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Turbidity-controlled suspended sediment sampling

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For estimating suspended sediment concentration (SSC) in rivers, turbidity is generally a much better predictor than water discharge. Turbidity is an optical measure of the cloudiness of water caused by light scattering from suspended particles, organics, and dissolved constituents. Although it is now possible to collect continuous turbidity data even at remote sites, sediment sampling and load estimation are still conventionally based on water discharge. With frequent calibration, the relation of turbidity to SSC can be used to estimate suspended loads more efficiently. The sampling can be automated using a programmable data logger which signals a pumping sampler to collect SSC specimens at specific turbidity thresholds. While our focus has been suspended sediment and turbidity, the method could also be applied for solute load estimation, using specific conductance in place of turbidity. The approach has potential for monitoring any water quality constituent whose concentration is better correlated with an easily measured (in situ) parameter, such as turbidity or conductance, than with water discharge.

The efficiency of such a system has been demonstrated (Lewis, 1996) using dense field records of SSC and turbidity collected at 10-minute intervals during five storm events in the Caspar Creek Experimental Watershed on the Jackson Demonstration State Forest in northern California. Caspar Creek is a small, mountainous, coastal watershed that exports predominantly fine sediment. In simulations, samples containing a mean of 4 to 11 specimens, depending on storm magnitude, were repeatedly selected from each storm's record and event loads were estimated by predicting SSC from regressions on turbidity. Using simple linear regression, the five storm loads were estimated with root mean square errors between 1.9 and 7.7% of the known loads, compared to errors of 8.8 to 23.2% from regressions on discharge. Sample sizes of five specimens were generally adequate to estimate the storm loads with root mean square error no greater than 5% of the correct value. For similar accuracy without turbidity, the best available estimation methods require sample sizes 3 to 10 times larger, hence are much more costly in terms of field work and lab processing costs.

In addition to facilitating load estimation, continuous measurement of turbidity provides a more detailed picture of sediment transport than is normally available. Complete records of turbidity and associated estimates of SSC are obtained. Sediment pulses are detected whether or not they are related to water discharge, and the turbidity threshold sampling procedure ensures that at least one SSC specimen will be collected during any significant pulse. The SSC values provide verification that the pulse was real and did not result from temporary fouling of the turbidity probe's optics. Pulses in the turbidity trace are often associated with sudden sediment inputs from events such as bank failures or debris flows. Such pulses provide an alert to watershed problems that may require closer investigation. If turbidity is monitored in nested watersheds, sediment pulses can be tracked as they move downstream.

It is important to remember that turbidity is an optical property, not a direct measure of SSC by volume or mass. A turbidity probe's sensitivity is related to the sensor design and the nature of the suspended material (Gippel, 1995). At the Caspar Creek sites, we deploy a backscatter in situ sensor that projects infrared light into the water column. The amount of light reflected back to the sensor is influenced by the quantity of particles, their size, shape, and composition. For instance, sensitivity to clay particles is several orders of magnitude higher than sand. The relation between SSC and turbidity is quite good when particle sizes and types remain nearly constant or are well-related to SSC. Applying storm-by-storm calibrations improves load estimates by accounting for the temporal variability in the relation between SSC and turbidity caused by particle variations, incremental contamination of the sensor's optics, and sensor drift.

The feasibility of the sampling system is being tested at eight gaging stations in Caspar Creek, where data have been collected continuously for the past winter. The equipment at each gaging station consists of a stream channel control structure, stilling well, pressure transducer, turbidity probe and housing, pumping sampler, and data logger. The sampling program in the data logger controls the collection of information from the pressure transducer and turbidity probe, and activates the pumping sampler at the appropriate turbidity thresholds. Programming demands on the data logger include calculating median turbidity and mean stage, evaluating rules for specimen collection, and logging data for subsequent retrieval. A high level language, such as BASIC, is desirable for ease of code generation, maintenance, and portability. Because few, if any, commercial data loggers fit these requirements, we built data loggers around a commercially available single-board computer. User interface circuits are designed and added via a stackable board, then all components are housed in a weather-proof enclosure. Data are retrieved from the data logger in the field with a palmtop computer during each site visit. A plotting program allows field personnel to check for valid program operation, examine stage and turbidity data for reasonable values, and detect equipment malfunctions. Although field visits have been reduced from previous studies, it is still desirable to visit sites during storms to check on equipment, remove interfering debris, and make manual measurements. At Caspar Creek, staff plates are read, depth-integrated SSC specimens are collected to calibrate fixed-intake pumped specimens, and discharge is measured to develop or validate stage-discharge rating equations.

The position of the turbidity probe in the stream is critical. The probe should remain fully submerged during all flows of interest. We have designed probe housings that protect the sensor from damage, exclude ambient sunlight, and reduce the functional minimum water depth. We are currently evaluating two types of housings and three mounting systems. The design challenge is to maintain hydraulic efficiency and exclude large organics, but not introduce cavitation. Bio-fouling of submerged optics is a commonly reported problem, typically degrading data 3 to 21 days after cleaning. A simple solution, if only storm data are of interest, is to mount the probe above inter-storm flows thus reducing opportunities for colonization. Another solution is provided by a manufacturer that offers a turbidity probe with an optical wiper that can be activated on command by the data logger.

The channel control structures at the eight gaging stations include two V-notch weirs, one rectangular section (rated by discharge measurements), and five Parshall flumes, each of which provides unique installation challenges. The watersheds vary from 21 to 424 hectares, flumes being sited in the smallest watersheds and weirs in the largest.

The smaller watersheds have very little depth of flow between storm events and present the greatest problem because the turbidity probes require complete submergence in order to function, yet they need to be above the level of bedload transport. To pond the water, funnel-shaped wooden structures were therefore constructed upstream of flumes with inadequate flow depths. Astroturf was placed in the throat of the funnels to increase friction and the probes were placed in the converging portion of the funnels where the greatest water depths were observed.

At the gaging station with the rectangular rated section, the turbidity probe is mounted on a depth-proportional intake boom (Eads and Thomas, 1983). A float on the surface end of the boom causes the boom to rise and fall, pivoting on the channel bed as the water depth changes and keeping the turbidity probe and pumping sampler intake at a fixed proportion of the water depth. This apparatus was installed with the intent of obtaining a more consistent relation between turbidity and average SSC in the cross-section. Use of a boom is most appropriate in streams where SSC mixing is incomplete.

At the weirs, the probes are mounted on the upstream face with the opening of the housing flush with one side of the V-notch. Holes drilled in the housing permit water to enter through the side and exit at the V-notch end. The higher velocity at the V-notch end creates a pressure differential which seems to be effective in maintaining flow through the housing.

Some experimentation was required this first winter with regard to turbidity thresholds, probe mounting, housing configurations, and software algorithms. For example, one of the tributaries was found to have much lower turbidity than any of the others and a special set of thresholds was implemented for only that gaging station to ensure that enough SSC specimens were collected to permit sediment load estimation. Despite the experimental nature of the operation during the first winter, initial results look promising, especially at the weirs (Figure 1), where the probe is nearly always submerged during flows of interest. Bio-fouling was not a problem at any of our stations, partly because of the type of streams, but also because we routinely cleaned the optics between each storm, and at least once every two weeks. Relations between SSC and turbidity were generally linear and often had remarkably little scatter (insets, Figures 1 and 2). We have reduced the number of pumped specimens collected at each gaging station to about one-sixth the number we formerly collected using a discharge-driven variable probability sampling method described by Thomas (1985); and the load estimates, at least during larger storm events, are of comparable quality. In addition, we have been able to obtain much more detailed records of sediment transport that have alerted us to active erosion in one of the tributaries (Figure 2).

We plan to test the turbidity-controlled sediment sampling system in a variety of environments. Next winter, the Hoopa Tribe will be implementing our methodology at six new gaging stations on tributaries of the Trinity River in northwest California. These are larger watersheds with different geology and soils than Caspar Creek and fine sediment transport is expected to be a smaller proportion of the total load. As long as particle sizes do not fluctuate widely over short time periods, a coarse load should not be an obstacle. Snowmelt runoff may present a challenge to the extent that some runoff events may be prolonged enough to encompass changes in the relation between SSC and turbidity. At one of the gaging stations, the Tribe will collect an intensive data set similar to that from the five Caspar Creek storms used in our sampling simulations. This will permit us to thoroughly investigate the method's potential at the new location after a single year of monitoring.

Additional information can be found at the Redwood Sciences Lab Website: http://www.rsl.psw.fs.fed.us, or you can reach the authors by email at: jl7001@axe.humboldt.edu or ree7001@axe.humboldt.edu.

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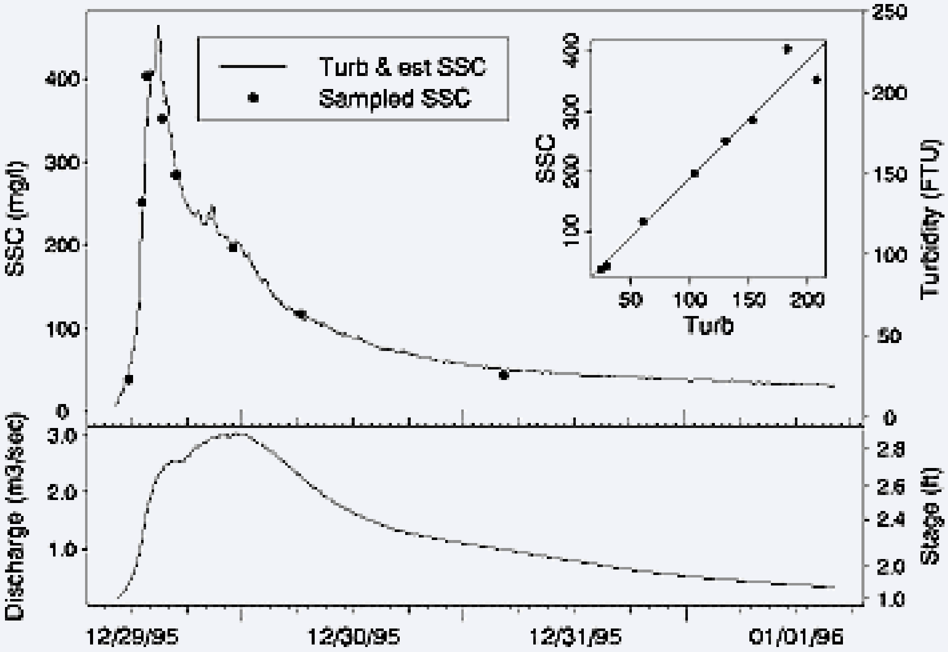

Figure 1.
Turbidity, estimated and actual (sampled) suspended sediment concentration, and water discharge from a storm event at the 424-hectare Caspar Creek North Fork Weir.

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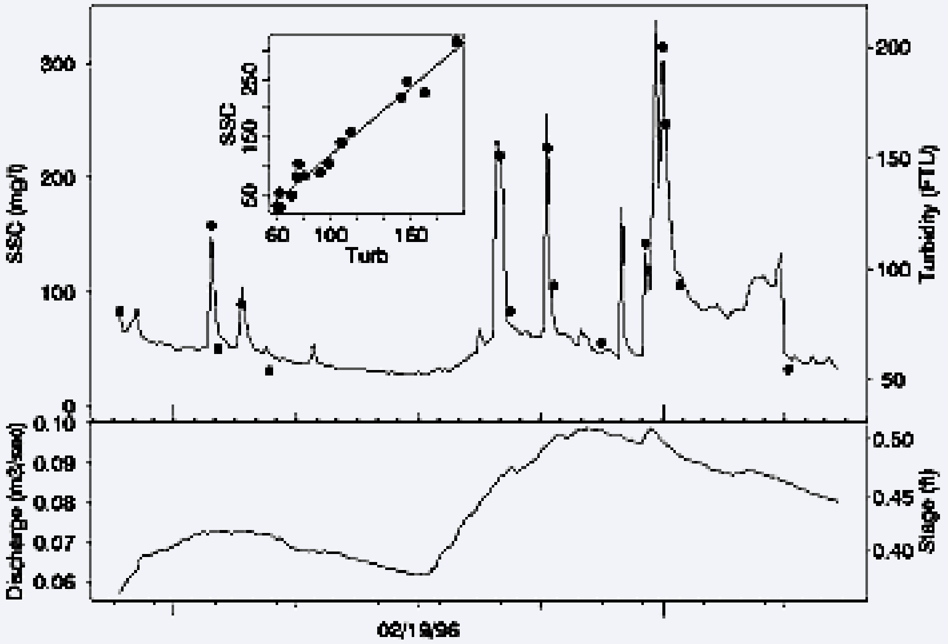

Figure 2.
Turbidity, estimated and actual (sampled) suspended sediment concentration, and water discharge from a storm event in a 27-hectare tributary of Caspar Creek.

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