SEDIMENT LOADS OF NORTH ISLAND RIVERS, NEW ZEALAND — A RECONNAISSANCE

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ABSTRACT

Suspended load, dissolved load, and bedload (for 23 catchments only) are calculated by approximate methods for 40 rivers in the North Island. The proportion of each type of load is roughly 88%, 10%, and 2% but the dissolved load is relatively more important in rivers draining catchments with slight erosion and the bedload more important in rivers draining directly from the eastern mountain ranges. The river catchments, mostly 150 to 1500 km^2 in area, have suspended sediment yields ranging from 35 t/km^2.yr to 28 000 t/km^2.yr with the highest yields being from catchments in the East Cape region.

INTRODUCTION AND SCOPE

Suspended load concentrations and flows have been sampled at river sites in the North Island of New Zealand since 1959 by the Ministry of Works and Development (MWD), but no regional analysis of the data has hitherto been made. For about 40 sites sufficient data are now available to estimate river loads and catchment yields.

The methods used here for calculating river loads are only an approximation to the ideal. For example, in this paper a single sediment concentration-flow relationship (rating) is used for each river, although detailed work on small catchments outside of New Zealand (e.g. Wood, 1977; Gregory and Walling, 1973) has shown that rating curves differ between seasons, and that separate curves may be justified for rising and falling flows (Walling, 1977). Almost without exception the sediment concentration data for New Zealand rivers are too sparse to enable such a detailed analysis. Hence I have chosen to use a single rating for each river, but have eye-fitted the rating line to take the rising stage concentrations into account.

Although the loads quoted below and in Table 1 are calculated by simplified methods, they have the important advantage that they have all been calculated in the same manner, and so can be directly compared.

This paper supplements the New Zealand sediment-yield data presented by Thompson and Adams (1979) for the eastern South Island and by Adams (1978) for the remainder of the South Island, both data sets being calculated by the same approximate methods used below. Sediment data for the northwestern part of the North Island are sparse and incomplete, but indicate yields rather lower than those reported here.

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	M.W.D. Site	River	Site	A	Q	R	S	a	b	e	h	C_5	Ys	Yd	Yb	Es
				(km^2)	(m^3/s)	(m/yr)	(10^{-4})					(mg/l)	--(kt/yr	)--		($t/km^2/yr$)
A		Waihou	Estuary	1500									55			35
1	15432	Rangitaiki	Kopuriki	2318	56	0.76		0.57	5	2.3	0.04	3100	210	212		90
2	15410	Whirinaki	Galatea	534	15	0.89	54	0.25	5	2.3	0.25	590	70	57	11	130
3	15514	Whakatane	Whakatane	1557	57.1	1.16	10	0.28	3	2.3	1.0	880	1590	216	53	1020
4	15511	Waimana	Gorge	440	21.8	1.56	8	0.19	4	2.3	1.3	670	600	83	9	1360
5	15901	Waioeka	Gorge	640	30.2	1.49	26	0.2	3	2.3	2.7	1650	4300	114	102	6630
6	16502	Motu	Waitangirua	293	13.5	1.45	47	0.2	3	2.3	2.7	380	440	51	82	1500
7	16501	Motu	Houpoto	1393	91.5	2.07	27	0.24	3	1.7	0.92	1700	4500	347	268	3200
8	17602	Mangatutu	S.H. 35	14	1.4	3.2		0.2	3	1.7	1.4	110	7	5		490
9	19711	Waingaromia	Terrace	174	8.4	1.5	11	0.2	3	1.7	1.4	9500	3500	32	12	20300
10	19716	Waipaoa	Kanakanaia	1582	41.8	0.83	8	0.21	3	1.7	1.3	13000	22300	158	41	14100
11	19712	Mangatu	Omapere	155	6.6	1.34	36	0.25	3	1.7	0.84	25000	4400	25	25	28000
12	19725	Waikohu	No. 3 Bridge	597	13.5	0.71		0.2	3	1.7	1.4	1300	775	51		1300
13	19709	Wharekopae	Killarney	170	3.9	0.72	13	0.18	3	1.7	1.8	260	58	15	7	340
14	21437	Hangaroa	Doneraille	578	(18)	(1.0)	12	(0.2)	(3)	1.7	1.4	1100	890	68	28	1500
15	21410	Waihi	Waihi	50	2.2	1.4		0.23	3	1.7	1.0	250	17	8		350
16	21409	Waiau	Otoi	513	27.4	1.7		(0.2)	(3)	1.7	1.4	1100	1330	104		2600
17	21801	Mohaka	Raupunga	2370	79.5	1.06	13	0.26	4	2.3	0.54	1700	2300	88	38	970
18	21803	Mohaka	Glenfalls	997	41.9	1.33	52	0.3	4	2.3	0.36	1400	670	46	69	670
B		Tutira	Lake Tutira													2125
19	22802	Esk	Waipunga Br.	253	5.2	0.65	10	0.1	4	2.3	2.4	220	87	6	5	340
20	23001	Tutaekuri	Puketapu	792	15.2	0.61	14	0.15	4	2.3	2.5	100	120	17	14	150
21	23104	Ngaruroro	Kuripango	370	17.0	1.45	83	0.40	3	2.3	0.36	1450	280	19	92	760
22	23106	Taruarau	Taihape Rd.	260	6.1	0.74		0.41	3	2.3	0.33	1050	70	7		250
23	23103	Ngaruroro	Whanawhana	1093	28.6	0.83	43	0.32	3	2.3	0.68	900	552	32	100	500
24	23201	Tukituki	Red Bridge	2380	48.2	0.64	19	0.22	3	2.3	2.1	700	2240	53	108	940
C		Tukituki	Folgers Lake	80											280	
D		Ruahine Str	Foothills	c.10												7000
25	29231	Taueru	Te Weraiti	373	5.5	0.47		0.14	3	1.7	3.0	150	78	6		210
26	29244	Whangaehu	Waihi	36	0.6	0.53		0.15	3	1.7	2.6	180	9	1		250
27	29201	Ruamahanga	Wardells	637	25	1.2		0.29	3	2.3	0.9	420	300	28		470
28	29202	Ruamahunga	Waihenga	2340	64	0.86		0.27	3	2.3	1.1	280	620	71		270
29	29808	Hutt	Kaitoke	89	7.7	2.7	36	0.22	3	-	-	-	-	9	33	-
30	31801	Otaki	Gorge	300	24	2.5	40	0.19	3	-	-	-	-	27	135	-
D		Otaki	Gorge	300												2600
E		Mangahao	No. 2 Dam	81	6	2.3								7		2000
31	32705	Rangitikei	Otara Br.	2865	83.6	0.92	18	0.51	3	2.3	0.19	5600	2800	198	77	980
32	32733	Moawhango	Moawhango	650	15.2	0.74		0.55	3	2.3	0.15	480	40	36		53
33	33301	Wanganui	Paetawa	6643	227	1.08		0.38	3	1.7	0.33	1250	3000	537		450
34	33309	Manganui	Ashworth	332	18.4	1.75		0.30	3	1.7	0.56	65	20	44		64
35	33302	Wanganui	Te Maire	2212	84	1.2		0.43	3	1.7	0.26	480	330	199		150
36	33311	Tangarakau	Tangarakau	238	11.7	1.55		0.25	3	1.7	0.85	220	70	28		290
37	33313	Ohura	Tokorima	668	23.6	1.11		0.3	3	1.7	0.56	200	80	56		125
38	43459	Tongariro	Turangi	780	49.1	2.0	39	0.5	4	2.3	0.09	2300	340	116	37	430
39	43460	Tongariro	Puketarata	495	35	2.2		0.6	3	2.3	0.13	380	50	83		110
40	43461	Tongariro	Upper Dam	174	11.6	2.1		0.3	3	2.3	0.8	150	44	27		250
F	43446	Waikato	Mercer	13701/4600	420	0.9	1.3						372	1000	220	80

TABLE — 1 River loads for North Island rivers and annual suspended sediment yields (Es. in t/km².yr) from their catchments. Other column notation is as in the text. Values in the body of the table that have been estimated are enclosed by brackets. The catchments are numbered and lettered in clockwise order from the northwest and are located on Fig. 1. Two catchment areas are given for the Waikato, the smaller excludes the catchment upstream of the Karapiro Dam. Site numbers beginning in 434 must be prefixed by "10". Letters refer to ungauged catchments for which yields are cited in the text.

CATCHMENT LOCATION AND DESCRIPTION

Forty catchments were considered to have sufficient flow and sediment data for analysis (Fig. 1). An attempt was made to include every river site that had high-flow sediment data. The catchments vary in size from 14 to 6640 km², with most being between 150 and 1500 km². Many of the catchments in the east include part of the eastern mountain ranges that parallel the eastern coast of the North Island. The eastern ranges include the Tararua, Ruahine, Huiarau, and Raukumara ranges. They are composed of Triassic to Lower Cretaceous greywackes that are flanked to east and west by younger, weaker, and softer sedimentary rocks, mainly Upper Tertiary siltstones. The ranges parallel the offshore trench that marks the Pacific-Indian plate boundary and are being uplifted as a result of plate movement. In the southern part of the island, Ghani (1978) measured coastal uplift of 1 to 2 mm/yr and deduced

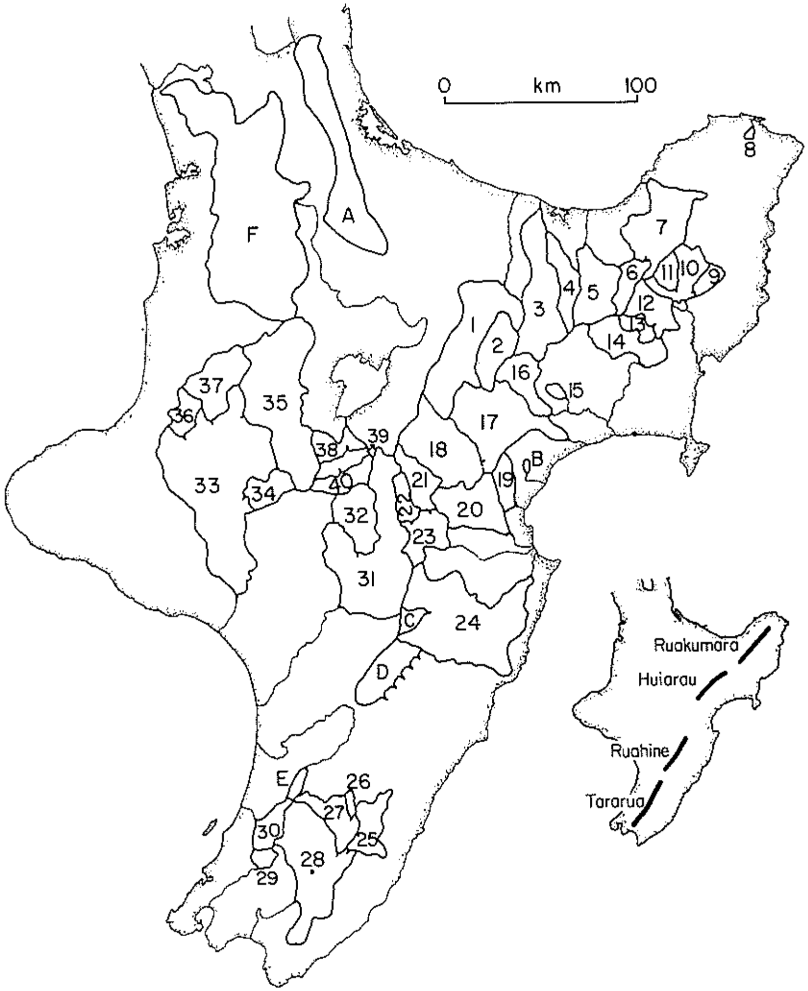

FIG. – 1 Map of most of the North Island, locating the river catchments for which load data is given in Table 1. Inset shows location of mountain ranges mentioned in the text.

the Tararua Range to be rising at 4 to 7 mm/yr. North of Napier, uplift of the ranges is unlikely to be less than 2 mm/yr. The high uplift may explain in part the relatively high erosion rates reported herein, since without rapid erosion, unreasonably high mountains might have been formed.

The Waihou, the Wanganui, and the Waikato are the only rivers considered here that do not drain at least partly from the eastern ranges. The Wanganui catchment is mostly in Tertiary sedimentary rocks similar to those flanking the eastern ranges, while the Waihou and the Waikato drain catchments of varied rock types that include greywackes, volcanics, and Tertiary sedimentary rocks.

Rivers draining from the eastern ranges carry greywacke gravel as bedload and carry suspended load from hillslope erosion and from abrasion of the gravel. Erosion of the softer sediments flanking the ranges provides little bedload but much suspended load, so that the gravel of the braided lower reaches of the rivers is almost entirely greywacke.

The ranges rise to about 1300 to 1500 m above sea level and receive more than 1000 mm of precipitation (mostly rain) a year. Most of the large rivers drain from the wet ranges across drier foothills and plains that have less regular precipitation but that have intense (more than 150 mm per 24 hours) rainstorms (Tomlinson, 1976).

Native forest originally covered most of the ranges and foothills, but from 1870 to 1910 much of the forest was cut and burned by European settlers to clear land for pasture. Most of the remaining forest is on the higher parts of the ranges, and is now preserved to protect the land from erosion. The clearing of some steep unstable hill land caused severe erosion locally.

DETERMINATION OF SEDIMENT LOADS

Suspended Load

Accurate determination of suspended sediment loads requires detailed knowledge of river discharge and of sediment concentration. Ideally both should be monitored continuously, or at very short time intervals, for a number of years, but for sediment the ideal is not yet economically justified in New Zealand. However, water levels ('stage') are automatically recorded every 15 minutes at certain sites and periodic direct measurements of stage and flow are used to convert ('rate') stage to flow. When rated, the stage data give a perfectly adequate flow record for the sampled period, and the flows can be computer processed to give mean flow and flow duration.

Almost all the flow and concentration data used here are now stored on magnetic tapes by the MWD, Wellington, New Zealand, and are available there. Some older concentration data were published by the Ministry of Works, Wellington in the 'Hydrology Annual' series from 1959 to 1968. This paper uses data available before April 1978; copies of the concentration-flow scatter plots and fitted lines are available from the Geology Department, Victoria University, and from the author.

Sediment concentration is measured using depth-integrating samplers at some of the flow sites during some of the direct flow measurements. The sampling program gives a number of instantaneous sediment determinations at a range of flows taken over a period of years. Traditionally, following United States experience, the instantaneous sediment load determinations are plotted against flow on log-log paper, a sediment rating (load–flow relation) is calculated by least squares regression, and the rating is applied to the continuous flow data to give the sediment load for the time period covered by the flow record.

An alternative method, derived by Thompson and Adams (1979) and suited to the sparse New Zealand data, is used in this paper. Thompson and Adams pointed out that the relation between sediment concentration and flow is not constant during a flood, the concentration being greater on the rising than on the falling stage. Such flushing or 'loop rating' behaviour, recently discussed by Wood (1977), has been demonstrated in New Zealand for the Mararoa River (Christian and Thompson, 1978). The measurement error is much smaller than the scatter of points due to the flushing effect.

Such data are not suited to least squares regression, and so Thompson and Adams (1979) eye-fitted the sediment rating line (usually a line with a given slope) to pass midway between the scatter of data points. In fitting the lines, samples with sediment concentrations less than 10 mg/l or with flows less than half the mean were given the least weight, and the line was fitted to the high concentration points most important for sediment transport.

Half the river sites have ten or fewer data points, and these sometimes give regression lines with high correlation coefficients ($r > 0.95$, significant at the 99% level). Such excellent correlations are inherently suspicious, as many factors are known to cause scatter about rating lines, and as other North Island rivers with much more data show that a well-developed rating is the exception rather than the rule. The implication is that the high correlations are spurious, and so therefore is the precision of the estimated slopes.

A form of weighted least squares regression, in which the data are weighted by the standard deviation (±0.15 log unit; estimated from rivers where the data are numerous) of the concentration data (method used by Crosson, 1976, Eq. 12 et seq.) typically gives slope-error estimates about three times larger than given by simple regression for sites with high correlation coefficients and few data points. In standard regression a single, isolated high point is commonly fitted as if it had little associated error, but the weighting method prevents such points from unduly reducing the slope-error estimate, although it still gives the same slope estimate.

In the present work, as in Thompson and Adams's analysis of the eastern South Island, the sediment rating ($C_i = a\,Q_i^p$) is described by the slope (p) of its line on log-log paper and by a point (C_5), the concentration in mg/l at a flow of five times the mean flow (Q). Then the concentration (C_i) for any instantaneous flow (Q_i) is:

$$C_i = C_5(Q_i/(5Q))^p \qquad (1)$$

The choice of C_5 for the point on the rating line stresses the importance of flows about five times the mean flow for sediment transport, as these carry most of the sediment on a long term basis (do maximum geomorphic work, in the magnitude-frequency concept of Wolman and Miller (1960)). In addition I propose to use only two values of p, 1.7 and 2.3. Typically these correspond to catchments in soft Tertiary sediments and in greywacke, respectively Values of p calculated by regression from available data may differ greatly between adjoining, but similar, rivers because sparse data and a poor distribution of data points can affect the slope of the regression line significantly. When lines of 1.7 or 2.3 are eye-fitted to the concentration-flow data, for most rivers the scatter about the line is about the same as about the regression line, and typically the values of p adopted are within the confidence interval of slopes calculated by the weighted regression.

A similar method that chose a regional value for the slope (p) of the rating equation has previously been applied by Jovanovic and Vukcevic (1957) to compare the erosion of catchments in Yugoslavia.

The flow distribution can be normalized by scaling to mean flow and described by two parameters (Thompson and Adams, 1979):

$$f=\exp(-aq-b+(a+b-0.7)/q) \qquad (2)$$

where f is the fraction of time that the normalized flow q ($q=Q_i/Q$) is exceeded, and a and b are parameters of the distribution (and are given for each river on Table 1). Equation 2 is designed to fit the flow distribution at the large flows that are the most important for sediment transport, and although Eq. 2 does not fit the distribution at flows near the mean very well, the difference does not affect the calculation of sediment yield by more than a few percent.

The magnitude-frequency concept gives the mean load (G, in grams per second) as the sum of the products of each value of flow by the concentration at that flow and by the fraction of time that the flow has that value, or in integral form:

$$G=\int_{f=0}^{1} Q_i C_i df \qquad (3)$$

Hence, in terms of the above equations for the sediment rating and flow duration curves, the annual yield (Ys, in tonnes per year) is:

$$Ys=31.56\,G=31.56\,h\,C_5\,Q \qquad (4)$$

where h is an integral evaluated numerically by Thompson and Adams (1979), and presented by them as a graph of h in terms of some useful values of a, b, and p ($0.15<a<0.6$; $b=3, 4, 5$; $p=1.7, 2.0, 2.3$). Their graph shows that the load estimate is sensitive to the exact value of p only when a is less than 0.25. The errors in C_5, h, and Q are estimated to be in the ratio 3:2:1. The accuracy of the calculated suspended sediment yields (ratio of calculated to actual load for the sampling period) is difficult to assess, but is probably better than ±50%.

A cautionary note on the use of sediment ratings was sounded by Walling (1977) who showed that for three Devon rivers their use overestimated the load (as calculated from a continuous record of turbidity) by more than 50%. On the positive side, Thompson and Adams' (1979) comparison of the approximate method used here to the accumulation of silt behind the Roxburgh and Matahina dams suggests the method to be accurate to better than ±20%. These uncertainties in the accuracy of the data should be considered when the reconnaissance results are used.

The suspended sediment yields in Table 1 were calculated by determining values of a and b from flow duration curves, values of p and C_5 from concentration-flow plots, values of h from a, b, p from Thompson and Adams (1979) and then applying Equation 4.

Dissolved Load

Insufficient data have been collected to determine accurately the dissolved load carried from the 40 catchments, but it can be estimated from routine drinking water analyses made by the Chemistry Division, New Zealand Department of Scientific and Industrial Research.

One detailed study of dissolved load is from the Riwaka River in the South

Island (Williams and Dowling, 1979, Fig. 7), where the dissolved load concentration decreased by only 15% as flows increased from 0.6 to 40 m^3/s. Although the Riwaka data are for a catchment that is largely limestone, a slight decrease or increase is also found for humid-temperate catchments in Devon (Gregory and Walling, 1973, Fig. 4.10B), and similar behaviour is to be expected for New Zealand rivers. Hence, in the lack of any evidence for drastic concentration changes with flow, the drinking water analyses are presumed to represent mean concentrations carried by the rivers. Cyclic salts blown in with the rain were excluded by subtracting twice the chloride concentration, as seawater salts are about 55% by weight chlorine. The non-cyclic concentrations (shown in Figure 19 of Adams, 1978) were averaged within three regions to give 120 mg/l for catchments 1 to 16, 35 mg/l for catchments 17 to 30, and 75 mg/l for catchments 31 to 40 and for the Waikato. The standard deviations of the averaged concentrations were about 40% of the mean, and so the dissolved load might be in error by a factor of two for any one catchment. The annual dissolved load (Yd) carried from each catchment was calculated from the corresponding mean concentration and mean annual water discharge, and is given in Table 1.

Bedload

The calculation of the bedload carried by gravel-bed rivers is made by a formula derived from the Einstein-Brown formula by Thompson (1976), who assumed that at all times the river-bed stone size was half the size readily transported. Thompson's derived equation was further modified by Adams (1978, p.41) who integrated the relationship with respect to $f=\exp(-aq-b)$ for the flow distribution and so included all high flows but only a small proportion of the low flows that are below the threshold required to transport gravel. The formula was compared by Adams (1978) to estimates of natural gravel replenishment at gravel extraction sites on some large rivers, and against estimates (Mosley, 1978) of erosion in the much smaller Ruahine streams where most of the load is bedload; the scatter of values was within + 75% and –40% of the calculated values. The formula used is:

$$Yb = 174 \times 10^6 \, n \, S \, Q/(a \exp(b)) \qquad (5)$$

where Yb is the annual bedload in tonnes, n is Manning's 'n' and is taken to be 0.03, S is the channel slope in radians, and Q, a, and b are as above. The form of Eq. 5 is plausible in that steep, rough, large rivers that exceed the flow threshold often (small values of a and b) will carry the most bedload. Equation 5 has been used to calculate the amount of bedload carried from some of the catchments (Table 1); others may lack mobile gravel beds and are not suited to the method.

Sediment Yields Previously Documented

In addition to the forty rates calculated here for the first time the following nine rates have been taken from the literature (Table 1). None are particularly accurate or valid as long-term rates. The Waihou River gives 35 $t/km^2.yr$ from the net seaward transport of suspended sediment in the estuary (Wilshire, 1971). The Matahina Dam on the Rangatiki River goes $100/km^2.yr$ (Thompson and Adams, 1979). An earlier analysis for the Waipaoa catchment gave 8000 $t/km^2.yr$ (Jones and Howie, 1970). Sediment in Lake Tutira 30 km north of Napier gives 2125 $t/km^2.yr$ (Grant, 1963). The upper Tukituki River was dammed by a landslide in 1968 to form Folgers Lake, and sediment accumulated in the lake gives 3500 t/km^2.yr for bedload alone, no estimate being made of the suspended load (deLeon, 1976, unpublished data quoted by Mosley, 1978). Streams draining the eastern Ruahines give an average rate of 7000 t/km^2.yr (Mosley, 1978). The Otaki River gives 2600 to 3200 t/km^2.yr (Manawatu Catchment Board, quoted by Mosley, 1978). On the Mangahao River the desilting of a reservoir gave 2000 t/km^2.yr (Thompson, 1976). On the lower Waikato River suspended load gives 80 t/km^2.yr for the catchment below the Karapiro Dam (Finley, 1974). Sediment supplied to the river above the dam is trapped by Karapiro and other dams and by Lake Taupo.

DISCUSSION

It will be clear from the above that the loads estimated in Table 1 are approximate values only, and that the analysis is of a reconnaissance nature. Despite this, the variations and relations shown by the data are in many cases significant, being much greater than a factor of two and hence greater than the probable error.

The sediment yields in Table 1 have a great range and show that there are a few catchments that are eroding very rapidly and a few that are eroding slowly. For the rapidly eroding catchments almost all the river load is carried in suspension, but for the slowly eroding catchments the dissolved load may exceed the suspended load. The bedload is normally 10% or less of the total load. On the basis of rivers draining into the sea, the total load recorded in Table 1 is 55 Mt, of which suspended load is 88%, dissolved load 10%, and bedload 2%. The percentages are close to the 93%, 4%, and 3% found for the South Island by Adams (1978, p.49), and indicate that for New Zealand as a whole the suspended load is by far the most important part of the total load.

Gregory and Walling (1973, p.340) state that "solute transport increases in magnitude with increase in annual runoff and approaches equality with sediment transport where runoff exceeds 600 mm. At greater runoff levels, it is likely that both exhibit a similar increase". They suggest that both yields are about 100 t/km^2.yr for a runoff of 1 m/yr. The loads in this paper, despite their inherent large errors, demonstrate that for New Zealand there is no simple relation between suspended load, dissolved load, and runoff as suggested by Gregory and Walling (Fig. 6.20C), and that the suspended load far exceeds the dissolved load except in catchments with relatively low erosion rates. There is a slight variation in dissolved yield between catchments of greatly differing erosion rate, concentrations varying by a factor of four for similar runoff, but it is clear that in New Zealand physical rather than chemical denudation dominates.

Since in most catchments the suspended load is the largest and best estimated part of the total load, the regional variations in river load will be discussed in terms of the suspended load alone.

The map of suspended sediment yields (Fig. 2) and Table 1 give erosion rates for catchments that may include rapidly eroding headwaters as well as slowly eroding lowlands in the average value. The variation of erosion rate within catchments is seldom known, but may reflect rainfall, relief, or uplift patterns as indicated for the eastern slopes of the Southern Alps by Thompson and Adams (1979). In some large rivers, storage of upland sediment in low-

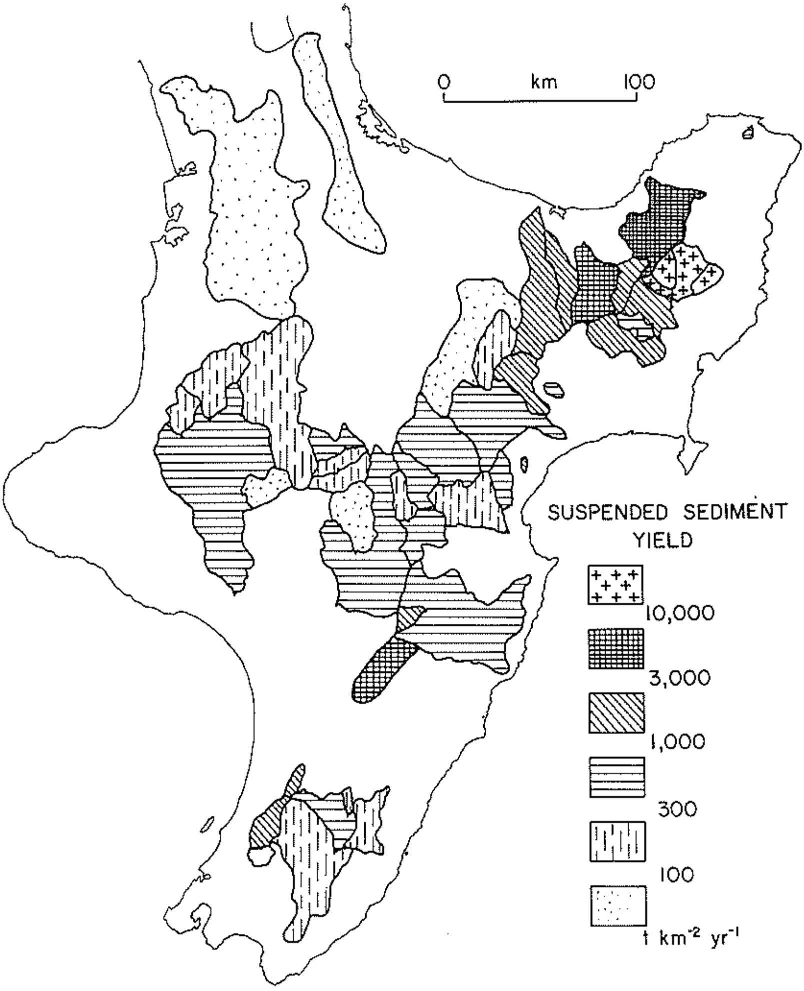

FIG. – 2 Map showing suspended sediment yields from catchments in Table 1. The catchments can be identified by reference to Fig. 1 and Table 1.

lands may be important, but this has been established only for the Waipaoa (Jones and Howie, 1970).

Figure 2 shows that erosion rates in the eastern ranges are very high north of the Mohaka River, lower between the Mohaka and the Tukituki, and then somewhat higher again in the Ruahine and Tararua ranges. The lowest rates are from the catchments farthest away from the eastern ranges and from the active plate boundary – the Waihou, Wanganui, and Waikato rivers – and these are also the catchments with the lowest average relief and that show the least evidence for rapid uplift. Average erosion rates (Table 1) cannot be used to deduce much about the local balance between uplift and erosion, since both may be restricted to a small part of the measured catchment. However they do suggest that for the Tararua Ranges the erosion rate is much less than the uplift rate inferred by Ghani (1978), and hence that the ranges are growing.

Unlike the suspended sediment yield data presented by Thompson and Adams (1979) for the eastern slopes of the Southern Alps, the catchment data here lack any overall relation between rainfall or runoff and erosion. There is also no simple relation between erosion rate and catchment area, some catchments of c. 10 km^2 (e.g. Ruahines) are eroding at 700 t/km^2.yr and one of 14 km^2 (Mangatutu) at 490 t/km^2.yr; some of 1500 km^2 (e.g. Waipaoa) eroding at 14000 t/km^2.yr and some (Waihou) at 35 t/km^2.yr. Nor is there any simple relation between relief and erosion, the Tararua and Raukumara ranges having comparable relief but greatly differing erosion rates.

The lack of such relations is probably due to large variations between catchments in rock type and uplift rate, and perhaps also to the varied extent of man-accelerated erosion. It is possible that within smaller regions (e.g. the Waipaoa basin) classic relations between erosion rate and relief-length ratio, drainage density, or percent undisturbed forest, may be shown, but they cannot be established for the entire North Island.

River transport of suspended sediment is supply-limited; that is much more sediment could be carried if it were to be supplied. In the South Island the suspended sediment loads calculated from the present (short-term, or about 20-year) river data were found to be only part of the total long-term load, additional load about equal to the calculated present load being supplied to the rivers by infrequent, earthquake-caused landslips (Adams, 1978). The additional load (termed "abnormal" by Adams, and almost all carried in suspension) is carried out to sea rapidly (most within the first five years), and with one exception (following the Inangahua earthquake (Adams, 1978, p.67–68)), has not been sampled by the MWD program. There has been no major earthquake in the North Island in the last 40 years, and so the sediment samples taken over the last 20 years and the loads calculated from them do not measure or include any abnormal load.

The earthquake-caused abnormal load in the South Island roughly doubles the erosion rate, but in the North Island the effects of earthquakes appear to be less important than those of storms. At Tutira, only 25 km from the epicentre of the magnitude 7.8, 1931 Hawkes Bay earthquake, Guthrie-Smith (1953, p.55) considered that "the weight of soil displaced by the earthquakes was less by far than that of one or other of the heaviest deluges of rain that have occurred during my occupation of Tutira". Possibly therefore, large intense storms (Guthrie-Smith recorded 325 mm in 24 hours in 1938) are a more important cause of erosion.

Although a magnitude-frequency relation for storms could probably be established for parts of the North Island, there is as yet insufficient data on the erosion caused by such storms. In contrast to the Southern Alps, where storms usually have a regional extent, local, intense storms are more important in the eastern North Island and may cause erosion in only part of a large catchment. However, to the extent that their river flow effects are estimated by the flow distribution equation (Eq. 2), and their sediment concentrations are estimated from an extrapolation of the sediment rating curve (Eq. 1), their contribution to erosion is already included in the sediment load calculations made in Table 1.

One possible way to check the 20-year river loads is to compare them with the sediment that has accumulated over a much longer period of time on the sea bed off the river mouths. Unfortunately offshore sedimentation rates are still poorly known. Although no firm conclusions should be drawn from the rough estimates in Table 2, to within the expected accuracy the sea-bed rates are about the same as the river load estimates for Hawkes Bay and the South Taranaki Bight. For the eastern Bay of Plenty, off the northwest slopes of the Raukumara Range, the sea-bed rate is a third the river load estimate, and either much sediment is passing the shelf, or the river load estimates are too high.

	Measured river load (Mt yr^{-1})	Estimated total supply (Mt yr^{-1})	Sea-bed Accumulation (Mt yr^{-1})	Sea-bed data source
E. Bay of Plenty	10.6	16.0	5.4+	After Kohn and Glasby (1978)
Hawkes Bay	7.5	13.0	9.6+	inshore (2.6) from data in Pantin (1966) offshore (7) from Lewis (1973)
S. Taranaki Bight	6.7	17.6	12.5±	Adams (1978, p.95) from Van der Linden, (1969)

Table – 2 A comparison of river load and sea-bed deposition rates for three regions off the North Island. The total supply from the land is estimated on a proportional-area basis from the measured load Units are Mt= 10^6 tonnes.

Around East Cape, buried soil horizons and dated tephras within floodplain sediments allow the estimation of the long term sediment accumulation rate and the change in rate that has occurred during the last 100 years because of European forest clearing. In the lower Waipaoa Valley the rate of sediment accumulation on the floodplain since 1932 is 5 to 10 times the average rate for the last 3400 years (Pullar and Penhale, 1970). Shoreline progradation also gives a similar change. At the mouth of the Waipaoa (Pullar and Penhale, 1970) and near the mouths of the Rangitaiki and Whakatane rivers in the Bay of Plenty (Pullar and Selby, 1971) the historic progradation rate is roughly double the 3400-year rate. Both types of change indicate some man-accelerated erosion in the East Cape region. By contrast, in his discussion of the rapid erosion rates from the eastern slopes of the Ruahines, Mosley (1978, p.43) concluded that the natural rates were so high that the additional erosion caused by man's influence (mainly through the introduction of deer, goats, and opossums and consequent deterioration of the vegetation cover), was of minor importance. Further work to refine the river load estimates and sea-bed accumulation rates and to relate the two might better establish both long and short term rates and their relationship.

CONCLUSIONS

River suspended loads calculated by the method derived by Thompson and Adams (1979) have been used to determine, in a reconnaissance manner, the regional pattern of erosion in the North Island. The most rapid erosion is from the eastern ranges, especially from catchments in the East Cape region, and the least rapid erosion is in the extreme west. Dissolved load and bedload have also been estimated, though with less confidence. The river load carried from the North Island is almost all suspended load, but from catchments with low sediment yields the dissolved load may equal or exceed the suspended load. The bedload is a relatively unimportant part of the load except in rivers draining directly from the eastern ranges.

One of the important objectives of future research must be to revise the load estimates presented in this paper and to separate the man-accelerated part (if any) from the natural erosion rate. Then geologists will be able to discuss the rates with respect to the long term evolution of the New Zealand region and soil conservators will know the magnitude of the problem they face.

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