Estimation Of Long-Term Sediment Loads In The Fitzroy Catchment, Queensland, Australia

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EXTENDED ABSTRACT

With a catchment area of nearly 140,000 km^2, the Fitzroy discharges a significant amount of sediment to the Great Barrier Reef lagoon. Sediment discharge is related to water turbidity which has a direct impact on coastal ecosystems. Previous estimates of the long-term average sediment load of the Fitzroy vary greatly 1.3 - 2.5 Mt (1 Mt = 10^9 kg). These estimates, however, were mostly based on an extrapolation of sediment loads from other catchments in Queensland. In addition, sediment loads from major tributaries of the Fitzroy have not been assessed for internal consistency in the estimated sediment loads.

Measured total suspended solids (TSS) concentrations from six sites in the Fitzroy were used to develop sediment rating curves. Sediment rating curves were corrected using smearing estimates to remove an inherent bias as a result of log-transformation. These rating curves combined with streamflow data were used to estimate long-term mean annual sediment load of the Fitzroy and its main tributaries for a common 30-year period 1974-2003.

Sediment rating curves for the six sites show considerable similarity, and variation in sediment discharge at given flow rates is considerably larger than between-site variations in the expected sediment discharge at the flow rate. The mean annual sediment load was estimated to be 3.09 Mt for the Fitzroy at the Gap for the 30-year period (see Table below). Most of the sediment of the Fitzroy comes from the Nogoa and Comet subcatchments. The combined loads of the four major tributaries are consistent with the total load estimated for the Fitzroy at the Gap. Load estimated for the MacKenzie site appeared to be low. At given level of runoff, sediment concentration on average was highest for the Nogoa and Comet subcatchments, and the lowest for the Isaac.

An intensified period of water quality monitoring since 1993 coincided with a period of relatively low streamflow. Flow for the period 1994-2003 was about half, on average, of the 30-year period investigated.

Site location, mean annual flow, and sediment loads in the Fitzroy for the period of 1974 – 2003.

Gauging Station	River	Location	Catchment area (km^2)	Mean annual discharge (GL)	Mean annual sediment load (Mt)	Upper 95% prediction interval of load (Mt)	Lower 95% prediction interval of load (Mt)
130219A	Nogoa	Duck Ponds	27,130	614	1.23	2.06	0.13
130504A	Comet	17.2 km	16,422	402	0.576	1.02	0.083
130401A	Isaac	Yatton	19,719	2,569	0.391	0.47	0.030
130105A	MacKenzie	Coolmaringa	76,645	3,922	1.73	3.04	0.26
130322A	Dawson	Beckers	40,500	853	0.246	0.44	0.064
130005A	Fitzroy	The Gap	135,757	5,227	3.09	5.19	0.63

1. INTRODUCTION

The Fitzroy is the largest coastal catchment in Queensland. With a catchment area of nearly 140,000 km^2, the Fitzroy discharges a significant amount of sediment to the Great Barrier Reef lagoon. Sediment discharge is related to water turbidity, which has a direct impact on coastal ecosystems. It is therefore important to accurately determine the amount of sediment the Fitzroy carries to the coastal areas. The Fitzroy basin is a priority catchment in the National Action Plan for Salinity and Water Quality (NAPSWQ), and has been identified as a high impact catchment in the Great Barrier Reef Marine Protection Plan.

Previous estimates of the long-term average sediment load of the Fitzroy vary greatly. Belperio (1979) estimated a mean annual load of 2.5 Mt (1 Mt = 10^9 kg) for the Fiztroy by assuming the sediment rating curve (an empirical relationship between water discharge and sediment discharge) derived for the Burdekin river.. Moss *et al* (1992) assumed a constant flow-weighted sediment concentration of 250 mgL^{-1} for catchments south of the Burdekin. This would lead to a mean annual load of 1.3 Mt using the streamflow data for the Fitzroy at the Gap (see Table 2). Neil and Yu (1996) modelled sediment rating curves for six catchments in Queensland, and developed relationships between runoff (mm) and mean sediment load per unit area per unit runoff (t km^{-1}mm^{-1}). Using this method, Neil and Yu (1996) estimated a mean annual sediment load of 2.4 Mt for the Fitzroy under natural conditions and up to 10.3 Mt when the catchment is fully disturbed as a result of agricultural production and urbanisation.

Previous investigations are mostly based on extrapolation of results from other catchments in Queensland. Estimates of sediment loads of the Fitzroy have been derived from measured total suspended solids (TSS) concentrations for the catchment. In addition, sediment loads from major tributaries of the Fitzroy have not been assessed for internal consistency in the estimated sediment loads. Spatial distribution of sediment load and sediment budget on a long-term basis are important for validating spatial sediment yield models such as SedNet (Fentie *et al*. 2005).

Ideally, streamflow and TSS concentration are continuously monitored so that the total sediment loads can be determined by integrating instantaneous loads for the required period at a particular site. In the absence of extensive and continuous long-term monitoring of TSS concentrations, sediment load is commonly estimated using sediment rating curves. With sediment rating curves, long-term flow records can be used to estimate instantaneous loads so that the total or average loads can be estimated for the required period. The limitations of using rating curves are many and generally known. These include a lack of sediment samples during high flows, sampling for certain flow ranges, disparate sediment discharge during rising and falling stages of the hydrograph, variations in TSS concentration as a result of different sediment generation mechanisms and different locations of the centre of storm events. Large variations around the rating curves lead to uncertainties about the functional form of the rating curves and parameter values associated with the rating curves. Despite these limitations, with irregularly collected TSS concentration data, this method remains the best available, and most accepted one to use to estimate long-term sediment loads.

The objectives of this paper are to develop discharge-sediment load relationships for six sites in the Fitzroy catchment, to estimate long-term sediment loads for a common 30-year period, and to assess the quality of the estimated sediment loads.

2. DATA AND METHOD

The main tributaries in the Fitzroy catchment are the Nogoa, Comet, Isaac, and Dawson rivers. The MacKenzie collects flows from the Nogoa, Comet, and Isaac. It then joins with the Dawson from the south to become the Fitzroy (Fig. 1). The long-term mean annual streamflow of the Fitzroy is 5227 GL at the Gap (Table 2) or 39 mm. The Isaac generates most water per catchment area with 127mm yr^{-1}, while the Dawson has the lowest runoff of 21 mm yr^{-1} among the four major tributaries.

The Queensland Department of Natural Resources and Mines collects water quality data, including TSS concentration, under its Surface Water Ambient Network program, since the 1970s and more intensively since 1990s. This program provides a large amount of TSS concentration data to allow an estimation of long-term sediment loads throughout the Fitzroy catchment. For this study, all available TSS concentration and flow data were extracted from the Department's HYDSYS surface water database for the period between 1974 and 2003 when the data were most complete.

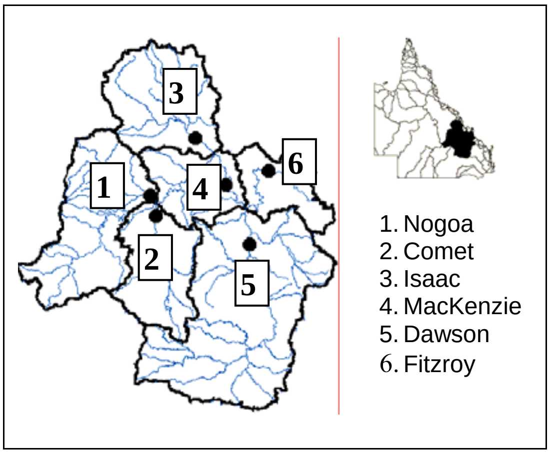

Figure 1. Subcatchments and TSS sampling sites in the Fitzroy catchment.

Long term flow data were available from 1974 at all sites except the Nogoa where flow monitoring commenced only in 1993. The streamflow at this site prior to 1993 was estimated by taking the differences between flows of the Comet River at 17.2 km (130504A) and that of the MacKenzie River at Carnangarra (area = 45,370 km^2) which is just downstream the Nogoa-Comet junction. The estimated and measured flows were compared for the period when streamflow was measured at all three sites (Fig. 2). The scatter for high flows is small, although at low flows there is a large amount of scatter around the 1:1 line. When the sediment load was estimated using observed and the estimated flow for the Nogoa, the difference is no more than 6% in estimated sediment loads for the period 1993 and 2003. Streamflow data for the Nogoa were extended to 1974 to create a complete data set for the 30-year period from October 1973 to September 2003 for all six sites in the catchment.

Total suspended sediment concentrations were measured occasionally from the 1970s at all sites except for the Nogoa where intensive sampling began in 1993 under the Department's Surface Water Ambient Network program. Both low (<80 percentile) and high flows (>80 percentile) were well sampled at all sites, however the upper 2 percentile of flows were well sampled only at the Nogoa and Fitzroy sites, moderately sampled in the MacKenzie and poorly sampled in the Comet, Isaac, and Dawson sites. In terms of maximum discharge sampled relative to the maximum discharge on record, the ratio was 65% for the Fitzroy site, 45% for the Comet and Dawson sites, 35% for the Nogoa, 18% for the MacKenzie, and was only 5% for the Isaac.

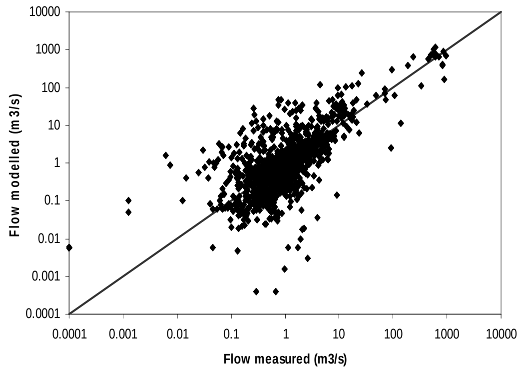

Figure 2 Modelled versus measured flow, Nogoa River at Duck Ponds for the period between 1993 and 2003.

Table 1. Comparison of measured and estimated mean annual flow and sediment loads for the Nogoa site (1993-2003).

	Mea'd	Est'd	Estimation Error (%)
Flow (GL)	2,513	2,668	6.1
Load (Mt)	3.54	3.75	5.9

Table 2. Site location, mean annual flow, and sediment loads for the period of 1974 – 2003.

Gauging Station	River	Location	Catchment area (km^2)	Mean annual discharge (GL)	Mean annual sediment load (Mt)	Upper 95% prediction interval of load (Mt)	Lower 95% prediction interval of load (Mt)
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Data on TSS concentrations were collected at irregular time intervals, often three to four times a year. All the TSS data were used to develop rating curves for the site. Measured instantaneous sediment discharge was calculated using TSS concentrations and corresponding flow measurements in the form of:

$$Q_s = x * Q * C \tag{1}$$

where Q_s is the instantaneous suspended sediment loads (t/d), Q the flow rate (m^3/s), C is the TSS concentration (mg/L), and x is a unit conversion factor (0.0864).

Measured instantaneous suspended sediment discharge was plotted against the flow rate for each site and rating curves were developed in the form of:

$$Q_s = a\, Q^b\, C_f \tag{2}$$

where a and b are regression constants using log-transformed flow and sediment data, and C_f is a correction factor to remove an inherent bias introduced as a result of log-transformation (Ferguson 1986). Smearing estimate was used to calculate this correction factor (Duan 1983):

$$C_f = \sum_{i=1}^{n} \frac{1}{n}\, 10^{\varepsilon_i} \tag{3}$$

where ε_i is the error term, or the residual, for each measurement:

$$\varepsilon_i = \log Q_{s_i} - \left(a + b \log Q_i\right) \tag{4}$$

and n the sample size. Standard error of load estimates, *SE*, was calculated as:

$$SE = t\, s \left(1 + \frac{1}{n} + \frac{(\log Q_i - \overline{\log Q})^2}{S_{QQ}}\right)^{0.5} \quad (5$$

where t is the Student's t distribution, $s = \sqrt{s^2}$ where s^2 is the variance, n is the sample size, and S_{QQ} $= \sum_{i=1}^{n}\left(\log Q_i - \overline{\log Q}\right)^2$.

These sediment rating curves were then used to convert continuous discharge measurements into instantaneous sediment discharge estimates. More detailed flow data were used in this study, while previous estimates of sediment loads were based on monthly and daily flows (Belperio 1983; Neil and Yu 1996). The time interval over which the flow rate is assumed to be constant varies as significant change in water stage occurs. For the Fitzroy at the Gap, for instance, about 50% of flow was recorded at time intervals less than six hours, and 85% of the flow recorded at time intervals < 12 hours. Estimated sediment discharge was integrated to determine long-term sediment load for the 30 year period between 1974 and 2003.

3. RESULTS AND DISCUSSION

Rating curves developed for the six sites are presented in Fig. 3. The grey plots under each graph show all data from all sites to indicate the distribution of TSS concentrations relative to other sites in the Fitzroy catchment. Sample size, estimated parameter values for rating curves are presented in Table 3. Table 3 also includes a sediment rating curve developed using all available TSS concentration data from all six sites.

Table 3 Sample size (n), estimated model parameters for ratings (a and b), and standard errors (ε), for the six sites in the Fitzroy catchments where sediment dicharge (Q_s) is in td^{-1} and discharge (Q) is in m^3s^{-1}.

Rivers	n	a	b	ε	r^2
Nogoa	95	6.62	1.53	2.36	0.89
Comet	53	22.9	1.30	1.98	0.94
Isaac	101	5.68	1.11	3.29	0.92
MacKenzie	99	4.44	1.28	1.96	0.92
Dawson	66	8.45	1.18	1.47	0.94
Fitzroy	116	2.45	1.39	1.71	0.95
Combined data set	530	3.28	1.27	2.64	0.92

Fig. 3 shows that of the four major tributaries of the Fitzroy, the Nogoa and Comet have higher sediment discharge at a given flow rate, especially during high flows. During low flows, the sediment discharge is generally lower for the Nogoa than that for the Comet. The Isaac has the lowest TSS and sediment discharge values of all sites, although TSS measurements at high flows are very limited at the site. The MacKenzie receives water and sediment from the Nogoa, Comet, and Isaac subcatchments and the TSS concentrations here appear to be diluted by streamflow from the Isaac subcatchment. In the Dawson River, the TSS concentrations lie in the mid-ranges although measurements of TSS