Total load

One way is to find the proper bedload and suspended load model and add the two together. However, this requires considerable data. As a result, simpler energetic methods were formulated.

These methods depend on the characteristics of the watershed. You can imagine that two scenarios exist:

Capacity-limited – The amount of sediment delivered to the river mouth is limited by the water supplied to the watershed. In other words, there is so much material available to be transported that sediment fluxes are limited by power supplied by the running water. Large foreland-basin rivers (e.g., the Mississippi) are an example.

Supply-limited – The amount of sediment available to be moved is limited. Bedrock mountain streams are an example.

One of the first models of total load was an approach by Bagnold (1956). Its simplicity makes it extremely powerful, though it was designed for capacity-limited streams only.

He introduces the concept of **stream power** –

$$\omega = \frac{\rho g Q S}{B} = \rho g D S u \tag{1}$$

where ω is the stream power, D is the flow depth, B is the flow width, S is the slope of the main channel and u is the mean flow velocity.

He related the stream power to 'submerged weight flux' of sediment i

$$i = Rg\left(U_b m_b + U_s m_s\right) \tag{2}$$

where U is mean transport velocity of each component (bedload and suspended load), and Rmg is the submerged weight of sediment. Bagnold (1966) theorized that the bedload flux would be associated with a friction coefficient α

$$Rm_b g U_b \tan\alpha = i_b \tan\alpha \tag{3}$$

and suspended load flux would have some component in the direction of shear such that

$$Rm_s g U_s \left(\frac{w_s}{U_s}\right) = i_s \left(\frac{w_s}{U_s}\right) \tag{4}$$

Now that the rates of work are set forth, he defined two efficiencies e_b and e_s, which can be related to the stream power

$$i_b \tan\alpha = e_b \omega \tag{5a}$$

$$i_s \frac{w_s}{U_s} = e_s \omega \left(1 - e_b\right) \tag{5b}$$

Combining (2), (3), (4) and (5) we find

$$i = \omega\left(\frac{e_b}{\tan\alpha} + 0.01\frac{u}{w_s}\right) \tag{6}$$

where the quantity $e_s(1-e_b)$ has been assumed equal to 0.01.

He used data from Gilbert (1914) to constrain the empirical quantities defined in his analysis.

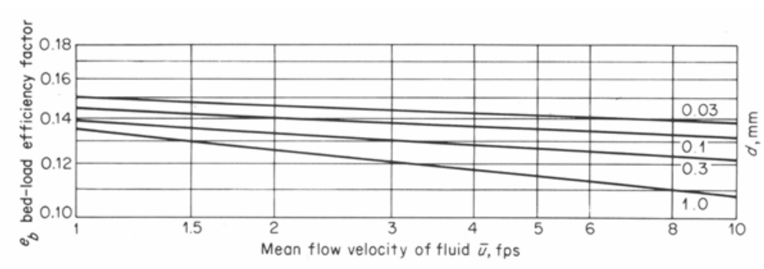

Fig. 9.3 The bedload efficiency factor. [*After* BAGNOLD (*1966*).]

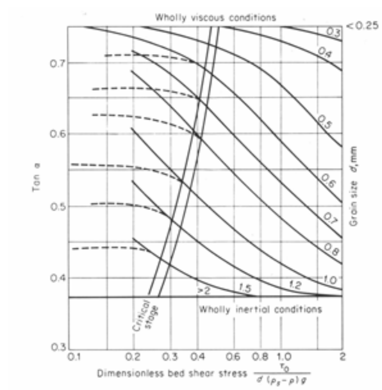

Fig. 9.4 The solid-friction coefficient. [*After* BAGNOLD (*1966*).]

More recent efforts have utilized Bagnold's approach and more sophisticated dimensional arguments. The most popular is that of Engelund and Hansen (1967).

$$C_w = 0.05\left(\frac{R+1}{R}\right)\frac{US}{(Rgd)^{1/2}}\frac{R_h S}{Rd} \tag{7}$$

where C_w is the weight concentration of sediment, R is the submerged specific gravity of the sediment, U is the mean velocity, g is the gravitational acceleration, R_h is the hydraulic radius, d is the mean grain size of sediment and S is the 'friction' slope, or the downstream slope of the water surface.

Estimating total load in unmonitored watersheds

Most rivers outside the US, Europe and Japan are not monitored. Even within the US, most streams only have flow discharges calculated from stage-discharge relationships.

A common method of estimating total sediment discharge in the absence of *in situ* hydraulic measurements is the **sediment rating curve**.

Sediment rating curves are empirical relations between the total (fluid) discharge and the sediment discharge. Most sediment rating curves implicitly assume capacity-limited conditions.

The standard form is:

$$Q_s = aQ^b \tag{8}$$

where Q_s is the sediment discharge, Q is the fluid discharge and a and b are empirical constants. a can vary wildly, but b

generally takes a value between 1.5 and 2.5. Because of this constraint on *b*, a value of *b* can be assumed and, with only one measurement, the value of *a* can be calculated.

However, very few rivers are capacity-limited ALL of the time. During extreme floods, even classic capacity-limited streams exhibit supply-limited behavior. It generally results in a **hysteresis** in the sediment-flow-discharge relationship.

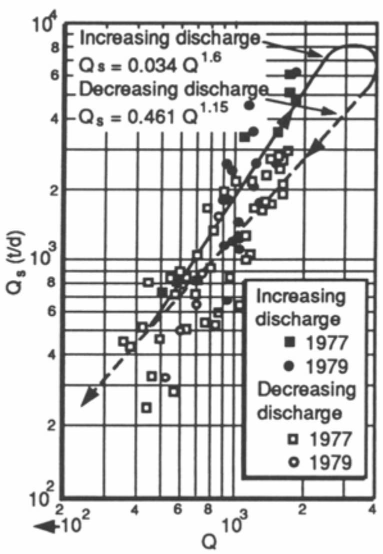

Figure 11.7. Sediment-rating curves of the Bell River (after Frenette and Julien, 1987)

The only way supply-limited rivers can be modeled in the absence of measurements is if a Garcia-Parker-like entrainment relationship is coupled with detailed routing of suspended load, along with the Parker et al. (1982) model for bedload. Suspended load is generally the component that presents biggest problems on supply-limited rivers.