Estimation of annual gravel influx to the gravel-bed reach of Fraser River

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The annual recruitment of bed material to the gravel-bed reach of Fraser River, in particular, to the unstable reach between Laidlaw and Sumas Mountain, is an important quantity necessary to know for improved management of the reach. There are no contemporary measurements. However, for a period of 20 years between 1967 and 1986, the Water Survey of Canada conducted bedload transport measurements at the Agassiz gauge, then operating immediately downstream from the Agassiz-Rosedale Bridge. The data of this measurement program constitute the available information upon which to base an estimate of annual recruitment of bed material.

The Agassiz measurements have been analysed by McLean et al. (1999). Briefly, a rating curve was constructed by plotting the available measurements against the discharge at which the measurement was taken. The rating curve, reproduced as Figure 1, exhibits great scatter. There are three plausible sources for the scatter:

1. Relatively few actual bedload samples were taken in each measurement—typically two or three samples in each of 5 or 6 verticals across the channel. On the other hand, bedload movement is known to be highly variable, both temporally and spatially, so substantial sampling variance is possible (McLean and Tassone, 1987, analysed the measurements in this light);

2. The bedload samplers used in Fraser River are subject to catch biases (as are all such samplers). Corrections have been made to the observed sampler catches based on calibration tests conducted for the various samplers. The calibrations and corrections are discussed in McLean et al (1999). Nevertheless, these manipulations remain a potential source of error.

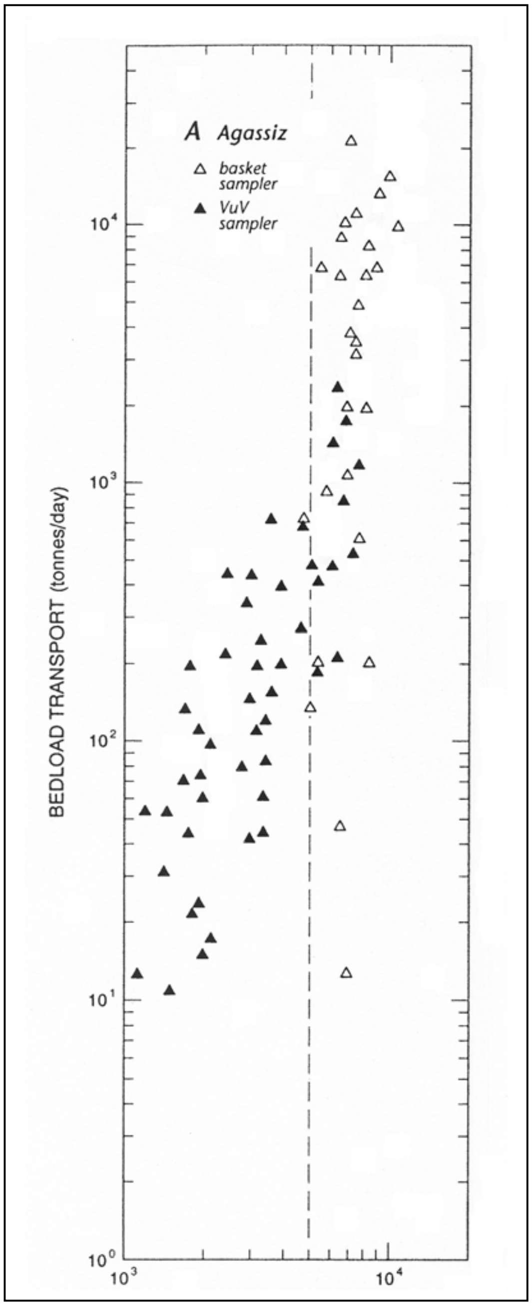
3. Bedload transport remains relatively low at all discharges in Fraser River. At low rates, the transport remains highly variable, being controlled as much by available supply as by the theoretical hydraulic capacity of the flow to transport material. Again, high sampling variance is the expected result.

Because the measurements remain relatively sparse, estimates of transport for extended periods were made by rating curve methods, despite the substantial sampling scatter. Analyses of grain size distributions of the trapped bedload showed that gravel transport commences at about 5000 m^3s^{-1}. Accordingly, McLean et al (1999) estimated the gravel transport for flows exceeding that level from a rating curve computed by regression:

$$\log_{10}G = -17.7 + 5.41 \log_{10}Q$$

with standard error of estimate ±0.43 $\log_{10}$ units (R^2 = 0.53), wherein G is gravel transport (tonnes/day) and Q is mean daily flow (m^3s^{-1}). The standard error of estimate translates into a 2-standard error estimate (i.e., encompassing a 95% range in probability) for an individual estimate of bedload transport of 0.14 to 6.9x the nominal result. This is much greater than the likely measurement error, confirming that real variability in transport at a given discharge contributes significantly to the apparent variation in bedload transport at Agassiz. It also should be noted that the absurdly small intercept of this equation is physically meaningless, since the range of validity of the expression is Q > 5000 m^3s^{-1}. At that threshold, the estimated load is 205 tonnes/day, and at 3000 m^3s^{-1}, the equation still predicts 13 tonnes/day.

Figure 1 The rating curve for gravel transport at the Agassiz-Rosedale Bridge, derived from measurements made by the Water Survey of Canada between 1967 and 1986. Only measurements made at Q<5000 m^3s^{-1} were used to derive the equation given in the text.



To estimate longer term transport, McLean et al. (1999) estimated the expected load from the regression and the 2s confidence range about the estimate for 1000 m^3s^{-1} steps in discharge. Using the flow duration curve, the fraction of the load falling within each flow class was determined, and the pooled weighted error was then determined for a longer term transport estimate. For an annual period, the calculations indicate that the load is specified to within ±40%. Further details of these calculations are given in McLean and Church (1986).

To estimate the annual influx of gravel to lower Fraser River, a more direct calculation is to regress the estimated annual loads against a relevant flow index. Possible flow indices include annual water volume (equivalent, from an information perspective, to mean annual flow) ; volume exceeding 5000 m^3s^{-1}, and annual maximum daily flow. Since gravel moves at flows greater than 5000 m^3s^{-1}, the second volume figure seems more relevant than the first and, since the transport is highly nonlinear (increasing at more than the 5th power of flow according to the rating curve), the maximum flow—which achieves most of the transport—may be the most relevant criterion of the three. Accordingly, estimated annual gravel loads at Agassiz (McLean et al., 1999; table 4) were regressed against annual maximum daily flow for all years (1967-1986) for which estimates of the transport exist. The result is

$$\log_{10}G_a = -18.668 + 6.037 \log_{10}Q_{max}$$

with standard error of estimate ±0.182 $\log_{10}$ units (R^2 = 0.873), wherein G_a is the annual gravel influx in tonnes and Q_{max} is the annual maximum daily flow, in m^3s^{-1}, measured at Hope. The standard error of estimate translates into a 95% range in probability (confidence interval) of between 0.43 and 2.3x the nominal result, which is larger than the estimated 40% variance range of an individual annual estimate. Hence, real variability in the year-to-year sediment delivery for a given peak flow introduces moderate additional variability. At the nominal threshold for gravel transport of 5000 m^3s^{-1}, the equation predicts 4600 tonnes. The analysis of variance is given in Table 1 and the equation is illustrated in Figure 2. The residuals from regression are shown in Figure 3: they show no structure at all, so the selected equation certainly is appropriate. The size of the residual is modestly correlated with the size of sediment load (Figure 4), indicating that the error of an annual load estimate is correlated with the size of the estimate (a characteristic feature of log-linear data).

Table 1 ANOVA for the regression of annual gravel influx to lower Fraser River

	Sum of squares	**df**	**Mean square**	**F**	**p**
Regression	4.307	1	4.367	131.7	$<10^{-6}$
Residual	4.964	18	0.0331		

Figure 2 $\log_{10}G_a$ (annual gravel transport) plotted versus $\log_{10}Q_{max}$ (annual maximum daily flow), based on measurements made at the Agassiz-Rosedale Bridge by the Water Survey of Canada between 1967 and 1986, and flows measured at Hope. Data in McLean et al. (1999). The plotted line is the regression solution for the best-fit relation

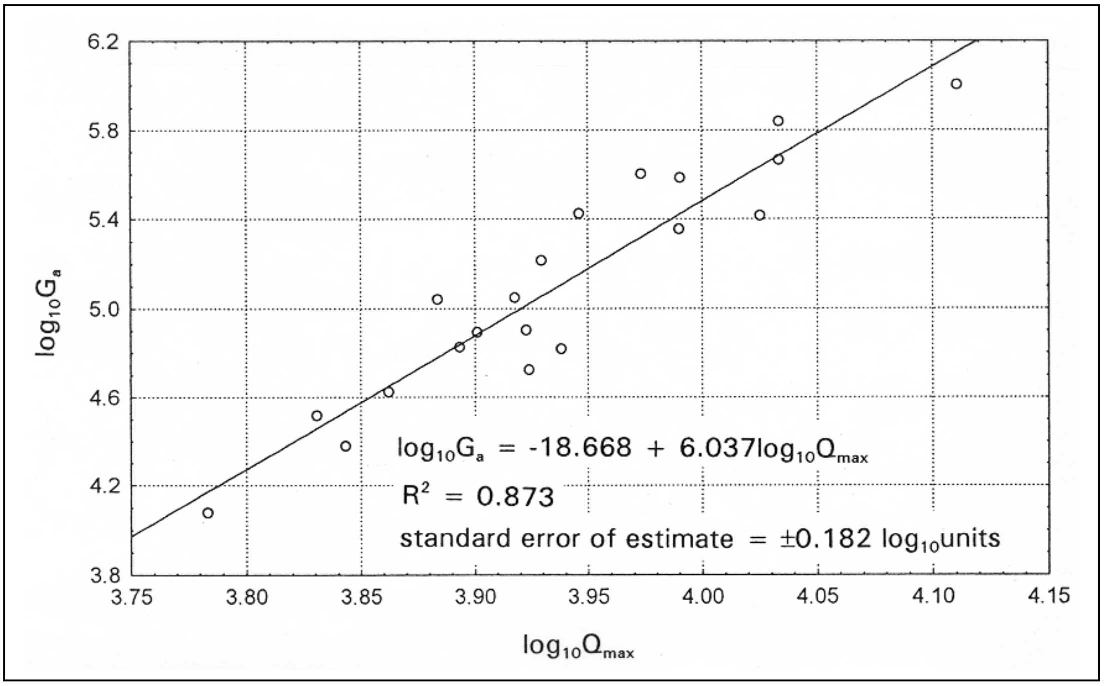


Figure 3 The correlation between residuals from the regression shown in figure 2 and Q_{max}. Inset: the distribution of the residuals. The small number makes the distribution uneven. A normal error distribution is superimposed.

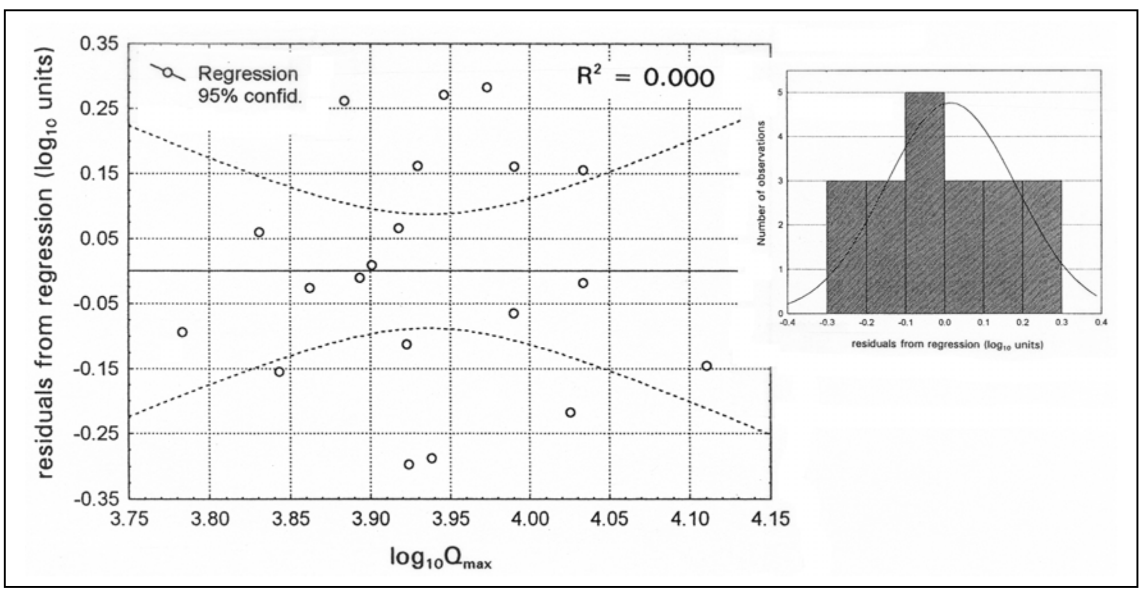
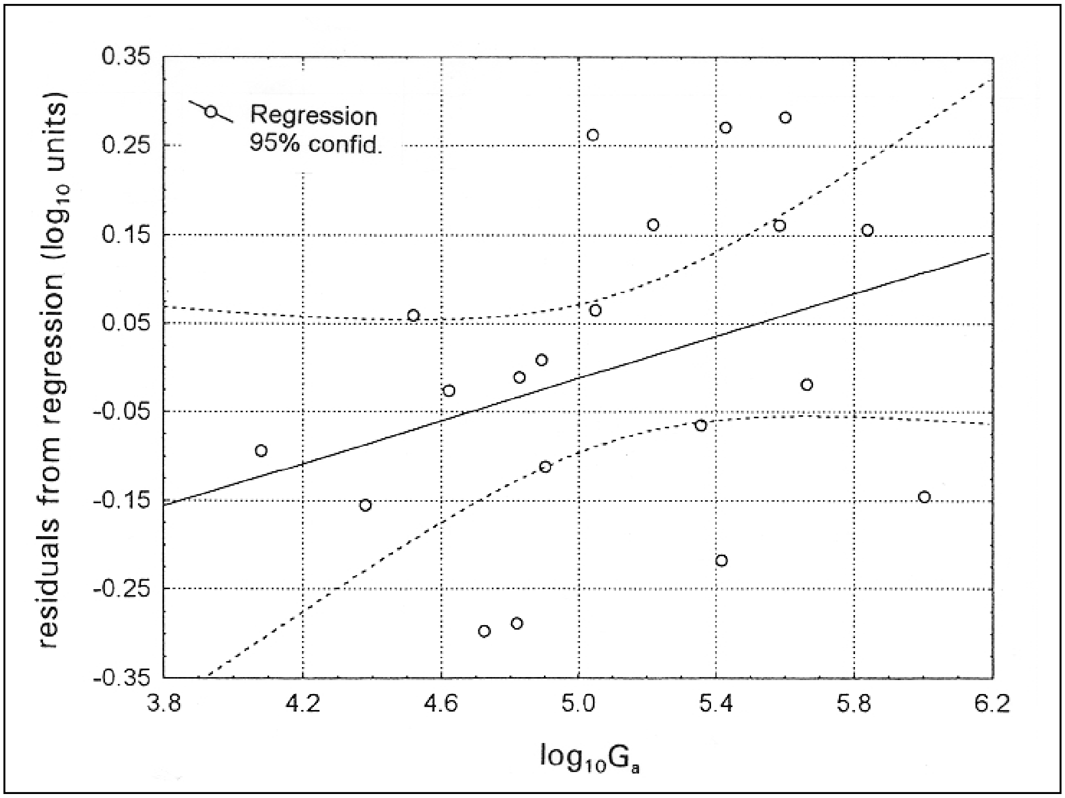


Figure 4 The correlation between the residuals from the regression shown in figure 2 and G_a.



The back-transformation of a logarithmic equation to ordinary numbers yields a median regression (rather than a mean regression). That is, the back-transformed equation yields median influx estimates, in comparison with the regression data, rather than mean estimates (This is a consequence of the nonlinear transformation). Given the asymmetric error bounds on the data, this is not unreasonable. However, it yields relatively lower estimates than would a mean regression and, in the current problem, a larger estimate may, for some purposes, appear more conservative. The adjustment for the back-transformation is

$$G_a = aQ_{max}^{\ b} \cdot 10^{\varepsilon}$$

where a is antilog$_{10}$(-18.668), in this case, b = 6.037, and $\varepsilon = s_{y|x}^{\ 2}/2$, s being the standard error of estimate in the logarithmic equation (here, ±0.182). Hence, the correction is to multiply the back-transformed equation by 1.039. The adjustment is small because the correlation is high. The adjusted, back-transformed equation is

$$G_a = 2.231 \times 10^{-19} Q_{max}^{\ 6.037}$$

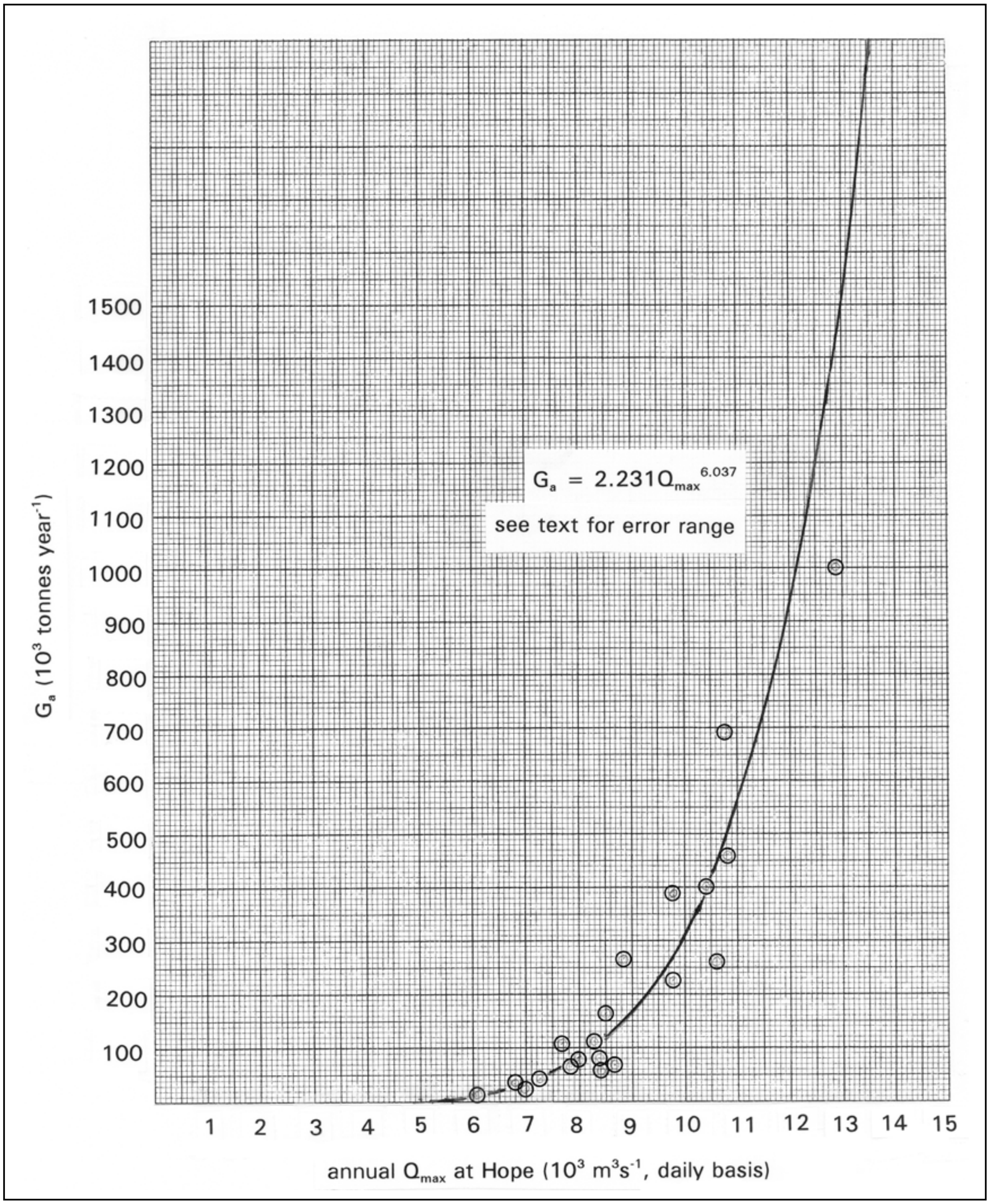
wherein G_a is given in tonnes/year and Q_{max} is given in m^3s^{-1} and referred to the Hope gauge. A short table of typical results is given as Table 2. The results are, of course, comparable with observations. Figure 5 gives the back-transformed rating curve.

The foregoing computations apply strictly to sediment transport through the reach at the Agassiz-Rosedale Bridge, since that is where the underlying observations were made. However, sediment budget surveys (Church et al., 2000) indicate that there is little net change in bedload transport between Laidlaw and Agassiz. Hence, the results can be accepted as a reasonable estimate of the influx to the reach. They represent the best estimate that is available.

Table 2 Estimated gravel-bedload introduced into the Laidlaw-Mission reach for given Q_{max} at Hope

Q_{max} (m^3s^{-1}; daily basis)	G_a (tonnes/year)	Q_{max}	G_a
5 000	4 780	5 500	8 490
6 000	14 360	6 500	23 290
7 000	36 430	7 500	55 250
8 000	81 570	8 500	117 620
9 000	166 080	9 500	230 190
10 000	313 730	10 500	421 190
11 000	557 760	11 500	729 400
12 000	943 150	12 500	1 206 700
13 000	1 529 100	13 500	1 920 400
14 000	2 391 900	14 500	2 956 200
15 000	3 627 600		

Figure 5 The back-transformed relation between G_a and Q_{max}. This is the same relation displayed in figure 2, but corrected for transform bias.



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