# Gravel transport rates in Rocky Mountain streams for normal annual highflow events

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**Abstract.** The Many stream studies, from channel restoration to watershed management, require knowledge of the gravel transport rate for the normal annually expectable high flow event. Bedload transport equations fail at this task in mountain streams because they are not designed for coarse and rough bed or variable sediment supply. Similarly unfavorable is that the computed numerical results are out of context, not offering a user any insight on whether a value is high or low for a given stream or in comparison to other streams. This study takes a different approach and embarks on a comparative analysis of gravel transport rates measured in mountain streams.

We compiled a world-wide set of 75 gravel transport relations measured predominantly in mountain streams with bedload samplers suited for coarse beds: bedload traps, vortex, baskets, and pit-type samplers. Power functions $Q_B = a \, Q^b$ (Eq. 1) were fitted to the sampled transport rates $Q_B$ (g/s) and the discharge $Q$ (m$^3$/s) at the time of sampling; two functions were fitted for curved trends. The bankfull gravel transport rate $Q_{B,bf}$ is interpolated by solving Eq. 1 for the discharge of a normal annually expectable highflow event, approximately the 1.5-year flood, a flow we term "bankfull" for simplicity. For comparison among streams, flow and transport rate were divided by the bankfull channel width to yield unit bankfull flow $q_{bf}$ and the unit bankfull transport rate $q_{B,bf}$. A modified unit stream power expression $\omega' = \rho \cdot q_{bf} \cdot S^{0.5} \cdot \%D_{sub<8}$ serves as predictor of $q_{B,bf}$ and includes the percentage of subsurface sediment < 8 mm ($\%D_{sub<8}$).

For Rocky Mountain streams, a positive, straight trend emerged when measured data of $q_{B,bf}$ were plotted vs. $\omega'$ in log-log space, and data fell within an envelope two orders of magnitude wide. The few outlier data reflected temporarily large (release from log jam) and temporarily small (upstream gravel entrapment) transport rates. Most of the world-wide data added to the plot of $q_{B,bf}$ vs. $\omega'$ fell into the extrapolated envelope of Rocky Mountain streams, such as Alpine step-pool and plane-bed streams near tree line. A regression fitted to data within the envelope yielded an r$^2$ of 0.74.

Below the envelope fell bankfull gravel transport rates in forested watersheds in south central British Columbia (possibly slowed by large wood), and likewise from Karakorum streams ($Q_{1.5}$ might be small compared to the $Q_{10}$ or $Q_{20}$ event). Bankfull transport rates much larger than in Rocky Mountain streams were measured in streams draining basins with high gravel supply. They included mountain torrents (wide gravel-cobble beds with incised step-pool low-flow channel) in steep, unstable watersheds in the Alps, in the SE Himalaya, and a recently deglaciated catchment in the Alberta. They also included plane-bed/pool-riffle channels at a multi-stream junction in the Alps, an unstable watershed at Northern Montana as well as steep channels in the Negev desert.

For Rocky Mountain streams, the envelope around plotted data of $q_{B,bf}$ vs. $\omega'$ facilitates a rough estimate of bankfull unit transport rates. Using aerial photography to assess visually the watershed sediment supply (e.g., hillslope-channel connection), active bank erosion, and downstream gravel conveyance potential (e.g., obstruction by beaver dams) narrows the estimate or places a stream inside or outside the central envelope in extreme cases.