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# Automatic Real-Time Control of Suspended Sediment Sampling Based Upon High Frequency *in situ* Measurements of Nephelometric Turbidity

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## *Abstract*

*For estimating suspended sediment concentration (SSC) in rivers, turbidity is potentially a much better predictor than water discharge. Since about 1990, it has been feasible to automatically collect high frequency turbidity data at remote sites using battery-powered turbidity probes that are properly mounted in the river or stream. With sensors calibrated to give a linear response to formazine standards, turbidity and sediment concentration should have a linear correlation close to unity for a given size and composition of suspended particles (Gippel, 1995; Foster et al., 1992). For events of limited duration, the physical properties of the suspended particles probably change very little in most streams. A few (less than 10) data pairs spanning the range of concentrations should be sufficient to reliably establish the relation between SSC and turbidity during such events (Lewis, 1996). This relationship provides a means for accurately estimating sediment loads during storm runoff events. In addition, the detailed turbidity record often contains the signature of sediment inputs to the channel from erosion and mass wasting (Lewis and Eads, 1996).*

*For estimating monthly or annual sediment loads, the relation between SSC and turbidity will vary over time with changes in sediment sources, organic loading, or sensor calibration (Gippel, 1995). Thus, the use of a single curve describing the long-term mean relation will yield greater errors than for short-event estimation. Nevertheless, turbidity is probably more useful than water discharge as a long-term predictor of SSC. If the turbidity-SSC relation is roughly linear, load estimates will be nearly unbiased. In contrast, with sediment rating curves (linear in the logarithms), variance estimation is much more complicated (Gilroy et al., 1990) and such models frequently fit the data poorly and are subject to large errors (Walling and Webb, 1988).*

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*has been experimenting with various approaches to estimating suspended sediment loads in small streams. We have developed a prototype system where a data logger program employs nephelometric turbidity to make SSC sampling decisions (i.e., to activate a pumping sampler) in real time (Lewis, 1996; Lewis and Eads, 1996). The algorithm uses a separate rising and falling series of threshold turbidity values. A falling condition is detected when turbidity drops a given percentage below the previous maximum, and a rising condition is detected when turbidity rises a given percentage above the prior minimum. Because the falling condition is usually much longer than the rising condition, the falling series has more thresholds. SSC specimens are collected whenever a threshold for the current condition is crossed. Additional constraints are imposed to limit sampling when turbidity is spiking or fluctuating rapidly.*

*High frequency noise in the data can be caused by air bubbles or momentary scraps of debris passing in front of the optics. With the probes we are using, these often result in large erroneous readings. Therefore, before recording a value, we first read turbidity at half-second intervals for a half-minute, storing 61 values temporarily in data logger memory. These values are then sorted and the median is recorded. The median is more appropriate than the mean because the mean is sensitive to outliers.*

*The prototype algorithm was designed and its performance evaluated by simulating sampling from 10-minute field records of SSC and turbidity (Lewis, 1996). These data had been collected during 5 storm events in a 946-acre rain-dominated watershed (Caspar Creek) with predominantly fine-grained sediments. The thresholds and algorithms were tuned to give a sample size of about 9 specimens in the largest event simulated (a 2-year peak flow), but the number depends on the temporal pattern of turbidity. For each sample, a linear regression was fit to SSC versus turbidity and used to estimate SSC for every 10-minute interval. The products of SSC and 10-minute discharge were summed to obtain a load estimate for the storm. Sampling variation was achieved by applying 15 sets of thresholds (each shifted slightly from the next) to each storm, resulting in 15 load estimates. "True" sediment loads were computed using the entire SSC record from each storm, enabling an assessment of the estimation errors. The root mean square errors varied from 1.9 to 7.7%, compared to errors of 8.8 to 23.2% for sediment rating curve estimates based on the same samples. These errors were achieved for samples sizes averaging between 4 and 11 SSC specimens per storm. While the errors were relatively small, it is difficult in practice to reliably estimate these errors from the sample, because (1) larger sample sizes are needed for reliable variance estimation, and (2) variance estimation is very sensitive to lack of fit.*

*Similar data to those collected at Caspar Creek are currently being collected from a 20,000 acre watershed (Grass Valley Creek) where suspended sediment transport is dominated by sand-size particles derived from decomposed granite. We plan to repeat the simulations using the Grass Valley Creek data with the expectation of defining some of the limitations of our methodology.*

*For the past 3 winters, we have used turbidity-controlled sampling in the Caspar Creek watershed at eight gaging stations. Basic issues that we have confronted are the type of probe housings to use, if any, and mounting configurations. Each gaging station has its own unique set of problems. In the small channels at Caspar Creek we mounted the probes inside black ABS pipe to exclude the influences of debris, sunlight, the water surface, and the channel bed on the probe's detector. But housings also can become clogged with sediment or debris. The ideal probe housing should shed debris and protect the probe from traumatic impacts, while allowing the stream suspension to flow through. Housing design is an area where more research and development is needed.*

*We mounted some of the probe housings close to the bed, some on depth-proportional floating booms that pivot on the bed, and two on the faces of V-notch weirs. It is imperative that the probes be mounted in such a way that they are not impacted by bedload. They must also be accessible at most times so that debris can be dislodged or the optics cleaned if necessary. At Grass Valley Creek, we have two probes mounted on an an articulating steel boom that is cantilevered over the channel and can be raised and moved to the bank by a cable system. The boom swings aside or rides over large debris when it is encountered.*

*Biological fouling of the optics (e.g., by invertebrates and algae) can be a problem under some conditions, particularly in low to moderate flows when probes are left unattended for weeks at a time. Probes with wipers have been marketed but so far seem to be unreliable. Housings may reduce biofouling to some degree, but probes should be serviced at least on a weekly basis to clean the optics and to remove sediment that may collect in the housings or snagged debris such as leaves, roots, and twigs.*

*Where the suspended load is sandy, we must also consider whether pumped point samples can adequately represent discharge-weighted mean concentrations. Where should the sampler intake be located and how should it be oriented? Are large particles under-sampled? Does cross-contamination occur between samples? To what extent can the limitations of pumped point samples be overcome through calibration with ETR (equal transit rate) or EDI (equal discharge interval) samples?*

*Another key issue is that a programmable data logger is needed for such tasks as calculating median turbidity and mean stage, and evaluating rules for sampling. A high level language such as BASIC is desirable for ease of code generation, maintenance, and portability. To meet this requirement, we built data loggers around a single-board computer. However, for the technology to be accepted, it will almost certainly have to be implemented with an off-the-shelf data logger. We are currently investigating whether the programming and sampling logic can be implemented on today's commercially available data loggers.*

## References


*Foster, I. D. L., R. Millington, and R. G. Grew, The impact of particle size controls on stream turbidity measurements; Some implications for suspended sediment yield estimation, in Erosion and Sediment Transport Monitoring Programmes in River Basins, IAHS Publ. 210, pp. 51-62, 1992.*

*Gilroy, E. J., R. M. Hirsch, and T. A. Cohn, Mean square error of regression-based constituent transport estimates, Water Resour. Res., 26(9), 2069-2077, 1990.*

*Gippel, C. J., Potential of turbidity monitoring for measuring the transport of suspended solids in streams, Hydrol. Processes, 9, 83-97, 1995.*

*Lewis, J. Turbidity-controlled suspended sediment sampling for runoff-event load estimation. Water Resour. Res., 32(7), 2299-2310, 1996.*

*Lewis, J., and R. Eads. Turbidity-controlled suspended sediment sampling. Watershed Management Council Newsletter 6(4): 1,4-5, 1996.*

*Walling, D. E. and B. W. Webb, The reliability of rating curve estimates of suspended sediment yield: some further comments, in Sediment Budgets, IAHS Publ. 174, pp. 337-350, 1988.*