Application Of SednetNZ With SLUI Erosion Mitigtion and Climate Change Scenarios in the Horizons Region to Support NPS-FM 2020 Implementation

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Manaaki Whenua – Landcare Research

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Summary

Project and Client

- Horizons Regional Council (HRC) contracted Manaaki Whenua – Landcare Research (MWLR) to model erosion and suspended sediment loads across the region for a range of erosion mitigation and climate change scenarios to support implementation of the National Policy Statement-Freshwater Management (NPS-FM) 2020. Erosion mitigation focused on works completed under the Sustainable Land Use Initiative (SLUI) and Whanganui Catchment Strategy (WCS).
- SLUI is New Zealand's largest hill country erosion programme. The initiative began in 2006 and is informed by the 'Highly Erodible Land' (HEL) map which identified that Manawatū-Whanganui has the largest area of HEL on private land in New Zealand. To date, SLUI has completed whole farm plans (WFPs) for over 700 farms covering more than 500,000 ha of land and completed more than 35,200 ha of works, predominantly in the form of afforestation, bush retirement, riparian retirement, space-planted trees, and gully tree planting.
- The scope of work involved: a) modelling region-wide suspended sediment and sediment-associated phosphorus loads under current land cover and SLUI/WCS work to date; b) assessing load reductions required to achieve NPS-FM (2020) attribute states for suspended fine sediment (visual clarity); c) comparing reductions in modelled suspended sediment loads under future SLUI implementation scenarios relative to the current baseline with the load reductions required to achieve each NPS-FM (2020) attribute state; and d) modelling suspended sediment loads under future climate change for SLUI implementation scenarios and assessing load reductions required to achieve each NPS-FM (2020) attribute state.

Objectives

- Model region-wide mean annual suspended sediment loads using SedNetNZ under contemporary climate conditions for the following scenarios:
  - SC1) current state representing SLUI/WCS erosion mitigation implementation and maturity to date across the region with an accompanying future scenario representing the maturation of existing works on farms with existing plans at 5-yearly intervals, while no further farm plans or works are completed
  - SC2) future state representing SLUI/WCS erosion mitigation implementation and maturity to date plus the future projected mapping rate of new farm plans, and the projected rate of on-farm erosion mitigation implementation and maturation of works across the region at 5-yearly intervals
  - SC3) future state representing SLUI/WCS erosion mitigation implementation and maturity to date plus a doubling of the future projected mapping rate of new farm plans, while maintaining the same on-farm rates of implementation and maturation of works as SC2 at 5-yearly intervals
- Model region-wide mean annual sediment-associated phosphorus loads using SedNetNZ under contemporary climate conditions

- Model the effect of future climate change projections on region-wide erosion and suspended sediment loads at mid- (2040) and end-century (2090) for the three SLUI/WCS scenarios
- Assess load reductions required to meet NPS-FM (2020) attribute bands and the national bottom line for suspended fine sediment (visual clarity) for the three SLUI/WCS scenarios with and without the effects of climate change.

Methods

- An updated version of the SedNetNZ model was applied to the Horizons region to estimate mean annual suspended sediment loads across the River Environment Classification v2 (REC2) digital river network for the three erosion mitigation scenarios with and without the effects of climate change.
- Sediment-associated phosphorus loads were estimated using the measured concentration of phosphorus in suspended sediment with the modelled suspended sediment loads.
- The effect of future climate change on erosion and suspended sediment loads for the three scenarios was modelled following a similar approach to that described by Basher et al. (2020). 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.
- Proportional and absolute load reductions required to meet NPS-FM (2020) attribute bands and bottom lines were assessed for each of the scenarios. These were summarised by length and proportion by length of REC2 segments achieving each attribute state.

Results

- Total erosion for the Horizons region was estimated at 9.0 Mt yr^{-1}, with a total net suspended sediment load of 8.5 Mt yr^{-1} reaching the coast. The highest rates of erosion (>2,500 t km^{-2} yr^{-1}) occur mostly in a band of erosion-prone land located in the Manawatū, Rangitīkei-Turakina and Whangaehu FMUs, as well as a limited number of REC2 segments that experience higher rates of bank erosion. Total erosion at 2100 was estimated as 8.8, 4.9, and 4.3 Mt yr^{-1} for SC1, SC2, and SC3, respectively. This equates to region-wide reduction of 4.1 and 4.7 Mt yr^{-1}, or 47% and 53% by 2100 for SC2 and SC3, respectively.
- Total net sediment-associated phosphorus load delivered to the coast was estimated at 4.3 kt yr^{-1}. The largest phosphorus loads were exported from the Whanganui (1.3 kt yr^{-1}) and Manawatū (1.2 kt yr^{-1}) rivers.
- The proportions (by length) of REC2 segments achieving Band A, B, and national bottom line in 2021 were 38, 60, and 75%, respectively. These proportions increase to 70, 82, and 88% for SC2 at 2100, and 76, 86, and 90% for SC3 at 2100. The proportion of REC2 segments achieving these targets decreased from low to high stream order REC2 segments. For example, in 2021, 38–43% of REC2 segments from stream orders ≤5, achieved Band A, while only 8 and 0% achieved Band A from stream orders 6 and 7, respectively.

- A large cluster of REC2 segments in the lowland coastal areas required large proportional reductions (albeit low absolute reductions) to achieve bottom line relative to the rest of the region, and most still do not achieve at 2100. This is likely due to 1) sediment reductions being primarily based on the SLUI programme, which focuses mitigations in hill country, 2) the selection order of new farm plans being based on SLUI priority classes where lowlands mostly fall within the lowest priority class, and 3) sensitivity to variations in visual clarity thresholds based on the spatial pattern in the suspended sediment class used to define threshold values.
- The projected total erosion under future climate change across all RCPs for SC1 ranged from 9.5 to 14.1 Mt yr^{-1} for mid-century, and 9.0 to 19.2 Mt yr^{-1} for late-century. This equates to an increase of 8–58%, and 2–119% for mid- and late-century, respectively, compared to loads modelled without the effect of climate change. Scenario SC2 results in a load change ranging from 7 to 58% and -5 to 93% for mid- and late-century, respectively, while SC3 results in a load change ranging from 7 to 58% and -5 to 90% for mid- and late-century, respectively (Figure A1).
- The proportion of REC2 segments (by length) achieving national bottom line under future climate change across all RCPs for SC1 equates to 25–38% at mid-century and 22–40% at late-century. This compares to an estimated 76% of REC2 segments (by length) which meet national bottom in the absence of impacts from climate change. For SC2, the proportions are 28–45% and 45–79% by mid-and late-century, while results for SC3 equate to 28–46% and 49–84% by mid-and late-century, respectively. By comparison, in the absence of impacts from climate change, 87 and 89% of REC2 segments by length achieve the national bottom line at 2090 under SC2 and SC3, respectively.

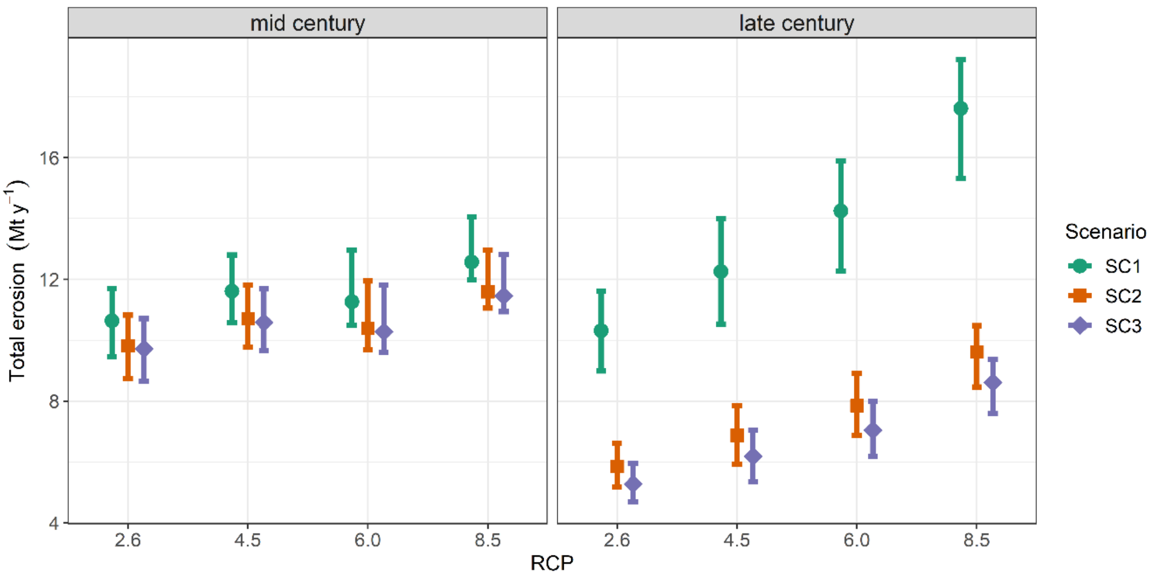

Figure A1 Total erosion loads under projected climate change for the Horizons region at mid- and late-century by RCP for each erosion mitigation scenario (reference Figure 17).

Model limitations

- There are limitations associated with the representation of erosion processes in the model.
  - The surficial erosion component is sensitive to the availability of input data and may be improved by acquisition of higher resolution soil data.
  - Shallow landslides are initiated by storm events over a triggering threshold and thus show significant inter-annual variability, which is not represented in the model. Instead, the storm-triggered landslide contribution to sediment load is averaged over a multi-decadal timescale.
  - Gully and earthflow erosion are represented using a spatial averaging approach for selected terrain types that are susceptible to these processes. This means it is possible that earthflow and gully erosion may be represented in some sub-catchments that do not contain these features or may not be represented where they are present.
  - Bank erosion prediction requires high resolution spatial data of riparian woody vegetation. However, identifying the extent this riparian vegetation can be challenging in places where the spatial correspondence between mapped channel locations and woody vegetation is reduced due to changes in channel planform since mapping.
- A high degree of uncertainty exists 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.
- Representing mean annual suspended sediment load reductions required to achieve visual clarity objectives involved several assumptions. For instance, the relationship between suspended sediment load and the flow frequency distribution remains 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.
- Significant uncertainty exists regarding the effectiveness, maturity, and implementation rates of SLUI WFPs, as well as the selection of new farms for implementation. The effectiveness and maturity rate of each erosion mitigation used values from previous SedNetNZ modelling, which was based on literature, but may deviate from actual values.
- The implementation rate of new works on a farm is one of the more difficult parameters to derive because there is no clear definition or measure of what 'fully implemented' represents for a given farm, which had to be approximated. The estimated minimum and maximum annual area of works are ~1,780 ha yr^{-1} and 4,990 ha yr^{-1} with a mean of ~3,380 ha yr^{-1} over the simulated period from 2021 to 2100 for SC2. New farms were randomly selected for implementation; however, we do not know how representative this selection will be of the actual order of new farms selected in the future. We also do not know how sensitive the annual local and region-wide loads are to the selection order of new farms.

Conclusions and Recommendations

- Model scenarios of future SLUI implementation produce large reductions in region-wide suspended sediment loads by late-century. The impact of projected climate change on suspended sediment loads decreases the proportion of REC2 segments achieving national bottom line. To some extent, SC2 and SC3 were able to mitigate the impacts of climate change, increasing the proportion of REC2 segments that achieve bottom line relative to SC1.
- Continued investment in SLUI or other programmes for erosion mitigation will be required to reduce potentially significant impacts of climate change on suspended sediment loads by late-century.
- Model predictions of sediment load reductions due to erosion mitigations could be improved with region-specific and local data related to the effectiveness in erosion control, as well as information on the levels of implementation and maturity of erosion mitigation work at the whole farm and catchment scales. Region-wide LiDAR would allow improved representation of erosion processes. Future work could also model works from other initiatives such as lowland interventions, which have an impact on suspended sediment loads.
- Further clarification of what constitutes a 'fully implemented' WFP would help improve estimates of the implementation rate for SLUI works on farms. This could include developing a standardised measure of the total 'mitigatable' area for each farm, ideally for both mapped and unmapped farms.
- Future work on reductions in phosphorus loads under the different mitigation scenarios could be beneficial.
- The impacts of climate change on erosion processes and catchment hydrology would benefit from further investigation to better predict potential changes in suspended sediment loads and effects on visual clarity. Additionally, further work could examine how implementation of erosion mitigations might differ when optimised for climate change resilience.

1 Introduction

Horizons Regional Council (HRC) contracted Manaaki Whenua – Landcare Research (MWLR) to model erosion and suspended sediment loads across the region using SedNetNZ for a range of erosion mitigation and climate change scenarios to support implementation of the NPS-FM (2020).

The scope of work for HRC involved: a) modelling region-wide suspended sediment and sediment-associated phosphorus loads under current land cover and Sustainable Land use Initiative (SLUI)/Whanganui Catchment Strategy (WCS) work to date; b) assessing load reductions required to achieve NPS-FM (2020) attribute states for suspended fine sediment (visual clarity); c) comparing reductions in modelled suspended sediment loads under future SLUI implementation scenarios relative to the current baseline with the load reductions required to achieve NPS-FM (2020) attribute states; and d) modelling suspended sediment loads under future climate change for SLUI implementation scenarios and assessing load reductions required to achieve NPS-FM (2020) attribute states.

2 Background

2.1 SedNetNZ

A range of erosion processes occur in the Horizons region. Previous work has reported the occurrence of landslides in response to intense rainfall events (Hancox 2004; Hancox & Wright 2005; Dymond et al. 2006; Basher 2013; Fuller et al. 2016) and the importance of streambank erosion as a sediment source (Fuller & Heerdegen 2005; Fuller 2008). Gully erosion in unconsolidated sands and silts has been a particularly significant erosion source in some Manawatū subcatchments (Miri 1999; Vale 2018; Vale et al. 2021a). Earthflows are also common in the soft-rock hill country, predominantly in the eastern Manawatū (e.g. Tiraumea, Neverman et al. 2020), and Puketoi ki Tai' FMUs (Dymond et al. 2006).

The SedNetNZ sediment budget model was developed to represent this diversity of erosion processes that occur in the Horizons region and more widely across New Zealand. This includes shallow landslide, earthflow, gully, and surficial erosion (Dymond et al. 2016), as well as streambank erosion using a recently improved bank erosion model (Smith et al. 2019a). 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 REC2 subcatchment level. While conceptually similar to the Australian SedNet model (Wilkinson et al. 2009), SedNetNZ differs in the 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 through its parameterisation using data from New Zealand (e.g. Betts et al. 2017).

SedNetNZ has previously been applied in the Horizons Region to assess the impact of SLUI on suspended sediment loads (Dymond et al. 2014; Basher et al. 2018). The effects of projected climate change on suspended sediment loads in the region were initially only represented for the landslide component of SedNetNZ and based on the IPCC's 4th Assessment Report (Manderson et al. 2015). This analysis was subsequently updated based on the 5th Assessment Report to assess the effect of climate change by mid- and late-century on hillslope erosion but excluded representation of climate change effects on bank erosion (Basher et al. 2018, 2020).

Since the completion of the previous work in the Horizons Region, SedNetNZ has undergone several significant updates. This includes an improved bank erosion model (Smith et al. 2019b, 2020) that replaced the previous model of bank erosion in SedNetNZ (Dymond et al. 2016). The improved bank erosion model is calibrated using data that includes measurements of reach-scale channel change from the Manawatū catchment (Smith et al. 2019b). The surficial erosion component of SedNetNZ now includes improved representation of surface runoff contributing areas (Smith et al. 2019a) 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. 2021a). Lake sediment trapping is now represented as part of the river network routing algorithm (Neverman et al. 2021a), 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. 2021b).

2.2 Sustainable Land Use Initiative (SLUI)

The Sustainable Land Use Initiative (SLUI) began in 2006 and is New Zealand's largest hill country erosion programme. It is funded from a mixture of Central Government's Hill Country Erosion Fund (HCEF) plus HRC's rates and farmer contributions (Horizons Regional Council 2019a). SLUI has completed whole farm plans (WFPs) for over 700 farms covering more than 500,000 ha of land and completed more than 35,200 ha of works, predominantly in the form of afforestation, bush retirement, riparian retirement, space-planted trees, and gully tree planting.

SLUI is informed by the 'Highly Erodible Land' (HEL) model, which was previously developed by Manaaki Whenua to spatially predict the amount of highly erodible land in the region. This analysis established that Manawatū-Whanganui has the largest area of HEL on private land in New Zealand, and approximately 263,000 ha of HEL in pasture-land use in the Manawatū-Whanganui region. To further target land management efforts, HRC developed a classification system within the region which separates land into top, high, low, and not priority. Top priority land is estimated to contribute 40–55% of the sediment in the region's rivers and high priority land is estimated to contribute a further 25–30% of the sediment. This has made top and high priority land the main target for the programme to date (Horizons Regional Council 2019b).

WFPs are used as a tool to bring on new land into the programme and for allocating grants. Approximately half of the top and high priority land in the region is within SLUI WFPs. The previously separate Whanganui Catchment Strategy (WCS) – established before the SLUI, has been integrated into the programme. This includes 39 WCS plans covering approximately 22,000 ha as at 30 June 2021 (Horizons Regional Council 2019b).

3 Objectives

The project had four main objectives; they were to:

- Model region-wide mean annual suspended sediment loads using SedNetNZ under contemporary climate conditions for the following scenarios:
  - SC1) current state representing SLUI/WCS erosion mitigation implementation and maturity to date across the region with an accompanying future scenario representing the maturation of existing works on farms with existing plans at 5-yearly intervals, while no further farm plans or works are completed
  - SC2) future state representing SLUI/WCS erosion mitigation implementation and maturity to date plus the future projected mapping rate of new farm plans, and the projected rate of on-farm erosion mitigation implementation and maturation of works across the region at 5-yearly intervals
  - SC3) future state representing SLUI/WCS erosion mitigation implementation and maturity to date plus a doubling of the future projected mapping rate of new farm plans, while erosion mitigation implementation and maturation of works continues across the region at the same rate as SC2 at 5-yearly intervals
- Model region-wide mean annual sediment-associated phosphorus loads using SedNetNZ under contemporary climate conditions
- Model the effect of future climate change projections on region-wide erosion and suspended sediment loads at mid- (2040) and end-century (2090) for the three SLUI/WCS scenarios
- Assess load reductions required to meet NPS-FM (2020) attribute bands and the national bottom line for suspended fine sediment (visual clarity) for the three SLUI/WCS scenarios with and without the effects of climate change.

4 Methods

This section provides a description of methods used in the application of SedNetNZ in the Horizons region. It outlines: 1) the SedNetNZ model components; 2) the model simulations for the SLUI scenarios and climate change projections; 3) the sediment-associated phosphorus load estimation; and 4) the method for estimating sediment load reductions required to achieve NPS-FM 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 NZUSLE (Dymond et al. 2010) model:

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

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 x 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 et al. (2019b), 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):

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

where L is 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, x = sin a+cos a, with α being the slope aspect.

The slope length exponent m is calculated depending on the rill to inter-rill ratio β and the slope gradient θ (Foster et al. 1977; 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. (2021b) to better represent the spatial variability of soil erodibility, utilising the Fundamental Soil Layer (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 6 PP classes, adapted from Rosewell and Loch (2002). The soil structure code was set at SS = 2 as 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 silt and clay:

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

where $Silt$ and $Clay$ are the percent 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 to be 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 that often reaches a stream (for 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:

$$EL = \rho \, SDR \, d_l f(s) \tag{8}$$

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 (Page et al. 1994; Reid & Page 2003); and $f(s)$ is determined from previous calibration of SedNetNZ in the Manawatū (Dymond et al. 2016; Betts et al. 2017). Permanent forest cover is estimated to reduce shallow landslide erosion by 90% compared with pasture (Basher 2013; Dymond et al. 2016).

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} a^{-1} is denoted by EE and is estimated as:

$$EE = \rho \, d_e \, v \, ED \tag{9}$$

[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).

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 a^{-1}), and ED is the mean length of stream intersecting earthflow toes in a square kilometre (m km^{-2}).

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 a^{-1} (average from published data; Guy 1977; Zhang et al. 1991; Marden et al. 2008, 2014). ED is set to 1,024 m km^{-2} (from digitising stream lengths on scanned aerial photographs – Dymond et al. 2016).

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} a^{-1}, is denoted by EG and is estimated by:

$$EG = \frac{\rho\, A_g\, GD}{T} \tag{10}$$

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 is set to 1.5 t m^{-3}; A_g is set to 900 m^2 (from field observations), GD is set to 220 m (from digitising gully lengths on scanned aerial photographs), and T was set to 120 years.

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):

$$B_j = \rho M_j H_j L_j \tag{11}$$

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, 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 results from the Waipaoa River catchment (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:

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

where M_j is the bank migration rate (m y^{-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 et al. 2019a).

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

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

where $Sinu_j$ is 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 percent silt + clay content (SC) and soil critical shear stress (τ_c) derived by Julian and Torres (2006) using data from Dunn (1959) as follows:

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

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:

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

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:

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

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 proportionally to the extent of woody riparian vegetation along the j^{th} stream link (equation 12). Stream links with complete 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 DEM-derived channel network because it tends to exhibit better planform accuracy which should improve 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 timescale, 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 2 × link length.

Inputs to the bank erosion model component of SedNetNZ were obtained from national-scale spatial datasets 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 narrow corridors of woody vegetation often found along channel banks.

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 47 gauging stations with records >10 years in length were obtained from an analysis of river flow data for the Horizons region (Henderson & Diettrich 2007). These data were used to fit regional 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 partitioning the gauging site data into three spatially discrete areas comprising a) Manawatū and adjacent coastal catchments ($MAF = 40q^{0.81}, R^2 = 0.97, n = 21$), b) Rangitīkei ($MAF = 34q^{0.66}, R^2 = 0.95, n = 9$), and c) Whanganui, Kai Iwi, Whangaehu, and Turakina catchments ($MAF = 26q^{0.79}, R^2 = 0.97, n = 17$). These discrete q-MAF relationships produced a small improvement over a single region-wide relationship ($R^2 = 0.94$). HRC also provided spatial data on stopbanks and channel protection works that have been included in the model simulations.

We used a dataset comprising available measured bank migration rates from the Manawatū and Kaipara catchments to calibrate the bank erosion model (Spiekermann et al. 2017; Smith et al. 2019a). Calibration of the bank migration model was performed by minimising the mean square error (MSE) 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 between measured and observed rates of bank migration (Smith et al. 2019a); Fig. 1).

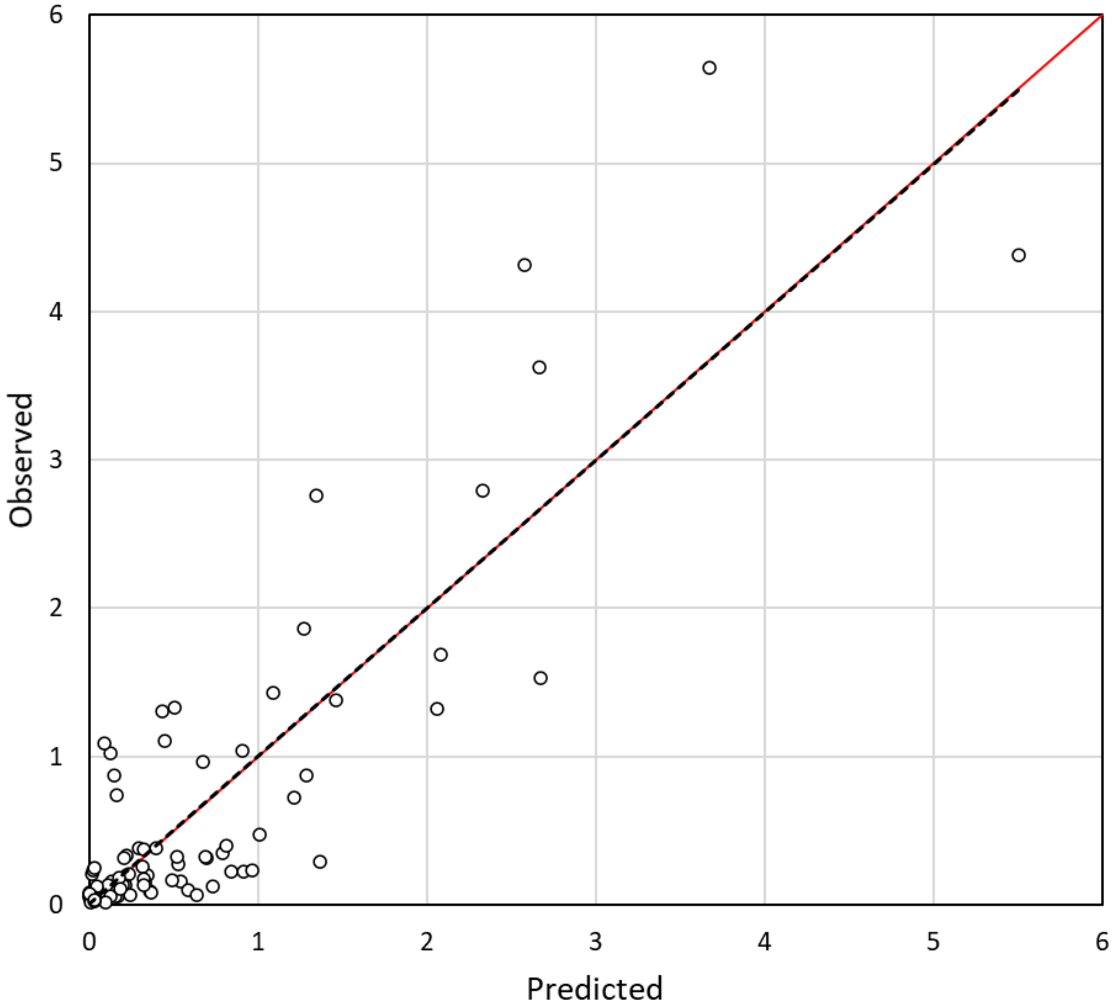

Figure 1. Plot comparing predicted versus observed bank migration rates (m yr^{-1}) based on calibrated parameter values for the sinuosity and erodibility factors. Fitted regression line (black dashed) and the 1:1 line (red) are also shown.

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 a 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 et al. (2019a).

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 the 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 SLUI scenarios

Region-wide simulations comprise 3 SLUI/WCS scenarios reflecting the application of WFPs under contemporary climate conditions for 2021 and 5-year intervals from 2025 to 2100. The scenarios are:

- SC1: current state representing SLUI/WCS erosion mitigation implementation and maturity to date across the region with an accompanying future scenario representing the maturation of existing works on farms with existing plans, while no further farm plans or works are completed
- SC2: future state representing SLUI/WCS erosion mitigation implementation and maturity to date plus the future projected mapping rate of new farm plans, and the projected rate of on-farm erosion mitigation implementation and maturation of works across the region
- SC3: future state representing SLUI/WCS erosion mitigation implementation and maturity to date plus a doubling of the future projected mapping rate of new farm plans, while maintaining the same projected rates of on-farm implementation and maturation of works as SC2.

The impact of projected climate change on suspended sediment loads was modelled for the 3 scenarios at mid-(2040) and late-(2090) century. Six regional climate models (RCMs) are used to select the minimum, median, and maximum model projected change across 4 representative concentration pathways (RCPs) for each of the scenarios.

Table 1. Summary of SedNetNZ SLUI/WCS scenarios

SLUI scenario	Description	Contemporary climate conditions	Projected future climate conditions
SC1: Current SLUI/WCS	This scenario represents recent land cover (LCDBv5) and SLUI/WCS works completed to date (2021) including the maturity level of implemented erosion mitigation. The 5-year intervals represent the maturation of existing works on mapped farms, while no further farm plans or works are completed.	Projections on mean annual suspended sediment loads modelled for 2021, and 5-year intervals from 2025 to 2100.	Climate change projections on mean annual suspended sediment loads at mid-(2040) and end-century (2090). Six regional climate models (RCMs) are used to select the minimum, median, and maximum model projected change across 4 representative concentration pathways (RCPs).
SC2: Future SLUI/WCS	This scenario represents recent land cover (LCDBv5) with both the SLUI/WCS works completed to date combined with the projected rate of new SLUI/WCS farm plan mapping and the projected rates of implementation and maturation of erosion mitigation.		
SC3: Future SLUI/WCS – doubled rate of new farm plans	This scenario represents recent land cover (LCDBv5) with both the SLUI/WCS works completed to date combined with a doubling of the projected rate of new SLUI/WCS farm plan mapping. The projected rates of implementation and maturation of erosion mitigation remains the same as SC2.		

4.2.2 SLUI sediment reduction

Sediment load reduction for each farm was estimated based on the effectiveness, implementation, and maturity of each type of erosion mitigation applied within SLUI WFPs. This approach was used for SLUI erosion mitigation mapped to date as well as future mitigation for mapped and unmapped farms.

Sediment load reduction for a farm can be represented by:

$$Sediment\ reduction = \sum_{w=1}^{n}\left(\frac{E_w}{100} \times \frac{I_w}{100} \times \frac{M_w}{100}\right) \quad (20)$$

where the E is effectiveness (%), I is the proportional extent of implementation (%), M is the maturity (%), w is the type of erosion mitigation, and n is the number of different types of erosion mitigation applied.

'Effectiveness' represents the capacity of the erosion mitigation applied to reduce sediment load once fully mature and is specific to each mitigation. Afforestation and bush retirement have an effectiveness value of 90% for mass movement erosion based on published data, while riparian retirement was estimated at 80% (Dymond et al. 2010, 2016). Space-planted trees and gully tree planting have a value of 70% based on published data from Hawley and Dymond (1988) and Dymond et al. (2010). The effectiveness of afforestation and bush retirement in reducing surficial erosion (Table 2) 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 rather than surficial erosion.

'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 2 based on values used in previous work (e.g. Manderson et al. 2011; McIvor et al. 2011; Basher et al. 2018). Maturity was determined for currently mapped erosion control works based on the recorded year of implementation. In some situations, recent afforestation and retirement mitigation (<10 years old) mapped in SLUI are already captured in LCDBv5, which would be modelled as fully mature forest. Similarly, mature afforestation and bush retirement (>10 years old) should be captured as woody cover in LCDBv5, but this is not always the case. To ensure the effect of erosion mitigation are not double-counted, mature afforestation and retirement works implemented earlier than 2012 (>10 years old) were burnt in to LCDBv5 and classified as woody vegetation, while immature afforestation and retirement works implemented later than 2012 were burnt in, classified as pasture, and matured to the appropriate age. This ensures the sediment load reduction is consistently applied for both past and future mitigation, with the appropriate maturity level at each time interval. All other mitigations such as space planting were considered to be represented as pasture in LCDBv5 as they typically do not achieve canopy cover and are generally too small in area to be captured in LCDB.

Table 2. Summary of maturity and effectiveness of the SLUI erosion mitigation after Basher et al. (2018)

Erosion mitigation	Years to fully mature	Annual maturity rate	Effectiveness
Afforestation	10	10%	90% (mass movement) 50% (surficial)
Bush retirement	10	10%	90% (mass movement) 50% (surficial)
Riparian retirement	2	50%	80%
Space-planted trees	15	6.66%	70%
Gully tree planting	15	6.66%	70%

'Implementation' represents the erosion works applied on a farm as a proportion of what may be considered full implementation of the WFP. Full implementation is difficult to estimate as there is not a clearly defined mitigatable area or area of works for a given farm to be considered fully implemented. HRC provided an estimated average rate of on-farm works implementation of 1.14% per year (or 88 years to be fully implemented), which was used to model future rates of WFP implementation. This was based on the area of works completed on pasture for mapped high and top priority farms as a proportion of the total area of mapped pasture on high and top priority land over the last 10 years. This estimate required an assumption that all erosion control works were mapped in what was initially pasture, regardless of its classification in the latest LCDBv5 layer. This is important since mature afforestation and bush retirement mitigations will appear as woody cover in the latest LCDB layers and could misrepresent the true extent of implementation on a farm.

The proportion of each erosion mitigation type implemented within each farm was estimated based on the proportional area of each erosion mitigation. The proportional implementation of future works was estimated based on the past proportion of each erosion mitigation within each SLUI priority class (Table 3) and weighted based on the erosion process loads occurring within each intersecting farm-REC2 watershed. This can be expressed as:

$$I_w = I_{wfp} \times \left(W_p \times Erosion\ load_p\right) \tag{21}$$

where, I_w is implementation of w^{th} erosion mitigation type, I_{wfp} is the extent of WFP implementation, W_p is the base proportion of each erosion mitigation for the associated SLUI priority class (Table 3), and $Erosion\ load_p$ is the combined load proportion for the erosion processes targeted by the w^{th} erosion mitigation (Table 3).

This approach ensures that erosion control works are not applied to areas that do not experience the types of erosion that the control works are designed to mitigate. For example, if only bank erosion occurred in a given farm-REC2 watershed intersection, then the proportion of works would be weighted to only include riparian retirement. Implementation continues until 100% implementation is reached for each WFP.

Table 3. Past proportions of erosion mitigation applied to each priority class

Erosion mitigation	Proportion (%)					Erosion process mitigated
	All land classes	Land priority classes				
		Not	Low	High	Top	
Afforestation	44.0	12.2	32.1	53.5	37.8	Shallow landslide, earthflow, surficial
Retirement	30.3	14.4	15.2	27.7	36.8	Shallow landslide, earthflow, surficial
Riparian Retirement	9.9	34.8	17.5	7.5	9.9	Bank erosion
Spaced Planting	14.3	37.2	33.1	9.9	13.8	Shallow landslide, earthflow
Gully Planting	1.6	1.4	2.1	1.4	1.7	Gully erosion

4.2.3 Selecting future SLUI farms

New WFPs were selected at a rate of 10,000 ha yr^{-1} based on the prescribed rate at which HRC expects to continue mapping WFPs (Horizons Regional Council personal communication, September 28, 2021). This significantly differs from the past rate of new WFP mapping, and from previous modelling which used a rate of 35,000 ha yr^{-1} (Dymond et al. 2014; Basher et al. 2018).

New WFPs were randomly selected from unmapped farm boundaries at approximately the same proportions of top-, high- low-, and not-priority SLUI farms as have been mapped in the past and therefore prioritises top and high priority SLUI farms. When there were no farms remaining in a given priority class, the relative proportions of the remaining classes were rescaled, and random sampling continued with the new proportions until there were no unmapped farms left. The approximate proportions of each priority class selected each year are provided in Fig. 2. The exact area of new farms mapped can exceed 10,000 ha if the final farm selected to reach the 10,000-ha threshold is large. This is evident for selected years in Fig. 2. A large proportion of top and high priority farms have already been mapped in the region (Fig. 3).

Table 4. Past proportions of each SLUI farm priority

SLUI Priority	Past proportion of mapped farms (%)	Future area of new mapped farms per year (ha)
Not	5	5,00
Low	20	2,000
High	40	4,000
Top	35	3,500
Total		**10,000**

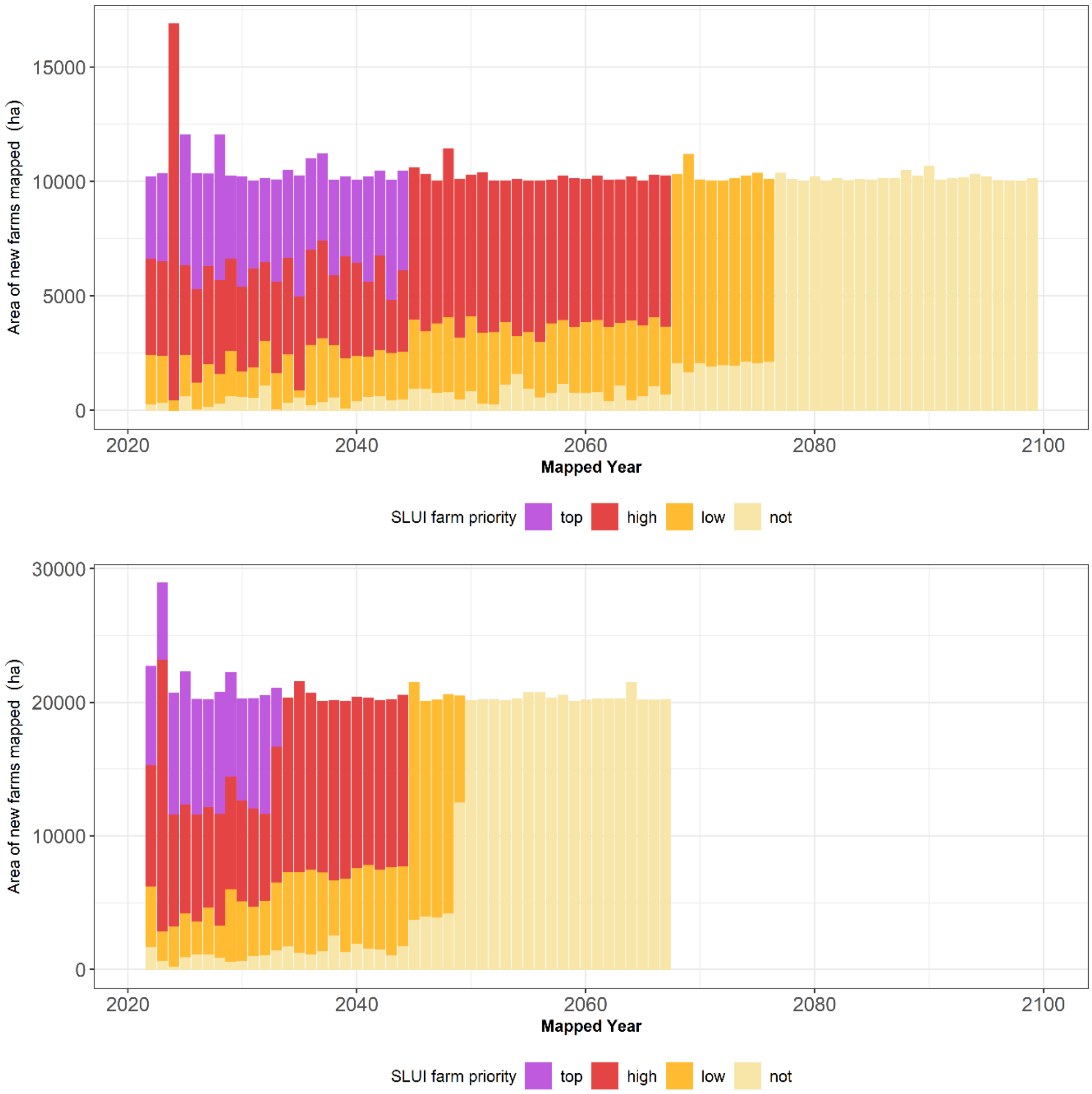

Figure 2. Proportions each priority class selected for new WFPs for SC2 (top) and SC3 (bottom).

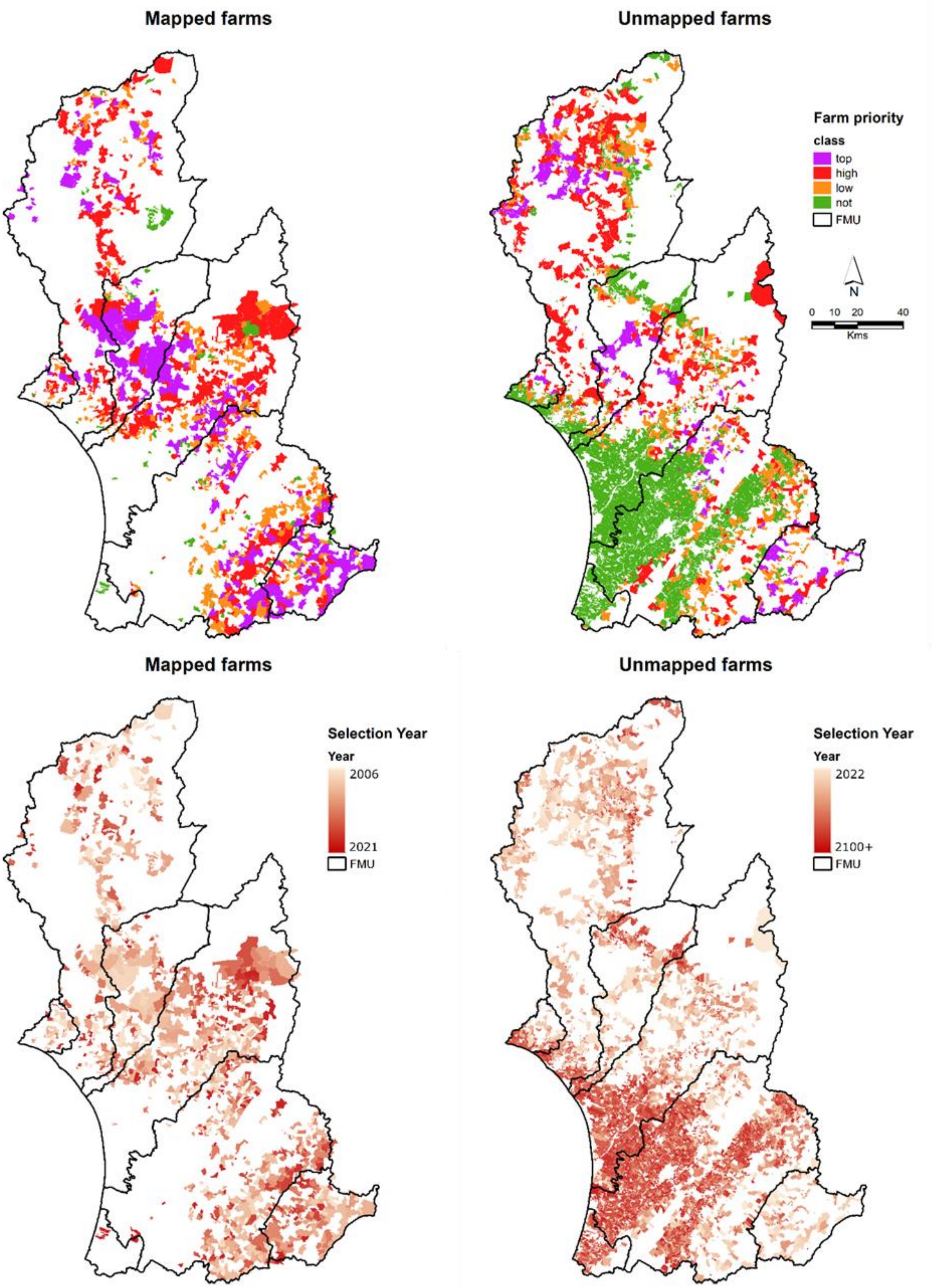

Figure 3. Distribution of mapped and unmapped farm priority classes (top) and the timing of selection for new WFPs for mapped and unmapped farms (bottom).

4.2.4 Climate change projections

The effect of future climate change on erosion and suspended sediment loads is modelled following the approach of (Basher et al. 2020). Six CMIP5 (Coupled Model Inter-comparison Project) 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 (Sood 2014) by Ministry for the Environment (2018) to characterize future temperature and precipitation to 2100 on a 5-km grid. Four forcing scenarios from the Inter-governmental Panel on Climate Change fifth assessment report (IPCC AR5) (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, which 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. (2021c).

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

$$R' = R(1 + \Delta T \; AF) \tag{22}$$

where R' is future rainfall, R is historic 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-year ARI 48-hour duration rainfall event, which 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 years across the region were selected from CliFlo (NIWA 2021) and used to represent historic rainfall. At each gauge, Equation 22 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-hour 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):

$$LD = mR_s + b \tag{23}$$

where LD is the density of shallow landslides per km^2, R_S is the total rainfall for the storm event, m is the slope of the linear relationship between LD and R_s and was 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 $R_s \leq$ 150 mm:

$$0 = 150m + b \tag{24}$$

$$b = -136.8 \tag{25}$$

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:

$$LD' = a\Delta T + LD \tag{26}$$

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:

$$CF = \frac{a}{LD} \tag{27}$$

CF was then interpolated spatially using Sibson's (1981) natural neighbours interpolation. Gauges from across the North Island were included in the interpolation, including five from the Horizons region. This differs from the previous model (Basher et al. 2018, 2020) which used Land Environments of New Zealand (LENZ) level 1 classes to spatialise change factors, using one gauge per LENZ class to derive the change factor and apply it uniformly for the associated class. Two LENZ classes cover most of the Horizons region, each represented by a single rain gauge from the region.

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

$$MM' = MM(1 + CF\Delta T_i) \tag{28}$$

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

The effect of climate change on riverbank erosion is represented using indicative change factors to estimate mean annual flood (MAF) for each scenario per REC2 reach used in the bank erosion model (Smith et al. 2019b). The change factors are based on NIWA's modelling of climate change effects on flow, where proportional changes in MAF were reported for the Manawatū River under RCPs 2.6, 4.5, 6.0, and 8.5 (Collins et al. 2018).

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 Sediment-associated phosphorus loads

Sediment-associated phosphorus loads were estimated for contemporary climate and land cover conditions using data from Parfitt et al. (2013) and followed the same approach used in previous SedNetNZ modelling for HRC (Basher et al. 2018). Parfitt et al. (2013) estimated that 95% of the total phosphorus load in the Manawatū River is due to particulate phosphorus in sediment. Other rivers in the Horizons region draining the Ruahine and Tararua ranges are likely to have similar proportions. Total phosphorus loads in rivers may then be estimated as a given fraction of the sediment load. This fraction is the average proportion of sediment that is particulate phosphorus. Parfitt et al. (2013) measured this fraction during 6 flood events of the Manawatū River to be 0.05% (i.e. 545 mg kg^{-1} from Table 4 of Parfitt et al. (2013)). This fraction is also within the range of phosphate contents of sandstone, mudstone, and greywacke rocks in the Wairarapa as directly measured by Eden and Parfitt (1992).

4.4 Reductions for NPS-FM visual clarity attribute bands

The reductions in suspended sediment loads required to meet NPS-FM (2020) suspended fine sediment objectives were estimated following Neverman et al. (2019); Neverman et al. (2021a); Neverman et al. (2021b), and Neverman and Smith (2022) using a national-scale empirical model relating reductions in average annual suspended sediment load to changes in median visual clarity developed by Hicks et al. (2019a). The baseline attribute state was based on modelled median visual clarity data for each segment of the REC2 river network supplied by HRC, while the attribute state thresholds were defined using Table 5 from the NPS-FM 2020 and the national sediment class map developed for the NPS-FM by Hicks and Shankar (2020). Figure 4 displays the spatial pattern in visual clarity national bottom line values across the Horizons region.

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

$$PR_v = 1 - (V_o/V_b)^{1/a} \quad (29)$$

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

Given the national bottom-line threshold overlaps with the bottom of the range for band C, our analysis examines reductions required to meet the national bottom line, band B, and band A. Achieving band C requires only a marginal increase in load reduction from that required to achieve the national bottom line.

To identify which attribute band a REC2 segment would comply with after existing erosion mitigation associated with WFPs are completed, the reduction in mean annual load between the 2021 baseline and future 5-year interval scenarios were compared to the required load reduction to achieve each attribute band. Where the achieved reduction was higher than the required load reduction, the associated attribute band is considered achievable.

Table 5. Attribute bands and numeric attribute states for fine suspended sediment. Reproduced from Table 8 in the NPS-FM 2020

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

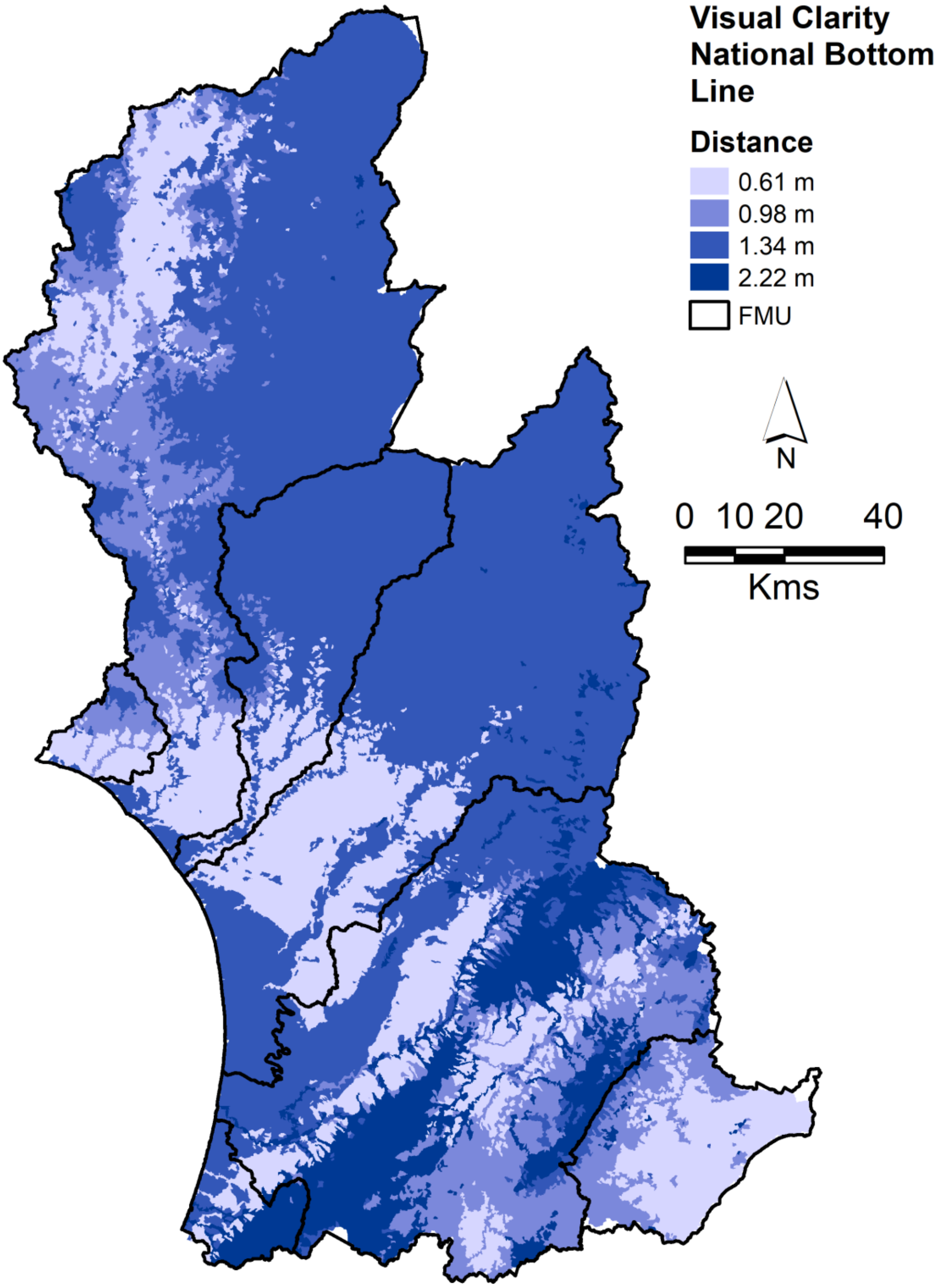

Figure 4. Required visual clarity for NPS-FM 2020 national bottom line according to sediment class.

5 Results

5.1 Suspended sediment loads

Mean suspended sediment loads are provided in two forms: ‘total erosion’, which represents the total suspended sediment load (t yr^{-1}) produced from all erosion processes in each REC2 watershed; and ‘total net load’, which represents the net suspended sediment load routed down the catchment to the coast accounting for lake trapping and floodplain deposition. These modelled loads do not include the impacts of climate change, which are described in section 5.4

Total erosion

Total erosion loads for each scenario are presented in Tables 6–8, and Figure 5. The tables summarise regional erosion loads by FMU from 2021 to 2100 and provide load reductions achieved relative to 2021 baseline loads for each scenario. Mean annual suspended sediment yields (t km^{-2} yr^{-1}) are provided for 2021 in Figure 6 and for 2100 for each scenario in Figure 7.

Region-wide total erosion was estimated as 9.0 Mt yr^{-1} for 2021. The highest sediment yields (>2,500 t km^{-2} yr^{-1}) occur in a band of gully and shallow landslide-prone land mostly restricted to hill country in the ‘Manawatū’, ‘Rangitīkei-Turakina’, and ‘Whangaehu’ FMUs. High sediment yields are also observed in a number of REC2 watersheds which produce high bank erosion loads (Fig. 6). Total erosion at 2100 was estimated as 8.8, 4.9, and 4.3 Mt yr^{-1} for SC1, SC2, and SC3, respectively. This equates to a region wide reduction of 4.1 and 4.7 Mt yr^{-1}, or 47% and 53% by 2100 for SC2 and SC3, respectively.

Proportional reductions at 2100 for individual FMUs ranged from 8 to 61% and 17 to 65% for SC2 and SC3, respectively. The smallest proportional reductions occurred in ‘Waiopehu’ and the largest occurred in ‘Puketoi ki Tai’. Absolute load reductions at 2100 for individual FMUs ranged from 0.01 to 1.1 Mt yr^{-1}, and 0.01 to 1.3 Mt yr^{-1} for SC2 and SC3, respectively. The smallest absolute reduction occurred in ‘Waiopehu’ and the largest occurred in ‘Manawatū’.

The rate of reduction observed for each FMU reflects the proportion of SLUI farm priority classes within each FMU combined with the selection order of new farms for implementation. This is illustrated in ‘Waiopehu’ where significant sediment load reduction for SC2 and SC3 appears to start later compared to other FMUs (Fig. 5). This is due to ‘Waiopheu’ mostly comprising ‘not’ priority farms in lowlands that, due to the order of selection, are mostly selected in the latter part of the century.

Total net load

Total net suspended sediment loads for each scenario are presented in Tables 9 to 11 and Figure 8. The tables summarise net sediment loads for selected rivers and total net load delivered to the coast from 2021 to 2100, and also provide load reductions achieved relative to 2021 baseline loads for each scenario. Mean annual net suspended sediment loads for 2021 are visualized in Figure 9.

Region-wide total net suspended sediment load delivered to the coast for 2021 was 8.5 Mt yr^{-1}. The largest net sediment loads occurred in the Whanganui (2.7 Mt yr^{-1}) and Manawatū (2.4 Mt yr^{-1}) rivers. Total net sediment load delivered to the coast at 2100 was 8.3, 4.6, and 4.1 Mt yr^{-1} for SC1, SC2, and SC3, respectively. This equates to a region-wide net sediment load reduction at 2100 of 3.9, and 4.4 Mt yr^{-1}, or 46% and 52% for SC2 and SC3, respectively.

Proportional net suspended sediment load reductions at 2100 for individual FMUs ranged from 9 to 60% and 16 to 64% for SC2 and SC3, respectively. The smallest proportional reductions occurred in the Ōhau river. The largest proportional reductions occurred in the Ākito river for SC2 and the Turakina river for SC3. Absolute net load reductions for selected rivers at 2100 ranged from 0.0 to 1.1 Mt yr^{-1} and 0.01 to 1.3 Mt yr^{-1} for SC2 and SC3, respectively. The smallest absolute load reduction occurred in the Ōhau river, and the largest reduction occurred in the Manawatū River. The Ōhau river is the main river within the 'Waiopheu' FMU and therefore shows a similar trend related to being comprised mostly of 'not' priority farms in lowlands.

Table 6. Total erosion load and difference from 2021 baseline for SC1

SC1	Total erosion (Mt yr^{-1})					Difference from 2021 baseline							
FMU	2021	2040	2060	2080	2100	2040		2060		2080		2100	
						Mt yr^{-1}	%	Mt yr^{-1}	%	Mt yr^{-1}	%	Mt yr^{-1}	%
Kai Iwi	0.11	0.11	0.11	0.11	0.11	-0.00	-4%	-0.00	-4%	-0.00	-4%	-0.00	-4%
Manawatū	2.55	2.49	2.49	2.49	2.49	-0.06	-2%	-0.06	-2%	-0.06	-2%	-0.06	-2%
Puketoi ki Tai	0.51	0.48	0.48	0.48	0.48	-0.03	-6%	-0.03	-6%	-0.03	-6%	-0.03	-6%
Rangitīkei-Turakina	1.97	1.93	1.93	1.93	1.93	-0.04	-2%	-0.04	-2%	-0.04	-2%	-0.04	-2%
Waiopehu	0.06	0.06	0.06	0.06	0.06	-0.00	0%	-0.00	0%	-0.00	0%	-0.00	0%
Whangaehu	0.99	0.96	0.96	0.96	0.96	-0.03	-3%	-0.03	-3%	-0.03	-3%	-0.03	-3%
Whanganui	2.81	2.75	2.75	2.75	2.75	-0.06	-2%	-0.06	-2%	-0.06	-2%	-0.06	-2%
Total	**9.99**	**8.79**	**8.79**	**8.79**	**8.79**	**-0.21**	**-1%**	**-0.21**	**-2%**	**-0.21**	**-2%**	**-0.21**	**-2%**

Table 7. Total erosion load and difference from 2021 baseline for SC2

SC2	Total erosion (Mt yr^{-1})					Difference from 2021 baseline							
FMU	2021	2040	2060	2080	2100	2040		2060		2080		2100	
						Mt yr^{-1}	%	Mt yr^{-1}	%	Mt yr^{-1}	%	Mt yr^{-1}	%
Kai Iwi	0.11	0.10	0.09	0.08	0.07	-0.01	-7%	-0.02	-16%	-0.03	-25%	-0.04	-34%
Manawatū	2.55	2.32	2.05	1.74	1.41	-0.22	-9%	-0.50	-20%	-0.81	-32%	-1.13	-45%
Puketoi ki Tai	0.51	0.44	0.36	0.28	0.21	-0.08	-15%	-0.15	-31%	-0.23	-47%	-0.30	-61%
Rangitīkei-Turakina	1.97	1.77	1.52	1.23	0.94	-0.19	-10%	-0.45	-23%	-0.73	-38%	-1.03	-53%
Waiopehu	0.06	0.06	0.06	0.06	0.06	-0.00	0%	-0.00	-2%	-0.01	-3%	-0.01	-8%
Whangaehu	0.99	0.87	0.72	0.56	0.41	-0.12	-13%	-0.27	-28%	-0.43	-45%	-0.58	-60%
Whanganui	2.81	2.62	2.38	2.06	1.75	-0.19	-7%	-0.43	-16%	-0.75	-27%	-1.06	-38%
Total	**8.99**	**8.19**	**7.18**	**6.02**	**4.85**	**-0.81**	**-9%**	**-1.82**	**-21%**	**-2.97**	**-34%**	**-4.14**	**-47%**

Table 8. Total erosion load and difference from 2021 baseline for SC3

SC3	Total erosion (Mt yr^{-1})					Difference from 2021 baseline							
FMU	2021	2040	2060	2080	2100	2040		2060		2080		2100	
						Mt yr^{-1}	%	Mt yr^{-1}	%	Mt yr^{-1}	%	Mt yr^{-1}	%
Kai Iwi	0.11	0.10	0.09	0.08	0.07	-0.01	-9%	-0.02	-19%	-0.03	-31%	-0.05	-42%
Manawatū	2.55	2.31	1.98	1.60	1.23	-0.24	-10%	-0.57	-23%	-0.95	-38%	-1.32	-53%
Puketoi ki Tai	0.51	0.43	0.35	0.27	0.19	-0.08	-16%	-0.17	-34%	-0.25	-50%	-0.32	-65%
Rangitīkei-Turakina	1.97	1.76	1.46	1.15	0.84	-0.21	-11%	-0.51	-26%	-0.82	-42%	-1.13	-58%
Waiopehu	0.06	0.06	0.06	0.06	0.05	-0.00	0%	-0.00	-3%	-0.01	-10%	-0.01	-17%
Whangaehu	0.99	0.86	0.69	0.53	0.37	-0.13	-13%	-0.29	-30%	-0.46	-48%	-0.62	-64%
Whanganui	2.81	2.59	2.26	1.91	1.57	-0.22	-8%	-0.55	-20%	-0.90	-33%	-1.23	-45%
Total	**8.99**	**8.11**	**6.89**	**5.57**	**4.32**	**-0.89**	**-10%**	**-2.11**	**-24%**	**-3.42**	**-39%**	**-4.67**	**-53%**

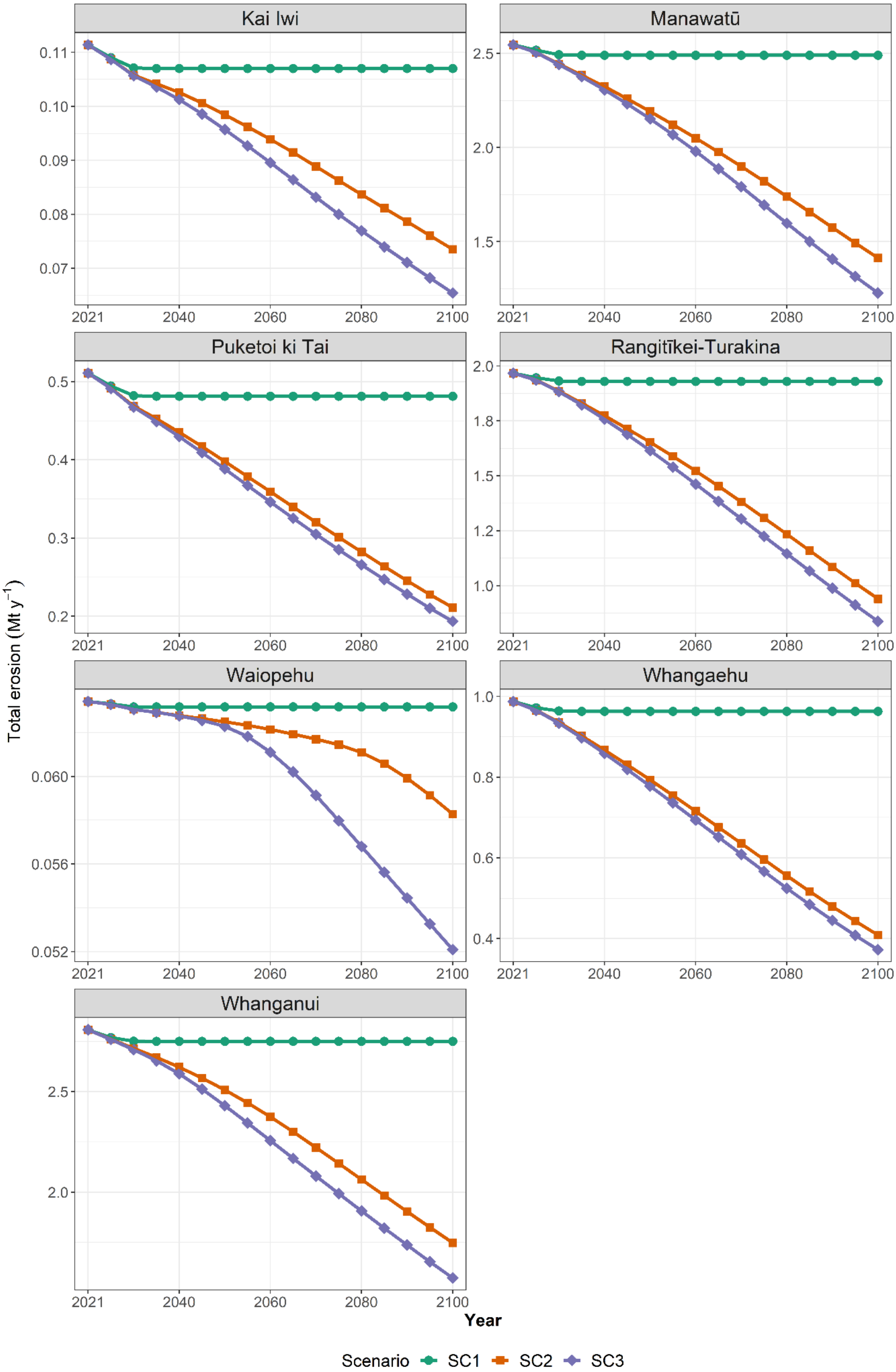

Figure 5. Total erosion loads (Mt yr^{-1}) summarised by FMU for SC1, SC2 and SC3 at 5-year intervals.

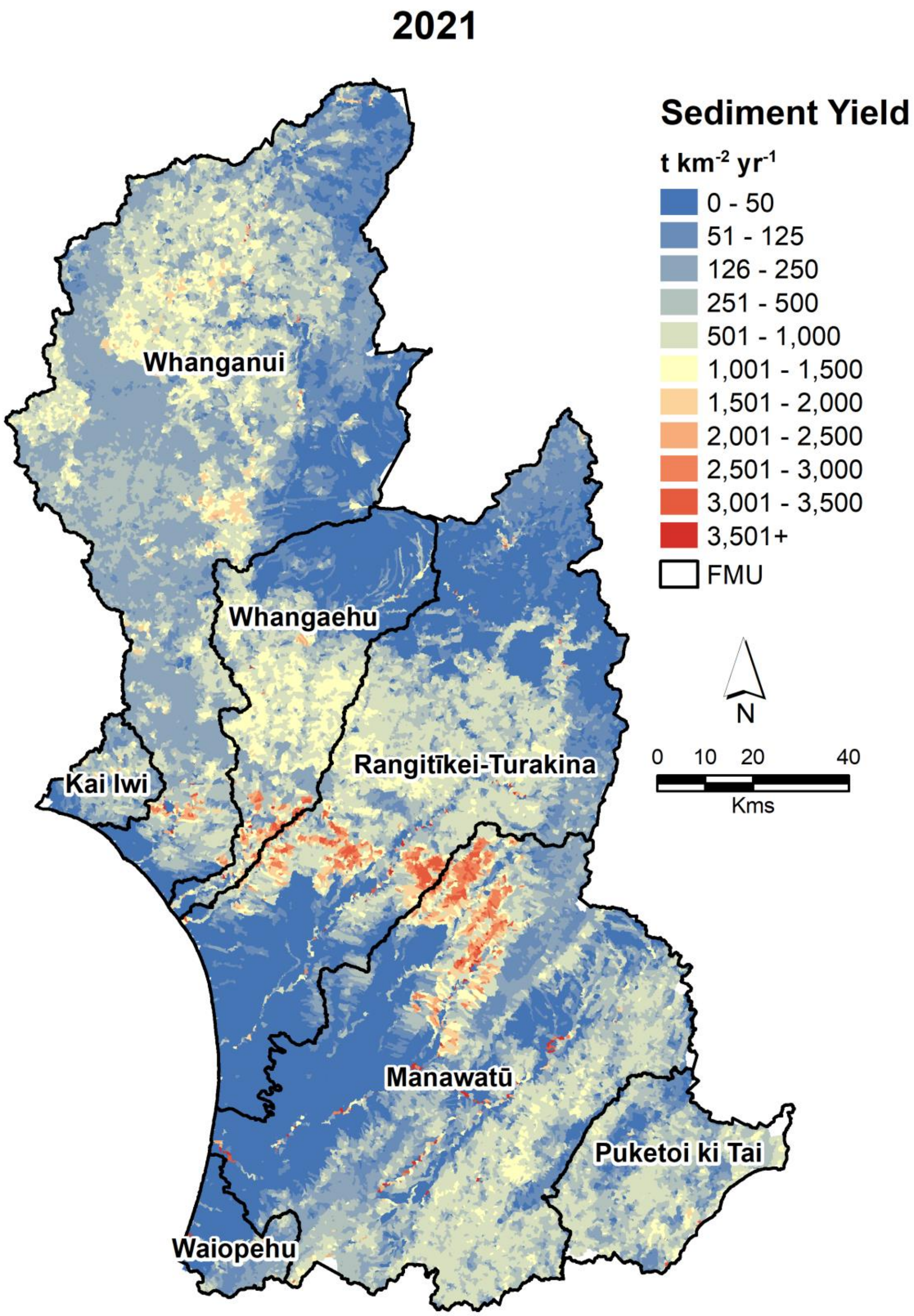

Figure 6. Mean annual sediment yield (t km^{-2} yr^{-1}) at 2021 baseline.

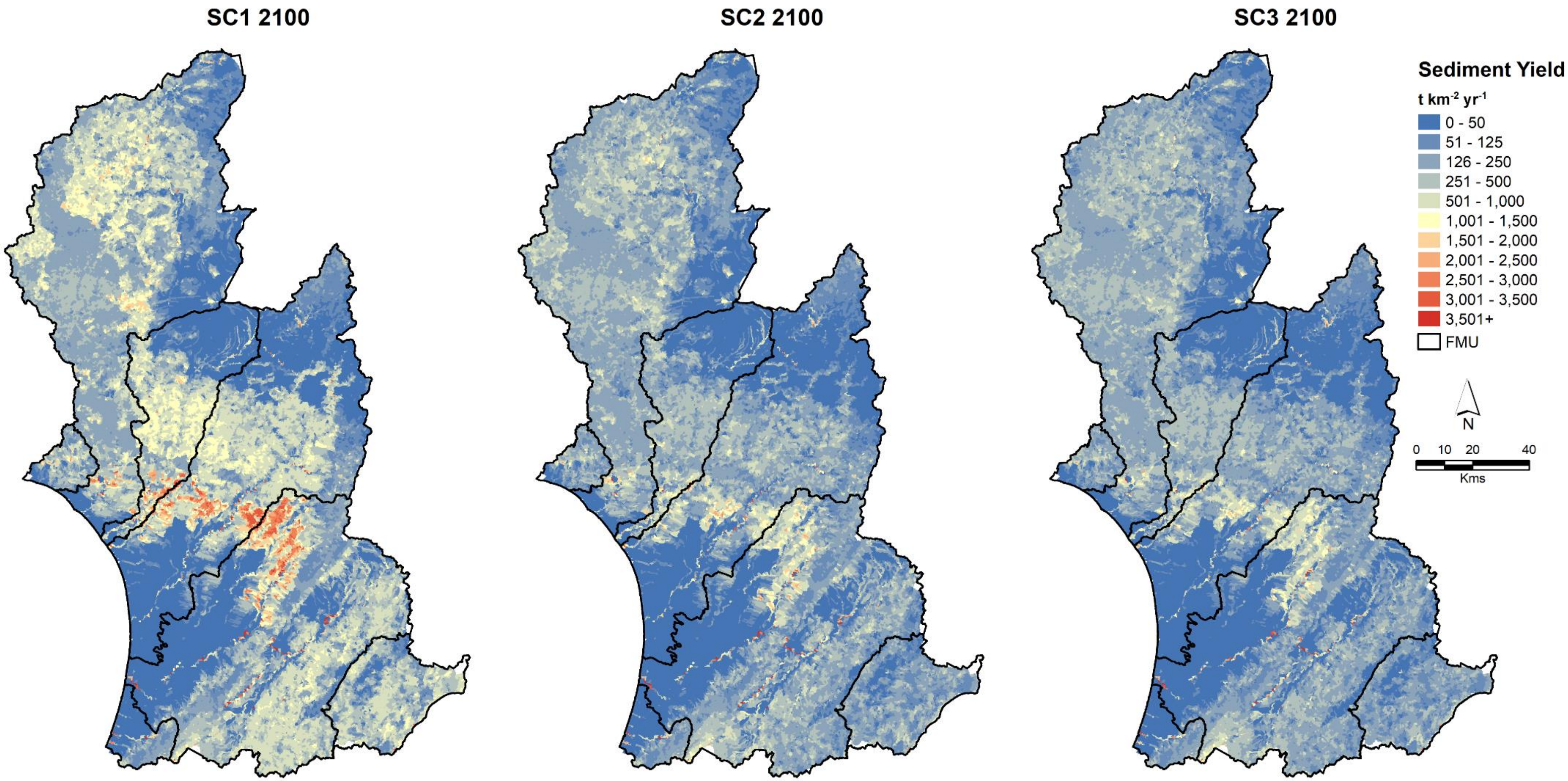

Figure 7. Mean annual sediment yield (t km^{-2} yr^{-1}) for SC1, SC2, and SC3 at 2100.

Table 9. Total net load and difference from 2021 of selected rivers for SC1. *Total is total net load delivered to the coast for the whole region.

SC1	Total net load (Mt yr^{-1})					Difference from 2021							
River	2021	2040	2060	2080	2100	2040		2060		2080		2100	
						Mt yr^{-1}	%	Mt yr^{-1}	%	Mt yr^{-1}	%	Mt yr^{-1}	%
Kai iwi	0.06	0.06	0.06	0.06	0.06	-0.00	-5%	-0.00	-5%	-0.00	-5%	-0.00	-5%
Whanganui	2.67	2.61	2.61	2.61	2.61	-0.06	-2%	-0.06	-2%	-0.06	-2%	-0.06	-2%
Whangaehu	0.94	0.92	0.92	0.92	0.92	-0.02	-3%	-0.02	-3%	-0.02	-3%	-0.02	-3%
Turakina	0.65	0.64	0.64	0.64	0.64	-0.01	-2%	-0.01	-2%	-0.01	-2%	-0.01	-2%
Rangitīkei	1.19	1.17	1.17	1.17	1.17	-0.03	-2%	-0.03	-2%	-0.03	-2%	-0.03	-2%
Manawatū	2.41	2.36	2.36	2.36	2.36	-0.05	-2%	-0.05	-2%	-0.05	-2%	-0.05	-2%
Ākito	0.22	0.21	0.21	0.21	0.21	-0.01	-6%	-0.01	-6%	-0.01	-6%	-0.01	-6%
Ōhau	0.04	0.04	0.04	0.04	0.04	-0.00	0%	-0.00	-0%	-0.00	-0%	-0.00	-0%
Total*	**8.52**	**8.32**	**8.32**	**8.32**	**8.32**	**-0.20**	**-2%**	**-0.20**	**-2%**	**-0.20**	**-2%**	**-0.20**	**-2%**

Table 10. Total net load and difference from 2021 of selected rivers for SC2. *Total is total net load delivered to the coast for the whole region.

SC2	Total net load (Mt yr^{-1})					Difference from 2021							
						2040		2060		2080		2100	
River	2021	2040	2060	2080	2100	Mt yr^{-1}	%	Mt yr^{-1}	%	Mt yr^{-1}	%	Mt yr^{-1}	%
Kai iwi	0.06	0.06	0.05	0.05	0.04	-0.01	-9%	-0.01	-17%	-0.02	-27%	-0.02	-34%
Whanganui	2.67	2.49	2.25	1.96	1.66	-0.18	-7%	-0.41	-15%	-0.71	-27%	-1.01	-38%
Whangaehu	0.94	0.83	0.68	0.53	0.39	-0.12	-12%	-0.26	-27%	-0.41	-44%	-0.55	-58%
Turakina	0.65	0.59	0.49	0.38	0.27	-0.07	-11%	- 0.17	-26%	-0.28	-42%	-0.39	-59%
Rangitīkei	1.19	1.08	0.94	0.78	0.61	-0.12	-10%	-0.26	-21%	-0.42	-35%	-0.59	-49%
Manawatū	2.41	2.20	1.94	1.64	1.33	-0.21	-9%	-0.47	-20%	-0.77	-32%	-1.08	-45%
Ākito	0.22	0.18	0.15	0.12	0.09	-0.04	-16%	-0.07	-32%	-0.10	-47%	-0.13	-60%
Ōhau	0.04	0.04	0.04	0.04	0.04	-0.00	-0%	-0.00	-2%	-0.00	-5%	-0.00	-9%
Total*	**8.52**	**7.75**	**6.79**	**5.69**	**4.59**	**-0.77**	**-9%**	**-1.73**	**-20%**	**-2.83**	**-33%**	**-3.94**	**-46%**

Table 11. Total net load and difference from 2021 baseline of selected rivers for SC3. *Total is total net load delivered to the coast for the whole region.

SC3	Total net load (Mt yr^{-1})					Difference from 2021 baseline							
						2040		2060		2080		2100	
River	2021	2040	2060	2080	2100	Mt yr^{-1}	%	Mt yr^{-1}	%	Mt yr^{-1}	%	Mt yr^{-1}	%
Kai iwi	0.06	0.06	0.05	0.04	0.04	-0.01	-11%	-0.01	-20%	-0.02	-31%	-0.03	-41%
Whanganui	2.67	2.46	2.14	1.81	1.49	-0.21	-8%	-0.52	-20%	-0.86	-32%	-1.17	-44%
Whangaehu	0.94	0.82	0.66	0.50	0.36	-0.12	-13%	-0.28	-30%	-0.44	-47%	-0.59	-62%
Turakina	0.65	0.58	0.47	0.35	0.24	-0.08	-11%	-0.19	-29%	-0.30	-46%	-0.42	-64%
Rangitīkei	1.19	1.07	0.90	0.72	0.54	-0.12	-10%	-0.29	-24%	-0.48	-40%	-0.66	-55%
Manawatū	2.41	2.18	1.87	1.51	1.15	-0.23	-9%	-0.54	-22%	-0.90	-38%	-1.26	-52%
Ākito	0.22	0.18	0.15	0.11	0.08	-0.04	-17%	-0.07	-34%	-0.11	-49%	-0.14	-63%
Ōhau	0.04	0.04	0.04	0.04	0.04	-0.00	0%	-0.00	-5%	-0.00	-9%	-0.01	-16%
Total*	**8.52**	**7.68**	**6.52**	**5.27**	**4.08**	**-0.84**	**-10%**	**-2.00**	**-23%**	**-3.25**	**-38%**	**-4.44**	**-52%**

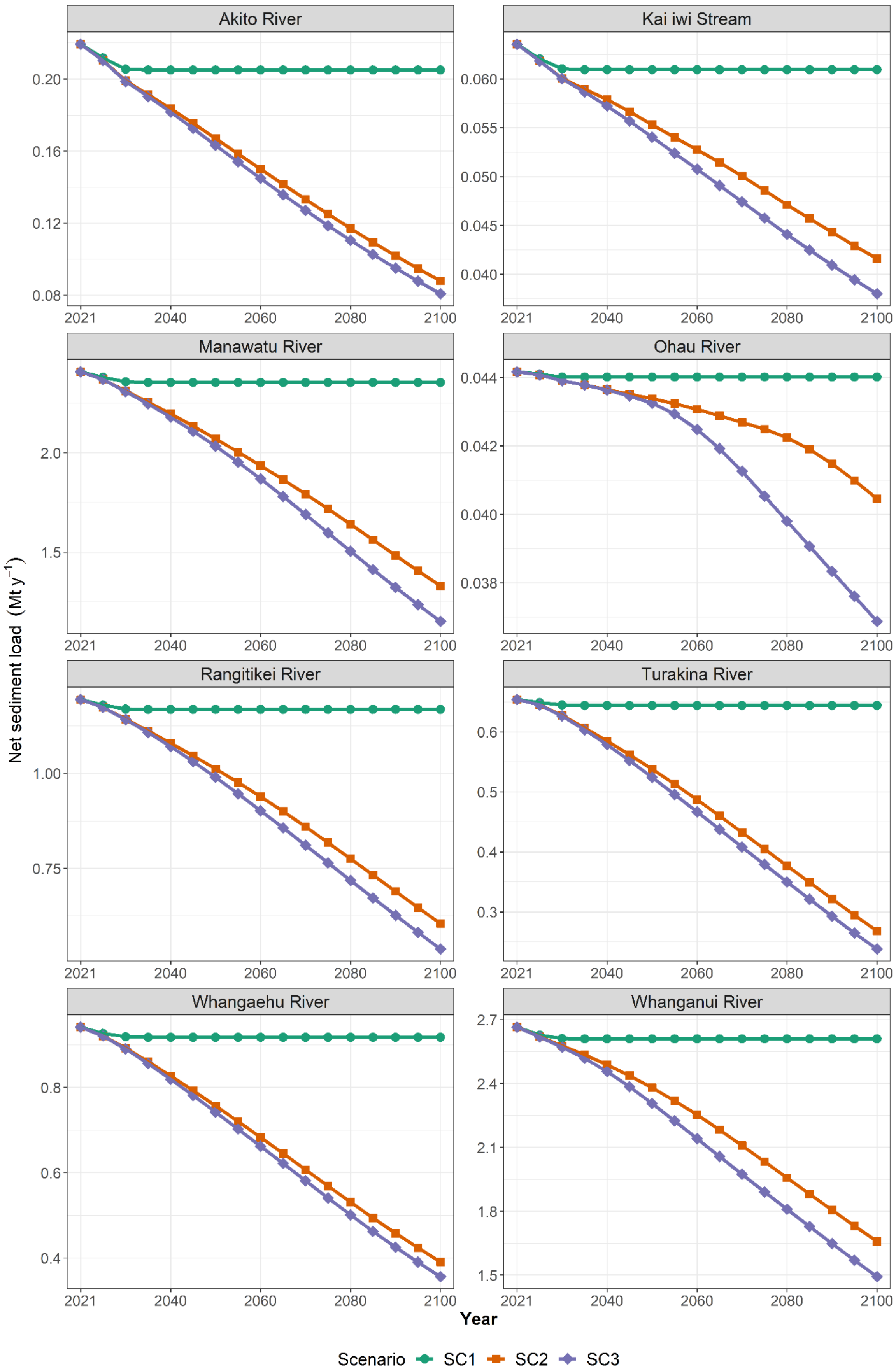

Figure 8. Total net sediment load (Mt yr^{-1}) summarised by selected river catchments for SC1, SC2, and SC3 at 5-year intervals.

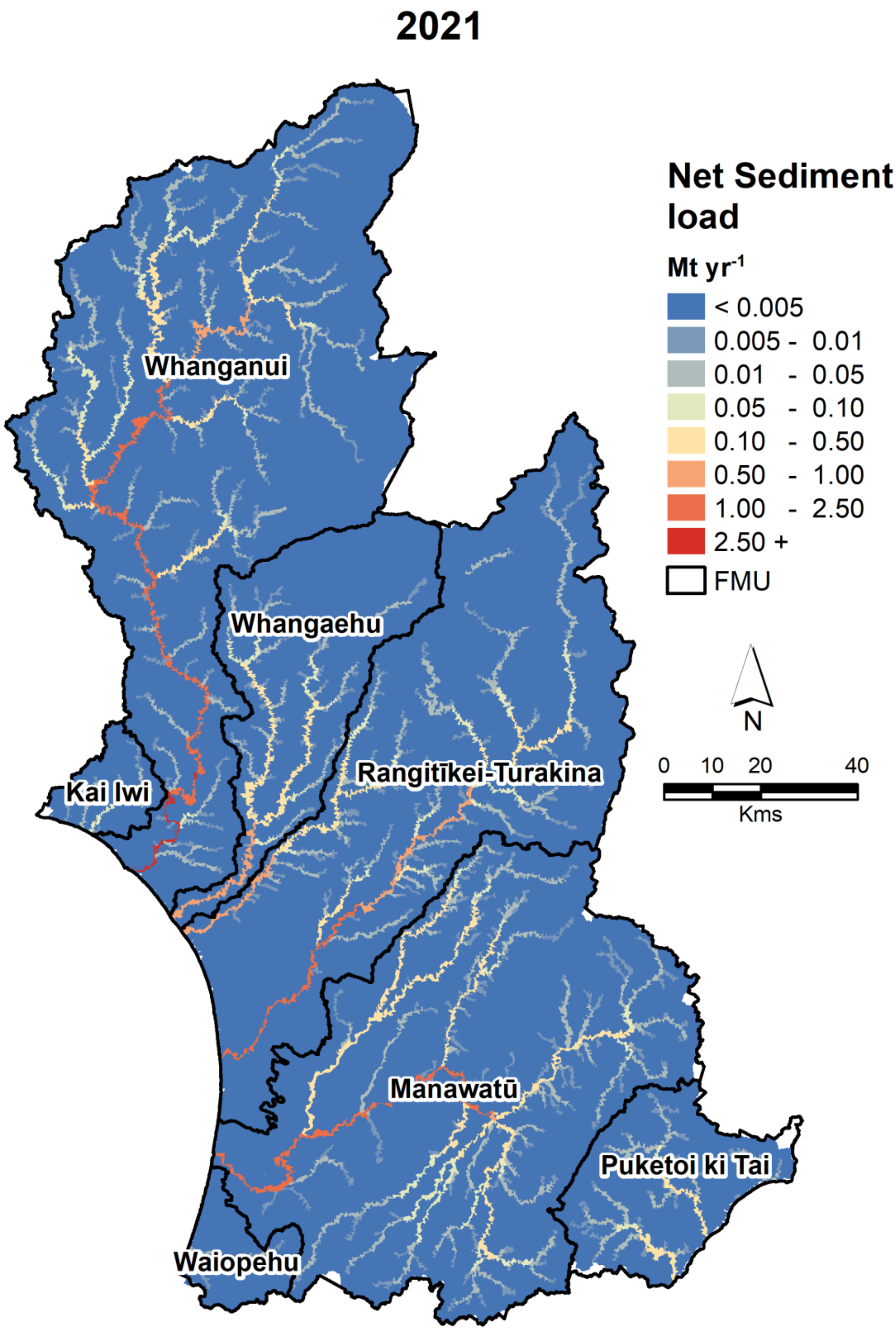

Figure 9. Mean annual net sediment load (Mt yr^{-1}) at 2021 baseline.

5.2 Phosphorus loads

Total net sediment-associated phosphorus loads delivered to the coast are presented in Table 12, and visualized in Figure 10. The table summarises net loads for selected rivers and streams for 2021.

Total net sediment-associated phosphorus loads to the coast was 4.3 kt yr^{-1}. The largest net sediment loads occurred in the Whanganui (1.3 kt yr^{-1}) and Manawatū (1.2 kt yr^{-1}) rivers. Sediment-associated phosphorus loads reflect the patterns of net suspended sediment load across the region since the phosphorus loads are based on the mean phosphorus content of suspended sediment.

Table 12. Total net sediment associated phosphorus load of selected rivers for 2021 baseline. *Total is total net load delivered to the coast for the whole region

2021	**Total net sediment-associated phosphorus load (kt yr^{-1})**
River	**2021**
Kai iwi stream	0.03
Whanganui River	1.33
Whangaehu River	0.47
Turakina River	0.33
Rangitīkei River	0.60
Manawatū River	1.20
Ākito River	0.11
Ōhau River	0.02
Total*	**4.26**

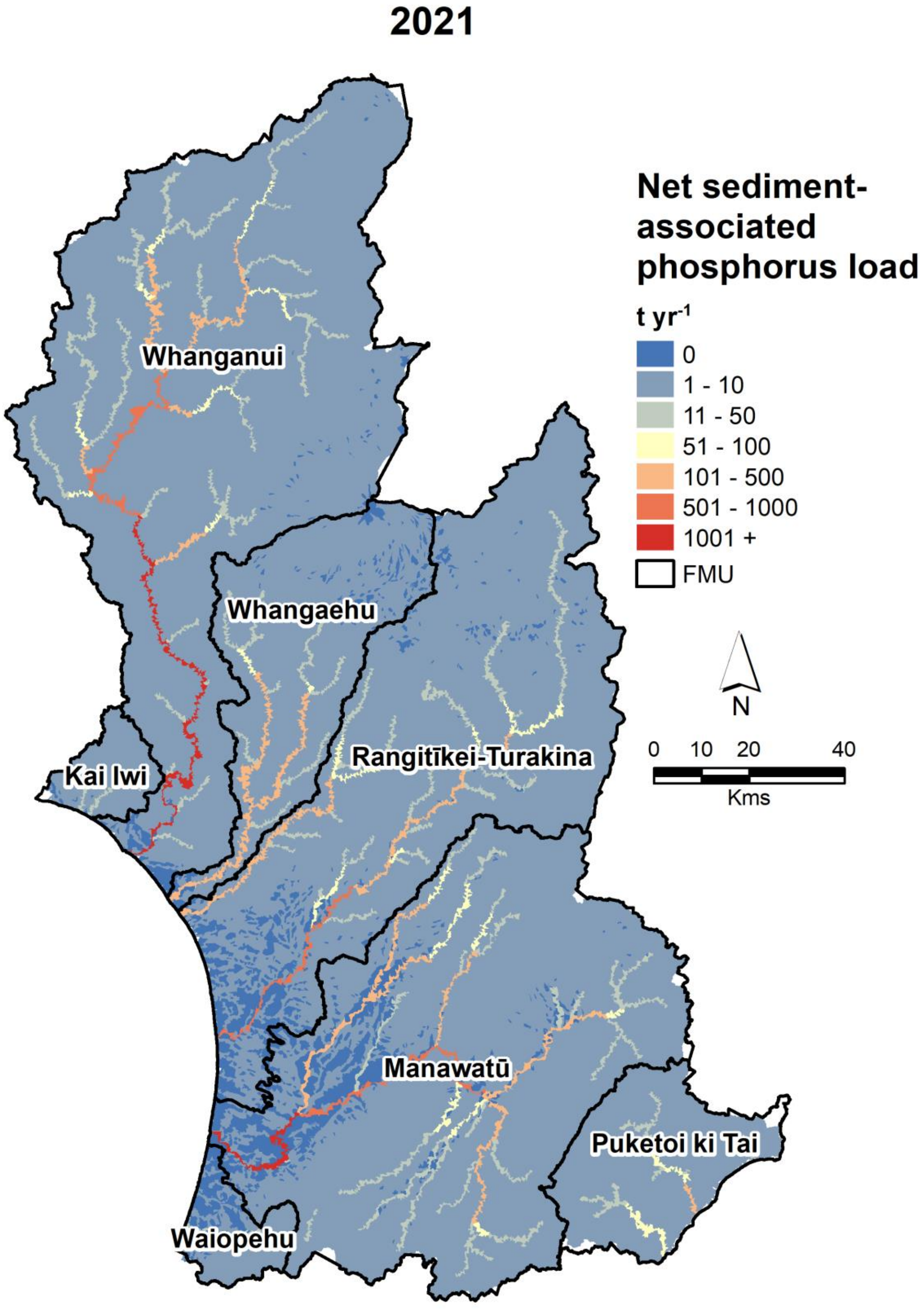

Figure 10. Mean annual net sediment-associated phosphorus load (t yr^{-1}) at 2021.

5.3 Sediment load reductions required to meet NPS-FM visual clarity attribute bands

Suspended sediment load reductions required to achieve NPS-FM 2020 attribute bands were modelled as proportional and absolute load reductions for each REC2 segment. These are summarised by length and proportion by length of REC2 segments achieving each attribute band in Tables 13–15. Required proportional reductions are visualized in Figures 11–13 and required absolute load reductions in Figures 14–16. Summaries of length and proportions of length according to stream order for each FMU are provided in Appendix 1.

The region-wide proportion of REC2 segments achieving Band A, B, and national bottom line in 2021 was 38, 60, and 75%, respectively. At 2100, these proportions increase to 70, 82, and 88% for SC2, and 76, 86, and 90% for SC3. The region-wide proportions are weighted towards lower order REC2 segments since lower order segments represent a significantly higher total stream length across the region than higher order REC2 segments.

The proportion of higher order REC2 segments achieving each attribute band was low relative to lower order REC2 stream segments. For example, in 2021, 38–43% of REC2 segments from stream orders ≤5, achieved Band A, while only 8 and 0% from stream orders 6 and 7, respectively, achieved A band. Similarly, 70–78% of REC2 segments from stream orders ≤5 achieved national bottom line, while only 46 and 13% from stream orders 6 and 7, respectively, achieved bottom line. The low number of REC2 segments achieving these targets in higher order streams is likely due to the large absolute load reductions required and the need for reductions throughout the upstream catchment area.

Large proportional reductions required at 2021 occur throughout the region; however, the highest reductions are particularly evident in the lowland coastal areas of 'Manawatū' and 'Rangitīkei-Turakina', and are also observed along a number of higher order REC2 segments (Fig. 11). The proportion of REC2 segments achieving national bottom line at 2100 increases for SC2 and SC3; however, a large area of the lowland REC2 segments still require relatively high proportional reductions to achieve bottom line at 2100, albeit these represent low absolute loads.

The regional pattern in sediment load reductions relates to 1) SLUI erosion mitigation which focuses mitigation in hill country, 2) the selection order of new farm plans being based on SLUI priority classes, and 3) sensitivity to variations in visual clarity thresholds based on the spatial pattern in the suspended sediment class used to define threshold values:

1 Sediment load reductions were modelled based on the type of works implemented within the SLUI programme. These works are predominantly focused on farms with highly erodible hill country. Additional works may occur in the region through other initiatives that may also have an impact on erosion, however since these are not captured in the SLUI programme they are not represented. This is particularly relevant to lowland areas where SLUI is not highly active. It is understood there are initiatives that result in fencing and riparian planting in some lowland areas. Including these

initiatives would have an impact on sediment loads and the subsequent proportional reduction required to achieve NPS-FM attribute bands in lowland areas.

2 SLUI prioritises 'top' and 'high' priority farms which typically occur in hill country and these farms are prioritised when selecting new farms for WFPs. Since most lowland farms are classed as 'not' priority they are the lowest priority (Figs 2 & 3). The implication is that at 2100, negligible works have been completed on most 'not' priority farms and the potential load reduction from erosion control would not be realized until after the modelling period.

3 The required visual clarity for a given REC2 segment is determined by the assigned sediment class. There are 4 sediment classes, and although they consider factors such as climate, topography, and geology through the River Environment Classification to assign the class (Ministry for the Environment 2020), they can result in abrupt changes in visual clarity thresholds and required load reductions between adjacent REC2 segments.

Table 13. Length and proportion of REC2 segments achieving each visual clarity attribute band summarized by stream order for SC1

SC1	Stream Order	Total length km	REC2 segments achieving for selected years									
			2021		2040		2060		2080		2100	
			km	%	km	%	km	%	km	%	km	%
Band A	1	18,148	7,221	40%	7,533	42%	7,533	42%	7,533	42%	7,533	42%
	2	9,101	3,565	39%	3,731	41%	3,731	41%	3,731	41%	3,731	41%
	3	4,521	1,779	39%	1,861	41%	1,861	41%	1,861	41%	1,861	41%
	4	2,381	905	38%	947	40%	947	40%	947	40%	947	40%
	5	1,388	593	43%	607	44%	607	44%	607	44%	607	44%
	6	676	52	8%	52	8%	52	8%	52	8%	52	8%
	7	505	-	0%	-	0%	-	0%	-	0%	-	0%
	Total	36,720	14,115	38%	14,732	40%	14,732	40%	14,732	40%	14,732	40%
Band B	1	18,148	11,386	63%	11,670	64%	11,670	64%	11,670	64%	11,670	64%
	2	9,101	5,619	62%	5,758	63%	5,758	63%	5,758	63%	5,758	63%
	3	4,521	2,762	61%	2,832	63%	2,832	63%	2,832	63%	2,832	63%
	4	2,381	1,399	59%	1,442	61%	1,442	61%	1,442	61%	1,442	61%
	5	1,388	793	57%	812	58%	812	58%	812	58%	812	58%
	6	676	130	19%	131	19%	131	19%	131	19%	131	19%
	7	505	4	1%	5	1%	5	1%	5	1%	5	1%
	Total	36,720	22,094	60%	22,650	62%	22,650	62%	22,650	62%	22,650	62%
National bottom line	1	18,148	14,116	78%	14,221	78%	14,221	78%	14,221	78%	14,221	78%
	2	9,101	6,909	76%	6,993	77%	6,993	77%	6,993	77%	6,993	77%
	3	4,521	3,412	75%	3,460	77%	3,460	77%	3,460	77%	3,460	77%
	4	2,381	1,751	74%	1,791	75%	1,791	75%	1,791	75%	1,791	75%
	5	1,388	978	70%	995	72%	995	72%	995	72%	995	72%
	6	676	308	46%	312	46%	312	46%	312	46%	312	46%
	7	505	66	13%	101	20%	101	20%	101	20%	101	20%
	Total	36,720	27,540	75%	27,875	76%	27,875	76%	27,875	76%	27,875	76%

Table 14. Length and proportion of REC2 segments achieving each visual clarity attribute band summarized by stream order for SC2

SC2	Stream Order	Total length Km	REC2 segments achieving for selected years									
			2021		2040		2060		2080		2100	
			km	%	km	%	km	%	km	%	km	%
Band A	1	18,148	7,221	40%	8,432	46%	9,995	55%	11,446	63%	12,419	68%
	2	9,101	3,565	39%	4,160	46%	4,919	54%	5,710	63%	6,324	69%
	3	4,521	1,779	39%	2,053	45%	2,436	54%	2,888	64%	3,243	72%
	4	2,381	905	38%	1,095	46%	1,337	56%	1,572	66%	1,814	76%
	5	1,388	593	43%	631	45%	671	48%	883	64%	1,032	74%
	6	676	52	8%	75	11%	149	22%	303	45%	536	79%
	7	505	-	0%	-	0%	4	1%	116	23%	177	35%
	Total	36,720	14,115	38%	16,445	45%	19,511	53%	22,920	62%	25,544	70%
Band B	1	18,148	11,386	63%	12,415	68%	13,491	74%	14,261	79%	14,823	82%
	2	9,101	5,619	62%	6,100	67%	6,686	73%	7,125	78%	7,452	82%
	3	4,521	2,762	61%	3,002	66%	3,295	73%	3,584	79%	3,751	83%
	4	2,381	1,399	59%	1,514	64%	1,713	72%	1,911	80%	2,052	86%
	5	1,388	793	57%	868	63%	1,008	73%	1,102	79%	1,201	87%
	6	676	130	19%	189	28%	325	48%	499	74%	582	86%
	7	505	4	1%	18	4%	113	22%	167	33%	241	48%
	Total	36,720	22,094	60%	24,107	66%	26,629	73%	28,648	78%	30,103	82%
National bottom line	1	18,148	14,116	78%	14,729	81%	15,170	84%	15,548	86%	15,831	87%
	2	9,101	6,909	76%	7,265	80%	7,530	83%	7,752	85%	7,919	87%
	3	4,521	3,412	75%	3,603	80%	3,767	83%	3,887	86%	3,984	88%
	4	2,381	1,751	74%	1,897	80%	2,008	84%	2,121	89%	2,190	92%
	5	1,388	978	70%	1,053	76%	1,119	81%	1,218	88%	1,272	92%
	6	676	308	46%	383	57%	462	68%	594	88%	634	94%
	7	505	66	13%	130	26%	179	35%	240	48%	321	64%
	Total	36,720	27,540	75%	29,059	79%	30,234	82%	31,359	85%	32,152	88%

Table 15. Length and proportion of REC2 segments achieving each visual clarity attribute band summarized by stream order for SC3

SC3	Stream Order	Total length Km	REC2 segments achieving for selected years									
			2021		2040		2060		2080		2100	
			km	%	km	%	km	%	km	%	km	%
Band A	1	18,148	7,221	40%	8,546	47%	10,517	58%	12,536	69%	13,687	75%
	2	9,101	3,565	39%	4,209	46%	5,190	57%	6,302	69%	6,906	76%
	3	4,521	1,779	39%	2,077	46%	2,580	57%	3,163	70%	3,488	77%
	4	2,381	905	38%	1,113	47%	1,394	59%	1,719	72%	1,970	83%
	5	1,388	593	43%	634	46%	716	52%	956	69%	1,086	78%
	6	676	52	8%	78	12%	170	25%	408	60%	558	83%
	7	505	-	0%	-	0%	5	1%	141	28%	230	46%
	Total	36,720	14,115	38%	16,658	45%	20,571	56%	25,225	69%	27,925	76%
Band B	1	18,148	11,386	63%	12,516	69%	13,918	77%	14,869	82%	15,463	85%
	2	9,101	5,619	62%	6,143	68%	6,901	76%	7,449	82%	7,765	85%
	3	4,521	2,762	61%	3,017	67%	3,406	75%	3,710	82%	3,907	86%
	4	2,381	1,399	59%	1,550	65%	1,784	75%	1,991	84%	2,164	91%
	5	1,388	793	57%	877	63%	1,038	75%	1,127	81%	1,250	90%
	6	676	130	19%	198	29%	379	56%	521	77%	617	91%
	7	505	4	1%	20	4%	123	24%	201	40%	286	57%
	Total	36,720	22,094	60%	24,320	66%	27,550	75%	29,868	81%	31,452	86%
National bottom line	1	18,148	14,116	78%	14,791	82%	15,372	85%	15,873	87%	16,269	90%
	2	9,101	6,909	76%	7,295	80%	7,635	84%	7,911	87%	8,108	89%
	3	4,521	3,412	75%	3,620	80%	3,810	84%	3,973	88%	4,107	91%
	4	2,381	1,751	74%	1,910	80%	2,025	85%	2,160	91%	2,248	94%
	5	1,388	978	70%	1,058	76%	1,136	82%	1,258	91%	1,321	95%
	6	676	308	46%	385	57%	505	75%	604	89%	676	100%
	7	505	66	13%	137	27%	190	38%	282	56%	428	85%
	Total	36,720	27,540	75%	29,196	80%	30,672	84%	32,061	87%	33,157	90%

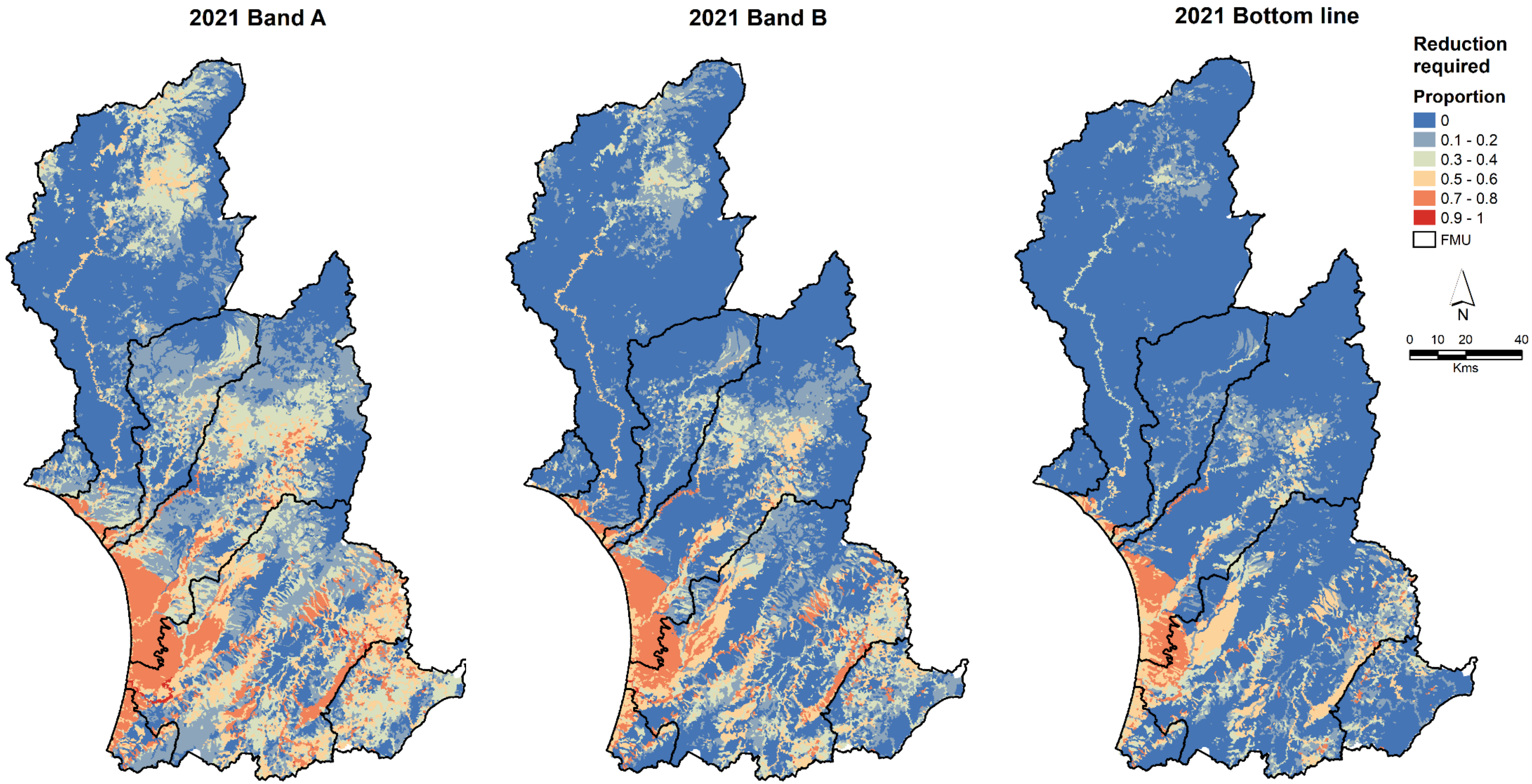

Figure 11. Proportional reduction required to achieve each NPS-FM visual clarity attribute band at 2021 for SC1.

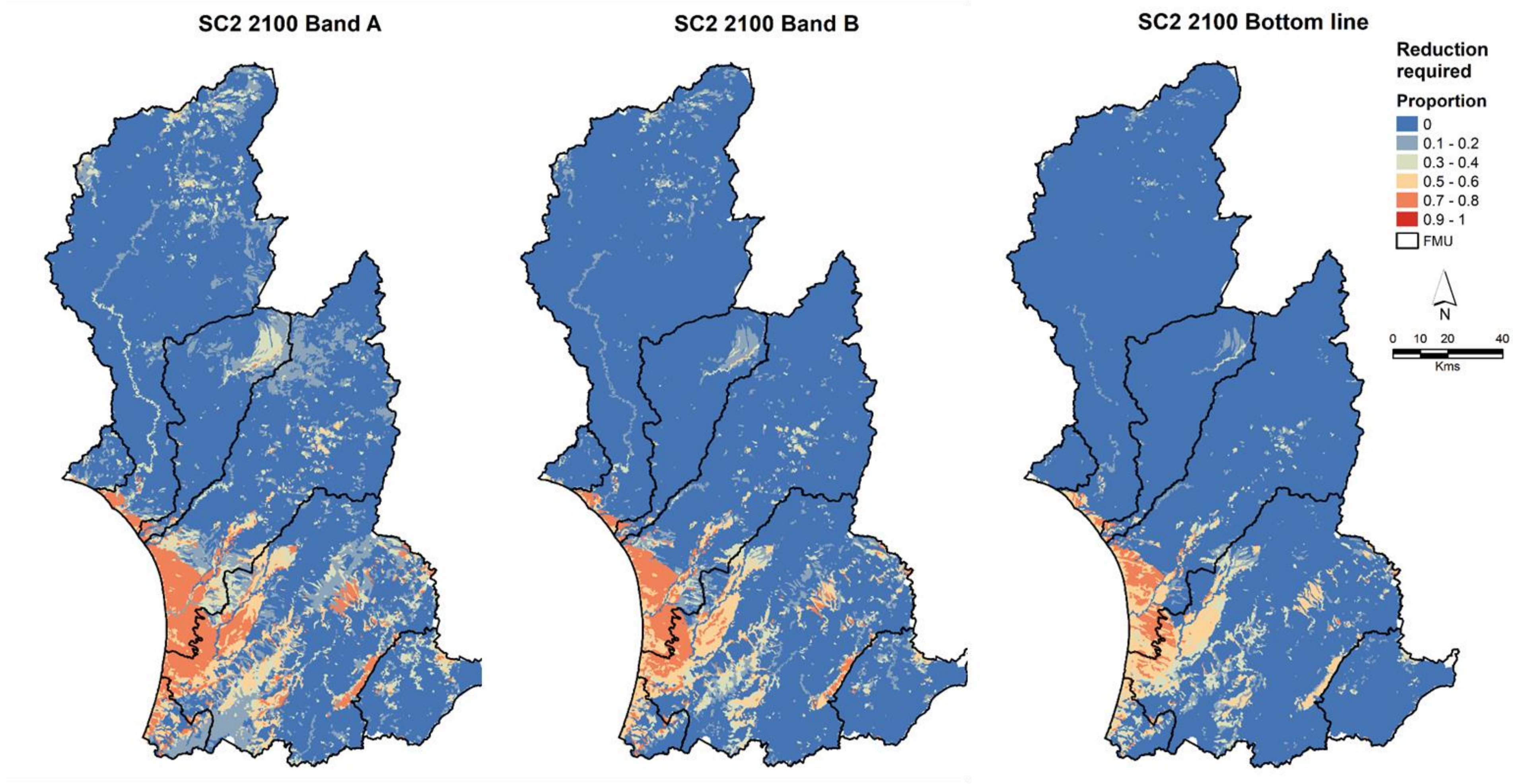

Figure 12. Proportional reduction required to achieve each NPS-FM visual clarity attribute band at 2100 for SC2.

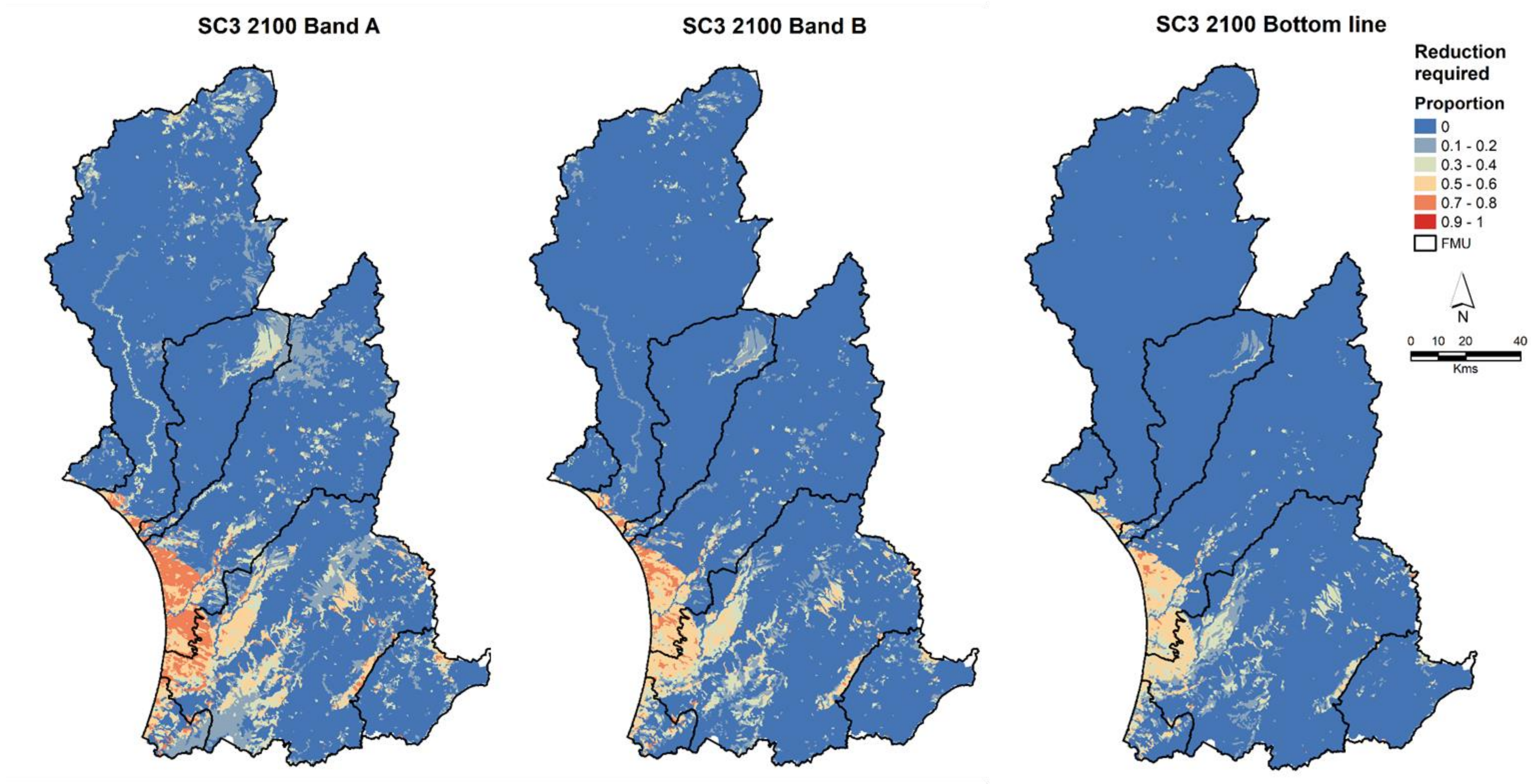

Figure 13. Proportional reduction required to achieve each NPS-FM visual clarity attribute band at 2100 for SC3.

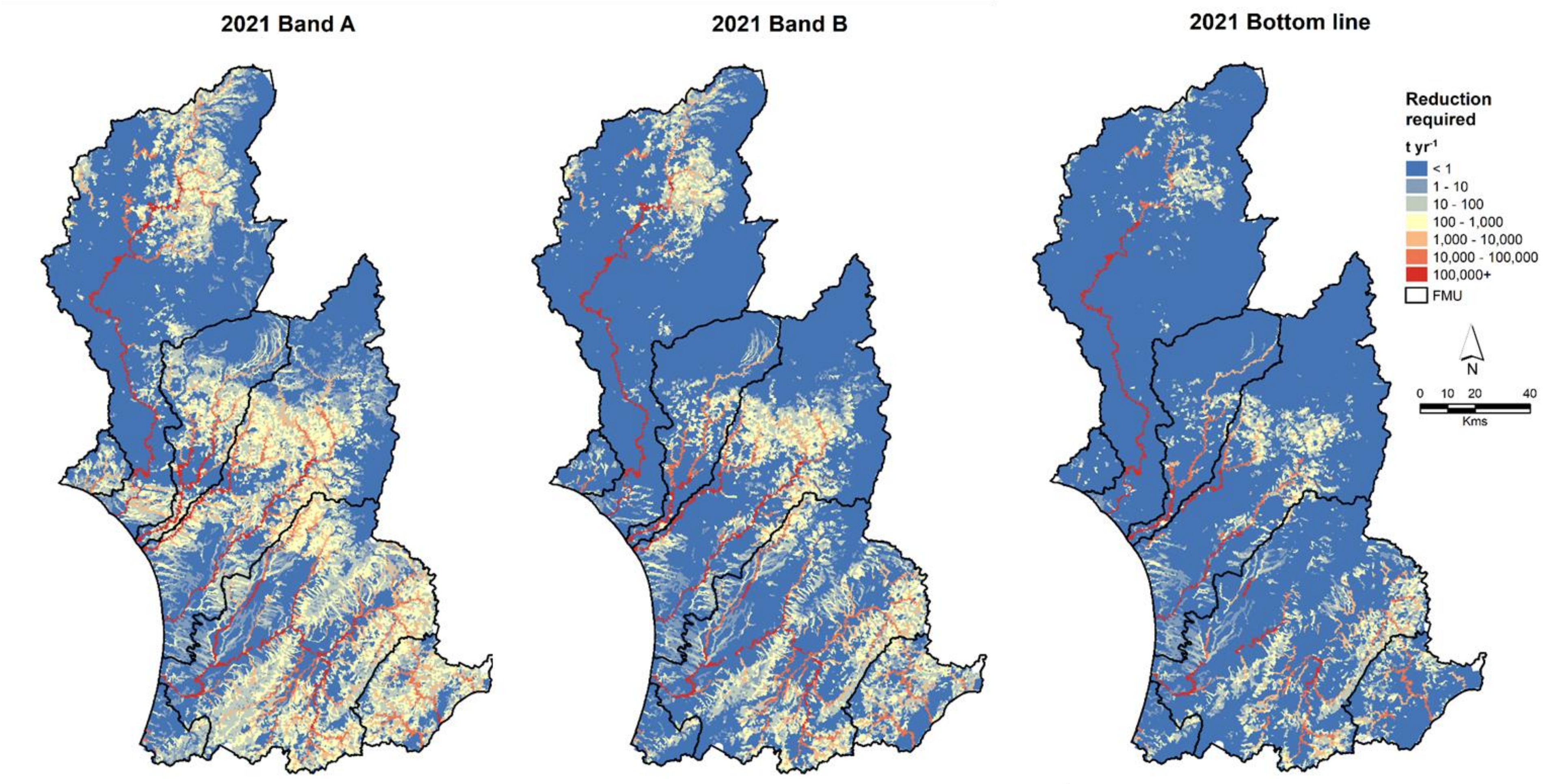

Figure 14. Absolute load reduction required to achieve each NPS-FM visual clarity attribute band at 2021 for SC1.

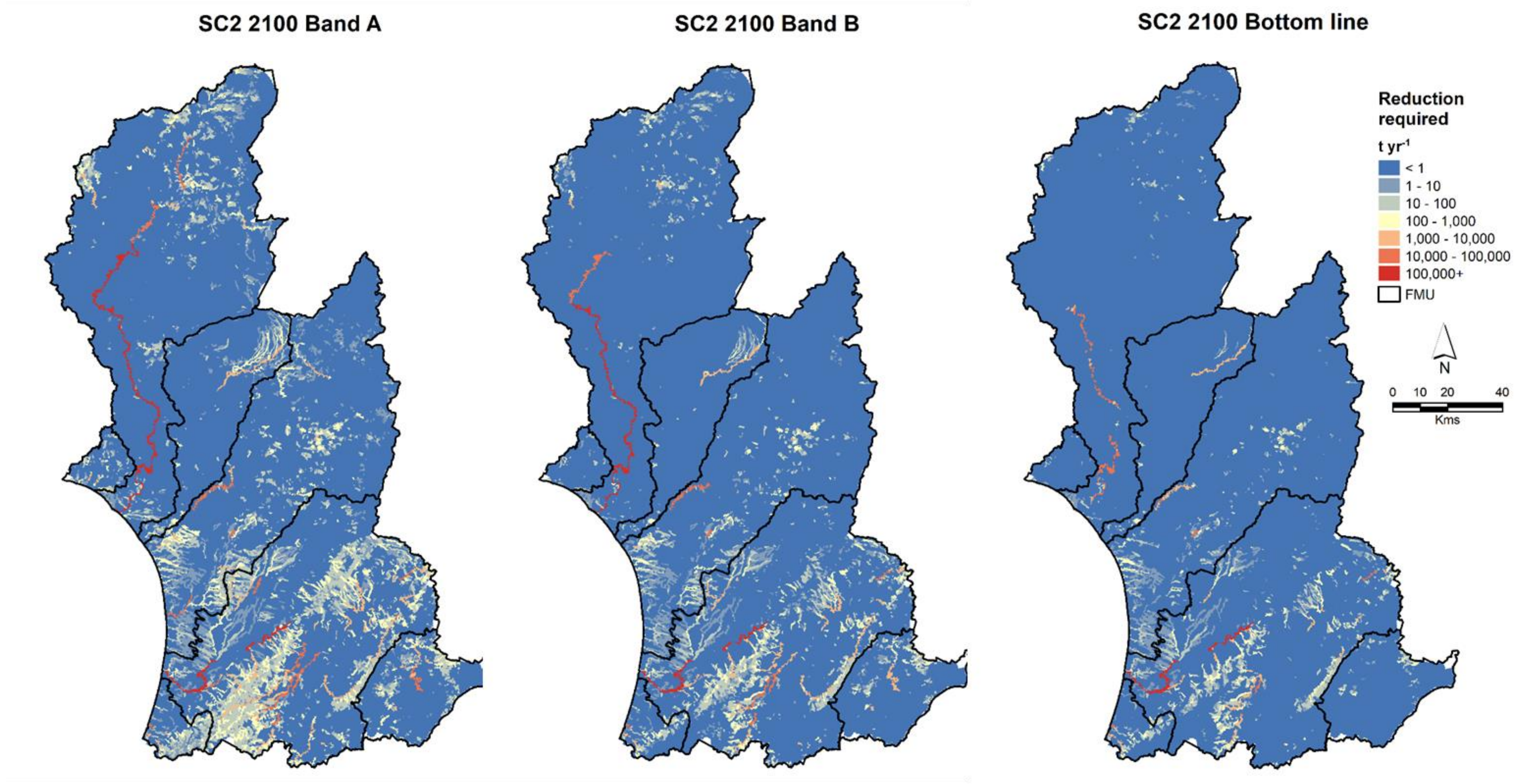

Figure 15. Absolute load reduction required to achieve each NPS-FM visual clarity attribute band at 2100 for SC2.

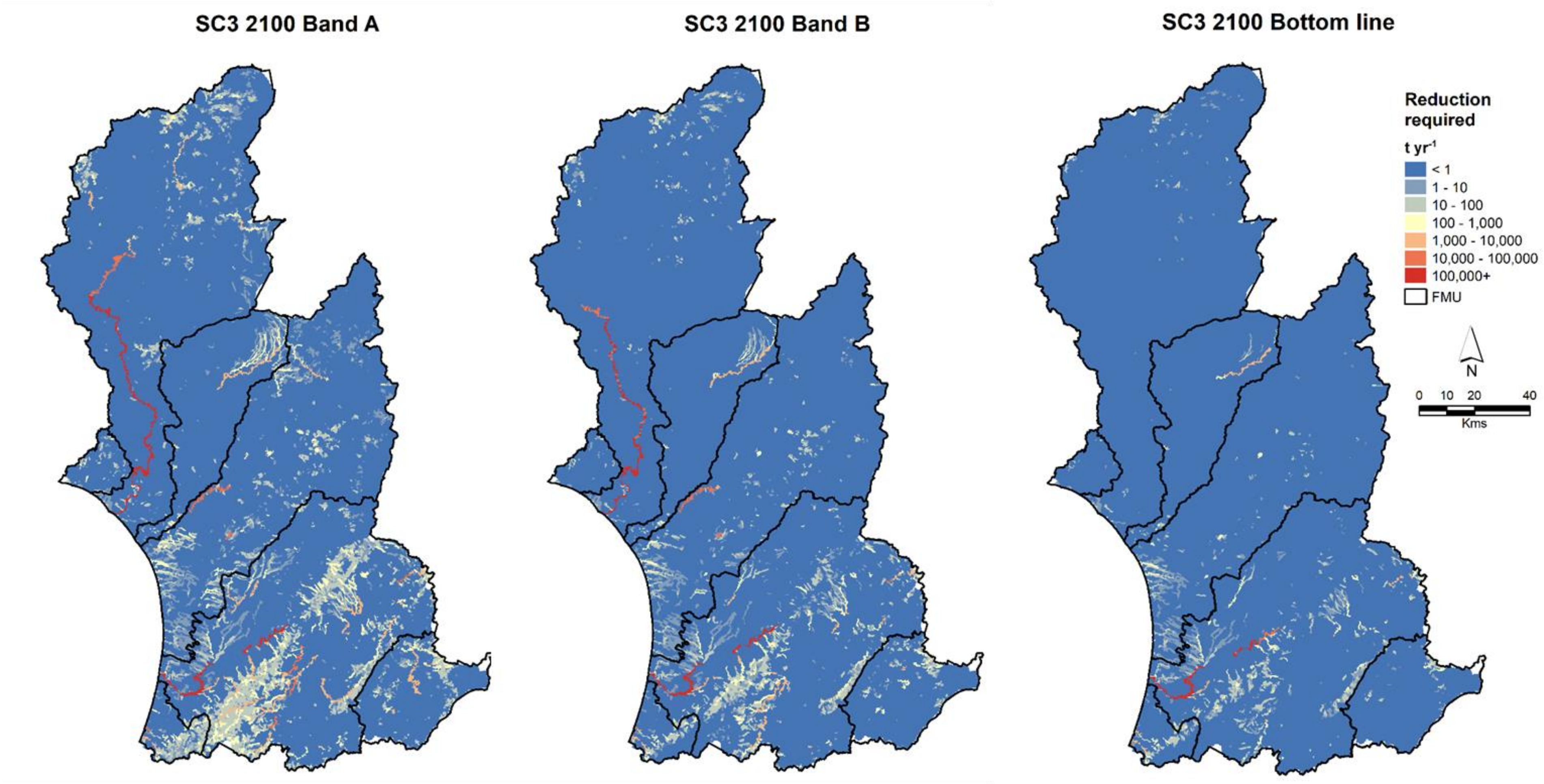

Figure 16. Absolute load reduction required to achieve each NPS-FM visual clarity attribute band at 2100 for SC3.

5.4 Impact of climate change

5.4.1 Climate change projected suspended sediment loads

Projected suspended sediment loads under climate change were modelled for SC1, SC2, and SC3. 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-century (2090).

Region-wide climate change projected total erosion loads are provided in Table 16 and visualised in Figure 17. Projected mean annual suspended sediment yields are visualized for minimum RCP2.6 and maximum RCP8.5 at mid- and late- century in Figures 18–20. Projected total erosion loads for individual FMUs are provided in Tables 17–22 and shown in Figure 21.

The modelled climate change projections result in a wide range in predicted changes to sediment loads. This reflects the variability between each of the climate models and the diverging climate trajectories each RCP represents. RCP2.6 represents a mitigation pathway resulting in the lowest sediment load increases with late-century being lower than mid-century. RCP4.5 and RCP6.0 are stabilization pathways, and RCP8.5 represents a pathway with very high greenhouse gas concentrations that results in large projected increases in sediment load. Therefore, total erosion is expected to increase from RCP 2.6 to RCP 8.5 at mid- and late- century with more pronounced differences between each RCP observed at late-century relative to mid-century projections (Fig. 17).

The projected total erosion across all RCPs for SC1 ranged from 9.5 to 14.1 Mt yr^{-1} for mid-century, and 9.0 to 19.2 Mt yr^{-1} for late-century. This equates to a difference of 8–60%, and 2–119% at mid- (2040)- and late (2090)-century, respectively, compared with loads modelled without the effect of climate change.

The projected total erosion across all RCPs for SC2 ranges from 8.7 to 13.0 Mt yr^{-1} for mid-century, and 5.2 to 10.5 Mt yr^{-1} for late-century. This equates to a difference of 7–58% and –5–93% for mid- and late-century, compared with loads modelled without the effect of climate change.

The projected total erosion across all RCPs for SC3 ranges from 8.6 to 12.8 Mt yr^{-1} for mid-century, and 4.7 to 9.4 Mt yr^{-1} for late-century. This equates to a change of 7–58% for mid-century and –5–90% for late-century. Only the minimum RCP2.6 projection at late-century results in a decrease in sediment load.

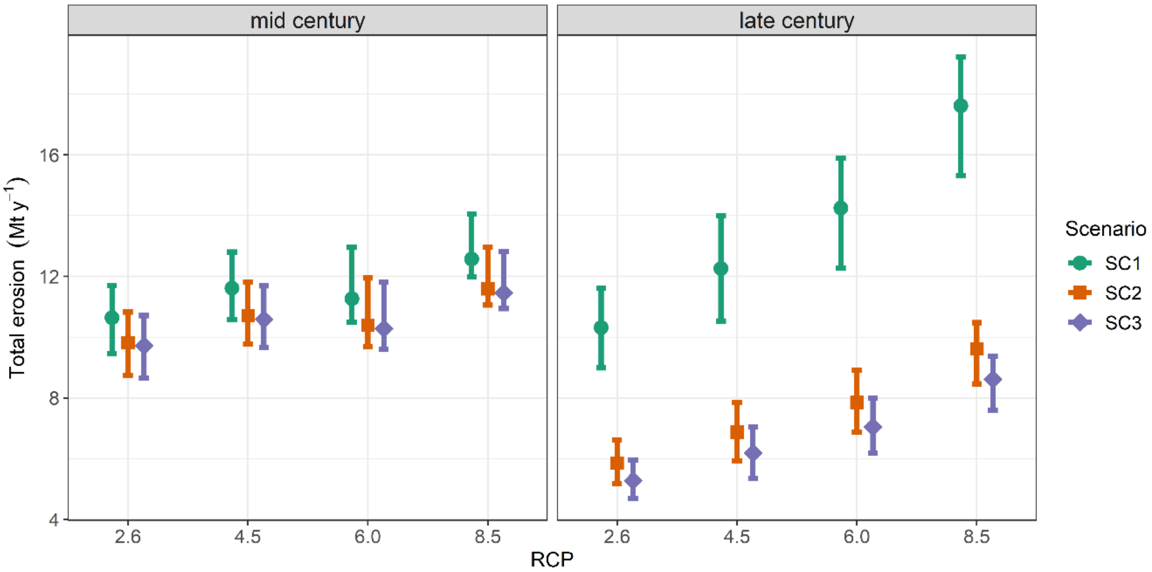

Figure 17. Total erosion loads under projected climate change for the Horizons region at mid- and late-century by RCP for each erosion mitigation scenario

Projected changes in total erosion under climate change varies across the region, giving rise to different proportional changes for each FMU. The largest reductions or smallest increases at mid- and late-century are observed in the 'Waiopehu' and 'Kai Iwi' FMUs, while the largest increases occur in the 'Manawatū' and 'Rangitīkei-Turakina FMUs (Tables 17 & 18). The FMU loads under climate change indicate a west-east pattern whereby FMUs dominated by western coastal catchments show the smallest increase, or a decrease, in load compared with the rest of the region. The patterns of spatial yield (Fig. 18) also suggest this whereby lowlands near the coast exhibit minimal change relative to inland hill country. The 'Waiopehu' FMU exhibits a significant range of values compared to other FMUs, which reflects a greater variability between the climate model projections in this area (Fig. 21).

Projected total erosion for scenarios SC2 and SC3 show similar patterns of relative change across the FMUs to SC1. However, the impact of mitigations becomes apparent with mid- and late-century loads being lower than SC1 loads. The impact can be seen in Figures 19 & 20 where increased sediment yield in the inland hill country is limited relative to the SC1 (Fig. 18). The impact of mitigations is particularly evident at late-century when a significant amount of mitigation works have been implemented across the region.

Table 16. Climate change projections of total erosion by mid- and late-century for each scenario, represented by minimum, median and maximum results for each RCP summarised for the whole region

Period	Scenario	Baseline load ($Mt\ yr^{-1}$) 2040 or 2090	Statistic	Total erosion ($Mt\ yr^{-1}$)				Difference from mid- and late-century baseline loads without climate change ($Mt\ yr^{-1}$, %)							
				RCP2.6	RCP4.5	RCP6.0	RCP8.5	RCP2.6		RCP4.5		RCP6.0		RCP8.5	
Mid-century	SC1	8.79	min	9.5	10.6	10.5	12.0	0.7	8%	1.8	20%	1.7	19%	3.2	36%
			med	10.6	11.6	11.3	12.6	1.9	21%	2.8	32%	2.5	28%	3.8	43%
			max	11.7	12.8	13.0	14.1	2.9	33%	4.0	46%	4.2	47%	5.3	60%
	SC2	8.19	min	8.7	9.8	9.7	11.1	0.6	7%	1.6	19%	1.5	18%	2.9	35%
			med	9.8	10.7	10.4	11.6	1.6	20%	2.5	31%	2.2	27%	3.4	42%
			max	10.8	11.8	11.9	13.0	2.6	32%	3.6	44%	3.8	46%	4.8	58%
	SC3	8.11	min	8.6	9.7	9.6	10.9	0.5	7%	1.6	19%	1.5	18%	2.8	35%
			med	9.7	10.6	10.3	11.5	1.6	20%	2.5	31%	2.2	27%	3.4	41%
			max	10.7	11.7	11.8	12.8	2.6	32%	3.6	44%	3.7	46%	4.7	58%
Late-century	SC1	8.79	min	9.00	10.5	12.3	15.3	0.2	2%	1.7	20%	3.5	40%	6.5	74%
			med	10.3	12.3	14.2	17.6	1.5	17%	3.5	39%	5.5	62%	8.8	101%
			max	11.6	14.0	15.9	19.2	2.8	32%	5.2	59%	7.1	81%	10.4	119%
	SC2	5.43	min	5.2	5.9	6.9	8.5	-0.3	-5%	0.51	9%	1.4	27%	3.0	56%
			med	5.9	6.9	7.9	9.6	0.4	8%	1.5	27%	2.4	45%	4.2	77%
			max	6.6	7.8	8.9	10.5	1.2	22%	2.4	45%	3.5	64%	5.1	93%
	SC3	4.93	min	4.7	5.4	6.2	7.6	-0.2	-5%	0.4	9%	1.3	25%	2.7	54%
			med	5.3	6.2	7.0	8.6	0.3	7%	1.6	25%	2.1	43%	3.7	75%
			max	6.0	7.0	8.0	9.4	1.0	21%	2.1	43%	3.1	62%	4.4	90%

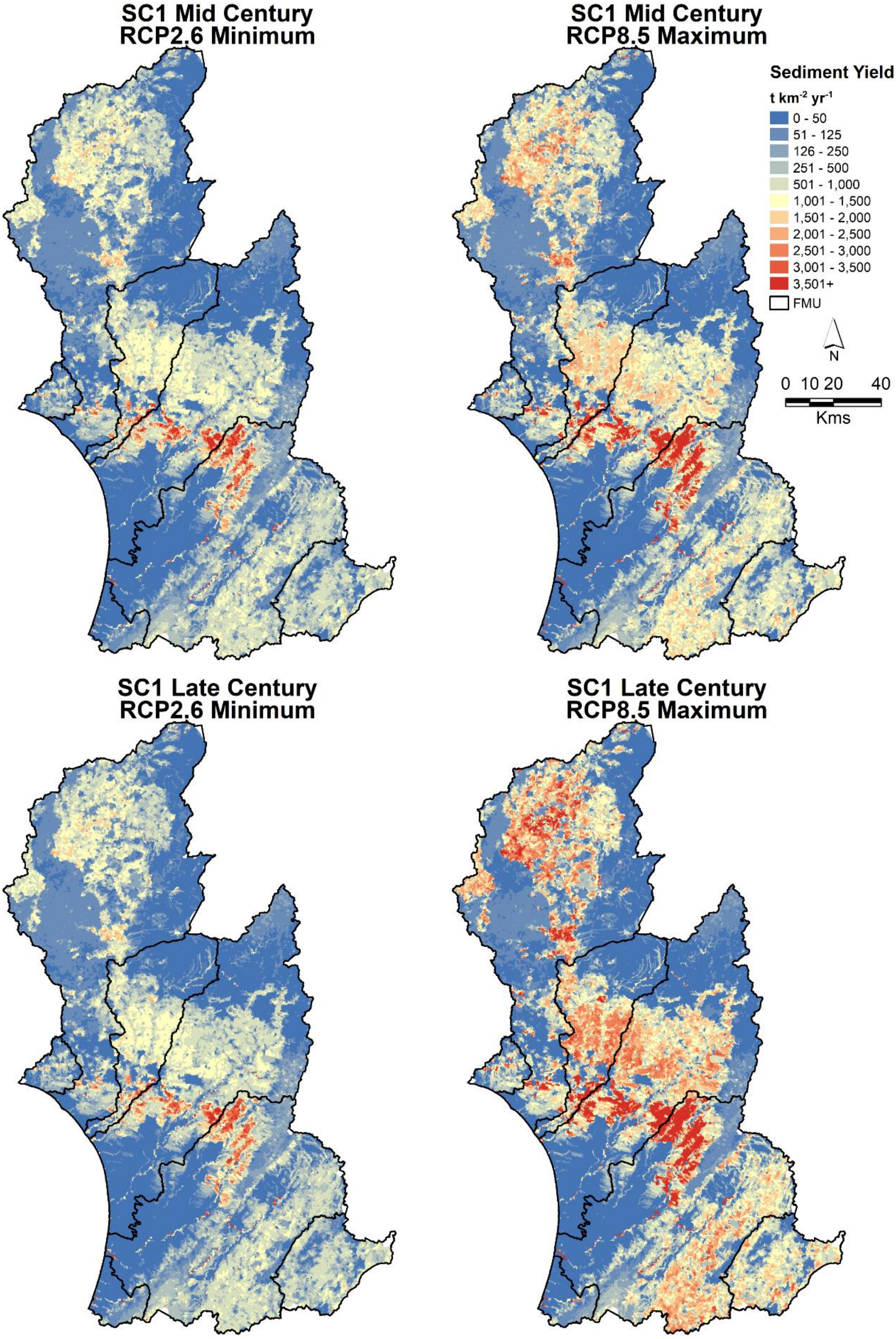

Figure 18. Climate change projected mean annual suspended sediment yield at mid- and late-century represented by RCP2.6 minimum and RCP8.5 maximum for SC1.

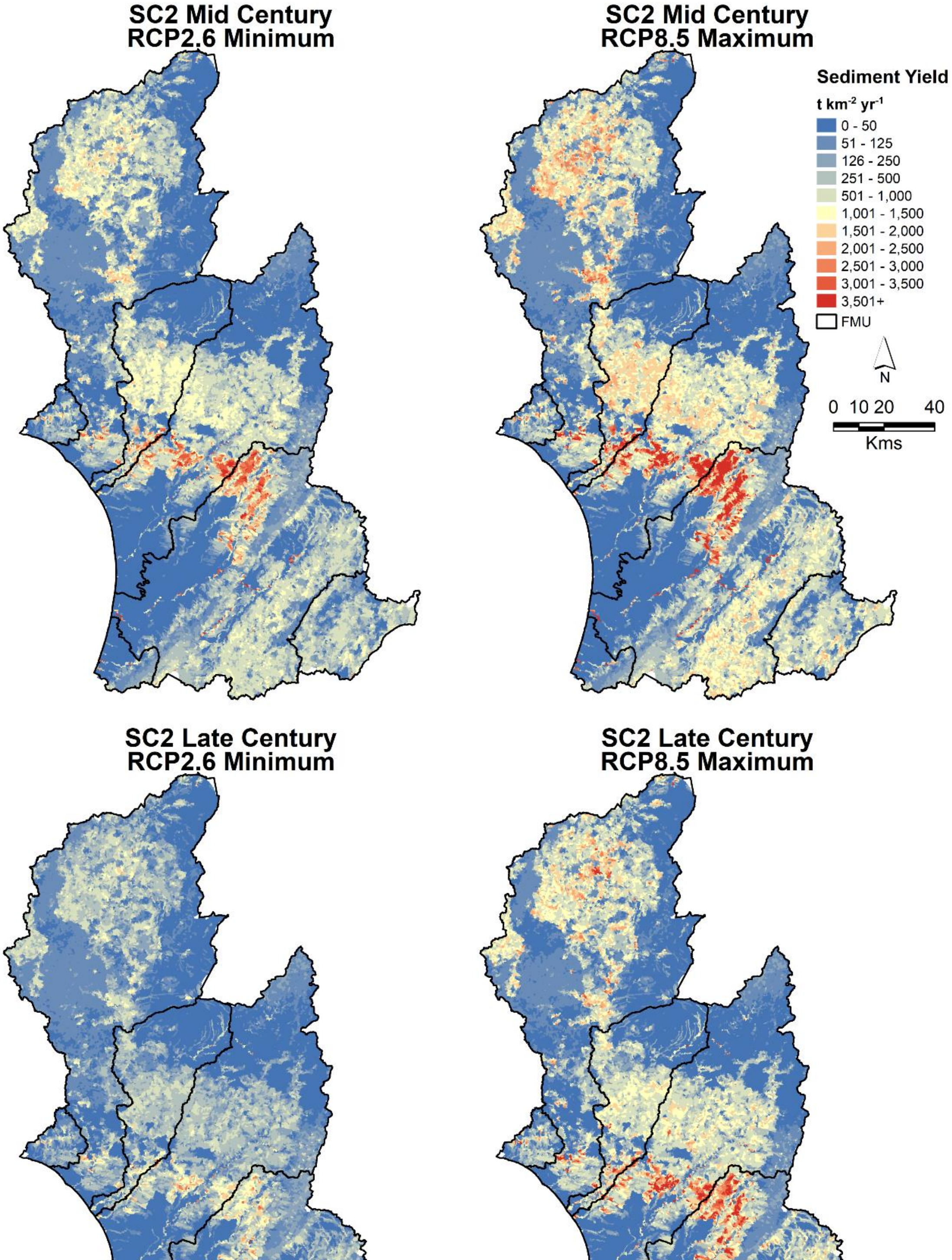

Figure 19. Climate change projected mean annual suspended sediment yield at mid- and late-century represented by RCP2.6 minimum and RCP8.5 maximum for SC2.

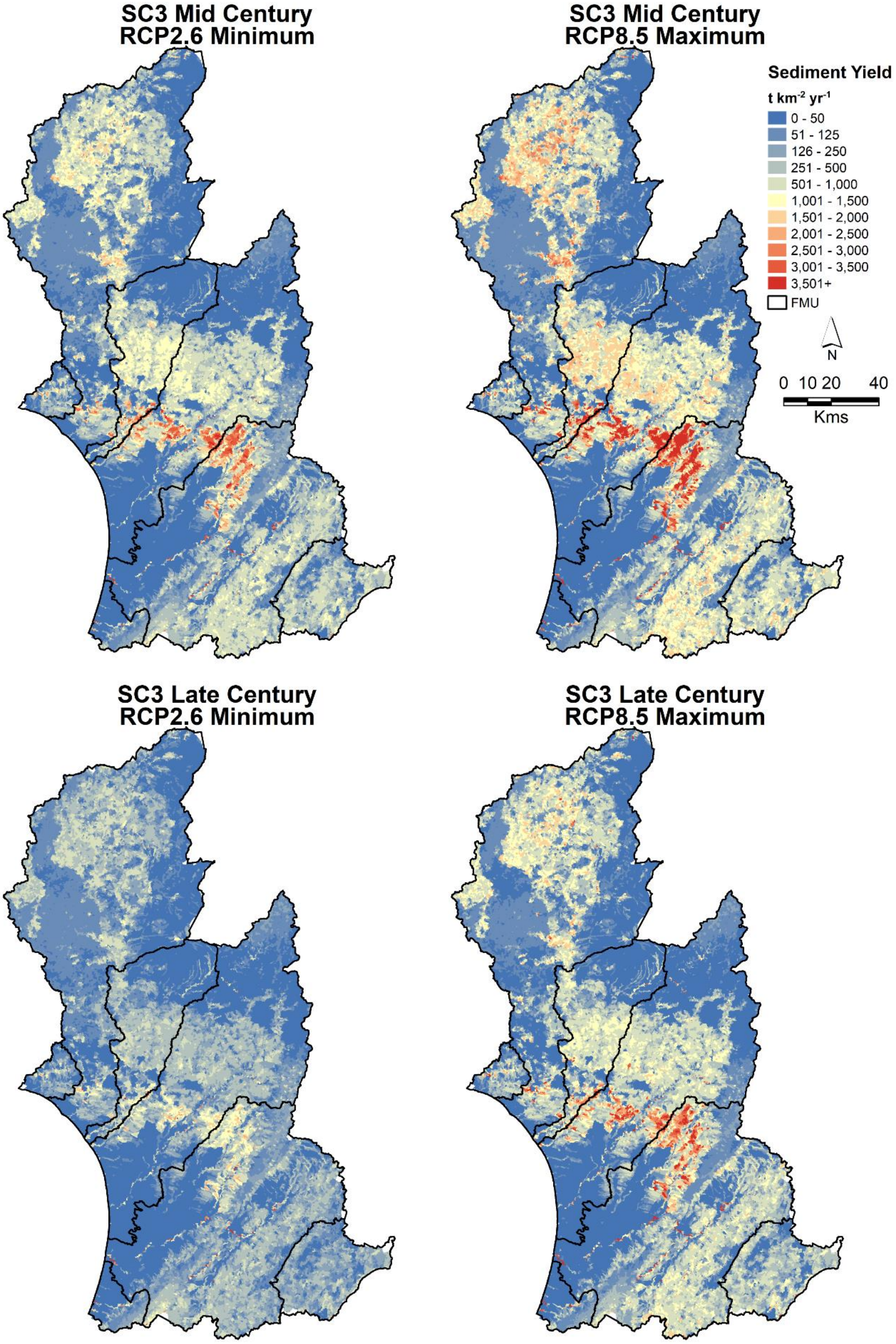

Figure 20. Climate change projected mean annual suspended sediment yield at mid- and late-century represented by RCP2.6 minimum and RCP8.5 maximum for SC3.

Table 17. Climate change projected total erosion loads at mid-century represented by minimum, median and maximum results for each RCP summarised by FMU for SC1

SC1	FMU	Baseline load ($Mt\ yr^{-1}$) 2040	Statistic	Total erosion ($Mt\ yr^{-1}$)				Difference from mid-century baseline load without climate change ($Mt\ yr^{-1}$, %)							
				RCP2.6	RCP4.5	RCP6.0	RCP8.5	RCP2.6		RCP4.5		RCP6.0		RCP8.5	
Mid-century	Kai Iwi	0.11	min	0.10	0.11	0.11	0.12	-0.01	-7%	0.00	2%	0.00	0%	0.01	13%
			med	0.11	0.12	0.12	0.13	0.00	2%	0.01	12%	0.01	7%	0.02	18%
			max	0.12	0.13	0.13	0.14	0.01	11%	0.02	22%	0.03	25%	0.03	32%
	Manawatū	2.49	min	2.82	3.17	3.15	3.59	0.33	13%	0.68	27%	0.66	26%	1.10	44%
			med	3.25	3.51	3.41	3.82	0.76	30%	1.02	41%	0.92	37%	1.33	53%
			max	3.66	3.97	3.99	4.31	1.17	47%	1.48	59%	1.50	60%	1.82	73%
	Puketoi ki Tai	0.48	min	0.53	0.60	0.59	0.67	0.05	11%	0.12	24%	0.11	22%	0.19	39%
			med	0.60	0.65	0.63	0.70	0.12	25%	0.17	34%	0.15	32%	0.22	46%
			max	0.65	0.71	0.73	0.79	0.17	35%	0.23	48%	0.25	51%	0.31	64%
	Rangitīkei-Turakina	1.93	min	2.21	2.44	2.45	2.79	0.28	15%	0.51	27%	0.52	27%	0.86	45%
			med	2.49	2.72	2.63	2.96	0.56	29%	0.79	41%	0.70	36%	1.03	53%
			max	2.67	2.95	2.99	3.25	0.74	38%	1.02	53%	1.06	55%	1.32	69%
	Waiopehu	0.06	min	0.06	0.07	0.06	0.07	-0.01	-8%	0.00	3%	0.00	0%	0.00	6%
			med	0.07	0.07	0.07	0.07	0.01	8%	0.00	3%	0.00	5%	0.01	8%
			max	0.08	0.08	0.07	0.07	0.02	32%	0.01	19%	0.01	13%	0.01	17%
	Whangaehu	0.96	min	1.07	1.19	1.19	1.35	0.11	12%	0.23	24%	0.22	23%	0.39	41%
			med	1.21	1.33	1.28	1.43	0.25	26%	0.36	38%	0.32	33%	0.47	49%
			max	1.31	1.44	1.46	1.58	0.35	36%	0.48	50%	0.49	51%	0.62	64%
	Whanganui	2.75	min	2.65	2.99	2.95	3.38	-0.10	-3%	0.24	9%	0.20	7%	0.63	23%
			med	2.91	3.23	3.13	3.47	0.16	6%	0.48	17%	0.38	14%	0.72	26%
			max	3.21	3.52	3.59	3.90	0.46	17%	0.77	28%	0.84	30%	1.15	42%

Table 18. Climate change projected total erosion loads at late-century represented by minimum, median and maximum results for each RCP summarised by FMU for SC1

SC1	FMU	Baseline load (Mt yr^{-1}) 2090	Statistic	Total erosion (Mt yr^{-1})				Difference from late-century baseline load without climate change (Mt yr^{-1}, %)							
				RCP2.6	RCP4.5	RCP6.0	RCP8.5	RCP2.6		RCP4.5		RCP6.0		RCP8.5	
Late-century	Kai Iwi	0.11	min	0.10	0.11	0.12	0.15	-0.01	-10%	0.00	4%	0.02	16%	0.04	41%
			med	0.11	0.12	0.14	0.17	0.00	2%	0.02	16%	0.04	33%	0.07	61%
			max	0.12	0.14	0.16	0.19	0.01	11%	0.03	31%	0.05	47%	0.08	73%
	Manawatū	2.49	min	2.69	3.16	3.68	4.58	0.20	8%	0.67	27%	1.19	48%	2.09	84%
			med	3.14	3.68	4.34	5.33	0.65	26%	1.19	48%	1.85	74%	2.84	114%
			max	3.52	4.30	4.91	5.84	1.03	42%	1.81	73%	2.42	97%	3.35	134%
	Puketoi ki Tai	0.48	min	0.52	0.60	0.69	0.86	0.04	8%	0.12	24%	0.21	44%	0.38	78%
			med	0.58	0.69	0.80	0.98	0.10	21%	0.21	43%	0.32	66%	0.50	105%
			max	0.65	0.79	0.87	1.07	0.17	35%	0.31	64%	0.39	81%	0.59	122%
	Rangitīkei-Turakina	1.93	min	2.08	2.45	2.88	3.60	0.15	8%	0.52	27%	0.95	49%	1.67	86%
			med	2.40	2.87	3.35	4.15	0.47	24%	0.94	49%	1.42	74%	2.22	115%
			max	2.69	3.26	3.66	4.55	0.76	39%	1.33	69%	1.73	90%	2.62	136%
	Waiopehu	0.06	min	0.06	0.06	0.06	0.07	-0.01	-8%	-0.01	-11%	0.00	-3%	0.01	10%
			med	0.06	0.07	0.07	0.08	0.00	-2%	0.00	5%	0.01	13%	0.01	19%
			max	0.07	0.08	0.09	0.08	0.01	13%	0.02	27%	0.03	40%	0.02	29%
	Whangaehu	0.96	min	1.02	1.19	1.38	1.73	0.06	6%	0.23	24%	0.42	44%	0.77	80%
			med	1.17	1.39	1.62	1.99	0.21	22%	0.43	44%	0.65	68%	1.02	106%
			max	1.31	1.58	1.78	2.18	0.35	36%	0.62	64%	0.82	85%	1.21	126%
	Whanganui	2.75	min	2.52	2.96	3.46	4.33	-0.23	-8%	0.21	8%	0.71	26%	1.58	58%
			med	2.85	3.43	3.93	4.93	0.10	3%	0.68	25%	1.18	43%	2.18	79%
			max	3.25	3.84	4.40	5.32	0.50	18%	1.09	40%	1.65	60%	2.57	93%

Table 19. Climate change projected total erosion loads at mid-century represented by minimum, median and maximum results for each RCP summarised by FMU for SC2

SC2	FMU	Baseline load (Mt yr^{-1}) 2040	Statistics	Total erosion (Mt yr^{-1})				Difference from mid-century baseline load without climate change (Mt yr^{-1}, %)							
				RCP2.6	RCP4.5	RCP6.0	RCP8.5	RCP2.6		RCP4.5		RCP6.0		RCP8.5	
Mid-century	Kai Iwi	0.10	min	0.10	0.10	0.10	0.12	-0.01	-8%	0.00	1%	0.00	-1%	0.01	12%
			med	0.10	0.11	0.11	0.12	0.00	0%	0.01	10%	0.01	6%	0.02	16%
			max	0.11	0.12	0.13	0.13	0.01	10%	0.02	20%	0.02	23%	0.03	30%
	Manawatū	2.32	min	2.62	2.95	2.92	3.33	0.30	13%	0.62	27%	0.60	26%	1.01	43%
			med	3.02	3.25	3.17	3.54	0.69	30%	0.93	40%	0.84	36%	1.21	52%
			max	3.40	3.68	3.70	3.99	1.08	46%	1.36	58%	1.37	59%	1.67	72%
	Puketoi ki Tai	0.44	min	0.48	0.54	0.53	0.60	0.04	10%	0.10	23%	0.09	22%	0.17	38%
			med	0.54	0.58	0.57	0.63	0.10	24%	0.15	33%	0.14	31%	0.19	45%
			max	0.58	0.64	0.65	0.71	0.15	34%	0.21	47%	0.22	50%	0.27	63%
	Rangitīkei-Turakina	1.77	min	2.02	2.23	2.24	2.55	0.25	14%	0.46	26%	0.46	26%	0.78	44%
			med	2.27	2.48	2.40	2.70	0.50	28%	0.71	40%	0.63	35%	0.93	52%
			max	2.44	2.69	2.73	2.97	0.67	38%	0.92	52%	0.95	54%	1.19	67%
	Waiopehu	0.06	min	0.06	0.06	0.06	0.07	-0.01	-10%	0.00	2%	0.00	-2%	0.00	5%
			med	0.07	0.06	0.07	0.07	0.01	8%	0.00	2%	0.00	5%	0.00	6%
			max	0.08	0.08	0.07	0.07	0.02	30%	0.01	19%	0.01	11%	0.01	17%
	Whangaehu	0.87	min	0.96	1.07	1.06	1.21	0.09	11%	0.20	23%	0.20	22%	0.34	40%
			med	1.08	1.18	1.14	1.28	0.22	25%	0.32	36%	0.28	32%	0.41	47%
			max	1.18	1.29	1.30	1.42	0.31	36%	0.42	49%	0.43	50%	0.55	63%
	Whanganui	2.62	min	2.50	2.82	2.78	3.18	-0.12	-5%	0.19	7%	0.16	6%	0.56	21%
			med	2.74	3.03	2.94	3.26	0.12	5%	0.41	16%	0.32	12%	0.64	24%
			max	3.02	3.31	3.37	3.66	0.40	15%	0.69	26%	0.75	28%	1.04	40%

Table 20. Climate change projected total erosion loads at late-century represented by minimum, median and maximum results for each RCP summarised by FMU for SC2

SC2	FMU	Baseline load (Mt yr^{-1}) 2090	Statistics	Total erosion (Mt yr^{-1})				Difference from late-century baseline load without climate change (Mt yr^{-1}, %)							
				RCP2.6	RCP4.5	RCP6.0	RCP8.5	RCP2.6		RCP4.5		RCP6.0		RCP8.5	
Late-century	Kai Iwi	0.08	min	0.07	0.08	0.08	0.10	-0.01	-18%	0.00	-5%	0.00	5%	0.02	28%
			med	0.07	0.08	0.10	0.11	-0.01	-8%	0.00	5%	0.02	20%	0.04	44%
			max	0.08	0.09	0.11	0.12	0.00	1%	0.02	19%	0.03	33%	0.04	56%
	Manawatū	1.58	min	1.65	1.88	2.18	2.67	0.08	5%	0.31	19%	0.60	38%	1.10	70%
			med	1.90	2.20	2.54	3.08	0.33	21%	0.62	39%	0.96	61%	1.50	95%
			max	2.13	2.57	2.93	3.37	0.56	35%	1.00	63%	1.36	86%	1.80	114%
	Puketoi ki Tai	0.25	min	0.25	0.29	0.33	0.40	0.01	3%	0.04	17%	0.09	35%	0.16	65%
			med	0.28	0.33	0.37	0.46	0.03	13%	0.08	33%	0.13	53%	0.21	87%
			max	0.31	0.37	0.41	0.50	0.07	27%	0.13	52%	0.17	68%	0.25	103%
	Rangitīkei-Turakina	1.09	min	1.12	1.30	1.51	1.87	0.04	3%	0.21	19%	0.43	39%	0.78	72%
			med	1.28	1.51	1.74	2.14	0.19	18%	0.43	39%	0.65	60%	1.05	97%
			max	1.43	1.72	1.93	2.34	0.35	32%	0.63	58%	0.84	78%	1.26	116%
	Waiopehu	0.06	min	0.06	0.05	0.06	0.06	-0.01	-8%	-0.01	-13%	0.00	-5%	0.00	7%
			med	0.06	0.06	0.07	0.07	0.00	-2%	0.00	3%	0.01	10%	0.01	15%
			max	0.07	0.08	0.08	0.07	0.01	12%	0.02	25%	0.02	38%	0.01	23%
	Whangaehu	0.48	min	0.48	0.55	0.63	0.78	0.00	0%	0.07	14%	0.15	31%	0.30	62%
			med	0.54	0.64	0.73	0.89	0.06	13%	0.16	33%	0.25	52%	0.41	86%
			max	0.61	0.73	0.82	0.98	0.13	27%	0.25	53%	0.35	72%	0.50	104%
	Whanganui	1.90	min	1.56	1.80	2.08	2.57	-0.34	-18%	-0.11	-6%	0.18	9%	0.67	35%
			med	1.73	2.06	2.31	2.87	-0.18	-9%	0.15	8%	0.41	21%	0.97	51%
			max	1.97	2.28	2.62	3.09	0.06	3%	0.38	20%	0.72	38%	1.19	62%

Table 21. Climate change projected total erosion loads at mid-century represented by minimum, median and maximum results for each RCP summarised by FMU for SC3

SC3	FMU	Baseline load (Mt yr^{-1}) 2040	Statistic	Total erosion (Mt yr^{-1}) RCP2.6	RCP4.5	RCP6.0	RCP8.5	Difference from mid-century baseline load without climate change (Mt yr^{-1}, %) RCP2.6		RCP4.5		RCP6.0		RCP8.5	
Mid-century	Kai Iwi	0.10	min	0.09	0.10	0.10	0.11	-0.01	-8%	0.00	1%	0.00	-1%	0.01	12%
			med	0.10	0.11	0.11	0.12	0.00	1%	0.01	11%	0.01	6%	0.02	16%
			max	0.11	0.12	0.13	0.13	0.01	11%	0.02	21%	0.02	24%	0.03	31%
	Manawatū	2.31	min	2.60	2.92	2.90	3.31	0.30	13%	0.62	27%	0.59	26%	1.00	43%
			med	2.99	3.23	3.14	3.51	0.69	30%	0.92	40%	0.84	36%	1.20	52%
			max	3.38	3.65	3.67	3.96	1.07	46%	1.34	58%	1.36	59%	1.65	72%
	Puketoi ki Tai	0.43	min	0.47	0.53	0.52	0.59	0.04	10%	0.10	23%	0.09	22%	0.16	38%
			med	0.53	0.57	0.56	0.62	0.10	24%	0.14	33%	0.13	31%	0.19	44%
			max	0.58	0.63	0.64	0.70	0.15	34%	0.20	47%	0.21	50%	0.27	62%
	Rangitīkei-Turakina	1.76	min	2.00	2.21	2.22	2.53	0.25	14%	0.45	26%	0.46	26%	0.77	44%
			med	2.25	2.46	2.38	2.67	0.49	28%	0.70	40%	0.62	35%	0.92	52%
			max	2.42	2.67	2.70	2.94	0.66	38%	0.91	52%	0.94	54%	1.18	67%
	Waiopehu	0.06	min	0.06	0.06	0.06	0.07	-0.01	-10%	0.00	2%	0.00	-2%	0.00	5%
			med	0.07	0.06	0.07	0.07	0.01	8%	0.00	2%	0.00	5%	0.00	6%
			max	0.08	0.08	0.07	0.07	0.02	30%	0.01	19%	0.01	11%	0.01	17%
	Whangaehu	0.86	min	0.95	1.06	1.05	1.20	0.09	11%	0.20	23%	0.19	22%	0.34	39%
			med	1.07	1.17	1.13	1.27	0.21	25%	0.31	36%	0.27	32%	0.41	47%
			max	1.17	1.28	1.29	1.40	0.31	36%	0.42	49%	0.43	50%	0.54	63%
	Whanganui	2.59	min	2.46	2.77	2.74	3.13	-0.13	-5%	0.19	7%	0.15	6%	0.54	21%
			med	2.70	2.98	2.90	3.21	0.11	4%	0.39	15%	0.31	12%	0.62	24%
			max	2.97	3.26	3.32	3.61	0.38	15%	0.67	26%	0.73	28%	1.02	39%

Table 22. Climate change projected total erosion loads at late-century represented by minimum, median and maximum results for each RCP summarised by FMU for SC3

SC3	FMU	Baseline load (Mt yr^{-1}) 2090	Statistic	Total erosion (Mt yr^{-1})				Difference from late-century baseline load without climate change (Mt yr^{-1}, %)							
				RCP2.6	RCP4.5	RCP6.0	RCP8.5	RCP2.6		RCP4.5		RCP6.0		RCP8.5	
Late-century	Kai Iwi	0.07	min	0.06	0.07	0.07	0.09	-0.01	-20%	-0.01	-8%	0.00	3%	0.02	24%
			med	0.06	0.07	0.08	0.10	-0.01	-10%	0.00	3%	0.01	17%	0.03	41%
			max	0.07	0.08	0.09	0.11	0.00	-1%	0.01	15%	0.02	30%	0.04	52%
	Manawatū	1.41	min	1.48	1.69	1.95	2.39	0.08	5%	0.28	20%	0.54	38%	0.98	70%
			med	1.70	1.96	2.26	2.74	0.29	21%	0.55	39%	0.86	61%	1.33	95%
			max	1.91	2.29	2.61	2.99	0.50	36%	0.89	63%	1.21	86%	1.59	113%
	Puketoi ki Tai	0.23	min	0.24	0.27	0.31	0.38	0.01	4%	0.04	17%	0.08	35%	0.15	65%
			med	0.26	0.31	0.35	0.43	0.03	14%	0.08	34%	0.12	53%	0.20	87%
			max	0.29	0.35	0.38	0.46	0.06	28%	0.12	53%	0.16	68%	0.24	103%
	Rangitīkei-Turakina	0.99	min	1.02	1.17	1.37	1.69	0.03	3%	0.19	19%	0.38	38%	0.70	70%
			med	1.16	1.37	1.57	1.93	0.17	17%	0.38	38%	0.58	59%	0.94	95%
			max	1.30	1.55	1.74	2.11	0.31	31%	0.56	57%	0.75	76%	1.12	113%
	Waiopehu	0.05	min	0.05	0.05	0.05	0.06	0.00	-7%	-0.01	-11%	0.00	-4%	0.00	7%
			med	0.05	0.06	0.06	0.06	0.00	-2%	0.00	4%	0.01	9%	0.01	13%
			max	0.06	0.07	0.07	0.07	0.01	11%	0.01	24%	0.02	37%	0.01	22%
	Whangaehu	0.45	min	0.44	0.51	0.59	0.72	0.00	0%	0.06	14%	0.14	31%	0.28	62%
			med	0.51	0.59	0.68	0.83	0.06	13%	0.15	33%	0.23	52%	0.38	85%
			max	0.57	0.68	0.77	0.91	0.12	27%	0.23	53%	0.32	72%	0.46	103%
	Whanganui	1.74	min	1.40	1.61	1.85	2.28	-0.34	-19%	-0.13	-8%	0.12	7%	0.55	31%
			med	1.54	1.83	2.04	2.53	-0.20	-11%	0.09	5%	0.30	17%	0.79	46%
			max	1.75	2.02	2.33	2.72	0.02	1%	0.29	16%	0.59	34%	0.99	57%

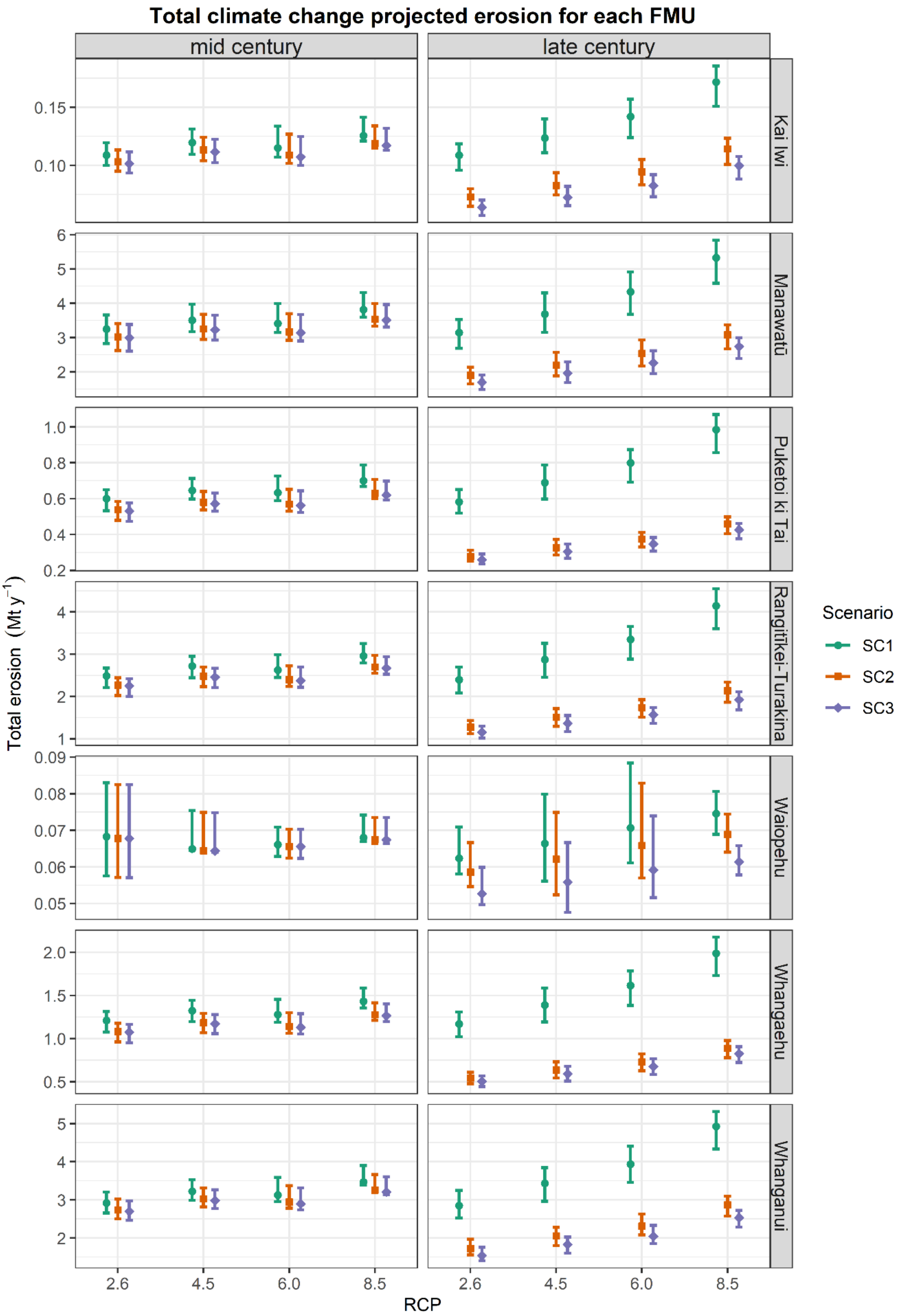

Figure 21.Climate change projected total erosion loads for each FMU at mid- and late-century represented by minimum, median and maximum results for each RCP scenario.

5.4.2 Climate change projected reductions required to meet NPS-FM visual clarity attribute bands

Climate change projected suspended sediment load reductions required to achieve NPS-FM attribute bands were modelled in terms of proportional and absolute load reductions for each REC2 segment. These are summarised by the length (in kms) and proportion by length of REC2 segments achieving each attribute band in Tables 23–25. REC2 segment summaries according to stream order are provided in Appendix 2. Proportional reductions are visualized in Figures 22–30 for each scenario.

The proportion of REC2 segments achieving target across all RCPs for SC1 ranged from 22 to 32% for Band A, 24 to 36% for Band B, and 25 to 38% for national bottom line at mid-century, and 21 to 33% for Band A, 22 to 38% for Band B, and 22 to 40% for national bottom line at late-century. The impact of projected climate change sediment loads on the proportional reductions required to be meet target can be seen spatially in Figures 22–24, where a large extent of the catchment does not meet target for SC1, particularly for RCP 8.5 maximums and Bands A and B. The required proportional load reductions in areas of pastoral hill country appear to be particularly impacted by the climate change projected loads.

Erosion mitigations applied in SC2 and SC3 increase the proportion of REC2 segments achieving the attribute bands and bottom line, particularly at late-century. The proportion of REC2 segments achieving target across all RCPs for SC2 ranged from 24 to 36% for Band A, 27 to 42% for Band B, and 28 to 45% for national bottom line at mid-century, and 38 to 66% for Band A, 42 to 74% for Band B, and 45 to 79% for national bottom line at late-century. In a similar pattern, the proportion of REC2 segments achieving target across all RCPs for SC3 ranged from 34 to 36% for Band A, 27 to 42% for Band B, and 28 to 46% for national bottom line at mid-century, and 40 to 73% for Band A, 45 to 80% for Band B, and 49 to 84% for national bottom line at late-century.

For comparison, proportional reductions required to achieve band A, B and national bottom line were 40, 62 and 76% at mid- (2040) and late-century (2090) for SC1 without the effect of climate change on sediment loads. For SC2, proportional reductions required to achieve band A, B and national bottom line were 45, 66 and 79% at mid-century (2040) and 66, 80, and 87% at late-century (2090) without the effect of climate change on sediment loads. For SC3, proportional reductions required to achieve band A, B and national bottom line were 45, 66 and 80% at mid-century (2040) and 73, 84, and 89% at late-century (2090) without the effect of climate change on sediment loads. A summary table of the proportional reductions with and without climate change is provided in Table 26.

The impact of climate change projected sediment loads on proportional reductions required to be meet target can be seen spatially in Figures 25–30 where, as with SC1, a large extent of the region still require large proportional reductions. This is particularly true for RCP 8.5 maximums and Bands A and B. The pattern of large proportional reductions in the lowland coastal REC2 segments is also observed for the climate change projections.

Table 23. Climate change projected length and proportion of REC2 segments achieving each visual clarity attribute band by mid- and late-century for SC1, represented by minimum, median and maximum results for each RCP

SC1			REC2 segments achieving for each RCP							
Period	Attribute band	Statistic	RCP2.6		RCP4.5		RCP6.0		RCP8.5	
			km	%	km	%	km	%	km	%
Mid-century	Band A	min	11,762	32%	9,241	25%	9,338	25%	9,210	25%
		med	9,925	27%	10,752	29%	9,922	27%	9,784	27%
		max	8,385	23%	9,536	26%	9,651	26%	8,843	24%
	Band B	min	13,272	36%	10,079	27%	10,328	28%	10,027	27%
		med	10,993	30%	12,062	33%	10,913	30%	10,830	29%
		max	8,994	24%	10,398	28%	10,515	29%	9,547	26%
	National bottom line	min	13,932	38%	10,501	29%	10,661	29%	10,402	28%
		med	11,374	31%	12,433	34%	11,278	31%	11,126	30%
		max	9,248	25%	10,669	29%	10,785	29%	9,806	27%
Late-century	Band A	min	12,058	33%	11,751	32%	9,135	25%	8,341	23%
		med	10,499	29%	8,836	24%	9,836	27%	9,306	25%
		max	9,263	25%	9,618	26%	7,598	21%	9,683	26%
	Band B	min	13,822	38%	13,232	36%	10,155	28%	9,172	25%
		med	11,908	32%	9,613	26%	10,745	29%	10,156	28%
		max	9,973	27%	10,617	29%	8,026	22%	10,254	28%
	National bottom line	min	14,675	40%	13,734	37%	10,596	29%	9,597	26%
		med	12,370	34%	9,909	27%	11,094	30%	10,400	28%
		max	10,268	28%	10,858	30%	8,227	22%	10,415	28%

Table 24. Climate change projected length and proportion of REC2 segments achieving each visual clarity attribute band by mid- and late-century for SC2, represented by minimum, median and maximum results for each RCP

SC2			REC2 segments achieving for each RCP							
Period	Attribute band	Statistic	RCP2.6		RCP4.5		RCP6.0		RCP8.5	
			km	%	km	%	km	%	km	%
Mid-century	Band A	min	13,218	36%	10,069	27%	10,180	28%	9,697	26%
		med	10,812	29%	11,341	31%	10,577	29%	10,198	28%
		max	8,879	24%	9,958	27%	10,073	27%	9,173	25%
	Band B	min	15,344	42%	11,264	31%	11,573	32%	10,729	29%
		med	12,235	33%	12,922	35%	11,900	32%	11,392	31%
		max	9,765	27%	10,944	30%	11,043	30%	9,940	27%
	National bottom line	min	16,576	45%	11,822	32%	12,092	33%	11,160	30%
		med	12,764	35%	13,362	36%	12,344	34%	11,734	32%
		max	10,126	28%	11,260	31%	11,369	31%	10,216	28%
Late-century	Band A	min	24,407	66%	22,779	62%	18,479	50%	14,918	41%
		med	22,173	60%	18,525	50%	17,497	48%	14,492	39%
		max	19,581	53%	17,744	48%	14,037	38%	13,897	38%
	Band B	min	27,193	74%	26,138	71%	21,546	59%	17,340	47%
		med	25,394	69%	21,328	58%	20,117	55%	16,549	45%
		max	22,360	61%	20,491	56%	16,047	44%	15,442	42%
	National bottom line	min	28,901	79%	27,614	75%	23,363	64%	19,083	52%
		med	26,956	73%	22,931	62%	21,867	60%	17,824	49%
		max	23,816	65%	22,113	60%	17,529	48%	16,405	45%

Table 25. Climate change projected length and proportion of REC2 segments achieving each visual clarity attribute band by mid- and late-century for SC3, represented by minimum, median and maximum results for each RCP

SC3			REC2 segments achieving for each RCP							
Period	Attribute band	Statistic	RCP2.6		RCP4.5		RCP6.0		RCP8.5	
			km	%	km	%	km	%	km	%
Mid-century	Band A	min	13,346	36%	10,165	28%	10,278	28%	9,728	26%
		med	10,922	30%	11,401	31%	10,648	29%	10,228	28%
		max	8,945	24%	10,000	27%	10,118	28%	9,192	25%
	Band B	min	15,533	42%	11,364	31%	11,676	32%	10,772	29%
		med	12,351	34%	13,002	35%	11,983	33%	11,434	31%
		max	9,851	27%	11,001	30%	11,087	30%	9,964	27%
	National bottom line	min	16,822	46%	11,934	32%	12,212	33%	11,216	31%
		med	12,905	35%	13,448	37%	12,435	34%	11,783	32%
		max	10,223	28%	11,318	31%	11,420	31%	10,245	28%
Late-century	Band A	min	26,756	73%	25,487	69%	20,740	56%	16,501	45%
		med	25,093	68%	20,861	57%	19,429	53%	15,743	43%
		max	21,967	60%	19,576	53%	15,283	42%	14,855	40%
	Band B	min	29,492	80%	28,784	78%	24,448	67%	19,644	53%
		med	28,492	78%	24,526	67%	22,812	62%	18,377	50%
		max	25,245	69%	23,083	63%	17,866	49%	16,701	45%
	National bottom line	min	31,004	84%	30,720	84%	26,336	72%	21,950	60%
		med	30,349	83%	26,227	71%	24,848	68%	20,098	55%
		max	26,940	73%	25,027	68%	19,774	54%	17,943	49%

Table 26. Summary comparing the ranges of REC2 segments achieving band A, band B and national bottom line across mid-(2040) and late-(2090) century with and without climate change impacts. The range of values with climate change includes the min, med, and max across all RCPs

Scenario	Period	Attribute band	% of REC2 segments by length achieving	
			Without climate-change	With climate-change
SC1	Mid-century (2040)	Band A	40%	23 - 32%
		Band B	62%	24 - 36%
		National bottom line	76%	25 - 38%
	Late-century (2090)	Band A	40%	21 - 33%
		Band B	62%	22 - 38%
		National bottom line	76%	22 - 40%
SC2	Mid-century (2040)	Band A	45%	24 - 36%
		Band B	66%	27 - 42%
		National bottom line	79%	28 - 45%
	Late-century (2090)	Band A	66%	38 - 66%
		Band B	80%	42 - 74%
		National bottom line	87%	45 - 79%
SC3	Mid-century (2040)	Band A	45%	24 - 36%
		Band B	66%	27 - 42%
		National bottom line	80%	28 - 46%
	Late-century (2090)	Band A	73%	40 - 73%
		Band B	84%	45 - 80%
		National bottom line	89%	49 - 84%

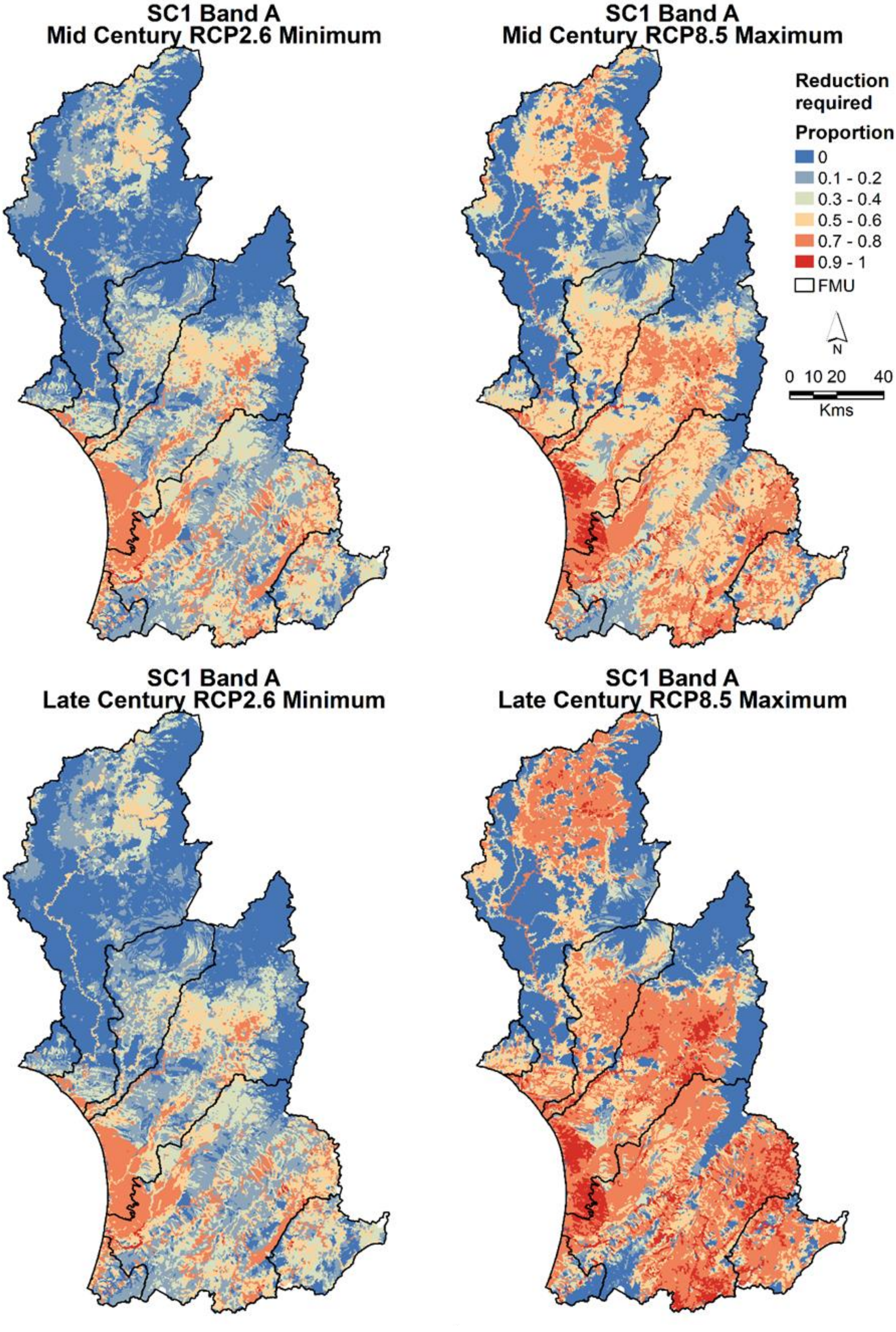

Figure 22. Proportional reduction required to meet NPS-FM attribute Band A from climate change projected sediment load at mid- and late-century, represented by RCP2.6 minimum and RCP8.5 maximum for SC1.

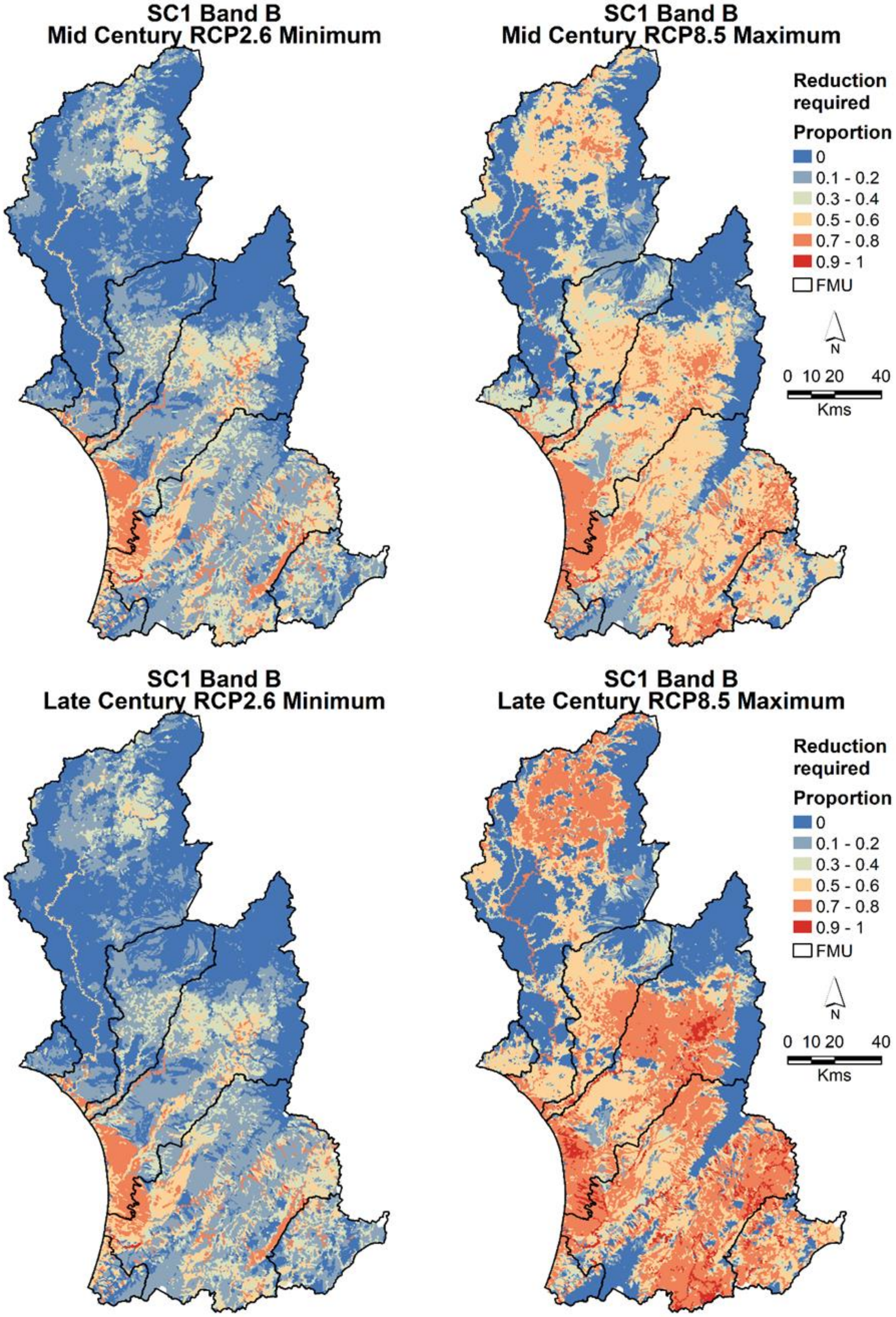

Figure 23. Proportional reduction required to meet NPS-FM attribute Band B from climate change projected sediment load at mid- and late-century, represented by RCP2.6 minimum and RCP8.5 maximum for SC1.

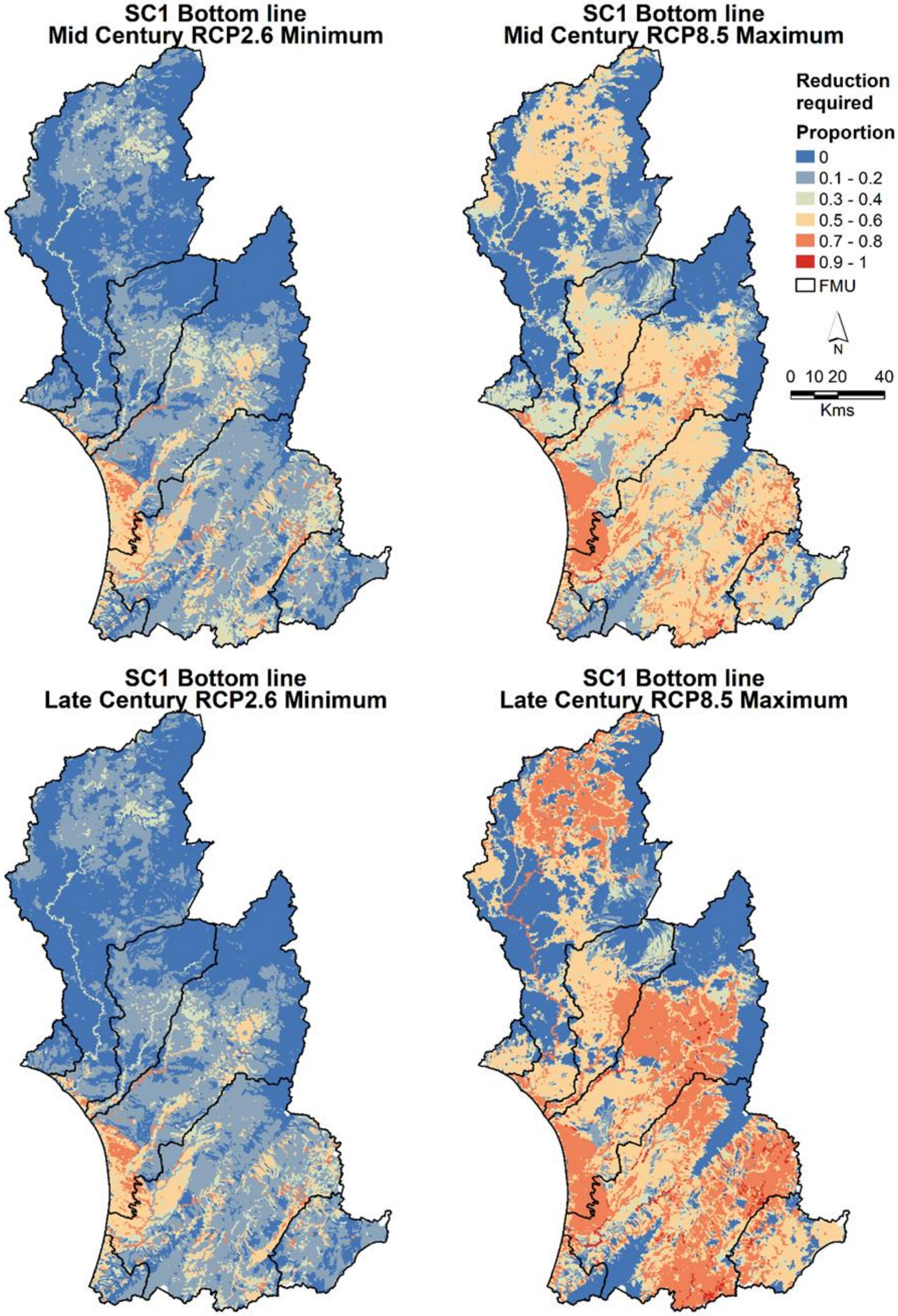

Figure 24. Proportional reduction required to meet NPS-FM attribute national bottom line from climate change projected sediment load at mid- and late-century, represented by RCP2.6 minimum and RCP8.5 maximum for SC1.

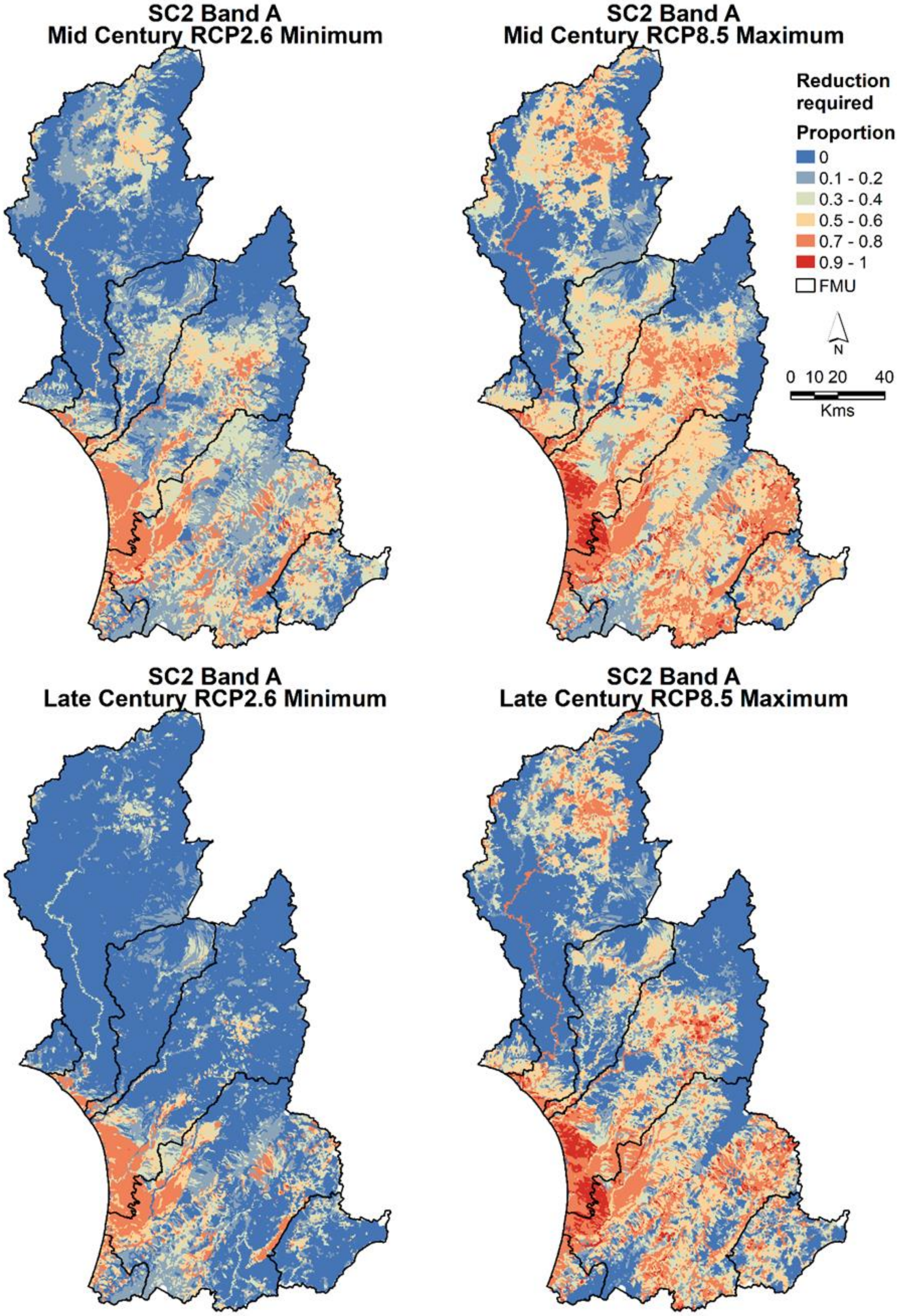

Figure 25. Proportional reduction required to meet NPS-FM attribute Band A from climate change projected sediment load at mid- and late-century, represented by RCP2.6 minimum and RCP8.5 maximum for SC2.

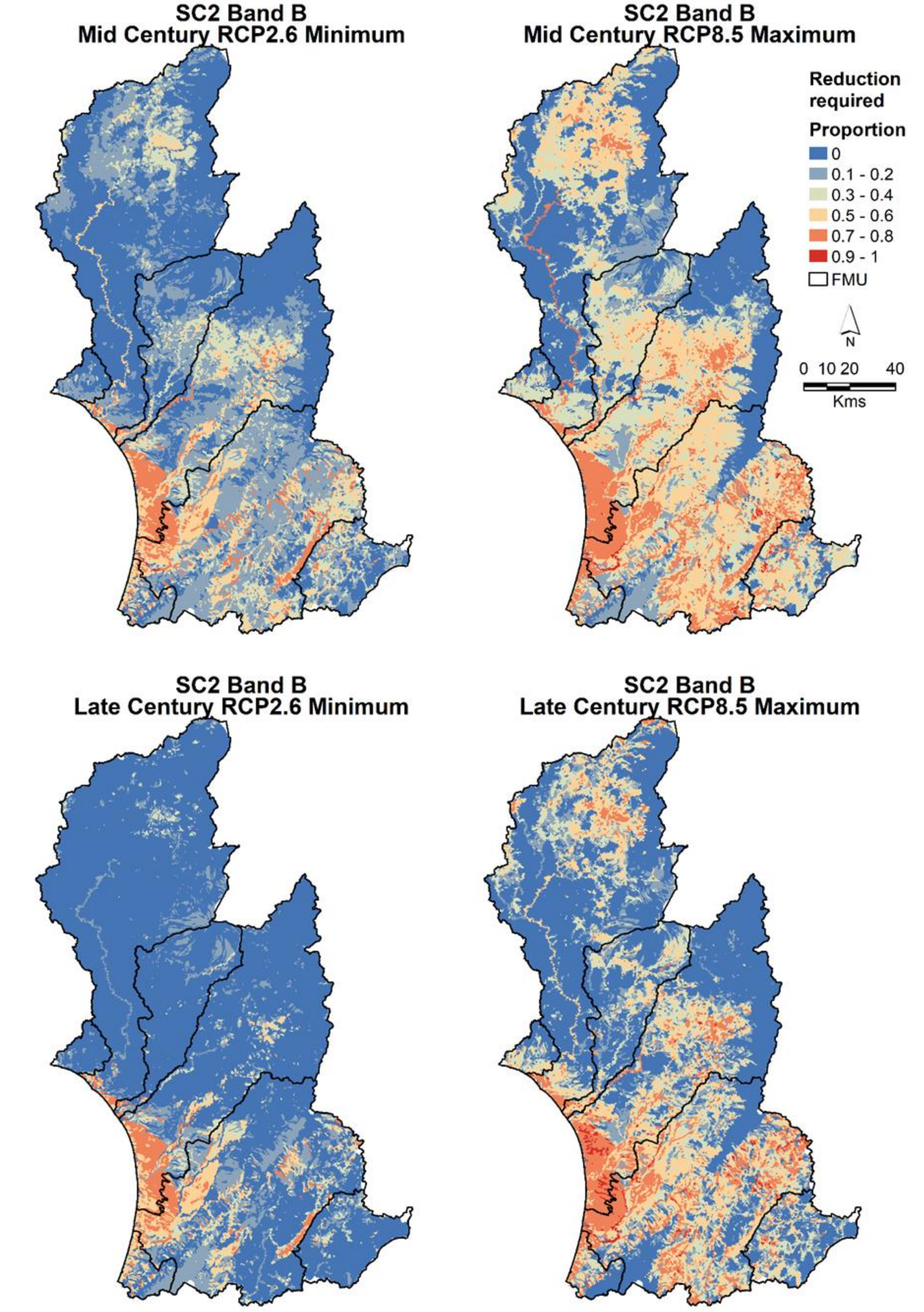

Figure 26. Proportional reduction required to meet NPS-FM attribute Band B from climate change projected sediment load at mid- and late-century, represented by RCP2.6 minimum and RCP8.5 maximum for SC2.

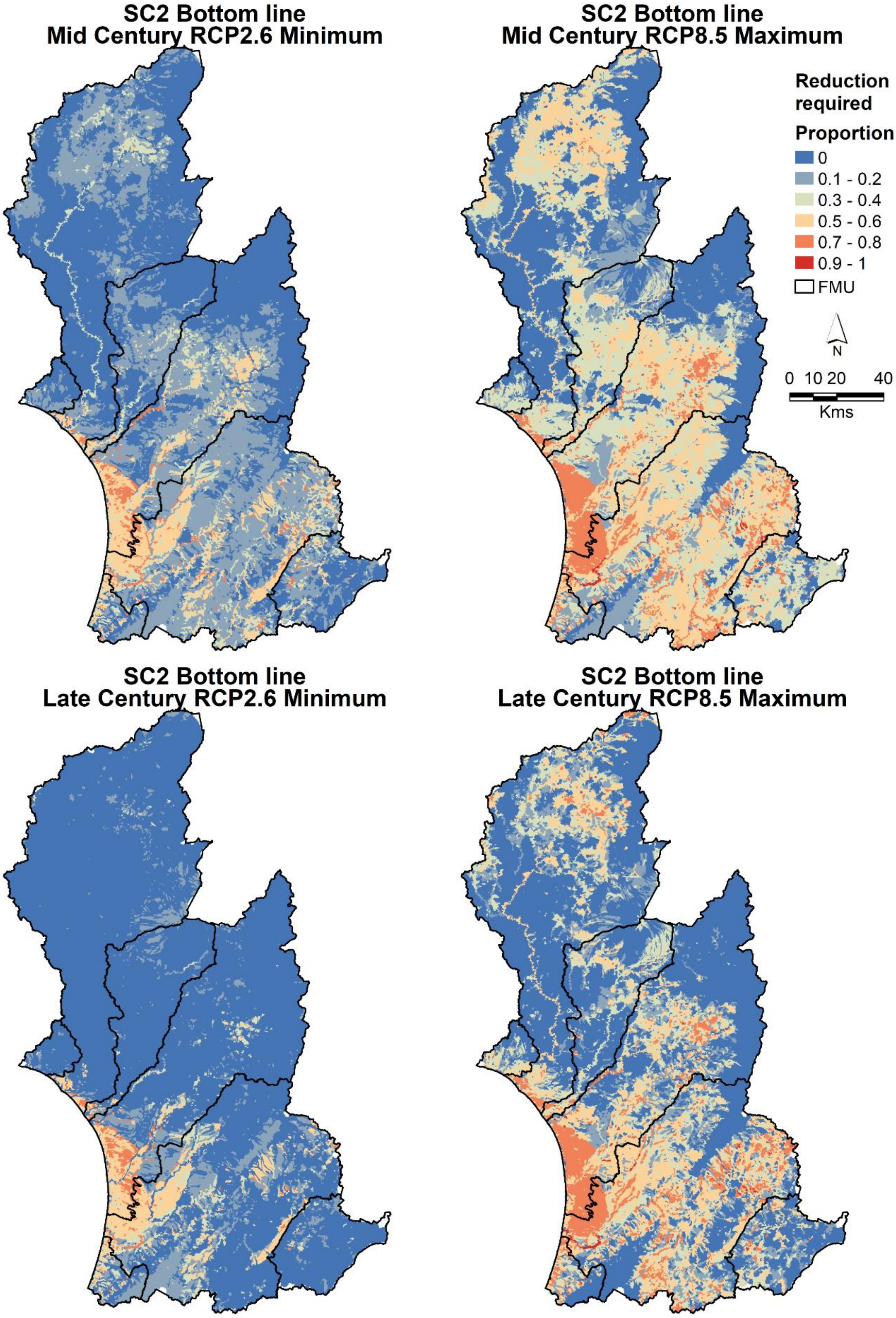

Figure 27. Proportional reduction required to meet NPS-FM attribute national bottom line from climate change projected sediment load at mid- and late-century, represented by RCP2.6 minimum and RCP8.5 maximum for SC3.

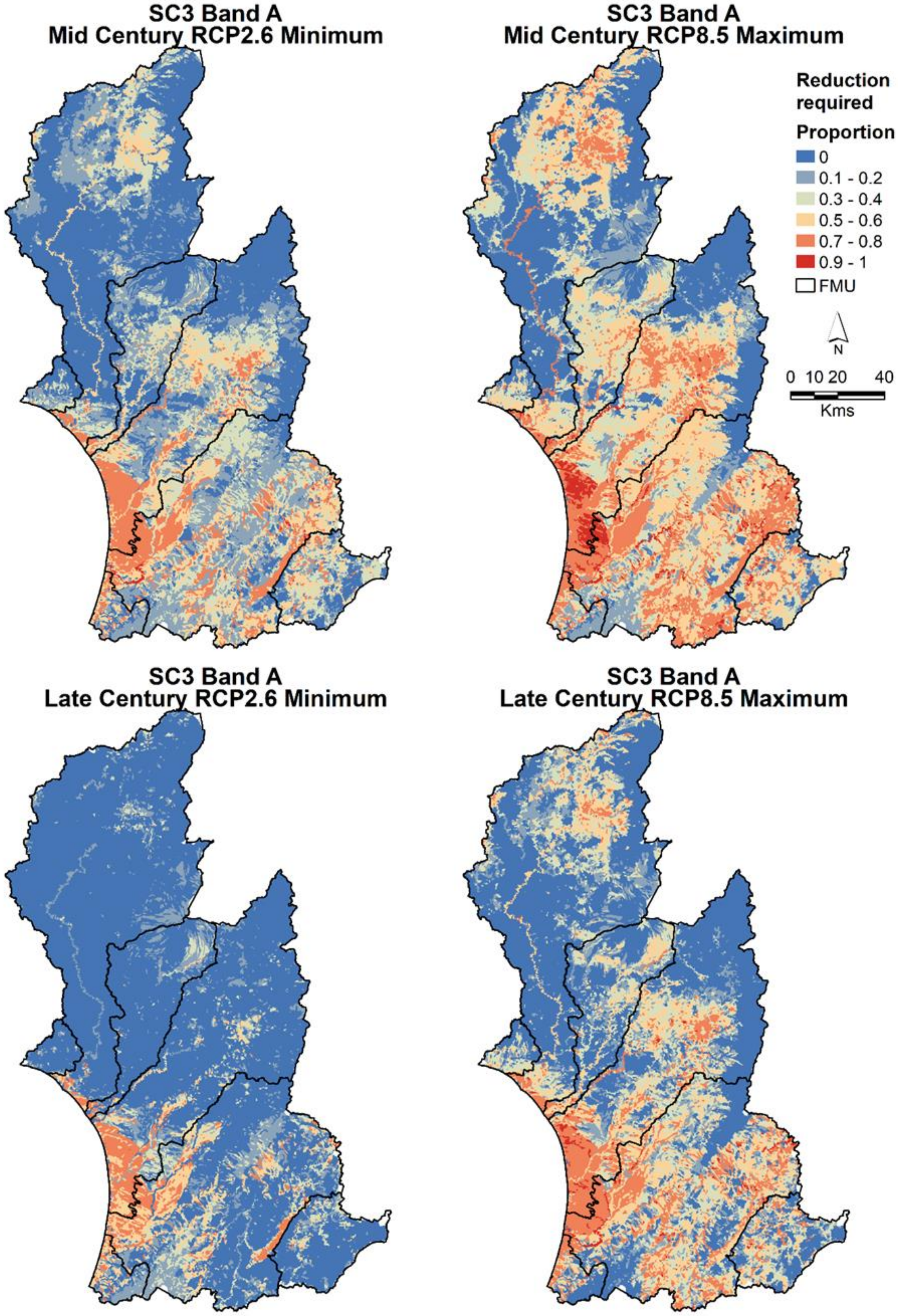

Figure 28. Proportional reduction required to meet NPS-FM attribute Band A from climate change projected sediment load at mid- and late-century, represented by RCP2.6 minimum and RCP8.5 maximum for SC3.

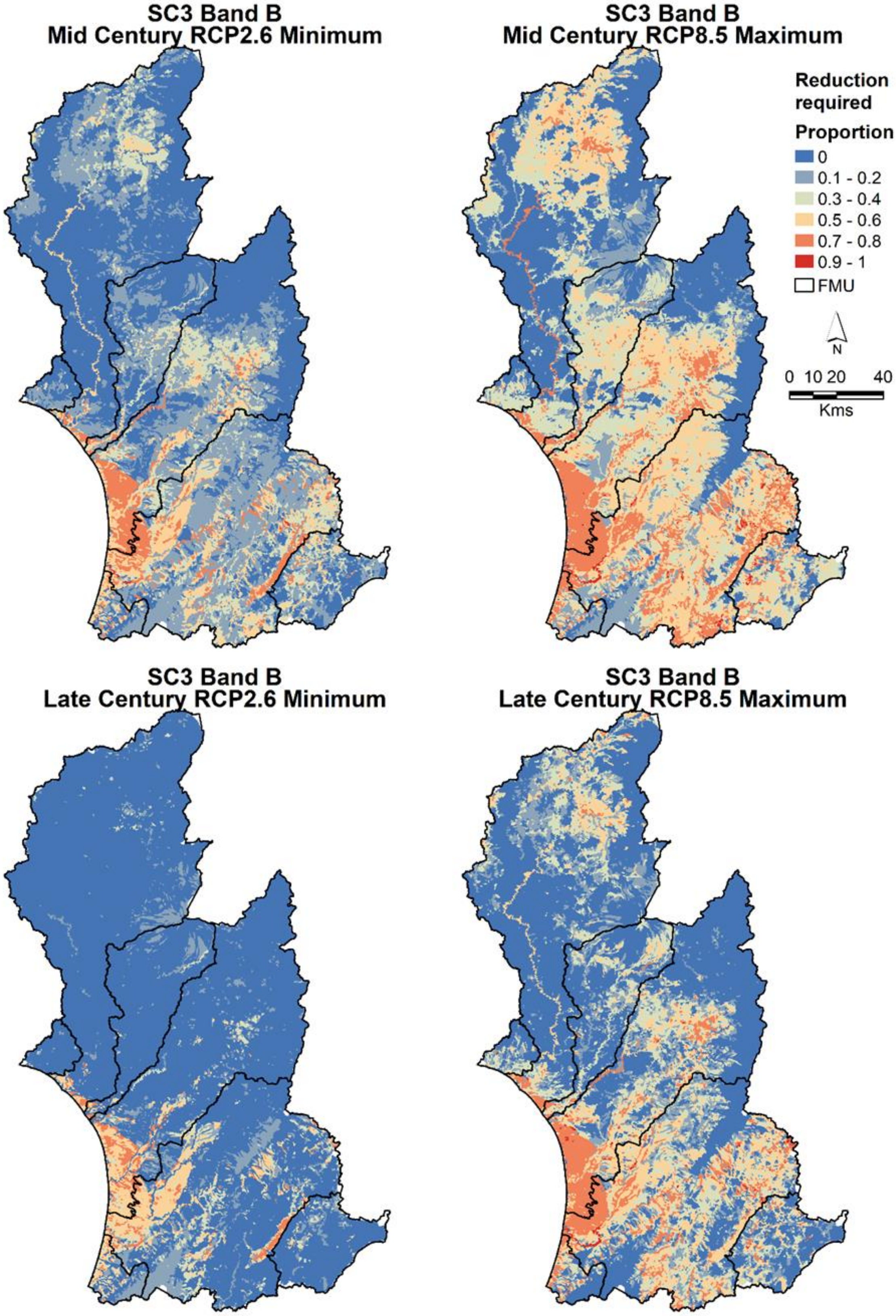

Figure 29. Proportional reduction required to meet NPS-FM attribute Band B from climate change projected sediment load at mid- and late-century, represented by RCP2.6 minimum and RCP8.5 maximum for SC3.

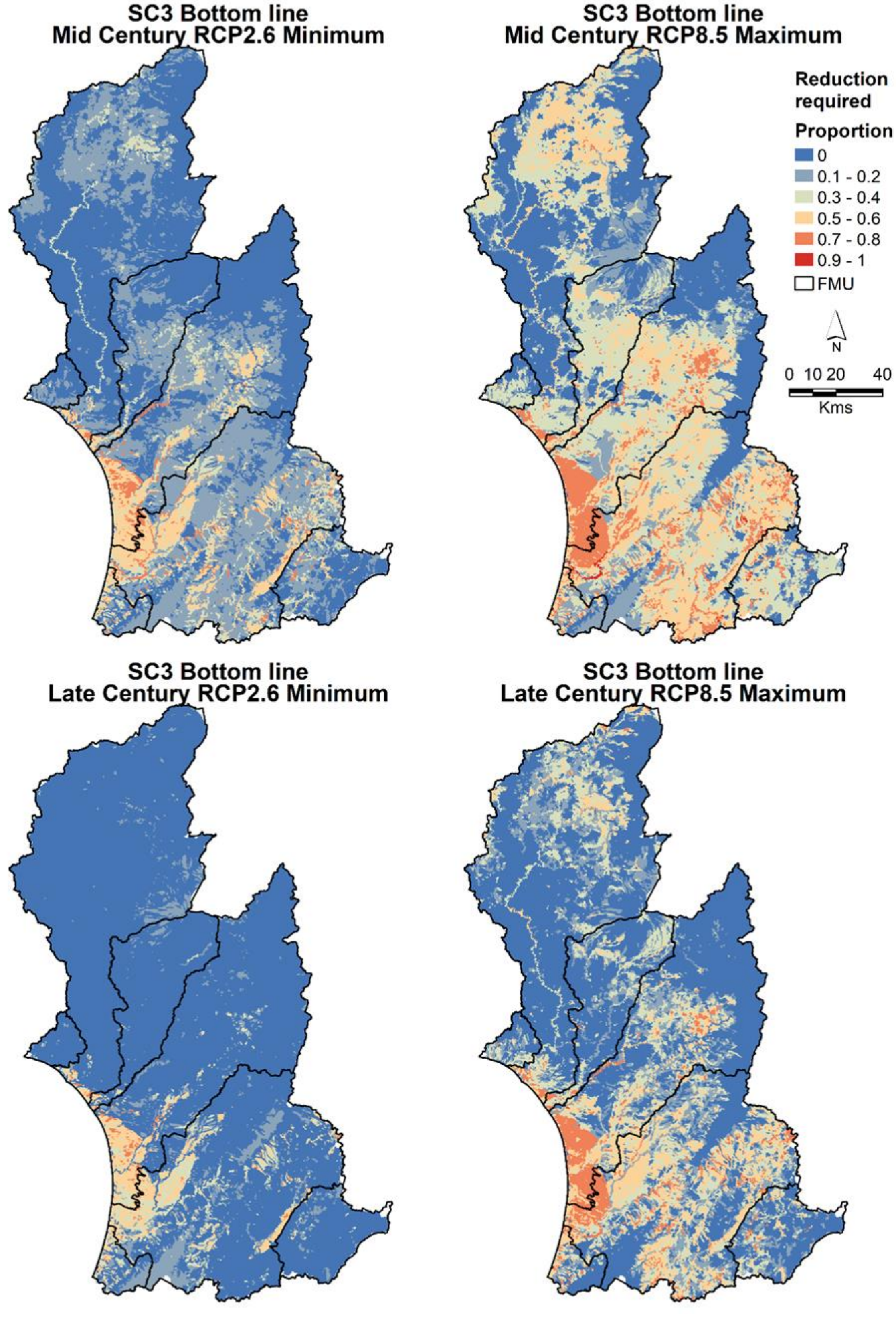

Figure 30. Proportional reduction required to meet NPS-FM attribute national bottom line from climate change projected sediment load at mid- and late-century, represented by RCP2.6 minimum and RCP8.5 maximum for SC3.

5.5 Model evaluation and limitations

5.5.1 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 model performance over such timescales 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 Horizons region and the resulting suspended sediment concentration (SSC) and discharge (Q) data used to estimate mean annual suspended sediment loads via SSC-Q rating curve methods (Hicks et al. 2019b). We have used these estimates of mean annual suspended sediment load (obtained from the Appendix D of Hicks et al. 2019b) to inform model calibration.

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 Fig. 31. There is generally good agreement between available measured loads and the calibrated model but this agreement varies between catchments. Sediment loads predicted using the updated version of SedNetNZ applied in the present report are either similar or improve on predictions using previous model versions when compared to measured loads in the Horizons region (Table 27).

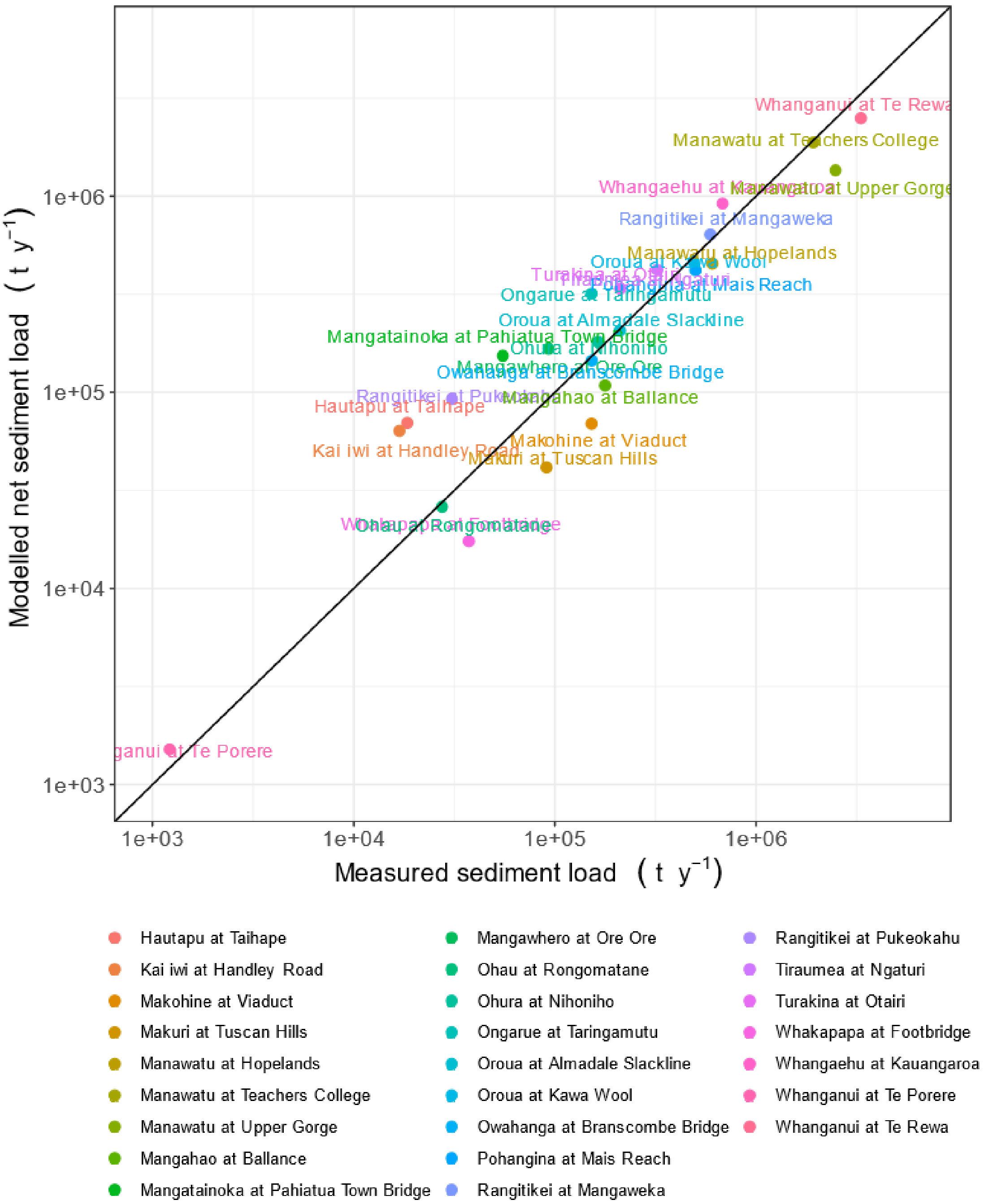

Figure 31. Mean annual suspended sediment loads estimated using SSC-Q rating curves versus modelled mean annual loads for river gauging stations in the Horizons region.

Table 27. Percent differences between modelled and measured suspended sediment loads summarised by Basher et al (2018) with reference to previous applications of SedNetNZ to the Horizons region. For comparison, percent differences between measured and modelled loads are reported for the updated version of SedNetNZ applied in the present report. The predicted sediment loads in this report are expected to be lower than previously measured and modelled sediment loads given the progress of SLUI programme

River gauging station	Dymond et al. (2013) %	Dymond et al. (2014) %	Vale et al. (2022) – present report %
Manawatū at Hopelands	–17	–21	–25
Manawatū at Teachers College	12	3	–2
Mangahao at Ballance	–32	–27	–39
Mangatainoka at PTB	143	170	179
Oroua at Almadale	39	72	–2
Pohangina at Mais Reach	–1	–53	–16
Tiraumea at Ngāturi	71	28	31
Makuri at Tuscan Hills		–44	–54
Ohura at Nihoniho		–14	10
Owahanga at Branscombe Bridge		38	–5
Rangitīkei at Mangaweka		159	7
Rangitīkei at Pukeokahu		1,273	200
Whanganui at Te Rewa		11	–25

The use of the updated version of SedNetNZ results in an overall decrease in the predicted region-wide suspended sediment load compared to previous model applications to the region. Dymond et al (2014) estimated the region-wide load at 13.4 Mt y^{-1} for 2004 and that reduced to 12.6 Mt y^{-1} in 2018 with SLUI implementation up to that date (Basher et al. 2020). These previous region-wide estimates of suspended sediment load compare with 8.5 Mt y^{-1} for 2021 in the present study. While part of the difference in load may be attributed to the further implementation of SLUI between 2018 and 2021, most of the difference reflects updates to the SedNetNZ model since previous applications to the region. Therefore, modelled suspended sediment loads cannot be directly compared between the present report using the updated version of SedNetNZ and previous reports.

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

5.5.2 Model limitations

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. 2014). The further acquisition of higher resolution soils data for the Horizons 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 the Manawatū (Dymond et al. 2016) was used to define the slope thresholds for landslide occurrence and density.

Both earthflow and gully erosion are represented in SedNetNZ using a spatial averaging approach based on 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. Aerial imagery was used to evaluate selected catchments and Erosion Terrain layers were adjusted if there was no evidence of active gully erosion.

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

Climate change projections

A high degree of uncertainty exists 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-hour event. A uniform triggering threshold of 150 mm in 48 hours 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). Projections for bank erosion rely on indicative changes to the modelled MAF from the Manawatū River based on available information (Collins et al. 2018) but this does not capture regional variablity in potential climate impacts on MAF. Nonetheless, this is an improvement on previous modelling of climate change effects using SedNetNZ that did not include representation of the impact on bank erosion (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).

In the present report, we applied a refined method for estimating the effect of projected climate change on erosion compared to previous work (Basher et al. 2018, 2020). The refinements included a) increasing the number of long-term rainfall records used to compute mass movement change factors (section 4.2.4) from two to five in the Horizons region, as well as including gauges bordering the Horizons region, and b) spatially interpolating change factor values across a continuous grid. The interpolation procedure replaces use of the Land Environments of New Zealand layer (LENZ; Leathwick et al, 2003) that previously formed the basis for uniformly applying change factors to LENZ classes within the region.

These changes in how we estimate the effects of climate change on erosion altered the magnitude of projected climate change impacts on suspended sediment loads compared to previous work. For instance, Basher et al. (2020) estimated a region-wide increase in sediment loads of 8.3–24% and 53–224% by 2043 and 2090, respectively, using the previous method. In contrast, we estimate an increase in regional load of 8–60% and 2–119% across all RCPs for SC1 by 2040 and 2090, respectively. This comparison shows a sizable reduction in the potential increase in sediment loads by end century using the refined method for determining climate change impacts. However, other factors contribute to these differences that somewhat limit direct comparison. These include a) use of different baselines for computing relative changes in load (i.e. 2004 in Basher et al. versus 2021 in the present report) and b) representation of hillslope erosion processes only by Basher et al. (2020) versus hillslope and bank erosion processes in the present study.

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 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 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 et al. 2019). As 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 REC2 segment compared with the 2021 baseline.

We have estimated the required load reductions using empirical models fitted to a national dataset. This should result in the models being fitted to a wide range of catchment variables and therefore representing the variability across Horizons, and sites from Horizons were used in the national dataset (see Hicks et al. 2019) but may lead to under or over estimation of required reductions at any one location. Additionally, 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

SLUI sediment load reduction

Significant uncertainty exists regarding the effectiveness, maturity, and implementation rates of SLUI WFPs, as well as the selection of new farms. The effectiveness of each erosion mitigation used values from previous SedNetNZ modelling, which are based on literature. Better data on the effectiveness of erosion mitigation at the whole-farm and whole-catchment scale are needed to improve the prediction of sediment load reduction, especially if values can be derived from or calibrated with local data. The maturity rate of each erosion mitigation could also benefit from better data that are locally calibrated to reflect tree species, growing conditions, and success rates of new plantings in the region.

The implementation rate of new works on a farm is one of the more difficult parameters to define. Here, we applied it as an average annual proportional rate relative to what would be considered fully implemented as opposed to a set area of works completed per year. The estimated implementation rate was provided by HRC. Since no clear definition or measure of what ‘fully implemented’ represents for a given farm exists, it is difficult to estimate the implementation rate. A standardised measure of the mitigatable area of each farm would be beneficial to improving the implementation rate.

A result of using a farm-based implementation rate also means that the total area of works implemented each year is modelled to increase as new farms are selected and added to the total number of farms having works applied. In practice, the total area of works funded and implemented annually across the region may remain relatively constant. For reasons noted above, estimating the area of works represented by the implementation rate for each farm is challenging. However, if we consider the maximum mitigatable area of a farm to be represented by the area of erodible, high, and top HEL pasture, and the minimum mitigable area to be represented by the area of high and top HEL pasture, then we can approximate a maximum and minimum average annual estimate of the total area of works for the modelling period (2021 to 2100). These maximum and minimum areas were determined for each mapped farm based on the SLUI farm data provided. These areas were then used to derive an average proportion of the pasture area for each SLUI priority class which could then be applied to unmapped farms at the rate of future selection and associated implementation rate. This results in a minimum and maximum annual average of ~1780 ha yr^{-1} and ~4,990 ha yr^{-1}, respectively, or a mean ~3,380 ha yr^{-1} over the simulated period from 2021 to 2100 for SC2 (Table 28).

An approximation of the average annual rate of works according to work type can also be estimated by using the proportion of works applied within the model simulation (Table 28). These proportions were based on the mapped area of past works for each priority class (Table 3) which recognises works vary based on WFP priority and the terrain they generally represent. The proportions were also weighted by erosion process loads to ensure works were not applied to areas where there were no modelled loads for the erosion process targeted by each works. The resulting approximations should not be overinterpreted since the works proportions they are based on were used to weight the effectiveness (which varies from 70 – 90 %) applied to each farm, and not to determine the actual area each type of work. A summary of the estimated region-wide proportion of works for the end of the simulated period, and by FMU, is provided in Table 29.

New farms were randomly selected for implementation based on the proportions of each SLUI priority class. We do not know how representative this selection will be of the actual order of new farms selected in the future. We also do not know how sensitive the mean annual local and region-wide loads are to the selection order of new farms. To evaluate the sensitivity of this component would require running multiple iterations of SedNetNZ using different farm selection orders.

Table 28 Estimated minimum, maximum, and mean annual average rate of works completed over the simulated period from 2021 to 2100

Erosion mitigation works	Estimated area of works per year (ha yr^{-1})					
	SC2			SC3		
	min	mean	max	min	mean	max
Afforestation	890	1,630	2,370	1,010	1,920	2,820
Bush retirement	450	760	1,080	710	1,300	1,880
Riparian retirement	110	290	470	220	660	1,110
Spaced planting	320	680	1,040	410	940	1,470
Gully planting	10	20	30	10	20	40
Total	1,780	3,380	4,990	2,360	4,840	7,320

Table 29 Estimated proportion of works for each erosion mitigation type at the end of the simulated period (2100), both region-wide and per FMU. Note, SC1 represents the past proportions from mapped works (based on HRC data) since no further works are applied in this scenario (Table 3).

Scenario	Erosion mitigation	Proportion of works (%)							
		Region-wide	FMU						
			Kai Iwi	Manawatū	Puketoi ki Tai	Rangitikei-Turakina	Waiopehu	Whangaehu	Whanganui
SC1	Afforestation	44	48	43	69	35	100	24	47
	Retirement	30	25	16	14	29	0	34	41
	Riparian retirement	10	6	14	7	18	0	12	5
	Spaced planting	14	15	26	10	17	0	22	6
	Gully planting	2	6	1	0	1	0	8	1
SC2	Afforestation	48	51	42	48	49	32	44	54
	Retirement	23	17	19	26	23	5	29	22
	Riparian retirement	9	3	15	4	9	29	9	5
	Spaced planting	20	27	24	22	18	33	18	18
	Gully planting	1	1	1	0	1	0	0	0
SC3	Afforestation	40	42	31	42	42	31	38	47
	Retirement	26	26	20	34	26	15	28	29
	Riparian retirement	14	5	25	3	14	22	15	6
	Spaced planting	20	27	23	20	18	32	18	17
	Gully planting	1	1	1	0	1	0	0	0

6 Conclusions & Recommendations

- Total erosion for the Horizons region was estimated at 9.0 Mt yr^{-1} for 2021. Most of this occurs in the 'Whanganui', 'Manawatū', and 'Rangitīkei-Turakina' FMUs. The predicted region-wide total net suspended sediment load delivered to the coast for 2021 was 8.5 Mt yr^{-1}.
- The proportion of REC2 segments achieving national bottom line at 2021 was 75%. Model scenarios of future SLUI implementation for SC2 and SC3 produce large reductions (47% and 53%) in region-wide suspended sediment loads. In the absence of impacts from climate change, this indicates that 88 and 90% of REC2 segments by length could achieve the national bottom line at 2100 under SC2 and SC3, respectively.
- A large area of the lowland REC2 segments still require relatively high proportional reductions to achieve national bottom line, although these are generally low absolute loads. The high proportional reductions required relate to 1) SLUI erosion mitigation which focuses mitigation mostly in hill country, 2) the selection order of new farm plans, and 3) the sensitivity of the required load reduction to the assigned sediment class.
- The projected total erosion under future climate change across RCPs for SC1 ranged from 9.5 to 14.1 Mt yr^{-1} for mid-century, and 9.0 to 19.2 Mt yr^{-1} for late-century. This equates to an increase of 8–58%, and 2–119% for mid- and late-century, respectively, compared with loads modelled without the effect of climate change. Scenario SC2 results in a load change ranging from 7 to 58% and –5 to 93% for mid- and late-century, respectively, while scenario SC3 results in a load change ranging from 7 to 58% and –5 to 90% for mid- and late-century, respectively, compared with loads modelled without the effect of climate change.
- The proportion of REC2 segments (by length) achieving national bottom line under future climate change across all RCPs for SC1 equates to 25–38% at mid-century and 22–40% at late-century. By comparison, the proportion of segments achieving bottom line for SC2 under projected climate change are 28–45% and 45–79% by mid- and late-century, while results for SC3 equate to 28–46% and 49–84% by mid- and late-century, respectively.
- Continued investment in SLUI or other programmes for erosion mitigation will be required to reduce potentially significant impacts of climate change on suspended sediment loads by late-century.
- Model predictions of sediment load reductions due to erosion mitigations could be improved with region-specific data related to the effectiveness in erosion control, as well as information on the levels of implementation and maturity of works at the farm scale. Region-wide LiDAR would allow improved representation of erosion processes.
- Further clarification of what constitutes a 'fully implemented' WFP would help improve estimates of the implementation rate for SLUI works on farms. This could include an assessment of total 'mitigatable' land for each farm, ideally for both mapped and unmapped farms.
- The impacts of climate change on erosion processes and catchment hydrology would benefit from further investigation to better predict potential changes in suspended sediment loads and effects on visual clarity.

7 Acknowledgements

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Appendix 1 – Length and proportion of River Environment Classification v2 (REC2) segments achieving each visual clarity attribute band summarized by Freshwater Management Unit (FMU) without the effects of climate change

Table 30. Length and proportion of REC2 segments achieving each visual clarity attribute band summarized by FMU and stream order for SC1

SC1				Length of REC2 segments achieving NPS-FM attribute band									
Attribute Band	FMU	Stream Order	Total Length (km)	2021		2040		2060		2080		2100	
				km	%	km	%	km	%	km	%	km	%
Band A	Kai Iwi	1	262	102	39%	112	43%	112	43%	112	43%	112	43%
		2	146	58	39%	60	41%	60	41%	60	41%	60	41%
		3	68	23	34%	24	36%	24	36%	24	36%	24	36%
		4	59	29	49%	32	54%	32	54%	32	54%	32	54%
		5	22	-	0%	2	7%	2	7%	2	7%	2	7%
		Total	558	212	38%	230	41%	230	41%	230	41%	230	41%
	Manawatū	1	4,825	1,203	25%	1,248	26%	1,248	26%	1,248	26%	1,248	26%
		2	2,484	561	23%	585	24%	585	24%	585	24%	585	24%
		3	1,261	257	20%	271	21%	271	21%	271	21%	271	21%
		4	651	75	12%	83	13%	83	13%	83	13%	83	13%
		5	439	73	17%	73	17%	73	17%	73	17%	73	17%
		6	162	5	3%	5	3%	5	3%	5	3%	5	3%
		7	119	-	0%	-	0%	-	0%	-	0%	-	0%
		Total	9,941	2,173	22%	2,264	23%	2,264	23%	2,264	23%	2,264	23%
	Puketoi ki Tai	1	875	202	23%	251	29%	251	29%	251	29%	251	29%
		2	435	84	19%	109	25%	109	25%	109	25%	109	25%
		3	259	39	15%	52	20%	52	20%	52	20%	52	20%

SC1 Attribute Band	FMU	Stream Order	Total Length (km)	Length of REC2 segments achieving NPS-FM attribute band 2021 km	2021 %	2040 km	2040 %	2060 km	2060 %	2080 km	2080 %	2100 km	2100 %
Band A (cont.)	Puketoi ki Tai (cont.)	4	139	13	9%	15	11%	15	11%	15	11%	15	11%
		5	71	-	0%	-	0%	-	0%	-	0%	-	0%
		6	46	-	0%	-	0%	-	0%	-	0%	-	0%
		Total	1,825	339	19%	427	23%	427	23%	427	23%	427	23%
	Rangitīkei-Turakina	1	4,349	1,241	29%	1,301	30%	1,301	30%	1,301	30%	1,301	30%
		2	2,111	592	28%	629	30%	629	30%	629	30%	629	30%
		3	1,035	289	28%	307	30%	307	30%	307	30%	307	30%
		4	480	207	43%	215	45%	215	45%	215	45%	215	45%
		5	293	127	43%	132	45%	132	45%	132	45%	132	45%
		6	156	19	12%	19	12%	19	12%	19	12%	19	12%
		7	139	-	0%	-	0%	-	0%	-	0%	-	0%
		Total	8,563	2,476	29%	2,602	30%	2,602	30%	2,602	30%	2,602	30%
	Waiopehu	1	322	69	21%	72	22%	72	22%	72	22%	72	22%
		2	161	25	15%	25	16%	25	16%	25	16%	25	16%
		3	92	27	29%	28	30%	28	30%	28	30%	28	30%
		4	38	19	50%	19	50%	19	50%	19	50%	19	50%
		5	34	19	57%	20	60%	20	60%	20	60%	20	60%
		Total	647	159	25%	165	25%	165	25%	165	25%	165	25%
	Whangaehu	1	1,682	588	35%	657	39%	657	39%	657	39%	657	39%
		2	892	326	37%	368	41%	368	41%	368	41%	368	41%
		3	409	171	42%	183	45%	183	45%	183	45%	183	45%

SC1				Length of REC2 segments achieving NPS-FM attribute band									
				2021		2040		2060		2080		2100	
Attribute Band	**FMU**	**Stream Order**	**Total Length (km)**	**km**	**%**	**km**	**%**	**km**	**%**	**km**	**%**	**km**	**%**
Band A (cont.)	Whangaehu (cont.)	4	223	50	22%	54	24%	54	24%	54	24%	54	24%
		5	126	42	33%	47	37%	47	37%	47	37%	47	37%
		6	145	-	0%	-	0%	-	0%	-	0%	-	0%
		Total	3,478	1,177	34%	1,310	38%	1,310	38%	1,310	38%	1,310	38%
	Whanganui	1	5,833	3,816	65%	3,891	67%	3,891	67%	3,891	67%	3,891	67%
		2	2,871	1,918	67%	1,955	68%	1,955	68%	1,955	68%	1,955	68%
		3	1,397	972	70%	996	71%	996	71%	996	71%	996	71%
		4	790	512	65%	530	67%	530	67%	530	67%	530	67%
		5	404	332	82%	334	83%	334	83%	334	83%	334	83%
		6	166	28	17%	28	17%	28	17%	28	17%	28	17%
		7	247	-	0%	-	0%	-	0%	-	0%	-	0%
		Total	11,709	7,579	65%	7,734	66%	7,734	66%	7,734	66%	7,734	66%
Band B	Kai Iwi	1	262	195	74%	203	77%	203	77%	203	77%	203	77%
		2	146	116	79%	121	83%	121	83%	121	83%	121	83%
		3	68	50	74%	52	76%	52	76%	52	76%	52	76%
		4	59	51	87%	51	87%	51	87%	51	87%	51	87%
		5	22	5	24%	5	24%	5	24%	5	24%	5	24%
		Total	558	418	75%	433	78%	433	78%	433	78%	433	78%
	Manawatū	1	4,825	2,185	45%	2,238	46%	2,238	46%	2,238	46%	2,238	46%
		2	2,484	1,076	43%	1,097	44%	1,097	44%	1,097	44%	1,097	44%
		3	1,261	529	42%	541	43%	541	43%	541	43%	541	43%

SC1 Attribute Band	FMU	Stream Order	Total Length (km)	Length of REC2 segments achieving NPS-FM attribute band 2021 km	2021 %	2040 km	2040 %	2060 km	2060 %	2080 km	2080 %	2100 km	2100 %
Band B (cont.)	Manawatū (cont.)	4	651	210	32%	218	33%	218	33%	218	33%	218	33%
		5	439	159	36%	174	40%	174	40%	174	40%	174	40%
		6	162	15	9%	15	9%	15	9%	15	9%	15	9%
		7	119	4	4%	5	5%	5	5%	5	5%	5	5%
		Total	9,941	4,179	42%	4,289	43%	4,289	43%	4,289	43%	4,289	43%
	Puketoi ki Tai	1	875	401	46%	477	55%	477	55%	477	55%	477	55%
		2	435	156	36%	196	45%	196	45%	196	45%	196	45%
		3	259	89	34%	96	37%	96	37%	96	37%	96	37%
		4	139	25	18%	37	27%	37	27%	37	27%	37	27%
		5	71	-	0%	2	3%	2	3%	2	3%	2	3%
		6	46	-	0%	-	0%	-	0%	-	0%	-	0%
		Total	1,825	671	37%	808	44%	808	44%	808	44%	808	44%
	Rangitīkei-Turakina	1	4,349	2,455	56%	2,555	59%	2,555	59%	2,555	59%	2,555	59%
		2	2,111	1,151	55%	1,202	57%	1,202	57%	1,202	57%	1,202	57%
		3	1,035	571	55%	590	57%	590	57%	590	57%	590	57%
		4	480	319	66%	323	67%	323	67%	323	67%	323	67%
		5	293	179	61%	179	61%	179	61%	179	61%	179	61%
		6	156	36	23%	36	23%	36	23%	36	23%	36	23%
		7	139	-	0%	-	0%	-	0%	-	0%	-	0%
		Total	8,563	4,710	55%	4,885	57%	4,885	57%	4,885	57%	4,885	57%

SC1 Attribute Band	FMU	Stream Order	Total Length (km)	Length of REC2 segments achieving NPS-FM attribute band 2021 km	2021 %	2040 km	2040 %	2060 km	2060 %	2080 km	2080 %	2100 km	2100 %
Band B (cont.)	Waiopehu	1	322	151	47%	153	48%	153	48%	153	48%	153	48%
		2	161	69	43%	71	44%	71	44%	71	44%	71	44%
		3	92	48	53%	48	53%	48	53%	48	53%	48	53%
		4	38	23	61%	26	68%	26	68%	26	68%	26	68%
		5	34	23	68%	23	68%	23	68%	23	68%	23	68%
		Total	647	315	49%	322	50%	322	50%	322	50%	322	50%
	Whangaehu	1	1,682	1,258	75%	1,278	76%	1,278	76%	1,278	76%	1,278	76%
		2	892	685	77%	692	78%	692	78%	692	78%	692	78%
		3	409	320	78%	322	79%	322	79%	322	79%	322	79%
		4	223	155	70%	156	70%	156	70%	156	70%	156	70%
		5	126	58	46%	58	46%	58	46%	58	46%	58	46%
		6	145	-	0%	-	0%	-	0%	-	0%	-	0%
		Total	3,478	2,476	71%	2,507	72%	2,507	72%	2,507	72%	2,507	72%
	Whanganui	1	5,833	4,742	81%	4,766	82%	4,766	82%	4,766	82%	4,766	82%
		2	2,871	2,366	82%	2,378	83%	2,378	83%	2,378	83%	2,378	83%
		3	1,397	1,154	83%	1,181	85%	1,181	85%	1,181	85%	1,181	85%
		4	790	615	78%	630	80%	630	80%	630	80%	630	80%
		5	404	369	91%	370	92%	370	92%	370	92%	370	92%
		6	166	79	47%	80	48%	80	48%	80	48%	80	48%
		7	247	-	0%	-	0%	-	0%	-	0%	-	0%
		Total	11,709	9,325	80%	9,406	80%	9,406	80%	9,406	80%	9,406	80%

SC1				Length of REC2 segments achieving NPS-FM attribute band									
Attribute Band	FMU	Stream Order	Total Length (km)	2021		2040		2060		2080		2100	
				km	%	km	%	km	%	km	%	km	%
National bottom line	Kai Iwi	1	262	240	92%	240	92%	240	92%	240	92%	240	92%
		2	146	143	98%	143	98%	143	98%	143	98%	143	98%
		3	68	67	98%	67	98%	67	98%	67	98%	67	98%
		4	59	56	95%	56	95%	56	95%	56	95%	56	95%
		5	22	15	67%	19	85%	19	85%	19	85%	19	85%
		Total	558	521	93%	525	94%	525	94%	525	94%	525	94%
	Manawatū	1	4,825	2,969	62%	3,013	62%	3,013	62%	3,013	62%	3,013	62%
		2	2,484	1,491	60%	1,520	61%	1,520	61%	1,520	61%	1,520	61%
		3	1,261	708	56%	731	58%	731	58%	731	58%	731	58%
		4	651	329	51%	338	52%	338	52%	338	52%	338	52%
		5	439	208	47%	209	48%	209	48%	209	48%	209	48%
		6	162	83	51%	84	52%	84	52%	84	52%	84	52%
		7	119	42	35%	42	35%	42	35%	42	35%	42	35%
		Total	9,941	5,829	59%	5,936	60%	5,936	60%	5,936	60%	5,936	60%
	Puketoi ki Tai	1	875	679	78%	699	80%	699	80%	699	80%	699	80%
		2	435	298	69%	313	72%	313	72%	313	72%	313	72%
		3	259	165	63%	169	65%	169	65%	169	65%	169	65%
		4	139	59	43%	71	51%	71	51%	71	51%	71	51%
		5	71	29	41%	29	41%	29	41%	29	41%	29	41%
		6	46	-	0%	-	0%	-	0%	-	0%	-	0%
		Total	1,825	1,231	67%	1,281	70%	1,281	70%	1,281	70%	1,281	70%

SC1 Attribute Band	FMU	Stream Order	Total Length (km)	Length of REC2 segments achieving NPS-FM attribute band 2021 km	2021 %	2040 km	2040 %	2060 km	2060 %	2080 km	2080 %	2100 km	2100 %
National bottom line (cont.)	Rangitīkei-Turakina	1	4,349	3,201	74%	3,223	74%	3,223	74%	3,223	74%	3,223	74%
		2	2,111	1,456	69%	1,476	70%	1,476	70%	1,476	70%	1,476	70%
		3	1,035	748	72%	758	73%	758	73%	758	73%	758	73%
		4	480	393	82%	397	83%	397	83%	397	83%	397	83%
		5	293	236	80%	236	80%	236	80%	236	80%	236	80%
		6	156	91	59%	91	59%	91	59%	91	59%	91	59%
		7	139	16	11%	49	35%	49	35%	49	35%	49	35%
		Total	8,563	6,140	72%	6,231	73%	6,231	73%	6,231	73%	6,231	73%
	Waiopehu	1	322	164	51%	169	53%	169	53%	169	53%	169	53%
		2	161	77	48%	82	51%	82	51%	82	51%	82	51%
		3	92	59	64%	59	64%	59	64%	59	64%	59	64%
		4	38	24	62%	30	80%	30	80%	30	80%	30	80%
		5	34	23	68%	25	74%	25	74%	25	74%	25	74%
		Total	647	347	54%	365	56%	365	56%	365	56%	365	56%
	Whangaehu	1	1,682	1,494	89%	1,500	89%	1,500	89%	1,500	89%	1,500	89%
		2	892	797	89%	801	90%	801	90%	801	90%	801	90%
		3	409	372	91%	375	92%	375	92%	375	92%	375	92%
		4	223	175	79%	175	79%	175	79%	175	79%	175	79%
		5	126	77	61%	87	69%	87	69%	87	69%	87	69%
		6	145	-	0%	-	0%	-	0%	-	0%	-	0%
		Total	3,478	2,915	84%	2,939	84%	2,939	84%	2,939	84%	2,939	84%

SC1 Attribute Band	FMU	Stream Order	Total Length (km)	Length of REC2 segments achieving NPS-FM attribute band 2021 km	2021 %	2040 km	2040 %	2060 km	2060 %	2080 km	2080 %	2100 km	2100 %
National bottom line (cont.)	Whanganui	1	5,833	5,368	92%	5,376	92%	5,376	92%	5,376	92%	5,376	92%
		2	2,871	2,647	92%	2,656	93%	2,656	93%	2,656	93%	2,656	93%
		3	1,397	1,294	93%	1,302	93%	1,302	93%	1,302	93%	1,302	93%
		4	790	715	90%	724	92%	724	92%	724	92%	724	92%
		5	404	391	97%	391	97%	391	97%	391	97%	391	97%
		6	166	134	80%	137	83%	137	83%	137	83%	137	83%
		7	247	9	4%	10	4%	10	4%	10	4%	10	4%
		Total	11,709	10,557	90%	10,597	91%	10,597	91%	10,597	91%	10,597	91%

Table 31. Length and proportion of REC2 segments achieving each visual clarity attribute band summarized by FMU and stream order for SC2

SC2				Length of REC2 segments achieving NPS-FM attribute band									
Attribute Band	FMU	Stream Order	Total Length (km)	2021		2040		2060		2080		2100	
				km	%	km	%	km	%	km	%	km	%
Band A	Kai Iwi	1	262	102	39%	128	49%	141	54%	164	62%	186	71%
		2	146	58	39%	71	48%	85	58%	106	72%	116	79%
		3	68	23	34%	26	38%	28	41%	45	66%	56	83%
		4	59	29	49%	40	68%	45	77%	50	85%	53	91%
		5	22	-	0%	3	12%	5	24%	5	24%	11	50%
		Total	558	212	38%	267	48%	305	55%	370	66%	423	76%
	Manawatū	1	4,825	1,203	25%	1,414	29%	1,802	37%	2,236	46%	2,558	53%
		2	2,484	561	23%	666	27%	848	34%	1,084	44%	1,310	53%
		3	1,261	257	20%	307	24%	399	32%	538	43%	678	54%
		4	651	75	12%	114	18%	206	32%	276	42%	338	52%
		5	439	73	17%	76	17%	98	22%	139	32%	214	49%
		6	162	5	3%	5	3%	25	16%	101	62%	139	85%
		7	119	-	0%	-	0%	4	4%	42	35%	42	35%
		Total	9,941	2,173	22%	2,582	26%	3,383	34%	4,416	44%	5,278	53%
	Puketoi ki Tai	1	875	202	23%	334	38%	497	57%	639	73%	700	80%
		2	435	84	19%	136	31%	218	50%	297	68%	348	80%
		3	259	39	15%	71	27%	110	42%	166	64%	213	82%
		4	139	13	9%	15	11%	31	22%	61	44%	114	82%
		5	71	-	0%	-	0%	1	1%	29	41%	44	63%
		6	46	-	0%	-	0%	-	0%	-	0%	22	48%
		Total	1,825	339	19%	556	30%	856	47%	1,192	65%	1,442	79%

SC2				Length of REC2 segments achieving NPS-FM attribute band									
Attribute Band	FMU	Stream Order	Total Length (km)	2021		2040		2060		2080		2100	
				km	%	km	%	km	%	km	%	km	%
Band A (cont.)	Rangitīkei-Turakina	1	4,349	1,241	29%	1,550	36%	2,077	48%	2,487	57%	2,742	63%
		2	2,111	592	28%	757	36%	997	47%	1,205	57%	1,355	64%
		3	1,035	289	28%	362	35%	507	49%	648	63%	712	69%
		4	480	207	43%	245	51%	316	66%	383	80%	404	84%
		5	293	127	43%	133	45%	133	45%	208	71%	243	83%
		6	156	19	12%	36	23%	57	36%	91	59%	104	66%
		7	139	-	0%	-	0%	-	0%	74	54%	122	88%
		Total	8,563	2,476	29%	3,082	36%	4,087	48%	5,098	60%	5,682	66%
	Waiopehu	1	322	69	21%	72	22%	72	22%	73	23%	77	24%
		2	161	25	15%	25	16%	25	16%	26	16%	35	21%
		3	92	27	29%	28	30%	28	30%	28	30%	28	30%
		4	38	19	50%	19	50%	19	50%	19	50%	20	52%
		5	34	19	57%	22	66%	23	68%	23	68%	23	68%
		Total	647	159	25%	167	26%	168	26%	169	26%	183	28%
	Whangaehu	1	1,682	588	35%	856	51%	1,041	62%	1,178	70%	1,244	74%
		2	892	326	37%	473	53%	572	64%	647	73%	671	75%
		3	409	171	42%	228	56%	272	67%	307	75%	316	77%
		4	223	50	22%	106	48%	130	58%	149	67%	168	75%
		5	126	42	33%	56	44%	62	49%	107	85%	107	85%
		6	145	-	0%	-	0%	-	0%	27	19%	135	93%
		Total	3,478	1,177	34%	1,718	49%	2,078	60%	2,414	69%	2,641	76%

SC2				Length of REC2 segments achieving NPS-FM attribute band									
Attribute Band	FMU	Stream Order	Total Length (km)	2021		2040		2060		2080		2100	
				km	%	km	%	km	%	km	%	km	%
Band A (cont.)	Whanganui	1	5,833	3,816	65%	4,077	70%	4,364	75%	4,669	80%	4,911	84%
		2	2,871	1,918	67%	2,032	71%	2,172	76%	2,345	82%	2,489	87%
		3	1,397	972	70%	1,032	74%	1,091	78%	1,156	83%	1,239	89%
		4	790	512	65%	556	70%	590	75%	635	80%	717	91%
		5	404	332	82%	341	85%	350	87%	372	92%	389	96%
		6	166	28	17%	34	21%	67	40%	84	50%	136	82%
		7	247	-	0%	-	0%	-	0%	-	0%	13	5%
		Total	11,709	7,579	65%	8,073	69%	8,634	74%	9,260	79%	9,895	85%
Band B	Kai Iwi	1	262	195	74%	206	79%	215	82%	221	84%	228	87%
		2	146	116	79%	126	86%	129	88%	130	89%	135	92%
		3	68	50	74%	57	83%	58	85%	61	90%	63	92%
		4	59	51	87%	51	87%	52	89%	57	96%	59	99%
		5	22	5	24%	5	24%	11	50%	19	85%	22	100%
		Total	558	418	75%	446	80%	465	83%	488	87%	506	91%
	Manawatū	1	4,825	2,185	45%	2,451	51%	2,810	58%	3,056	63%	3,254	67%
		2	2,484	1,076	43%	1,203	48%	1,379	56%	1,524	61%	1,657	67%
		3	1,261	529	42%	591	47%	666	53%	779	62%	859	68%
		4	651	210	32%	234	36%	310	48%	359	55%	434	67%
		5	439	159	36%	180	41%	201	46%	243	55%	302	69%
		6	162	15	9%	40	25%	99	61%	107	66%	146	90%
		7	119	4	4%	18	15%	42	35%	42	35%	42	35%
		Total	9,941	4,179	42%	4,717	47%	5,508	55%	6,110	61%	6,693	67%

SC2				Length of REC2 segments achieving NPS-FM attribute band									
Attribute Band	FMU	Stream Order	Total Length (km)	2021		2040		2060		2080		2100	
				km	%	km	%	km	%	km	%	km	%
Band B (cont.)	Puketoi ki Tai	1	875	401	46%	569	65%	676	77%	730	83%	762	87%
		2	435	156	36%	247	57%	314	72%	359	83%	383	88%
		3	259	89	34%	116	45%	166	64%	210	81%	231	89%
		4	139	25	18%	46	33%	72	52%	111	79%	130	94%
		5	71	-	0%	14	19%	29	41%	42	59%	56	79%
		6	46	-	0%	-	0%	-	0%	22	48%	22	48%
		Total	1,825	671	37%	992	54%	1,257	69%	1,474	81%	1,585	87%
	Rangitīkei-Turakina	1	4,349	2,455	56%	2,807	65%	3,094	71%	3,316	76%	3,484	80%
		2	2,111	1,151	55%	1,300	62%	1,461	69%	1,586	75%	1,667	79%
		3	1,035	571	55%	652	63%	737	71%	802	78%	832	80%
		4	480	319	66%	350	73%	386	80%	423	88%	430	89%
		5	293	179	61%	203	69%	246	84%	263	90%	285	97%
		6	156	36	23%	57	36%	91	59%	104	66%	114	73%
		7	139	-	0%	1	1%	71	51%	100	72%	139	100%
		Total	8,563	4,710	55%	5,370	63%	6,086	71%	6,595	77%	6,950	81%
	Waiopehu	1	322	151	47%	153	48%	154	48%	156	48%	158	49%
		2	161	69	43%	71	44%	73	45%	75	47%	82	51%
		3	92	48	53%	48	53%	48	53%	48	53%	52	56%
		4	38	23	61%	26	68%	26	69%	26	69%	26	69%
		5	34	23	68%	23	68%	23	68%	25	74%	25	74%
		Total	647	315	49%	322	50%	324	50%	331	51%	343	53%

SC2				Length of REC2 segments achieving NPS-FM attribute band									
				2021		2040		2060		2080		2100	
Attribute Band	FMU	Stream Order	Total Length (km)	km	%	km	%	km	%	km	%	km	%
Band B (cont.)	Whangaehu	1	1,682	1,258	75%	1,349	80%	1,440	86%	1,487	88%	1,507	90%
		2	892	685	77%	719	81%	764	86%	787	88%	793	89%
		3	409	320	78%	334	82%	362	88%	365	89%	367	90%
		4	223	155	70%	163	73%	181	81%	199	89%	204	91%
		5	126	58	46%	62	49%	107	85%	107	85%	107	85%
		6	145	-	0%	-	0%	9	6%	128	88%	139	96%
		Total	3,478	2,476	71%	2,627	76%	2,862	82%	3,073	88%	3,116	90%
	Whanganui	1	5,833	4,742	81%	4,879	84%	5,103	87%	5,295	91%	5,432	93%
		2	2,871	2,366	82%	2,434	85%	2,566	89%	2,662	93%	2,735	95%
		3	1,397	1,154	83%	1,203	86%	1,257	90%	1,319	94%	1,348	97%
		4	790	615	78%	644	82%	686	87%	736	93%	770	97%
		5	404	369	91%	381	94%	391	97%	404	100%	404	100%
		6	166	79	47%	92	56%	125	75%	137	83%	160	97%
		7	247	-	0%	-	0%	1	0%	25	10%	61	25%
		Total	11,709	9,325	80%	9,634	82%	10,128	86%	10,578	90%	10,910	93%
National Bottom line	Kai Iwi	1	262	240	92%	242	92%	243	93%	249	95%	249	95%
		2	146	143	98%	143	98%	143	98%	144	99%	144	99%
		3	68	67	98%	67	99%	67	99%	68	100%	68	100%
		4	59	56	95%	59	99%	59	100%	59	100%	59	100%
		5	22	15	67%	19	85%	22	100%	22	100%	22	100%
		Total	558	521	93%	530	95%	535	96%	542	97%	542	97%

SC2				Length of REC2 segments achieving NPS-FM attribute band									
				2021		2040		2060		2080		2100	
Attribute Band	FMU	Stream Order	Total Length (km)	km	%	km	%	km	%	km	%	km	%
National Bottom line (cont.)	Manawatū	1	4,825	2,969	62%	3,217	67%	3,354	70%	3,494	72%	3,611	75%
		2	2,484	1,491	60%	1,603	65%	1,688	68%	1,767	71%	1,844	74%
		3	1,261	708	56%	777	62%	842	67%	903	72%	954	76%
		4	651	329	51%	363	56%	395	61%	461	71%	512	79%
		5	439	208	47%	223	51%	252	57%	310	71%	350	80%
		6	162	83	51%	101	62%	102	63%	161	99%	162	100%
		7	119	42	35%	42	35%	42	35%	42	35%	42	35%
		Total	9,941	5,829	59%	6,326	64%	6,675	67%	7,138	72%	7,474	75%
	Puketoi ki Tai	1	875	679	78%	738	84%	784	90%	806	92%	822	94%
		2	435	298	69%	345	79%	378	87%	395	91%	403	93%
		3	259	165	63%	187	72%	211	81%	241	93%	250	96%
		4	139	59	43%	100	72%	109	78%	129	93%	139	100%
		5	71	29	41%	29	41%	43	61%	59	84%	71	100%
		6	46	-	0%	22	48%	22	48%	22	48%	46	100%
		Total	1,825	1,231	67%	1,422	78%	1,548	85%	1,652	91%	1,731	95%
	Rangitīkei-Turakina	1	4,349	3,201	74%	3,361	77%	3,498	80%	3,623	83%	3,719	86%
		2	2,111	1,456	69%	1,559	74%	1,650	78%	1,724	82%	1,783	84%
		3	1,035	748	72%	800	77%	840	81%	855	83%	881	85%
		4	480	393	82%	412	86%	447	93%	450	94%	457	95%
		5	293	236	80%	247	84%	263	90%	288	98%	289	99%
		6	156	91	59%	104	66%	104	66%	104	66%	114	73%
		7	139	16	11%	74	54%	100	72%	139	100%	139	100%
		Total	8,563	6,140	72%	6,557	77%	6,902	81%	7,182	84%	7,382	86%

SC2				Length of REC2 segments achieving NPS-FM attribute band									
Attribute Band	**FMU**	**Stream Order**	**Total Length (km)**	**2021**		**2040**		**2060**		**2080**		**2100**	
				km	**%**	**km**	**%**	**km**	**%**	**km**	**%**	**km**	**%**
National Bottom line (cont.)	Waiopehu	1	322	164	51%	170	53%	171	53%	173	54%	173	54%
		2	161	77	48%	82	51%	82	51%	86	53%	87	54%
		3	92	59	64%	59	64%	59	64%	60	65%	60	65%
		4	38	24	62%	30	80%	30	80%	30	80%	31	82%
		5	34	23	68%	25	74%	25	74%	25	74%	25	74%
		Total	647	347	54%	366	56%	366	57%	373	58%	376	58%
	Whangaehu	1	1,682	1,494	89%	1,541	92%	1,572	93%	1,593	95%	1,599	95%
		2	892	797	89%	823	92%	836	94%	841	94%	841	94%
		3	409	372	91%	389	95%	392	96%	394	96%	394	96%
		4	223	175	79%	189	85%	203	91%	205	92%	205	92%
		5	126	77	61%	107	85%	110	87%	110	87%	112	88%
		6	145	-	0%	18	13%	95	65%	140	96%	145	100%
		Total	3,478	2,915	84%	3,069	88%	3,208	92%	3,283	94%	3,296	95%
	Whanganui	1	5,833	5,368	92%	5,460	94%	5,547	95%	5,610	96%	5,658	97%
		2	2,871	2,647	92%	2,708	94%	2,752	96%	2,796	97%	2,816	98%
		3	1,397	1,294	93%	1,324	95%	1,356	97%	1,367	98%	1,378	99%
		4	790	715	90%	744	94%	765	97%	788	100%	788	100%
		5	404	391	97%	403	100%	404	100%	404	100%	404	100%
		6	166	134	80%	137	83%	139	83%	166	100%	166	100%
		7	247	9	4%	13	5%	37	15%	60	24%	140	57%
		Total	11,709	10,557	90%	10,790	92%	11,000	94%	11,190	96%	11,350	97%

Table 32. Length and proportion of REC2 segments achieving each visual clarity attribute band summarized by FMU and stream order for SC3

SC3				Length of REC2 segments achieving NPS-FM attribute band									
Attribute band	FMU	Stream Order	Total Length (km)	2021		2040		2060		2080		2100	
				km	%	km	%	km	%	km	%	km	%
Band A	Kai Iwi	1	262	102	39%	130	50%	158	60%	189	72%	212	81%
		2	146	58	39%	73	50%	98	67%	118	81%	129	88%
		3	68	23	34%	26	38%	39	57%	56	83%	62	90%
		4	59	29	49%	43	73%	48	81%	52	89%	59	99%
		5	22	-	0%	3	12%	5	24%	7	32%	19	85%
			558	212	38%	274	49%	348	62%	423	76%	479	86%
	Manawatū	1	4,825	1,203	25%	1,436	30%	1,923	40%	2,609	54%	3,032	63%
		2	2,484	561	23%	678	27%	927	37%	1,278	51%	1,542	62%
		3	1,261	257	20%	314	25%	432	34%	644	51%	781	62%
		4	651	75	12%	115	18%	229	35%	306	47%	405	62%
		5	439	73	17%	78	18%	113	26%	183	42%	241	55%
		6	162	5	3%	5	3%	28	17%	101	62%	147	90%
		7	119	-	0%	-	0%	5	5%	42	35%	42	35%
			9,941	2,173	22%	2,626	26%	3,657	37%	5,164	52%	6,190	62%
	Puketoi ki Tai	1	875	202	23%	343	39%	531	61%	678	78%	731	84%
		2	435	84	19%	139	32%	233	54%	329	76%	364	84%
		3	259	39	15%	74	28%	116	45%	177	68%	223	86%
		4	139	13	9%	15	11%	39	28%	69	50%	128	92%
		5	71	-	0%	-	0%	2	3%	29	41%	53	74%
		6	46	-	0%	-	0%	-	0%	22	48%	22	48%
			1,825	339	19%	570	31%	921	50%	1,306	72%	1,521	83%

SC3				Length of REC2 segments achieving NPS-FM attribute band									
Attribute band	FMU	Stream Order	Total Length (km)	2021		2040		2060		2080		2100	
				km	%	km	%	km	%	km	%	km	%
Band A (cont.)	Rangitīkei-Turakina	1	4,349	1,241	29%	1,587	36%	2,215	51%	2,768	64%	3,128	72%
		2	2,111	592	28%	766	36%	1,048	50%	1,358	64%	1,510	72%
		3	1,035	289	28%	364	35%	550	53%	710	69%	779	75%
		4	480	207	43%	251	52%	322	67%	403	84%	425	89%
		5	293	127	43%	133	45%	140	48%	217	74%	254	87%
		6	156	19	12%	36	23%	62	39%	104	66%	113	72%
		7	139	-	0%	-	0%	-	0%	93	67%	139	100%
			8,563	2,476	29%	3,136	37%	4,336	51%	5,653	66%	6,348	74%
	Waiopehu	1	322	69	21%	72	22%	75	23%	84	26%	92	28%
		2	161	25	15%	26	16%	26	16%	36	22%	42	26%
		3	92	27	29%	28	30%	28	30%	28	30%	33	36%
		4	38	19	50%	19	50%	19	50%	20	52%	24	64%
		5	34	19	57%	22	66%	23	68%	23	68%	23	68%
			647	159	25%	168	26%	171	26%	191	30%	215	33%
	Whangaehu	1	1,682	588	35%	866	51%	1,115	66%	1,315	78%	1,370	81%
		2	892	326	37%	480	54%	620	69%	697	78%	733	82%
		3	409	171	42%	233	57%	294	72%	331	81%	338	83%
		4	223	50	22%	111	50%	134	60%	170	76%	178	80%
		5	126	42	33%	58	46%	77	61%	107	85%	107	85%
		6	145	-	0%	-	0%	-	0%	72	49%	138	95%
			3,478	1,177	34%	1,748	50%	2,239	64%	2,691	77%	2,864	82%

Attribute band	FMU	Stream Order	Total Length (km)	2021 km	2021 %	2040 km	2040 %	2060 km	2060 %	2080 km	2080 %	2100 km	2100 %
	SC3			Length of REC2 segments achieving NPS-FM attribute band									
Band A (cont.)	Whanganui	1	5,833	3,816	65%	4,113	71%	4,501	77%	4,892	84%	5,123	88%
		2	2,871	1,918	67%	2,047	71%	2,237	78%	2,486	87%	2,586	90%
		3	1,397	972	70%	1,037	74%	1,122	80%	1,217	87%	1,272	91%
		4	790	512	65%	559	71%	603	76%	699	88%	751	95%
		5	404	332	82%	341	85%	356	88%	389	96%	389	96%
		6	166	28	17%	37	22%	80	48%	109	65%	139	83%
		7	247	-	0%	-	0%	-	0%	6	2%	49	20%
			11,709	7,579	65%	8,135	69%	8,899	76%	9,797	84%	10,309	88%
Band B	Kai Iwi	1	262	195	74%	209	80%	221	84%	231	88%	236	90%
		2	146	116	79%	126	86%	131	89%	138	94%	140	96%
		3	68	50	74%	57	83%	60	89%	63	92%	68	100%
		4	59	51	87%	51	87%	53	91%	59	99%	59	100%
		5	22	5	24%	6	25%	13	60%	22	98%	22	100%
			558	418	75%	449	80%	479	86%	512	92%	525	94%
	Manawatū	1	4,825	2,185	45%	2,479	51%	2,930	61%	3,254	67%	3,516	73%
		2	2,484	1,076	43%	1,217	49%	1,436	58%	1,649	66%	1,788	72%
		3	1,261	529	42%	595	47%	703	56%	829	66%	935	74%
		4	651	210	32%	252	39%	331	51%	386	59%	508	78%
		5	439	159	36%	181	41%	214	49%	247	56%	342	78%
		6	162	15	9%	44	27%	101	62%	119	73%	162	100%
		7	119	4	4%	19	16%	42	35%	42	35%	42	35%
			9,941	4,179	42%	4,787	48%	5,757	58%	6,526	66%	7,294	73%

SC3				Length of REC2 segments achieving NPS-FM attribute band									
Attribute band	FMU	Stream Order	Total Length (km)	2021		2040		2060		2080		2100	
				km	%	km	%	km	%	km	%	km	%
Band B (cont.)	Puketoi ki Tai	1	875	401	46%	583	67%	698	80%	754	86%	785	90%
		2	435	156	36%	254	58%	332	76%	370	85%	393	90%
		3	259	89	34%	121	47%	177	68%	222	86%	236	91%
		4	139	25	18%	47	34%	81	58%	114	82%	131	94%
		5	71	-	0%	18	26%	29	41%	42	59%	66	93%
		6	46	-	0%	-	0%	22	48%	22	48%	35	76%
			1,825	671	37%	1,023	56%	1,340	73%	1,524	84%	1,646	90%
	Rangitīkei-Turakina	1	4,349	2,455	56%	2,826	65%	3,201	74%	3,483	80%	3,683	85%
		2	2,111	1,151	55%	1,308	62%	1,514	72%	1,659	79%	1,782	84%
		3	1,035	571	55%	654	63%	772	75%	829	80%	880	85%
		4	480	319	66%	354	74%	401	83%	434	90%	453	94%
		5	293	179	61%	206	70%	249	85%	280	96%	285	97%
		6	156	36	23%	57	36%	104	66%	104	66%	114	73%
		7	139	-	0%	1	1%	74	54%	122	88%	139	100%
			8,563	4,710	55%	5,406	63%	6,315	74%	6,910	81%	7,337	86%
	Waiopehu	1	322	151	47%	153	48%	154	48%	157	49%	163	51%
		2	161	69	43%	73	45%	73	45%	78	49%	85	53%
		3	92	48	53%	48	53%	49	53%	52	57%	56	61%
		4	38	23	61%	26	68%	26	69%	26	69%	27	73%
		5	34	23	68%	23	68%	23	68%	25	74%	25	74%
			647	315	49%	323	50%	325	50%	339	52%	357	55%

SC3				Length of REC2 segments achieving NPS-FM attribute band									
Attribute band	FMU	Stream Order	Total Length (km)	2021		2040		2060		2080		2100	
				km	%	km	%	km	%	km	%	km	%
Band B (cont.)	Whangaehu	1	1,682	1,258	75%	1,358	81%	1,467	87%	1,517	90%	1,535	91%
		2	892	685	77%	720	81%	782	88%	801	90%	803	90%
		3	409	320	78%	334	82%	364	89%	366	89%	367	90%
		4	223	155	70%	167	75%	184	83%	204	91%	204	91%
		5	126	58	46%	62	49%	107	85%	107	85%	107	85%
		6	145	-	0%	-	0%	16	11%	139	96%	139	96%
			3,478	2,476	71%	2,641	76%	2,920	84%	3,134	90%	3,155	91%
	Whanganui	1	5,833	4,742	81%	4,908	84%	5,246	90%	5,474	94%	5,545	95%
		2	2,871	2,366	82%	2,445	85%	2,633	92%	2,754	96%	2,774	97%
		3	1,397	1,154	83%	1,208	86%	1,281	92%	1,349	97%	1,363	98%
		4	790	615	78%	653	83%	708	90%	768	97%	782	99%
		5	404	369	91%	381	94%	402	100%	404	100%	404	100%
		6	166	79	47%	97	58%	136	82%	137	83%	166	100%
		7	247	-	0%	-	0%	7	3%	37	15%	105	43%
			11,709	9,325	80%	9,692	83%	10,413	89%	10,923	93%	11,139	95%
National bottom line	Kai Iwi	1	262	240	92%	242	92%	248	94%	249	95%	249	95%
		2	146	143	98%	143	98%	144	99%	144	99%	144	99%
		3	68	67	98%	67	99%	68	100%	68	100%	68	100%
		4	59	56	95%	59	100%	59	100%	59	100%	59	100%
		5	22	15	67%	19	85%	22	100%	22	100%	22	100%
			558	521	93%	530	95%	541	97%	542	97%	542	97%

SC3				Length of REC2 segments achieving NPS-FM attribute band									
Attribute band	FMU	Stream Order	Total Length (km)	2021		2040		2060		2080		2100	
				km	%	km	%	km	%	km	%	km	%
National bottom line (cont.)	Manawatū	1	4,825	2,969	62%	3,231	67%	3,416	71%	3,637	75%	3,883	80%
		2	2,484	1,491	60%	1,606	65%	1,720	69%	1,833	74%	1,953	79%
		3	1,261	708	56%	780	62%	863	68%	945	75%	1,022	81%
		4	651	329	51%	364	56%	404	62%	493	76%	566	87%
		5	439	208	47%	226	51%	263	60%	340	77%	397	91%
		6	162	83	51%	101	62%	122	75%	162	100%	162	100%
		7	119	42	35%	42	35%	42	35%	42	35%	42	35%
			9,941	5,829	59%	6,350	64%	6,828	69%	7,450	75%	8,025	81%
	Puketoi ki Tai	1	875	679	78%	741	85%	799	91%	816	93%	834	95%
		2	435	298	69%	348	80%	382	88%	401	92%	411	94%
		3	259	165	63%	188	73%	220	85%	246	95%	254	98%
		4	139	59	43%	101	72%	111	80%	132	95%	139	100%
		5	71	29	41%	29	41%	46	65%	67	95%	71	100%
		6	46	-	0%	22	48%	22	48%	22	48%	46	100%
			1,825	1,231	67%	1,429	78%	1,580	87%	1,685	92%	1,754	96%
	Rangitīkei-Turakina	1	4,349	3,201	74%	3,382	78%	3,544	81%	3,726	86%	3,832	88%
		2	2,111	1,456	69%	1,573	75%	1,675	79%	1,788	85%	1,838	87%
		3	1,035	748	72%	807	78%	844	82%	885	86%	929	90%
		4	480	393	82%	414	86%	447	93%	453	94%	461	96%
		5	293	236	80%	250	85%	266	91%	288	98%	290	99%
		6	156	91	59%	104	66%	104	66%	107	69%	156	100%
		7	139	16	11%	75	54%	111	80%	139	100%	139	100%
			8,563	6,140	72%	6,603	77%	6,992	82%	7,387	86%	7,645	89%

SC3				Length of REC2 segments achieving NPS-FM attribute band									
Attribute band	FMU	Stream Order	Total Length (km)	2021		2040		2060		2080		2100	
				km	%	km	%	km	%	km	%	km	%
National bottom line (cont.)	Waiopehu	1	322	164	51%	170	53%	171	53%	175	54%	186	58%
		2	161	77	48%	82	51%	82	51%	87	54%	94	58%
		3	92	59	64%	59	64%	59	64%	60	65%	61	67%
		4	38	24	62%	30	80%	30	80%	31	82%	31	82%
		5	34	23	68%	25	74%	25	74%	25	74%	25	74%
			647	347	54%	366	56%	366	57%	377	58%	397	61%
	Whangaehu	1	1,682	1,494	89%	1,547	92%	1,581	94%	1,601	95%	1,605	95%
		2	892	797	89%	824	92%	839	94%	841	94%	843	94%
		3	409	372	91%	390	95%	393	96%	394	96%	396	97%
		4	223	175	79%	189	85%	205	92%	205	92%	205	92%
		5	126	77	61%	107	85%	110	87%	112	88%	112	88%
		6	145	-	0%	20	14%	101	70%	145	100%	145	100%
			3,478	2,915	84%	3,078	88%	3,229	93%	3,298	95%	3,305	95%
	Whanganui	1	5,833	5,368	92%	5,479	94%	5,613	96%	5,669	97%	5,680	97%
		2	2,871	2,647	92%	2,718	95%	2,792	97%	2,817	98%	2,825	98%
		3	1,397	1,294	93%	1,329	95%	1,364	98%	1,376	99%	1,378	99%
		4	790	715	90%	753	95%	769	97%	788	100%	788	100%
		5	404	391	97%	403	100%	404	100%	404	100%	404	100%
		6	166	134	80%	137	83%	155	94%	166	100%	166	100%
		7	247	9	4%	21	8%	37	15%	102	41%	247	100%
			11,709	10,557	90%	10,840	93%	11,135	95%	11,321	97%	11,488	98%

Appendix 2 – Length and proportion of River Environment Classification v2 (REC2) segments achieving each visual clarity attribute band summarized by mid- and late-century for each representative concentration pathway (RCP)

Table 33. Climate change projected length and proportion of REC2 segments achieving each visual clarity attribute band by mid-century for SC1, represented by minimum, median, and maximum results for each RCP

SC1					REC2 segments achieving for each RCP							
Period	Band	Stat	Stream Order	Total length km	RCP2.6		RCP4.5		RCP6.0		RCP8.5	
					km	%	km	%	km	%	km	%
Mid century	Band A	min	1	18,148	5,878	32%	4,785	26%	4,799	26%	4,839	27%
			2	9,101	3,057	34%	2,413	27%	2,433	27%	2,423	27%
			3	4,521	1,545	34%	1,170	26%	1,181	26%	1,155	26%
			4	2,381	801	34%	565	24%	599	25%	541	23%
			5	1,388	434	31%	291	21%	299	22%	252	18%
			6	676	47	7%	18	3%	28	4%	-	0%
			7	505	-	0%	-	0%	-	0%	-	0%
			Total	36,720	11,762	32%	9,241	25%	9,338	25%	9,210	25%
		med	1	18,148	5,225	29%	5,713	31%	5,261	29%	5,265	29%
			2	9,101	2,570	28%	2,796	31%	2,574	28%	2,519	28%
			3	4,521	1,213	27%	1,345	30%	1,227	27%	1,196	26%
			4	2,381	613	26%	621	26%	598	25%	555	23%
			5	1,388	288	21%	277	20%	263	19%	248	18%
			6	676	16	2%	-	0%	-	0%	-	0%
			7	505	-	0%	-	0%	-	0%	-	0%
			Total	36,720	9,925	27%	10,752	29%	9,922	27%	9,784	27%

SC1					REC2 segments achieving for each RCP							
Period	Band	Stat	Stream Order	Total length km	RCP2.6		RCP4.5		RCP6.0		RCP8.5	
					km	%	km	%	km	%	km	%
Mid century (cont.)	Band A (cont.)	max	1	18,148	4,541	25%	5,153	28%	5,193	29%	4,864	27%
			2	9,101	2,171	24%	2,500	27%	2,533	28%	2,310	25%
			3	4,521	992	22%	1,146	25%	1,189	26%	1,036	23%
			4	2,381	473	20%	509	21%	514	22%	452	19%
			5	1,388	208	15%	228	16%	223	16%	181	13%
			6	676	-	0%	-	0%	-	0%	-	0%
			7	505	-	0%	-	0%	-	0%	-	0%
			Total	36,720	8,385	23%	9,536	26%	9,651	26%	8,843	24%
	Band B	min	1	18,148	6,671	37%	5,218	29%	5,299	29%	5,284	29%
			2	9,101	3,449	38%	2,609	29%	2,683	29%	2,623	29%
			3	4,521	1,714	38%	1,264	28%	1,300	29%	1,249	28%
			4	2,381	882	37%	633	27%	665	28%	595	25%
			5	1,388	464	33%	325	23%	339	24%	272	20%
			6	676	92	14%	31	5%	42	6%	5	1%
			7	505	-	0%	-	0%	-	0%	-	0%
			Total	36,720	13,272	36%	10,079	27%	10,328	28%	10,027	27%
		med	1	18,148	5,789	32%	6,477	36%	5,809	32%	5,859	32%
			2	9,101	2,834	31%	3,097	34%	2,810	31%	2,767	30%
			3	4,521	1,353	30%	1,473	33%	1,343	30%	1,294	29%

SC1					REC2 segments achieving for each RCP							
Period	**Band**	**Stat**	**Stream Order**	**Total length km**	**RCP2.6**		**RCP4.5**		**RCP6.0**		**RCP8.5**	
					km	**%**	**km**	**%**	**km**	**%**	**km**	**%**
Mid century (cont.)	Band B (cont.)	med (cont.)	4	2,381	658	28%	675	28%	647	27%	615	26%
			5	1,388	330	24%	334	24%	297	21%	291	21%
			6	676	30	4%	6	1%	6	1%	3	0%
			7	505	-	0%	-	0%	-	0%	-	0%
			Total	36,720	10,993	30%	12,062	33%	10,913	30%	10,830	29%
		max	1	18,148	4,879	27%	5,680	31%	5,699	31%	5,287	29%
			2	9,101	2,320	25%	2,705	30%	2,734	30%	2,483	27%
			3	4,521	1,065	24%	1,230	27%	1,278	28%	1,113	25%
			4	2,381	506	21%	546	23%	553	23%	478	20%
			5	1,388	220	16%	234	17%	246	18%	185	13%
			6	676	5	1%	2	0%	5	1%	-	0%
			7	505	-	0%	-	0%	-	0%	-	0%
			Total	36,720	8,994	24%	10,398	28%	10,515	29%	9,547	26%
	National bottom line	min	1	18,148	6,954	38%	5,428	30%	5,451	30%	5,498	30%
			2	9,101	3,594	39%	2,726	30%	2,765	30%	2,721	30%
			3	4,521	1,834	41%	1,312	29%	1,360	30%	1,295	29%
			4	2,381	926	39%	662	28%	690	29%	611	26%
			5	1,388	507	37%	341	25%	353	25%	272	20%
			6	676	117	17%	31	5%	42	6%	5	1%
			7	505	-	0%	-	0%	-	0%	-	0%
			Total	36,720	13,932	38%	10,501	29%	10,661	29%	10,402	28%

SC1					REC2 segments achieving for each RCP							
Period	Band	Stat	Stream Order	Total length km	RCP2.6		RCP4.5		RCP6.0		RCP8.5	
					km	%	km	%	km	%	km	%
Mid century (cont.)	National bottom line	med	1	18,148	5,999	33%	6,692	37%	6,011	33%	6,034	33%
			2	9,101	2,920	32%	3,177	35%	2,881	32%	2,832	31%
			3	4,521	1,405	31%	1,527	34%	1,399	31%	1,335	30%
			4	2,381	674	28%	688	29%	663	28%	627	26%
			5	1,388	346	25%	338	24%	313	23%	294	21%
			6	676	30	4%	11	2%	11	2%	5	1%
			7	505	-	0%	-	0%	-	0%	-	0%
			Total	36,720	11,374	31%	12,433	34%	11,278	31%	11,126	30%
		max	1	18,148	5,022	28%	5,838	32%	5,869	32%	5,449	30%
			2	9,101	2,375	26%	2,758	30%	2,788	31%	2,531	28%
			3	4,521	1,103	24%	1,272	28%	1,308	29%	1,142	25%
			4	2,381	519	22%	561	24%	569	24%	499	21%
			5	1,388	224	16%	235	17%	247	18%	185	13%
			6	676	5	1%	5	1%	5	1%	-	0%
			7	505	-	0%	-	0%	-	0%	-	0%
			Total	36,720	9,248	25%	10,669	29%	10,785	29%	9,806	27%

Table 34. Climate change projected length and proportion of REC2 segments achieving each visual clarity attribute band by late-century for SC1, represented by minimum, median, and maximum results for each RCP

SC1					REC2 segments achieving for each RCP							
					RCP2.6		RCP4.5		RCP6.0		RCP8.5	
Period	Band	Stat	Stream Order	Total length km	km	%	km	%	km	%	km	%
Late century	Band A	min	1	18,148	5,944	33%	6,108	34%	4,782	26%	4,559	25%
			2	9,101	3,085	34%	3,077	34%	2,391	26%	2,202	24%
			3	4,521	1,581	35%	1,463	32%	1,162	26%	991	22%
			4	2,381	865	36%	727	31%	549	23%	407	17%
			5	1,388	517	37%	345	25%	251	18%	182	13%
			6	676	66	10%	31	5%	-	0%	-	0%
			7	505	-	0%	-	0%	-	0%	-	0%
			Total	36,720	12,058	33%	11,751	32%	9,135	25%	8,341	23%
		med	1	18,148	5,444	30%	4,719	26%	5,465	30%	5,136	28%
			2	9,101	2,689	30%	2,321	26%	2,532	28%	2,452	27%
			3	4,521	1,314	29%	1,075	24%	1,148	25%	1,126	25%
			4	2,381	673	28%	506	21%	491	21%	432	18%
			5	1,388	343	25%	215	15%	199	14%	160	12%
			6	676	35	5%	-	0%	-	0%	-	0%
			7	505	-	0%	-	0%	-	0%	-	0%
			Total	36,720	10,499	29%	8,836	24%	9,836	27%	9,306	25%
		max	1	18,148	4,944	27%	5,283	29%	4,273	24%	5,448	30%
			2	9,101	2,405	26%	2,491	27%	1,984	22%	2,528	28%
			3	4,521	1,123	25%	1,163	26%	856	19%	1,108	25%

SC1					REC2 segments achieving for each RCP							
Period	Band	Stat	Stream Order	Total length km	RCP2.6		RCP4.5		RCP6.0		RCP8.5	
					km	%	km	%	km	%	km	%
Late century (cont.)	Band A (cont.)	max (cont.)	4	2,381	549	23%	481	20%	349	15%	426	18%
			5	1,388	243	18%	199	14%	136	10%	173	12%
			6	676	-	0%	-	0%	-	0%	-	0%
			7	505	-	0%	-	0%	-	0%	-	0%
			Total	36,720	9,263	25%	9,618	26%	7,598	21%	9,683	26%
	Band B	min	1	18,148	6,821	38%	6,975	38%	5,351	29%	5,048	28%
			2	9,101	3,553	39%	3,421	38%	2,670	29%	2,419	27%
			3	4,521	1,813	40%	1,621	36%	1,267	28%	1,076	24%
			4	2,381	984	41%	778	33%	603	25%	444	19%
			5	1,388	541	39%	382	28%	260	19%	185	13%
			6	676	109	16%	54	8%	5	1%	-	0%
			7	505	-	0%	-	0%	-	0%	-	0%
			Total	36,720	13,822	38%	13,232	36%	10,155	28%	9,172	25%
		med	1	18,148	6,163	34%	5,136	28%	6,021	33%	5,639	31%
			2	9,101	3,053	34%	2,522	28%	2,738	30%	2,641	29%
			3	4,521	1,486	33%	1,160	26%	1,226	27%	1,212	27%
			4	2,381	746	31%	551	23%	540	23%	459	19%
			5	1,388	411	30%	240	17%	219	16%	205	15%
			6	676	49	7%	5	1%	-	0%	-	0%
			7	505	-	0%	-	0%	-	0%	-	0%
			Total	36,720	11,908	32%	9,613	26%	10,745	29%	10,156	28%

SC1					REC2 segments achieving for each RCP							
					RCP2.6		RCP4.5		RCP6.0		RCP8.5	
Period	Band	Stat	Stream Order	Total length km	km	%	km	%	km	%	km	%
Late century (cont.)	Band B (cont.)	max	1	18,148	5,318	29%	5,868	32%	4,538	25%	5,820	32%
			2	9,101	2,588	28%	2,729	30%	2,092	23%	2,651	29%
			3	4,521	1,211	27%	1,273	28%	896	20%	1,160	26%
			4	2,381	591	25%	525	22%	359	15%	446	19%
			5	1,388	260	19%	223	16%	142	10%	178	13%
			6	676	5	1%	-	0%	-	0%	-	0%
			7	505	-	0%	-	0%	-	0%	-	0%
			Total	36,720	9,973	27%	10,617	29%	8,026	22%	10,254	28%
	National bottom line	min	1	18,148	7,181	40%	7,223	40%	5,588	31%	5,286	29%
			2	9,101	3,725	41%	3,512	39%	2,769	30%	2,537	28%
			3	4,521	1,969	44%	1,697	38%	1,340	30%	1,128	25%
			4	2,381	1,062	45%	798	34%	624	26%	462	19%
			5	1,388	584	42%	431	31%	265	19%	185	13%
			6	676	143	21%	73	11%	10	1%	-	0%
			7	505	11	2%	-	0%	-	0%	-	0%
			Total	36,720	14,675	40%	13,734	37%	10,596	29%	9,597	26%
		med	1	18,148	6,402	35%	5,305	29%	6,245	34%	5,797	32%
			2	9,101	3,149	35%	2,582	28%	2,811	31%	2,689	30%
			3	4,521	1,545	34%	1,200	27%	1,263	28%	1,241	27%
			4	2,381	777	33%	573	24%	555	23%	468	20%
			5	1,388	429	31%	244	18%	219	16%	205	15%

SC1					REC2 segments achieving for each RCP							
					RCP2.6		RCP4.5		RCP6.0		RCP8.5	
Period	Band	Stat	Stream Order	Total length km	km	%	km	%	km	%	km	%
Late century (cont.)	National bottom line (cont.)	med (cont.)	6	676	67	10%	5	1%	-	0%	-	0%
			7	505	-	0%	-	0%	-	0%	-	0%
			Total	36,720	12,370	34%	9,909	27%	11,094	30%	10,400	28%
		max	1	18,148	5,483	30%	6,014	33%	4,673	26%	5,935	33%
			2	9,101	2,646	29%	2,784	31%	2,128	23%	2,677	29%
			3	4,521	1,260	28%	1,302	29%	913	20%	1,175	26%
			4	2,381	607	26%	535	22%	371	16%	450	19%
			5	1,388	266	19%	223	16%	142	10%	178	13%
			6	676	6	1%	-	0%	-	0%	-	0%
			7	505	-	0%	-	0%	-	0%	-	0%
			Total	36,720	10,268	28%	10,858	30%	8,227	22%	10,415	28%

Table 35. Climate change projected length and proportion of REC2 segments achieving each visual clarity attribute band by mid-century for SC2, represented by minimum, median, and maximum results for each RCP

SC2					REC2 segments achieving for each RCP							
					RCP2.6		RCP4.5		RCP6.0		RCP8.5	
Period	Band	Stat	Stream Order	Total length km	km	%	km	%	km	%	km	%
Mid century	Band A	min	1	18,148	6,563	36%	5,162	28%	5,191	29%	5,066	28%
			2	9,101	3,393	37%	2,625	29%	2,658	29%	2,568	28%
			3	4,521	1,724	38%	1,272	28%	1,276	28%	1,204	27%
			4	2,381	914	38%	642	27%	675	28%	592	25%
			5	1,388	550	40%	326	23%	338	24%	267	19%
			6	676	74	11%	43	6%	41	6%	-	0%
			7	505	-	0%	-	0%	-	0%	-	0%
			Total	36,720	13,218	36%	10,069	27%	10,180	28%	9,697	26%
		med	1	18,148	5,618	31%	5,965	33%	5,544	31%	5,452	30%
			2	9,101	2,796	31%	2,942	32%	2,739	30%	2,634	29%
			3	4,521	1,308	29%	1,425	32%	1,312	29%	1,242	27%
			4	2,381	706	30%	671	28%	649	27%	608	26%
			5	1,388	345	25%	312	22%	301	22%	263	19%
			6	676	38	6%	26	4%	32	5%	-	0%
			7	505	-	0%	-	0%	-	0%	-	0%
			Total	36,720	10,812	29%	11,341	31%	10,577	29%	10,198	28%
		max	1	18,148	4,771	26%	5,350	29%	5,372	30%	5,008	28%
			2	9,101	2,326	26%	2,615	29%	2,641	29%	2,393	26%
			3	4,521	1,054	23%	1,188	26%	1,243	28%	1,081	24%

SC2					REC2 segments achieving for each RCP							
					RCP2.6		RCP4.5		RCP6.0		RCP8.5	
Period	Band	Stat	Stream Order	Total length km	km	%	km	%	km	%	km	%
Mid century (cont.)	Band A (cont.)	max (cont.)	4	2,381	505	21%	558	23%	573	24%	499	21%
			5	1,388	224	16%	247	18%	244	18%	191	14%
			6	676	-	0%	-	0%	-	0%	-	0%
			7	505	-	0%	-	0%	-	0%	-	0%
			Total	36,720	8,879	24%	9,958	27%	10,073	27%	9,173	25%
	Band B	min	1	18,148	7,665	42%	5,756	32%	5,854	32%	5,624	31%
			2	9,101	3,942	43%	2,918	32%	3,006	33%	2,819	31%
			3	4,521	1,988	44%	1,423	31%	1,471	33%	1,330	29%
			4	2,381	1,033	43%	729	31%	781	33%	655	27%
			5	1,388	609	44%	366	26%	394	28%	288	21%
			6	676	108	16%	71	11%	67	10%	13	2%
			7	505	-	0%	-	0%	-	0%	-	0%
			Total	36,720	15,344	42%	11,264	31%	11,573	32%	10,729	29%
		med	1	18,148	6,341	35%	6,869	38%	6,237	34%	6,119	34%
			2	9,101	3,144	35%	3,329	37%	3,084	34%	2,930	32%
			3	4,521	1,496	33%	1,569	35%	1,458	32%	1,358	30%
			4	2,381	791	33%	732	31%	715	30%	674	28%
			5	1,388	400	29%	374	27%	350	25%	307	22%
			6	676	64	9%	49	7%	57	8%	5	1%
			7	505	-	0%	-	0%	-	0%	-	0%
			Total	36,720	12,235	33%	12,922	35%	11,900	32%	11,392	31%

SC2					REC2 segments achieving for each RCP							
					RCP2.6		RCP4.5		RCP6.0		RCP8.5	
Period	**Band**	**Stat**	**Stream Order**	**Total length km**	**km**	**%**	**km**	**%**	**km**	**%**	**km**	**%**
Mid century (cont.)	Band B (cont.)	max	1	18,148	5,244	29%	5,935	33%	5,939	33%	5,467	30%
			2	9,101	2,559	28%	2,849	31%	2,875	32%	2,588	28%
			3	4,521	1,163	26%	1,301	29%	1,342	30%	1,167	26%
			4	2,381	555	23%	599	25%	610	26%	522	22%
			5	1,388	239	17%	255	18%	272	20%	196	14%
			6	676	5	1%	5	1%	5	1%	-	0%
			7	505	-	0%	-	0%	-	0%	-	0%
			Total	36,720	9,765	27%	10,944	30%	11,043	30%	9,940	27%
	National bottom line	min	1	18,148	8,150	45%	6,024	33%	6,084	34%	5,862	32%
			2	9,101	4,187	46%	3,055	34%	3,122	34%	2,927	32%
			3	4,521	2,202	49%	1,496	33%	1,567	35%	1,374	30%
			4	2,381	1,129	47%	777	33%	824	35%	678	28%
			5	1,388	709	51%	381	27%	410	30%	304	22%
			6	676	174	26%	90	13%	85	13%	16	2%
			7	505	26	5%	-	0%	-	0%	-	0%
			Total	36,720	16,576	45%	11,822	32%	12,092	33%	11,160	30%
		med	1	18,148	6,608	36%	7,110	39%	6,479	36%	6,317	35%
			2	9,101	3,255	36%	3,425	38%	3,176	35%	3,009	33%
			3	4,521	1,584	35%	1,629	36%	1,522	34%	1,403	31%
			4	2,381	826	35%	760	32%	746	31%	687	29%
			5	1,388	417	30%	389	28%	363	26%	313	23%

SC2					REC2 segments achieving for each RCP							
					RCP2.6		RCP4.5		RCP6.0		RCP8.5	
Period	**Band**	**Stat**	**Stream Order**	**Total length km**	**km**	**%**	**km**	**%**	**km**	**%**	**km**	**%**
Mid century (cont.)	National bottom line (cont.)	med (cont.)	6	676	75	11%	49	7%	57	8%	5	1%
			7	505	-	0%	-	0%	-	0%	-	0%
			Total	36,720	12,764	35%	13,362	36%	12,344	34%	11,734	32%
		max	1	18,148	5,436	30%	6,118	34%	6,133	34%	5,634	31%
			2	9,101	2,632	29%	2,912	32%	2,943	32%	2,641	29%
			3	4,521	1,214	27%	1,352	30%	1,383	31%	1,200	27%
			4	2,381	586	25%	616	26%	628	26%	544	23%
			5	1,388	254	18%	257	19%	276	20%	197	14%
			6	676	6	1%	5	1%	5	1%	0	0%
			7	505	-	0%	-	0%	-	0%	-	0%
			Total	36,720	10,126	28%	11,260	31%	11,369	31%	10,216	28%

Table 36. Climate change projected length and proportion of REC2 segments achieving each visual clarity attribute band by late-century for SC2, represented by minimum, median, and maximum results for each RCP

SC2					REC2 segments achieving for each RCP							
					RCP2.6		RCP4.5		RCP6.0		RCP8.5	
Period	Band	Stat	Stream Order	Total length km	km	%	km	%	km	%	km	%
Late century	Band A	min	1	18,148	11,933	66%	11,484	63%	9,392	52%	7,904	44%
			2	9,101	6,049	66%	5,711	63%	4,659	51%	3,801	42%
			3	4,521	3,077	68%	2,823	62%	2,297	51%	1,802	40%
			4	2,381	1,736	73%	1,548	65%	1,272	53%	851	36%
			5	1,388	990	71%	880	63%	715	52%	493	35%
			6	676	463	69%	263	39%	144	21%	66	10%
			7	505	159	32%	68	13%	1	0%	-	0%
			Total	36,720	24,407	66%	22,779	62%	18,479	50%	14,918	41%
		med	1	18,148	11,109	61%	9,473	52%	9,312	51%	7,786	43%
			2	9,101	5,508	61%	4,675	51%	4,424	49%	3,732	41%
			3	4,521	2,768	61%	2,270	50%	2,103	47%	1,760	39%
			4	2,381	1,553	65%	1,247	52%	1,034	43%	767	32%
			5	1,388	896	65%	700	50%	534	38%	402	29%
			6	676	255	38%	153	23%	90	13%	46	7%
			7	505	84	17%	6	1%	-	0%	-	0%
			Total	36,720	22,173	60%	18,525	50%	17,497	48%	14,492	39%
		max	1	18,148	9,993	55%	9,342	51%	7,560	42%	7,611	42%
			2	9,101	4,891	54%	4,489	49%	3,547	39%	3,543	39%
			3	4,521	2,408	53%	2,152	48%	1,661	37%	1,648	36%

SC2					REC2 segments achieving for each RCP							
					RCP2.6		RCP4.5		RCP6.0		RCP8.5	
Period	**Band**	**Stat**	**Stream Order**	**Total length km**	**km**	**%**	**km**	**%**	**km**	**%**	**km**	**%**
Late century (cont.)	Band A (cont.)	max (cont.)	4	2,381	1,333	56%	1,082	45%	785	33%	691	29%
			5	1,388	755	54%	590	42%	419	30%	362	26%
			6	676	186	27%	89	13%	64	9%	41	6%
			7	505	16	3%	-	0%	-	0%	-	0%
			Total	36,720	19,581	53%	17,744	48%	14,037	38%	13,897	38%
	Band B	min	1	18,148	13,185	73%	12,959	71%	10,675	59%	9,125	50%
			2	9,101	6,751	74%	6,455	71%	5,336	59%	4,414	49%
			3	4,521	3,456	76%	3,224	71%	2,674	59%	2,096	46%
			4	2,381	1,951	82%	1,811	76%	1,524	64%	1,021	43%
			5	1,388	1,093	79%	1,006	72%	864	62%	574	41%
			6	676	544	80%	519	77%	358	53%	102	15%
			7	505	212	42%	164	32%	115	23%	8	2%
			Total	36,720	27,193	74%	26,138	71%	21,546	59%	17,340	47%
		med	1	18,148	12,421	68%	10,591	58%	10,546	58%	8,913	49%
			2	9,101	6,244	69%	5,309	58%	4,984	55%	4,237	47%
			3	4,521	3,165	70%	2,628	58%	2,416	53%	2,009	44%
			4	2,381	1,830	77%	1,487	62%	1,288	54%	861	36%
			5	1,388	1,050	76%	862	62%	690	50%	475	34%
			6	676	516	76%	333	49%	178	26%	53	8%
			7	505	169	33%	117	23%	16	3%	-	0%
			Total	36,720	25,394	69%	21,328	58%	20,117	55%	16,549	45%

SC2					REC2 segments achieving for each RCP							
					RCP2.6		RCP4.5		RCP6.0		RCP8.5	
Period	Band	Stat	Stream Order	Total length km	km	%	km	%	km	%	km	%
Late century (cont.)	Band B (cont.)	max	1	18,148	11,086	61%	10,576	58%	8,585	47%	8,512	47%
			2	9,101	5,519	61%	5,087	56%	4,045	44%	3,910	43%
			3	4,521	2,763	61%	2,497	55%	1,932	43%	1,815	40%
			4	2,381	1,548	65%	1,354	57%	928	39%	772	32%
			5	1,388	902	65%	760	55%	466	34%	387	28%
			6	676	418	62%	202	30%	92	14%	46	7%
			7	505	123	24%	16	3%	-	0%	-	0%
			Total	36,720	22,360	61%	20,491	56%	16,047	44%	15,442	42%
	National bottom line	min	1	18,148	13,820	76%	13,560	75%	11,310	62%	9,827	54%
			2	9,101	7,114	78%	6,776	74%	5,739	63%	4,775	52%
			3	4,521	3,670	81%	3,448	76%	2,954	65%	2,324	51%
			4	2,381	2,067	87%	1,949	82%	1,671	70%	1,215	51%
			5	1,388	1,201	87%	1,113	80%	998	72%	656	47%
			6	676	603	89%	550	81%	523	77%	215	32%
			7	505	428	85%	218	43%	168	33%	71	14%
			Total	36,720	28,901	79%	27,614	75%	23,363	64%	19,083	52%
		med	1	18,148	13,043	72%	11,131	61%	11,228	62%	9,533	53%
			2	9,101	6,557	72%	5,638	62%	5,335	59%	4,502	49%
			3	4,521	3,344	74%	2,865	63%	2,665	59%	2,154	48%
			4	2,381	1,965	83%	1,635	69%	1,421	60%	961	40%
			5	1,388	1,158	83%	973	70%	755	54%	539	39%

SC2					REC2 segments achieving for each RCP							
					RCP2.6		RCP4.5		RCP6.0		RCP8.5	
Period	**Band**	**Stat**	**Stream Order**	**Total length km**	**km**	**%**	**km**	**%**	**km**	**%**	**km**	**%**
Late century (cont.)	National bottom line (cont.)	med (cont.)	6	676	569	84%	517	77%	372	55%	118	17%
			7	505	320	63%	172	34%	90	18%	16	3%
			Total	36,720	26,956	73%	22,931	62%	21,867	60%	17,824	49%
		max	1	18,148	11,623	64%	11,162	62%	9,184	51%	9,031	50%
			2	9,101	5,839	64%	5,439	60%	4,334	48%	4,123	45%
			3	4,521	2,983	66%	2,735	60%	2,115	47%	1,926	43%
			4	2,381	1,680	71%	1,474	62%	1,115	47%	834	35%
			5	1,388	976	70%	839	60%	552	40%	436	31%
			6	676	526	78%	368	54%	167	25%	56	8%
			7	505	189	37%	96	19%	62	12%	-	0%
			Total	36,720	23,816	65%	22,113	60%	17,529	48%	16,405	45%

Table 37. Climate change projected length and proportion of REC2 segments achieving each visual clarity attribute band by mid-century for SC3, represented by minimum, median, and maximum results for each RCP

SC3					REC2 segments achieving for each RCP							
Period	Band	Stat	Stream Order	Total length km	RCP2.6		RCP4.5		RCP6.0		RCP8.5	
					km	%	km	%	km	%	km	%
Mid century	Band A	min	1	18,148	6,613	36%	5,184	29%	5,209	29%	5,074	28%
			2	9,101	3,431	38%	2,647	29%	2,669	29%	2,577	28%
			3	4,521	1,745	39%	1,290	29%	1,299	29%	1,209	27%
			4	2,381	931	39%	659	28%	704	30%	600	25%
			5	1,388	551	40%	341	25%	355	26%	269	19%
			6	676	74	11%	45	7%	42	6%	-	0%
			7	505	-	0%	-	0%	-	0%	-	0%
			Total	36,720	13,346	36%	10,165	28%	10,278	28%	9,728	26%
		med	1	18,148	5,640	31%	5,978	33%	5,559	31%	5,461	30%
			2	9,101	2,813	31%	2,952	32%	2,756	30%	2,639	29%
			3	4,521	1,331	29%	1,434	32%	1,326	29%	1,249	28%
			4	2,381	727	31%	679	29%	661	28%	615	26%
			5	1,388	367	26%	320	23%	310	22%	265	19%
			6	676	43	6%	37	5%	34	5%	-	0%
			7	505	-	0%	-	0%	-	0%	-	0%
			Total	36,720	10,922	30%	11,401	31%	10,648	29%	10,228	28%
		max	1	18,148	4,790	26%	5,358	30%	5,384	30%	5,012	28%
			2	9,101	2,337	26%	2,623	29%	2,653	29%	2,399	26%
			3	4,521	1,065	24%	1,199	27%	1,250	28%	1,085	24%

Period	Band	Stat	Stream Order	Total length km	RCP2.6 km	RCP2.6 %	RCP4.5 km	RCP4.5 %	RCP6.0 km	RCP6.0 %	RCP8.5 km	RCP8.5 %
SC3					REC2 segments achieving for each RCP							
Mid century (cont.)	Band A (cont.)	max (cont.)	4	2,381	510	21%	568	24%	581	24%	506	21%
			5	1,388	236	17%	251	18%	250	18%	191	14%
			6	676	8	1%	-	0%	1	0%	-	0%
			7	505	-	0%	-	0%	-	0%	-	0%
			Total	36,720	8,945	24%	10,000	27%	10,118	28%	9,192	25%
	Band B	min	1	18,148	7,746	43%	5,775	32%	5,878	32%	5,634	31%
			2	9,101	3,993	44%	2,940	32%	3,019	33%	2,835	31%
			3	4,521	2,016	45%	1,442	32%	1,494	33%	1,335	30%
			4	2,381	1,050	44%	749	31%	805	34%	661	28%
			5	1,388	616	44%	385	28%	411	30%	294	21%
			6	676	111	16%	72	11%	68	10%	13	2%
			7	505	-	0%	-	0%	-	0%	-	0%
			Total	36,720	15,533	42%	11,364	31%	11,676	32%	10,772	29%
		med	1	18,148	6,363	35%	6,887	38%	6,258	34%	6,134	34%
			2	9,101	3,166	35%	3,345	37%	3,108	34%	2,941	32%
			3	4,521	1,519	34%	1,579	35%	1,472	33%	1,365	30%
			4	2,381	814	34%	743	31%	726	31%	681	29%
			5	1,388	422	30%	389	28%	360	26%	308	22%
			6	676	67	10%	60	9%	59	9%	5	1%
			7	505	-	0%	-	0%	-	0%	-	0%
			Total	36,720	12,351	34%	13,002	35%	11,983	33%	11,434	31%

SC3					REC2 segments achieving for each RCP							
Period	Band	Stat	Stream Order	Total length km	RCP2.6		RCP4.5		RCP6.0		RCP8.5	
					km	%	km	%	km	%	km	%
Mid century (cont.)	Band B (cont.)	max	1	18,148	5,263	29%	5,949	33%	5,952	33%	5,474	30%
			2	9,101	2,577	28%	2,863	31%	2,884	32%	2,595	29%
			3	4,521	1,182	26%	1,314	29%	1,349	30%	1,169	26%
			4	2,381	561	24%	610	26%	618	26%	529	22%
			5	1,388	255	18%	260	19%	278	20%	197	14%
			6	676	13	2%	5	1%	5	1%	-	0%
			7	505	-	0%	-	0%	-	0%	-	0%
			Total	36,720	9,851	27%	11,001	30%	11,087	30%	9,964	27%
	National bottom line	min	1	18,148	8,248	45%	6,043	33%	6,108	34%	5,875	32%
			2	9,101	4,239	47%	3,078	34%	3,141	35%	2,945	32%
			3	4,521	2,245	50%	1,519	34%	1,597	35%	1,379	30%
			4	2,381	1,150	48%	800	34%	850	36%	688	29%
			5	1,388	737	53%	402	29%	428	31%	312	22%
			6	676	176	26%	93	14%	89	13%	18	3%
			7	505	27	5%	-	0%	-	0%	-	0%
			Total	36,720	16,822	46%	11,934	32%	12,212	33%	11,216	31%
		med	1	18,148	6,639	37%	7,134	39%	6,502	36%	6,334	35%
			2	9,101	3,278	36%	3,440	38%	3,200	35%	3,020	33%
			3	4,521	1,616	36%	1,641	36%	1,538	34%	1,410	31%
			4	2,381	849	36%	770	32%	760	32%	694	29%
			5	1,388	439	32%	404	29%	373	27%	322	23%

		SC3			REC2 segments achieving for each RCP							
Period	**Band**	**Stat**	**Stream Order**	**Total length km**	**RCP2.6**		**RCP4.5**		**RCP6.0**		**RCP8.5**	
					km	**%**	**km**	**%**	**km**	**%**	**km**	**%**
Mid century (cont.)	National bottom line (cont.)	med (cont.)	6	676	84	12%	60	9%	61	9%	5	1%
			7	505	-	0%	-	0%	-	0%	-	0%
			Total	36,720	12,905	35%	13,448	37%	12,435	34%	11,783	32%
		max	1	18,148	5,458	30%	6,133	34%	6,149	34%	5,642	31%
			2	9,101	2,649	29%	2,926	32%	2,952	32%	2,646	29%
			3	4,521	1,232	27%	1,364	30%	1,391	31%	1,205	27%
			4	2,381	598	25%	626	26%	639	27%	553	23%
			5	1,388	272	20%	264	19%	282	20%	197	14%
			6	676	14	2%	5	1%	6	1%	2	0%
			7	505	-	0%	-	0%	-	0%	-	0%
			Total	36,720	10,223	28%	11,318	31%	11,420	31%	10,245	28%

Table 38. Climate change projected length and proportion of REC2 segments achieving each visual clarity attribute band by late-century for SC3, represented by minimum, median, and maximum results for each RCP

SC3					REC2 segments achieving for each RCP							
					RCP2.6		RCP4.5		RCP6.0		RCP8.5	
Period	Band	Stat	Stream Order	Total length km	km	%	km	%	km	%	km	%
Late century	Band A	min	1	18,148	13,056	72%	12,641	70%	10,390	57%	8,575	47%
			2	9,101	6,698	74%	6,384	70%	5,212	57%	4,210	46%
			3	4,521	3,389	75%	3,181	70%	2,614	58%	2,007	44%
			4	2,381	1,869	79%	1,727	73%	1,464	61%	1,023	43%
			5	1,388	1,040	75%	971	70%	820	59%	601	43%
			6	676	525	78%	441	65%	219	32%	85	13%
			7	505	179	35%	143	28%	21	4%	-	0%
			Total	36,720	26,756	73%	25,487	69%	20,740	56%	16,501	45%
		med	1	18,148	12,373	68%	10,510	58%	10,124	56%	8,354	46%
			2	9,101	6,230	68%	5,256	58%	4,901	54%	4,012	44%
			3	4,521	3,163	70%	2,604	58%	2,360	52%	1,919	42%
			4	2,381	1,770	74%	1,459	61%	1,249	52%	895	38%
			5	1,388	962	69%	803	58%	672	48%	499	36%
			6	676	446	66%	208	31%	123	18%	64	9%
			7	505	149	30%	21	4%	0	0%	-	0%
			Total	36,720	25,093	68%	20,861	57%	19,429	53%	15,743	43%
		max	1	18,148	11,046	61%	10,110	56%	8,089	45%	8,007	44%
			2	9,101	5,486	60%	4,959	54%	3,878	43%	3,774	41%
			3	4,521	2,726	60%	2,429	54%	1,850	41%	1,787	40%

SC3					REC2 segments achieving for each RCP							
Period	Band	Stat	Stream Order	Total length km	RCP2.6 km	RCP2.6 %	RCP4.5 km	RCP4.5 %	RCP6.0 km	RCP6.0 %	RCP8.5 km	RCP8.5 %
Late century (cont.)	Bank A (cont.)	max (cont.)	4	2,381	1,513	64%	1,253	53%	903	38%	779	33%
			5	1,388	879	63%	692	50%	483	35%	468	34%
			6	676	256	38%	133	20%	80	12%	41	6%
			7	505	62	12%	1	0%	-	0%	-	0%
			Total	36,720	21,967	60%	19,576	53%	15,283	42%	14,855	40%
	Band B	min	1	18,148	14,349	79%	14,209	78%	11,914	66%	10,012	55%
			2	9,101	7,353	81%	7,174	79%	6,045	66%	4,908	54%
			3	4,521	3,694	82%	3,606	80%	3,096	68%	2,390	53%
			4	2,381	2,038	86%	1,957	82%	1,774	75%	1,330	56%
			5	1,388	1,133	82%	1,099	79%	1,000	72%	771	56%
			6	676	568	84%	533	79%	460	68%	211	31%
			7	505	357	71%	205	41%	159	32%	23	4%
			Total	36,720	29,492	80%	28,784	78%	24,448	67%	19,644	53%
		med	1	18,148	14,013	77%	12,008	66%	11,591	64%	9,746	54%
			2	9,101	7,079	78%	6,088	67%	5,598	62%	4,662	51%
			3	4,521	3,578	79%	3,067	68%	2,796	62%	2,234	49%
			4	2,381	1,961	82%	1,758	74%	1,555	65%	1,042	44%
			5	1,388	1,118	81%	995	72%	862	62%	596	43%
			6	676	530	78%	451	67%	319	47%	96	14%
			7	505	212	42%	159	32%	91	18%	-	0%
			Total	36,720	28,492	78%	24,526	67%	22,812	62%	18,377	50%

SC3					REC2 segments achieving for each RCP							
					RCP2.6		RCP4.5		RCP6.0		RCP8.5	
Period	Band	Stat	Stream Order	Total length km	km	%	km	%	km	%	km	%
Late century (cont.)	Band B (cont.)	max	1	18,148	12,371	68%	11,660	64%	9,273	51%	9,043	50%
			2	9,101	6,245	69%	5,729	63%	4,458	49%	4,209	46%
			3	4,521	3,182	70%	2,866	63%	2,172	48%	1,997	44%
			4	2,381	1,805	76%	1,568	66%	1,153	48%	899	38%
			5	1,388	1,007	73%	873	63%	614	44%	502	36%
			6	676	464	69%	298	44%	180	27%	50	7%
			7	505	172	34%	88	18%	16	3%	-	0%
			Total	36,720	25,245	69%	23,083	63%	17,866	49%	16,701	45%
	National bottom line	min	1	18,148	14,931	82%	14,984	83%	12,686	70%	10,889	60%
			2	9,101	7,688	84%	7,572	83%	6,494	71%	5,406	59%
			3	4,521	3,918	87%	3,856	85%	3,384	75%	2,704	60%
			4	2,381	2,158	91%	2,098	88%	1,927	81%	1,492	63%
			5	1,388	1,247	90%	1,210	87%	1,093	79%	866	62%
			6	676	634	94%	583	86%	540	80%	445	66%
			7	505	428	85%	417	83%	212	42%	148	29%
			Total	36,720	31,004	84%	30,720	84%	26,336	72%	21,950	60%
		med	1	18,148	14,776	81%	12,694	70%	12,384	68%	10,487	58%
			2	9,101	7,439	82%	6,478	71%	6,049	66%	4,976	55%
			3	4,521	3,776	84%	3,316	73%	3,060	68%	2,459	54%
			4	2,381	2,104	88%	1,916	80%	1,733	73%	1,201	50%
			5	1,388	1,225	88%	1,073	77%	967	70%	702	51%

SC3					REC2 segments achieving for each RCP							
Period	Band	Stat	Stream Order	Total length km	RCP2.6		RCP4.5		RCP6.0		RCP8.5	
					km	%	km	%	km	%	km	%
Late century (cont.)	National bottom line (cont.)	med (cont.)	6	676	600	89%	540	80%	481	71%	216	32%
			7	505	428	85%	212	42%	175	35%	57	11%
			Total	36,720	30,349	83%	26,227	71%	24,848	68%	20,098	55%
		max	1	18,148	13,085	72%	12,366	68%	10,018	55%	9,655	53%
			2	9,101	6,636	73%	6,153	68%	4,871	54%	4,476	49%
			3	4,521	3,386	75%	3,142	69%	2,436	54%	2,147	47%
			4	2,381	1,949	82%	1,736	73%	1,343	56%	970	41%
			5	1,388	1,097	79%	966	70%	701	50%	573	41%
			6	676	551	81%	489	72%	320	47%	105	16%
			7	505	237	47%	175	35%	86	17%	16	3%
			Total	36,720	26,940	73%	25,027	68%	19,774	54%	17,943	49%

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