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Suspended sediment yields from New Zealand rivers

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Abstract

River suspended sediment yield estimates from 233 New Zealand catchments are presented and used to calibrate an empirical, raster-type GIS model for predicting suspended sediment yield from any river in New Zealand. The calibration dataset is mostly based on suspended sediment gaugings and flow records, but includes data from lake and fiord bed sedimentation studies. The model relates sediment yield to the spatial integration of the product of a 'driving' factor and a 'supply' factor. The driving factor is $P^{1.7}$, where P is the local mean annual precipitation extracted from a precipitation grid. The supply factor depends on an erosion terrain classification that spreads erosion potential by slope and lithology, and to some extent by erosion process. With 74 unique terrains defined for New Zealand, coefficients for each terrain were determined by a range of approaches based on the availability of calibration data. Comparison of measured yields with those predicted by a preliminary calibration procedure highlighted several regions with systematic over- or under-prediction. These regions have differences in land cover, glacial history, tectonic regime, and/or climate that are not incorporated into the erosion terrain classification or the driving factor based on mean annual rainfall. Separate coefficients were determined for the dominant erosion terrains in each special region. With these adjustments, the model explained 97% and 96% of the variance in the measured South and North Island (log-transformed) yields, respectively, while the standard errors of the predictions equated to factors of 1.55 and 1.8 for the South and North Islands catchments, respectively. The factorial error in predicted yield decreased as catchment area increased. When totalled over all measured catchments, the predicted yield differed from the measured yield by only 2.3% in the South Island and 6.5% in the North Island. Summing measured yields and model-predicted yields from ungauged catchments, the South Island yield is 91 Mt/y and the North Island yield is 118 Mt/y. Natural lakes intercept 14% of the potential sediment yield of the South Island but only ~ 1% of that of the North Island. Hydro-lakes intercept ~ 3% of the South Island yield and ~ 0.3% of the North Island yield. Overall, floodplains and estuaries intercept only a small percentage of the total sediment delivery to the coast (although this may not be the case for particular floodplains or estuaries). The ~ 209 Mt/y total suspended sediment yield from New Zealand amounts to ~ 1.7% of the global sediment delivery to the oceans, making New Zealand a significant contributor on a unit area basis by virtue of its steep terrain, high rainfall, and tectonic activity. The sediment yield model is available in an easily used form on the Internet (http://wrenz.niwa.co.nz/webmodel), but in its present form it is not suited to assessing the effects of changes in land cover or land use on sediment delivery because this was not explicitly included as a controlling factor.

Key words

Suspended sediment, empirical sediment yield model, erosion terrain, WRENZ

Introduction

Estimates of mean annual suspended sediment load in New Zealand's rivers and streams (equivalent to catchment suspended sediment yield) are required for many purposes. Examples include assessing sediment entrapment rates in new and existing reservoirs (e.g., Young *et al.*, 2004) and focussing catchment restoration efforts on the most needy areas to meet soil conservation objectives and to improve in-stream habitat and water clarity (e.g., Davies-Colley and Smith, 2001). Suspended sediment load estimates are used for estimating fine sediment inputs to coastal waters, including estuaries, coastal embayments, the open coast and continental shelf, for issues relating to coastal erosion, water clarity, coastal ecosystems, fish nurseries and marine farming, and for marine sedimentological and geological studies relating to shelf sediment deposition and transfer (e.g., Griffiths and Glasby, 1985; Zeldis *et al.*, 2009). The coastal delivery of sediment is also of interest for global-scale studies of sediment flux to the oceans (Milliman and Meade, 1983) and for determining the fluxes of associated constituents that contribute to oceanic geochemical budgets and cycles, e.g., particulate organic carbon (Lyons *et al.*, 2002) and heavy metals (Carey *et al.*, 2002).

The mean annual suspended sediment yield (*SY*) past any river station can be established either by measurement or by empirical model. As detailed, e.g., by Hicks and Gomez (2003), measurement typically involves either continuously monitoring water discharge (*Q*) and suspended sediment concentration (*SSC*), or a proxy such as turbidity, or by just monitoring discharge continuously and developing a 'rating' relationship between *Q* and *SSC* based on a suspended sediment sampling program. All such approaches require considerable field effort and expense and must be sustained for an adequate number of years so that annual variability may be averaged. Accordingly, measurement tends to be done at only a selection of hydrological stations, while the *SY*s from un-gauged catchments are estimated by empirical methods calibrated using data from the gauged stations. The empirical approaches range from simply scaling the specific sediment yield (*SSY,* t/km^2/y) from a nearby gauged catchment by area of the un-gauged catchment (which assumes identical catchment physical and hydrological characteristics) to regression-type models that relate *SSY* or *SY* to catchment physical and hydrological properties.

Thomson and Adams (1979) and Adams (1979, 1980) calculated *SSY* for South and North Island rivers using results from suspended sediment sampling at discharge monitoring stations, using the sediment rating approach. Thompson and Adams noted a relationship between *SSY* and runoff combined with NW-SE distance from the main divide for catchments of the eastern Southern Alps. Similarly, Griffiths (1981, 1982), using an expanded dataset from flow monitoring sites around the South and North Islands with the sediment rating approach, developed regional power-law equations based on linear regression to predict *SSY.* He identified eight regions (four in the North Island, four in the South Island) but excluded the Nelson area and the northern third of the North Island due to paucity of data; the regional boundaries largely reflect hydrologic and geologic regimes. Generally, he found that *SSY* related best simply to catchment mean annual precipitation (P), but for the Canterbury-Marlborough region he found that *SSY* was better predicted from catchment area and the runoff rate associated with the mean annual flood discharge. Griffiths and Glasby (1985) used Griffiths' (1981, 1982) results to estimate total sediment yield to the coast, while the Griffiths and Glasby results have, in turn, been used in compilations of river sediment yield to the global ocean (e.g., Milliman and Syvitski, 1992).

Griffiths' and Adams' analyses were based on sediment gauging and water discharge data collected until the late 1970s, mainly by the Ministry of Works in support of hydro-power development and/or soil conservation works. Since then, more data have been collected by the Ministry of Works, catchment authorities and their recent equivalents in Regional Councils, by NIWA as part of its National Hydrometric Network, and by various other organisations. The data on-hand to 1995 were analysed by Hicks *et al.* (1996), who again mainly used the sediment rating approach to calculate sediment yield, and they found power-law regression relations between *SSY* and catchment mean rainfall and catchment lithology.

Two limitations of the above empirical *SSY* models are that (i) they do not apply to the whole of New Zealand, and (ii) they are (for the most part) forced non-linearly by catchment-averaged properties such as mean annual precipitation and lithology. The first limitation can be mitigated by increasing the spatial coverage of the yield data. The second limitation—catchment averaging—creates scaling confusions both in model calibration and application due to the typically high precipitation gradients and variable lithologies found over New Zealand. The calibration catchments for the models described above certainly covered a wide range of areas and physical gradients, while in applying them, for example, the same specific yield would be predicted from a small uniform catchment that had the same spatially-averaged mean annual rainfall as a large catchment traversing a high rainfall gradient wherein the bulk of its sediment is derived from the high rainfall headwater zone. A related application problem is that mass is not conserved down river networks. For example, let us consider applying Griffiths' (1981) West Coast South Island equation, which has $SSY \sim P^{3.65}$, to estimate the yields from two adjoining catchments with the same areas but with one having twice the precipitation of the other. The sum of the predicted yields from the two individually is 54% greater than the yield predicted from their combined catchment. This means that such models can confuse attempts to compile catchment sediment budgets. Such problems can be avoided by formulating the predictive model on a raster basis, in which each unit area may reasonably be assumed to have uniform physical and hydrological characteristics. GIS technology (in its infancy when the earlier models were developed) greatly facilitates this.

In this paper, we describe, and discuss results from, an empirical raster-based suspended sediment yield predictor that has been calibrated using a more expansive dataset of sediment yield measurements than has been used previously. The motivation came from several directions (see above), but the primary one was to provide a New Zealand-wide *SSY* GIS raster layer to underpin estimates of the delivery to the ocean of particulate organic carbon (POC) derived from soil erosion. This was a keystone of Landcare Research's Erosion-Carbon Study, which sought to improve the accuracy of New Zealand's carbon budget (Tate *et al.*, 2000; Trustrum *et al.*, 2002; Preston *et al.*, 2003; Hicks *et al.*, 2004; Scott *et al.*, 2006). The *SSY* GIS layer has subsequently been used to estimate the riverine delivery of suspended sediment and soil organic carbon to the New Zealand coast by region and in total (Hicks and Shankar, 2003; Hicks *et al.*, 2004; Zeldis *et al.*, 2009).

It has also been used to underpin estimates of the flux to the ocean of heavy metals (Carey *et al.*, 2002); and it is the basis of an internet-based GIS tool for estimating suspended sediment yield from any New Zealand river or stream (http://wrenz.niwa.co.nz/webmodel).

Methods and data

Basic approach

The aim was to develop a national sediment yield GIS grid (or raster-implemented model) from which could be extracted the mean annual suspended sediment yield delivered downstream from any defined river catchment. This does not necessarily match the amount of sediment eroded from hillslopes, since typically not all of this is delivered to, or is transferred through, the stream network (e.g., Ferro and Minacapilli, 1995; Fryirs *et al.*, 2007).

As the approach is empirical rather than process-based, it does not explicitly consider primary hillslope erosion processes and delivery processes to the channel (although these are incorporated implicitly in the erosion terrain classification) or in-channel processes that supply suspended sediment, such as bank-erosion and abrasion of bedload or bedrock channels. Instead, the basic model structure relates SSY from an assumed uniform unit area to two factors: a 'driving' factor, D, that implicitly governs the rate at which erosion and delivery processes can potentially operate in the landscape, and a 'supply' factor, b, that moderates the availability of sediment in the landscape and the proportion delivered to the channel network. The driving factor explicitly relates to the power generated by rainfall and runoff. The supply factor relates to geological factors (lithology, induration, weathering, deformation, etc), erosion processes, soils, and physiography (mainly slope). It has an implicit link to land cover only insofar as land cover is often associated with these other factors. A fundamental assumption is that all of these supply-regulating factors can be bundled into one coefficient that may be considered uniform for a given erosion terrain.

This approach differs little in concept from other empirical erosion or sediment yield predictors that are based on a string of parameters that quantify the physical characteristics of uniform hillslope elements. For example, the Universal Soil Loss Equation (USLE) (Wischmeier and Smith, 1978) is $A_{\mathrm{USLE}} = K \times C \times P_{USLE} \times R \times (L\,S)$, where A_{USLE} is erosion rate (t/ha/y), K = soil erodibility factor (t/unit of R), C = vegetation cover factor (dimensionless), P_{USLE} = erosion control practice factor (dimensionless), R = rainfall erosion index (J/ha), and LS = slope length and steepness factor (dimensionless). In the USLE, $R \times (LS)$ equates to our driving factor, while $K \times C \times P_{\mathrm{USLE}}$ equates to our supply factor.

Thus, with the present approach, the suspended sediment yield from a catchment is estimated as $SY = \Sigma b_{\mathrm{i}} D_{\mathrm{i}} \Delta \mathrm{A}_{\mathrm{i}}$, where i signifies a unit-area pixel with area ΔA_{i}, and b_{i} and D_{i} are derived for each pixel from GIS layers. The primary tasks for model development were, using the calibration dataset of river sediment load measurements, to (i) identify the driving factor function, D, and (ii) derive values of the supply-coefficient, b, for each erosion terrain. Applying this empirical model to GIS layers of the driving and supply factors produced a preliminary sediment yield raster layer or grid. We then made two further refinements to the grid. First, a residuals analysis showed the need for systematic adjustment of the predicted yield grid over some regions. Second, the yield grid over catchments with measured sediment yield was uniformly scaled to ensure that the predicted yield equalled the measured yield where known.

A further assumption of the approach is zero net losses of sediment to floodplain storage, thus sediment mass is conserved along the drainage network unless an explicit adjustment is made for entrapment in lakes. This assumption is considered further in the Discussion section.

Suspended sediment load dataset

The yield model was developed mainly from a set of mean annual suspended sediment loads compiled by the first author in the mid 1990s for some 230 river monitoring stations (Table 1, Fig. 1). In most instances, these were calculated using the sediment rating approach. That is, relationships were developed between near instantaneous discharge-weighted, cross-section mean *SSC* and water discharge (*Q*), which were then combined with the full flow record (compressed into flow-duration tables) to calculate a mean annual load. The *SSC* data were in most instances collected using depth-integrating samplers by hydrological technicians using standard methods (Hicks and Fenwick, 1994), while the matching water discharges were measured by current meter. *SSC* and water discharge data pairs were generally collected during flood gaugings. Data were available for over 300 sites, but sites were rejected for the current analysis where too little data had been collected or if there were insufficient data at high discharges: both cases can induce large uncertainties in *SY* estimated by the rating approach. In a few cases, *SSC* data were collected using automatic pumping samplers, and these had *SSC* adjusted to cross-section mean values based on calibration sampling with depth-integrating samplers. At several sites, the suspended sediment yield estimates were based on lake or fiord-bed surveys (Pickrill and Irwin, 1983; Pickrill, 1993; Hicks *et al.*, 1990; Gilliland, 1983).

The sediment ratings were fitted to the log-transformed *SSC* and discharge data with either LOcally-Weighted Scatterplot Smoothing (LOWESS; Cleveland, 1979) or the Minimum Variance Unbiased Estimator (MVUE) of Cohn *et al.* (1989). Generally, LOWESS was preferred, as the relationships were often curved in log-log space. With LOWESS-based estimates, log-log bias detransformation (Duan, 1983; Ferguson, 1986; Hicks and Gomez, 2003) was applied when residuals were observed to be normally distributed (otherwise no adjustment was applied), and the standard factorial error on the mean yield estimate was estimated using standard regression methods (Herschy, 1978). With the MVUE approach, log-bias correction and standard error estimation were as described in Cohn *et al.* (1989). At some sites, the high-end tail of the rating relations were manually adjusted down after it was found that the *SSC* predicted at the maximum flow on record was unrealistically high. In such cases, the maximum *SSC* was estimated using *SSC* data collected from rivers in the same region. Sites were generally rejected if the standard factorial error of the estimated *SY* exceeded 2, if the maximum gauged discharge was less than 50% of the mean annual flood discharge, or if more than 50% of the estimated *SY* was carried by discharges exceeding the maximum gauged discharge. Thus sites requiring excessive extrapolation of the sediment rating relation were typically discarded.

In total, 85 sites were selected from the South Island and 148 from the North Island. The sites are reasonably well distributed around both islands (Fig. 1); they are located on many of the large rivers and collectively capture 53% of the North Island area and 31% of the South Island area. However, at least at the time of the analysis in the mid 1990s, some regions had sparse data coverage, notably Auckland, Northland, Marlborough, Fiordland and the eastern South Island lowlands. Catchment areas ranged from 0.34 to 6540 km^2; 8% of catchments were less than 10 km^2, 24% were between 10 and 100 km^2, 51% were between 100 and 1000 km^2, and 17% exceeded 1000 km^2. Where appropriate, the area of catchment

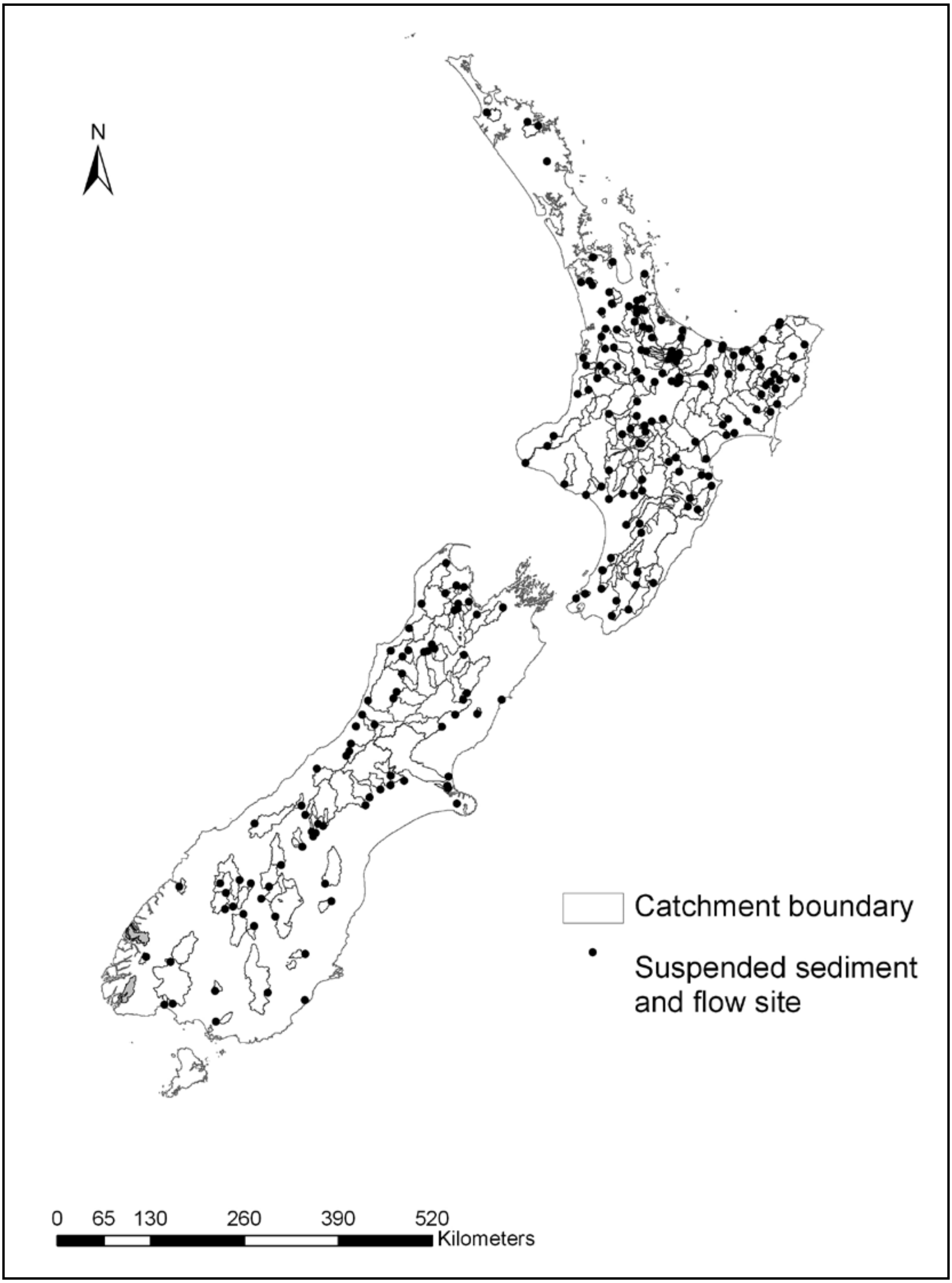


Figure 1 – River suspended sediment gauging and flow recording sites and catchments, and catchments contributing to fiord and lake sediment traps. Fiord catchments are shaded.

contributing sediment was reduced to the area downstream of lakes. Generally, the flow records span several decades (often from the 1960s through 1990s), but in some cases the record spans only a few years (Table 1). The sediment gaugings were typically scattered across the duration of the flow record but were sometimes clustered in time.

The yield estimates for selected sites in Table 1 have been discussed in Hicks *et al.* (1996) and Hicks *et al.* (2004).

Erosion terrain classification

The New Zealand Erosion Terrain Classification (NZETC) was developed by staff from Landcare Research. It defines an erosion terrain as a landscape with a unique combination of erosion processes and/or rate of processes, leading to characteristic sediment yields (Page, 2008; Dymond *et al.*, 2010). The classification was derived from slope, rock-type, soil, and erosion process information recorded in the New Zealand Land Resource Inventory (NZLRI; NWASCO, 1979) and expert knowledge. Generally, the Land Use Capability (LUC) units from the NZLRI provided the basic area elements, although as necessary these were divided to capture greater detail. While land use/management and vegetation cover are important controls on erosion severity, these were omitted from the definition of erosion terrains in an attempt to represent the intrinsic erosion responses independent of factors that can change with time.

A three-level hierarchical classification was used for both the North and South Islands. For the North Island (Table 2), the highest level classification had 9 groups defined on the basis of landform and slope. These were subdivided into 26 sub-groups on the basis of lithology, while at the third level 53 erosion terrain classes reflected differing erosion processes and rates and further detail on rock characteristics (including lithology, degree of crushing, and weathering). For the South Island (Table 3), the highest grouping of 9 was also based on landform and slope; the secondary sub-grouping was based primarily on differences in rock type, induration, and the presence or absence of significant loess; while at the finest level 37 individual erosion terrain classes were further distinguished by degree of weathering and erosion processes. Only 16 erosion terrain classes were common to both islands, reflecting the diversity and complexity of the New Zealand landscape, geology, and soil parent material, giving a total of 74 unique erosion terrains.

The distribution of erosion terrains by total area over New Zealand (Fig. 2) is reasonably broad, apart from the expected concentration of steep-land in the South Island. In the South Island, the total catchment area gauged for sediment shows a bias towards the steep-land terrains at the expense of the lowland terrains. In both islands, a number of terrains are poorly represented by gauged catchments or are not represented at all.

Extracting 74 supply coefficients from only 230 calibration values, with some terrains not sampled at all, poses some daunting statistical issues. Thus a preliminary task in the sediment yield model development was to condense the New Zealand Erosion Terrain Classification down to a smaller number of groups. This involved 'mapping' each class onto a two-dimensional landform vs lithology matrix (Table 4) and then using a subjective ranking of relative sediment production based on expert knowledge to re-group the classes. By this process, 23 lithology-landscape groups were identified: 8 common to both islands, 6 unique to the South Island, and 9 unique to the North Island.

Driving factor

The first stage in developing the sediment yield model was to formulate and calibrate the driving factor function. This involved identifying groups of gauged catchments with reasonably uniform erosion terrains or

Table 1 – Sediment yield measurements for catchments used to calibrate the suspended sediment yield model, and ratio of predicted to observed sediment yield. Details included on flow and sediment gauging records and sediment rating method where yield is based on sediment rating method. Sites marked with an asterisk are nested within a larger gauged catchment. Site numbers for fiords are informal. For sediment yield (SY) calculation method: SS Rating is instantaneous water discharge and SSC rating; EY rating is event yield rating based on auto-samples. For rating-fitting methods: LOWESS is Locally-WEighted Scatterplot Smoothing (Cleveland, 1979); MVUE is Minimum Value Unbiased Estimator (Cohn *et al.*, 1989); LR is linear regression; QMLE indicates Quasi Maximum Likelihood Estimator (Ferguson, 1986) used to correct for logarithmic bias; SM indicates Smearing Estimator (Duan, 1983) used to correct for logarithmic bias; No BC indicates no bias correction; Adj indicates high-discharge end of rating manually adjusted.

Site Number	River	Site name	Area (km^2 GIS based)	Easting (NZMG)	Northing (NZMG)	Mean flow (m^3/s)	Mean Precipitation (mm)
North Island sites							
1316	Awanui	School Cut	216.8	2535225	6676069	6.1	1619
3506	Maungaparerua	Tyrees Ford	10.3	2591273	6662528	0.446	2359
3722	Waitangi	Wakelins	306.2	2606139	6657724	7.9	2023
5023	Mangahao	Machine	81.9	2721205	6064140	6.0	4055
8203	Manukau	Somervilles	0.3	2682318	6474566	0.004	1203
8604	Orere	Bridge	40.7	2709671	6468213	1.0	1285
9112*	Waitoa	Waharoa Control	116.9	2751769	6378574	1.6	1183
9114*	Waitoa	SH26	245.5	2742700	6397200	3.5	1191
9140	Piako	Paeroa Tahuna Rd Br	533.1	2731805	6406761	7.0	1198
9175*	Piako	Kiwitahi	109.8	2739806	6385681	1.7	1209
9179	Waitoa	Mellon Rd	375.6	2742540	6404719	5.3	1202
9205*	Waihou	Te Aroha Br	1127.4	2749432	6402603	41.9	1454
9209	Waihou	Tirohia	1218.6	2743742	6414838	41.8	1455
9213	Ohinemuri	Karangahake	304.6	2750577	6417205	12.7	1901
9224*	Waihou	Okauia	803.3	2760191	6375591	26.4	1443
9228	Waiorongomai	Old Quarry	7.9	2753686	6401020	0.435	1627
12301	Tairua	Broken Hills	118.3	2753661	6451784	5.9	2454

Sediment yield method	Flow data time span	Sediment data time span	No SS Gaugings	Rating-fitting method	Measured SY (t/y)	SSY (t/km^2/y)	Std Error on Obs SY	Pred/Obs	Source of SY data
SS rating	Jan 58 - Jan 98	May 92 - Jul 97	11	LOWESS (Adj) + QMLE	19500	90	1.28	2.35	This study
SS rating	Nov 67 - Jan 96	Jun 92 - Dec 96	122	LOWESS (Adj) + No BC	1030	100	1.13	0.79	This study
SS rating	Feb 79 - Jan 98	Jun 92 - Jun 97	50	MVUE	62850	205	1.13	1.58	This study
Stratigraphy	NA	NA	NA	NA	61421	750	NA	0.89	Gilliland (1983)
SS rating	Jun 69 - Jan 87	Feb 83 - Sep 85	188	LOWESS (Adj) + No BC	25	73	1.12	0.51	This study
SS rating	Jun 78 – Jan 95	Feb 79 - Aug 95	8	MVUE +	6028	148	1.97	1.00	This study
SS rating	May 84 – Nov 96	May 86 - Jul 91	59	MVUE +	4590	39	1.17	0.86	This study
SS rating	Nov 88 - Nov 92	Jan 90 - Jul 91	25	LOWESS + QMLE	4037	16	1.24	2.14	This study
SS rating	Jul 72 - Nov 96	Jan 90 - Jul 95	70	LOWESS + QMLE	10919	20	1.13	2.05	This study
SS rating	Apr 80 - Nov 96	Sep 89 - Jul 91	23	LOWESS + QMLE	1563	14	1.23	2.49	This study
SS rating	May 86 - Nov 96	Jan 90 - Oct 92	41	LOWESS + QMLE	7337	20	1.19	1.83	This study
SS rating	Jan 65 - Nov 96	Mar 88 - Apr 91	16	LOWESS + QMLE	80411	71	1.20	0.67	This study
SS rating	Mar 66 - Nov 96	Apr 86 - Jan 95	46	MVUE	67306	55	1.11	0.85	This study
SS rating	Nov 56 - Jan 97	Jun 86 - Sep 94	35	MVUE	66583	219	1.46	0.26	This study
SS rating	Mar 82 - Dec 96	Aug 90 - Dec 91	5	MVUE	44510	55	1.11	0.84	This study
SS rating	Dec 70 - Jan 95	Jul 71 - Aug 75	7	LOWESS (Adj) + No BC	339	43	3.12	1.03	This study
SS rating	Apr 76 - Dec 96	Jul 86 - Jun 92	23	LOWESS (Adj) + No BC	10842	92	1.50	0.86	This study

Site Number	River	Site name	Area (km² GIS based)	Easting (NZMG)	Northing (NZMG)	Mean flow (m^3/s)	Mean Precipitation (mm)
13901	Mangawhai	Mokoroa	3.0	2776724	6387744	0.069	1600
14603	Waiteti	Tauranga Rd Bridge	71.2	2791549	6342876	1.3	2147
14604	Awahou	Tauranga Rd Bridge	19.9	2792167	6345327	1.7	2258
14606	Waingaehe	SH30 Bridge	10.4	2800341	6336865	0.239	1532
14607	Waiohewa	SH30 Bridge	10.5	2801755	6341580	0.344	1768
14610	Utuhina	SH5 Bridge	59.6	2794200	6336398	2.1	1599
14614	Kaituna	Te Matai	316.0	2806403	6373275	39.0	1987
14625	Puarenga	FRI Bridge	71.3	2796122	6333234	1.7	1567
14628	Mangorewa	Saunders Farm	178.7	2804654	6363173	6.3	2380
15302	Tarawera	Wakaponga	493.0	2841208	6355733	31.3	1981
15408*	Rangitaiki	Murupara	1143.7	2832905	6298355	21.6	1516
15410	Whirinaki	Galatea	508.6	2837043	6295952	14.8	1582
15432	Rangitaiki	Kopuriki	2255.6	2841305	6314029	54.0	1517
15453	Waihua	Gorge	45.0	2845702	6320763	1.6	1627
15514	Whakatane	Whakatane	1563.7	2860910	6347493	56.7	1960
15534	Wairere	Wainui Road	2.7	2861969	6352584	0.037	1588
15536	Waimana	Ogilvies Bridge	206.0	2870354	6312932	8.1	2338
15802	Waiotahi	McNabs Road Bridge	105.7	2877314	6339070	4.0	1797
15901	Waioeka	Gorge Cableway	661.1	2887710	6321950	31.7	2364
16006	Otara	Gault Road Br(No.2)	320.5	2889977	6343832	14.4	2385
16205	Waiaua	Edwards	92.0	2895725	6346594	5.0	2067

Sediment yield method	Flow data time span	Sediment data time span	No SS Gaugings	Rating-fitting method	Measured SY (t/y)	SSY (t/km^2/y)	Std Error on Obs SY	Pred/Obs	Source of SY data
SS rating	Mar 71 - Jul 95	May 71 - May 77	13	MVUE	105	35	1.31	1.20	This study
SS rating	Feb 76 - Feb 81	Feb 74 - Aug 79	21	LOWESS + SM	2138	30	1.20	2.28	This study
SS rating	May 75 - Mar 78	Dec 74 - Jul 77	20	LOWESS (Adj) + No BC	925	46	1.85	1.62	This study
SS rating	Nov 75 - Feb 84	May 70 - Mar 79	20	LOWESS (Adj) + No BC	630	61	1.34	0.95	This study
SS rating	Apr 75 - Jan 79	Feb 74 - Jul 77	21	LOWESS (Adj) + No BC	604	58	1.18	1.14	This study
SS rating	Sep 67 - Dec 82	Jan 69 - Aug 79	23	LOWESS + No BC	4248	71	1.19	0.52	This study
SS rating	May 55 - Dec 82	Feb 64 - Aug 79	18	LOWESS + SM	51716	164	1.26	1.17	This study
SS rating	May 75 - Jul 91	Dec 74 - Dec 77	15	LOWESS + SM	3237	45	1.23	1.04	This study
SS rating	Jul 67 - Nov 92	Jul 68 - Mar 79	12	LOWESS (Adj) + No BC	24669	138	1.76	0.61	This study
SS rating	May 48 - Mar 93	Sep 62 - Nov 88	27	LOWESS + SM	97773	198	1.16	0.75	This study
SS rating	Jun 48 - Jul 95	Feb 65 - Nov 94	42	LOWESS + SM	24706	22	1.15	2.44	This study
SS rating	Dec 52 - Jul 95	Dec 63 - Nov 94	67	LOWESS + SM	68890	135	1.15	0.78	This study
SS rating	Jul 66 - May 80	Dec 67 - Nov 78	41	MVUE	182274	81	1.28	0.91	This study
SS rating	Dec 79 - Jul 95	Jul 80 - Aug 94	16	LOWESS + QMLE	4496	100	1.24	1.79	This study
SS rating	Jan 57 - Jul 95	Jul 63 - Aug 92	27	MVUE	592417	379	1.29	0.65	This study
SS rating	Sep 67 - Jan 94	Nov 67 - Mar 79	26	LOWESS (Adj) + No BC	205	77	1.24	0.58	This study
SS rating	Feb 68 - Jan 94	Sep 69 - Feb 91	38	LOWESS (Adj) + No BC	135916	660	1.16	0.52	This study
SS rating	Jun 80 - Nov 83	Apr 76 - Feb 84	27	LOWESS + QMLE	11037	104	1.90	2.06	This study
SS rating	Mar 58 - Jul 95	Nov 63 - Mar 96	55	LOWESS (Adj) + No BC	653349	988	1.38	0.40	This study
SS rating	Oct 79 - Sep 82	Feb 79 - Feb 84	20	LOWESS (Adj) + No BC	92573	289	2.32	1.49	This study
SS rating	May 83 - Oct 84	Dec 80 - Sep 83	13	LOWESS + QMLE	64689	703	1.66	0.52	This study

Site Number	River	Site name	Area (km² GIS based)	Easting (NZMG)	Northing (NZMG)	Mean flow (m^3/s)	Mean Precipitation (mm)
16501	Motu	Houpoto	1379.7	2918077	6360863	91.0	2390
16502*	Motu	Waitangirua	292.7	2914723	6323286	12.9	2106
16511	Takaputahi	Ngawhakatatara	142.3	2912369	6333777	8.7	2540
17101	Raukokore	SH35 Bridge	352.4	2940032	6380444	30.6	2429
17301	Tauranga	Maruhinemaka	5.4	2941525	6384699	0.086	1307
17601	Wharekahika	Hicks Bay Rd Br	148.6	2976630	6389705	10.9	1888
18304	Mata	Pouturu	364.6	2959571	6337830	15.0	1864
18309	Waiapu	Rotokautuku	1374.2	2975576	6354104	86.0	2208
18913	Mangaheia	Willowbank	40.4	2963346	6306547	0.827	1600
19701	Waipaoa	Kanakanaia Bridge	1569.8	2935447	6293166	34.7	1407
19702*	Waipaoa	Waipaoa Station	181.6	2933895	6312593	3.2	1588
19704*	Waipaoa	Matawhero	1921.5	2937944	6271518	50.1	1370
19708	Waikohu	Mahaki	142.0	2922317	6297652	3.9	1480
19711	Waingaromia	Terrace	174.2	2941064	6304253	4.9	1594
19712	Mangatu	Omapere	183.5	2928765	6302590	7.2	1432
19716*	Waipaoa	Kanakanaia Cableway	1570.8	2935881	6292331	33.0	1407
19741	Wharekopae	Rangimoe Stn	175.6	2916008	6284756	3.9	1457
19766	Te Arai	J. Pykes	86.6	2928578	6260353	2.0	1938
21401	Wairoa	Marumaru	1810.8	2896203	6247185	70.7	1944
21409	Waiau	Otoi	533.6	2861966	6242663	21.1	2045

Sediment yield method	Flow data time span	Sediment data time span	No SS Gaugings	Rating-fitting method	Measured SY (t/y)	SSY (t/km^2/y)	Std Error on Obs SY	Pred/Obs	Source of SY data
SS rating	Apr 57 - Jul 95	Sep 56 - Aug 91	101	LOWESS (Adj) + No BC	3525526	2555	1.16	0.62	This study
SS rating	Jun 60 - Jul 95	Sep 63 - Sep 95	55	MVUE	123614	422	1.24	1.17	This study
SS rating	Oct 78 - Jan 84	Feb 79 - Sep 83	21	LOWESS + SM	66916	470	1.44	1.05	This study
SS rating	Dec 79 - Apr 95	Apr 76 - Sep 95	33	MVUE	4705940	13354	1.57	0.70	This study
SS rating	Sep 68 - Jan 93	Feb 69 - Oct 87	19	LOWESS + No BC	2060	382	1.45	0.54	This study
SS rating	May 93 - Dec 95	Apr 72 - Sep 96	41	LOWESS + QMLE	1621576	10915	2.03	0.64	This study
SS rating	Feb 89 - Jul 96	Nov 88 - Jan 97	38	LOWESS (Adj) + No BC	9018618	24739	1.81	0.65	This study
SS rating	Jan 75 - Oct 97	Feb 73 - Oct 96	79	LOWESS (Adj) + No BC	28276986	20577	1.42	1.12	This study
SS rating	Dec 88 - Jan 93	Jul 89 - Apr 96	12	LOWESS (Adj) + No BC	81148	2010	1.34	2.37	This study
SS rating	Jan 60 - Oct 96	Jan 62 - Nov 96	300	LOWESS (Adj) + No BC	10670031	6797	1.10	0.96	This study
SS rating	Jan 79 - Jan 88	Aug 57 - Sep 96	44	LOWESS + No BC	1242393	6840	1.64	3.22	This study
SS rating	Aug 62 - Dec 96	Aug 65 - Nov 96	94	LOWESS (Adj) + No BC	13864903	7216	1.22	0.79	This study
SS rating	Oct 79 - Jan 97	Sep 65 - Sep 96	93	LOWESS (Adj) + No BC	318278	2242	1.39	1.61	This study
SS rating	May 79 - Dec 96	Apr 63 - Oct 96	69	LOWESS (Adj) + No BC	5671737	32555	1.41	0.36	This study
SS rating	Aug 83 - Jan 97	May 68 - Nov 96	172	LOWESS (Adj) + No BC	2112254	11514	1.21	0.97	This study
SS rating	Nov 72 - Jul 95	May 67 - Mar 90	185	LOWESS + SM	8535662	5434	1.17	1.20	This study
SS rating	Dec 83 - Jan 97	Feb 81 - Aug 96	71	LOWESS (Adj) + No BC	258504	1472	1.67	0.33	This study
SS rating	Jan 84 - Jan 97	Sep 81 - Aug 96	48	LOWESS (Adj) + No BC	380439	4392	1.93	1.58	This study
SS rating	Feb 80 - Jan 96	Aug 68 - Jun 97	40	LOWESS + No BC	921394	509	1.58	4.05	This study
SS rating	Aug 68 - Jul 95	Jan 70 - Apr 95	70	LOWESS + QMLE	366242	686	1.59	0.87	This study

Site Number	River	Site name	Area (km^2 GIS based)	Easting (NZMG)	Northing (NZMG)	Mean flow (m^3/s)	Mean Precipitation (mm)
21410	Waihi	Waihi	50.3	2869868	6250488	1.9	2115
21437	Hangaroa	Doneraille Park	608.0	2908662	6264206	16.5	1652
21601	Tahekenui	Glenstrae	21.4	2878188	6230958	0.5	1631
21801	Mohaka	Raupunga	2370.8	2867237	6228523	80.7	1804
21803*	Mohaka	Glenfalls	1039.8	2823979	6218769	38.4	2060
22802	Esk	Waipunga Bridge	252.5	2839047	6195298	5.5	1521
23102*	Ngaruroro	Fernhill	1941.4	2833016	6172786	40.2	1635
23103*	Ngaruroro	Whanawhana	1110.0	2801878	6177780	39.3	1934
23104*	Ngaruroro	Papango	384.8	2796945	6197400	16.9	2442
23106	Taruarau	Taihape Road	263.4	2787262	6191363	6.4	1802
23150	Ngaruroro	Chesterhope Bridge	2001.3	2842492	6171513	42.5	1614
23201	Tukituki	Red Bridge	2438.0	2846597	6158135	45.4	1330
23203*	Tukituki	Waipukurau	734.8	2813765	6129060	11.6	1364
23209	Otane	Glendon	23.4	2816652	6140596	0.162	1105
23210	Omakere	Fordale	53.7	2827646	6125010	0.9	1203
25902	Whareama	Waiteko Bridge	400.2	2766036	6023110	6.6	1232
27303	Pahao	Hinakura	566.6	2731692	5986487	11.5	1274
29202	Ruamahanga	Waihenga	2368.8	2714559	5998412	81.1	1621
29231	Taueru	Te Weraiti	395.0	2742074	6020132	6.6	1154
29244*	Whangaehu	Waihi	36.3	2744137	6038004	0.529	1228
29250	Ruakokopatuna	Iraia	15.6	2708481	5977820	0.694	1973
29808	Hutt	Kaitoke	87.2	2694176	6015002	7.6	3182

Sediment yield method	Flow data time span	Sediment data time span	No SS Gaugings	Rating-fitting method	Measured SY (t/y)	SSY (t/km^2/y)	Std Error on Obs SY	Pred/Obs	Source of SY data
SS rating	Aug 68 - Jul 95	Aug 69 - Jun 95	63	LOWESS (Adj) + No BC	14718	293	1.47	1.10	This study
SS rating	May 74 - Jan 95	May 74 - Jul 86	14	LOWESS + No BC	886406	1458	1.49	1.88	This study
SS rating	Mar 75 - Jul 95	May 70 - Sep 95	72	LOWESS + SM	42476	1985	1.50	0.28	This study
SS rating	Mar 57 - Jan 95	Feb 56 - Oct 95	71	LOWESS + SM	1341544	566	1.21	0.97	This study
SS rating	Mar 62 - Jan 95	Mar 65 - May 95	85	LOWESS + SM	274552	264	1.43	2.12	This study
SS rating	Nov 63 - Jul 95	Jun 63 - Nov 92	95	LOWESS (Adj) + No BC	348257	1379	1.51	0.21	This study
SS rating	Aug 52 - Aug 92	Nov 58 - Mar 88	74	LOWESS (Adj) + No BC	1083916	558	1.26	0.65	This study
SS rating	Sep 60 - Oct 92	Dec 62 - Mar 88	64	LOWESS (Adj) + No BC	339774	306	1.41	0.64	This study
SS rating	Sep 63 - Jan 95	Mar 64 - Jul 95	78	LOWESS + QMLE	58545	152	1.36	1.81	This study
SS rating	Dec 63 - Jan 95	Aug 68 - Nov 94	67	LOWESS + SM	18455	70	1.41	2.34	This study
SS rating	Nov 76 - Jun 95	Jun 77 - Mar 93	21	LOWESS + SM	1317380	658	1.26	0.54	This study
SS rating	May 68 - Jul 95	Jul 61 - Mar 93	70	LOWESS (Adj) + No BC	1033230	424	1.45	2.03	This study
SS rating	Jun 88 - May 92	Mar 65 - Mar 75	42	LOWESS (Adj) + No BC	404425	550	1.73	0.99	This study
SS rating	Apr 64 - Jul 95	Aug 68 - Oct 94	17	LOWESS + SM	831	36	1.50	4.14	This study
SS rating	Sep 63 - Jul 95	Jun 65 - Oct 94	24	LOWESS + No BC	13546	252	1.69	1.29	This study
SS rating	Apr 70 - Jul 95	Aug 77 - Oct 92	32	LOWESS + SM	604071	1510	1.15	0.35	This study
SS rating	Sep 86 - Jul 95	Aug 86 - Jun 96	21	LOWESS (Adj) + No BC	405333	715	1.44	0.48	This study
SS rating	Dec 56 - Jan 93	May 68 - Mar 87	13	MVUE	534148	225	1.21	1.18	This study
SS rating	Dec 69 - Jan 93	May 68 - May 81	15	MVUE	140058	355	1.18	0.96	This study
SS rating	May 67 - Jan 95	May 68 - Apr 95	28	LOWESS + QMLE	12011	331	1.23	1.30	This study
SS rating	May 69 - Jul 95	Aug 79 - Apr 91	8	LOWESS + SM	2529	162	1.65	2.11	This study
SS rating	Dec 67 - Jul 95	May 81 - May 96	20	LOWESS + SM	17417	200	1.43	2.20	This study

Site Number	River	Site name	Area (km² GIS based)	Easting (NZMG)	Northing (NZMG)	Mean flow (m^3/s)	Mean Precipitation (mm)
30516	Mill Creek	Papanui	9.1	2658853	6001653	0.134	1188
30802	Pauatahanui	Gorge	38.5	2671481	6008242	0.727	1485
31803	Otaki	Tuapaka	307.9	2695194	6041044	29.3	3939
31807*	Otaki	Pukehinau	305.6	2695536	6040211	31.7	3959
32106	Ohau	Rongomatane	102.3	2707194	6057715	6.3	2443
32563	Oroua	Kawa Wool	574.8	2728716	6103752	11.3	1302
32576*	Pohangina	Mais Reach	488.4	2746780	6105344	17.4	1705
32702	Rangitikei	Mangaweka	2689.4	2750370	6151340	62.6	1562
32726	Hautapu	Taihape	294.5	2750624	6166790	4.5	854
32754	Makohine	Viaduct	98.7	2739488	6144971	1.2	944
33004	Turakina	Otairi	508.6	2723633	6147067	9.4	1034
33101	Whangaehu	Kauangaroa	1887.5	2704493	6139744	39.8	1516
33111	Mangawhero	Ore Ore	510.7	2704520	6179436	13.7	1522
33301	Whanganui	Paetawa	6538.4	2693722	6156603	213.6	1790
33316	Ongarue	Taringamutu	1076.8	2704269	6257822	34.4	1606
33320	Whakapapa	Footbridge	173.3	2722578	6229318	8.1	3124
33347*	Whanganui	Te Porere	27.5	2734403	6236757	1.3	3042
33502	Kaiiwi	Handley Road	190.2	2672645	6145495	1.5	1191
34202	Whenuakra	Nicholson Road	445.6	2642790	6160151	9.7	1312
36001	Punehu	Pihama	31.0	2588581	6189945	1.1	2440
39501	Waitara	Tarata	704.9	2627766	6227063	33.7	2284
39508	Manganui	SH3	19.2	2618865	6213047	1.5	4039

Sediment yield method	Flow data time span	Sediment data time span	No SS Gaugings	Rating-fitting method	Measured SY (t/y)	SSY (t/km^2/y)	Std Error on Obs SY	Pred/Obs	Source of SY data
SS rating	Apr 69 - Jul 95	Jun 78 - Oct 90	10	LOWESS + SM	685	75	1.60	1.78	This study
SS rating	May 75 - Jul 95	Jun 75 - Jun 96	26	LOWESS (Adj) + No BC	2958	77	1.53	1.88	This study
SS rating	May 72 - Jan 81	Apr 78 - Aug 80	9	LOWESS + QMLE	168530	547	1.27	1.22	This study
SS rating	Jul 80 - Jul 95	Aug 80 - Nov 94	25	LOWESS + QMLE	314281	1029	1.15	0.66	This study
SS rating	Jul 78 - Jul 95	Apr 81 - Oct 84	9	LOWESS (Adj) + No BC	27471	269	1.32	1.21	This study
SS rating	Feb 67 - Feb 92	Aug 61 - Jul 78	22	LOWESS + No BC	488597	850	1.19	0.41	This study
SS rating	Jun 69 - Sep 91	Jul 57 - Aug 79	37	LOWESS + No BC	2836942	5809	1.26	0.07	This study
SS rating	Apr 69 - Jul 95	Dec 80 - Oct 95	19	LOWESS + No BC	965543	359	1.32	0.55	This study
SS rating	May 63 - Jan 96	Oct 90 - Oct 97	12	LOWESS + SM	18459	63	1.55	1.38	This study
SS rating	Mar 77 - Jul 95	Nov 90 - Oct 95	47	LOWESS + SM	152014	1540	1.18	0.17	This study
SS rating	Apr 91 - Jan 93	Aug 91 - Jun 95	8	LOWESS + No BC	211256	415	1.91	0.65	This study
SS rating	Jun 71 - Jul 94	Apr 87 - Jul 92	13	LOWESS (Adj) + No BC	681259	361	1.35	0.64	This study
SS rating	May 62 - Jul 95	Oct 62 - Nov 95	18	LOWESS (Adj) + No BC	93145	182	1.74	1.19	This study
SS rating	Jul 57 - Jan 95	Mar 50 - Apr 95	68	LOWESS + QMLE	4561911	698	1.15	0.76	This study
SS rating	Aug 62 - Jan 95	Sep 62 - May 93	19	LOWESS + No BC	151711	141	1.78	2.16	This study
SS rating	Nov 59 - Jan 95	Apr 60 - Aug 91	18	LOWESS + No BC	37348	216	1.80	0.72	This study
SS rating	Jan 66 - Jan 95	Feb 71 - Sep 95	35	LOWESS (Adj) + No BC	1216	44	1.50	2.01	This study
SS rating	Apr 78 - Jan 96	Oct 88 - Apr 97	40	LOWESS (Adj) + No BC	16868	89	1.17	4.01	This study
SS rating	Mar 83 - Jul 95	Apr 87 - Oct 95	16	LOWESS + SM	275171	618	1.20	0.77	This study
SS rating	Dec 69 - Jul 95	Sep 70 - Nov 94	47	LOWESS + QMLE	1982	64	1.16	1.61	This study
SS rating	Dec 68 - Jul 95	Aug 66 - Oct 95	28	LOWESS + QMLE	890047	1263	1.26	0.80	This study
SS rating	May 72 - Jul 95	Oct 87 - May 96	103	LOWESS + QMLE	7492	390	1.11	0.50	This study

Site Number	River	Site name	Area (km² GIS based)	Easting (NZMG)	Northing (NZMG)	Mean flow (m^3/s)	Mean Precipitation (mm)
40703	Mangakowhai	Kaingapipi	14.1	2688480	6307472	0.636	1961
40708	Mokau	Totoro Bridge	1038.6	2675937	6290816	36.6	1791
40810	Awakino	Gorge	226.0	2660965	6285294	12.7	2453
41301	Marokopa	Falls	95.1	2672613	6325298	4.3	2401
41601	Oteke	Kinohaku	8.8	2668605	6335563	0.304	1616
43431	Puniu	Pokuru Br	513.8	2711450	6349991	15.8	1520
43433	Waipa	Whatawhata	2822.2	2699656	6376025	86.6	1566
43435*	Waipapa	Ngaroma Rd	134.1	2742516	6316644	5.63	1600
43472	Waiotapu	Reporoa	231.8	2801553	6302169	3.7	1416
43481*	Waipa	Otewa	310.3	2715637	6323441	13.5	1602
43489	Matahuru	Waiterimu Rd	104.8	2708328	6410993	1.92	1200
43602*	Waitangi	SH Br	17.9	2665521	6440098	0.234	1383
43876	Whangapouri	Pollock Rd	2.2	2677192	6442056	0.05	1348
46645	Kokopu	McBeths	2.8	2618372	6607716	0.061	1600
325000	Manawatu	Teachers College	3911.4			103.4	1536
1009213	Oraka	Pinedale	124.8	2756206	6344700	2.8	1552
1009246	Rapurapu	Kinlochs Farm	22.3	2764243	6363679	0.889	1618
1014641	Ngongotaha	SH5 Bridge	79.3	2789951	6341366	1.8	1720
1014644	Waiowhiro	Bonningtons Farm	4.7	2793536	6338795	0.367	1605
1014645	Pomare	Diana Place	0.7	2792234	6334808	0.016	1579
1014647*	Utuhina	Hunts Farm	7.0	2787261	6333576	0.199	1601
1014648*	Waipa	Whaka Forest	7.1	2797497	6330086	0.336	1542
1043419	Pokaiwhenua	Puketurua	417.5	2749023	6346184	4.9	1574
1043427	Mangakino	Dillon Road	337.1	2748905	6306494	11.4	1566

Sediment yield method	Flow data time span	Sediment data time span	No SS Gaugings	Rating-fitting method	Measured SY (t/y)	SSY (t/km^2/y)	Std Error on Obs SY	Pred/Obs	Source of SY data
SS rating	Jan 71 - Jan 96	Jun 71 - Oct 90	20	LOWESS (Adj) + No BC	1128	80	1.23	2.70	This study
SS rating	Apr 79 - Jul 95	Oct 79 - Jun 88	14	LOWESS (Adj) + No BC	165635	159	1.23	2.32	This study
SS rating	Apr 79 - Jul 95	Nov 79 - Sep 95	11	LOWESS + SM	59109	261	1.16	2.47	This study
SS rating	Apr 79 - Jul 95	Jul 79 - Apr 96	10	LOWESS (Adj) + No BC	13219	139	2.22	1.65	This study
SS rating	Mar 71 - Jan 93	Jun 75 - Jun 77	4	MVUE	1030	117	1.26	1.49	This study
SS rating	May 85 - Nov 96	Aug 90 - Jul 91	9	LOWESS + SM	10329	20	1.12	2.83	This study
SS rating	Sep 69 - Oct 92	May 90 - Aug 97	60	LOWESS + SM	184002	65	1.14	1.52	This study
SS rating	Apr 64 - Nov 96	Apr 64 - Nov 96	19	LOWESS + SM	4309	32	1.65	1.39	This study
SS rating	Feb 60 - Apr 97	Jul 66 - Jul 98	50	LOWESS + SM	18000	78	1.24	0.54	This study
SS rating	May 85 - Nov 96	Aug 90 - Aug 96	48	LOWESS + SM	48525	156	1.16	0.34	This study
SS rating	Jul 84 - Nov 96	Jul 84 - Nov 96	87	LOWESS + SM	7490	71	1.17	1.28	This study
SS rating	Mar 66 - Jul 95	Jun 84 - Jun 93	6	LOWESS + SM	291	16	1.50	2.16	This study
EY rating	Dec 88 - Jul 93	Jan 89 - May 93	NA	LR + No BC	88	49	1.11	1.10	Basher et al. (1997)
EY rating	Jun 77 - Aug 86	Jan 82 - Dec85	NA	LR + No BC	208	67.5	ND	0.87	Hicks (1990)
SS rating	Jan 61 - Apr 96	Aug 61 - Jun 81	23	MVUE	3197368	817	1.25	0.40	This study
SS rating	Jul 79 - Dec 96	Oct 89 - Dec 90	5	MVUE	8787	70	2.09	0.58	This study
SS rating	Dec 85 - Oct 92	Oct 89 - Aug 90	3	LOWESS + No BC	601	27	1.29	1.68	This study
SS rating	May 75 - Jul 95	Jun 75 - May 96	42	LOWESS + SM	3579	45	1.22	1.10	This study
SS rating	Oct 75 - Mar 78	Jan 76 - Jun 77	16	LOWESS + SM	297	63	1.47	0.49	This study
SS rating	Feb 76 - Jul 86	Apr 76 - Jul 76	8	LOWESS + SM	13	19	1.85	1.14	This study
SS rating	Jun 76 - Feb 78	Nov 76 - Jun 77	5	MVUE	221	31	1.39	1.29	This study
SS rating	Nov 75 - Apr 78	Jun 76 - Jun 77	8	MVUE	129	18	1.40	2.75	This study
SS rating	Feb 92 - Apr 94	Sep 63 - May 90	10	LOWESS + No BC	7244	17	1.15	2.31	This study
SS rating	Apr 64 - Apr 97	Nov 64 - Jul 98	24	LOWESS + SM	14637	43	1.15	1.04	This study

Site Number	River	Site name	Area (km^2 GIS based)	Easting (NZMG)	Northing (NZMG)	Mean flow (m^3/s)	Mean Precipitation (mm)
1043428	Tahunaatara	Ohakuri Road	195.3	2778749	6313972	4.6	1600
1043434	Mangakara	Hirsts	21.6	2798763	6300510	0.375	1568
1043459	Tongariro	Turangi	789.3	2753749	6241697	41.0	2610
1043460*	Tongariro	Puketarata	502.8	2754968	6233066	27.9	2852
1043461*	Tongariro	Upper Dam	182.4	2749288	6216582	11.9	2989
1043466	Waihohonu	Desert Rd	95.9	2746291	6217307	v6.2	3057
1043468	Kuratau	State Highway 41	121.0	2742682	6254632	4.2	1889
1143402	Whangamarino	Slackline	131.7	2705103	6426359	2.06	1203
1143409	Purukohokohu	Puruki Flume	0.3	2791245	6303101	0.006	1600
1143427	Te Tahi	Puketotara	3.4	2699142	6348144	0.155	2095
1143450	Awaroa	Sansons Br Rotowaro	45.4	2694837	6399666	1.0	1591
1232566*	Manawatu	Upper Gorge	3189.5	2749358	6093014	85.1	1537
1543413	Tauranga-Taupo	Te Kono	195.8	2763601	6247272	9.8	2057
1543424	Waihaha	SH32	134.5	2743434	6274731	5.7	1662
1543497	Mangaonua	Dreadnought	85.2	2715443	6374755	2.1	1201
1643457	Whakapipi	SH22-Tuakau	45.5	2681059	6436459	0.918	1251
1643461	Kaniwhaniwha	Limeworks Rd	26.5	2693855	6364939	1.4	2290
1643462	Mangaokewa	Te Kuiti Pumping Stn	185.7	2699702	6316209	5.3	1557
1943481	Waitomo	Ruakuri Caves Br	28.4	2692068	6324382	1.9	2198
2043441	Waipapa	Mulberry Rd	85.4	2767708	6301938	1.55	1376
2043493*	Waiotapu	Campbell Rd	68.8	2802363	6308182	1.4	1536
2743464	Hinemaiaia	Maungatera	123.8	2779524	6250846	5.5	2150

Sediment yield method	Flow data time span	Sediment data time span	No SS Gaugings	Rating-fitting method	Measured SY (t/y)	SSY (t/km^2/y)	Std Error on Obs SY	Pred/Obs	Source of SY data
SS rating	Apr 64 - Jul 95	Dec 64 - Jul 95	39	LOWESS + SM	13509	69	1.19	0.69	This study
SS rating	Jun 69 - Jan 94	Dec 64 - May 93	63	LOWESS + SM	2314	107	1.12	0.52	This study
SS rating	Jan 57 - Jan 95	Mar 57 - Jun 93	25	LOWESS (Adj) + No BC	137000	174	1.12	0.83	This study
SS rating	Dec 59 - Jan 97	Feb 60 - Feb 67	10	LOWESS + No BC	176341	351	2.61	0.50	This study
SS rating	Jan 60 - Jan 97	Jul 59 - Aug 95	16	LOWESS + SM	24279	133	1.27	2.35	This study
SS rating	Aug 61 - Jan 97	Aug 91 - Nov 96	50	LOWESS (Adj) + No BC	2869	30	1.31	1.33	This study
SS rating	Nov 78 - Oct 92	Aug 90 - Sep 92	23	MVUE	2477	20	1.16	3.24	This study
SS rating	Dec 67 - Apr 92	Dec 67 - Apr 92	12	LOWESS (Adj) + No BC	22701	172	1.67	0.51	This study
SS rating	Dec 68 - Jan 93	Sep 69 - Nov 71	24	MVUE	4	13	1.29	3.76	This study
SS rating	Apr 71 - Jan 93	Jul 71 - Sep 75	10	LOWESS + No BC	202	60	1.34	1.16	This study
SS rating	Nov 85 - Jan 97	Aug 91 - Sep 96	35	MVUE	4712	104	2.04	2.25	This study
SS rating	Jul 79 - Jul 95	Aug 61 - Dec 66	32	LOWESS (Adj) + No BC	2482699	778	1.29	0.44	This study
SS rating	Feb 76 - Oct 92	Aug 90 - Jul 95	41	LOWESS + QMLE	15923	81	1.31	1.63	This study
SS rating	May 76 - Oct 92	Aug 90 - Sep 92	24	LOWESS + SM	2268	17	1.22	2.72	This study
SS rating	Nov 80 - Nov 96	Aug 91 - Jul 97	53	LOWESS + SM	1764	21	1.15	2.96	This study
SS rating	Mar 84 - Nov 96	Aug 91 - Aug 96	32	LOWESS + SM	1776	39	1.47	1.37	This study
SS rating	Jun 84 - Nov 92	Aug 90 - Nov 94	36	LOWESS + QMLE	3312	125	1.60	2.32	This study
SS rating	Mar 83 - Nov 96	Aug 90 - Sep 96	62	LOWESS + SM	9188	49	1.11	2.01	This study
SS rating	Aug 86 - Nov 96	Aug 90 - Nov 96	61	LOWESS + SM	6914	244	1.23	0.36	This study
SS rating	Apr 70 – Jan 98	Mar 86 - Aug 94	25	LOWESS + SM	5180	57	1.36	0.68	This study
SS rating	Dec 86 - Jan 97	Sep 91 - May 97	47	LOWESS + SM	1162	17	1.06	2.73	This study
SS rating	Apr 87 - Jan 97	Aug 90 - Jul 96	54	MVUE	5195	42	1.13	2.23	This study

Site Number	River	Site name	Area (km² GIS based)	Easting (NZMG)	Northing (NZMG)	Mean flow (m³/s)	Mean Precipitation (mm)
South Island sites							
52003	Aorere	Devils Boot	566.9	2478499	6051075	73.3	5260
52902	Takaka	Harwoods	190.0	2493031	6019500	14.7	2679
52916*	Cobb	Trilobite	46.8	2477305	6008805	3.8	3753
56901	Riwaka	Moss Bush	46.6	2503403	6017211	2.5	2231
56905	Apahai	Hickmotts	0.7	2509094	6016421	0.022	1510
56906	Kaiteriteri	Water Supply	0.8	2509938	6018424	0.016	1530
57009	Motueka	Woodstock	1758.9	2495112	5994300	59.7	1972
57014*	Stanleybrook	Barkers	82.3	2494861	5987712	1.2	1378
57025*	Wangapeka	Walter Peak	470.2	2490152	5985070	22.6	
57101	Moutere	Old House Road	58.0	2510152	5997029	0.5	1200
57502	Wairoa	Gorge	456.4	2521069	5979115	16.5	1972
58902	Pelorus	Bryants	376.5	2557281	5989068	19.9	2323
60114	Wairau	Dip Flat	521.0	2503477	5923767	26.6	1653
62103	Acheron	Clarence	972.1	2507075	5870251	22.9	1658
62105	Clarence	Jollies	439.8	2502300	5861114	15.0	1557
63501	Rosy Morn	Weir	1.7	2555512	5861056	0.030	1192
64602	Waiau	Marble Point	2029.7	2491416	5840804	97.2	1817
64610	Stanton	Cheddar Valley	41.9	2521571	5841800	0.532	1195
65104	Hurunui	Mandamus	743.4	2472514	5824007	51.8	1918
66401	Waimakariri	Old HW Bridge	3187.7	2481804	5754678	123.1	1200
66602	Avon	Gloucester St Br	46.2	2480478	5741944	0.229	680
66612	Heathcote	Buxton Terrace	44.1	2481546	5738487	0.36	680
67602	Hukahuka	Lathams Br	16.3	2493630	5717490	0.23	1270

Sediment yield method	Flow data time span	Sediment data time span	No SS Gaugings	Rating-fitting method	Measured SY (t/y)	SSY (t/km²/y)	Std Error on Obs SY	Pred/Obs	Source of SY data
SS rating	Mar 76 - Jan 95	Aug 92 - Mar 96	35	MVUE	98066	173	1.21	1.06	This study
SS rating	Mar 75 - Jan 95	Oct 83 - Mar 96	15	LOWESS + SM	18400	97	1.66	0.46	This study
SS rating	May 69 - Jul 95	Jun 69 - Jan 96	47	LOWESS + SM	2810	60	1.17	1.57	This study
SS rating	Dec 61 - Oct 94	Sep 65 - Jan 70	39	LOWESS (Adj) + No BC	3342	72	1.48	0.62	This study
SS rating	Sep 95 - Nov 96	Sep 94 - Aug 96	18	MVUE	368	528	1.44	0.69	This study
SS rating	Sep 94 - Nov 96	Sep 94 - Aug 96	13	LOWESS + SM	149	192	1.32	1.94	This study
SS rating	Feb 69 - Jul 95	Jun 67 - Jul 92	32	LOWESS + SM	315163	179	1.34	1.42	This study
SS rating	Jan 70 - May 94	Dec 69 - May 95	12	LOWESS + SM	13892	169	1.24	0.93	This study
SS rating	Apr 81 - Nov 94	Nov 94 - Nov 94	4	LOWESS + SM	22079	47	1.18	0.90	This study
SS rating	Dec 61 - Jan 86	Nov 65 - Oct 69	39	LOWESS + QMLE	5284	91	1.66	1.20	This study
SS rating	Nov 57 - Nov 92	Jan 76 - Nov 90	30	MVUE	61925	136	1.26	2.83	This study
SS rating	Oct 77 - Jan 95	Sep 82 - Oct 95	23	MVUE	126649	336	1.38	1.51	This study
SS rating	Jun 51 - Feb 93	Nov 65 - Nov 94	36	LOWESS + No BC	109698	211	1.46	0.80	This study
SS rating	Apr 58 - Apr 95	Oct 62 - Oct 83	32	MVUE	298601	307	1.78	0.55	This study
SS rating	Jan 60 - Jul 95	Jul 66 - Dec 95	53	LOWESS (Adj) + No BC	62393	142	1.57	1.06	This study
SS rating	Feb 78 - Jul 95	Oct 90 - Jul 96	51	MVUE	118	70	1.40	1.41	This study
SS rating	Oct 67 - Jan 94	Oct 67 - Dec 90	58	LOWESS (Adj) + No BC	2377408	1171	1.21	0.85	This study
SS rating	Jan 68 - Jul 95	Jul 68 - Apr 96	65	LOWESS + No BC	58011	1385	1.44	0.99	This study
SS rating	Oct 56 - Aug 95	Aug 65 - Nov 94	41	LOWESS (Adj) + No BC	400213	538	1.44	1.53	This study
SS rating	Dec 66 - May 95	ND	17	MVUE	3174246	996	1.30	0.98	This study
SS rating	Dec 87 - Jul 96	Apr 95 - Oct 95	60	LR + No BC	1330	29	ND	1.00	Hicks (1993)
SS rating	Dec 89 - Jul 96	Apr 95 - Oct 95	101	LR + No BC	2810	64	ND	0.96	Hicks (1993)
SS rating	Apr 95 – Oct 95	Apr 95 - Oct 95	41	LOWESS + SM	1463	90	1.45	1.83	This study

Site Number	River	Site name	Area (km² GIS based)	Easting (NZMG)	Northing (NZMG)	Mean flow (m^3/s)	Mean Precipitation (mm)
68001	Selwyn	Whitecliffs	163.3	2420550	5748731	3.4	1095
68502	Rakaia	Gorge	2220.5	2401459	5742444	203.6	2278
68529*	Dry Acheron	Water race	6.2	2401951	5755804	0.21	1082
68806	South Ashburton	Mt Somers	538.9	2372580	5726105	11.2	1531
68810	North Ashburton	Old Weir	276.0	2387572	5736616	9.0	1357
69302	Rangitata	Klondyke	1461.0	2366562	5714932	101.4	2531
71103	Hakataramea	Above Highway Br	895.9	2311170	5606221	6.1	687
71106	Maerewhenua	Kellys Gully	185.3	2319738	5581958	3.0	954
71116*	Ahuriri	South Diadem	566.0	2249726	5632009	23.4	1775
71121*	Twizel	State Highway Br	270.3	2279354	5657315	4.6	948
71122	Maryburn	Mt McDonald	54.4	2292327	5678303	0.6	919
71125	Hooker	Ball Hut Road Br	107.2	2278325	5714626	24.9	8111
71127	Maryburn	Maryhill	89.2	2294187	5671478	0.684	820
71128	Irishman	Windy Ridge	150.8	2297753	5676572	1.3	920
71129	Forks	Balmoral	99.6	2301368	5689163	3.2	1527
71131	Lake Tekapo	Spillway	1284.2	2307917	5685989	NA	2130
71135	Jollie	Mt Cook Station	140.0	2283491	5701918	8.1	2285
74338	Sutton Stream	SH 87	150.9	2283172	5508439	1.4	710
74701	Noble	Bull Creek Road	9.6	2282529	5444968	0.110	800
75218	Lindis	Crossing Bridge	914.0	2222030	5585533	5.6	665
75219*	Lindis	Lindis Peak	546.0	2233349	5601914	6.5	780

Sediment yield method	Flow data time span	Sediment data time span	No SS Gaugings	Rating-fitting method	Measured SY (t/y)	SSY (t/km²/y)	Std Error on Obs SY	Pred/Obs	Source of SY data
SS rating	May 64 - Jul 95	Aug 65 - Jul 96	124	LOWESS (Adj) + No BC	21288	130	1.42	0.62	This study
SS rating	Dec 57 - Jul 80	Aug 65 - Oct 73	74	LOWESS (Adj) + No BC	4336496	1953	1.29	0.81	This study
SS rating	Apr 79 - Jul 91	Apr 80	ND	LOWESS + SM	227	37	ND	2.73	This study
SS rating	Apr 67 - Apr 95	Apr 67 - Dec 73	51	LOWESS + QMLE	73379	136	2.15	1.15	This study
SS rating	May 82 - Feb 99	Aug 86 - Aug 86	9	LOWESS (Adj) + No BC	155000	562	1.54	1.32	This study
SS rating	Aug 79 - Sep 2000	Jan 80 - Dec 95	33	LOWESS (Adj) + No BC	1576000	1079	1.26	1.85	This study
SS rating	Jan 64 - Jul 95	Jun 66 - Jan 96	52	LOWESS + SM	39244	44	1.66	0.59	This study
SS rating	Mar 70 - Jul 95	Jul 70 - Jun 95	64	LOWESS + SM	24030	130	1.52	0.62	This study
SS rating	Sep 63 - Jul 95	Jan 65 - Dec 95	69	LOWESS (Adj) + No BC	114904	203	1.28	1.07	This study
SS rating	Jul 62 - Jun 70	Jan 65 - Apr 70	25	LOWESS + SM	23310	86	2.15	0.72	This study
SS rating	Oct 69 - Jan 97	Jan 70 - Jun 83	45	LOWESS + QMLE	139	3	1.17	0.63	This study
SS rating	Sep 60 - Jun 95	Aug 65 - Mar 95	17	LOWESS (Adj) + No BC	278276	2596	1.27	1.04	This study
SS rating	Dec 63 - Jan 72	Nov 65 - Dec 71	24	LOWESS + No BC	140	2	1.61	1.34	This study
SS rating	Jul 62 - Jan 72	Jun 66 - Jan 72	38	LOWESS + No BC	828	5	1.56	2.63	This study
SS rating	Jul 62 - Jul 95	Nov 65 - Nov 94	65	LOWESS (Adj) + No BC	8856	89	1.25	1.66	This study
Stratigraphy	NA	NA	NA	NA	807000	628	NA	0.65	Pickrill & Irwin (1983)
SS rating	Dec 64 - Jul 95	Aug 65 - Nov 94	122	MVUE	66615	476	1.25	0.62	This study
SS rating	Jul 86 - Jul 95	Aug 92 - Jun 96	31	LOWESS (Adj) + No BC	3368	22	1.46	1.53	This study
SS rating	Jun 70 - Jul 95	Jun 71 - Dec 95	38	LOWESS + SM	201	21	1.35	1.08	This study
SS rating	Nov 72 - May 77	Nov 73 - Jul 76	10	MVUE	69950	77	1.58	1.41	This study
SS rating	Sep 76 - Feb 95	May 77 - Nov 94	35	MVUE	57710	106	1.29	1.21	This study

Site Number	River	Site name	Area (km² GIS based)	Easting (NZMG)	Northing (NZMG)	Mean flow (m³/s)	Mean Precipitation (mm)
75232	Pomahaka	Burkes Ford	1882.2	2231433	5454884	26.9	968
75253	Manuherikia	Ophir	2106.9	2241754	5560834	14.9	682
75259	Fraser	Old Man Range	118.3	2212194	5547152	2.3	1020
75265	Nevis	Wentworth Station	693.4	2197367	5563892	15.8	1098
75272	Arrow	Beetham Creek	201.0	2182921	5574514	3.4	1019
75276	Shotover	Bowens Peak	1078.6	2172199	5571035	41.1	2007
75278*	Shotover	16 Mile Gorge	167.6	2164890	5606912	11.9	2793
75279*	Shotover	Strohles	574.4	2173080	5593532	31.7	2479
75290	Cardrona	Albert Town	333.3	2207857	5606398	2.9	716
75294	Matukituki	West Wanaka	787.4	2191955	5611416	65.6	2458
78503	Waihopai	Kennington	156.6	2159632	5414641	1.9	1196
78625	Otapiriri	McBrides Bridge	108.8	2158083	5457655	2.4	1194
79701	Waiau	Tuatapere	2959.4	2099363	5439848	140.4	2785
79737*	Mararoa	Cliffs	859.2	2096818	5497901	31.9	1484
79740	Spey	West Arm	95.8	2062544	5504524	14.2	4550
80201	Rowallanburn	Old Mill	66.7	2087881	5438192	1.3	1234
84701	Cleddau	Milford	138.0	2108594	5602251	28.9	8591
86802	Haast	Roaring Billy	1025.6	2212857	5689490	190.6	7412
89301	Whataroa	SHB	453.3	2299352	5765574	134.0	7923
90102	Ivory	Ripplerock	2.2	2340177	5783776	0.75	9591
90604	Hokitika	Colliers Creek	343.9	2346463	5800351	99.0	6535

Sediment yield method	Flow data time span	Sediment data time span	No SS Gaugings	Rating-fitting method	Measured SY (t/y)	SSY (t/km²/y)	Std Error on Obs SY	Pred/Obs	Source of SY data
SS rating	Aug 61 - Jul 95	Jul 71 - Sep 95	49	MVUE	67300	36	1.15	1.73	This study
SS rating	Feb 71 - Jul 95	Jul 71 - Dec 95	57	LOWESS + SM	108876	52	1.21	0.92	This study
SS rating	May 69 - Jan 94	Aug 71 - Aug 91	20	LOWESS (Adj) + No BC	8017	68	1.72	1.69	This study
SS rating	Apr 77 - Jul 90	Jun 77 - Jun 90	30	LOWESS (Adj) + No BC	179569	259	1.47	0.85	This study
SS rating	Apr 81 - Jan 94	Oct 81 - Jun 93	14	LOWESS (Adj) + No BC	78642	391	1.39	0.61	This study
SS rating	Jun 67 - Apr 95	Feb 65 - Oct 91	124	LOWESS (Adj) + No BC	1314631	1219	1.09	0.67	This study
SS rating	Sep 77 - Apr 86	Dec 77 - Jun 80	14	LOWESS (Adj) + No BC	182148	1087	1.28	1.08	This study
SS rating	Dec 79 - Jun 87	Jun 80 - Dec 86	7	LOWESS + No BC	607650	1058	1.32	1.00	This study
SS rating	Sep 78 - Jan 97	Jan 79 - Dec 95	25	LOWESS (Adj) + No BC	52967	159	1.36	0.55	This study
SS rating	Aug 79 - Jul 97	Oct 79 - Oct 96	13	LOWESS + No BC	708462	900	1.28	1.35	This study
SS rating	Jul 58 - Jul 78	Jul 71 - Jan 76	26	LOWESS (Adj) + No BC	7572	48	1.39	1.38	This study
SS rating	Dec 62 - Jul 92	Feb 65 - Mar 80	36	LOWESS (Adj) + No BC	4335	40	1.40	0.98	This study
SS rating	Jan 73 - Dec 03	Jun 73 - Oct 95	27	LOWESS + SM	794000	268	NA	0.31	This study
SS rating	Apr 76 - Dec 81	May 77 - Oct 96	72	LOWESS + SM	155093	181	1.16	0.39	This study
SS rating	Dec 91 - Jan 97	Jun 95 - Dec 95	95	LOWESS + QMLE	11085	116	1.25	1.06	This study
SS rating	Mar 89 - Oct 93	Nov 71 - Oct 93	51	LOWESS + SM	2998	45	1.18	2.20	This study
SS rating	Mar 63 - Jun 80	Nov 71 - May 80	14	LOWESS (Adj) + No BC	10734	78	1.95	1.46	This study
SS rating	Apr 70 - Jan 95	Aug 67 - Dec 95	45	LOWESS (Adj) + No BC	4176090	4072	1.29	1.53	This study
SS rating	Dec 85 - Jan 95	May 86 - Oct 90	13	LOWESS + SM	4594861	10136	1.32	1.20	This study
Stratigraphy	Apr 76 – Nov 79	Aug 76 -Mar 86	NA	NA	31000	13851	1.05	1.23	Hicks et al. (1990)
SS rating	May 71 - Jan 95	Mar 71 - Apr 96	NA	LOWESS + QMLE	2035129	5918	1.25	1.50	This study

Site Number	River	Site name	Area (km² GIS based)	Easting (NZMG)	Northing (NZMG)	Mean flow (m^3/s)	Mean Precipitation (mm)
90605	Butchers Creek	Lk Kaniere Road	4.4	2353443	5824163	0.348	3450
90607*	Cropp	Gorge	13.2	2344362	5790070	4.8	11200
91103*	Taipo	SHB	182.1	2379372	5826640	42.8	6765
91104	Taramakau	Greenstone Bridge	876.3	2362208	5840325	155.4	4847
91401	Grey	Dobson	3396.2	2369993	5860128	357.5	3065
91404*	Grey	Waipuna	642.1	2410022	5872000	57.5	2902
91407*	Ahaura	Gorge	820.7	2405514	5863231	95.7	3107
93202*	Buller	Longford	841.3	2458970	5937980	75.1	1983
93203	Buller	Te Kuha	5745.0	2401960	5929475	428.6	2670
93206*	Inangahua	Landing	991.2	2418204	5921165	75.1	2934
93207*	Inangahua	Blacks Point	232.0	2417249	5897644	16.0	2779
93208*	Buller	Woolfs	3964.9	2426101	5929719	256.5	2348
93209*	Maruia	Falls	987.7	2447819	5927267	59.0	2497
93211*	Matakitaki	Mud Lake	879.5	2453189	5928733	55.7	2330
93212*	Mangles	Gorge	284.3	2462364	5932187	9.9	1963
94302	Mokihinui	Burkes Creek	683.1	2427391	5960380	89.2	4686
95102	Karamea	Gorge	1162.6	2444631	5994429	124.5	4738
183001	Long Sound	Narrows	377.3	NA	NA	NA	5551
183002	Thompson-Bradshaw Sd	Mouth	425.7	NA	NA	NA	7921
183003	Nancy Sd	Mouth	73.6	NA	NA	NA	7576

Sediment yield method	Flow data time span	Sediment data time span	No SS Gaugings	Rating-fitting method	Measured SY (t/y)	SSY (t/km²/y)	Std Error on Obs SY	Pred/Obs	Source of SY data
SS rating	Jul 71 - Jan 94	Jul 71 - Nov 90	NA	LOWESS (Adj) + No BC	1529	346	1.83	0.55	This study
SS rating	Dec 79 - Feb 95	Dec 87 - Feb 97	37	LOWESS (Adj) + No BC	424613	32127	1.12	0.55	This study
SS rating	May 78 - Jan 95	Aug 71 - Sep 95	28	LOWESS (Adj) + No BC	662080	3637	1.31	1.25	This study
SS rating	Feb 79 - Jan 95	Dec 70 - Aug 95	32	LOWESS (Adj) + No BC	2143810	2447	1.20	0.87	This study
SS rating	Jul 68 - Jul 95	Mar 68 - Oct 93	40	LOWESS (Adj) + No BC	1919590	565	1.28	0.79	This study
SS rating	Mar 69 - Jul 97	Aug 71 - Aug 94	46	LOWESS + No BC	249751	389	1.34	1.07	This study
SS rating	May 68 - Jan 93	Jul 71 - Nov 95	29	LOWESS (Adj) + No BC	346160	422	1.45	1.58	This study
SS rating	Oct 63 - Apr 95	Nov 64 - Sep 88	62	LOWESS + SM	217973	259	1.18	1.04	This study
SS rating	Jul 63 - Jun 95	Nov 65 - Sep 91	40	LOWESS + QMLE	4964127	864	1.34	0.52	This study
SS rating	Nov 63 - Sep 91	Jul 66 - Jun 88	25	LOWESS + SM	366064	369	1.35	0.71	This study
SS rating	May 65 - Jul 95	Nov 65 - Sep 94	71	LOWESS (Adj) + No BC	44764	193	1.36	0.85	This study
SS rating	Oct 63 - Jan 93	Nov 64 - May 90	30	MVUE	1845723	466	1.42	0.93	This study
SS rating	Dec 63 - Aug 91	Nov 64 - Sep 85	27	LOWESS (Adj) + No BC	446117	452	1.49	0.90	This study
SS rating	Nov 63 - Aug 91	Nov 64 - Mar 88	46	LOWESS (Adj) + No BC	759837	864	1.23	0.48	This study
SS rating	Jan 58 - Oct 90	Apr 81 - Dec 85	8	LOWESS + SM	13105	46	1.28	0.63	This study
SS rating	Mar 72 - Oct 80	Mar 73 - May 76	16	LOWESS (Adj) + No BC	218062	319	1.76	0.43	This study
SS rating	Jun 77 - May 97	Dec 66 - Oct 96	46	MVUE	146520	126	1.32	1.18	This study
Stratigraphy	NA	NA		NA	16330	43	NA	1.24	Pickrill (1993)
Stratigraphy	NA	NA		NA	29870	70	NA	1.41	Pickrill (1993)
Stratigraphy	NA	NA		NA	8660	118	NA	0.78	Pickrill (1993)

Table 2 – North Island Erosion Terrain classes. Groups distinguished by landscape or characteristic slope; sub-groups distinguished by lithology; erosion terrain classes distinguished by dominant erosion type association. Erosion types: Sb (stream bank), Sh (sheet), Sc (scree creep), Ss (Soil slip), W (wind), G (gully), D (deposition), Da (debris avalanche), R (rill), T (tunnel gully), eF (earthflow), Su (slump), Rf (rock fall), Ls (landslide).

Group	Sub-group	Class	Landscape/Slope & Rock type	Dominant erosion	Equivalent South Island Class
1	1.1	1.1.1	**Active flood plains** built from undifferentiated alluvium by modern overbank depositional events. Parts may be peaty. Includes non-peaty wetlands	Sb, D	1.1.1
2			**Sand country**		
	2.1	2.1.1	with recent fresh dune sand	W	2.1.1
		2.1.2	with mature moderately weathered dune sand	W, Sh, G, Ls	
3	3.1	3.1.1	**Peatland** with Organic Soils on deep peat	Sb	3.1.1
4			**Terraces, low fans, laharic aprons (most slopes <8°)**		
	4.1	4.1.1	with loess	Sb, W	4.2.1
		4.1.2	with young tephra (Waimihia and younger)	Sb, W, G	
		4.1.3	basins infilled with Taupo tephra flow deposits—intensely gullied	G, Sh, Sb, Ls	
		4.1.4	with mid-aged (late Pleistocene/early Holocene) tephra, or older tephra, or tephric loess	Sb, G	
	4.2	4.2.1	with fine, weathered, undifferentiated terrace alluvium—above the level of the modern flood plain	Sb	
	4.3	4.3.1	with gravelly soils on alluvial terrace gravels or gravelly laharic aprons—above the level of the modern flood plain	Sb, W	4.1.1
5			**Downland (most slopes 8–15°)**		
	5.1	5.1.1	with loess	Sh, R, W	5.2.1
		5.1.2	with young tephra (Waimihia and younger), over older tephra	Sh, R, W, G	
		5.1.3	with mid-aged (late Pleistocene/early Holocene) tephra, or older tephra, or tephric loess	Sh	
	5.2	5.2.1	on young basalt lava fields and low domes (parts are flatter than typical downland)	Sh	
	5.3	5.3.1	on weathered sedimentary and non-tephric igneous rocks	Sh, R	
6			**Hill country (most slopes 16–25°)**		
	6.1	6.1.1	with loess	Ls, Sh, T	6.2.1
		6.1.2	with young (Waimihia or younger) tephra, usually over older tephra—a shallow (0.3–1.0 m) tephra profile	Ls, Sh, T, G	
		6.1.3	with young (Waimihia or younger) tephra, usually over older tephra—a deep (>1.0 m) tephra profile	Sh, G, T	
		6.1.4	with mid-aged (late Pleistocene/early Holocene) tephra, or tephric loess	Ls, Sh	
	6.2	6.2.1	on relatively young basalt domes and cones	Ls, Sh	
	6.3	6.3.1	on Tertiary-aged mudstone	Ls, Sh, eF, G	6.3.1
		6.3.2	on crushed Tertiary-aged mudstone, sandstone; argillite, or ancient volcanic rock (frequently, also with a significant cover of tephra in Gisborne–East Coast area)—with moderate earthflow-dominated erosion	eF, G, T, Su	
		6.3.3	on crushed mudstone or argillite—with severe earthflow-dominated erosion	eF, G, Su, Ls, Sh	
		6.3.4	on crushed argillite, sandstone, or greywacke—with severe gully-dominated erosion	G, Sh, Ls, Su, T, eF	
	6.4	6.4.1	on moderately to strongly consolidated Tertiary sandstone	Ls, Sh	6.3.2

Group	Sub-group	Class	Landscape/Slope & Rock type	Dominant erosion	Equivalent South Island Class
		6.4.2	on unconsolidated Tertiary sandstone	Ls, Sh, Su, eF, T, G	
	6.5	6.5.1	on limestone	Sh	6.3.4
	6.6	6.6.1	on greywacke/argillite	Ls, Sh	6.4.1
		6.6.2	on 'white argillite'	Sh, W	
	6.7	6.7.1	on strongly and often deeply weathered Tertiary sedimentary rock	Ls, Sh, Su, T	
		6.7.2	on strongly and often deeply weathered ancient basalt and andesite	Ls, Sh, W, G	
		6.7.3	on strongly and often deeply weathered welded rhyolite	Ls, Sh, G	
		6.7.4	on strongly and often deeply weathered greywacke/ argillite	Ls, Sh, Su, G	
7			**Hilly steeplands (most slopes >25°)**		
	7.1	7.1.1	with young (Waimihia and younger) tephra, usually over older tephra—a shallow (0.3–1.0 m) tephra profile	Ls, Sh, T, G	
		7.1.2	with young (Waimihia and younger) tephra, usually over older tephra—a deep (>1.0 m) tephra profile	Sh, G, Ls, T	
		7.1.3	with mid-aged (late Pleistocene/early Holocene) tephra	Ls, Sh	
	7.2	7.2.1	on relatively fresh welded rhyolitic rock, or bouldery andesitic lahar deposits	Ls, Sh	
	7.3	7.3.1	on Tertiary-aged mudstone	Ls, Sh, eF, G	7.1.1
		7.3.2	on crushed argillite with gully-dominated erosion	G, Sh, eF	
	7.4	7.4.1	on moderately to strongly consolidated Tertiary-aged sandstone	Ls, Sh	7.1.2
		7.4.2	on weakly consolidated to unconsolidated Tertiary-aged sandstone and younger sandy gravel and gravelly sands	Ls, G, Sh	
	7.5	7.5.1	on limestone	Sh, Rf	7.2.4
	7.6	7.6.1	on greywacke/argillite	Ls, Sh, Sc	7.2.1
		7.6.2	on 'white argillite'	Sh, W, Sc, Ls	
	7.7	7.7.1	on strongly and often deeply weathered basalt and andesite	Ls, Sh, G, W	
		7.7.2	on strongly and often deeply weathered welded rhyolite	Ls, Sh, G	
		7.7.3	on strongly and often deeply weathered greywacke/ argillite	Ls, Sh, Su, G	
		7.7.4	on strongly and often deeply weathered Tertiary sedimentary rock	Ls, Sh, Su, T	
8	8.1	8.1.1	**Upland plains and plateaux with tephra cover**	W, Sh, G	
9			**Mountain steeplands and upland hills**		
	9.1	9.1.1	on greywacke/argillite/younger sedimentary rocks of the main ranges prone to landslide erosion	Ls, Sc, G, Sh	
		9.1.2	on greywacke/argillite/younger sedimentary rocks of the main ranges prone to sheet/wind/scree erosion	Sh, W, Sc, G, Ls	8.1.1
	9.2	9.2.1	on volcanic rock	Ls, Sh, Sc	
		9.2.2	upper flanks of volcanoes	Sc, W, Sh, G	

Table 3 – South Island Erosion Terrain classes. Groups distinguished by landscape or characteristic slope; sub-groups distinguished by lithology; erosion terrain classes distinguished by dominant erosion type association. Erosion types: Sb (stream bank), Sh (sheet), Sc (scree creep), Ss (soil slip), W (wind), G (gully), D (deposition), Da (debris avalanche), R (rill), T (tunnel gully).

Group	**Sub-group**	**Class**	**Landscape/slope & Rock type**	**Dominant erosion**
1			**Recent (young), active floodplains and fans - flat to gently sloping < 3 degrees**	
	1.1	1.1.1	developed on alluvium from various sources	W, Sb, D
2			**Coastal & inland sand dunes & beach ridges - flat to moderately sloping**	
	2.1	2.1.1	sands and gravels from various sources	W
3			**Peat deposits - flat to gently undulating peat swamps, domed and upland peats**	
	3.1	3.1.1	lowland and upland peats	W
4			**Terraces and fans - flat to gently sloping above the recent floodplain <3 degrees usually < 7 degrees**	
	4.1	4.1.1	on alluvium	W, Sh
		4.2.1	on loess mantled terraces and fans	W, Sh
5			**Downlands, >4<15 degrees**	
	5.1	5.1.1	developed on moraine and dissected alluvium	Sh, W, Ss
	5.2	5.2.1	developed on deep >1m loess	W, Sh, R
	5.3	5.3.1	developed on soft sedimentary rocks	Sh, R, W
	5.4	5.4.1	developed on hard sedimentary rocks	Sh, W, R
		5.4.2	developed on hard schist rocks	Sh, W, R
		5.4.3	developed on hard coarse grained igneous or metamorphic and fine igneous rocks	Sh, W, Ss
6			**Hill country (16 to 25 degrees) strongly rolling to moderately steep**	
	6.1	6.1.1	developed on moraine and dissected alluvium	Sh, W, Ss
	6.2	6.2.1	developed on deep >1m loess	Sh, T, Ss
	6.3	6.3.1	developed on soft sedimentary mudstone	Ss, Sh, G
		6.3.2	developed on soft sedimentary sandstone	Ss, Sh, W, G
		6.3.3	developed on soft sedimentary conglomerate	Ss, Sh, G
		6.3.4	developed on soft calcareous sediments and limestone	Sh, Ss
	6.4	6.4.1	developed on hard sedimentary rocks	Sh, Ss
		6.4.2	developed on hard schist rocks	Sh, W
		6.4.3	developed on hard coarse grained igneous or metamorphic rocks	Ss, Sh
		6.4.4	developed on hard fine grained igneous rocks	Ss, Sh
7			**Hilly Steeplands - moderately steep to steep hill country >25 degrees**	
	7.1	7.1.1	developed on soft sedimentary mudstone	Ss, Sh, G
		7.1.2	developed on soft sedimentary sandstone	Ss, Sh, W, G
		7.1.3	developed on soft sedimentary conglomerate	Ss, Sh, G
	7.2	7.2.1	developed on hard sedimentary rocks	Sh, Ss, W
		7.2.2	developed on hard schist rocks	Sh, Ss, W
		7.2.3	developed on hard coarse grained igneous or metamorphic rocks	Sh, Ss
		7.2.4	developed on hard carbonate rocks	Sh, Ss, Sc
		7.2.5	developed on hard fine grained igneous rocks	Sh, Ss
	7.3	7.3.1	developed on weathered hard schist & greywacke rocks, Marlborough Sounds especially lower slopes	Ss, Sh
		7.3.2	developed on weathered coarse grained igneous rocks, e.g. Motueka catchment	Ss, Sh, G
8			**Mountain steeplands, steep to very steep (25 to 35+) slopes of the axial and subsidiary mountain range**	
	8.1	8.1.1	developed on hard sedimentary rocks	Sh, Sc, W, G
		8.1.2	developed on hard schist rocks	Sh, Ss, Da, Sc

Group	Sub-group	Class	Landscape/slope & Rock type	Dominant erosion
		8.1.3	developed on hard coarse grained igneous and metamorphic rocks (including ultramafic terrain)	Sh, Ss, Da, Sc
		8.1.4	developed on hard fine grained igneous and tuffaceous sedimentary rocks	Sh, Ss, Sc
		8.1.5	developed on weathered coarse grained igneous rocks, e.g. Motueka catchment	Sh, Ss, G
9			**Alpine**	Sc
10			**Ice and snow**	
11			**Water**	
12			**Other (e.g. urban)**	

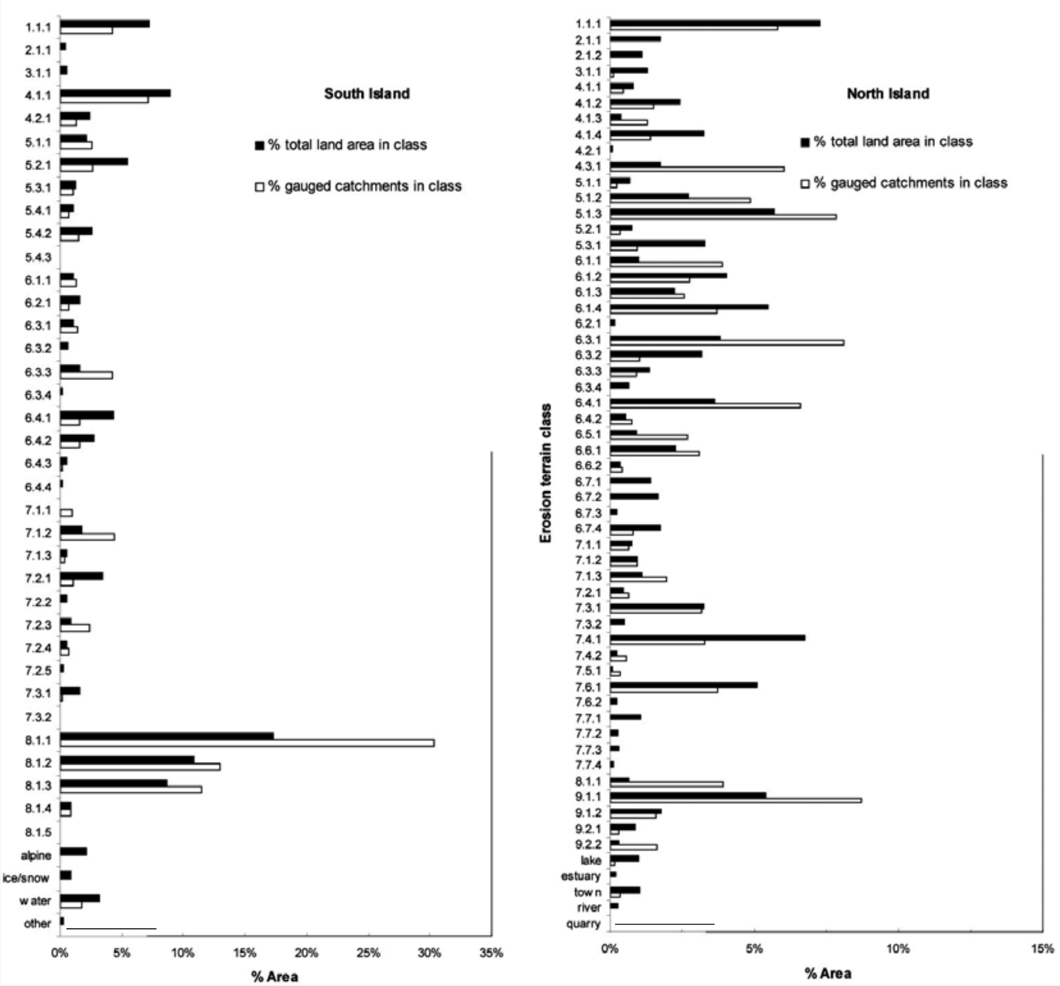
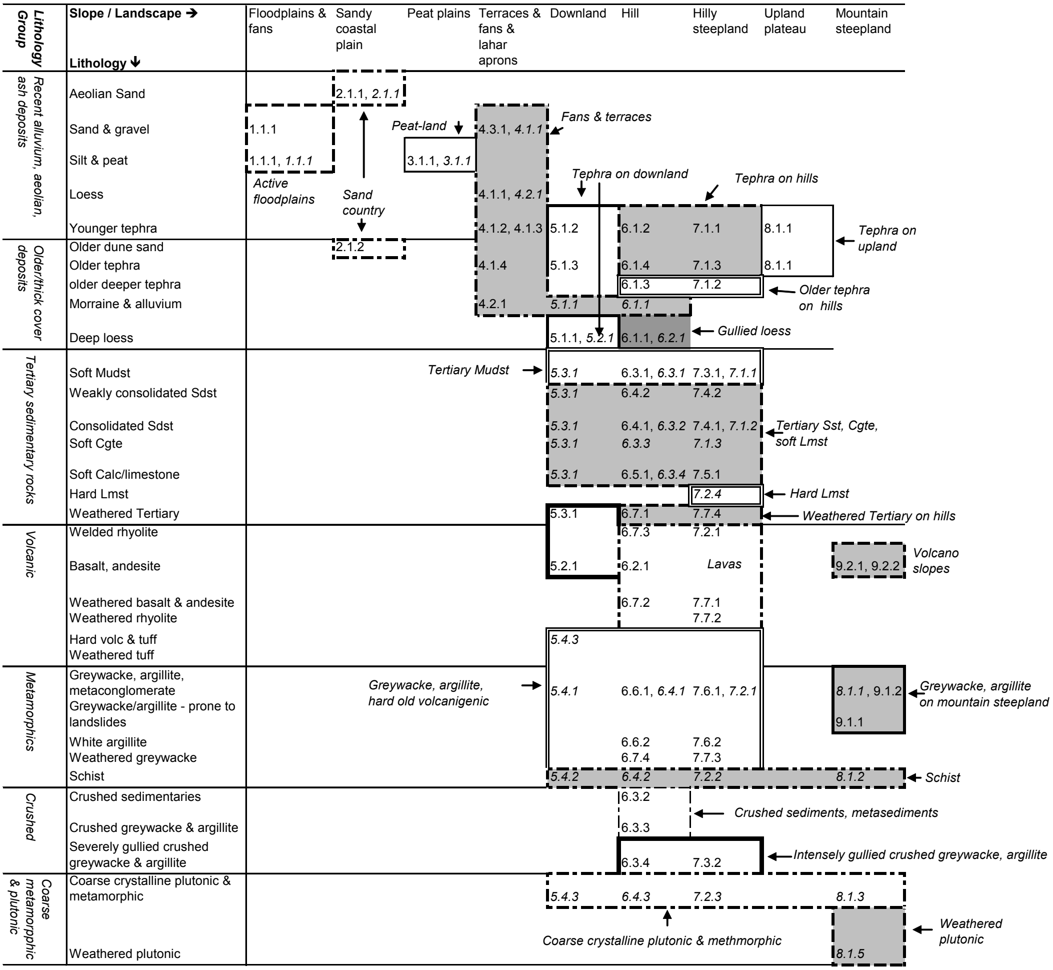


Figure 2 – Percentages of total land area and area of gauged catchments in individual erosion terrain classes for South Island (left) and North Island (right).

Table 4 – Re-grouping of erosion terrain classes (arrows) across lithology-landform space. North Island terrain classes in normal type, South Island classes in italics. Combinations of different borders and shading are used to distinguish groups.



Lithology Group	**Slope / Landscape ➔** **Lithology 🡻**	Floodplains & fans	Sandy coastal plain	Peat plains	Terraces & fans & lahar aprons	Downland	Hill	Hilly steepland	Upland plateau	Mountain steepland
Recent alluvium, aeolian, ash deposits	Aeolian Sand		2.1.1, *2.1.1*							
	Sand & gravel	1.1.1			4.3.1, *4.1.1*					
	Silt & peat	1.1.1, *1.1.1*		3.1.1, *3.1.1*						
	Loess				4.1.1, *4.2.1*					
	Younger tephra				4.1.2, 4.1.3	5.1.2	6.1.2	7.1.1	8.1.1	
Older/thick cover deposits	Older dune sand		2.1.2							
	Older tephra				4.1.4	5.1.3	6.1.4	7.1.3	8.1.1	
	older deeper tephra						6.1.3	7.1.2		
	Morraine & alluvium				4.2.1	*5.1.1*	*6.1.1*			
	Deep loess					5.1.1, *5.2.1*	6.1.1, *6.2.1*			
Tertiary sedimentary rocks	Soft Mudst					*5.3.1*	6.3.1, *6.3.1*	7.3.1, *7.1.1*		
	Weakly consolidated Sdst					*5.3.1*	6.4.2	7.4.2		
	Consolidated Sdst					*5.3.1*	6.4.1, *6.3.2*	7.4.1, *7.1.2*		
	Soft Cgte					*5.3.1*	*6.3.3*	*7.1.3*		
	Soft Calc/limestone					*5.3.1*	6.5.1, *6.3.4*	7.5.1		
	Hard Lmst							*7.2.4*		
	Weathered Tertiary					5.3.1	6.7.1	7.7.4		
Volcanic	Welded rhyolite						6.7.3	7.2.1		
	Basalt, andesite					5.2.1	6.2.1			9.2.1, 9.2.2
	Weathered basalt & andesite						6.7.2	7.7.1		
	Weathered rhyolite							7.7.2		
	Hard volc & tuff					*5.4.3*				
	Weathered tuff									
Metamorphics	Greywacke, argillite, metaconglomerate					*5.4.1*	6.6.1, *6.4.1*	7.6.1, *7.2.1*		*8.1.1*, 9.1.2
	Greywacke/argillite - prone to landslides									9.1.1
	White argillite						6.6.2	7.6.2		
	Weathered greywacke						6.7.4	7.7.3		
	Schist					*5.4.2*	*6.4.2*	*7.2.2*		*8.1.2*
Crushed	Crushed sedimentaries						6.3.2			
	Crushed greywacke & argillite						6.3.3			
	Severely gullied crushed greywacke & argillite						6.3.4	7.3.2		
Coarse metamorphic & plutonic	Coarse crystalline plutonic & metamorphic					*5.4.3*	*6.4.3*	*7.2.3*		*8.1.3*
	Weathered plutonic									*8.1.5*

terrain-associations. This was possible for six groups, including the South Island (Table 3) mountain greywacke and argillites (SI 8.1.1), South Island mountain schist (SI 8.1.2), Fiordland coarse-crystalline rocks (SI 8.1.3), coarse-grained igneous and hard sedimentary rocks from north Westland (SI 8.1.1, 8.1.3), and North Island (Table 2) hill and mountain greywacke (NI 6.6.1, 6.6.2, 9.1.1, 9.1.2) and North Island downland and hill-country tephra (NI 5.1.2, 6.1.2). For each group of sites, in the first instance measured *SSY* was regressed against catchment-averages of mean annual precipitation (*P*), mean annual runoff (*R*), and the products $P \times S$ and $R \times S$ (where *S* is slope and these products are effectively rain power and stream power per unit area, respectively). *P* was derived from a 1-km raster mean annual precipitation GIS surface developed from maps of rainfall normals (Tomlinson and Sansom, 1994; Fig. 3), *S* was extracted from a 30-m grid-size national

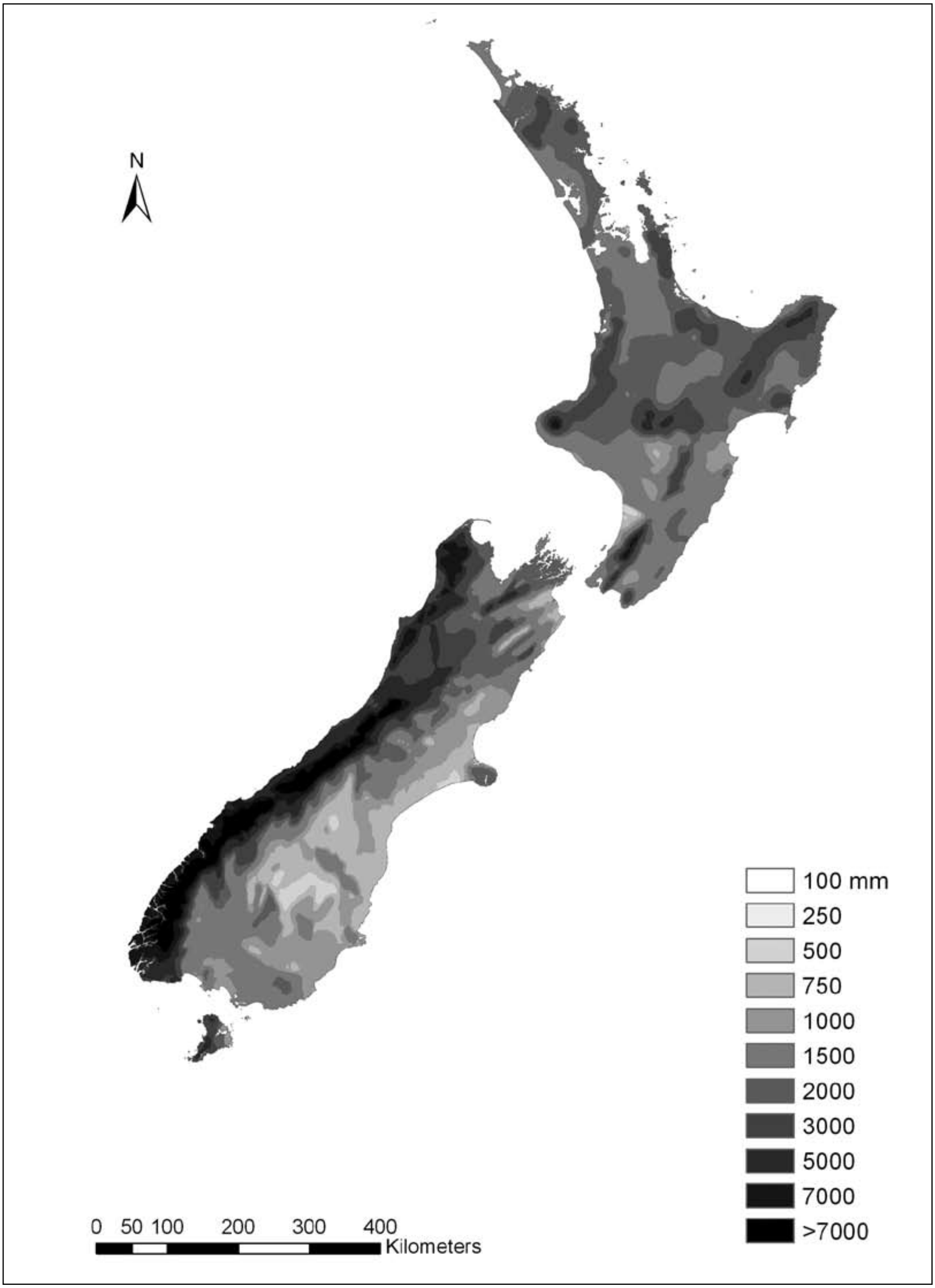


Figure 3 – Raster map of mean annual precipitation (mm) based on 30-year (1961-90) rainfall normal map of Tomlinson and Sansom (1994).

digital elevation model, while R was derived from a 5-km raster modelled runoff surface (Woods *et al.*, 2006a). The catchment-averaged P, R, $P \times S$, and $R \times S$ were all highly inter-correlated (r^2 values of P with R, $P \times S$, and $R \times S$ for the pooled set of South Island gauged catchments were 0.99, 0.97, and 0.97, respectively). No regression model improvement accrued from using either the $P \times S$ or $R \times S$ products; indeed, SSY generally correlated best simply with P (Table 5). Quite likely, this result stems from grouping the data by dominant erosion terrain, which all have characteristic slope associations. Thus while a driving factor based on rain or stream-power has some attraction because stream-power is a popular forcing parameter with landscape evolution models (e.g., Howard *et al.*, 1994; Whipple and Tucker, 1999), in this case a driving factor of the form $SSY \sim P^m$ was pursued (with the expectation that any slope dependence would be captured implicitly within the erosion-terrain-dependent sediment supply factor).

Table 5 – Correlation coefficients (r^2) between specific suspended sediment yield and spatially-averaged precipitation ($<P>$), runoff ($<R>$), precipitation x slope ($<P\times S>$), and runoff x slope ($<R\times S>$) for six groups of catchments with reasonably uniform erosion terrain. Data have been log-transformed.

Site group	No. sites	<P>	<R>	<P×S>	<R×S>
Schist	13	0.93	0.90	0.92	0.90
South Is Greywacke	11	0.71	0.43	0.62	0.24
Hard crystalline – Fiordland	5	0.60	0.56	0.54	0.52
Hard crystalline – NW South Is	5	0.58	0.60	0.56	0.6
North Is Greywacke	11	0.71	0.63	0.69	0.64
Tephra	29	0.18	0.17	0.008	0.08

To derive a raster model of this form, the precipitation grid over the gauged catchments was interrogated to compile tables of spatially-averaged P^m ($<P^m>$) for a range of m values between 1 and 2.5. Then, for each group of sites, SY was regressed against $<P^m>\times A$ (which is the same as $\Sigma(P_i^m \, \Delta A_i)$, where A is catchment total area and ΔA_i is the area of the ith raster unit or pixel), and the exponent of the power-law regression model, d, was determined for each m. A value of $d = 1$ indentifies a linear relationship between SY and $<P^m>\times A$, and this was found to occur when m was in the range 1.43 to 1.90, with an average of $m = 1.69$ (Fig. 4). Thus the driving function for the raster model was taken as $D_i \sim P_i^{1.7}$. The regression coefficients for this model ranged from 0.34 to 0.97 for the site groups analysed (Fig. 5).

Preliminary supply factor determination

The calibration exercise involved determining b values, or sediment supply factors, for each erosion terrain class. A robust, universal statistical solution, such as using multiple regression with data from all the calibration catchments to simultaneously derive b values for all terrain classes at the third hierarchal level, was not feasible for several reasons relating to ill-conditioned data. First, there were a relatively small number of gauged sites (233) in relation to the number of erosion

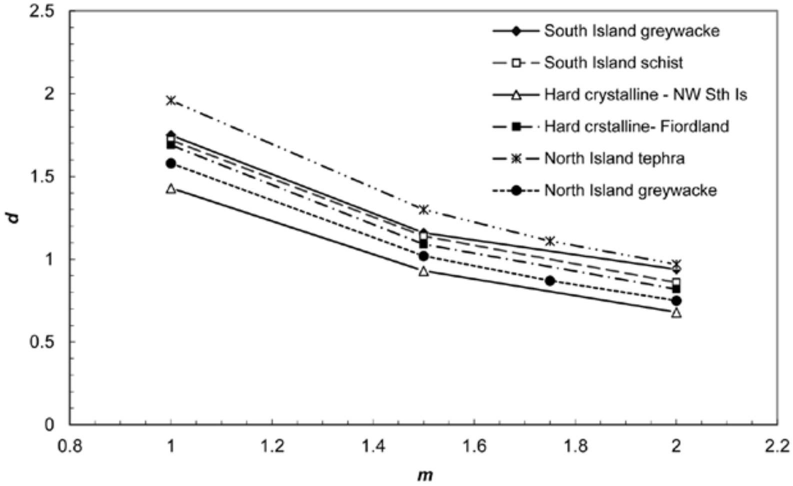


Figure 4 – Exponent *d* for power-law relations between sediment yield (*SY*) and $<P^m>A$ for a range of *m* for catchment groups with reasonably uniform erosion terrain. $<P^m>$ is spatially-averaged *m*th moment of precipitation; *A* is catchment area. Power-law relations are linear when $d = 1$.

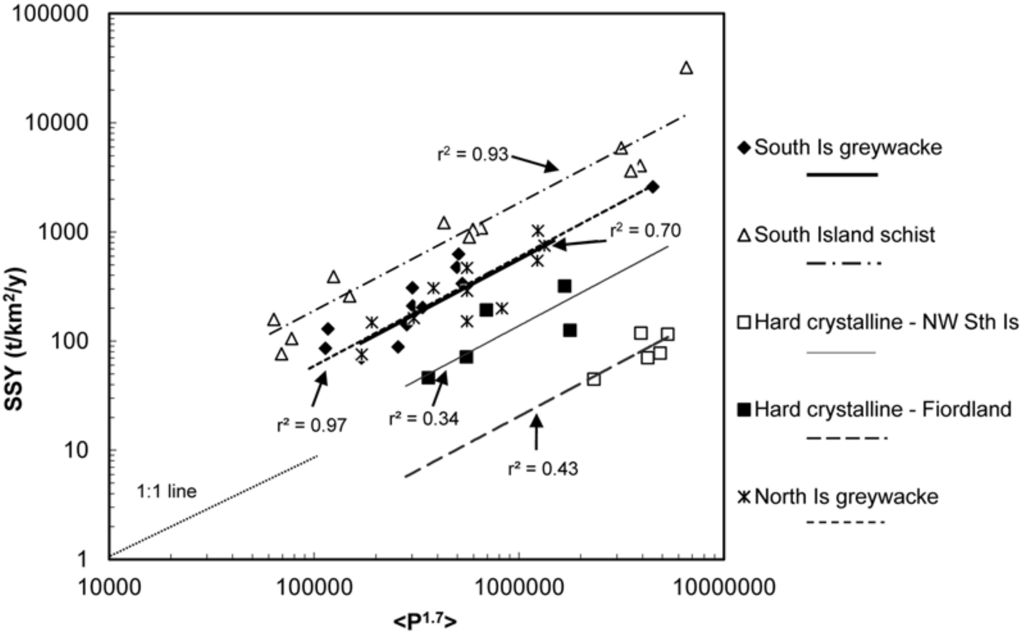


Figure 5 – Relationships between specific suspended sediment yield (*SSY*) and spatially-averaged precipitation to the power of 1.7 ($<P^{1.7}>$) for catchment groups with reasonably uniform erosion terrain.

terrains (74). Second, there was an uneven distribution of terrains amongst the gauged catchments, with some terrains not sampled at all (Fig. 2). Third, there was a large, factor-of-ten-thousand, range of sediment yields associated with different terrains at a given rainfall, thus the variance associated with the high sediment-yielding terrains tended to swamp any variance contributed by low-yielding terrains within the same catchment.

For these reasons, *b* values were determined systematically for small groups of terrain classes, usually corresponding to the re-grouping defined in Table 4. In practice, this typically led to analyses being conducted with regional clusters of gauged catchments. The *b* values were then refined for the erosion terrains within each group by a variety of methods. In some cases, there were adequate data within the regional basin clusters to derive a regression result for several *b* values. In these cases, the regression model solved the set of linear equations $SY_i = \Sigma_{ji}\ b_j <P^{1.7}>_{ji} A_{ji}$, where SY_i is the sediment yield from the *i*th catchment, b_j is the coefficient to be solved for the *j*th erosion terrain, and $<P^{1.7}>_{ji}$ is $P^{1.7}$ spatially averaged over the partial area A_{ji} of the *j* th erosion terrain in catchment *i*. In other cases, where one or more catchments were composed substantially of one erosion terrain that was likely to dominate over the other terrains present, *b* values for the dominant terrain were solved for each catchment using the partial areas of that terrain in each catchment (assuming zero yield from other terrains), and a representative *b* value was obtained by averaging the results from all catchments in the cluster (for example, where catchments comprised high-yielding mudstone steeplands and low-yielding river terraces, the latter's contribution was ignored). Where there was no suitable calibration data for an erosion terrain, either the default *b* value for the primary landform-lithology group was retained or it was adjusted based on expert knowledge. The *b* values so derived, and their derivation method, are summarised in Tables 6 and 7 for the South and North Islands, respectively.

While inducing varying uncertainty for the *b* determinations, the mixture of methods was a pragmatic way to calibrate the sediment yield model to every erosion terrain in the country, which was required to meet the objective of estimating the national yield of sediment and particulate organic carbon to the ocean.

The *b* coefficients were then combined with the national precipitation and erosion terrain grid layers to generate a preliminary national grid of *SSY*. For this, the raster dimension was set arbitrarily at 100 m. This was set simply to reasonably faithfully render the boundaries of the erosion terrain polygons and the gradients within the precipitation surface. There is no implication that the predicted yield should be accurate to this level of spatial detail. Indeed, as discussed later, there are good reasons why it should not be.

Regional adjustments of supply factor

Two further iterations were made to better align the *SSY* model with the in-river measurements and also appreciations of erosion intensity not captured within the gauged catchments. The first involved some broad regional adjustments. The need for this became apparent when, by using the preliminary set of *b* values for each erosion terrain, predicted sediment yields were compared with the gauged yields and their ratio mapped. This showed systematic bias in predicted/measured yield over two North Island regions—the tephra and greywacke-argillite hill-country of the Central North Island, including the Urewera-Kaimanawa Ranges and the Taupo Basin, and the East Cape-Hawkes Bay hill country (Fig. 6A), and four South Island regions—Northwest Nelson, Fiordland, the central/axial Southern Alps, and the Mackenzie Country (Fig. 6B). Adjustments were made to the

Table 6 – Supply factor *b*-coefficients for South Island erosion terrain classes and the basis of their determination. Basis includes catchments and statistical method used, or a representative terrain where no direct determination possible. Special region *b*-coefficients over-ride those from erosion classes listed for that region. Erosion terrains are defined in Table 3. Primary groups are defined in Table 4.

Primary Group	Erosion Terrain	*b*	Basis
Active floodplains	1.1.1	5.10E-04	66402
Sand country	2.1.1	5.10E-04	Assumed equal to 1.1.1
Peat-land	3.1.1	1.00E-04	Estimated
Fans and terraces	4.1.1	4.10E-04	71122, 71127, 71128, 90605, 66612, 67602: regression
	4.2.1	4.10E-04	As per 4.1.1
	5.1.1	4.10E-04	As per 4.1.1
	6.1.1	4.10E-04	As per 4.1.1
Loess downland	5.2.1	4.10E-04	As per 4.1.1
Loess on hills	6.2.1	1.30E-03	As per 4.1.1
Tertiary mudstone	5.3.1	5.90E-04	57101
	6.3.1	3.50E-04	80201
	7.1.1	1.70E-03	Assumed equal to 6.3.4
Tertiary sandstone and conglomerate	6.3.2	1.50E-02	64610
	6.3.3	9.20E-04	57014, 57101: average
	6.3.4	1.70E-03	91401, 91404, 91407, 93202, 93203, 93206, 93207, 93208, 93209, 93211, 94302: regression
	7.1.2	1.70E-03	Assumed equal to 6.3.4
	7.1.3	9.20E-04	Assumed equal to 6.3.3
Greywacke & argillite	5.4.1	3.10E-04	Assumed equal to 6.4.1
	5.4.3	3.10E-04	Assumed equal to 6.4.2
	6.4.1	3.10E-04	78625
	7.2.1	5.80E-04	Assumed equal to 8.1.1
Mountain greywacke & argillite	8.1.1	5.80E-04	58902, 60114, 62103, 62105, 63501, 71103, 71106, 71116, 71121, 71129, 71135, 8712: regression
Schist	5.4.2	5.20E-04	74338,75259, 75253 : regression
	6.4.2	5.20E-04	Assumed equal to 5.4.2
	7.2.2	1.90E-03	Assumed equal to 8.1.2
	8.1.2	1.90E-03	74338, 75259, 75253, 75218, 75219, 75253, 75259, 75265, 75272, 75276, 75278, 75279, 75290, 75294 : regression
Fine-grained igneus and tuffaceous rocks	6.4.4	3.10E-04	Assumed equal to 6.4.1
	7.2.5	3.10E-04	Assumed equal to 6.4.1
	8.1.4	3.10E-04	78625
Hard coarse-crystalline plutonic & metamorphic rocks	6.4.3	8.30E-05	56901, 93212, 94302, 95102: regression
	7.2.3	8.30E-05	As per 6.4.3
	8.1.3	8.30E-05	As per 6.4.4
Hard limestone	7.2.4	1.30E-04	56901
Weathered schist & greywacke	7.3.1	3.60E-04	57502
Weathered igneus	7.3.2	1.50E-03	56905, 56906: average
	8.1.5	1.50E-03	Assumed equal to 7.3.2
Minor other terrain	9	2.70E-03	Assumed equal to axial Southern Alps
	10	5.80E-04	Assumed equal to 8.1.1
	11		Assumed zero
	12	5.10E-04	66602
Special regions			
NW Nelson	All terrains	2.30E-05	183001, 183002, 183003, 84701, 79740: regression
Fiordland	All terrains	8.00E-05	52003, 52902, 52916, 56901, 57025, 93212, 95102: regression
Central/axial Southern Alps	5.4.1-5.4.3, 6.4.1, 6.4.2, 7.2.2, 7.3.1, 8.1.1, 8.1.2	2.70E-03	65104, 66401, 68502, 68806, 69302,86802, 89301, 90102, 90604, 90607, 91103, 91104 : regression
McKenzie Country	1.1.1-5.2.1, 6.1.1-6.2.1	1.40E-05	71122, 71127, 71128: average

Table 7 – Supply factor *b*-coefficients for North Island erosion terrain classes and the basis of their determination. Basis includes catchments and statistical method used, or a representative terrain where no direct determination possible. Special region *b*-coefficients over-ride those from erosion terrain classes listed for that region.

Primary Group	Erosion Terrain	*b*	Basis
Active floodplains	1.1.1	2.00E-04	Estimated, based on 4.1.1-4.1.3
Sand country	2.1.1	1.40E-04	Assumed equal to 5.1.1-5.1.2
	2.1.2	1.40E-04	Assumed equal to 5.1.1-5.1.3
Peat-land	3.1.1	1.00E-05	Estimated as per South Island (Table 6)
Fans and terraces	4.1.1	2.20E-04	8203, 15408, 36001, 43876, 1543492: average
	4.1.2	2.20E-04	As per 4.1.1
	4.1.3	2.20E-04	As per 4.1.2
	4.1.4	8.40E-05	43876, 1543492: averaging
	4.2.1	4.30E-04	8203
	4.3.1	2.20E-04	8203, 15408, 36001, 43876, 1543492: averaging
Tephra on downland	5.1.1	1.40E-04	3506, 9175, 9140, 13901, 14603, 14604, 15534, 43602, 1009246, 1009213, 1014647, 1043419, 1043428, 1014641, 1143427: regression
	5.1.2	1.40E-04	As per 5.1.1
	5.1.3	8.80E-05	14603, 1014647: average
	5.2.1	1.90E-04	3506
	5.3.1	1.40E-04	As per 5.1.1
Gullied loess	6.1.1	1.40E-04	As per 5.1.1
Tephra on hills	6.1.2	1.60E-04	As per 5.1.1
	6.1.4	2.50E-04	13901, 15534, 40703, 41301, 41601, 1009246, 1143427, 1943481: average
	7.1.1	1.60E-04	As per 5.1.1
	7.1.3	1.60E-04	As per 5.1.1
Older tephra on hills	6.1.3	2.30E-04	14606, 14607, 15302, 1014648, 1043434, 2743464: average
	7.1.2	2.30E-04	As per 6.1.3
Tertiary mudstone	6.3.1	2.20E-03	23210, 29244, 33004: average
	7.3.1	8.40E-03	18913, 19766, 21601: average
Tertiary sandstone, conglomerate, soft limestone	6.4.1	1.80E-03	34202, 29244, 33502: average
	6.4.2	1.80E-03	As per 6.4.1
	6.5.1	2.40E-04	23209
	7.4.1	1.80E-03	As per 6.4.1
	7.4.2	1.80E-03	As per 6.4.1
	7.5.1	1.80E-03	As per 6.4.1
Crushed sediments and meta-sediments	6.3.2	5.00E-03	Estimated, based on average of 6.3.1 & 7.3.1
	6.3.3	5.00E-03	As per 6.3.2
Intensely gullied crushed argillite & greywacke	6.3.4	5.00E-03	As per 6.3.2
	7.3.2	5.00E-03	As per 6.3.2

Primary Group	Erosion Terrain	*b*	Basis
Weathered Tertiary on hills	6.7.1	3.20E-04	1316
	7.7.4	3.20E-04	As per 6.7.1
Lavas	6.2.1	1.54E-04	9228, 12301: average
	6.6.1	8.70E-04	5023, 8604, 15453, 16006, 16205, 16511, 23104, 23106, 29250, 29808, 30516, 31803, 31807, 32106, 1043461: regression
	6.7.2	1.54E-04	As per 6.2.1
	6.7.3	1.54E-04	As per 6.2.1
	7.2.1	1.54E-04	As per 6.2.1
	7.7.1	1.54E-04	As per 6.2.1
	7.7.2	1.54E-04	As per 6.2.1
Greywacke and argillite, hard old volcanigenic	6.6.2	2.40E-04	23209
	6.7.4	8.70E-04	As per 6.6.1
	7.6.1	8.70E-04	As per 6.6.1
	7.6.2	8.70E-04	As per 6.6.1
	7.7.3	8.70E-04	As per 6.6.1
Tephra on upland	8.1.1	4.40E-05	33347, 1043466: average
Greywacke & argillite on mountain steepland	9.1.1	4.40E-05	As per 8.1.1
	9.1.2	4.70E-04	As per 6.6.1
Volcano slopes	9.2.1	4.40E-05	As per 8.1.1
	9.2.2	4.40E-05	As per 8.1.1
Minor other terrain		0	Assumed zero
		7.10E-05	1014645
Special regions			
Central region	5.1.2, 6.1.2, 6.1.3, 6.1.4	3.00E-05	Trial & error to remove bias in residuals
	7.4.1	4.00E-04	Trial & error to remove bias in residuals
	6.4.2, 7.4.2	8.00E-04	Trial & error to remove bias in residuals
	9.1.1, 9.1.2	8.70E-04	Assumed equal to 7.6.1, 7.6.2
East coast region	6.1.2, 7.1.1	6.50E-04	Trial & error to remove bias in residuals
	6.3.2, 6.3.3	7.20E-02	16501, 17101, 17601, 18309, 18913, 19701, 19704, 19712, 19716, 19741, 19766, 21437, 23210, 25902, 27303, 29231: regression
	6.3.4, 7.3.2	1.80E-01	As above

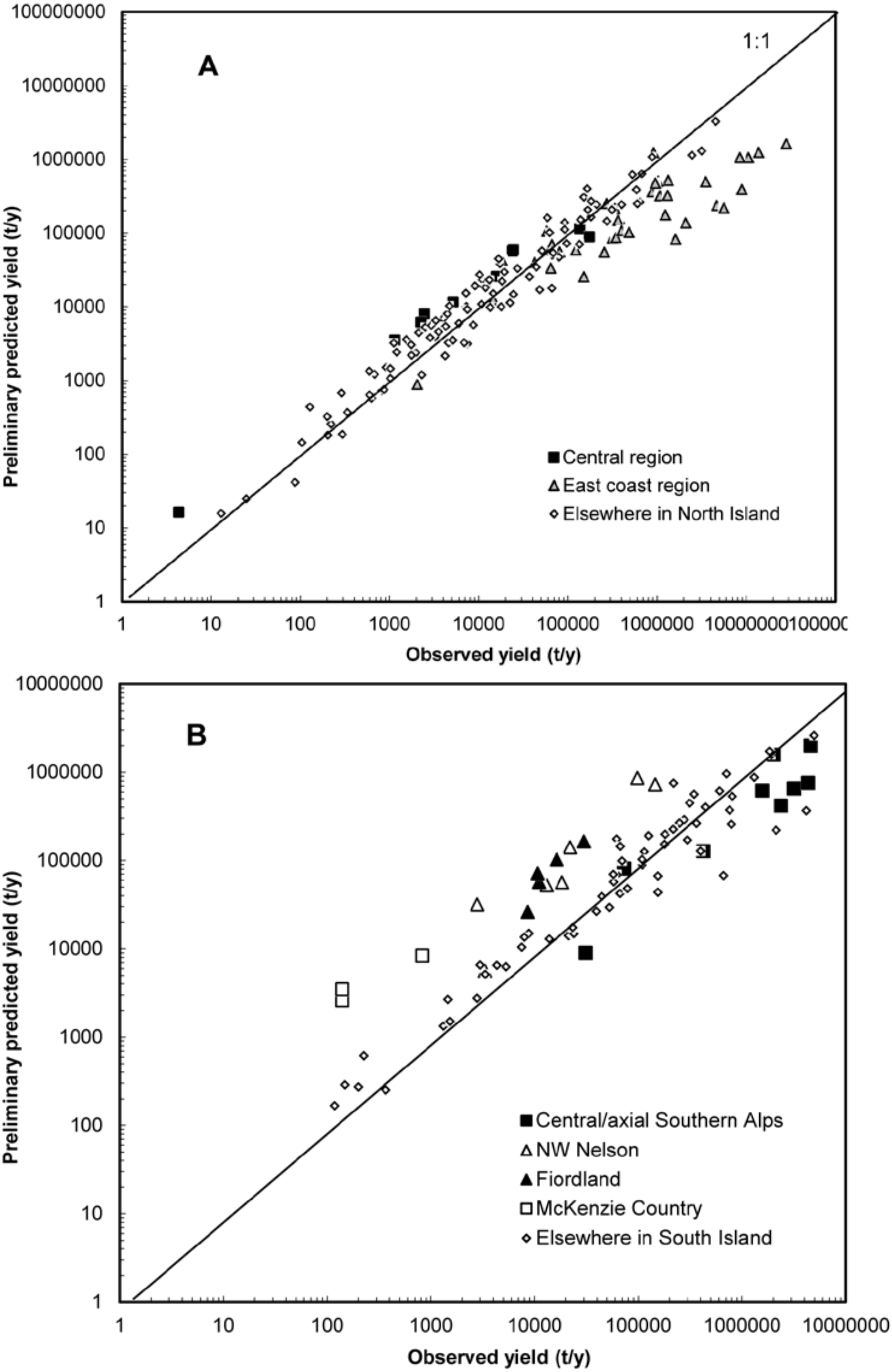


Figure 6 – Preliminary predicted yield versus observed yield, highlighting data for outlier regions. A: North Island, B: South Island.

b values in these regions by restricting the calibration catchments to those within the region boundaries. As with the preliminary determination of *b* values, the derivation method varied in robustness according to the data available, varying between linear regression to trial-and-error adjustments to minimise bias in the residuals (Tables 6 and 7). Generally, adjustments were made only to the *b*-coefficients for the dominant erosion terrains. However, the Fiordland and NW Nelson South regions were each assigned a special regionally-uniform erosion terrain class. This was because while the preliminary mapping of predicted *SSY* often showed high lithology-driven variability, this did not accord with field observations. For example, it was noticed that the predicted yields from the Tertiary sedimentary country of eastern Fiordland were higher than would be expected from field observations. In the absence of data to quantify the yields from this region, it was therefore estimated that the *b*-coefficient determined from the mainly coarse crystalline igneous and metamorphic terrain should apply to all of Fiordland. The boundaries of these outlier regions (Fig. 7) were drawn subjectively, based on a combination of broad geological suites and features (e.g., Alpine Fault, Median Tectonic Line) and the landform-lithology groupings of erosion terrains (Table 4).

The need for this step was not surprising, given that several factors known to influence sediment yield (regional tectonic setting, glacial history, land cover) are not explicitly recognised in the erosion terrain classification, nor is climate variability fully captured by the mean-annual-rainfall-based driving factor. Thus, the axial Southern Alps showed higher sediment yields relative to other mountain greywacke terrain, probably by virtue of their proximity to the Alpine Fault (Indian/Pacific plate boundary) and associated higher tectonic uplift rates (Adams, 1980; Hicks *et al.*, 1996; Little *et al.*, 2005), plus their prolonged history of intense glacial activity over the past million years or so and relatively recent glacial unloading, and probably also their high-intensity rainfall. Similarly, the strong glacial signature, combined with its relatively arid climate, renders the Mackenzie Country distinct from depositional terrace surfaces elsewhere. Northwest Nelson, formed for the most part on ancient crystalline rocks of igneous or metamorphic origin, differs from the equivalent terrain in Fiordland in terms of tectonic setting (it is on the opposite side of the Indian/Pacific plate boundary and has lower uplift), and by having had less glaciation and more chemical weathering. Similarly, the Tertiary belt of eastern Fiordland, with its glacial history and dense native forest cover, contrasts with the deforested Tertiary country of the South Island east coast. The higher-yielding, sheared greywacke and argillite basement terrain of the East Cape–Hawkes Bay region is distinguished from other North Island greywacke hill-country (e.g., Northland, West coast) by its active tectonism associated with the subducting plate boundary, by the substantial removal of native forest (Hicks *et al.*, 2000a), and by increased exposure to high-intensity rainstorms (Glade 1998). The lower-yielding central area of the North Island is distinguished by its relatively greater cover of native forest (e.g., Ureweras) and porous soils of tephra origin (e.g., Taupo Basin), which both tend to inhibit erosion.

Errors and uncertainties

After applying these regional adjustments, the yields predicted for the 85 South Island calibration catchments were found to match the observed yields acceptably well (Fig. 8), with the model explaining 97% of the variance in observed yields (using log-transformed values). The predicted/measured yield ratios showed a log-normal distribution (Kolmogorov-Smirnov test), with a mean log residual of 0.01 (not significantly different from zero) and a standard log residual

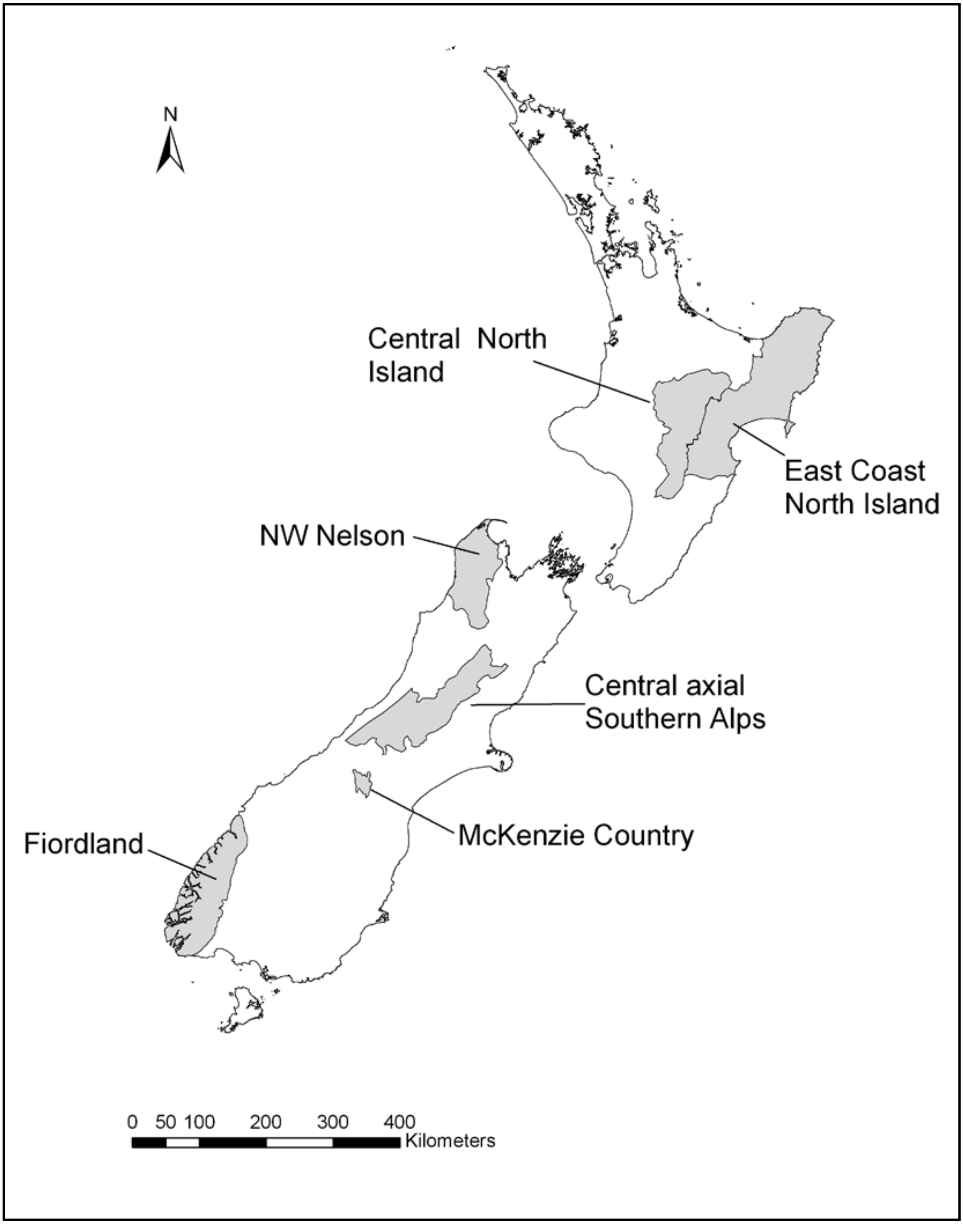


Figure 7 – The six special regions in which the general *SSY* model required regional adjustment.

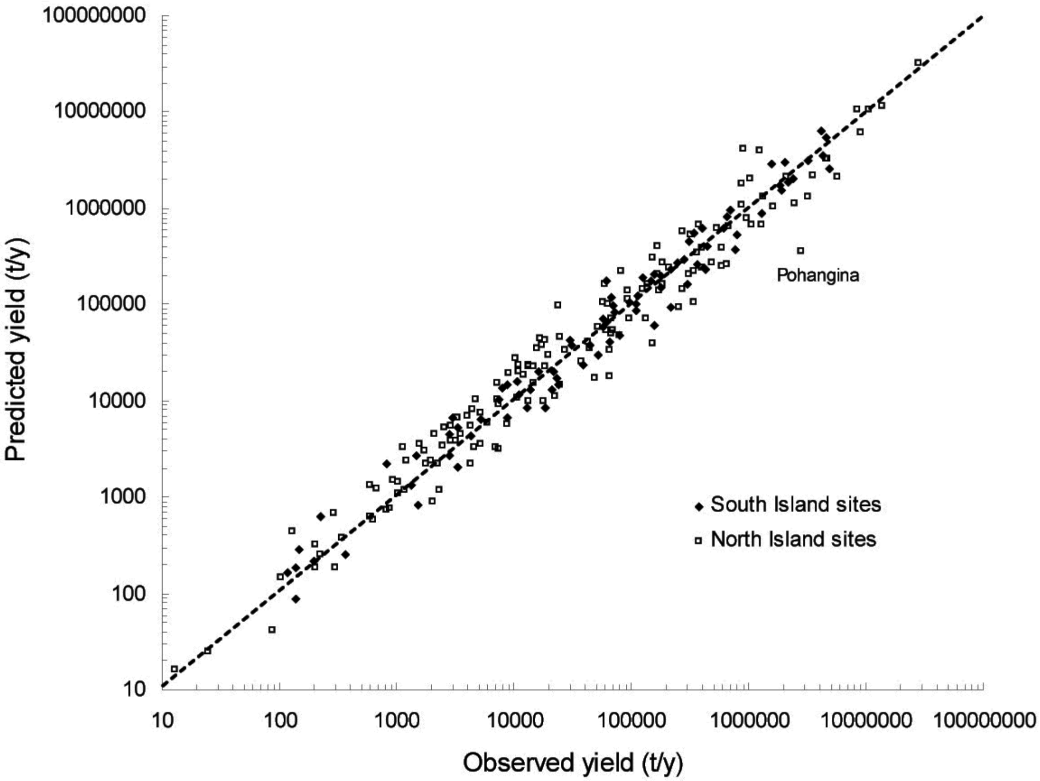


Figure 8 – Final predicted yield versus observed yield, after regional adjustment step.

of 0.44. The latter equates to a standard factorial error (SFE) of 1.55 on the predicted yield and a 95% confidence factorial error of 2.4. It was also observed (Fig. 9) that the log residuals tended to decrease as gauged catchment area increased. After ranking the data by catchment area (A, in km^2), the five-point running standard log residual, s_{eln}, showed the weak trend $s_{\mathrm{eln}} = 0.58A^{-0.081}$ ($r^2 = 0.09$). This indicates, for example, that the standard factorial error should decrease from 1.70 to 1.62 to 1.49 to 1.39 as catchment area increases from 1 to 10 to 100 to 1000 km^2, respectively. An outlier to this trend (and excluded from the trend statistics) was Buller at Te Kuha. This site has a large uncertainty in its observed yield, due to a lack of samples at high flows, and its inclusion in the dataset was marginal. The sum of the predicted yields from the gauged catchments (excluding sub-catchments nested upstream from mainstem sites), covering 31% of the South Island area, is 38.9 ± 3.9 Mt/y, which compares well with the observed sum of 38.0 ± 2.9 Mt/y (where the uncertainties are found by summing the variances associated with the estimated factorial errors on the observed and predicted values). The agreement between the two totals is to 2.3%, which is consistent with their individual uncertainties.

The 148 North Island sites showed less reliable predictions on average, although the model still explained 96% of the variance in the observed (log-transformed) yields (Fig. 8). The predicted/measured yield ratios also showed a log-normal distribution, while the standard log residual of 0.59 equates to a

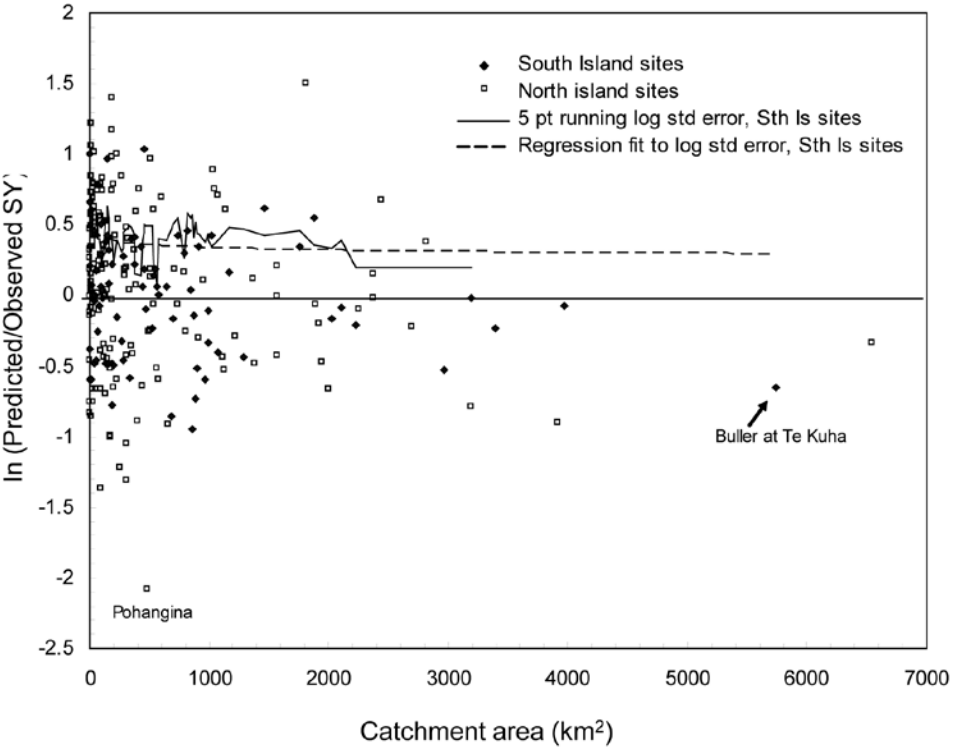


Figure 9 – Final predicted/observed yield versus catchment area.

standard factorial error of 1.8 on the predicted yield and a 95% confidence factorial error of 3.25. There appeared to be a slight tendency for the log residuals to decrease with catchment area, but this was not statistically significant (Fig. 9, $r^2 = 0.0005$), thus the 1.8 SFE should be applied irrespective of area. The result from the Pohangina River (a major tributary of the Manawatu River), wherein the predicted yield is only 7% of the observed yield (Fig. 8), is regarded as an outlier and is excluded from the above statistics. This is because the Pohangina SSC dataset was collected mostly during the 1960s at a time when the catchment was experiencing extensive accelerated erosion. That erosion has since declined as a result of soil conservation works (Lough, 1993), thus the measured yield value almost certainly overestimates the yield of recent decades. The sum of the predicted yields from the gauged North Island catchments (excluding sub-catchments nested upstream from mainstem sites), covering 53% of the North Island area, is 84 ± 28 Mt/y, which compares with the observed sum of 90 ± 15 Mt/y (uncertainties derived as per South Island sites). The agreement between the two totals is 6.5%, which is well within their individual uncertainties.

Thus, while the predicted catchment yields involve substantial uncertainty, more in the North Island than the South Island and particularly for small catchments, the uncertainty in the yield totalled over regions and for the country overall should be relatively small (i.e., less than ~10%). Exceptions are the regions with little or no data, notably Marlborough and the Coramandel-Auckland-Northland region, where the uncertainty is more likely of the order of a factor of two. Considerably more data have been collected from the Auckland region over the past decade, thus a re-analysis for that region would be timely.

The raster dimension for the sediment yield grid was set arbitrarily at 100 m (1 hectare area) to adequately register the boundaries of the erosion terrain polygons and the gradients within the precipitation surface, however the predicted yields are not likely to be reliable to this level of detail. Indeed, partly from the above error analysis, but mainly from knowledge of the variability of sediment yields from discrete erosion sites, it is likely that the predicted yield at the hectare scale could be uncertain by a factor of 10 or more. This GIS model should thus be used only to predict sediment yields from catchments with areas exceeding ~10 km^2; it is not recommended at the field scale.

Catchment adjustments and national yield surfaces

The final adjustment made to the national *SSY* grid was to systematically adjust the sediment yield over each gauged catchment so that the predicted yields at the gauged sites matched the gauged yields. The rationale for this adjustment stemmed from the need to develop a tool to provide the most reliable estimate of the total suspended sediment flux from New Zealand's rivers to the ocean. The implicit, and quite reasonable, assumption was that measured sediment yields should be more reliable than modelled yields. This meant that the suspended sediment yield from 40% of the country could be derived from in-river measurements, with the yield from the remaining, ungauged area predicted from the empirical model. Where a catchment had more than one sediment gauging station, to ensure continuity of sediment delivery throughout the catchment, the adjustment was applied only to the catchment of the station farthest downstream.

Computing yields

The final national *SSY* grid surface so generated (Fig. 10) enables an estimate of the suspended sediment yield from any defined catchment by integrating the *SSY* grid within the catchment boundary. The public-domain internet-based WRENZ tool (http://wrenz.niwa.co.nz/webmodel) automates both definition of the catchment boundary upstream from any point on the national stream network and the *SY* integration. The WRENZ implementation ignores sediment entrapment in lakes, thus where the catchment of interest contains a lake it is necessary to estimate the lake's sediment input and trap efficiency, then discount the yield past the target site accordingly.

Resulting regional and national suspended sediment yields

Specific yields

The *SSY* grid shows wide variability in specific suspended sediment yields around New Zealand (Fig. 10), reflecting the wide variability in the underpinning precipitation (Fig. 3) and erosion terrain grids. In the South Island, the highest *SSY*s (up to 32,000 t/km^2/y) occur in South Westland, due to a combination of steep slopes, heavy rainfall, high uplift rates on the eastern side of the Alpine Fault, and relatively erodible schist lithologies. In contrast, and despite high rainfall, *SSY*s in Fiordland (~40-120 t/km^2/y) are substantially lower due to its more erosion-resistant plutonic and gneissic lithologies. The lowest *SSY*s (< 10 t/km^2/y) occur in the low relief, relatively low rainfall zones along the east coast plains and the inland basins (such as the Mackenzie Country). In the North Island, the highest *SSY*s (~20,000 t/km^2/y) occur in the East Cape area, on the eastern flanks of the Raukumara Range, due to a combination of moderately high rainfall, highly erodible lithologies such as mudstone

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Figure 10 – Raster map of specific yield of river suspended sediment generated by empirical GIS model and sediment yields to coast (Mt/y) totalled by region. Yield totals are adjusted for sediment entrapment in natural lakes and hydro-lakes. Figures in brackets give yields without hydro-lakes. Hatched areas show large natural lake catchments.

and sheared argillites and greywackes, tectonic uplift associated with the adjacent subducting plate boundary, and removal of the forest. Generally, the *SSY*s decrease going northeast across the North Island away from the plate boundary, although they remain relatively high (~ 700 t/km^2/y) in the Whanganui-King Country belt of 'papa' mudstone. The high South Westland yields occur despite native forest cover there, highlighting the influence of precipitation and geological factors. The influence of land cover appears more substantial in the high-yield regions of the North Island, but this relates at least in part to the transient surge in yield associated with deforestation and less extreme rainfall gradients.

Yields to the coast

Hicks and Shankar (2003) used the *SSY* grid reported here to estimate sediment yields from all major rivers draining to the New Zealand coast and also the yields by region (Table 8, Fig. 10). Regionally, suspended sediment yields to the New Zealand coast are dominated by the East Cape area (~ 69 Mt/y) and South Westland (~ 62 Mt/y). The Waiapu and Waipaoa Rivers at East Cape deliver 35 Mt/y and 15 Mt/y, respectively, and their combined yield represents 42% of the yield from the North Island and 24% of the total yield to the New Zealand coast. In South Westland, the Arawhata, Haast, Hokitika, and Whataroa Rivers each deliver 5–7 Mt/y and their combined yield amounts to ~ 27% of the South Island yield. The national total coastal yield (209 Mt/yr) is split reasonably equally between the North Island (118 Mt/y) and the South Island (91 Mt/y). Gauged catchments contributed 42% of the suspended sediment yield from the South Island, 76% of that from the North Island, and 61% of the national yield. Since only ~ 40% of the area of the country was gauged, these figures indicate that the gauged catchments produce higher-than-average yields.

Hicks and Shankar (2003) also integrated the suspended sediment yields delivered to large natural lakes. Assuming 100% trap efficiency, they found that the large natural South Island lakes in total should trap 15 Mt/y of suspended sediment, compared to less than 1 Mt/y for the North Island lakes. These entrapments represent 14% and ~1% of the potential sediment delivery from South and North Island catchments. In contrast, Hicks and Shankar reported that South Island man-made hydro-lakes trap ~ 2.4 Mt/y, while the North Island hydro-lakes trap ~ 0.4 Mt/y (based on measured or calculated trap-efficiencies from Jowett, 1984; Hicks *et al.*, 2000a; Hicks, *et al.*, 2001). Thus, on a national basis, natural lakes intercept a significant portion of the potential sediment yield from the South Island, but hydro-lakes intercept only a small fraction.

Previously, Griffiths and Glasby (1985) estimated total sediment yields of 105 Mt/y from the North Island and 284 Mt/y from the South Island. These were based on the empirical suspended sediment predictor relations of Griffiths (1981, 1982) and assumed a bedload equivalent to 3% of the suspended load. Discounting this bedload component, their North Island suspended sediment yield (102 Mt/y) is much the same as that reported herein, but their South Island suspended sediment yield (276 Mt/y) is three times larger. The largest difference can be traced (Fig. 10) to the Fiordland coast (compare ~ 79 Mt/y from Griffiths and Glasby with 1.3 Mt/y for this analysis), which Griffiths (1981) placed in the same high-sediment-yielding region as Westland, based on his analysis of data from the Cleddau River, which at the time was the only site in Fiordland with sediment gaugings (Hicks *et al.*, 1996). The present estimates of Fiordland sediment yields derive from six catchments (three gauged rivers and the three fiord sediment-trap estimates from Pickrill, 1993), and while these still represent only

Table 8 – Suspended sediment yields to the coast from main New Zealand rivers.

River	Catchment area (km2)	Natural yield (Mt/y)	Yield with hydrolakes (Mt/y)	% of island yield
North Island				
Waiapu	1728	35.07	35.07	29.72%
Waipaoa	2206	14.66	14.66	12.42%
Hikuwai	557	4.96	4.96	4.20%
Wairoa	3669	4.71	4.71	3.99%
Whanganui	7072	4.70	4.70	3.98%
Manawatu	5885	3.74	3.74	3.17%
Motu	1422	3.51	3.51	2.98%
Mohaka	2444	1.37	1.37	1.16%
Ngaruroro	2549	1.33	1.33	1.13%
Rangitikei	3926	1.10	1.10	0.94%
Wairoa	3622	1.10	1.10	0.93%
Tukituki	2480	1.04	1.04	0.88%
Waitara	1154	0.97	0.97	0.82%
Waioeka	844	0.69	0.69	0.59%
Whangaehu	1981	0.69	0.69	0.58%
Whareama	530	0.67	0.67	0.57%
Mokau	1453	0.66	0.66	0.56%
Whakatane	1774	0.61	0.61	0.51%
Ruamahanga	3433	0.60	0.60	0.51%
Waitotara	1172	0.48	0.48	0.40%
Pahaoa	650	0.44	0.44	0.37%
Porangahau	846	0.41	0.41	0.35%
Waikato	14490	0.53	0.37	0.31%
Esk	274	0.35	0.35	0.30%
Patea	1054	0.31	0.31	0.26%
Turakina	973	0.30	0.30	0.25%
Tataekuri	833	0.20	0.20	0.17%
Otaki	367	0.17	0.17	0.15%
Waihou	1984	0.16	0.16	0.13%
Hutt	639	0.13	0.13	0.11%
Awakino	382	0.10	0.10	0.09%
Rangitaiki	2934	0.36	0.08	0.07%
Tarawera	1044	0.07	0.07	0.06%
Waitangi	327	0.07	0.07	0.06%
Kaituna	1228	0.04	0.04	0.03%
Wairoa	471	0.04	0.04	0.03%
Piako	1462	0.03	0.03	0.03%
Tairua	281	0.02	0.02	0.02%
South Island				
Arawhata	934	7.18	7.18	7.89%
Hokitika	1142	6.20	6.20	6.81%
Haast	1347	5.93	5.93	6.52%
Whataroa	589	4.82	4.82	5.29%
Rakaia	2861	4.15	4.15	4.56%
Waiho	288	3.41	3.41	3.75%
Waimakariri	3573	3.14	3.14	3.45%
Waitaha	318	2.82	2.82	3.10%
Waiau	3325	2.80	2.80	3.08%
Buller	6396	2.71	2.71	2.98%
Taramakau	997	2.20	2.20	2.41%
Grey	3952	2.07	2.07	2.28%
Rangitata	1715	1.60	1.60	1.76%
Wairau	4177	0.84	0.84	0.92%
Waiau	8173	0.78	0.78	0.85%
Mataura	5382	0.69	0.69	0.76%
Clarence	3304	0.65	0.65	0.71%
Hurunui	2678	0.53	0.53	0.59%
Clutha	21062	2.39	0.39	0.43%
Motueka	2079	0.35	0.35	0.38%
Waitaki	11913	0.69	0.34	0.37%
Taieri	5703	0.32	0.32	0.35%
Ashburton	1655	0.31	0.31	0.34%
Mokihinui	751	0.28	0.28	0.31%
Oreti	3503	0.26	0.26	0.28%
Pelorus	893	0.24	0.24	0.26%
Conway	504	0.22	0.22	0.24%
Awatere	1621	0.21	0.21	0.23%
Opihi	2373	0.16	0.16	0.18%
Karamea	1234	0.15	0.15	0.16%
Waimea	765	0.11	0.11	0.12%
Kakanui	887	0.11	0.11	0.12%
Aorere	705	0.11	0.11	0.12%
Aparima	1570	0.09	0.09	0.10%
Ashley	1309	0.09	0.09	0.10%
Takaka	932	0.08	0.07	0.08%
Orari	781	0.06	0.06	0.07%
Shag	541	0.06	0.06	0.07%
Waipara	726	0.06	0.06	0.06%
Pareora	538	0.05	0.05	0.05%
Waihao	562	0.03	0.03	0.04%
		145.33	142.55	

a small sample of the Fiordland area, their *SSY* estimates are all over a factor-of-ten less than Griffiths' estimate. Elsewhere in the South Island, the present yield estimates also tend to be lower. While they cover most of the gauging sites analysed by Griffiths and also employ the sediment rating approach, the present estimates generally benefit from ~ 15 further years of sediment gaugings and discharge records, more sites, and a more robust method of fitting sediment rating curves, hence they may be regarded as being more reliable generally.

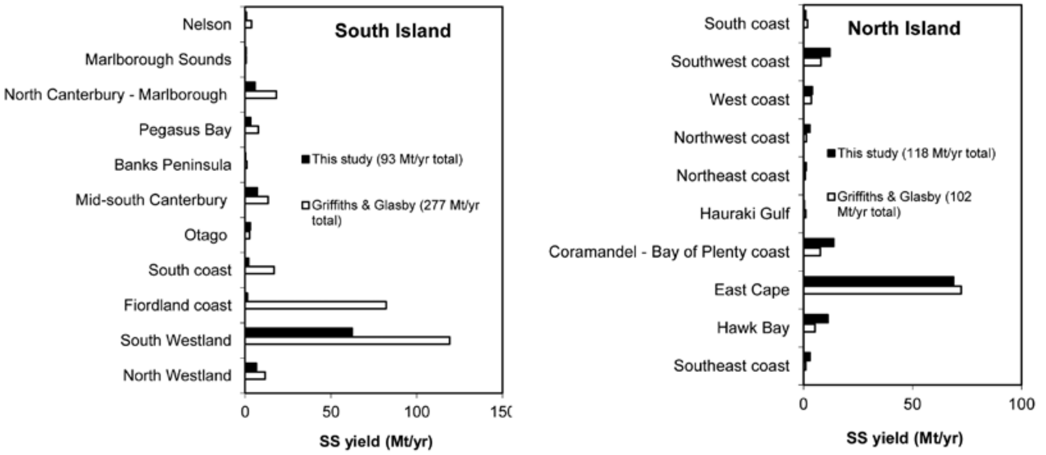

Figure 11 – Comparison of suspended sediment delivery to the New Zealand South and North Island coasts by region from this study and from Griffiths and Glasby (1983).

Discussion

Sediment interception by floodplains and estuaries

The above results on suspended sediment delivery to the 'coast' probably overestimate the true delivery of sediment to the ocean, since they do not consider net sediment entrapment on floodplains and in estuaries.

Floodplain sequestration is likely to have a small effect for several reasons. First, on a long-term average basis, sediment losses to floodplain deposition will be offset to some degree by bank erosion along alluvial reaches. Second, the suspended sediment yields of the large-yielding catchments have typically been measured at gorge outlets to narrow coastal plains, and thus already include any influence by floodplains further upstream. Third, where they cross coastal plains, most New Zealand rivers are either naturally confined within terraces or high banks or have been artificially confined within flood-protection banks. This both limits the area available for deposition and discourages deposition by keeping floodplain velocities relatively high. Moreover, most floodplains between stopbanks are grassed and present low hydraulic roughness, which further hinders sediment deposition. Thus, in contemporary times, the coastal reaches of New Zealand rivers are generally effective conduits for transferring suspended sediment to the coast, and the proportion diverted to floodplains is likely less than the uncertainty in the yield determination. A typical example is the Waipaoa River which, with a sediment yield of 15 Mt/y, carries ~ 14% of the North Island yield. Gomez *et al.* (1999) used floodplain cores, cross-section surveys, and suspended load inflow measurements from the 44-km long coastal reach of the Waipaoa River to show that its floodplain intercepted only 5% of the suspended load over an 11-year period (1979–1990). More particularly, floodplain sequestration amounted to only 16% of the suspended load carried during events that exceeded the bankfull discharge, which included the 70-year return-period flood of March 1988 associated with Cyclone Bola (Peacock and Philpott, 2009). Supporting this, Hicks *et al.* (2000a) used an extensive set of suspended sediment gaugings to show that 86% of the Waipaoa River's suspended load was carried at sub-bankfull flows.

GIS analysis using a database of New Zealand estuaries (Hume *et al.*, 2007) shows that ~ 48% of the total sediment yield is delivered to estuaries. While the sediment trap efficiency will vary from estuary to estuary and has not been systematically determined, it is clear that almost all of the largest load-carrying rivers, e.g., the Waiapu, Waipaoa, Hikuwai, Arawhata, Haast, Hokitika, and Rakaia Rivers (Table 8) connect to the ocean through very small estuaries and the bulk of their loads must pass directly into the ocean. Thus, estuarine interception should amount to only a small fraction of the total suspended sediment flux to the New Zealand open coast, even if the larger estuaries on the relatively low sediment yielding areas, such as the northern North Island and southern South Island coasts, are efficient traps. In Fiordland, while the fiords are effective sediment traps and there is minimal sediment flux to the open coast (Pickrill, 1993), the Fiordland sediment yield is only ~ 0.6% of the national yield. It is concluded, therefore, that at least at a national scale, the above yield figures should be representative of the total delivery of suspended sediment to the open coast.

Global significance of suspended sediment yield from New Zealand rivers

Recent estimates put the contemporary global flux of sediment to the oceans at ~ 12,600 Mt/y (Syvitski *et al.*, 2005; Walling, 2008). New Zealand's yield of suspended sediment amounts to ~ 1.7% of this global total, despite it covering less than 0.2% of the land area. This high average specific yield concurs with previous studies (e.g., Milliman and Meade, 1983; Milliman and Syvitski, 1992) that show the relative importance of small (on a global scale) mountain rivers in tectonically-active coastal settings (e.g., New Zealand, Taiwan, New Guinea), which collectively contribute ~ 33% of the contemporary global total yield.

Syvitski *et al.* (2005) and Walling (2008) note how the contemporary global sediment yield is strongly influenced by human effects: on the one hand, accelerated erosion associated with land use and deforestation has increased sediment delivery into river systems; on the other hand, reservoirs have reduced the delivery from river systems to the ocean. While their figures differ in the magnitude of these effects, the net effect has been a ~ 10% reduction in sediment delivery to the ocean compared with pre-human times. For example, Syvitski *et al.*'s figures indicate human land-use activities have increased the potential sediment flux by ~ 16% but reservoir sedimentation has trapped ~ 22% of this potential flux, whereas Walling estimates a 160% increase in the potential flux due to land-use activities and a 66% reduction in this potential due to reservoir entrapment).

In comparison, at the New Zealand scale, the major hydro-electric reservoirs have reduced the contemporary sediment flux to the ocean by ~ 3.0% for the South Island, 0.33% for the North, and 1.3% for the country overall (using results from this study). The extent to which the contemporary total New Zealand sediment yield reported here has been increased by anthropogenic deforestation and land use has not been determined. Estimates for the more erodible soft-rock hill country of the North Island suggest at least an order-of-magnitude increase in erosion following deforestation. Page and Trustrum (1997) observed a ~10-fold increase in sedimentation rates after European settlement, in cores from Lake Tutira (Hawkes Bay). Similarly, Kettner *et al.* (2007), using a simulation model that incorporated the effects of land cover on runoff and sediment yield, estimated that the suspended sediment yield of the Waipaoa River had increased by 350% after European arrival, when pastoral farming began on the coastal lowlands of Poverty Bay, and by 660% once the catchment headwaters were deforested. Increases in river sediment yield following European settlement are evident in cores from the Waipaoa River floodplain and from the continental shelf off the Waipaoa river mouth (Gomez *et al.*, 2007). In coastal Hawkes Bay hill country, a pasture catchment produced about four times more sediment than a forested catchment (Eyles and Fahey, 2006). For much of New Zealand, however, the sediment yield response to deforestation and European settlement has not been quantified.

The suspended sediment load also serves as a vector or proxy for the oceanward flux of other constituents, including particulate organic carbon (POC) and heavy metals. The national SSY grid described herein was used to estimate the yield of carbon derived from soil erosion (Trustrum *et al.*, 2002; Preston *et al.*, 2003; Hicks *et al.*, 2004; Scott *et al.*, 2006). This involved weighting the SSY grid with soil organic carbon (SOC) loading and erosion depth factors. The SOC loading (which in large part consists of particulate organic carbon) was mapped for three soil-depth bands (Scott *et al.*, 2002), while erosion depth was related to erosion process and severity, as indicated in the erosion terrain classes (Tables 2 and 3). The resulting source grid for SOC was then integrated to derive yields to the coast (after discounting entrapment in lakes), producing a national SOC yield of ~ 4 Mt/y. As detailed elsewhere (Hicks *et al.*, 2004; Zeldis *et al.*, 2009), the highest SOC yields are from the East Cape area, reflecting the depletion of SOC stocks due to human-accelerated, deep soil erosion, and from the South Island west coast, where erosion rates are high and the SOC loading is high and sustained by virtue of the forest cover. These spatial patterns in SOC yield have been verified by several campaigns to directly sample particulate organic carbon loading in major rivers (Lyons *et al.*, 2002; Gomez *et al.*, 2003; Carey *et al.*, 2005; Scott *et al.*, 2006). As with suspended sediment, New Zealand's organic carbon yield ranks high on a global average basis; indeed, Lyons *et al.* (2002) estimated that New Zealand, along with the other high-standing large islands of the western Pacific (Taiwan, Indonesia, Papua-New Guinea, Malaysia, Philippines), contribute 17–35% of the global particulate organic carbon supply to the ocean.

Carey *et al.* (2002) determined heavy metal (Cu, Zn, Ni, Mn, Cr, Co, and Pb) loadings in sediment sampled from 21 New Zealand rivers, focusing on the major sediment-carrying rivers of South Westland, Canterbury, and East Cape (which collectively contribute 89 Mt/y or 43% of the national sediment yield – Table 8). As with other constituents, this showed a significant contribution from New Zealand to global total fluxes. Lyons *et al.* (2005) used flood-water samples from the same 21 sites to estimate dissolved constituent loadings indicative of chemical weathering rates. They concluded that while physical weathering (as indicated by suspended sediment loads) greatly exceeded chemical weathering (as indicated by the dissolved loads) by virtue of the energetic physical erosion and transport processes, the chemical weathering was still higher than expected and was apparently due to the rapid production of fresh bedrock surfaces resulting from the physical processes. Thus, the high rates of physical erosion also increase New Zealand's relative contribution to global ocean chemistry.

Bedload contribution to coastal sediment yield

While measurement of average annual river suspended load is not a trivial exercise, it usually pales in difficulty compared with measuring the bedload (Hicks and Gomez, 2003). Consequently, the availability of bedload information from New Zealand rivers is much less extensive than for suspended load, and this hinders estimation of the total sediment load delivered to the coast. Griffiths and Glasby (1985) assumed that bedload equated to a uniform 3% of the suspended load for all rivers, based on the limited amount of information available at the time. While conceivably this might be a reasonable proportion on a national average basis for coastal reaches, it is now known to be unreliable on a river-by-river basis.

Certainly, down an 'ideal', simple river system, the bedload to suspended load ratio diminishes, with a transition from bedload dominance in headwater reaches, where the bulk of the sediment load is derived, to suspended load dominance near the coast. This occurs in response to progressive conversion of bedload to suspended load through abrasion and to stranding of the coarser bedload fractions in alluvial storage zones due to waning competence of the river, usually associated with decreasing channel slope. However, in many rivers, and particularly those in tectonically active, geologically variable, and geomorphically dynamic landscapes like New Zealand's, downstream variability in sediment sources and calibre, in river grade, and in bed-material transport capacity and competence are the norm. Moreover, there is often unsteadiness in bed-material transfers from primary source, to alluvial storage reach, to depositional sink over the timescales driven by glacial cycles or extreme geologic events such as fault ruptures, earthquakes, and volcanic eruptions. The upshot is that while the suspended load invariably increases downstream, the bedload may increase or decrease.

In terms of the coastal bedload yield, a major factor is the stability of the coastline at the river mouth over the past ~7000 years (late Holocene sea-level still-stand) relating to coastal erosion, progradation, and tectonic movement. For example, while the Waimakariri River carries a bedload of greywacke gravel equivalent to 13% of its suspended load across the northern Canterbury Plains (Carson and Griffiths, 1989, for bedload; this study for suspended load), all of its gravel bedload is deposited several kilometres upstream of the coast at the slope-break caused by late Holocene progradation of the coastal plain into Pegasus Bay (Griffiths, 1979; Wilson 1985). In contrast, the large braided, gravel-bed rivers crossing the south-central Canterbury Plains (e.g., Waitaki, Rangitata, Ashburton, Rakaia Rivers) deliver significant volumes of gravelly bedload to the coast (~13% equivalent of their suspended load, in comparison to the Waimakariri River figures above) because the retreat of that coast ensures that their channels remain relatively steep. Indeed, they pick-up additional bedload along their coastal reaches due to the rejuvenated grade associated with coastal retreat (Leckie, 1994). In comparison, the Waipaoa River at East Cape has a low bedload equivalent (<1% of its suspended load, Gomez *et al.*, 2009) even at the upstream end of its prograding coastal plain due to high abrasion rates for the relatively soft mudstone and sheared argillite found in its catchment and also simply because of the very high generation rate of muddy suspended load at source (Trustrum *et al.*, 1999; Hicks *et al.*, 2000a). For these reasons, and because of the large uncertainty in estimating bedload proportions using empirical methods (Turowski *et al.*, 2010), a systematic attempt at an improved estimate of the national bedload yield to the New Zealand coast is beyond the scope of this study.

Effect of land cover on sediment yield – alternative models

A limitation of the predictive model developed here is that it does not explicitly include the effect of land cover, even though its influence on erosion and sediment delivery rates is well known from international studies (e.g., Wischmeier and Smith, 1978; Jones *et al.*, 2001; Kettner and Syvitski, 2008) and from New Zealand studies (e.g., Pain, 1971; Selby, 1972; Hicks, 1990; Marden and Rowan, 1993; Quinn and Stroud, 2002; Fahey *et al.*, 2003; Marden *et al.*, 2005).

Land cover is included implicitly in the model described here insofar as the various erosion terrains are typically associated with a certain land cover (e.g., downland with pasture, mountain steeplands with forest) and there is an association between rainfall and land cover (e.g., high rainfall areas are typically forested). Moreover, there is a clear influence of native forest cover for several of the special, low-yielding regions that were isolated during the analysis of residuals. Thus, explicit inclusion of a land-cover factor would likely have explained some of the variance shown in this regional adjustment (although some sub-regions appear also to be influenced by regional differences in geologic/ tectonic setting, glacial history, and climate). However, while it may reasonably represent the landscape with its land cover over the 1960s to 1990s epoch when most of the calibration data were collected, the present model cannot be applied easily to predicting changes in sediment yield as a result of future or past changes in land cover.

In this regard, the more recently developed model of Elliott *et al.* (2008) is an improvement. This is based on the SPARROW model (SPAtially Referenced Regression On Watershed attributes, Smith *et al.*, 1997), and it is calibrated using almost the same set of river suspended sediment yields that are used here. Effectively, it relates suspended sediment yield (at the scale of sub-catchments averaging ~ 0.5 km^2 in area) to mean annual rainfall, slope, a simplified version of the erosion terrain classification reported here, and a simple land-cover factor. The latter is assigned a base value for forest and scrub, which is then modified for pasture (yields increased by a factor of 4.56), high-country tussock (no significant difference in yield apparent), and other non-tree land cover. A statistical solution with the extra variables required reducing the erosion terrain classification down to 10 lithology-based classes (plus one more combining urban and horticultural areas). Thus, in effect, the slope dimension was removed from the erosion terrain classification (c.f. projecting Table 4 onto its lithology axis), and slope was explicitly quantified in the model. The model of Elliott *et al.* (2008) explained 93% of the (log-transformed) variance in the observed sediment yields from the New Zealand-wide dataset (214 sites) and had a standard factorial error of 2.2. While slightly less accurate than the model described herein (97% and 96% variance explained, SFE of 1.55 and 1.80 for South Island and North Island, respectively), it does allow estimation of the effects of land-cover change and so has been added into the CLUES (Catchment LandUse Environmental Sustainability) modelling system (Woods *et al.*, 2006b).

Dymond *et al.* (2010) developed a similar, national raster-based model that relates sediment yield to the product of mean annual rainfall squared, an erosion factor, and a land-cover factor. As with this study, their erosion factor was determined for each of the New Zealand Erosion Terrain Classification terrains (as in Tables 2 and 3). Their land-cover factor was assigned either a base value of 1 for woody vegetation or a value of 10 for herbaceous vegetation cover or bare ground, based in part on assessment of the impact of historical deforestation (Page and Trustrum, 1997) and in part on observations of erosion distribution during recent large storms. Land cover was classified from recent satellite imagery. Their method of calibrating the erosion terrain coefficients is vague, but it apparently included using sediment yield estimates extracted from a web-published version of the model grid developed in the current study (Fig. 10). Their erosion terrain coefficients should not match those derived herein because (i) they used a different exponent for rainfall (2.0 rather than 1.7), (ii) their coefficients will have been influenced by the land-cover factor, and (iii) this study includes some regional adjustment of the coefficients. Dymond *et al.* used the older suspended sediment yield results of Griffiths

(1981, 1982), from 80 river catchments on the North and South Islands (which were re-analysed for use in this study along with other sites, as in Table 1), to assess the accuracy of their model, finding that it explained 65% of the variance in (log-transformed) measured yield and had a standard error equating to a factor of 2.48. Based on these statistics, it would appear to be less accurate than either the present model or that of Elliot *et al.* (2008).

Two cautions attend such predictions of the effects of change in land cover or land use on mean annual sediment yield. First, the Elliot *et al.* (2008) and Dymond *et al.* (2010) models assume that the land-cover factor is uniform and independent of the other controls, that is, it is not influenced by climate, lithology, erosion terrane, slope, etc. This is likely only a first-order approximation, since it is hard to imagine the geological susceptibility to erosion not influencing the response to change in vegetation cover. Indeed, Hicks (1990) showed that the ratio of sediment yields from established pasture and exotic-forest land covers in paired catchments from different parts of New Zealand on different lithologies ranged from 1.6–4.8. Second, models such as those of Elliott *et al.* (2008) and Dymond *et al.* (2010) only enable comparisons of mean-annual sediment yields under contrasting land covers after the catchments have stabilised followed the disturbance created by the land-cover change. Such disturbances, notably where deforestation is involved, may induce a phase of accelerated erosion, with yields of the order of 10–100 fold higher than under the previous established land cover. This phase may last (albeit decaying exponentially) anywhere from several years (e.g., Hicks and Harmsworth, 1989; Fahey *et al.*, 2003) to a century (e.g., Kettner *et al.*, 2007; see earlier discussion on Waipaoa catchment), depending on how extensive the land-cover conversion is, while the landscape adjusts and the new land cover matures. These factors may help explain why the forested/un-forested land-cover coefficients of Elliot *et al.* (2008) and Dymond *et al.* (2010) differ by a factor of ~ 2; indeed, it appears that the higher Dymond *et al.* factor has been influenced by the transient component of the European deforestation.

The exponent (m =1.7) for the mean-annual rainfall “driving-factor” derived in the present model is lower than that from other empirical models derived from related versions of the calibration dataset. For example: Elliot *et al.* (2008) derived an exponent of 2.02; Hicks *et al.* (1996) derived an exponent of 2.3; and Griffiths (1981, 1982) derived exponents ranging from 2.81 to 6.18 for his regional relations for the North and South Islands (the raster-based model of Dymond *et al.* (2010) used an exponent of 2.0, but this value was simply assumed and was not derived). There are two likely reasons for this. The first relates to the relatively high-resolution, raster form of the present model, which allows unbiased integration of the non-linear predictive relationship over catchments with large rainfall gradients. It is often the case, for example in the large catchments draining east from the Southern Alps, that the rainfall (and sediment generation) is concentrated near the catchment headwaters and decays exponentially down-catchment. In such circumstances, $<P^m>$ will always be greater than $<P>^m$ (where <> indicates spatial averaging), thus a model based on catchment- or sub-catchment-averaged precipitation $<P>$ should always indicate an apparently higher exponent. Secondly, as noted earlier, in the present model, slope is captured within the erosion terrain classification (c.f., Table 4), whereas the Griffiths (1981, 1982) and Hicks *et al.* (1996) models, by relating sediment yield only to rainfall, will have a higher exponent due to the cross-correlation between slope and rainfall. Elliot *et al.* (2008), whose model does include slope, considered that its exponent on $<P>$ would have increased to 2.6 if the slope factor was removed.

Model accuracy, and areas with limited data coverage

The comparisons of predicted vs. observed yield for the gauged catchments suggest that predictions of yields from un-gauged catchments might generally be expected to have standard factorial errors of 1.55–1.8, with some improvement expected for larger catchments and certainly when averaged over regions. However, less reliable estimates (SFE ~ 2–3) are expected from those regions with little or no data, including Marlborough, the Coramandel-Auckland-Northland region, and the glacier catchments of the South Island West Coast (c.f. Figs. 1 and 10). More data have been collected by Regional Councils from the Auckland, Waikato and Manawatu-Wanganui regions in recent years, thus a re-analysis for those regions would be timely once the yield results are available, but for the other areas listed above new data collection initiatives are required.

Summary and conclusions

The raster-type, GIS-based empirical model developed here enables prediction of the mean annual yield of suspended sediment from any river catchment in New Zealand. For a given unit area, the model relates suspended sediment yield to $P^{1.7}$ (where P is derived from a national grid of mean annual precipitation) times a coefficient that depends on the local erosion terrain and region.

The erosion terrain classification essentially spreads erosion potential by slope and rock-type, with some further differentiation by erosion process. The regional adjustments were required to compensate for other factors that influence sediment yield but were not fully captured by the erosion terrain classification, including land cover, glacial history, and tectonic regime.

The resulting sediment yield grid was scaled uniformly over gauged catchments so that their predicted yields matched the measured yields. The model thus faithfully reproduces the measured yields from the 40% of New Zealand that has been gauged.

Before this adjustment, the predictive model explained 97% of the variance in the log-transformed sediment yields measured at the South Island calibration sites, with a standard prediction error equating to a factor of 1.55. The model explained 96% of the variance in the yield measured at the North Island sites, where the standard factorial error was 1.8. The factorial error in predicted yield decreased weakly as catchment area increases, but became smaller when yield was integrated over larger regions, reducing to only a few % for the total gauged catchment areas in the North and South Islands. These statistics give a measure of the model's accuracy when applied to un-gauged catchments. Less reliable yield estimates (SFE ~ 2–3) are expected for several regions where there was little measured data available for this study, notably Marlborough, the glacier catchments of the South Island West Coast, and the Coramandel-Auckland-Northland region. This could be mitigated by recalibrating the model with data that has been collected from the latter region over the past decade, but elsewhere new data collection initiatives would be required to improve yield predictions.

While defined on a 1-hectare grid, it is recommended that the model is used to predict sediment yields only from catchments with areas exceeding ~ 10 km^2.

After adjusting for lake entrapment, the model indicates total suspended sediment yields to the coast of 91 Mt/y from the South Island and 118 Mt/y from the North Island, with much of this delivered from the East Cape and South Westland regions. Natural lakes intercept 14% of the potential sediment yield of the South Island, but only ~ 1% of that of the North Island, while hydro-lakes intercept ~ 3% of the South Island yield and ~ 0.3% of the North Island yield. Floodplains and estuaries are considered to intercept only a small percentage of the total sediment delivery to the coast. The total suspended sediment yield from New Zealand amounts to ~ 1.7% of the global sediment delivery to the oceans.

The sediment yield model developed here can be, and has been, used for estimating the oceanic delivery of other constituents that use suspended sediment as a vector, including particulate organic carbon and heavy metals. However, in its present form the model is not suited to assessing the effects of changes in land cover or land use on sediment delivery because this was not explicitly included as a controlling factor. Some recently-published related models do incorporate a land-cover factor, but they are less accurate overall at predicting yields from the current New Zealand landscape.

Future research could consider developing a sediment yield predictor that combines the lessons of previous empirical models (including this one) by taking explicit account of regional variations in geological history and tectonic setting, using a rainfall parameter (such as the erosivity index) that is more directly linked to erosion intensity, incorporating a wide range of land uses, and considering the transient effects of land-use change on sediment yield. Also, such advances will need to be underpinned by more sediment yield data, both from regions where data is currently sparse and from catchments that better sample the range of controlling factors.

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