The East St. Louis Creek debris basin: serving a variety of research questions

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Abstract. Working at the Fraser Experimental Forest for more than 20 years, Chuck Troendle used the data of continuous streamflow and annual sediment load collected at the weir ponds/debris basins to analyze the effect of logging on runoff and sediment yield. He also predicted the annual sediment loads accumulated in the basins from hydrological data. Chuck then turned to using weir ponds/debris basins as a calibration tool to evaluate the sampling efficiency of bedload sampling devices. With this, he initiated several successor studies. Some evaluated if different placement of Helley-Smith samplers affected their catch and if different types of Helley-Smith samplers collected different amounts. Another study assessed if transport rates collected in hanging baskets match those predicted from a transport equation, while two others analyzed the sampling efficiency of bedload traps. These two studies indicated that substantial refinements in the estimates of the debris basin gravel mass and the computation of annual load from the bedload traps was needed before their sampling efficiency could be assessed which then ranged from -1.8 to 1.2. Improvements in the remaining uncertainty require that bedload be sampled or monitored continuously over the entire highflow season. The East St. Louis Creek debris basin has not only answered many of Chuck's research questions. It has also been very useful to the research of others and has the potential to become a nationally recognized research site.

1. Introduction

A weir pond/debris basin is an artificially excavated basin that catches all debris (organic material and bedload) supplied by the incoming stream. Surveys before and after emptying the basin each year provide an estimate of the annual debris volume. The weir at the downstream end of the basin facilitates a stage record that directly transfers into a streamflow hydrograph. Detailed hydrographs together with information on annual debris load make these data useful for both long-term evaluations of the effects of watershed management and natural change on runoff and sediment yield as well as evaluations of the sampling efficiency of bedload samplers.

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2. Chuck and the Fraser debris basins

When Chuck Troendle arrived at the Fraser Experimental Forest in the early 1980ies, weir ponds/debris basins already existed, but he brought new life to their use. He added several basins and ensured that data of annual flow and debris volume met high quality standards. Chuck used these data to analyze changes in runoff and sediment yield due to logging, different cut patterns, snow accumulation and reforestation (e.g., Troendle and Leaf 1981; Troendle and Meiman 1984; Troendle and King 1985, 1987). In the 1990ies, Chuck worked on the prediction of annual sediment loads collected in the debris basins from hydrological parameters such as annual water yield, annual peak flow, peakflow duration (Tronedle 1993; Troendle and Olsen 1994), and effective discharge (Troendle et al. 1996). However, the natural variability of both the water and sediment yield make the detection and prediction of post-management change notoriously difficult (Bunte and MacDonald 1999). Chuck also realized that weir ponds/debris basins can be of more use to researchers. With a detailed record of flow together with annual sediment load and its particle size-distribution, a weir pond/debris basin can serve as a calibration tool for different bedload sampling devices. If bedload is sampled throughout a highflow season, annual bedload discharge can be computed from the samples and compared to the amount of bedload accumulated in the debris basin. Differences reflect the sampling efficiency of a particular device and its deployment specifics.

3. The East St. Louis Creek debris basin

The weir pond/debris basin at East St. Louis Creek, a small step-pool stream, has been particularly useful for this kind of study. Chuck was involved in research comparing the annual debris basin load with the load computed from samples collected with a 3-inch Helley-Smith sampler. For example, Wilcox et al. (1996) found that a Helley-Smith sampler placed on the bed collected similar particle sizes as the debris basin, although some of the fines appeared to have escaped under the sampler, while the coarsest particle sizes in the debris basin were not found in the bedload samples. Ryan and Porth (1999) compared the sampler efficiency between three different types of pressure-difference samplers (Fig. 1 a). While the standard Helley-Smith sampler collected about 55%, and the less flared BLH 84 about 20% of the debris basin catch, the thin-walled sheet metal variant collected 140% of the debris basin load. The East St. Louis Creek debris basin was also a suitable site to deploy large, almost stream spanning hanging baskets (Fig. 1 b) for accurately sampling coarse gravel and cobble bedload. Wilcock (2000, 2001) found that the Parker (1990) bedload equation could be used to predict the transport rates computed from the collected material.

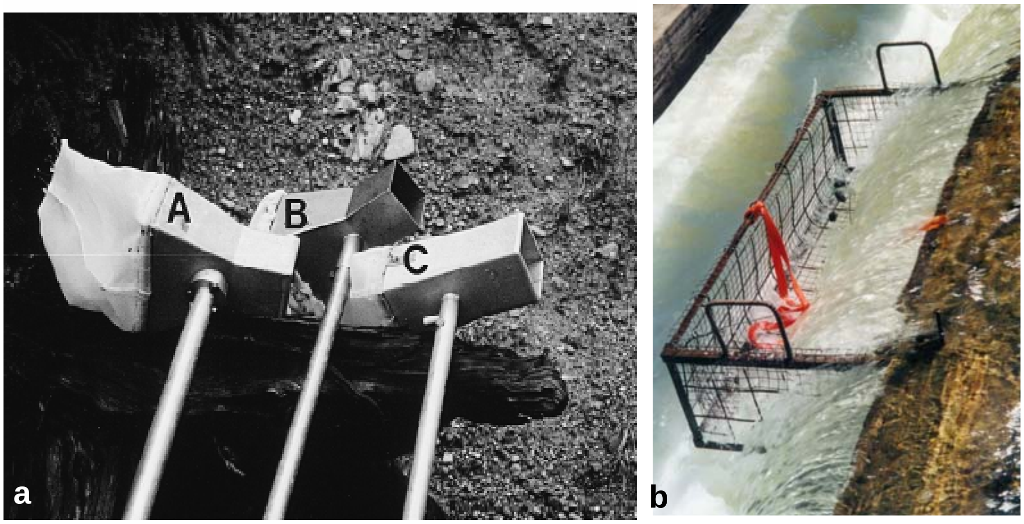


Figure 1 a and b: Three pressure-difference samplers compared by Ryan and Port (1999): Original Helley-Smith sampler (A), sheet-metal Helley-Smith sampler (B) and the BLH 84 (C) (a) (copied from Ryan and Porth (1999)). Hanging baskets mounted on the log at the debris basin entrance (b).

3.1 Bedload traps studies at East St. Louis Creek

In 2001 and 2003, Bunte (2002) and Bunte and Swingle (2003) used the East St. Louis Creek debris basin to evaluate the sampling efficiency of bedload traps (Fig. 2). Bedload traps are 1-ft wide samplers that are temporarily mounted on ground plates. Gravel bedload is collected typically over 1-hour sampling times and stored in a net attached to the sampler entrance (Bunte et al. 2005).

Figure 2: Four bedload traps installed in front of a footbridge just upstream from the East St. Louis Creek debris basin. Note the gauging hut and the weir in the background.

3.1.1 The 2001 study. The 2001 study compared annual gravel loads computed from bedload trap samples with those estimated from the debris basin volumes for 29 individual years. The underlying assumption was that if the computed annual load did not exactly match the estimated debris basin gravel mass for each individual year, inter-annual differences would average out over the long run. However, to obtain a valid comparison, several refinements were needed regarding a) how the gravel mass was estimated from the surveyed debris basin volume, and b) how annual load was computed from the bedload trap samples. Factors to evaluate when estimating the gravel mass from the surveyed debris basin volume included:

How well does the surveyed debris volume relate to the debris mass? A small surveying error of the 613 ft^2 debris basin bed before and after excavation can result in a large volume error, particularly for years of small annual loads. A concrete bottom of the basin would permit an accurate annual cleanout and be useful to reduce this error.

What proportion of the debris basin volume is organic debris? Although higher flows gather organic debris from a larger streambed area and have the competence to transport bigger chunks of organic debris, higher water levels and turbulence in the debris basin also re-suspend and whirl more organic material out of the basin. The absolute amount of organic debris accumulated in the basin was therefore assumed to be constant for all years, meaning that the organics proportion and the bulk density of the debris basin contents would decrease for years with higher annual loads. To be applicable to all years, the bulk density estimated from debris basin samples in 2001 was adjusted by a correction factor that linearly increased from 1.0 for years with low water yields to 1.25 for years with high water yields in order to improve the bulk sediment density estimates for all 29 years.

What proportion of the debris basin volume is gravel? As debris basins collect sand, organic material and gravel, while bedload traps collect gravel 4 mm and larger, the gravel amount in the debris basin had to be estimated for all years. The percent gravel computed from the debris basin samples in 2001 could not be assumed as a constant value for all years, but needed to vary between years depending on the amount of runoff. Using the linear increase of the gravel portion with increasing flow observed in the numerous Helley-Smith samples available for East St. Louis Creek as a model (Fig. 3 a), the gravel proportion was estimated to increase linearly with annual water yield, comprising 9% in low-flow and 44% in high-flow years.

A variety of factors also needed to be evaluated when using a rating curve approach to compute annual sediment load. These included:

Extrapolation of the measured rating curve to unmeasured high flows. Due to a low runoff in 2001, the rating curve reached 75% of bankfull only. The question arose whether to extrapolate the existing steep trend to the highest long term flows of 2.5 times bankfull, or whether to flatten the rating curve for flows above bankfull? Although we have not observed a flattening of gravel

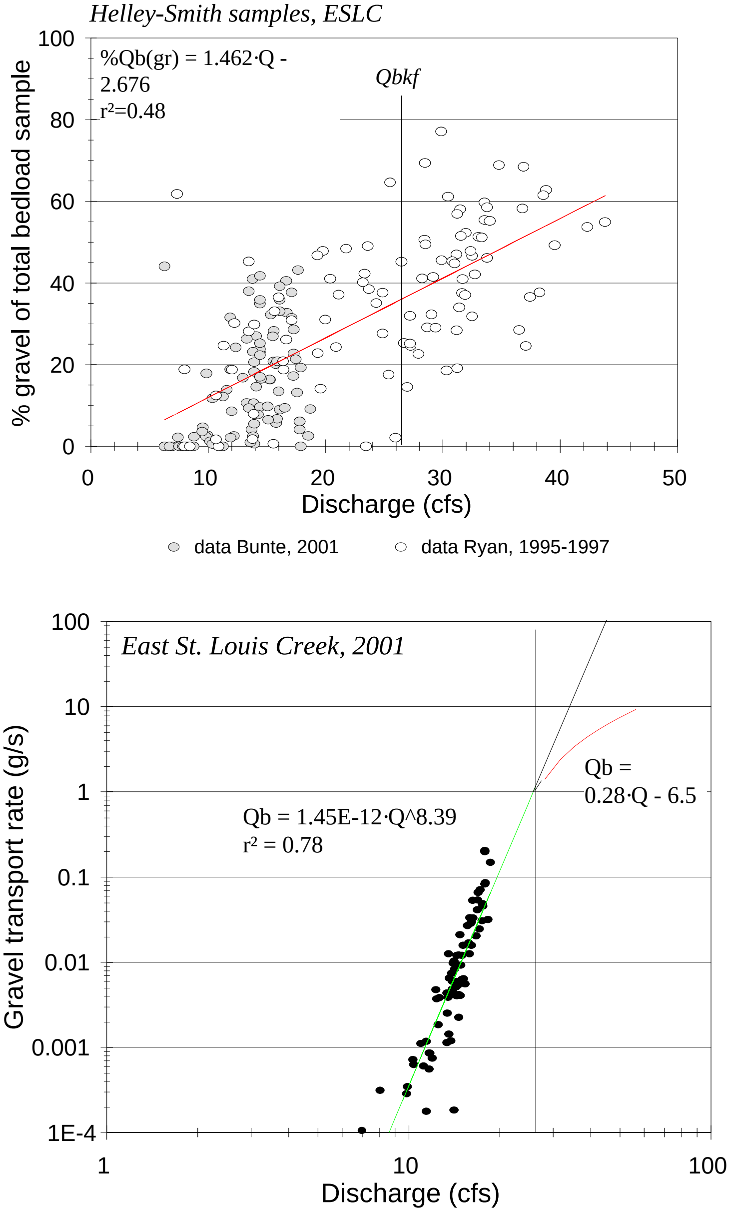


Figure 3 a and b: Increase in gravel portion for Helley-Smith samples (a). Extrapolation of the existing trend in the 2001 gravel bedload rating curve or assumption of a flattened trend (b).

rating curves in mountain gravel and cobble-bed streams, at least not in flows up to 1.4 times bankfull, the gravel transport rate of more than 2 kg/s predicted for 2.5 times bankfull flow from an extrapolation of the existing trend appeared to exceed the capacity of small East St. Louis Creek. We therefore decided to use a flattened, linear rating curve for flows above bankfull, particularly because this resulted in a better match between measured and computed annual gravel load for 2001 (Fig. 3 b).

Bias correction factor to account for the systematic underestimation of loads by rating curves. Sediment load computed from the 2001 rating curve were adjusted by multiplication with a bias correction factor (the one proposed by

Ferguson (1986, 1987). The factor increases with the scatter of the data and typically ranges between 1.2 and 2.5 for rating curves fitted to bedload samples. The correction factor, that was 1.4 for the 2001 bedload samples, does not correct mispredictions of annual load resulting from a misfit rating curve, e.g., one that neglects hysteresis effects.

Increase in the temporal scale of annual load computations from a day to an hour. We found that the computed daily gravel load is underpredicted when computed from mean daily flow compared to predictions based on mean hourly flow. This effect becomes more pronounced the larger the daily fluctuation of flow. The underprediction is relatively low (10% or less) for rating curve exponents of 2 – 4, typical of Helley-Smith samples, but it reaches 50 and 80% for steep rating curves with exponents of 8 and 16, typical of bedload traps (Fig. 4 a). The temporal scale of the annual load computation was therefore increased from mean daily flows to mean hourly flows.

Following these improvements, annual gravel load computed from bedload traps ranged within a factor of ±2 of the debris basin gravel load for 20 out of 29 years (Fig. 4 b).

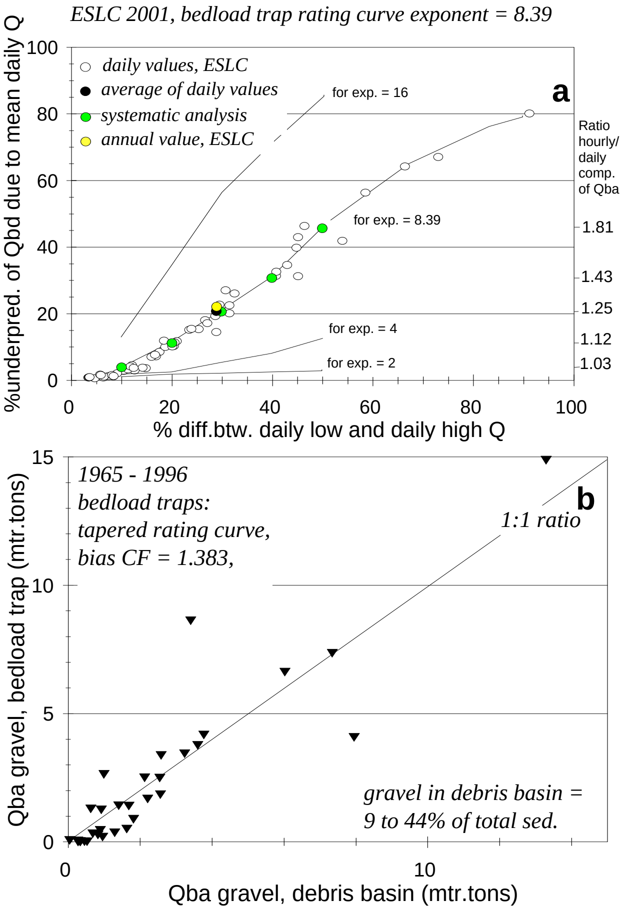


Figure 4 a and b: Effect of time increment used for computation and rating curve exponent on annual load (a). Annual ratios between annual gravel load computed from bedload traps samples with annual gravel loads estimated for the debris basin (b).

3.1.2 The 2003 study. Based on the difficulties involved in correctly estimating the gravel mass from the surveyed debris basin volume and on the problems of correctly extrapolating a rating curve, the 2003 study focused on a single year and compared the gravel load computed from the 2003 bedload samples to that year's gravel mass collected in the debris basin (Bunte and Swingle 2003). Again, improvements were necessary to increase the accuracy a) in the estimate of the gravel mass in the debris basin and b) in the computation of annual gravel load from bedload trap samples. Improvements in estimating the debris basin gravel load included:

- Lining the debris basin with geotextile in the fall before the highflow to ensure that exactly the debris collected in a specific year would be excavated and available for further analysis (Fig. 5 a).
- Placement of all excavated sand and gravel onto a tarp for repeated surveyed from which to compute its volume (Fig. 5 b). Much of the organic material was sluiced through the basin.

Figures 5 a and b: Excavation of the lined debris basin (a). Excavated debris pile on a tarp with samples being collected (b)

- Collection of 31 sediment samples with a combined mass of more than 1 ton for an accurate particle-size analysis. Samples were field sieved for particles larger than 4 mm (the smallest size collected in bedload traps). This gravel portion comprised 50% of the debris basin sediment mass.

Annual load was computed from the bedload samples using both a rating curve and a summation approach.

Rating curve approach. A variety of different bedload transport rating curves were obtained depending on the data set to which the rating curve was fitted, i.e.:

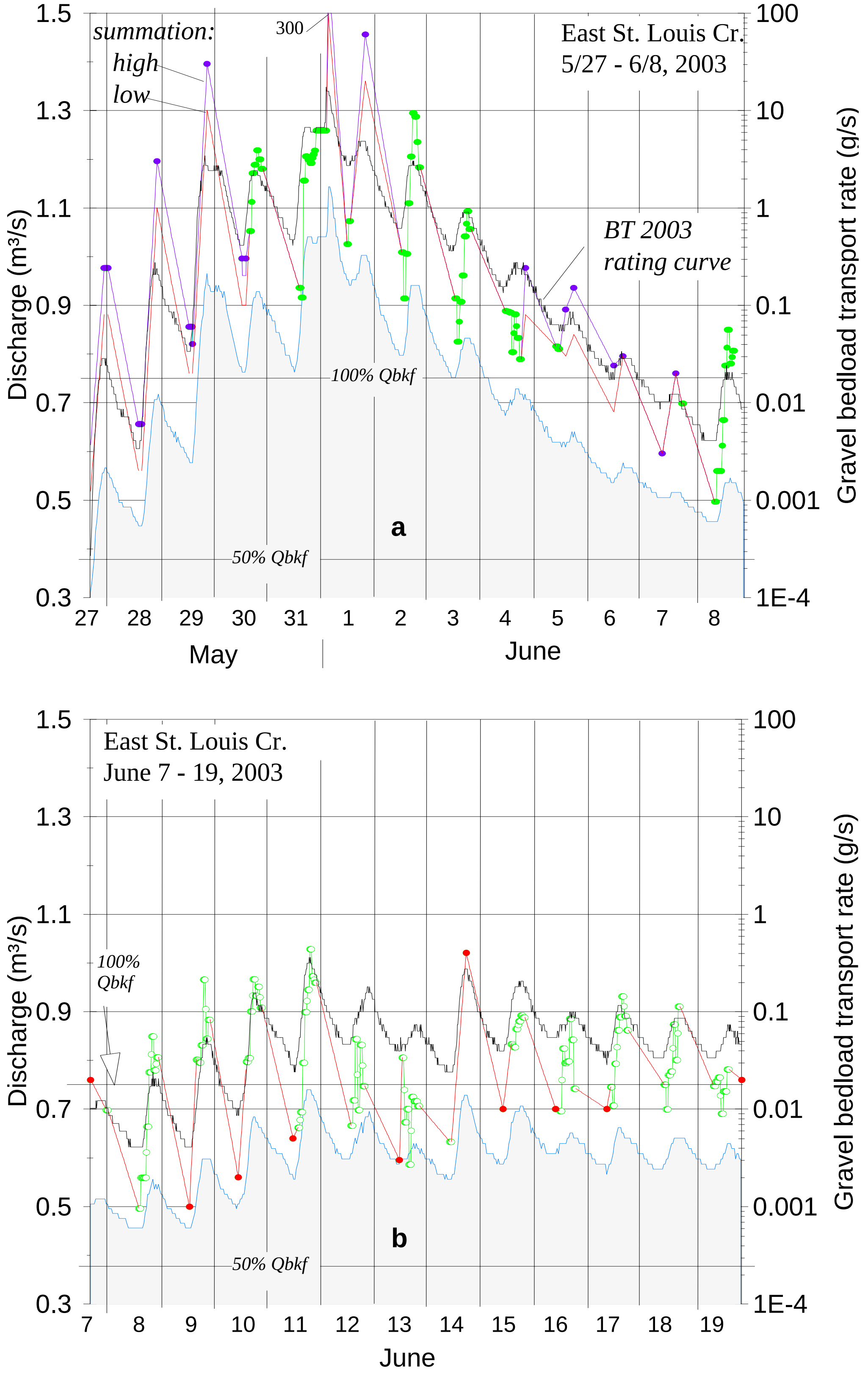
- whether the 2001 or the 2003 rating curve was used for the analysis (For unknown reasons, the 2003 rating curves yielded rates 1/10th of those measured in 2001).
- whether separate relations were fitted to rising and falling limbs,

- whether samples with zero transport rates were included in the rating curve computation or not,
- whether and how transport that occurred during unmeasured (e.g., nightly) peak flows was accounted for,
- whether a bias correction factor was applied, and
- whether computations were based on hourly or daily increments of flow.

Because all these factors affected the computed annual load, the rating curve approach resulted in gravel load estimates that ranged from -2.5 to 6.5 times the debris basin gravel mass.

Summation approach. The summation approach for computing annual load requires a more or less continuous time series of bedload transport measurements. The relatively large number (133) of bedload samples collected over the highflow season generally made it possible to sum bedload transport in hourly time increments over the highflow season (Fig. 6 a and b). For unmeasured times, however, transport rates needed to be estimated. Daily gaps between the evening and the next morning were filled by interpolation which assumed that no bedload waves occurred within this time interval. Gaps that extended over one or several days were filled with hourly transport rates that were estimated based on hysteresis patterns observed for measured times. However, there was uncertainty, particularly in the estimate of transport rates for the unmeasured peakflow that occurred during a night-time rain-on-snow event.

Because the specific values estimated for hourly bedload transport rates affect the computed annual load, particularly for peakflow estimates, results ranged from -1.8 to 1.2 times the debris basin load (Fig. 7 a and b). The uncertainty might be decreased if the already very labor intensive field work is intensified still further. Minor improvements are possible in the survey accuracy and the sampling and sieving of the debris basin contents. Significant improvements could be gained if bedload sampling was continuous throughout the highflow season, such that the highest flows - that tend to occur at night or unexpectedly - are represented by samples. This would either require several field crews working around the clock, or the additional installation of a device that provides a continuous temporal record of bedload transport, such as a hydrophone. Calibration of signal intensity versus bedload transport rates would provide an estimate of transport rates for unmeasured times that is probably more accurate than estimates derived from inter- and extrapolation methods.



Figures 6 a and b: Hydrograph (light blue), and hourly gravel loads: measured (green), predicted from the 2003 gravel bedload rating curve (black) and interpolated/extrapolated to fill time series gaps (red and purple) for May 5 to June 8 (a) and June 7 to June 19 (b).

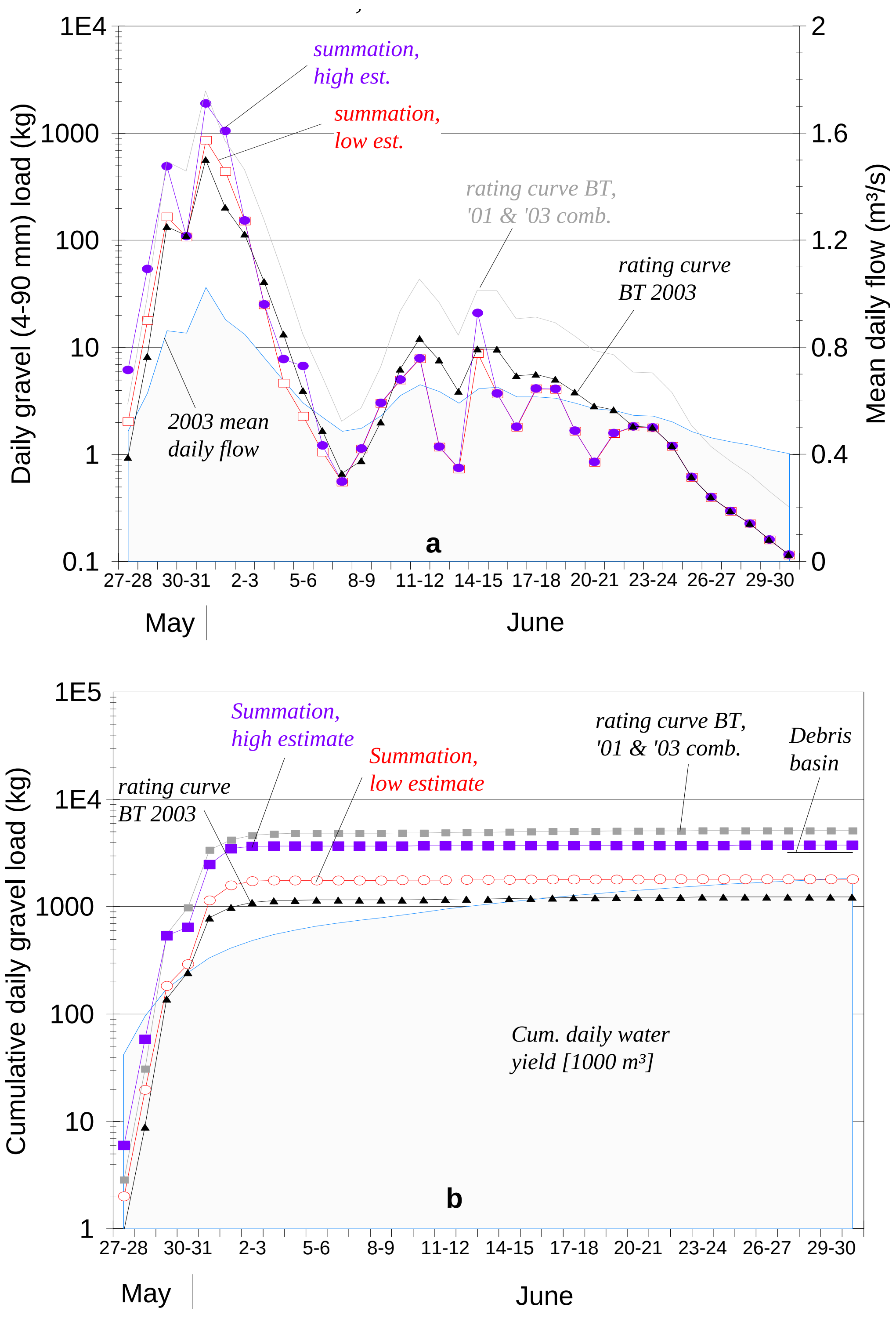


Figure 7 a and b : Daily gravel load (a) and cumulative daily gravel load (b) computed from rating curve and summation approaches at East St. Louis Creek, 2003.

3.2 The research potential of the Fraser weir ponds/debris basins

The weir pond/debris basins in the Fraser Experimental Forest have solved many research questions for Chuck Troendle and continue to serve well for studies that build on Chuck's research. The Fraser weir ponds/debris basins (particularly once they have concrete beds) have a great potential to become a nationally recognized research site for bedload transport studies, mainly for their detailed hydrographs and annual debris loads, but also for support logistics such as housing and internet-available real-time record of flow from the main stream leaving the catchment (St. Louis Creek) as well as the snow water equivalent from a nearby S*notel* site.

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