THE USE OF RATING (TRANSPORT) CURVES TO PREDICT SUSPENDED SEDIMENT CONCENTRATION: A MATTER OF TEMPORAL RESOLUTION

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ABSTRACT

In the absence of actual suspended sediment concentration (SSC) data, hydrologists have used rating (sediment transport) curves to estimate (predict) SSCs for flux calculations. Evaluations from a long-term, ongoing, daily sediment-measuring site on a large river, indicate that relatively accurate (<±20%) annual suspended sediment fluxes can be obtained from hydrologically based monthly sampling. For a 5-year period, similar results can be obtained from sampling once every 2 months. Over a 20-year period, errors of <1% can be achieved using a single rating curve based on data spanning the entire period. However, better annual estimates, within the 20-year period, can be obtained if individual annual rating curves are used.

INTRODUCTION

Since the 1970's, there has been growing interest in estimating the fluvial transport of suspended sediment. The reasons are numerous and diverse, and include such issues as contaminant transport, water-quality trends, reservoir sedimentation, channel and harbor silting, soil erosion and loss, as well as ecological and recreational impacts (Walling, 1977; Ferguson, 1986; de Vries and Klavers, 1994; Horowitz et al., 2001). The calculation of fluxes or loads requires both discharge and concentration data (e.g., de Vries and Klavers, 1994; Phillips, et al., 1999). Typically, continuous, or near-continuous discharge data are available from *in situ* devices such as a stage/discharge recorder. On the other hand, suspended sediment concentration (SSC) data typically result from manually collected individual samples taken at fixed temporal intervals; occasionally, the fixed interval samples are supplemented by event samples. More recently, continuous or near-continuous SSC data have been generated by employing automatic samplers, or by measuring applicable surrogates such as turbidity (e.g., Horowitz, 1995). These newer approaches for determining SSC require site-specific calibrations to produce cross-sectionally representative data. Further, whereas the requisite equipment (e.g., *in situ* turbidometers, automatic samplers) is fairly inexpensive to obtain, operational and maintenance costs are relatively high. Hence, currently, continuous or near-continuous SSC data are rare.

For more than sixty years, in the absence of actual continuous or near-continuous SSC data, hydrologists have used rating (sediment transport) curves to estimate (predict) SSCs for flux calculations. Although there are more than 20 methods for developing rating curves, the most common is a power function (regression) that relates SSC to water discharge, with the discharge measurement constituting the independent variable (e.g., Phillips, et al., 1999; Asselman, 2000). This requires the log-transformation of SSC and discharge data prior to the analysis. Comparisons of actual and predicted SSC, partially as a result of scatter about the regression line, as well as the conversion of results from log-space to arithmetic-space, indicate that rating curves can substantially underpredict actual concentrations (Walling and Webb, 1988; Asselman, 2000). To compensate, various method modifications have been applied; these include dividing the SSC/ discharge data into seasonal or hydrologic groupings, developing various correction factors, or using non-linear regression equations (Duan, 1983, Ferguson, 1986; Walling and Webb, 1988; de Vries and Klavers, 1994; Phillips, et al., 1999; Asselman, 2000).

In 1995-1996 the U.S. Geological Survey's (USGS) National Stream Quality Accounting Network (NASQAN) was revised from an occurrence and distribution-based network to a large-river flux-based water-quality monitoring network (Horowitz, et al., 2001). SSCs were required to calculate fluxes for sediment, as well as for various sediment-associated constituents (e.g., trace elements, nutrients). Due to resource constraints, the requisite SSCs/fluxes had to be determined from site-specific rating curves. Over the past 7 years, the effect of using the rating-curve approach, relative to such issues as sampling frequency, temporal resolution, and errors associated with flux estimates continue to be evaluated. Some of these evaluations are discussed herein.

METHODS

Within NASQAN, the Mississippi River at Thebes site is unique because it constitutes the only long-term, ongoing, daily sediment-measuring site in the network. As such, the data from this site are uniquely suited to evaluating such issues as sampling frequency, temporal resolution, and flux calculation/estimation errors. All calculations used in these evaluations are based on a 20-year data set covering water years (October-September) spanning 1981 to 2000.

All regression analyses were performed using Statview® 5.0 on a desktop computer. Linear and non-linear regression equations were calculated; comparison with actual data indicated that the predicted concentrations represented underestimates. These underestimates were substantially reduced by applying a 'smearing' correction (Duan, 1983).

RESULTS AND DISCUSSION

The first evaluation entailed an examination of the temporal resolution, and associated errors, of estimated suspended sediment fluxes at the Thebes site covering the first 5 years (1996-2000) of the revised NASQAN program. The actual flux for that 5-year period was 414 Mt (megatonnes), whereas the predicted flux, using daily values, was 404 Mt, a 3% underestimate. Despite this close agreement for the entire 5-year period, maximum errors in daily estimates of SSC ranged from -290% to +260%. The 5-year suspended sediment flux estimate using the approximately monthly NASQAN samples was 439 Mt, a 6% overestimate. The various errors associated with different levels of temporal resolution also were calculated for the same 5-year period; the errors tend to decline with increasing temporal resolution (table 1). This accrues because the rating-curve approach underestimates highs and overestimates lows. Hence, the longer the period of interest, the greater the chance for the over- and underestimates to balance each other out.

Table 1. Various levels of temporal resolution and their asociated errors for the Mississippi River at Thebes site for the five-year period 1996 - 2000.

Temporal Resolution	Maximum Underestimate Relative Percent	Maximum Overestimate Relative Percent	Average Absolute Error Relative Percent
Daily	-61	+65	27
Weekly	-60	+135	23
Monthly	-42	+35	18
Quarterly	-32	+28	13
Yearly	-13	+6	6

The effect of sampling frequency on the accuracy and associated errors of 5-year suspended sediment flux estimates also was investigated as part of the same evaluation. This entailed using the daily SSC values for the Thebes site and calculating a large number of rating curves to predict daily SSC values assuming different levels of sampling intensity. The sampling frequencies evaluated in this way corresponded to: (1) once a day; (2) once every other day; (3) once every 3 days; (4) once every 4 days; (5) once every 5 days (weekly); (6) once every 10 days, (7) once every 25 days (monthly); and once every 50 days (every other month). Not surprisingly the accuracy of the 5-year estimates decreased, and the size of the associated errors increased with decreasing sampling frequency (fig. 1a). Interestingly, there was little difference between sampling frequencies ranging from 1- to 5-days. On the other hand, estimation errors from sampling frequencies on the order of once every 2 months (once every 50 days) were little compromised, and tended to fall within a range of ±20%. As the calculations were based solely on calendar distributions, they probably represent the maximum error likely to occur with this level of sampling frequency (fig. 1a). If the same level of sampling (once every 50 days) were hydrologically distributed such as to encompass some 80 to 85% of the typical range of discharge, the associated estimation errors likely would be substantially less (e.g., Horowitz, 1995). The effect of sampling frequency on the accuracy and associated errors of annual suspended sediment

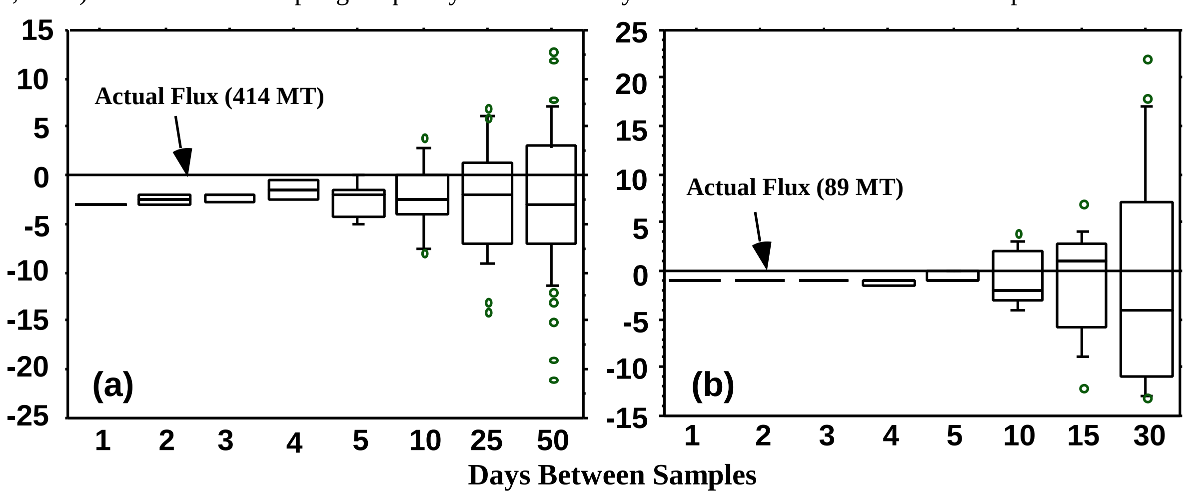

Fig. 1. Effect of sampling frequency on the errors associated with the estimation of suspended sediment fluxes over a 5-year (1996 - 2000 WY) period (a) and for a 1-year (1995 WY) period (b) for the Mississippi River at Thebes.

flux estimates also was investigated concurrently (fig. 1b). These evaluations covered high (1982), median (1995), and low (1989) flux years. The sampling frequencies evaluated in this way corresponded to: (1) once a day; (2) once every other day; (3) once every 3 days; (4) once every 4 days; (5) once every 5 days (weekly); (6) once every 10 days, (7) once every 15 days (fortnightly); and once every 30 days (every month). Note that as with the 5-year study, there is little difference between 1- and 5-day sampling. Further, even collecting a sample as infrequently as once a month only produced errors on the order of ±20%, regardless of the flow conditions (high, low, or median). The same caveats apply to the annual study as to the 5-year study, hence, hydrologically based sampling, as opposed to calendar-based sampling, is likely to produce substantially more accurate estimates.

The actual 20-year suspended sediment flux for the Thebes site for the period 1981 to 2000 was 1,200 Mt. A single rating curve, using the entire 20-year data set, yielded a similar estimate, representing an error of <1%. This is a fairly standard approach for generating site-specific rating curves where long-term data are available, and is based on the assumption that all the data from the site are part of the same statistical population. Note that the annual errors associated with this single rating-curve approach can be significant (fig.3a). However, when individual annual rating curves are calculated for the same 20-year period, it is apparent that the data are not part of the same statistical population. Some curves are linear whereas others are non-linear (both concave and convex). Interestingly, the sum of the annual fluxes for the 20-year period is still 1,200 Mt; however, the individual annual estimates are significantly closer to the actual fluxes (fig. 3b). Hence, although the estimate of total flux does not improve through the use of annual rating curves as opposed to a single rating curve, better annual estimates within the 20-year period can be obtained if individual calculations are used.

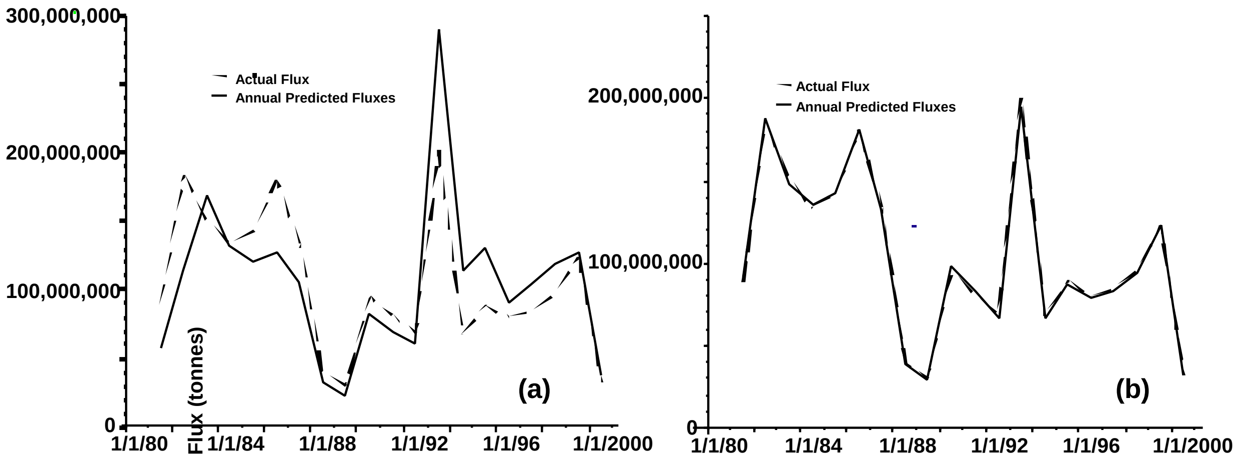

Fig.3. Comparisons of annual fluxes calculated by using a 20-year rating curve (a) and by calculating individual annual rati curves (b) for the Mississippi River at Thebes site for the period 1981 - 2000.

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