ESTIMATION OF SUSPENDED SEDIMENT FLUX IN STREAMS USING CONTINUOUS TURBIDITY AND FLOW DATA COUPLED WITH LABORATORY CONCENTRATIONS

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The widening use of sediment surrogate measurements such as turbidity necessitates consideration of new methods for estimating sediment flux. Generally, existing methods can be simply be used in new ways. The effectiveness of a method varies according to the quality of the surrogate data and its relation to suspended sediment concentration (SSC). For this discussion, it is assumed that for each estimated period the surrogate data are accompanied by corresponding SSC data. If they are not, then the suspended sediment flux (i.e. yield or load) estimates are likely to be very poor. The accuracy of estimates is probably more dependent on sampling design and data quality than on the estimation method (Eads, 2002)

Sampling Design. Effective sampling designs focus on the important sources of variability. For example, if most of the variation in sediment flux occurs during summer thunderstorms, then sampling should target summer thunderstorms. In most streams the relation between turbidity and SSC varies significantly between events. Differences in turbidity for a given SSC can easily vary by a factor of 2 or 3. Therefore, numerous events must be sampled to properly represent the average relationship. And a relationship from one event will not serve well to estimate SSC in another.

A hypothetical sample was simulated from an intensively monitored storm event (Figures 1a-b) using the Turbidity Threshold Sampling (TTS) method (Lewis, 1996; Lewis and Eads, 2001), which obtains regression data (SSC vs. turbidity) covering the range of SSC in each episode of sediment transport. In practice, a data logger uses real-time turbidity data to govern the collection of pumped SSC samples. Regressions are later applied to the continuous turbidity data to obtain continuous SSC estimates. Depth-integrated samples are also collected for a subset of pumped samples so that SSC can be adjusted if necessary to reflect cross-sectional averages, but spatial variability of SSC in streams is generally small compared to temporal variability.

Data Quality. The importance of turbidity data quality cannot be emphasized enough (Eads and Lewis, 2002). Turbidity sensors with mechanical wipers can prevent fouling by detritus, and proper mounting of the sensor can reduce fouling from larger debris, but it is virtually impossible to collect perfect turbidity data. All data must be plotted and scrutinized carefully with reference to detailed field notes in order to properly identify, flag and correct problem areas. Some patterns of fouling are readily identifiable with experience, but others require comparison with SSC such as those from pumped TTS samples. Ephemeral fouling can usually be corrected by interpolation, but extended fouling is usually not correctable and can only be omitted or flagged with quality codes.

Flux Estimation. Custom computer algorithms are essential for sediment flux estimation, but the process cannot be entirely automated because many subjective decisions are required. Suitable models can vary between and within transport events. The choice of appropriate models for an event depends on the completeness and quality of the surrogate data and its relationship with SSC. If the turbidity sensor was fouled during a portion of an event, then the SSC may have to be estimated from its relationship with flow. When the sensor is fouled and the turbidity readings are fluctuating, TTS can trigger extra pumped samples. If both turbidity and flow are poorly related to SSC, there are often enough pumped samples to permit reliable estimation of SSC by linear time-interpolation (Figure 1b).

Regressions of SSC vs. turbidity (turbidity-SSC rating curves) are often quite linear with low variance. Therefore, when reliable turbidity data are accompanied by SSC samples, sediment flux can be estimated quite accurately (Figures 1c-d). Sometimes a quadratic or power model, or two linear models, are superior (Lewis, 1996), but in most cases, the variability and small sample sizes are inadequate to support a nonlinear model. A nonlinear model relating SSC to turbidity may improve variance estimation somewhat, but will not usually improve flux estimates (Lewis, 1996). Additionally, the preferred method of flux variance estimation with models for log-transformed SSC (Gilroy et al., 1990) is quite complex.

During periods when turbidity is of poor quality, relationships between flow and SSC may be needed (Figures 1e-f). As with turbidity-SSC rating curves, it is generally best to use only data collected during or immediately

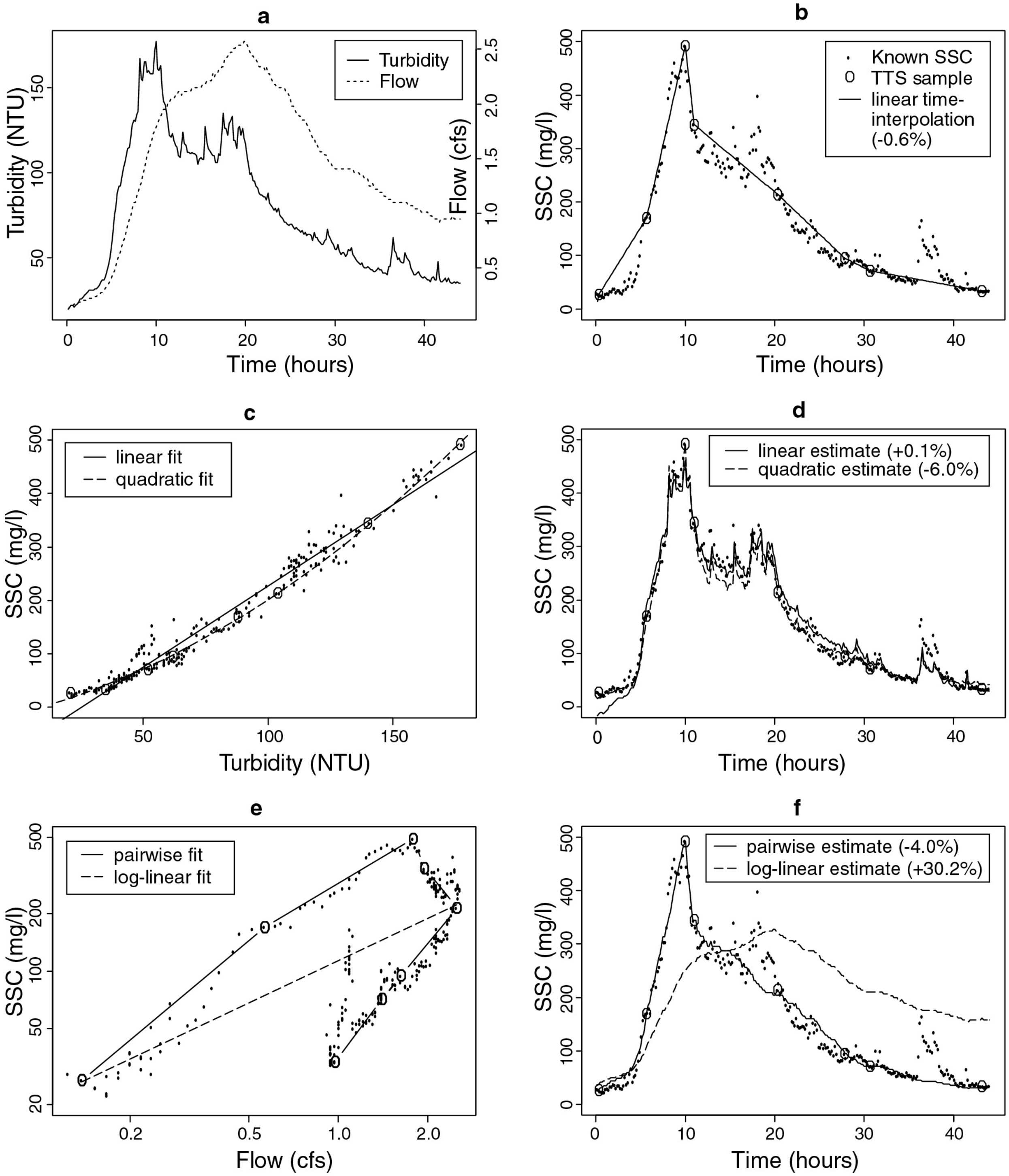

Figure 1. Estimation of suspended sediment concentration (SSC) and flux using 5 different methods for a storm event at Arfstein station, Caspar Creek, California. (a) Continuous turbidity and flow. (b) Measured SSC and 8 hypothetical samples obtained using Turbidity Threshold Sampling, showing linear interpolation of SSC as a function of time. (c) A linear and quadratic model of SSC vs. turbidity. (d) Estimated SSC from models shown in frame **c**. (e) Pairwise hysteresis fit and log-linear discharge-SSC rating curve. (f) Estimated SSC from models shown in frame **e**. Errors in estimated flux associated with each method are shown in parentheses in legends of frames **b, d,** and **f**.

surrounding the estimated event. When modeling SSC as a function of flow, it may be useful to employ a piecewise or pairwise model, in which each segment of the curve is applied only to the period of time between the sampling times of its endpoints (Figures 1e-f). Such a model can handle hysteresis, but produces inverted sedigraphs for negatively-sloping segments, in which flow peaks are modelled as SSC troughs. And if no smoothing is applied, pairwise models often include over-steepened segments that produce wild predictions. Discharge-SSC rating curves and piecewise hysteresis models are often more useful for representing segments of events than entire events.

Custom software could greatly simplify implementation of the above processes. A useful procedure would present the analyst with a series of choices as follows:

1. Select a time period to be estimated.
2. Select a set of SSC samples (default selection would be those from the selected time period) .
3. If needed, adjust SSC to the cross-section average using a user-supplied equation.
4. Select surrogate and constituent (SSC or adjusted SSC) variables.
    - For time-interpolation between concentrations, select only constituent variable.
5. View a scatter plot of the variables selected in step 4.
    - Omit erroneous points or add new points.
6. Choose an appropriate model (linear, power, polynomial, piecewise).
7. View a time series plot of estimated and measured concentrations for the period of estimation.
8. View statistics such as estimated total and variance, and sample size.
9. Save the results and repeat steps 1-8 for next time period.
10. Finally view complete time series plots and summary statistics.

As with TTS, the above procedure would be equally applicable to any water quality constituent for which a continuous surrogate measurement is available.

The TTS method was designed for, and has been applied to, storm event flux estimates. It can also be used for annual flux estimation, although it collects more samples than may be needed. The total flux can be estimated by summing individual event fluxes, or by applying a single model to all the data. The latter approach is easier to apply but less accurate, and requires surrogate data that are complete and correct. Intermediate approaches are also possible, for example using submodels for snowmelt and storm runoff, or early season and late season flux.

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