Modelling suspended sediment loads: Insight into the past and future of the Waipaoa catchment, North Island, New Zealand

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INTRODUCTION

Waipapa Sedimentary System

Deforested and steep hillsopes composed of weak mudstone and argillite lithologies.

Vigorous maritime climate.

One of the highest sediment yields on Earth.

Mean annual suspended sediment yield of 6780 t km^{-2} yr^{-1}, compared with ~1000 tonne km^{-2} yr^{-1} prior to anthropogenic influences.

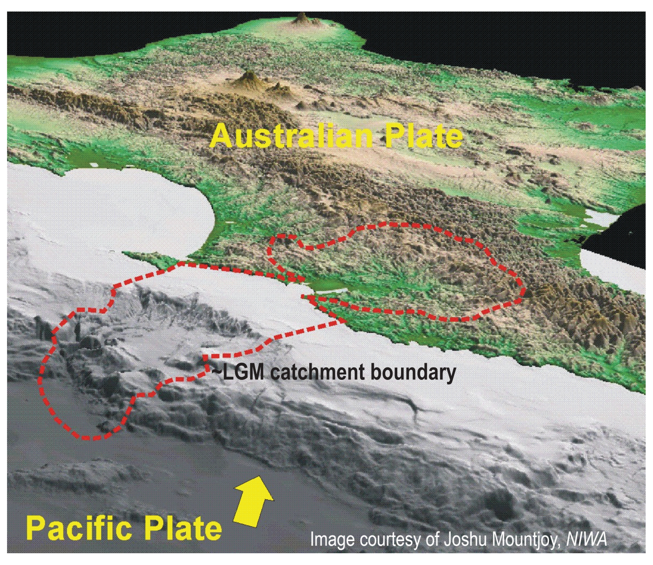
We are using HydroTrend to help us understand:

How the sediment flux has changed through time?
1. From the Last Glacial Maximum to the present day.
2. As a result of deforestation.
3. Has the catchment reached saturation with respect to transporting sediment?

What records can we use to investigate the past climate/sediment signals?

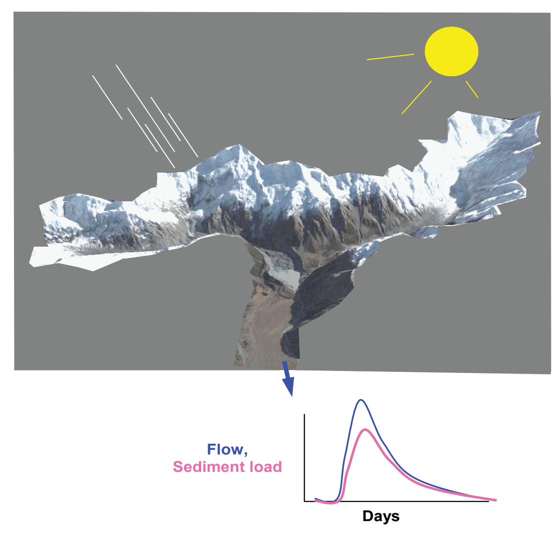
How might the sediment flux change with climate change?

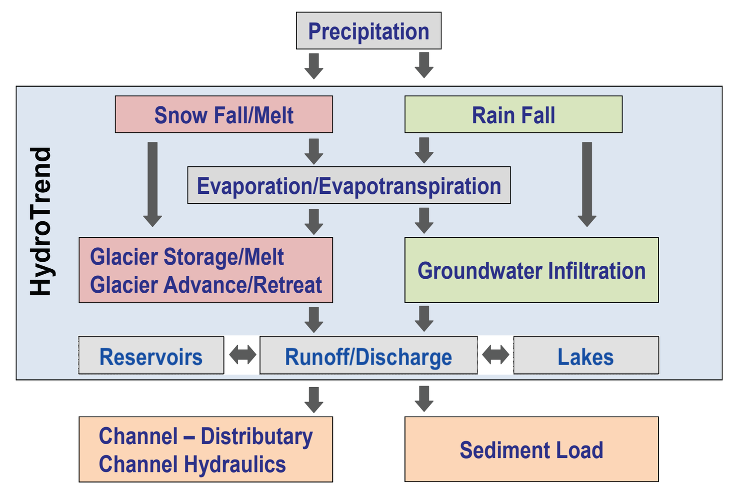
How do events (storms and earthquakes) affect the sediment load?



HYDROTREND

Climate-driven hydrological model (Syviski et al., 1998)

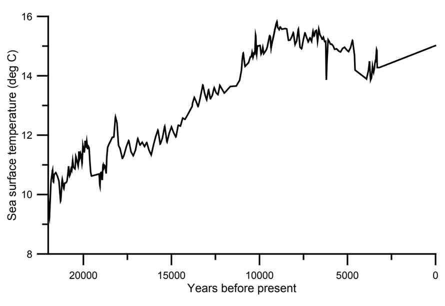




CLIMATE AND EROSION FACTOR INPUT

Sea Surface Temperatures

Calculated from mid-shelf core, MD972121 (Carter et al., 2002)

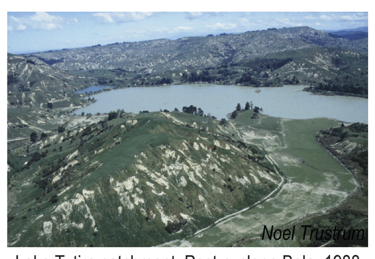


Using a relationship between sea surface temperature (SST), land temperature today and Drost et al.'s (2007) LGM climate model, we use SST as a proxy for temperature and precipitation in the Waipaoa from 22 ka to the present day.

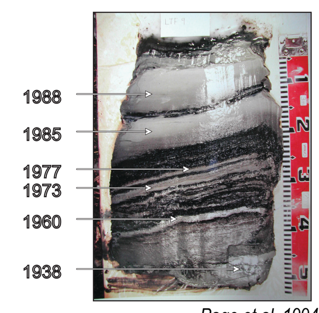
We then test the validity of using SST as a proxy for rainfall by approximating rainfall from storm layers in sediment cores from Lake Tutira (Page et al., 2010). This record goes back almost 7ka.

Lake Tutira Core

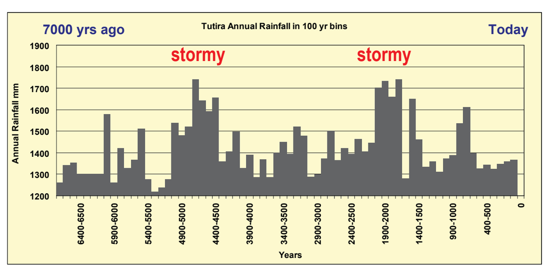
Estimate 100 yearly average rainfall based on the storminess as shown by the thickness and number of storm layers



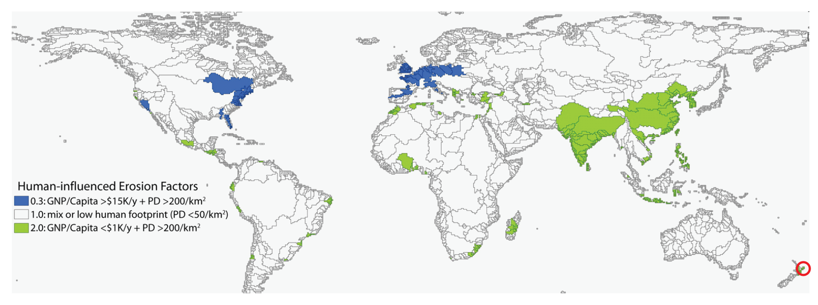
Lake Tutira catchment, Post-cyclone Bola, 1988



Page et al. 1994



Syvitski and Milliman (2007) Human Influenced Erosion Factors



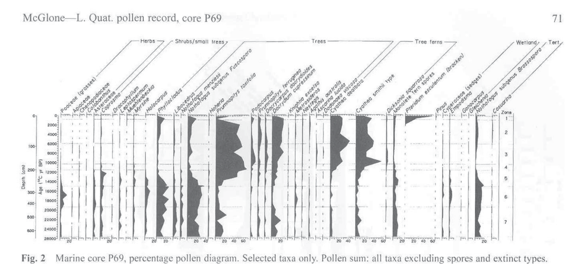
Present day
Waipapa E_h = 8, Sheep farming and forest clearance

Pre-Anthropogenic Influences
Waipapa E_h = 1, nearly 100% forest cover

Last Glacial Maximum
Waipapa E_h ~ 4, grasses and shrubs dominate the landscape. Rivers carry significant bedload

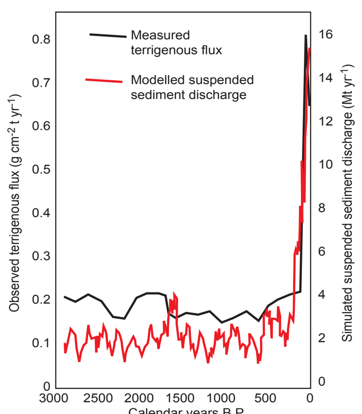
Vegetation/Human Influence Index

Based on % Grass Pollen/% Tree Pollen in core P69 (McGlone 2001)



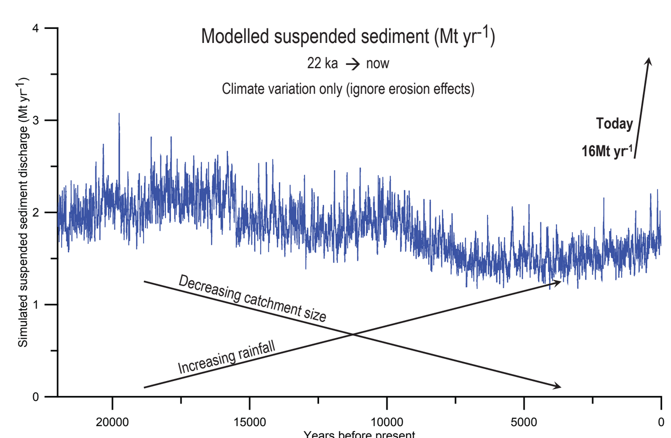
MODEL RESULTS

Previous work - deforestation signal (Kettner et al. 2007)

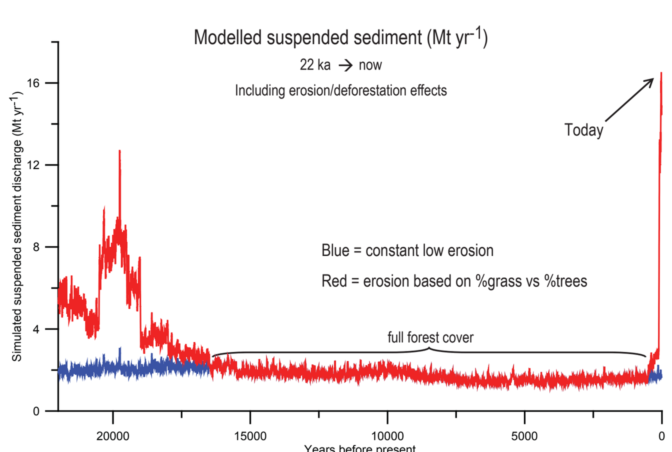


Model from Last Glacial Maximum (LGM, 22ka) to present day

Model #1 - Ignores changes in erosion

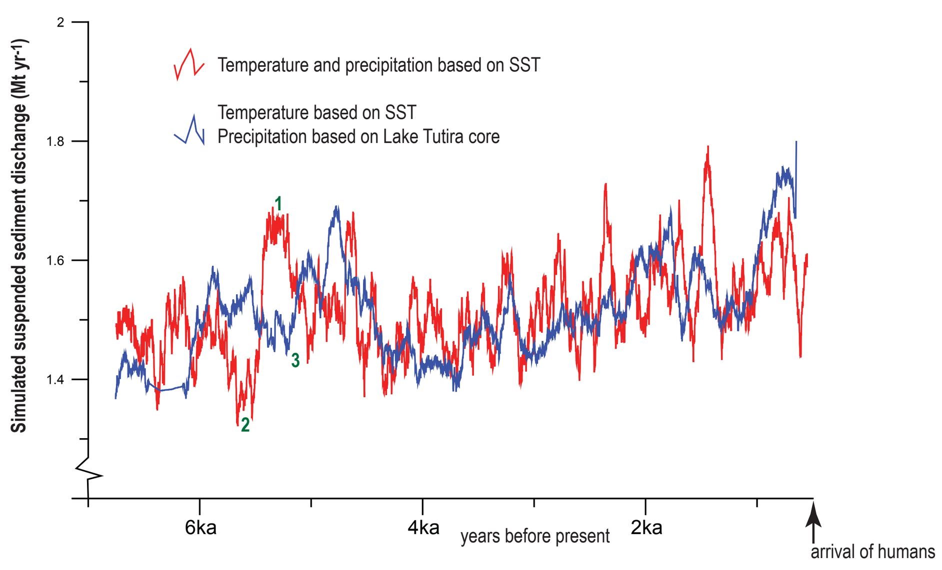


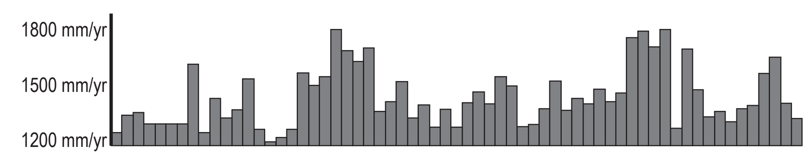
Model #2 - Includes changes in erosion due to changing veggetation cover and deforetion



Precipitation proxies: comparison of SST (red) and Lake Tutira storms (blue)

results shown as 100 year running averages





Esimated rainfall from Lake Tutira in 100 year bins

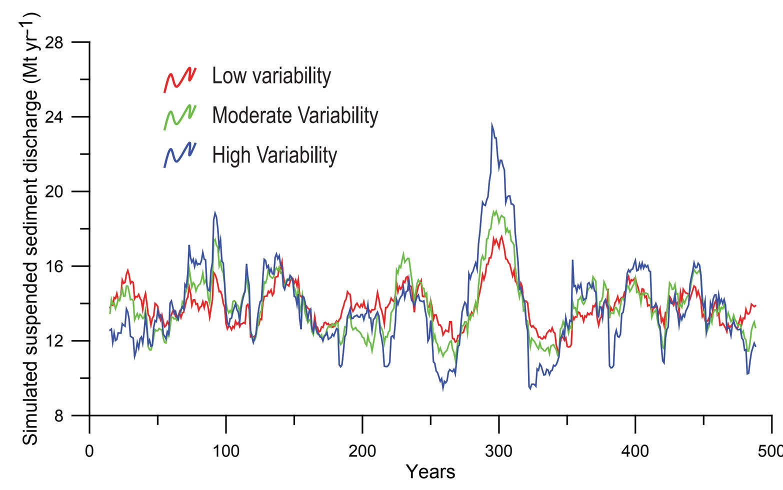
Red = climate is based on the SST, temperature and precipitation
Blue = climate is based on SST (temperature) and Lake Tutira (precipitation)

Peaks in precipitation are matched by peaks in the blue predicted suspended sediment load.

The overall pattern matches the predictions using SST temperature reasonably well. A high in SST at ~5.2ka (**1**) is not matched by storm layers in Lake Tutira or alternatively the lows in the SST (**2**) and Lake Tutira (**3**) are slightly offset from one another. This is possible if one or both of the age models are uncertain at this time.

Much of the variation in the SST model comes from HydroTrend's climate model, which has been run over 500 years for these simulations. We nned to take care not to over interpret these results. Trends are more useful than actual values.

Increasing variability in precipitation, modelled over 500 years

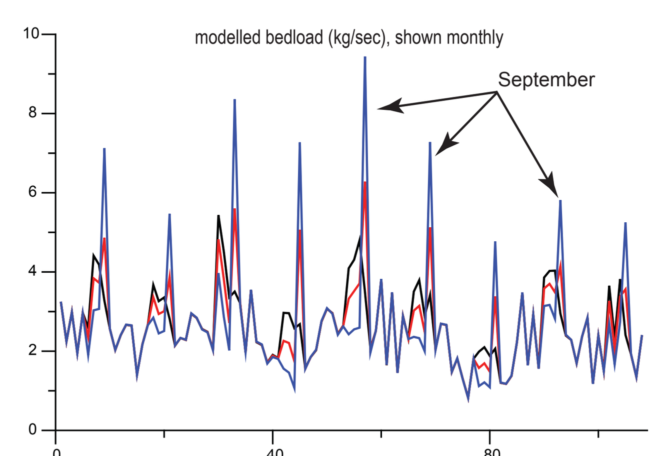


	Sediment Load (Q_{SS})	% of sediment from events daily Q > 2000 cm^3 sec^{-1}
(red)	13.91 Mt yr^{-1}	4.5%
(green)	13.86 Mt yr^{-1}	6.4%
(blue)	13.82 Mt yr^{-1}	8.3%

LGM bedload, coarser than today despite lower overall sediment yield

Could this be due to a snowmelt event during the LGM spring?

Models looking at the effect of lower winter temperatures



LGM temperature and precipitation model from Drost et al. (2007).

Winter Temperature 1° cooler

Winter Temperature 3° cooler

It is possible that the coarse bedload seen in the W1 sediments could have been transported during the springmelt.

DISCUSSION AND IMPLICATIONS

LGM to present day suspended sediment load in the Waipaoa

Today the Waipaoa River carries more sediment than at anytime during the past 22ka, including the Last Glacial Maximum (LGM).

At LGM the watershed was larger, the climate was colder and drier and the vegetation a mixture of grasses and scrubs. These factors combine to give a predicted suspended sediment load that was approximately a third to a half of what it is now.

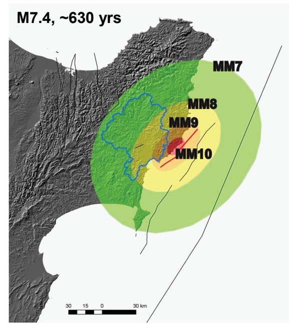
- Larger watershed → higher discharge and higher suspended sediment load
- Colder climater → reduced weathering and availability of material to be eroded
- Drier climate → less water to transport material to the ocean
- LGM vegetation → native grasses and shrubs leave the landscape more vunerable to erosion than full forest cover but less vunerable than todays situtation of 95% deforestation, short introduced grasses and sheep farming.

Climate change scenarios suggest that the Waipaoa is likely to become warmer and slightly drier (Gomez et al., 2009; IPCC 2001). An increase in the temperature will enhance weathering and hence erosion. A decrease in the precipitation will reduce the amount of sediment transported by the system. However, changes in erodibilty due to vegetation changes are significantly more dramatic than changes due to the climate. Gomez et al. (2009) show that predicted increase in sediment yield from the worse case climate change scenarios can be offset but a 35% increase in forests within the catchment.

Even if the amount of precipitation does decrease with climate change, it is predicted that the unpredictibility of storms and the number of large storms will increase. The models show that a decrease in precipitation but an increase in variability leads to lower sediment yields but a higher percentage of sediment being transported during major storm events. Again these effects can be mitigated by increasing forest planting within the catchment.

What would be the sediment response to a large earthquake in the Waipaoa catchment?

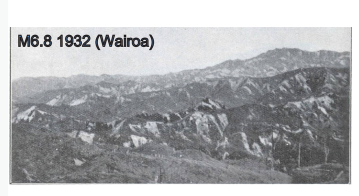
Strong ground shaking
(Modified Mercalli Intensity)



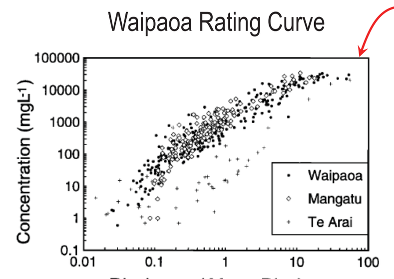
Return times of strong ground shaking

Catchment	MM7	MM8	MM9	MM10
Waipaoa	130	620	10,000	-

Litchfield et al. (2009)



Waipaoa Rating Curve



Hicks et al. (2000)

Bending over of rating curve at high dischange suggests the system is transport-limited not supply-limited.

Is the system capable of transporting more sediment if an earthquake loosened the hillslope material?

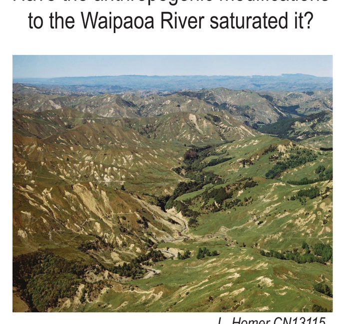
Taiwan - the rivers can carry a lot more sediment than usual following a large earthquake

e.g. Choshui River, Western Taiwan

Q_{SS} (average) ~ 40 Mt yr^{-1}
Q_{SS} (post-ChiChi) ~ 200 Mt yr^{-1}
(Milliman, WPGM 2010).

BUT - Taiwan rivers are not as modified as the Waipaoa River:

Have the anthropogenic modifications to the Waipaoa River saturated it?



L. Homer CN13115

Haiti would be the place to look following the January 2010 earthquake.

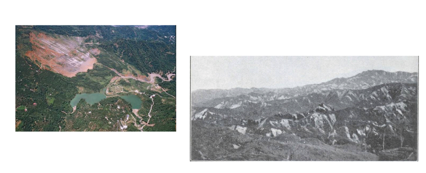
Summary:

Erodibility has a much more significant influence on sediment load than climate variability (see also Gomez et al. 2009).

As a first approximation, SST appears to be a reasonable proxy for onland climate approximations.

A drier, more variable climate will increase the significance of climate events.

An earthquake is likely to increase sediment flux but by how much is uncertain. Observations of sediment yields from Haiti following the 2010 Mw 7.1 earthquake may be the best proxy for the Waipaoa catchment given the similar deforestation histories.



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