Climate change impacts on water quality outcomes from the Sustainable Land Use Initiative (SLUI)

horizons regional council

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Contents

Summary

Project

Horizons Regional Council (HRC) has contracted Landcare Research to investigate climate change implications for future sediment yield as it relates to the Sustainable Land Use Initiative (SLUI).

Objectives

Use SedNetNZ to estimate sediment yields for the Horizons Region under four climate scenarios, all of which assume that SLUI continues according to the management scenario #3 of Dymond et al. (2014). Climate scenarios include:

1. No climate change
2. Minor climate change
3. Moderate climate change
4. Major climate change.

Summarise and discuss the relative change in sediment yield by Water Management Zones, and make recommendations regarding the future management of SLUI under climate change.

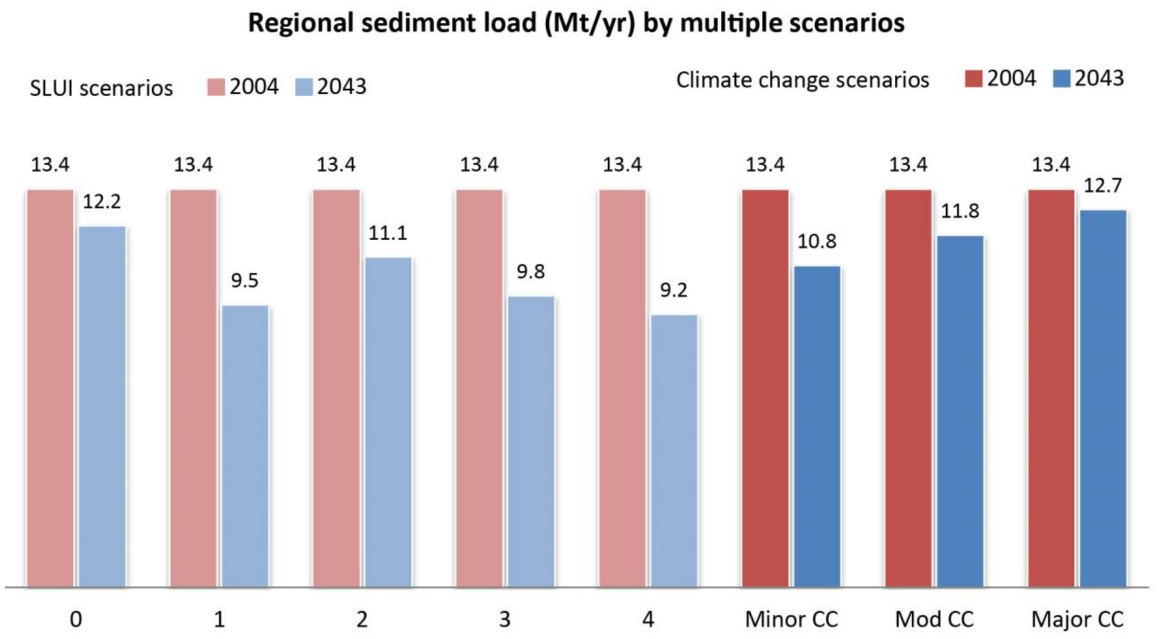
Methods

- Representative climate-change scenarios are drawn from the IPCC 4th assessment, and include A1F1 (major climate change impact) and A1B (moderate impact); and we construct a minor impact scenario as the conceptual transition between A1B and the status quo. Downscaled IPCC 5th assessment results were not available at the time of analysis.
- Impact on future sediment yields are modelled by relating regional temperature change to storm magnitude, then storm magnitude to landslide density (landslides being the most significant source of sediment in most North Island landscapes). A spatial covariate layer of change for each scenario is generated and used to weight the shallow landslide component of SedNetNZ.

Results and conclusions

- Under all scenarios, climate change is projected to increase sediment loading in the Region’s rivers:
  - For the minor impact scenario, regional sediment yield is estimated to increase from the 2043 baseline of 9.81 Mt/yr up to 10.83 Mt/yr (10.4% increase)
  - Under the moderate impact scenario (IPCC 4th assessment A1B), sediment is estimated to increase to 11.85 Mt/yr (20.8% increase)
  - Under the major impact scenario (IPCC 4th assessment A1F1) sediment is estimated to increase to 12.71 Mt/yr (+26.9%).
- The rate of increase varies by Water Management Zone. Increases range from 2 to 15%, 5 to 29%, and 5 to 42% for the minor, moderate, and major impact scenarios respectively.

- Regional sediment yield estimates across all climate change scenarios are still less than 2004 pre-SLUI levels. This is attributed to the level of improvement that would be imparted through the baseline SLUI management scenario (scenario #3).
- Climate change will reduce the long-term effectiveness of SLUI (Fig. A). The level of reduction under SLUI management scenario #3 (no climate change) of 3.6 Mt/yr would decrease to 2.6 Mt/yr, 1.6 Mt/yr, and 0.7 Mt/yr for the minor, moderate, and major impact climate scenarios.
- As an approximation, adopting either SLUI management scenario #1 or #2 will improve long-term sediment reduction under climate change by 1.1–2.9 Mt/yr and 1.5–3.3 Mt/yr, respectively.



SLUI Management scenarios (Dymond et al. 2014)
0. No new WFPs from 2014
1. WFPs@55,000 ha/yr & AGS
2. WFPs @35,000/ha/yr; no AGS; capped afforestration
3. WFPs @35,000/ha/yr; no AGS; uncapped afforestration
4. WFPs@55,000 ha/yr & AGS, for highest priority farms

Climate change scenarios
Minor CC: Minor impact scenario (constructed)
Mod CC: IPCC 4th assessment A1B scenario
Major CC: IPCC 4th assessment A1F1 scenario

Tabulated results

Scenario	Total Soil Erosion (Mt yr^{-1})		Percent change
	2004	*2043*	
0	13.4	12.2	-9%
1	13.4	9.5	-29%
2	13.4	11.1	-17%
3	13.4	9.8	-27%
4	13.4	9.2	-31%
Minor CC	13.4	10.8	-19%
Mod CC	13.4	11.8	-12%
Major CC	13.4	12.7	-5%

Figure A: Comparison of climate change scenarios with SLUI management scenarios (Dymond et al. 2014) using a 2004 as a start date (2004 is used as it predates the mitigating influence of SLUI. While 2004 experienced a major storm event, SedNet is a long-term average model, and annualised results are cumulative averages rather than absolute quantities for any given year). Scenario 3 (9.8 Mt/yr) is the baseline used in this report.

Recommendations

Like the IPCC, we are unable to indicate whether any one emission scenario is more likely than another, and acknowledge that any projective modelling over extended timeframes is fraught with uncertainties. Nevertheless, we have developed what we consider to be a defensible estimate of how sediment yield in the Horizons Region may change according to three climate change scenarios. With this in mind, we make the following suggestions:

- Consider prioritising Water Management Zones that have the highest sediment yield rates **and** the highest rates of increase under climate change. We have provided a ranked list for this purpose.
- Consider adopting one of the more intensive SLUI management scenarios from the Dymond et al. (2014) analysis if the long-term aim is to achieve a meaningful sediment reduction. While scenario #3 used in this report is adequate to keep future sediment yield levels lower than pre-SLUI levels, the magnitude of reduction is much reduced under climate change. If substantial reductions are required, then we recommend that Horizons adopt either SLUI management scenario #1 or #4.
- Consider investing more in the types of works that promote long-term protection from erosion, such as land retirement and natural regeneration. Climate change is a long game, and techniques such as space-planting and afforestation do not have the same degree and assurance of protection over comparable periods.
- Consider revaluating all SLUI management scenarios under the latest IPCC fifth assessment climate change scenarios. These are considerably different from the fourth assessment scenarios used in this report, both in terms of design and the quality of modelling data. Likewise, the fourth assessment scenarios are already out of date.
- Further work is recommended to identify storm magnitude triggers for the Horizons Region. In this report we use a representative value of 150 mm taken from literature, but it is likely that different climate-landscape combinations in the Manawatu-Wanganui will have their own respective trigger levels.

1 Introduction

The Sustainable Land Use Initiative (SLUI) is a regional programme that aims to reduce soil erosion and sediment loss from hill country farms in the Manawatu-Wanganui Region. Over 560 Whole Farm Plans have been developed since 2006 (Mitchell & Cooper 2015), with approximately 80–85% having implemented some on-the-ground works to control or mitigate erosion and sediment losses.

Most of the works implemented as part of a Whole Farm Plan involve the use of woody vegetation types (trees and shrubs) for afforestation, natural reversion, riparian planting, or strategic 'space-planting' of high risk areas such as slopes or gullies. However, full effectiveness is not achieved until the vegetation type reaches maturity, which can be 15 to 20 years for *Populus* spp. and *Pinus radiata* respectively (Douglas et al. 2008). Further, the uptake of Whole Farm Plans is a gradual process, and it may take several decades to achieve widespread implementation of soil conservation works across the Region's most at risk landscapes. Because of these reasons, Horizons Regional Council has commissioned several modelling-based investigations to help estimate the long-term implications of current soil conservation activities and policies:

- Schierlitz et al. (2006) applied the NZ Empirical Erosion Model (NZeem) to a land use change scenario for the Upper Manawatu Catchment. Implementing Whole Farm Plans in priority areas was predicted to reduce sediment loads to the Manawatu River by 47%.
- Douglas et al. (2008) developed the Conservation Planting Effectiveness (CPE) model, and applied it to a case-study farm to produce an estimated sediment reduction of 70% over 20 years.
- Manderson et al. (2012) applied the CPE model to the actual implemented works of 419 SLUI farms. Over a 20-year period, erosion was estimated to reduce by 10% and sediment loading reduced by 13%.
- Dymond et al. (2014) used the SedNetNZ model to predict sediment reduction out to 2043 according to five future SLUI-management scenarios. Annual sediment loads were predicted to reduce by 9–41% over 40 years depending on the scenario.

These studies did not consider the implications of climate change. For the Manawatu-Wanganui, climate is predicted to become 2.1°C warmer by 2090, with related increases in rainfall (~16% more rain) and storminess (MfE 2008). Climate and erosion are closely linked, so there is a strong theoretical argument that increased temperature, rainfall and storminess will lead to increased rates of erosion and sediment yield, although this has yet to demonstrated conclusively (Crozier 2010; Basher et al. 2012; Collins et al. 2012).

The purpose of this study is to examine the implications of climate change on the outcomes of the Sustainable Land Use Initiative. We use downscaled scenarios from the IPCC Fourth Assessment[1], and climate-erosion relationships developed by Schierlitz (2008) and Petro (2013) through a modified version of SedNetNZ.

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[1] IPCC Fifth Assessment scenarios were published in October 2014, but they have yet to be downscaled for NZ at the time of analysis.

2 Objectives

Use SedNetNZ to estimate sediment yields for the Horizons Region under four climate scenarios, all of which assume that SLUI continues according to the management scenario #3 of Dymond et al. (2014)[2]:

1. No climate change
2. Minor climate change
3. Moderate climate change
4. Major climate change.

Summarise and discuss the relative change in sediment yield by Water Management Zones, and make recommendations regarding the future management of SLUI under climate change.

3 Background

3.1 SedNetNZ model description

SedNet is a spatially distributed, time-averaged (decadal to century) model that routes sediment through the river network, based on a relatively simple physical representation of hillslope and channel processes at the reach scale, accounting for losses in water bodies (reservoirs, lakes) and deposition on floodplains.

SedNet was first developed by CSIRO for the National Land and Water Audit of Australia (Prosser et al. 2001). Since this time it has been gradually adapted for NZ conditions, by incorporating landslides, earthflows, large-scale gully erosion, and stream bank erosion types (De Rose & Basher 2011), and through several other developments achieved under the 'Clean Water Productive Land' programme (see Mackay et al. 2011). It has been renamed as SedNetNZ to reflect these differences. Application has involved a diversity of catchments and regions (e.g. Upper Manawatu, Tirimea, Tukituki, Waipa, Kaipara, Ruamahanga, Whangarei, and all of Horizons).

The basic element in this model is the stream link, typically several kilometres or more in length. Each link has an associated catchment area (stream link) that drains overland flow and delivers sediment to that link.

The main outputs from the model are predictions of mean annual suspended sediment loads in each stream link, throughout the tributary network. Because source erosion is spatially linked to sediment loads, it is also possible to examine the proportionate contribution that

[2] SLUI continues "under no AGS funding with the variation to the MPI contract reducing the area to 35 000 ha of new plans per year, and afforestation is not constrained" p. iv.

specific areas of land make to downstream export of sediment. By adjusting input data and model parameters it is possible to simulate river loads for natural conditions (pre-European) and examine the potential consequences of future land use scenarios. If discharge-sediment concentration flow rating curves are known, then mean annual suspended sediment concentrations for indicative discharge events can be back-calculated from predicted loads.

SedNetNZ has three main components (1) an erosion sub-model, (2) a hydrological sub-model, and (3) a sediment-routing sub model of which each sub-model has its own model algorithms. SedNetNZ is a relatively straightforward model to execute and run; however, data preparation and getting the data into the required format before running the model can be time consuming.

A full description of model development and parameterisation for the Horizons Region is provided by Dymond et al. (2014), including calibration results using measured sediment loads from the Horizons freshwater monitoring network. Good agreement was achieved between measured and modelled loads at all sites, except within the Rangitikei Catchment at both Pukeokahu and Mangaweka sites.

3.2 Climate change scenarios

The Intergovernmental Panel on Climate Change (IPCC) was established in 1988, with a purpose to evaluate the most up-to-date scientific, technical, and socioeconomic research on climate change. Approximately every 6 years since 1988, the IPCC has produced an assessment of the state of knowledge regarding climate change. Since 2001 (the third assessment), the IPCC has used *emission scenarios* based on potential changes in population growth, land use, economic development, and other driving forces, to project future climate impact. The design and definition of scenarios has changed between assessments.

3.2.1 IPCC fourth assessment scenarios

The IPCC developed 40 different future emission scenarios as part of the fourth IPCC assessment. These were grouped into four families (A1, A2, B1, B2), with each representing a future with differing levels of human development and greenhouse gas mitigation. There are six illustrative marker scenarios (A1FI, A1B, A1T, A2, B1, and B2) that are broadly representative of each family (Table 1), and are thus often used as the basis for climate change evaluations. Climate change projections for each scenario are typically split into two time periods, 1990–2040 and 1990–2090, assuming that current temperatures are based on present day (1990) data.

Table 1 IPCC fourth assessment illustrative marker scenarios

Family	Economic Growth	Population Growth	Technologies	Group	Technology Specifics
A1	Rapid	Global peak in mid-century	New and efficient, rapid introduction	A1FI	Fossil intensive
				A1T	Non-fossil energy
				A1B	Balanced
A2	Slow	High	Slow change		
B1	Rapid	Global peak in mid-century	n/a		
B2	Intermediate	Intermediate	n/a		

Horizons requested three climate change scenarios be modelled, specifically a 'minimum', 'medium', and 'maximum' scenario. We have interpreted these criteria according to the projected greenhouse gas emissions impacts, whereby A1B represents a moderate impact, and A1F1 represents a major impact (Fig. 1). In principle, B1 could be interpreted as the minor impact scenario. However, B1 is a somewhat Arcadian in that future impacts will actually be lower than today (by postulating a population decline paired with rapid global social, economic, and technological advances). This is not a minor impact but rather an improvement, and we have only limited criteria available to model improvements (e.g. from MfE 2008 we have criteria to model increased storminess from temperature increase, but not the reverse). For these reasons we use the halfway point between the status quo and A1B to represent the minor impact scenario.

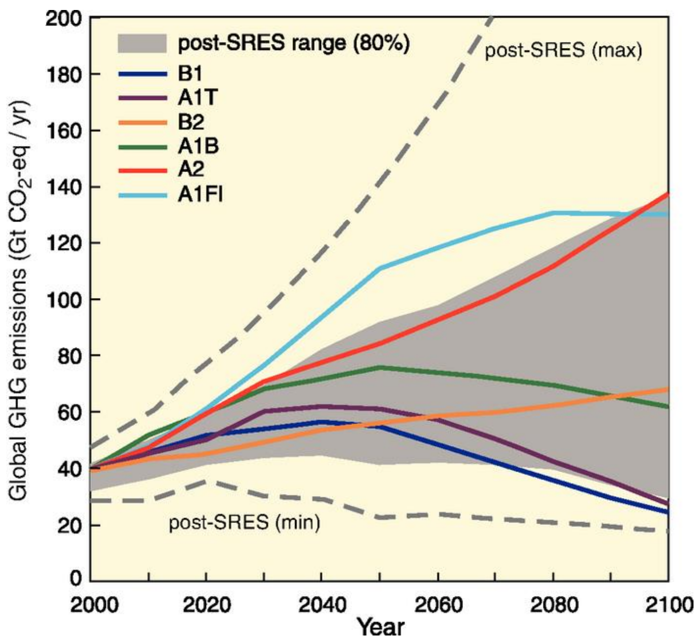


Figure 1 Global GHG emissions (in $GtCO_2$-eq per year) in the absence of additional climate policies (IPCC 2007).

3.2.2 Scenario downscaling

The IPCC assessments are based on global models that need to be downscaled to understand the implications of climate change for New Zealand. The method is described by MfE (2008), whereby historical measurements are used to develop regression equations that relate local climate fluctuations to changes at the global scale. Historical measurements are replaced by modelled changes in the regressions to produce fine-scale projections expressed on a 0.05° grid covering New Zealand. The IPCC time periods were aggregated to 1990 (1980–1999), 2040 (2030–2049), and 2090 (2080–2099), and thus represent 50- and 100-year periods of change. This report uses predictions for the 50 year period of change.

Downscaled variables that are available for sediment yield modelling include temperature and annual rainfall. For the Horizons Region, mean annual temperature change is projected to range from 0.6 to 1.3°C in the first 50 years and from 1.3 to 3.0°C over the 100-year period (Table 2). Annual rainfall is projected to increase by 2–2.5% for the same periods (Table 3). For several regional council areas, different parts of the regions are projected to receive a range of change in rainfall. Rainfall changes for Horizons are reported for Wanganui and Taumarunui meteorological stations, but the geographical extent that these 'local areas' represent is not given (and thus the two individual values cannot be used in this report).

Table 2 Projected Mean Annual Temperature Change (MfE 2008)

Regional Council	Temperature Change (°C)									
	50 year projection					100 year projection				
	B1	B2/A1T	A1B*	A2	A1FI	B1	B2/A1T	A1B	A2	A1FI
Northland	0.6	0.8	0.9	1.1	1.3	1.3	1.7	2.1	2.5	3.0
Auckland	0.6	0.8	0.9	1.1	1.3	1.4	1.8	2.1	2.5	3.0
Waikato	0.6	0.8	0.9	1.1	1.3	1.4	1.8	2.1	2.5	3.0
Bay of Plenty	0.6	0.8	0.9	1.1	1.3	1.4	1.8	2.1	2.5	3.0
Taranaki	0.6	0.8	0.9	1.1	1.3	1.4	1.8	2.1	2.5	3.0
Horizons	0.6	0.8	0.9	1.1	1.3	1.3	1.7	2.1	2.5	3.0
Hawke's Bay	0.6	0.8	0.9	1.1	1.3	1.3	1.7	2.1	2.5	3.0
Gisborne	0.6	0.8	0.9	1.1	1.3	1.4	1.8	2.1	2.5	3.0
Wellington	0.6	0.8	0.9	1.1	1.3	1.3	1.7	2.1	2.5	3.0
Tasman-Nelson	0.6	0.8	0.9	1.1	1.3	1.3	1.7	2.0	2.5	2.9
Marlborough	0.6	0.8	0.9	1.1	1.3	1.3	1.7	2.0	2.5	2.9
West Coast	0.6	0.8	0.9	1.1	1.3	1.3	1.7	2.0	2.4	2.9
Canterbury	0.6	0.8	0.9	1.1	1.3	1.3	1.7	2.0	2.5	2.9
Otago	0.6	0.7	0.9	1.1	1.3	1.3	1.7	2.0	2.4	2.8
Southland	0.6	0.7	0.8	1.1	1.2	1.3	1.6	1.9	2.3	2.8

* A1B range for Horizons is 0.2°C (low), 0.9°C (medium), and 2.2°C (high).

Table 3 Aggregated projected annual rainfall change (MfE 2008)

Regional Council	Rainfall Change (%)	
	50-year projection	100-year projection
Northland	–3.5	–6.5
Auckland	–2	–4
Waikato	0.5	0
Bay of Plenty	–1	–2
Taranaki	2	1
Horizons	2.5	2
Hawke's Bay	–3	–4
Gisborne	–4	–5
Wellington	0.5	0.5
Tasman-Nelson	2	4
Marlborough	1	2
West Coast	5	8
Canterbury	0.6	7
Otago	4.5	8
Southland	4	7

3.2.3 Status of IPCC fifth assessment scenarios

The IPCC released the final synthesis report for its fifth assessment in October 2014. At the time of writing (June 2015), the downscaled results for New Zealand are not yet available. For this reason this report's analysis is based on IPCC fourth assessment scenarios, with an acknowledgement that the results are already likely to be out of date. IPCC fifth assessment scenarios have changed significantly, and the projections made represent the most up-to-date state of knowledge regarding climate change.

3.3 Rainfall vs. storminess

Schierlitz (2008) investigated how climate change might influence future sediment loads in the Manawatu Catchment. Sediment loading was estimated using the NZeem model (Dymond et al. 2010), while the relationship between climate and erosion rate was examined using two methods based on increased mean annual precipitation and increased storminess.

Using mean annual precipitation changes (same as previous Table 3), the change in predicted sediment yield was modest and variable (–2.7 to 3.1% by catchment), leading Schierlitz (2008) to conclude that changes in mean annual rainfall will not dramatically affect mean erosion rate or sediment yields (i.e. rainfall alone is inadequate). Increased storminess on the other hand, resulted in a notable sediment loss across all catchments, and a net 52% increase across the whole catchment (Fig. 2). The storminess method also produced lower levels of error.

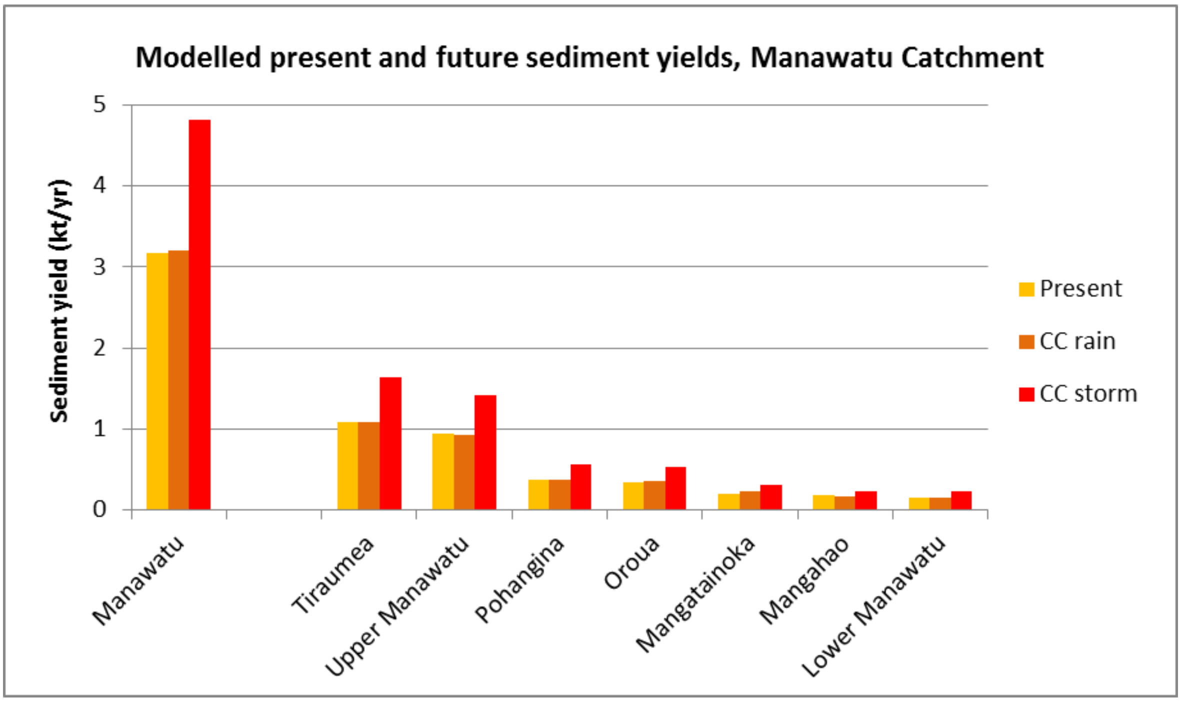


Figure 2 Present and future sediment yield under projected mean annual rainfall (CC rain) and increased storminess (CC storm) for Manawatu Catchment and sub-catchments (Schierlitz 2008).

The increased storminess method was further developed by Petro (2013), and it is this modified version that is used in this report (as outlined in the following sections).

4 Method

4.1 Storm rainfall datasets

Daily rainfall data from meteorological sites from around New Zealand were obtained from the CliFlo database (NIWA 2013) and analysed for continuity and completeness. Datasets with a complete record history of more than 75 years were selected, and an exercise was undertaken to representatively match a core set to Land Environments New Zealand (LENZ; Leathwick et al. 2003). LENZ is a spatial database that integrates climate variability across New Zealand, and is used here as a proxy to help distribute the point datasets.

Rainfall records for a final 50 meteorological sites were analysed using a Python script that isolated storm rainfall according to the definition of Reid and Page (2008). These datasets represent an historical record of storms and their magnitude throughout New Zealand for the past 75 years. They are used here as the starting point for climate change projections regarding erosion.

4.2 Projected change in storm rainfall due to climate change

All climate change scenarios considered in this report involve increased temperature. As temperature increases, the atmosphere is able to hold more water vapour, and will thus have an increased capacity for heavy rainfall. MfE (2008) provide percentage adjustments for estimating the change in heavy rainfall according to each 1°C temperature change attributed to climate change (Table 4).

Table 4 Percentage adjustments to apply to extreme rainfall per 1°C of warming (MfE 2008)

ARI (years) → Duration ↓	**2**	**5**	**10**	**20**	**30**	**50**	**100**
< 10 minutes	8.0	8.0	8.0	8.0	8.0	8.0	8.0
10 minutes	8.0	8.0	8.0	8.0	8.0	8.0	8.0
30 minutes	7.2	7.4	7.6	7.8	8.0	8.0	8.0
1 hour	6.7	7.1	7.4	7.7	8.0	8.0	8.0
2 hours	6.2	6.7	7.2	7.6	8.0	8.0	8.0
3 hours	5.9	6.5	7.0	7.5	8.0	8.0	8.0
6 hours	5.3	6.1	6.8	7.4	8.0	8.0	8.0
12 hours	4.8	5.8	6.5	7.3	8.0	8.0	8.0
24 hours	4.3	5.4	6.3	7.2	8.0	8.0	8.0
48 hours	3.8	5.0	6.1	7.1	7.8	8.0	8.0
72 hours	3.5	4.8	5.9	7.0	7.7	8.0	8.0

Table 4 is too comprehensive for the datasets used in this report. We therefore assume average storm duration of three hours, and use the median value across all storm return intervals (7.8% increase in storm rainfall for every 1°C increase in temperature). This adjustment factor is applied to the projected temperature increases of each climate change scenario (from previous Table 2). For example, a storm rainfall of 180 mm under the A1F1 scenario (1.3°C increase over 50 years) would have a projected change to 198 mm, based on equation 4.1:

$$R_x = R + (\Delta℃_x \times j \times R) \qquad (4.1)$$

Where R is the original storm rainfall, R_x is the new rainfall magnitude under climate change scenario x, $\Delta℃_x$ is the projected temperature increase for climate change scenario x, and j is the extreme rainfall adjustment factor (as a proportion). Equation 4.1 was applied to each storm rainfall dataset for the two climate change scenarios.

4.3 Relating landslide density to storm rainfall magnitude

When considered over long timeframes, landslides account for much of the sediment entering North Island rivers (Schierlitz 2008; Dymond et al. 2013). Reid and Page (2003) measured a temporal sequence of landslides in an East Coast catchment, and correlated landslide density with storm magnitude. They concluded that landslides directly contributed 15±5% of the suspended sediment load in the catchment's river, and that 75% of the sediment production from landslides had occurred during storms with a recurrence less than 27 years.

Reid and Page (2003) defined storm magnitude as "the sum of daily rainfalls during a period bounded by days with less than 10 mm of rain" (p. 76). As part of their study they found a linear relationship of landslide density by storm rainfall (Fig. 3).

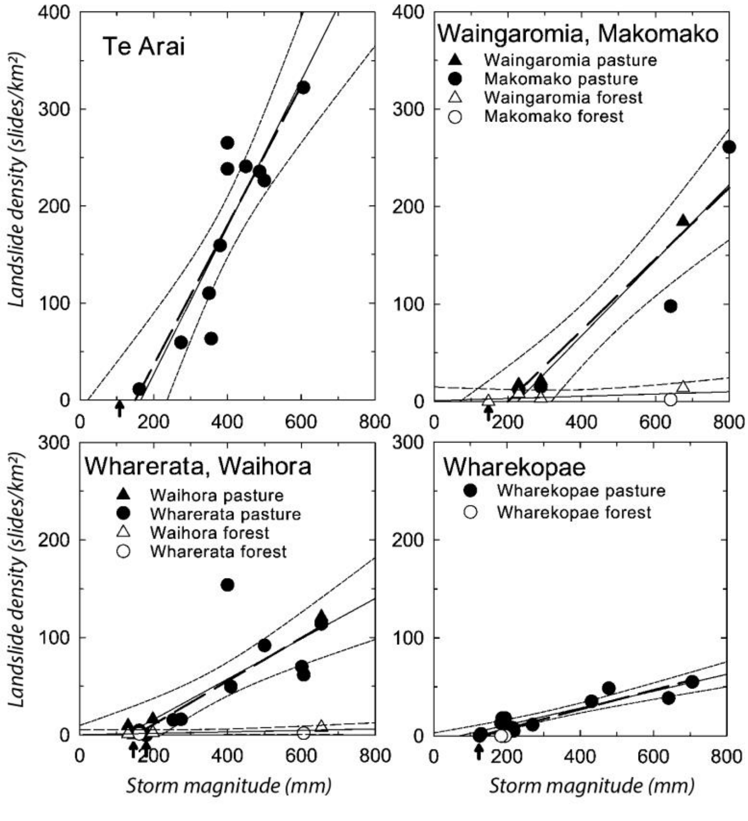


Figure 3 Relationship between landslide density and storminess by six land types within the Waipaoa Catchment (Reid & Page 2008). Arrows on the horizontal axes indicate the storm rainfall thresholds that triggered erosion (with 150 mm being a representative value).

According to Reid and Page's findings, landslide density can be determined by the following formula (Petro 2013):

$$L = mR + b \tag{4.2}$$

Where L is landslide density in slides per km^2, m is the slope of the line, R is the storm rainfall in mm, and b is the y-intercept.

For the landslide-prone land system Te Arai, equation 4.1 can be applied, to solve for slope:

$$m = \frac{\Delta L}{\Delta R} = \frac{400}{(700-150)} = \frac{400}{550} = 0.73 \tag{4.3}$$

Assuming that landslide density (L) is zero when storm rainfall (R) is less than 150 mm, solve for the y-intercept (b):

$$0 = 0.73 \times 150 + b$$
$$b = -109.5 \tag{4.4}$$

The y-intercept (b) is rounded to -110 for subsequent calculations. The equation for landside density by storminess is:

$$L = 0.73R - 110 \tag{4.5}$$

With minor modifications to link climate change scenarios (represented by x):

$$L_x = 0.73R_x - 110 \tag{4.6}$$

In equation 4.4 we use a storm magnitude trigger of 150 mm as a representative value. It is often used as a 'rule of thumb' value in the absence of better data. However, trigger values for landslide erosion are known to vary widely in New Zealand (Basher et al. 2012). Reid and Page (2008) actually identified three trigger values for their six land systems (125 mm, 150 mm, & 200 mm). Page et al. (1994) identified 20 significant erosion-triggering storms in excess of 150 mm (Tutira), while Glade (1998) identified 120 mm as a landslide trigger in the Wairarapa. Few data are available for the Manawatu-Wanganui, although we note that the 2004 storm that resulted in widespread landslides had a storm rainfall of 150 mm or more in parts of the Region.

Equation 4.6 was applied to each of the climate change storm rainfall datasets. Resulting landslide density projections were plotted and fitted with a linear trend (Fig. 4).

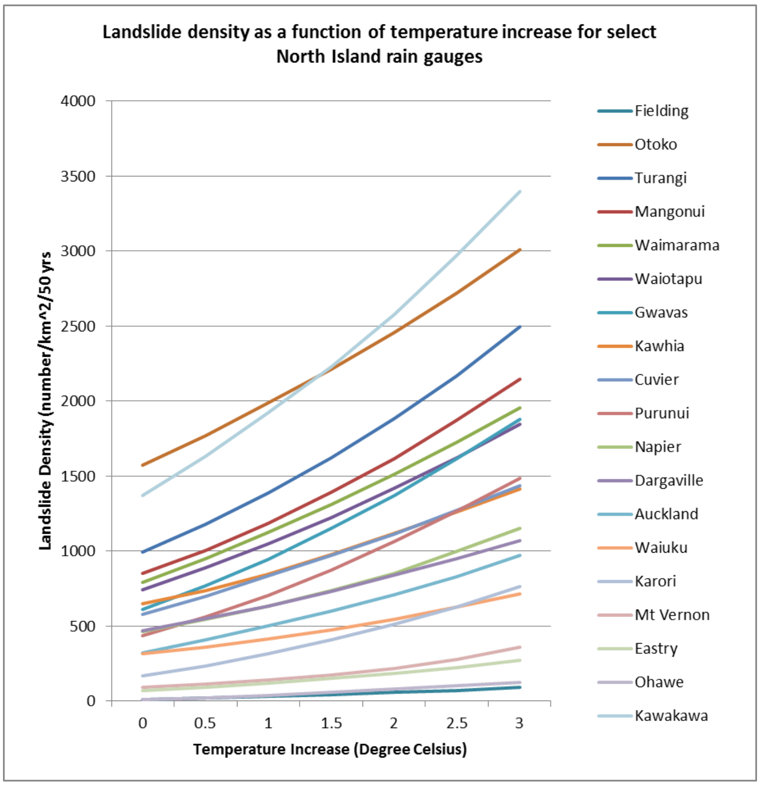


Figure 4 Landslide density as temperature and storminess increase for select North Island meteorological sites. A value of zero on the x axis represents the historical status quo for storms >150 mm magnitude.

Equations from each linear plot were assigned to LENZ environments and multiplied across a reference sediment yield layer for each of the two climate change scenarios. This resulted in the creation of three 'coefficient of change' rasters that were used to update the landslide component of SedNetNZ. Compilation and river networking scripts were then run to make the final projections (in effect we reran the final sub-model in SedNetNZ). Results were aggregated to Horizons Water Management Zones for comparison against the target SLUI management scenario (i.e. Scenario 3 of Dymond et al. 2014).

4.4 Potential refinements

Climate change and erosion involve complex systems that are difficult to predict. While modelling is undertaken with all care according to our current state of knowledge, there will always be the potential for improvement as our understanding improves. Several potential improvements have been identified but were not developed because the method used in this report is applicable only to IPCC fourth assessment climate change scenarios, which have already been superseded by IPCC fifth assessment scenarios.

- We use a storm magnitude trigger of 150 mm as a representative value drawn from Reid and Page (2008). However, such trigger values range widely depending on time- and space-related factors. Further work is required to identify appropriate trigger values for the Horizons Region.

- Storminess was defined on a daily basis. An improved method is the use of pluviographs (or equivalent), which isolate storms from temporally intensive data (or from temporally disaggregated data), as recommended for the calculation of rainfall erosivity (R factor) in the Universal Soil Loss Equation (USLE).
- We used LENZ to spatially distribute the landslide projections. An improved method may be through regression with annual rainfall on an erosion terrain basis, similar to methods used to regionally-relate USLE R factor to annual rainfall.
- We have focused exclusively on modifying the landslide component of SedNetNZ on the basis that landslides make a disproportionately large contribution of sediment to North Island rivers. While contributions from other erosion types may be relatively less, they may be particularly higher for some landscapes and thus have an influence for individual catchments. For example, Nearing et al. (2004) used spatial modelling to predict a 1.7% increase in surficial erosion for every 1% climate-change induced change in annual rainfall for cropping farms in the United States.
- The storminess method used in the analysis is based on storm magnitude. An improved representation of the likely effects of climate change would be expected if storm frequency was also integrated into the model (Schierlitz 2008).

5 Results

5.1 Regional sediment load

Climate change is projected to increase sediment loading in the Region's rivers from a baseline of 9.81 Mt/yr (SLUI scenario #3 of Dymond et al. 2014), up to 10.83 Mt/yr under a climate change with minor impact (+10.4%), 11.85 Mt/yr for the moderate impact scenario (+20.8%), and 12.71 Mt/yr for the major impact scenario (+29.6%). Full results are presented in Appendix 1.

5.2 Water Management Zone sediment loads

Climate change implications vary according to catchment climate and type of erosion terrain (Fig. 5). Under the minor impact scenario, catchments average an 8% increase over baseline loads (SLUI scenario #3[3] of Dymond et al. 2014), although this ranges from as little as 2% (Waitarere, Lake Papitonga, Southern Whanganui Lakes, Northern Manawatu Lakes) through to 15% (Upper Rangitikei). Average percent change increases to 17% and ranges from 5% to 29% under the moderate impact scenario, while under a major impact climate change sediment loads are estimated to average 23% with a range of 5% to 42%.

Catchments with the highest percent increases across all scenarios (ranked from highest to lowest) include the Upper Rangitikei, Middle Whanganui, Middle Rangitikei, Pipiriki, Te Maire, and Upper Whanganui catchments.

However, these catchments are not necessarily the most important from a policy perspective. When sediment generation rate (t/km^2) is ranked against the maximum degree of change (%) under climate change scenario A1F1 (Appendix 2), the five most important catchments include the Upper Whangaehu (2987 t/yr; +29%), Coastal Whangaehu (785 t/yr; +6%), Upper Whanganui (682 t/yr; +35%), Upper Rangitikei (660 t/yr; +42%), and Middle Manawatu (526 t/yr; +30%) catchments.

[3] SLUI scenario #3 is described as: Under no AGS funding with the variation to the MPI contract reducing the area to 35 000 ha of new whole farm plans per year; afforestation is not constrained (Dymond et al. 2014).

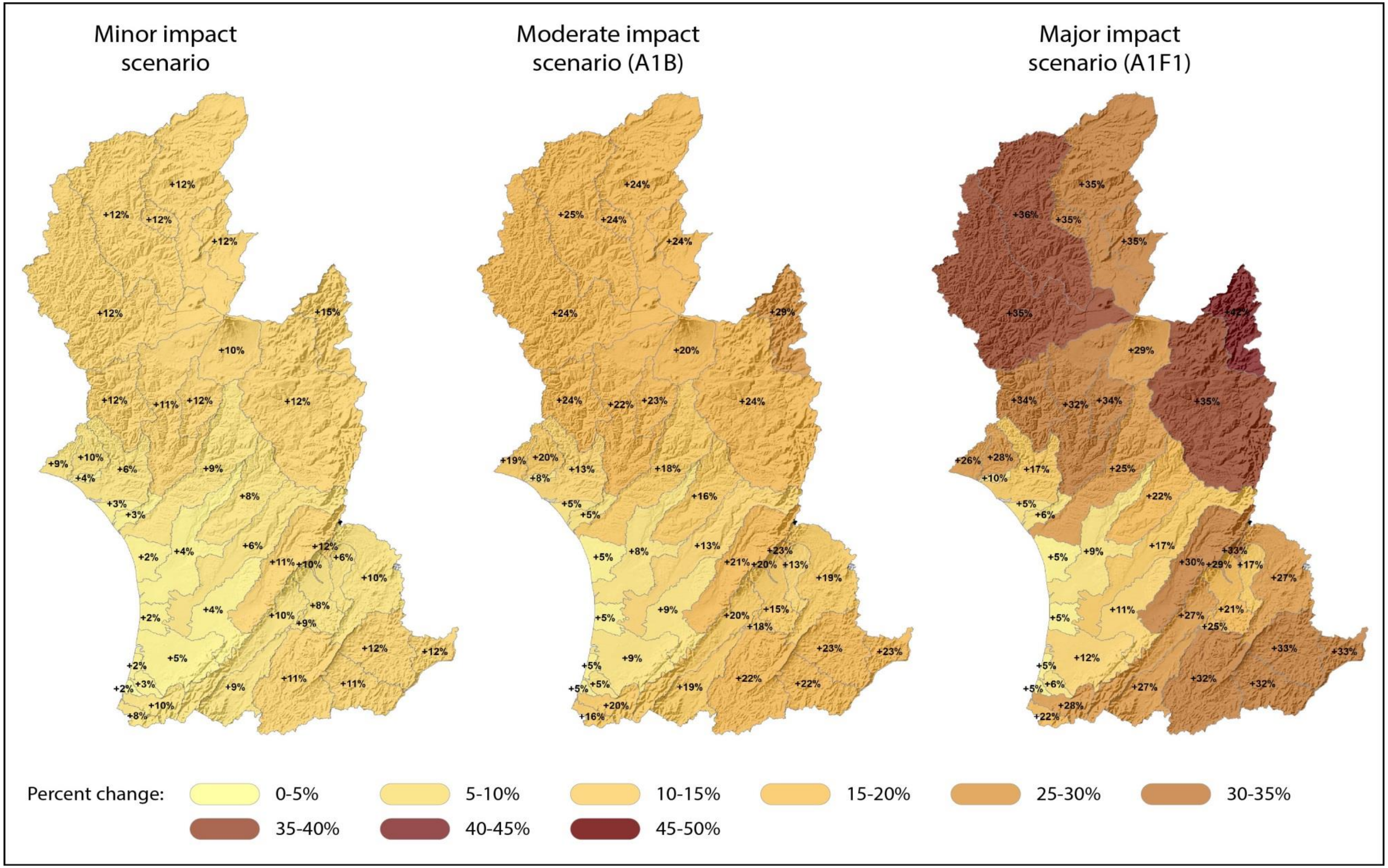
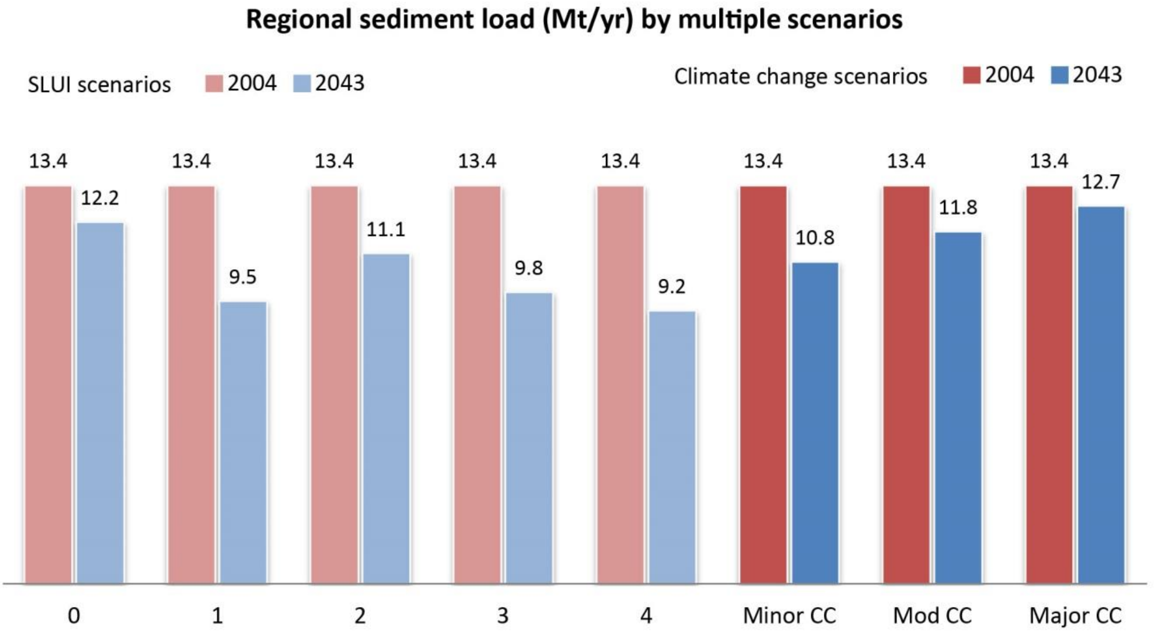


Figure 5 Percent change (%) from baseline of projected sediment yield by water management zone for three climate change scenarios (Dymond et al. 2014, SLUI scenario #3 as the baseline).

5.3 Comparison with Dymond et al. (2014)

Results from each climate change scenario are compared with results by SLUI management scenarios (Fig. 6). Relative to the 2043 baseline (SLUI management scenario #3), sediment yield is projected to increase significantly for each successive climate change scenario. On the positive, sediment levels are still below those prior to SLUI becoming operational (2004), and the upper estimate of 12.7 Mt/yr is much the same as SLUI management scenario #0 (no more WFPs from 2014).



SLUI Management scenarios (Dymond et al. 2014)

0. No new WFPs from 2014
1. WFPs@55,000 ha/yr & AGS
2. WFPs @35,000/ha/yr; no AGS; capped afforestration
3. WFPs @35,000/ha/yr; no AGS; uncapped afforestration
4. WFPs@55,000 ha/yr & AGS, for highest priority farms

Climate change scenarios

Minor CC: Minor impact scenario (constructed)
Mod CC: IPCC 4th assessment A1B scenario
Major CC: IPCC 4th assessment A1F1 scenario

Tabulated results

Scenario	Total Soil Erosion (Mt yr^{-1})		Percent change
	2004	*2043*	
0	13.4	12.2	-9%
1	13.4	9.5	-29%
2	13.4	11.1	-17%
3	13.4	9.8	-27%
4	13.4	9.2	-31%
Minor CC	13.4	10.8	-19%
Mod CC	13.4	11.8	-12%
Major CC	13.4	12.7	-5%

Figure 6 Comparison of climate change scenarios with SLUI management scenarios (Dymond et al. 2014) using 2004 as a reference. Scenario 3 (9.8 Mt/yr) is the baseline used in this report.

On the downside, climate change will have a net negative impact on the rate of SLUI effectiveness (Fig. 7). The previously modelled sediment reduction of 3.6 Mt/yr for SLUI management scenario #3 between 2004 and 2043 (Dymond et al. 2014) reduces to 2.6 Mt/yr under a minor impact climate change scenario; to 1.6 Mt/yr under a moderate impact scenario; and down to a relatively modest 0.7 Mt/yr reduction under a worse case climate change scenario.

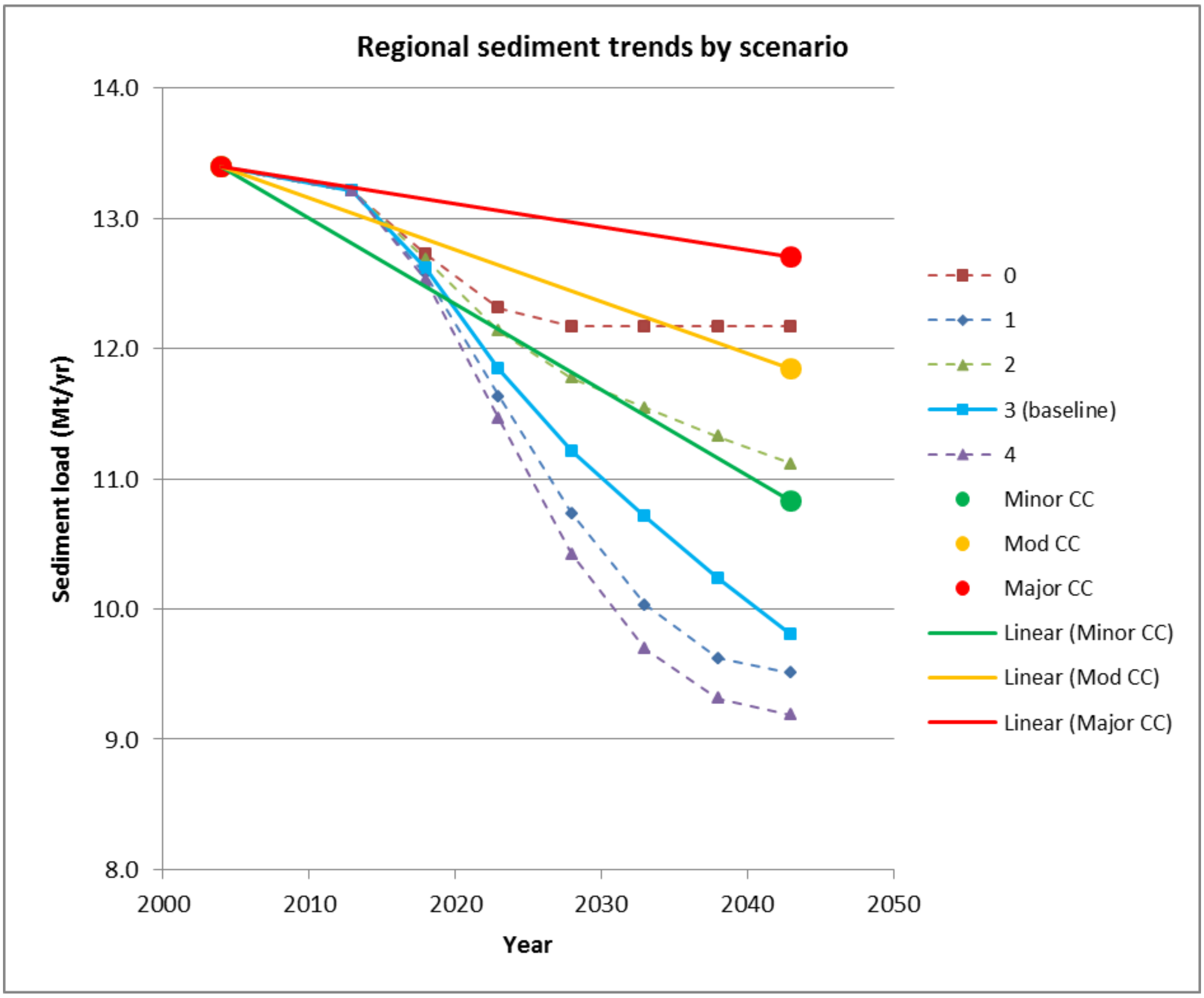


Figure 7 Regional sediment trends by scenario. All trends start at a 2004 pre-SLUI sediment yield estimate of 13.4 Mt/yr (Dymond et al. 2014).

Horizons would need to adopt a more intensive SLUI management scenario (i.e. #1 or #4) if reductions in 2043 need to be greater than 0.7–2.6 Mt/yr (5–19% reduction). As a rough guide based on total percent differences, adopting SLUI management scenario #1 may result in a 1.1–2.9 Mt/yr (8–22%) reduction by 2043, while adopting #4 may result in a 1.5–3.3 Mt/yr (11–24%) reduction. However, both ranges are still below the 3.6 Mt/yr (27%) reduction level previously estimated for SLUI management scenario #3 (without climate change).

6 Conclusions

- Under all scenarios, climate change is projected to increase sediment loading in the region's rivers:
    - For the minor impact scenario, regional sediment yield is estimated to increase from the 2043 baseline of 9.81 Mt/yr up to 10.83 Mt/yr (10.4% increase).
    - Under the moderate impact scenario (IPCC 4th assessment A1B), sediment is estimated to increase to 11.85 Mt/yr (20.8% increase).
    - Under the major impact scenario (IPCC 4th assessment A1F1) sediment is estimated to increase to 12.71 Mt/yr (+26.9%).
- The rate of increase varies by Water Management Zone. Increases range from 2 to 15%, 5 to 29%, and 5 to 42% for the minor, moderate, and major impact scenarios respectively.
- Regional sediment yield estimates across all climate change scenarios are still less than 2004 pre-SLUI levels. This is attributed to the level of improvement that would be imparted through the baseline SLUI management scenario (scenario #3).
- Climate change will reduce the long-term effectiveness of SLUI. The level of reduction under SLUI management scenario #3 (no climate change) of 3.6 Mt/yr would decrease to 2.6 Mt/yr, 1.6 Mt/yr, and 0.7 Mt/yr for the minor, moderate, and major impact climate scenarios.
- As an approximation, adopting either SLUI management scenario #1 or #2 will improve long-term sediment reduction under climate change by 1.1–2.9 Mt/yr and 1.5–3.3 Mt/yr, respectively.

7 Recommendations

Like the IPCC, we are unable to indicate whether any one emission scenario is more likely than another, and that any projective modelling over extended timeframes is fraught with uncertainties. Nevertheless, we have developed what we consider to be a defensible estimate of how sediment yield in the Horizons Region may change according to three climate change scenarios. With this in mind, we make the following suggestions:

- Consider prioritising Water Management Zones that have the highest sediment yield rates **and** the highest rates of increase under climate change. We have provided a ranked list for this purpose.
- Consider adopting one of the more intensive SLUI management scenarios from the Dymond et al. (2014) analysis if the long-term aim is to achieve a meaningful sediment reduction. While scenario #3 used in this report is adequate to keep future sediment yield levels lower than pre-SLUI levels, the magnitude of reduction is much reduced under climate change. If substantial reductions are required, then we recommend that Horizons adopt either SLUI management scenario #1 or #4.
- Consider investing more in the types of works that promote long-term protection from erosion, such as land retirement and natural regeneration. Climate change is a long game, and techniques such as space-planting and afforestation do not have the same degree and assurance of protection over comparable periods.
- Consider revaluating all SLUI management scenarios under the latest IPCC fifth assessment climate change scenarios. These are considerably different than the fourth assessment scenarios used in this report, both in terms of design and the quality of modelling data. Likewise, the fourth assessment scenarios are already out of date.
- Further work is recommended to identify storm magnitude triggers for the Horizons Region. In this report we use a representative value of 150 mm taken from literature, but it is likely that different climate-landscape combinations in the Manawatu-Wanganui will have their own respective trigger levels.

8 Acknowledgements

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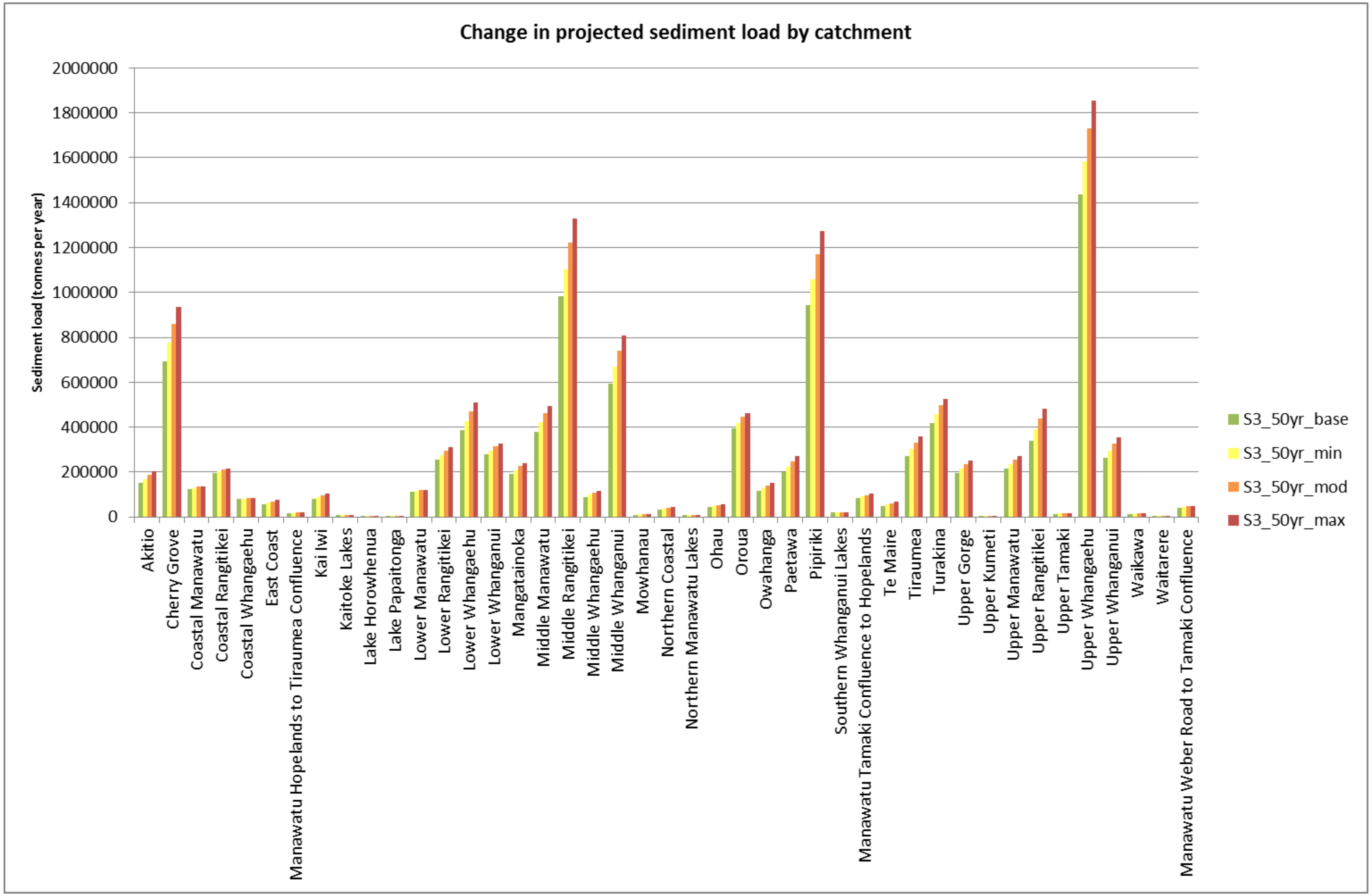
Appendix 1 – Results by Water Management Zone

Management zone	Base sediment yield (tonnes/yr)	50 yr projected sediment yield (tonnes/yr)			Percent change from base yield		
		Minor	Moderate	Major	%Δ_minor	%Δ_moderate	%Δ_major
Akitio	151682	169209	186735	202155	12%	23%	33%
Cherry Grove	694404	777482	860560	933975	12%	24%	35%
Coastal Manawatu	123513	129210	134907	137798	5%	9%	12%
Coastal Rangitikei	195863	203548	211232	214367	4%	8%	9%
Coastal Whangaehu	79221	81349	83477	83649	3%	5%	6%
East Coast	56961	63576	70191	76027	12%	23%	33%
Hopelands – Tiraumea	16750	18231	19711	20903	9%	18%	25%
Kai Iwi	81494	89536	97579	104320	10%	20%	28%
Kaitoke Lakes	8857	9079	9301	9302	3%	5%	5%
Lake Horowhenua	5380	5525	5670	5682	3%	5%	6%
Lake Papitonga	851	872	893	893	2%	5%	5%
Lower Manawatu	110310	115033	119756	121958	4%	9%	11%
Lower Rangitikei	254339	274800	295260	311092	8%	16%	22%
Lower Whangaehu	385087	428146	471205	508695	11%	22%	32%
Lower Whanganui	277463	295475	313488	325923	6%	13%	17%
Mangatainoka	190747	208765	226782	241392	9%	19%	27%
Middle Manawatu	380500	420726	460952	494924	11%	21%	30%
Middle Rangitikei	982788	1103130	1223471	1329283	12%	24%	35%
Middle Whangaehu	88200	98519	108839	117948	12%	23%	34%
Middle Whanganui	595279	668462	741646	806676	12%	25%	36%
Moawhanau	10402	10820	11238	11415	4%	8%	10%
Northern Coastal	34545	37767	40989	43637	9%	19%	26%

Management zone	Base sediment yield (tonnes/yr)	50 yr projected sediment yield (tonnes/yr)			Percent change from base yield		
		Minor	Moderate	Major	%Δ_minor	%Δ_moderate	%Δ_major
Northern Manawatu Lakes	9568	9806	10044	10044	2%	5%	5%
Ohau	43130	47370	51611	55060	10%	20%	28%
Oroua	394918	419946	444975	461702	6%	13%	17%
Owhanga	114408	127082	139756	150774	11%	22%	32%
Paetawa	201238	225247	249256	270562	12%	24%	34%
Pipiriki	943121	1057551	1171981	1273536	12%	24%	35%
Southern Whanganui Lakes	18887	19357	19827	19827	2%	5%	5%
Tamaki – Hopelands	84774	91225	97676	102508	8%	15%	21%
Te Maire	50006	56033	62060	67414	12%	24%	35%
Tiraumea	272118	302115	332113	358150	11%	22%	32%
Turakina	420274	458334	496394	527328	9%	18%	25%
Upper Gorge	197237	216468	235700	251311	10%	20%	27%
Upper Kumeti	2753	3032	3310	3538	10%	20%	29%
Upper Manawatu	215076	235564	256052	273063	10%	19%	27%
Upper Rangitikei	340194	389790	439386	483470	15%	29%	42%
Upper Tamaki	13888	15501	17114	18510	12%	23%	33%
Upper Whangaehu	1438260	1584879	1731498	1853704	10%	20%	29%
Upper Whanganui	264444	296286	328128	356241	12%	24%	35%
Waikawa	13428	14495	15561	16368	8%	16%	22%
Waitarere	2328	2386	2444	2444	2%	5%	5%
Weber – Tamaki	42496	45174	47853	49667	6%	13%	17%
Total	9807182	10826901	11846621	12707235			


Change in projected sediment load by catchment
Sediment load (tonnes per year)
2000000
1800000
1600000
1400000
1200000
1000000
800000
600000
400000
200000
0
Akitio
Cherry Grove
Coastal Manawatu
Coastal Rangitikei
Coastal Whangaehu
East Coast
Manawatu Hopelands to Tiraumea Confluence
Kai Iwi
Kaitoke Lakes
Lake Horowhenua
Lake Papaitonga
Lower Manawatu
Lower Rangitikei
Lower Whangaehu
Lower Whanganui
Mangatainoka
Middle Manawatu
Middle Rangitikei
Middle Whangaehu
Middle Whanganui
Mowhanau
Northern Coastal
Northern Manawatu Lakes
Ohau
Oroua
Owahanga
Paetawa
Pipiriki
Southern Whanganui Lakes
Manawatu Tamaki Confluence to Hopelands
Te Maire
Tiraumea
Turakina
Upper Gorge
Upper Kumeti
Upper Manawatu
Upper Rangitikei
Upper Tamaki
Upper Whangaehu
Upper Whanganui
Waikawa
Waitarere
Manawatu Weber Road to Tamaki Confluence
S3_50yr_base
S3_50yr_min
S3_50yr_mod
S3_50yr_max

Appendix 2 – Catchments ranked by sediment rate and percent change under climate change

Name	Sediment rate (t/km^2)	Max CC change (%)	Rank	Name	Sediment rate (t/km^2)	Max CC change (%)	Rank
Upper Whangaehu	2987	29%	1	Upper Manawatu	299	27%	23
Coastal Whangaehu	785	6%	2	Coastal Rangitikei	297	9%	24
Upper Whanganui	682	35%	3	Northern Coastal	290	26%	25
Upper Rangitikei	660	42%	4	Tiraumea	289	32%	26
Middle Manawatu	526	30%	5	East Coast	285	33%	27
Lower Whanganui	525	17%	6	Middle Whangaehu	280	34%	28
Middle Rangitikei	452	35%	7	Owahanga	267	32%	29
Mangatainoka	441	27%	8	Manawatu Weber to Tamaki	257	17%	30
Turakina	439	25%	9	Akitio	256	33%	31
Oroua	437	17%	10	Manawatu Tamaki to Hopelands	251	21%	32
Lower Rangitikei	433	22%	11	Ohau	228	28%	33
Kai Iwi	425	28%	12	Lower Manawatu	225	11%	34
Upper Tamaki	424	33%	13	Upper Kumeti	222	29%	35
Pipiriki	413	35%	14	Coastal Manawatu	218	12%	36
Cherry Grove	409	35%	15	Waikawa	169	22%	37
Manawatu Hopelands to Tiraumea	403	25%	16	Kaitoke Lakes	127	5%	38
Te Maire	380	35%	17	Southern Whanganui Lakes	97	5%	39
Middle Whanganui	379	36%	18	Lake Horowhenua	77	6%	40
Upper Gorge	375	27%	19	Northern Manawatu Lakes	76	5%	41
Mowhanau	359	10%	20	Waitarere	69	5%	42
Lower Whangaehu	351	32%	21	Lake Papaitonga	38	5%	43
Paetawa	338	34%	22				

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