	16–46%	0–31%	0–18%	0–32%	12–44%	0–29%	0–15%	0–30%	9–42%	0–29%	0–15%	0–30%	9–42%	0–28%	0–13%	0–29%	7–40%
	Mangaharakeke Stm (Atiamuri) at SH30 (Off Jct SH1)	359_1	D	16–42%	42–60%	52–67%	60–73%	8–36%	36–56%	47–63%	56–69%	3–33%	33–53%	45–61%	54–68%	<1–30%	31–52%	43–60%	52–67%	0–28%	29–50%	41–59%	51–66%
	Mangakara Stm (Reporoa) at SH5	380_2	D	19–47%	65–77%	71–81%	76–84%	0–31%	55–70%	63–75%	69–79%	0–22%	49–66%	58–72%	65–77%	0–8%	40–60%	50–67%	58–72%	0–0%	32–54%	43–62%	53–68%
	Mangakino Stm (Whakamaru) at Sandel Rd	388_1	B	15–42%	0–22%	5–35%	21–46%	15–42%	0–22%	5–35%	21–46%	10–39%	0–18%	<1–32%	17–43%	8–37%	0–15%	0–30%	15–42%	2–32%	0–9%	0–25%	9–37%
	Mangamingi Stm (Tokoroa) at Paraonui Rd Br	407_1	D	0–27%	50–66%	59–72%	66–77%	0–25%	49–65%	58–71%	65–76%	0–24%	48–65%	57–71%	64–76%	0–13%	41–59%	51–67%	59–72%	0–7%	37–56%	48–64%	57–70%
	Otamakokore Stm at Hossack Rd	683_4	D	18–45%	29–52%	41–60%	51–67%	0–26%	6–36%	22–47%	35–56%	0–19%	0–30%	16–42%	30–52%	0–19%	0–30%	16–42%	30–52%	0–13%	0–25%	9–38%	24–48%
	Pokaiwhenua Stm at Puketurua	786_2	D	0–28%	22–46%	36–55%	46–63%	0–28%	22–46%	35–55%	46–63%	0–24%	18–43%	32–53%	43–60%	0–20%	14–40%	29–50%	41–58%	0–15%	9–36%	25–47%	38–56%
	Pueto Stm at Broadlands Rd Br	802_1	B	18–47%	0–36%	17–47%	31–56%	0–6%	0–0%	0–5%	0–21%	0–0%	0–0%	0–0%	0–10%	0–0%	0–0%	0–0%	0–0%	0–0%	0–0%	0–0%	0–0%
	Tahunaatara Stm at Ohakuri Rd	934_1	D	15–39%	31–50%	43–59%	52–66%	7–33%	24–45%	38–55%	48–62%	1–28%	20–41%	34–52%	45–60%	0–20%	11–35%	27–46%	39–55%	0–15%	7–31%	23–43%	36–53%
	Waikato River at Karapiro Tailrace	1131_79	D	7–37%	33–55%	45–63%	54–69%	2–33%	29–52%	42–60%	51–67%	0–28%	24–48%	37–57%	48–64%	0–23%	19–45%	34–55%	45–62%	0–16%	13–40%	28–50%	40–59%
	Waikato River at Lake Ohakuri Boat Ramp	1131_82	C	16–44%	1–34%	19–46%	32–55%	0–25%	0–12%	0–27%	10–39%	0–13%	0–0%	0–16%	0–30%	0–<1%	0–0%	0–4%	0–20%	0–0%	0–0%	0–0%	0–9%
	Waikato River at Ohaaki Br	1131_105	A	11–41%	0–0%	0–0%	0–0%	0–6%	0–0%	0–0%	0–0%	0–0%	0–0%	0–0%	0–0%	0–0%	0–0%	0–0%	0–0%	0–0%	0–0%	0–0%	0–0%
	Waikato River at Waipapa Tailrace	1131_143	D	14–42%	21–47%	35–56%	46–63%	12–40%	19–45%	33–55%	44–62%	8–37%	16–42%	30–53%	42–60%	4–34%	12–39%	27–50%	39–58%	0–29%	6–35%	22–46%	35–55%
	Waikato River at Whakamaru Tailrace	1131_147	C	14–41%	10–39%	26–49%	38–58%	0–29%	0–26%	12–39%	27–49%	0–24%	0–20%	6–34%	22–45%	0–18%	0–14%	0–29%	16–41%	0–10%	0–6%	0–22%	9–35%
	Waiotapu Stm at Campbell Rd Br	1186_2	D	17–43%	38–57%	49–65%	58–71%	4–33%	28–50%	41–59%	51–66%	<1–30%	26–48%	39–57%	49–64%	0–24%	19–43%	33–53%	44–61%	0–12%	8–35%	24–46%	36–55%
	Waipapa Stm (Mokai) at Tirohanga Rd Br	1202_7	D	15–43%	32–54%	43–62%	53–69%	6–37%	24–49%	37–58%	48–65%	0–31%	17–44%	32–54%	43–62%	0–30%	16–43%	31–53%	42–61%	0–22%	7–37%	23–48%	36–56%
	Whakauru Stm at U/S SH1 Br	1287_7	D	3–34%	80–86%	83–88%	86–90%	3–34%	80–86%	83–88%	86–90%	3–34%	80–86%	83–88%	86–90%	0–25%	77–84%	81–87%	84–89%	0–20%	76–83%	80–86%	83–89%

CMZ	Site name	Site ID	Base state	Contemporary baseline				Mitigation scenarios															
				C2022				M20				M30				M40				M50			
				Base	C (NBL)	B	A	Base	C (NBL)	B	A	Base	C (NBL)	B	A	Base	C (NBL)	B	A	Base	C (NBL)	B	A
Waihou Piako (18)	Hikutaia River at Old Maratoto Rd	169_2	A	12–25%	0–0%	0–0%	0–0%	10–22%	0–0%	0–0%	0–0%	9–21%	0–0%	0–0%	0–0%	3–16%	0–0%	0–0%	0–0%	0–12%	0–0%	0–0%	0–0%
	Kauaeranga River at Smiths Cableway Recorder	234_11	A	11–20%	0–0%	0–0%	0–0%	11–20%	0–0%	0–0%	0–0%	11–20%	0–0%	0–0%	0–0%	11–20%	0–0%	0–0%	0–0%	9–18%	0–0%	0–0%	0–0%
	Mangawhero Stm (Kaihere) at Mangawara Rd	489_2	B	14–38%	0–1%	0–26%	21–43%	14–38%	0–1%	0–26%	21–43%	14–38%	0–1%	0–26%	21–43%	14–38%	0–1%	0–26%	21–43%	0–25%	0–0%	0–10%	7–31%
	Ohinemuri River at Karangahake	619_16	A	9–25%	0–0%	0–0%	0–0%	5–21%	0–0%	0–0%	0–0%	2–18%	0–0%	0–0%	0–0%	0–13%	0–0%	0–0%	0–0%	0–8%	0–0%	0–0%	0–0%
	Ohinemuri River at Queens Head	619_19	A	9–28%	0–0%	0–0%	0–0%	4–24%	0–0%	0–0%	0–0%	0–19%	0–0%	0–0%	0–0%	0–10%	0–0%	0–0%	0–0%	0–<1%	0–0%	0–0%	0–0%
	Ohinemuri River at SH25 Br	619_20	A	13–31%	0–0%	0–0%	0–0%	3–23%	0–0%	0–0%	0–0%	0–17%	0–0%	0–0%	0–0%	0–0%	0–0%	0–0%	0–0%	0–0%	0–0%	0–0%	0–0%
	Oraka Stm at Lake Rd	669_6	D	10–36%	46–62%	56–69%	63–74%	7–34%	44–60%	54–67%	62–73%	1–29%	41–58%	51–65%	59–71%	0–26%	38–56%	49–63%	58–69%	0–21%	35–53%	46–61%	55–68%
	Piako River at Kiwitahi	749_10	B	15–43%	0–19%	<1–33%	17–44%	13–41%	0–17%	0–31%	15–43%	7–37%	0–10%	0–26%	9–38%	0–29%	0–0%	0–17%	0–31%	0–24%	0–0%	0–12%	0–26%
	Piako River at Paeroa-Tahuna Rd Br	749_15	B	15–45%	0–23%	12–42%	32–56%	<1–35%	0–9%	0–32%	21–48%	0–27%	0–0%	0–23%	11–41%	0–17%	0–0%	0–13%	<1–33%	0–6%	0–0%	0–2%	0–25%
	Piakonui Stm at Piakonui Rd	753_4	D	15–40%	32–52%	44–61%	53–67%	15–40%	32–52%	44–61%	53–67%	15–40%	32–52%	44–61%	53–67%	7–33%	25–47%	38–56%	49–63%	0–27%	19–41%	33–52%	44–60%
	Waihou River at Okauia	1122_18	D	9–34%	33–52%	45–60%	54–67%	5–31%	30–49%	42–58%	52–65%	<1–27%	27–46%	40–56%	50–63%	0–22%	23–43%	37–53%	47–61%	0–18%	20–40%	34–50%	45–59%
	Waihou River at Te Aroha	1122_34	A	4–28%	0–0%	0–5%	2–27%	<1–25%	0–0%	0–0%	0–23%	0–22%	0–0%	0–0%	0–20%	0–18%	0–0%	0–0%	0–16%	0–15%	0–0%	0–0%	0–13%
	Waihou River at Whites Rd	1122_41	A	11–38%	0–0%	0–0%	0–0%	8–36%	0–0%	0–0%	0–0%	6–35%	0–0%	0–0%	0–0%	2–31%	0–0%	0–0%	0–0%	2–31%	0–0%	0–0%	0–0%
	Waiomou Stm at Matamata-Tauranga Rd	1174_4	D	10–33%	19–40%	33–50%	44–58%	4–29%	13–35%	28–46%	40–55%	0–24%	7–31%	23–43%	36–52%	0–18%	0–25%	17–38%	31–49%	0–14%	0–22%	14–36%	28–46%
	Waitakaruru River (Hauraki Plains) at Coxhead Rd Br	1230_1	A	15–39%	0–0%	0–13%	6–33%	7–33%	0–0%	0–4%	0–26%	2–30%	0–0%	0–0%	0–23%	0–21%	0–0%	0–0%	0–13%	0–17%	0–0%	0–0%	0–9%
	Waitekauri River at U/S Ohinemuri conflu	1239_32	A	9–20%	0–0%	0–0%	0–0%	9–20%	0–0%	0–0%	0–0%	6–17%	0–0%	0–0%	0–0%	5–16%	0–0%	0–0%	0–0%	3–15%	0–0%	0–0%	0–0%
	Waitoa River at Landsdowne Rd Br	1249_15	C	13–42%	8–39%	24–50%	37–58%	9–39%	4–36%	21–47%	34–56%	5–36%	0–32%	17–44%	31–54%	0–28%	0–24%	7–37%	23–48%	0–17%	0–12%	0–27%	12–39%
	Waitoa River at Mellon Rd Recorder	1249_18	B	11–40%	0–3%	0–27%	17–44%	7–37%	0–0%	0–24%	14–42%	4–35%	0–0%	0–21%	11–40%	0–28%	0–0%	0–12%	2–33%	0–18%	0–0%	0–<1%	0–23%
Waipā (17)	Firewood Creek at Waingaro Road Bridge	124_8	B	15–40%	0–5%	<1–29%	24–46%	1–30%	0–0%	0–17%	11–37%	0–23%	0–0%	0–10%	3–31%	0–17%	0–0%	0–3%	0–25%	0–8%	0–0%	0–0%	0–17%
	Kaniwhaniwha Stm at Wright Rd	222_16	D	8–34%	58–70%	65–75%	71–79%	0–22%	51–65%	60–71%	66–76%	0–18%	49–63%	58–69%	65–74%	0–13%	46–61%	56–68%	63–73%	0–0%	39–54%	49–62%	58–69%
	Mangaohoi Stm at South Branch Maru Rd	411_9	D	13–32%	14–33%	29–45%	41–54%	13–32%	14–33%	29–45%	41–54%	13–32%	14–33%	29–45%	41–54%	13–32%	14–33%	29–45%	41–54%	13–32%	14–33%	29–45%	41–54%
	Mangaokewa Stm at Lawrence Street Br	414_6	D	15–41%	51–66%	59–72%	66–76%	4–32%	45–61%	54–68%	62–73%	0–26%	40–57%	50–65%	59–70%	0–16%	33–51%	45–60%	54–67%	0–8%	28–47%	41–56%	50–64%
	Mangapiko Stm (Pirongia/Te Awamutu) at Bowman Rd	438_3	D	12–40%	71–80%	76–84%	80–86%	0–29%	66–76%	72–80%	76–84%	0–20%	62–73%	68–78%	74–82%	0–10%	58–70%	65–75%	71–79%	0–0%	52–66%	61–72%	67–77%
	Mangapu River at Otorohanga	443_3	D	16–41%	72–81%	77–84%	81–87%	7–35%	70–79%	75–82%	79–85%	2–31%	68–77%	73–81%	78–84%	0–24%	65–75%	71–79%	76–83%	0–18%	63–73%	69–78%	74–82%
	Mangatutu Stm (Waikeria) at Walker Rd Br	476_7	D	11–34%	18–39%	32–50%	43–58%	3–28%	11–33%	27–45%	39–54%	0–23%	7–29%	23–42%	36–51%	0–20%	3–26%	20–39%	33–49%	0–16%	0–23%	17–36%	31–47%
	Mangauika Stm at Te Awamutu Borough W/S Intake	477_10	A	0–16%	0–0%	0–0%	0–0%	0–16%	0–0%	0–0%	0–0%	0–16%	0–0%	0–0%	0–0%	0–16%	0–0%	0–0%	0–0%	0–16%	0–0%	0–0%	0–0%
	Ohote Stm at Whatawhata/Horotiu Rd	624_5	D	0–0%	17–30%	38–47%	53–60%	0–0%	17–30%	38–47%	53–60%	0–0%	17–30%	38–47%	53–60%	0–0%	17–30%	38–47%	53–60%	0–0%	17–30%	38–47%	53–60%
	Puniu River at Bartons Corner Rd Br	818_2	D	13–41%	48–65%	57–71%	64–76%	5–36%	44–62%	54–68%	61–74%	0–30%	39–58%	50–66%	58–71%	0–22%	34–54%	45–62%	54–68%	0–15%	28–50%	41–59%	50–65%
	Puniu River at Wharepapa Rd Bridge	818_40	D	16–46%	21–49%	35–58%	45–65%	8–40%	13–44%	28–54%	40–61%	0–33%	4–37%	20–48%	34–57%	0–23%	0–27%	8–40%	23–50%	0–15%	0–20%	0–34%	16–45%
	Waipa River at Mangaokewa Rd	1191_5	A	15–42%	0–15%	0–30%	14–42%	15–42%	0–15%	0–30%	14–42%	15–42%	0–15%	0–30%	14–42%	0–23%	0–0%	0–7%	0–22%	0–23%	0–0%	0–7%	0–22%
	Waipa River at Ngaruawahia Br	1191_6	D	11–37%	69–78%	75–82%	79–85%	0–28%	65–75%	71–79%	76–83%	0–22%	63–73%	69–78%	74–81%	0–15%	60–70%	67–76%	72–80%	0–7%	57–68%	64–73%	70–78%

CMZ	Site name	Site ID	Base state	Contemporary baseline				Mitigation scenarios															
				C2022				M20				M30				M40				M50			
				Base	C (NBL)	B	A	Base	C (NBL)	B	A	Base	C (NBL)	B	A	Base	C (NBL)	B	A	Base	C (NBL)	B	A
Waipā (17) (cont.)	Waipa River at Pukehoua Bridge on Baffin Road	1191_2	D	13–38%	67–77%	73–81%	77–84%	3–30%	63–74%	70–78%	75–82%	0–24%	61–71%	68–76%	73–80%	0–18%	58–69%	65–74%	71–79%	0–11%	55–66%	62–72%	69–77%
	Waipa River at SH3 Otorohanga	1191_12	D	12–35%	40–56%	51–64%	59–70%	2–27%	34–50%	45–59%	54–66%	0–19%	28–45%	40–54%	50–62%	0–12%	22–40%	36–50%	47–59%	0–3%	16–34%	30–45%	42–55%
	Waitomo Stm at SH31 Otorohanga	1253_5	D	17–41%	77–84%	81–87%	84–89%	12–37%	76–83%	80–86%	83–88%	9–35%	75–82%	80–85%	83–88%	5–32%	74–81%	79–85%	82–87%	0–22%	71–79%	76–83%	80–85%
	Waitomo Stm at Tumutumu Rd	1253_7	D	17–41%	43–60%	53–67%	61–72%	8–34%	37–55%	48–63%	57–69%	7–33%	37–54%	48–62%	56–68%	4–30%	34–53%	46–61%	55–67%	0–26%	31–49%	43–58%	52–65%
West Coast (14)	Awakino River at Gribbon Rd	33_6	D	0–28%	4–39%	21–49%	34–58%	0–24%	0–35%	14–47%	28–55%	0–23%	0–34%	12–46%	27–55%	0–22%	0–34%	11–45%	26–54%	0–21%	0–32%	9–44%	24–53%
	Awakino River at SH3 Awakau Rd Junction	33_9	A	17–41%	0–0%	0–0%	0–12%	0–28%	0–0%	0–0%	0–0%	0–23%	0–0%	0–0%	0–0%	0–18%	0–0%	0–0%	0–0%	0–12%	0–0%	0–0%	0–0%
	Manganui River at off Manganui Rd	410_4	A	3–34%	0–0%	0–0%	0–7%	0–28%	0–0%	0–0%	0–0%	0–23%	0–0%	0–0%	0–0%	0–19%	0–0%	0–0%	0–0%	0–17%	0–0%	0–0%	0–0%
	Mangaotaki River at SH3 Br	428_3	D	18–44%	45–63%	55–70%	62–75%	0–28%	31–52%	43–60%	52–67%	0–21%	25–48%	38–57%	48–64%	0–11%	17–41%	31–52%	43–60%	0–2%	8–35%	24–46%	37–55%
	Marokopa River at Speedies Rd (off Te Anga Rd)	513_3	D	16–38%	44–59%	54–66%	61–72%	<1–25%	34–50%	45–59%	54–66%	0–22%	31–48%	43–57%	53–64%	0–18%	27–45%	40–55%	50–62%	0–13%	23–42%	36–52%	47–60%
	Mokau River at Awakau Rd	556_2	D	16–43%	30–53%	48–65%	60–73%	0–28%	13–40%	35–55%	50–65%	0–20%	6–34%	30–50%	46–62%	0–13%	0–28%	24–46%	42–58%	0–5%	0–21%	18–41%	37–55%
	Mokau River at Mangaokewa Rd (off SH30)	556_5	D	12–35%	32–50%	44–59%	53–65%	4–28%	27–45%	39–54%	49–62%	4–28%	27–45%	39–54%	49–62%	<1–25%	24–42%	37–52%	48–60%	0–13%	14–33%	29–45%	41–54%
	Mokau River at Totoro Rd Recorder	556_9	D	16–44%	43–62%	53–68%	61–74%	0–28%	29–51%	41–60%	51–66%	0–21%	23–47%	36–56%	47–63%	0–13%	15–41%	30–51%	42–59%	0–4%	7–34%	23–46%	36–55%
	Mokauiti Stm at Three Way Point - Aria	557_5	B	18–47%	0–28%	18–46%	37–59%	0–29%	0–4%	0–28%	18–45%	0–19%	0–0%	0–19%	8–38%	0–9%	0–0%	0–8%	0–29%	0–0%	0–0%	0–0%	0–19%
	Ohautira Stm at Waingaro Te Uku Rd	616_1	A	2–28%	0–0%	0–0%	0–17%	0–10%	0–0%	0–0%	0–0%	0–10%	0–0%	0–0%	0–0%	0–8%	0–0%	0–0%	0–0%	0–5%	0–0%	0–0%	0–0%
	Oparau River at Langdon Rd (off Okupata Rd)	658_1	A	14–35%	0–0%	0–0%	0–0%	0–18%	0–0%	0–0%	0–0%	0–7%	0–0%	0–0%	0–0%	0–3%	0–0%	0–0%	0–0%	0–0%	0–0%	0–0%	0–0%
	Tawarau River at off Speedies Rd	976_1	D	17–40%	39–56%	49–63%	58–69%	0–25%	26–45%	39–54%	49–62%	0–22%	22–42%	35–52%	46–60%	0–16%	17–38%	31–49%	43–57%	0–10%	11–34%	26–45%	39–54%
	Waingaro River (Pukemiro) at Ruakiwi Rd off SH22	1167_4	B	14–37%	0–0%	0–23%	19–41%	1–27%	0–0%	0–11%	7–32%	0–19%	0–0%	0–1%	0–24%	0–13%	0–0%	0–0%	0–18%	0–4%	0–0%	0–0%	0–10%
	Waitetuna River at Te Uku-Waingaro Rd	1247_2	B	14–38%	0–0%	0–21%	16–40%	2–29%	0–0%	0–9%	4–30%	0–24%	0–0%	0–3%	0–26%	0–19%	0–0%	0–0%	0–20%	0–12%	0–0%	0–0%	0–13%

Table A3.2. Proportional reductions (%) in suspended sediment load required to achieve attribute bands and the NBL, and to maintain the base state at SOE monitoring sites under the contemporary baseline and future mitigation scenarios under project climate change at late century

CMZ	Site name	Site ID	Base state	Contemporary baseline				Mitigation scenarios																			
				C2022				M20				M30				M40				M50				M100			
				Base	C (NBL)	B	A	Base	C (NBL)	B	A	Base	C (NBL)	B	A	Base	C (NBL)	B	A	Base	C (NBL)	B	A	Base	C (NBL)	B	A
Central Waikato (10)	Karapiro Stm at Hickey Rd Bridge – Cambridge	230_5	D	10–59%	52–78%	60–82%	67–85%	6–57%	50–77%	58–81%	65–84%	0–52%	45–74%	54–79%	62–82%	0–46%	38–71%	49–76%	58–80%	0–37%	29–66%	41–72%	51–77%	0–0%	0–40%	5–51%	21–59%
	Kirikiriroa Stm at Tauhara Dr	253_4	D	0–3%	33–46%	50–60%	61–69%	0–3%	33–46%	50–60%	61–69%	0–3%	33–46%	50–60%	61–69%	0–3%	33–46%	50–60%	61–69%	0–3%	33–46%	50–60%	61–69%	0–3%	33–46%	50–60%	61–69%
	Mangakotukutuku Stm (Rukuhia) at Peacockes Rd	398_1	D	0–0%	7–20%	30–40%	47–54%	0–0%	7–20%	30–40%	47–54%	0–0%	7–20%	30–40%	47–54%	0–0%	7–20%	30–40%	47–54%	0–0%	7–20%	30–40%	47–54%	0–0%	5–19%	29–39%	46–53%
	Mangaone Stm (Waikato) at Annebrooke Rd Br	417_7	B	0–0%	0–0%	0–0%	0–0%	0–0%	0–0%	0–0%	0–0%	0–0%	0–0%	0–0%	0–0%	0–0%	0–0%	0–0%	0–0%	0–0%	0–0%	0–0%	0–0%	0–0%	0–0%	0–0%	0–0%
	Mangaonua Stm at Hoeka Rd	421_10	B	8–58%	0–37%	0–53%	22–64%	0–51%	0–27%	0–46%	10–58%	0–49%	0–24%	0–43%	6–56%	0–42%	0–14%	0–35%	0–50%	0–37%	0–6%	0–30%	0–46%	0–0%	0–0%	0–0%	0–7%
	Mangaonua Stm at Te Miro Rd (a.k.a Waitakaruru Stm)	421_16	A	10–59%	0–9%	0–32%	0–48%	0–53%	0–0%	0–22%	0–40%	0–50%	0–0%	0–17%	0–37%	0–45%	0–0%	0–10%	0–31%	0–40%	0–0%	0–<1%	0–24%	0–0%	0–0%	0–0%	0–0%
	Mangawhero Stm (Cambridge) at Cambridge-Ohaupo Rd	488_1	D	11–61%	77–90%	83–92%	87–94%	0–48%	70–86%	77–90%	83–92%	0–39%	64–84%	73–88%	80–91%	0–19%	53–79%	65–84%	73–88%	0–8%	48–76%	61–82%	70–86%	0–0%	26–65%	45–74%	57–80%
	Waikato River at Horotiu Br	1131_69	D	<1–53%	46–75%	55–79%	63–82%	0–48%	40–72%	51–77%	59–81%	0–43%	35–69%	46–74%	55–78%	0–37%	29–65%	41–72%	51–76%	0–30%	22–62%	36–68%	46–74%	0–0%	0–38%	4–49%	20–57%
	Waikato River at Narrows Boat Ramp	1131_328	D	1–54%	34–69%	45–74%	54–79%	0–49%	27–66%	40–72%	50–76%	0–43%	20–62%	34–68%	45–74%	0–37%	13–58%	28–65%	40–71%	0–30%	4–53%	21–61%	34–68%	0–0%	0–24%	0–38%	2–48%
	Waitawhiriwhiri Stm at Edgecumbe Street	1236_2	D	0–0%	41–50%	56–62%	66–71%	0–0%	41–50%	56–62%	66–71%	0–0%	41–50%	56–62%	66–71%	0–0%	41–50%	56–62%	66–71%	0–0%	41–50%	56–62%	66–71%	0–0%	41–50%	56–62%	66–71%
Coromandel (4)	Tapu River at Tapu-Coroglen Rd	954_5	A	6–24%	0–0%	0–0%	0–0%	6–24%	0–0%	0–0%	0–0%	6–24%	0–0%	0–0%	0–0%	6–24%	0–0%	0–0%	0–0%	6–24%	0–0%	0–0%	0–0%	3–21%	0–0%	0–0%	0–0%
	Waiau River at E309 Rd Ford	1105_3	A	7–37%	0–0%	0–0%	0–11%	7–37%	0–0%	0–0%	0–11%	7–37%	0–0%	0–0%	0–11%	7–37%	0–0%	0–0%	0–11%	7–37%	0–0%	0–0%	0–11%	5–35%	0–0%	0–0%	0–9%
	Waiwawa River at SH25 Coroglen	1257_3	A	6–26%	0–0%	0–0%	0–0%	6–26%	0–0%	0–0%	0–0%	6–26%	0–0%	0–0%	0–0%	5–25%	0–0%	0–0%	0–0%	3–23%	0–0%	0–0%	0–0%	0–15%	0–0%	0–0%	0–0%
	Wharekawa River at SH25	1312_3	A	9–43%	0–0%	0–6%	0–22%	9–43%	0–0%	0–6%	0–22%	9–43%	0–0%	0–6%	0–22%	9–43%	0–0%	0–6%	0–22%	8–42%	0–0%	0–4%	0–20%	5–39%	0–0%	0–<1%	0–17%
Lake Taupō (6)	Hinemaiaia River at SH1	171_5	A	0–42%	0–0%	0–14%	0–29%	0–42%	0–0%	0–14%	0–29%	0–42%	0–0%	0–14%	0–29%	0–42%	0–0%	0–14%	0–29%	0–42%	0–0%	0–14%	0–29%	0–42%	0–0%	0–14%	0–29%
	Kuratau River at SH41 Moerangi	282_4	A	8–52%	0–4%	0–21%	0–34%	8–52%	0–4%	0–21%	0–34%	8–52%	0–4%	0–21%	0–34%	8–52%	0–4%	0–21%	0–34%	8–52%	0–4%	0–21%	0–34%	8–52%	0–4%	0–21%	0–34%
	Mapara Stm (Lake Taupō) at Off Mapara Rd (Whakaipo Res) T1	504_2	D	5–59%	21–66%	35–72%	45–77%	5–59%	21–66%	35–72%	45–77%	5–59%	21–66%	35–72%	45–77%	5–59%	21–66%	35–72%	45–77%	0–51%	6–59%	22–66%	35–72%	0–0%	0–0%	0–10%	0–25%
	Tauranga-Taupo River at 20 metres U/S SH1 Bridge	971_5	A	0–22%	0–0%	0–0%	0–2%	0–22%	0–0%	0–0%	0–2%	0–22%	0–0%	0–0%	0–2%	0–22%	0–0%	0–0%	0–2%	0–22%	0–0%	0–0%	0–2%	0–22%	0–0%	0–0%	0–2%
	Waihaha River at SH32	1106_4	A	6–49%	0–0%	0–0%	0–11%	6–49%	0–0%	0–0%	0–11%	6–49%	0–0%	0–0%	0–11%	6–49%	0–0%	0–0%	0–11%	6–49%	0–0%	0–0%	0–11%	4–48%	0–0%	0–0%	0–8%
	Waitahanui River at Blake Rd	1226_1	A	5–54%	0–0%	0–13%	0–27%	5–54%	0–0%	0–13%	0–27%	5–54%	0–0%	0–13%	0–27%	5–54%	0–0%	0–13%	0–27%	5–54%	0–0%	0–13%	0–27%	1–52%	0–0%	0–9%	0–24%
Lower Waikato (18)	Awaroa River (Waiuku) at Otaua Rd Br opp Moseley Rd	41_9	D	0–21%	73–81%	78–84%	81–87%	0–21%	73–81%	78–84%	81–87%	0–21%	73–81%	78–84%	81–87%	0–21%	73–81%	78–84%	81–87%	0–21%	73–81%	78–84%	81–87%	0–0%	66–74%	72–78%	77–82%
	Awaroa Stm (Rotowaro) at Sansons Br @ Rotowaro-Huntly Rd	39_11	A	8–52%	0–0%	0–3%	0–26%	0–47%	0–0%	0–0%	0–17%	0–46%	0–0%	0–0%	0–15%	0–36%	0–0%	0–0%	0–<1%	0–28%	0–0%	0–0%	0–0%	0–4%	0–0%	0–0%	0–0%
	Komakorau Stm at Henry Rd	258_4	D	0–0%	80–83%	85–87%	88–90%	0–0%	80–83%	85–87%	88–90%	0–0%	80–83%	85–87%	88–90%	0–0%	80–83%	85–87%	88–90%	0–0%	80–83%	85–87%	88–90%	0–0%	80–83%	85–87%	88–90%
	Mangatangi River at SH2 Maramarua	453_6	D	8–50%	35–64%	51–73%	62–80%	2–46%	31–62%	48–71%	60–78%	0–44%	28–60%	46–70%	59–77%	0–41%	24–58%	43–69%	57–76%	0–35%	18–54%	38–65%	53–74%	0–0%	0–27%	8–45%	30–58%
	Mangatawhiri River at Lyons Rd at Buckingham Br	459_6	A	8–47%	0–0%	0–0%	0–17%	8–47%	0–0%	0–0%	0–17%	8–47%	0–0%	0–0%	0–17%	8–47%	0–0%	0–0%	0–17%	6–46%	0–0%	0–0%	0–15%	0–35%	0–0%	0–0%	0–0%
	Mangawara Stm at Rutherford Rd Br	481_7	D	10–59%	79–91%	84–93%	88–95%	0–54%	77–89%	83–92%	87–94%	0–50%	75–88%	81–91%	86–93%	0–42%	72–87%	79–90%	84–92%	0–35%	69–85%	77–89%	82–91%	0–0%	54–77%	66–83%	74–87%
	Northern Outlet Canal at DownStream of Control Gates	3021_3	D	8–57%	99–99%	99–100%	99–100%	0–45%	98–99%	99–99%	99–99%	0–37%	98–99%	98–99%	99–99%	0–29%	98–99%	98–99%	99–99%	0–20%	98–99%	98–99%	98–99%	0–0%	96–98%	97–98%	97–99%
	Ohaeroa Stm at SH22 Br	612_9	B	4–46%	0–19%	0–40%	17–54%	4–46%	0–19%	0–40%	17–54%	4–46%	0–19%	0–40%	17–54%	0–41%	0–12%	0–34%	11–49%	0–37%	0–5%	0–29%	5–46%	0–0%	0–0%	0–0%	0–0%

CMZ	Site name	Site ID	Base state	Contemporary baseline				Mitigation scenarios																					
				C2022				M20				M30				M40				M50				M100			
				Base	C (NBL)	B	A	Base	C (NBL)	B	A	Base	C (NBL)	B	A	Base	C (NBL)	B	A	Base	C (NBL)	B	A	Base	C (NBL)	B	A
Lower Waikato (18) (cont.)	Opuatia Stm at Ponganui Rd	665_5	D	8–54%	28–64%	46–73%	58–79%	0–43%	11–55%	33–67%	49–74%	0–39%	4–51%	28–64%	45–72%	0–33%	0–47%	22–60%	40–70%	0–23%	0–39%	10–54%	31–65%	0–0%	0–13%	0–34%	3–50%
	Waerenga Stm at Taniwha Rd	1098_1	C	12–60%	0–50%	16–62%	36–71%	0–50%	0–37%	0–53%	20–64%	0–35%	0–18%	0–39%	0–53%	0–20%	0–0%	0–24%	0–42%	0–16%	0–0%	0–20%	0–39%	0–0%	0–0%	0–0%	0–21%
	Waikato River at Huntly–Tainui Br	1131_77	D	5–53%	71–86%	76–88%	80–90%	0–46%	67–84%	73–86%	78–89%	0–41%	65–82%	71–85%	76–88%	0–36%	62–80%	69–84%	74–86%	0–30%	59–78%	66–82%	72–85%	0–0%	44–68%	54–73%	62–78%
	Waikato River at Mercer Br	1131_91	D	5–53%	81–91%	85–92%	87–94%	0–45%	79–89%	83–91%	85–93%	0–40%	77–88%	81–90%	84–92%	0–34%	75–87%	80–89%	83–91%	0–27%	73–86%	78–88%	82–90%	0–0%	63–79%	70–83%	75–86%
	Waikato River at Rangiriri Br	1131_117	D	5–53%	71–86%	76–88%	80–90%	0–46%	68–84%	74–87%	78–89%	0–41%	65–82%	72–85%	76–88%	0–35%	63–81%	69–84%	74–87%	0–29%	60–79%	67–82%	72–85%	0–0%	45–68%	55–74%	62–78%
	Waikato River at Tuakau Br	1131_133	D	5–52%	80–90%	84–92%	86–93%	0–45%	77–89%	81–91%	84–92%	0–40%	76–87%	80–90%	83–91%	0–34%	74–86%	78–89%	82–91%	0–27%	71–85%	76–88%	80–90%	0–0%	61–78%	68–81%	73–85%
	Whakapipi Stm at SH22 Br	1282_8	D	1–45%	3–45%	20–55%	33–62%	1–45%	3–45%	20–55%	33–62%	1–45%	3–45%	20–55%	33–62%	0–42%	0–43%	16–53%	30–61%	0–34%	0–35%	6–46%	22–55%	0–0%	0–0%	0–10%	0–25%
	Whangamarino River at Island Block Rd	1293_7	D	7–55%	97–99%	98–99%	98–99%	0–46%	97–98%	97–99%	98–99%	0–38%	96–98%	97–98%	97–99%	0–30%	96–98%	96–98%	97–99%	0–21%	95–98%	96–98%	97–98%	0–0%	94–97%	95–97%	96–98%
	Whangamarino River at Jefferies Rd Br	1293_9	D	9–59%	69–86%	77–89%	82–92%	0–49%	62–83%	72–87%	78–90%	0–39%	55–79%	66–84%	74–88%	0–28%	47–75%	60–82%	70–86%	0–16%	39–71%	54–78%	65–83%	0–0%	17–60%	38–70%	52–77%
	Whangape Stm at Rangiriri-Glen Murray Rd	1302_1	D	5–51%	98–99%	98–99%	99–99%	0–40%	98–99%	98–99%	98–99%	0–32%	97–99%	98–99%	98–99%	0–25%	97–98%	98–99%	98–99%	0–15%	97–98%	97–99%	98–99%	0–0%	95–97%	96–98%	97–98%
Upper Waikato (18)	Kawaunui Stm at SH5 Br	240_5	D	10–55%	30–65%	42–71%	52–76%	10–55%	30–65%	42–71%	52–76%	0–42%	13–55%	28–63%	40–69%	0–28%	0–44%	15–54%	29–62%	0–28%	0–44%	15–54%	29–62%	0–0%	0–16%	0–30%	3–42%
	Little Waipa Stm at Arapuni–Putaruru Rd	335_1	C	0–52%	0–43%	0–53%	11–61%	0–50%	0–40%	0–51%	7–59%	0–48%	0–38%	0–49%	4–57%	0–48%	0–38%	0–49%	4–57%	0–47%	0–37%	0–48%	2–57%	0–0%	0–0%	0–0%	0–0%
	Mangaharakeke Stm (Atiamuri) at SH30 (Off Jct SH1)	359_1	D	12–58%	39–71%	50–76%	58–80%	3–54%	33–68%	45–73%	54–78%	0–51%	30–66%	42–72%	52–77%	0–49%	28–65%	40–71%	50–76%	0–48%	26–64%	39–70%	49–75%	0–43%	20–61%	34–68%	45–73%
	Mangakara Stm (Reporoa) at SH5	380_2	D	14–62%	63–84%	69–86%	74–89%	0–52%	52–79%	61–83%	67–85%	0–45%	46–76%	55–80%	63–83%	0–35%	36–71%	47–76%	56–80%	0–25%	28–67%	40–73%	50–78%	0–0%	0–43%	<1–53%	17–61%
	Mangakino Stm (Whakamaru) at Sandel Rd	388_1	B	9–58%	0–43%	0–53%	16–61%	9–58%	0–43%	0–53%	16–61%	5–56%	0–40%	0–51%	12–59%	3–54%	0–39%	0–49%	10–58%	0–51%	0–34%	0–45%	4–54%	0–23%	0–0%	0–15%	0–29%
	Mangamingi Stm (Tokoroa) at Paraonui Rd Br	407_1	D	0–47%	47–75%	56–80%	64–83%	0–45%	46–75%	55–79%	63–82%	0–44%	45–74%	54–79%	62–82%	0–36%	37–70%	48–75%	57–79%	0–31%	33–68%	45–73%	54–78%	0–0%	0–48%	17–57%	31–64%
	Otamakokore Stm at Hossack Rd	683_4	D	13–61%	25–66%	38–72%	48–77%	0–48%	<1–55%	18–63%	31–69%	0–43%	0–51%	11–59%	26–66%	0–43%	0–51%	11–59%	26–66%	0–38%	0–47%	4–56%	20–63%	0–0%	0–0%	0–17%	0–31%
	Pokaiwhenua Stm at Puketurua	786_2	D	0–46%	18–60%	32–67%	44–72%	0–46%	18–59%	32–67%	43–72%	0–43%	14–57%	29–65%	41–71%	0–40%	10–55%	25–63%	38–69%	0–36%	5–52%	21–60%	34–67%	0–3%	0–27%	0–40%	8–50%
	Pueto Stm at Broadlands Rd Br	802_1	B	13–63%	0–54%	12–62%	27–69%	0–33%	0–19%	0–33%	0–44%	0–24%	0–7%	0–23%	0–36%	0–10%	0–0%	0–10%	0–25%	0–2%	0–0%	0–1%	0–18%	0–0%	0–0%	0–0%	0–0%
	Tahunaatara Stm at Ohakuri Rd	934_1	D	11–56%	28–64%	40–70%	50–75%	3–51%	21–60%	35–67%	46–73%	0–47%	16–57%	31–65%	42–71%	0–41%	8–52%	24–60%	37–67%	0–38%	3–49%	20–58%	34–65%	0–8%	0–25%	0–38%	10–48%
	Waikato River at Karapiro Tailrace	1131_79	D	2–54%	30–67%	42–73%	52–77%	0–51%	25–65%	39–71%	49–76%	0–47%	20–62%	34–68%	45–74%	0–43%	15–59%	30–66%	42–72%	0–38%	8–55%	24–63%	37–69%	0–<1%	0–28%	0–41%	5–51%
	Waikato River at Lake Ohakuri Boat Ramp	1131_82	C	11–60%	0–53%	14–62%	28–68%	0–46%	0–37%	0–48%	5–57%	0–38%	0–28%	0–40%	0–50%	0–28%	0–16%	0–31%	0–42%	0–19%	0–5%	0–22%	0–35%	0–0%	0–0%	0–0%	0–0%
	Waikato River at Ohaaki Br	1131_105	A	6–58%	0–0%	0–0%	0–14%	0–31%	0–0%	0–0%	0–0%	0–22%	0–0%	0–0%	0–0%	0–11%	0–0%	0–0%	0–0%	0–2%	0–0%	0–0%	0–0%	0–0%	0–0%	0–0%	0–0%
	Waikato River at Waipapa Tailrace	1131_143	D	10–58%	17–61%	32–68%	43–73%	7–56%	14–60%	29–67%	41–72%	3–54%	11–58%	27–65%	39–71%	0–52%	7–56%	23–63%	36–70%	0–48%	<1–52%	18–61%	32–67%	0–24%	0–30%	0–42%	6–52%
	Waikato River at Whakamaru Tailrace	1131_147	C	10–58%	6–56%	22–63%	35–69%	0–49%	0–46%	8–56%	23–63%	0–44%	0–42%	1–52%	18–60%	0–40%	0–37%	0–48%	12–57%	0–34%	0–31%	0–43%	4–52%	0–6%	0–2%	0–19%	0–32%
	Waiotapu Stm at Campbell Rd Br	1186_2	D	13–59%	35–70%	46–75%	55–79%	0–52%	25–64%	38–71%	48–76%	0–50%	22–63%	36–70%	47–75%	0–46%	16–60%	30–67%	42–72%	0–37%	4–53%	21–61%	34–68%	0–9%	0–32%	0–44%	9–53%
	Waipapa Stm (Mokai) at Tirohanga Rd Br	1202_7	D	11–60%	28–67%	41–73%	50–78%	<1–55%	20–63%	34–70%	45–75%	0–50%	13–60%	28–67%	40–72%	0–50%	12–59%	27–66%	39–72%	0–43%	2–54%	19–62%	33–69%	0–0%	0–10%	0–26%	0–38%
	Whakauru Stm at U/S SH1 Br	1287_7	D	0–51%	78–90%	82–92%	85–93%	0–51%	78–90%	82–92%	85–93%	0–51%	78–90%	82–92%	85–93%	0–45%	76–88%	80–90%	83–92%	0–41%	75–88%	79–90%	83–92%	0–9%	63–81%	69–84%	74–87%
Waihou Piako (18)	Hikutaia River at Old Maratoto Rd	169_2	A	9–39%	0–0%	0–0%	0–4%	7–36%	0–0%	0–0%	0–0%	6–35%	0–0%	0–0%	0–0%	<1–30%	0–0%	0–0%	0–0%	0–26%	0–0%	0–0%	0–0%	0–17%	0–0%	0–0%	0–0%
	Kauaeranga River at Smiths Cableway Recorder	234_11	A	9–31%	0–0%	0–0%	0–0%	9–31%	0–0%	0–0%	0–0%	9–31%	0–0%	0–0%	0–0%	9–31%	0–0%	0–0%	0–0%	7–29%	0–0%	0–0%	0–0%	<1–21%	0–0%	0–0%	0–0%
	Mangawhero Stm (Kaihere) at Mangawara Rd	489_2	B	10–55%	0–27%	0–46%	18–58%	10–55%	0–27%	0–46%	18–58%	10–55%	0–27%	0–46%	18–58%	10–55%	0–27%	0–46%	18–58%	0–44%	0–11%	0–33%	2–49%	0–29%	0–0%	0–16%	0–35%
	Ohinemuri River at Karangahake	619_16	A	6–42%	0–0%	0–0%	0–0%	3–39%	0–0%	0–0%	0–0%	0–36%	0–0%	0–0%	0–0%	0–33%	0–0%	0–0%	0–0%	0–28%	0–0%	0–0%	0–0%	0–11%	0–0%	0–0%	0–0%
	Ohinemuri River at Queens Head	619_19	A	5–46%	0–0%	0–0%	0–0%	0–42%	0–0%	0–0%	0–0%	0–38%	0–0%	0–0%	0–0%	0–32%	0–0%	0–0%	0–0%	0–23%	0–0%	0–0%	0–0%	0–0%	0–0%	0–0%	0–0%
	Ohinemuri River at SH25 Br	619_20	A	9–48%	0–0%	0–0%	0–0%	0–41%	0–0%	0–0%	0–0%	0–37%	0–0%	0–0%	0–0%	0–21%	0–0%	0–0%	0–0%	0–19%	0–0%	0–0%	0–0%	0–2%	0–0%	0–0%	0–0%

CMZ	Site name	Site ID	Base state	Contemporary baseline				Mitigation scenarios																					
				C2022				M20				M30				M40				M50				M100			
				Base	C (NBL)	B	A	Base	C (NBL)	B	A	Base	C (NBL)	B	A	Base	C (NBL)	B	A	Base	C (NBL)	B	A	Base	C (NBL)	B	A
Waihou Piako (18) (cont.)	Oraka Stm at Lake Rd	669_6	D	6–52%	44–71%	53–76%	61–80%	2–50%	42–70%	52–76%	60–80%	0–47%	38–68%	49–74%	58–78%	0–44%	36–67%	47–72%	56–77%	0–40%	32–64%	44–71%	53–76%	0–19%	13–51%	28–60%	40–67%
	Piako River at Kiwitahi	749_10	B	11–58%	0–41%	0–51%	13–59%	8–57%	0–39%	0–50%	11–58%	2–53%	0–34%	0–46%	4–55%	0–47%	0–26%	0–39%	0–49%	0–44%	0–21%	0–34%	0–45%	0–0%	0–0%	0–0%	0–<1%
	Piako River at Paeroa-Tahuna Rd Br	749_15	B	11–60%	0–45%	7–58%	29–68%	0–53%	0–34%	0–51%	17–62%	0–47%	0–26%	0–44%	7–57%	0–39%	0–15%	0–37%	0–51%	0–31%	0–4%	0–28%	0–45%	0–0%	0–0%	0–0%	0–12%
	Piakonui Stm at Piakonui Rd	753_4	D	11–55%	29–64%	41–71%	51–76%	11–55%	29–64%	41–71%	51–76%	11–55%	29–64%	41–71%	51–76%	2–50%	21–60%	35–67%	46–72%	0–45%	15–56%	30–64%	42–70%	0–8%	0–27%	0–39%	13–49%
	Waihou River at Okauia	1122_18	D	5–50%	30–63%	43–70%	52–75%	<1–47%	27–61%	40–68%	50–73%	0–44%	24–59%	37–66%	48–72%	0–41%	20–56%	34–64%	45–70%	0–37%	16–54%	31–62%	42–68%	0–12%	0–35%	10–47%	25–56%
	Waihou River at Te Aroha	1122_34	A	<1–45%	0–2%	0–26%	0–44%	0–42%	0–0%	0–23%	0–41%	0–40%	0–0%	0–19%	0–38%	0–36%	0–0%	0–15%	0–35%	0–33%	0–0%	0–11%	0–32%	0–11%	0–0%	0–0%	0–9%
	Waihou River at Whites Rd	1122_41	A	7–54%	0–0%	0–0%	0–0%	4–52%	0–0%	0–0%	0–0%	2–51%	0–0%	0–0%	0–0%	0–48%	0–0%	0–0%	0–0%	0–48%	0–0%	0–0%	0–0%	0–34%	0–0%	0–0%	0–0%
	Waiomou Stm at Matamata-Tauranga Rd	1174_4	D	8–49%	16–54%	31–62%	42–68%	2–45%	11–50%	26–59%	39–66%	0–41%	6–47%	22–56%	35–63%	0–36%	0–42%	17–52%	31–60%	0–33%	0–39%	15–50%	29–58%	0–6%	0–15%	0–30%	9–41%
	Waitakaruru River (Hauraki Plains) at Coxhead Rd Br	1230_1	A	10–55%	0–14%	0–35%	<1–51%	2–50%	0–5%	0–29%	0–45%	0–48%	0–0%	0–25%	0–42%	0–41%	0–0%	0–15%	0–35%	0–38%	0–0%	0–11%	0–32%	0–13%	0–0%	0–0%	0–5%
	Waitekauri River at U/S Ohinemuri conflu	1239_32	A	7–34%	0–0%	0–0%	0–0%	7–34%	0–0%	0–0%	0–0%	4–31%	0–0%	0–0%	0–0%	3–30%	0–0%	0–0%	0–0%	1–28%	0–0%	0–0%	0–0%	0–16%	0–0%	0–0%	0–0%
	Waitoa River at Landsdowne Rd Br	1249_15	C	9–58%	4–55%	21–63%	34–69%	5–55%	0–53%	17–61%	31–67%	<1–53%	0–50%	13–59%	28–66%	0–47%	0–44%	3–54%	19–61%	0–38%	0–35%	0–46%	8–55%	0–0%	0–0%	0–0%	0–14%
	Waitoa River at Mellon Rd Recorder	1249_18	B	7–56%	0–28%	0–46%	13–59%	3–54%	0–25%	0–44%	10–57%	0–52%	0–22%	0–42%	7–55%	0–46%	0–13%	0–35%	0–50%	0–39%	0–<1%	0–25%	0–43%	0–0%	0–0%	0–0%	0–0%
Waipā (17)	Firewood Creek at Waingaro Road Bridge	124_8	B	9–55%	0–30%	0–47%	18–60%	0–48%	0–18%	0–38%	5–53%	0–43%	0–10%	0–33%	0–49%	0–38%	0–3%	0–27%	0–44%	0–31%	0–0%	0–19%	0–38%	0–0%	0–0%	0–0%	0–9%
	Kaniwhaniwha Stm at Wright Rd	222_16	D	2–51%	56–78%	63–81%	69–85%	0–41%	49–73%	58–78%	65–82%	0–38%	46–72%	56–77%	63–81%	0–34%	43–70%	53–75%	61–80%	0–23%	36–65%	47–71%	56–76%	0–0%	13–50%	28–58%	40–65%
	Mangaohoi Stm at South Branch Maru Rd	411_9	D	11–48%	13–49%	28–58%	40–65%	11–48%	13–49%	28–58%	40–65%	11–48%	13–49%	28–58%	40–65%	11–48%	13–49%	28–58%	40–65%	11–48%	13–49%	28–58%	40–65%	0–29%	0–30%	9–42%	25–52%
	Mangaokewa Stm at Lawrence Street Br	414_6	D	9–57%	47–75%	57–79%	64–83%	0–50%	41–71%	51–76%	59–80%	0–45%	36–68%	47–74%	56–78%	0–38%	29–64%	41–70%	51–75%	0–32%	23–60%	37–67%	47–73%	0–0%	0–41%	14–51%	28–59%
	Mangapiko Stm (Pirongia/Te Awamutu) at Bowman Rd	438_3	D	8–56%	70–85%	75–88%	79–90%	0–47%	64–83%	70–86%	75–88%	0–41%	60–80%	67–84%	72–86%	0–33%	56–78%	63–82%	69–85%	0–23%	50–75%	59–79%	66–82%	0–0%	31–62%	43–69%	53–74%
	Mangapu River at Otorohanga	443_3	D	9–57%	70–86%	75–88%	80–90%	<1–52%	67–84%	73–87%	77–89%	0–49%	65–83%	71–86%	76–89%	0–44%	63–82%	69–85%	74–87%	0–40%	60–80%	67–84%	73–86%	0–8%	44–70%	54–75%	62–79%
	Mangatutu Stm (Waikeria) at Walker Rd Br	476_7	D	6–50%	14–54%	29–62%	41–68%	0–45%	7–49%	23–58%	36–65%	0–41%	2–46%	19–55%	32–63%	0–39%	0–43%	16–53%	30–61%	0–35%	0–40%	13–51%	27–59%	0–10%	0–17%	0–32%	8–43%
	Mangauika Stm at Te Awamutu Borough W/S Intake	477_10	A	0–19%	0–0%	0–0%	0–0%	0–19%	0–0%	0–0%	0–0%	0–19%	0–0%	0–0%	0–0%	0–19%	0–0%	0–0%	0–0%	0–19%	0–0%	0–0%	0–0%	0–19%	0–0%	0–0%	0–0%
	Ohote Stm at Whatawhata/Horotiu Rd	624_5	D	0–0%	18–31%	38–48%	53–60%	0–0%	18–31%	38–48%	53–60%	0–0%	18–31%	38–48%	53–60%	0–0%	18–31%	38–48%	53–60%	0–0%	18–31%	38–48%	53–60%	0–0%	18–31%	38–48%	53–60%
	Puniu River at Bartons Corner Rd Br	818_2	D	8–57%	46–74%	55–79%	63–82%	<1–53%	41–72%	51–77%	59–81%	0–48%	36–69%	47–75%	56–79%	0–43%	30–66%	42–72%	52–77%	0–37%	24–63%	38–69%	48–74%	0–0%	0–35%	2–47%	18–55%
	Puniu River at Wharepapa Rd Bridge	818_40	D	11–61%	17–63%	31–70%	43–75%	3–57%	9–60%	25–67%	37–72%	0–52%	0–55%	16–63%	30–69%	0–44%	0–47%	3–56%	19–64%	0–38%	0–42%	0–52%	12–60%	0–0%	0–0%	0–9%	0–24%
	Waipa River at Mangaokewa Rd	1191_5	A	10–58%	0–39%	0–49%	9–58%	10–58%	0–39%	0–49%	9–58%	10–58%	0–39%	0–49%	9–58%	0–44%	0–17%	0–32%	0–43%	0–44%	0–17%	0–32%	0–43%	0–24%	0–0%	0–8%	0–23%
	Waipa River at Ngaruawahia Br	1191_6	D	6–53%	67–84%	73–87%	78–89%	0–46%	63–81%	70–84%	75–87%	0–41%	60–80%	67–83%	73–86%	0–35%	57–78%	65–82%	71–85%	0–29%	54–75%	62–80%	68–83%	0–0%	38–64%	49–70%	58–75%
	Waipa River at Pukehoua Bridge on Baffin Road	1191_2	D	7–54%	65–83%	71–86%	76–88%	0–48%	61–80%	68–84%	73–86%	0–43%	58–79%	66–82%	71–85%	0–38%	55–77%	63–81%	69–84%	0–32%	52–74%	60–79%	67–82%	0–0%	35–62%	46–68%	55–74%
	Waipa River at SH3 Otorohanga	1191_12	D	7–52%	37–67%	48–73%	57–77%	0–45%	30–62%	42–69%	52–74%	0–38%	24–58%	37–65%	47–71%	0–32%	18–54%	32–62%	44–68%	0–25%	12–49%	27–58%	39–65%	0–0%	0–27%	7–39%	22–50%
	Waitomo Stm at SH31 Otorohanga	1253_5	D	10–57%	76–88%	80–90%	83–92%	5–54%	74–87%	79–90%	82–91%	2–52%	73–87%	78–89%	82–91%	0–50%	72–86%	77–89%	81–91%	0–42%	69–84%	74–87%	78–89%	0–22%	60–79%	67–82%	72–85%
	Waitomo Stm at Tumutumu Rd	1253_7	D	10–57%	39–70%	49–76%	58–80%	0–51%	32–67%	44–73%	53–77%	0–50%	31–66%	43–72%	53–77%	0–48%	29–65%	41–71%	51–76%	0–45%	25–63%	38–69%	48–74%	0–23%	1–47%	18–57%	32–64%
West Coast (14)	Awakino River at Gribbon Rd	33_6	D	8–41%	22–50%	35–59%	46–66%	1–36%	16–46%	30–55%	42–63%	0–35%	13–44%	29–54%	40–62%	0–34%	12–43%	28–53%	40–61%	0–32%	9–42%	25–52%	38–60%	0–27%	2–37%	19–48%	33–57%
	Awakino River at SH3 Awakau Rd Junction	33_9	A	12–56%	0–0%	0–15%	0–35%	0–46%	0–0%	0–0%	0–19%	0–41%	0–0%	0–0%	0–13%	0–37%	0–0%	0–0%	0–7%	0–32%	0–0%	0–0%	0–0%	0–21%	0–0%	0–0%	0–0%
	Manganui River at off Manganui Rd	410_4	A	11–49%	0–0%	0–6%	0–28%	3–43%	0–0%	0–0%	0–19%	0–39%	0–0%	0–0%	0–14%	0–35%	0–0%	0–0%	0–8%	0–33%	0–0%	0–0%	0–6%	0–21%	0–0%	0–0%	0–0%
	Mangaotaki River at SH3 Br	428_3	D	10–60%	40–74%	51–78%	59–82%	0–48%	24–65%	38–71%	48–76%	0–43%	18–62%	32–69%	44–74%	0–35%	10–57%	25–65%	38–71%	0–28%	<1–52%	18–61%	32–67%	0–7%	0–39%	0–49%	17–58%

CMZ	Site name	Site ID	Base state	Contemporary baseline				Mitigation scenarios																			
				C2022				M20				M30				M40				M50				M100			
				Base	C (NBL)	B	A	Base	C (NBL)	B	A	Base	C (NBL)	B	A	Base	C (NBL)	B	A	Base	C (NBL)	B	A	Base	C (NBL)	B	A
West Coast (14) (cont.)	Marokopa River at Speedies Rd (off Te Anga Rd)	513_3	D	9–54%	39–69%	50–74%	58–79%	0–43%	29–62%	41–69%	51–74%	0–41%	26–61%	39–68%	49–73%	0–37%	23–58%	36–65%	47–71%	0–33%	19–55%	33–63%	44–69%	0–21%	9–47%	24–57%	37–64%
	Mokau River at Awakau Rd	556_2	D	10–59%	25–66%	44–75%	57–80%	0–47%	7–56%	31–67%	47–75%	0–42%	0–52%	25–64%	42–72%	0–36%	0–47%	19–60%	38–69%	0–30%	0–41%	13–56%	33–66%	0–9%	0–24%	0–43%	19–57%
	Mokau River at Mangaokewa Rd (off SH30)	556_5	D	7–51%	28–62%	41–69%	51–74%	0–45%	22–58%	36–65%	47–71%	0–45%	22–58%	36–65%	47–71%	0–43%	20–56%	34–64%	45–70%	0–33%	10–48%	26–57%	38–65%	0–18%	0–37%	15–48%	29–57%
	Mokau River at Totoro Rd Recorder	556_9	D	9–60%	38–73%	49–77%	58–81%	0–48%	23–65%	37–71%	47–76%	0–43%	17–61%	31–68%	43–73%	0–37%	9–57%	25–65%	37–71%	0–30%	<1–52%	18–60%	32–67%	0–4%	0–34%	0–46%	12–55%
	Mokauiti Stm at Three Way Point - Aria	557_5	B	12–62%	0–49%	11–62%	32–71%	0–49%	0–32%	0–49%	11–61%	0–42%	0–22%	0–42%	<1–55%	0–34%	0–12%	0–34%	0–49%	0–24%	0–0%	0–24%	0–41%	0–0%	0–0%	0–0%	0–15%
	Ohautira Stm at Waingaro Te Uku Rd	616_1	A	0–45%	0–0%	0–18%	0–37%	0–31%	0–0%	0–0%	0–21%	0–31%	0–0%	0–0%	0–21%	0–30%	0–0%	0–0%	0–19%	0–28%	0–0%	0–0%	0–17%	0–8%	0–0%	0–0%	0–0%
	Oparau River at Langdon Rd (off Okupata Rd)	658_1	A	10–50%	0–0%	0–0%	0–14%	0–37%	0–0%	0–0%	0–0%	0–27%	0–0%	0–0%	0–0%	0–23%	0–0%	0–0%	0–0%	0–20%	0–0%	0–0%	0–0%	0–2%	0–0%	0–0%	0–0%
	Tawarau River at off Speedies Rd	976_1	D	10–55%	33–67%	45–73%	54–77%	0–44%	20–58%	34–66%	45–71%	0–41%	16–56%	31–64%	43–70%	0–37%	12–53%	27–61%	39–68%	0–32%	7–49%	23–58%	36–65%	0–21%	0–42%	14–52%	28–60%
	Waingaro River (Pukemiro) at Ruakiwi Rd off SH22	1167_4	B	7–53%	0–23%	0–42%	13–56%	0–45%	0–10%	0–33%	<1–49%	0–39%	0–0%	0–25%	0–43%	0–34%	0–0%	0–19%	0–38%	0–27%	0–0%	0–11%	0–32%	0–0%	0–0%	0–0%	0–4%
	Waitetuna River at Te Uku-Waingaro Rd	1247_2	B	9–54%	0–21%	0–41%	11–55%	0–46%	0–8%	0–31%	0–47%	0–43%	0–3%	0–27%	0–44%	0–39%	0–0%	0–22%	0–40%	0–33%	0–0%	0–14%	0–34%	0–11%	0–0%	0–0%	0–12%