The use of automatically collected point samples to estimate suspended sediment and associated trace element concentrations for determining annual mass transport

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ABSTRACT Attempts to quantify the mass transport or annual fluxes of suspended sediment and associated trace elements usually are complicated by a lack of adequate data coverage for substantial portions of the annual hydrograph and/or for major discharge events (e.g., storms, floods, spring snowmelt). Potentially, this problem could be addressed by the installation of automatic samplers at appropriate sites. Automatic sampling equipment at a site normally collects a point sample at a single depth in a fluvial cross section. Data from such samples often cause over- or underestimates of suspended sediment and associated trace element concentrations when compared to depth-and-width integrated sample data. However, studies on two different U.S. rivers indicate that data from near-simultaneously collected point (two, an upper and lower one) and depth-and-width integrated samples, obtained over a wide range of discharges ($\geq 90\%$ of the hydrograph) and suspended sediment concentrations, can be used to calculate regression equations that relate the former to the latter. Comparisons of sampled and calculated (using the regression equations) depth-and-width integrated suspended sediment and associated trace element concentrations indicate that it is feasible to use automatic point samplers to estimate fluvial cross-sectional concentrations within $\pm 20\%$ of actual (as defined by a depth-and-width integrated sample) levels.

INTRODUCTION

Recent evidence indicates that a majority of fluvial trace elements are transported in association with suspended sediments (Meybeck and Helmer, 1989; Horowitz et al., 1990; Windom et al., 1991; Horowitz, 1991). Thus, accurate data on the transport of suspended sediments and associated trace elements for a river requires detailed sampling of suspended sediments for a substantial portion of the annual hydrograph. Estimations of annual suspended sediment and associated trace element transport for a river, or a major river reach, would require multiple sampling sites at appropriate loca tions. Finally, such data for a large number of rivers, would be a requisite for estimating trace-element geochemical cycles, for evaluating global trends in point and nonpoint sources of pollution, and for determining annual off-continent trace-element fluxes to regional seas and the world's oceans (Forstner and Wittmann, 1981; Solomons and Forstner, 1984; Meybeck and Helmer, 1989; Horowitz, 1991).

As a result of resource constraints, accurate estimates of annual suspended sediment and associated trace element transport usually are confounded by a lack of adequate sample coverage for much of the annual hydrograph. This lack falls into two major categories: a) insufficient samples to delimit cross-sectional temporal variations in suspended sediment and associated trace element concentrations occurring during periods of constant discharge; data on cross-sectional spatial variations are also lacking, and b) insufficient samples to delimit temporal cross-sectional variations in suspended sediment and associated trace element concentrations for major discharge events such as large storms, floods, spring snowmelt and runoff, etc. (e.g., Horowitz et al, 1990).

There is ample evidence that the adequate determination of suspended sediment and associated trace element concentrations requires the collection of depth-and-width-integrated samples composited from a series of verticals obtained at equal-width or equaldischarge increments (Porterfield, 1972; OWDC, 1978; Inland Waters Directorate, 1988; Horowitz et al., 1990). Sampling by these procedures is time-consuming and labor intensive and usually requires from 1 to 3 hours for each sample. Intensive sampling using these methods is usually performed infrequently, typically no more than once a month. Thus, sampling of this type does not represent much of the annual hydrograph, and usually is insufficient to assess the substantial temporal variations in suspended sediment and associated trace element concentrations (up to an order of magnitude or more) that can occur (e.g., Meybeck and Helmer, 1989; Horowitz et al., 1990).

Historically, the problem of inadequate data coverage for major portions of the annual hydrograph for suspended sediment concentrations, has been addressed by the manual collection of a single, daily-collected depth-integrated vertical, or an automatically collected point sample. However, single verticals or point samples collected in a river often do not reflect accurate cross-sectional suspended sediment concentrations (Feltz and Culbertson, 1972; Porterfield, 1972; Horowitz et al., 1990). This discrepancy is usually accounted for by the determination of a 'box' equation, or the calculation of an appropriate cross-section vs. point sample coefficient (e.g., Porterfield, 1972; OWDC, 1978; Inland Waters Directorate, 1988). These mathematical expressions relate suspended sediment concentrations under a variety of discharge conditions, in the single point or vertical samples, to a limited number of accurate cross-sectional suspended sediment concentrations determined from a simultaneously collected depthand-width integrated sample. Once the expressions have been developed, they are subsequently applied to additional single point or vertical samples to obtain estimated cross-sectional suspended sediment concentration data. This type of procedure improves coverage of the annual hydrograph, but still may be insufficient to assess annual temporal variations (e.g., Horowitz et al., 1990).

The purpose of this study was to evaluate the expanded use of automatic point samplers to collect samples that could be utilized, with appropriate regression equations, to improve estimates of the annual transport of suspended sediments by providing data on a substantially larger segment of the annual hydrograph. In addition, an attempt would be made to apply the same technique to suspended-sediment associated trace elements, thereby providing a means to more accurately estimate annual trace element transport and fluxes.

SAMPLE SITES, FIELD AND LABORATORY METHODS, AND STATISTICAL PROCEDURES

Sample Sites

Two different sites where stage/discharge relationships had previously been established

were selected to evaluate automatic samplers for collecting suspended sediment samples for the determination of cross-sectional suspended sediment and associated trace element concentrations. The first site was the Arkansas River at Portland, Colorado. At this site streamflow is derived from snowmelt from inbasin tributaries and from transmountain diversions. The river is moderately controlled by dams and drains some $10,422 \text{km}^2$ (4024mi²). Land use is primarily agricultural, but upper portions of the basin are still affected by heavy metal-rich acid mine drainage from abandoned precious-metal mines. For the 29 year record (1940-52, 1975-91), suspended sediment is mostly coarse silt/fine sand and has ranged from <10mg/L to over 6800mg/L. Stream-

flow has varied from $<2.1\text{m}^3$ /s ($<74\text{ft}^3$ /s) to 595m³/s ($21,010\text{ft}^3$ /s); average discharge has been 22.2m³/s (785ft^3 /s). The second was the Chattahoochee River at Fairburn, Georgia. This is a highly controlled (by dams) mid-sized piedmont river draining 5440 km² (2100mi^2). With the exception of major inputs from the city of Atlanta [some 34 km (21mi) upstream], land use is mostly rural/agricultural. For the last 10 years, suspended sediment usually has been silt/clay with a fairly high organic carbon content, and has ranged from <10mg/L to more than 1400mg/L, discharge has ranged from $<30\text{m}^3$ /s (<1,000 ft³/s) to 850m³/s (30,000 ft³/s); median discharge has been 73.3m³/s (2790ft³/s).

Sample Collection and Treatment

Depth-and width integrated suspended sediment samples were collected at each site using either equal-width (Arkansas River, 18 to 20 verticals) or equal-discharge increments (Chattahoochee River, 5 verticals). In most cases, each vertical was occupied from 2 to 3 times, in sequence, to obtain sufficient suspended-sediment masses. Simultaneous, or near-simultaneous point samples were also collected, using a variety of pumps, from upper and lower fixed or floating intakes (see Fig. 1). Point and depth-and-width integrated sample volumes ranged from 40 to 70 liters. The sand fraction (>63µm) was separated from each sample, on site, using a non-metallic sieve; this material was subsequently washed from the sieves using deionized water. Except for the initial samples from the Arkansas River (dewatered with a laboratory centrifuge), the silt/clay fractions were dewatered with flow-through centrifuges in a laboratory/office environment and then frozen (Horowitz et al., 1989). During sampling, stage height was recorded from automatic gages and subsequently was converted to discharge.

Laboratory Procedures

Prior to analysis, the samples were freeze-dried (Horowitz and Elrick, 1987. Chemical analyses for Fe, Mn, Al, Ti, Cu, Zn, Cd, Pb, Ni, Co, Cr, As, Sb, and Se were performed using a HNO₃/HF/HClO₄ digestion and AAS quantitation (Horowitz and Elrick, 1987). Total organic carbon (TOC) was determined, on sample aliquots pretreated with 10% HCl using an IR carbon analyzer. Analytical accuracy, based on simultaneously analyzed NIST and USGS standards was better than $\pm 8\%$; precision, based on replicate sample analyses, was comparable to accuracy. No significant bias was detected. Surface area (SA) was determined on appropriately sized sample aliquots using a single point BET method following the procedures of Horowitz and Elrick (1987). The minimum, maximum, mean and median values for the various laboratory-and field-derived constituents/measurements are presented in Table 1.

Statistical Procedures

A series of multiple linear regression equations were calculated for suspended sediment and each trace element concentration for the two separate sample sets (one for the

Sampling Scheme for the Arkansas River at Portland, Colorado



FIG. 1 Schematic sampling schemes for the Arkansas and Chattahoochee Rivers (looking upstream). An equal-width incremental sampling method was used on the Arkansas River while an equal-discharge incremental method was used on the Chattahoochee River. The grey vertical lines for the Arkansas schematic diagram represent the location of the equal-width integrated verticals. The dashed lines on the Chattahoochee schematic diagram represent the depth-integrated verticals, while the solid lines delimit the equal-discharge increments. The numbers following the "D"s in the boxes are the distances from the left bank in meters.

Arkansas River and one for the Chattahoochee River), after the data had been log-transformed, using a forward stepwise procedure. The depth-and-width integrated sample concentrations were set as the dependent variables while concentrations of selected physical and chemical parameters/constituents from the upper and lower point samples, plus discharge, were used as independent variables. Once a model was generated, the independent variables were examined for collinearity. Wherever possible, attempts were made to reduce correlations to less than 0.5, between independent variables, either by substitution or elimination. A residual analysis then was performed to determine if any of the individual data points represented outliers that exerted a high influence on the final model. In some instances, the residual analyses led to the removal of a limited number of samples from the data set where there was a 'lack of fit' (i.e., the residual analysis indicated a non-random relation between a dependent and an independent vari-

	Arkans	sas River	(n = 55)		Chattahoochee River $(n = 36)$			
Parameter	Min.	Max.	Mean	Median	Min.	Max.	Mean	Median
$Q(ft^3/s)$	160	4325	1357	1256	1333	16,400	5464	3970
S.S. (mg/L)	9	1700	327	199	13	416	89	45
S.A. (m ³ /g)	3.7	38.1	11.0	7.9	5.9	18.5	11.6	11.2
% Coarse	12	79	51	58	5	70	31	29
% Fine	21	88	49	43	30	95	69	71
Cu (mg/kg)	33	111	53	50	23	166	74	70
Pb (mg/kg)	28	327	101	95	33	240	107	99
Zn (mg/kg)	215	1270	745	725	96	490	265	260
Cd (mg/kg)	1.0	7.6	3.8	3.9	0.9	14.2	4.4	3.1
Cr (mg/kg)	ND*	ND*	ND*	ND*	38	104	75	75
Ni (mg/kg)	ND*	ND*	ND*	ND*	12	49	32	32
Co (mg/kg)	7	17	12	12	10	26	20	21
As (mg/kg)	3.8	13.6	6.6	6.4	1.7	7.8	5.2	5.2
Sb(mg/kg)	0.5	2.6	0.9	0.8	0.4	4.0	1.4	1.6
Se(mg/kg)	0.3	3.0	0.9	0.7	0.2	1.1	0.6	0.6
Fe (wt. %)	2.2	4.5	3.4	3.4	2.6	5.4	4.5	4.6
Mn (wt. %)	0.08	0.27	0.13	0.12	0.07	0.27	0.18	0.20
Al (wt. %)	5.1	9.0	7.1	7.1	5.3	10.9	10.2	10.5
Ti (wt. %)	0.22	0.44	0.33	0.34	0.32	0.64	0.52	0.53
TOC (wt. %)	ND*	ND*	ND*	ND*	1.6	7.4	4.0	3.7

TABLE 1 Summary of Minimum (Min.), Maximum (Max.), Mean, and Median Values for Both Data Sets.

ND^{*} - not determined Q - discharge

Q - discharge S.S. - suspended sediment S.A. - surface area

% Coarse - percent of sample >63µm % Fine - percent of sample <63µm

able). Where this occurred, the problematic data point(s) was removed, and a new model was calculated using the smaller data set (Table 2). Correlation coefficients were calculated for fitted (equation-calculated) and measured concentrations to provide an indication of how closely the models estimated the measured suspended sediment and trace element concentrations (\mathbb{R}^* in Table 2).

RESULTS AND DISCUSSION

Multiple Linear Regression Models

The multiple linear regression equations for suspended sediment and associated trace element concentrations are presented in Table 2. Note that data from the coarse (>63 μ m) fractions appear as independent variables at a similar frequency to that for the fine (<63 μ m) fractions. Correlation coefficients (R*) between the measured and fitted concentrations for the Arkansas River range from a low of 0.80 (Co) to a high of 0.99 (suspended sediment) while those for the Chattahoochee River range from a low of 0.82 (Ti) to a high of 0.98 (suspended sediment). Clearly, this procedure (using point samples to estimate cross-sectional concentrations) appears to be most accurate for suspended sediment measurements, but it also appears to work satisfactorily for most trace elements. Table 2 also provides data on the mean concentration (\bar{X}), and the mean error (Resid) for each site between the measured and calculated concentrations. In most

TABLE 2 Comparison of regression equations for the Arkansas (A) and Chattahoochee (C) Rivers.

Paramete	er River	E	quation	R*	X	Resid.	
S. Sed.	A	SS = .983USS + .129			327	35	
	С	SS = 1.044L SS + .55	08	80	14		
C		$C_{\rm H} = 1060 \pm 4241$	Mn - 54811 AL + 3 136	87	53	6	
		$C_{\rm H} = 1.210115$ Fe = 2	016UE Ti + 305	.07	74	o o	
		Db = 97211 Db + 044	85	101	14		
10	ĉ	Pb = 67511C Pb + 3040	TOLETOC . 5841 S AL	.05	101	14	
C	C	ru = .0/303 ru + .3	70LF 10C + .504LS AI	05	107	17	
Zn	٨	7n = 71110F7n = 00000000000000000000000000000000000	250 . 070	04	1270	70	
Ln A		$Z_{\rm II} = ./110F Z_{\rm II} = .06$	0051 AL 64511TE 1 321	07	265	17	
	-	$L_{II} = 1.0560 L_{II} + 1.000 L_{$	21 E SA _ 0381 AL +	.91	205	1/	
	A	C0 = .3650 C0 + .15	2LF 3A330L AI +	80	12	1	
	C	Co - 06211 Co + 28	3115 CA . 306T C AL. 500	.00	20	2	
CA	-	Cd = 634UE Cd = 400	061 S AL + 473	.05	3.8	0.5	
Ca .	ĉ	Cd = .0340FCu4	(531 CA 27711 CC 1 592	.07	3.0	1.4	
		$C_0 = 2.70105 \text{ AI} + .0$	150L Cd - 2770 55 - 1.562	.0/	4,4	0.6	
AS	ĉ	AS = .5650 AS170	71 AL POST T: 1 509	.00	5.0	0.0	
Ch	<u> </u>	AS = 1.4050 AS + .95	7/L AI0920 11 - 1.596	.95	5.4	0.5	
30	A	SD = .541UF SD17	2Q41605 11 + .2510 F %	07	0.0		
	C	208 Ch. 1.4001 C.A.L. 0	PATECH 1220	.8/	0.9	0.1	
0.	<u> </u>	SD = 1.402LS AI + .0	80LF 50 - 1.520	.90	1.4	0.3	
Se	A	Se = ./45UF Se20.	5Q42/US FE + .891	.92	0.9	0.1	
	C	5e = 1.008LF 5e + .8	13L F % + .843US SA	00	0.4	0.1	
-		- 2.325		.90	0.0	0.1	
re	A	Fe = .052L 55 + .449	L Fe080 5%32/UF A	1 01	24	0.1	
0	0	+.5/3		.81	3.4	0.1	
14-	<u> </u>	Fe = .898L AI089	1 55 + .1930 5A327	.92	4.5	0.3	
Mn A C	A	Mn = .718L Mn - 1.1	159L AI + .043LF 55 + .033	.80	0.13	0.01	
	<u> </u>	Mn = 1.02L Mn + .4	49US SA401	.90	0.18	0.01	
	A	AI = .572LF AI + .04	9U SA + .296	.88	7.1	0.2	
	С	AI = 1.138L AI + .253US SA044US TOC					
		361		.93	10.2	0.5	
11	A	$T_1 = .2200 F\% + .05$	50 SS + .480F Ti +	1000			
C		.116L Mn680			0.33	0.02	
	С	Ti = .933L AI + .391	LF Ti + .111LF TOC	2023	12122	10100000	
	-	- 1.218		.82	0.52	0.03	
Ni	<u>C</u>	Ni = 1.206US AI + .2	87LF Ni16LF Mn228	.85	32	3	
Cr	C	Cr = .299U SA + .65	3L TOC + .282LS Cr + .900	.90	75	5	
			Key to Table				
SS - suspended sediment (mg/L) Q - discharge (CFS) SA - surface area (m ² /g) F% - percent fine fraction represents in sample S% - percent sand fraction represents in sample L - entire lower point sample			Cu - copper (mg/kg)	Thus, for example, UF SS means			
			Pb - lead (mg/kg)	lead (mg/kg) the suspended sediment co			
			Zn - zinc (mg/kg)	tration of the upper point fine fraction, or L Al means the alum inum concentration in the entire			
			Co - cobalt (mg/kg)				
			Cd - cadmlum (mg/kg)				
			As - arsenic (mg/kg)	lower pol	nt sample,	etc.	
J - entire upper point sample			Sb - antimony (mg/kg)	R* - correlation coefficient be-			
F - lower point fine fraction (<63 µm)			Se - selenium (mg/kg)	tween the measured and calcu-			
S - lower point sand fraction (>63 um)			Fe - iron (%)	lated cross-sectional concentra-			
F - upper p	olnt fine fi	raction (<63 µm)	Mn - manganese (%)	tion.			
US - upper point sand fraction (>63 μm) FOC - total organic carbon (%)			Al - aluminum (%)	X - mean concentration			
			Ti - titanium (%)	Resid - mean error (±) in calc			
			Ni - nickel (mg/kg)	lated con	centration		
			Co - cobalt (mg/kg)				

cases, the error is less than $\pm 16\%$. Examination of the actual data pairs (1219) indicates that about 90% of the calculated concentrations (~1100) fall within $\pm 20\%$ of the measured depth-and-width integrated cross-sectional concentrations. This increases to more than 95% when normal analytical errors for such low concentration elements as Se, Sb, Co, As, and Cd are considered.

Many of the independent variables found in the models can be viewed as logical and/ or can be explained on the basis of geochemical principles. On the other hand, several factors were included in some of the models that were unexpected. In some instances, the appearance of these 'atypical' factors resulted from the eliminations/substitutions required to reduce collinearity. The independent variables used in the models were evaluated and selected on the basis of statistical considerations (e.g., to eliminate collinearity) and on predictive capability (e.g., how closely the models could predict trace element concentrations based on R^*), and thus, may not reflect cause-and-effect relations. The costs associated with the determination of the various independent variables were not used as a basis for retaining/eliminating any independent variables.

Model Development Caveats

Initial sample collection at the Arkansas River site began in May and was completed in August 1989; 30 paired samples (point and depth-and-width integrated) were used to calculate a set of regression equations relating point sample suspended sediment and selected trace element concentrations, to depth-and-width integrated (accurate crosssectional) concentrations. Based on comparisons between the calculated and measured cross-sectional concentrations, it initially appeared as if the site could be characterized with only one (the upper point sampler) rather than two point samplers, with only a slight loss in accuracy (see Fig. 1). However, analysis of the first few samples from a second year's (1989-90) collection indicated that the initial equations were inadequate. An examination of discharge records for the past 10 years revealed that the May-August 1989 sampling period was atypical for the site (sampling covered only some 35% of a normal annual hydrograph). Discharges were substantially lower (less than half) than normal due to a sparcity of winter snow which, in turn, lead to less snowmelt runoff than usual. Further, the initial sampling period did not include any sample collection during baseflow. Thus, the equations lacked data for both the high and low ends of the annual hydrograph. The inclusion of several baseflow samples from the winter of 1989-1990, as well as a number of high-flow samples from the spring and summer of 1990, lead to a much more robust set of equations. The new equations proved that the site could not be characterized readily with only one point sampler. This experience, while frustrating, lead to a useful empirical 'rule of thumb' for establishing regression equations relating point sample suspended sediment and associated trace element to depth-and-width integrated data; the samples used to establish the equations need to cover at least 90% of the range of historic annual hydrographs. This indicates the need for a long-term discharge record at a site prior to developing accurate regression equations, to insure adequate coverage of site-specific conditions.

With the Arkansas River experience in mind, the Chattahoochee River collection, which began in February 1990, went more smoothly. Discharge records for the past 10 years were examined prior to collecting most of the 30 sample pairs. Samples were spaced to cover a sufficiently wide range of discharge conditions to limit the initial collections for regression equation development to a planned set of 30. This required that initial sampling be made over a 7 month period, rather than the originally planned 4 month period; however, as a result, fewer samples were required to characterize the Chattahoochee River site than the Arkansas River site.

When this study began, there was some initial hope that equations generated at one site also might be applicable to other sites, despite potential regional differences. However, examination of the regression equations for the two sites (Table 2) indicates how dissimilar they can be for the same constituent. On the other hand, the current study did not examine multiple sampling sites along a limited river reach, nor along the entire length of a single river. Under such circumstances, the equations established at one site might be more transferrable to other sites. This possibility remains to be investigated.

Automatic Samplers and Model Utilization

The purpose of evaluating automatic samplers for the estimation of suspended sediment and associated trace elements was to improve sampling coverage of the annual hydro-

graph beyond a single sample per day. The need for more frequent samples is predicated on the fact that suspended sediment and associated trace element concentrations can display marked temporal variations over relatively short (on the order of 20 minutes or less) time periods (e.g., Horowitz, et al., 1990). Once acceptable regression equations that relate point sample and depth-and-width integrated suspended sediment and associated trace element concentrations have been developed, the issue then becomes how frequently should samples be taken, and what is the most appropriate method for triggering an automatic sampler? Triggering methods and sampling frequency are technical problems because typically, automatic samplers are triggered by changes in stage (discharge). However, temporal variations in suspended sediment and associated trace element concentrations can occur with and without detectable changes in discharge (Horowitz, et al., 1990). Further, many fluvial systems display hysteresis loops with regard to discharge and suspended sediment; that is, the suspended sediment peak may precede, or lag behind, the stream discharge peak. Thus, stage may not be the most appropriate method to trigger samplers to obtain adequate coverage of temporal changes. A potential solution is a more direct measure of changes in suspended sediment concentration by using nephelometers, transmissometers, or some other device capable of providing a proxy for suspended sediment concentration. Such instruments need to be evaluated as potential triggering devices for automatic samplers. In the absence of such evaluations, the most pragmatic solution may be to collect a sample at a fixed time interval.

The number and volume of samples collected, also represents a potential financial concern. Once the automatic sampling equipment has been purchased and installed, and the regression equations established, the greatest cost associated with determining the annual transport of suspended sediment and associated trace elements is analytical. Based on the current study, each 'sample' would require the chemical and physical analyses of four separate sample aliquots (a >63- μ m and <63- μ m fraction from both an upper and lower point sample). Thus, each sample represents a considerable investment in analytical resources.

The joint problems of adequate sample coverage to deal with temporal variations, plus that of finite financial resources to cover analytical costs, can probably be addressed with a single solution — composite samples. The limitations would be 1) the flexibility of the automatic samplers in use (individual sample sizes, total maximum sample volume), and 2) the length of time composite samples can be preserved, prior to retrieval, for subsequent analysis. In theory, if a sufficiently large-volume automatic sampler was available, and if preservation was feasible, a single composite sample could be collected such that it would represent an entire year's suspended sediment and associated trace element transport. In practice, such long-term preservation is impractical, and most automatic samplers have limited sample volume capacities. Further, although automatic samplers are reasonably reliable, they need periodic maintenance. Therefore, a practical scheme for estimating annual suspended sediment and associated trace element transport would entail the collection of a series of composite samples to represent the annual hydrograph. Finally, as with current practices for determining suspended sediment concentration data from automatic point samples, it is highly advisable to periodically collect simultaneous point and depth-and-width integrated samples to insure the continued viability of the regression equations.

A potential sampling scheme, based on a 24-liter automatic sampler (a typical capacity for many commercially available units) would be as follows: the sampler is triggered to collect 100mL every hour. If filled to capacity, this would produce a 24 liter composite sample representative of ten days of the annual hydrograph; thus, 36 samples would be collected each year. Each of the 36 composites would be dewatered and analyzed separately. The point-sample data would be converted to cross-sectional data by applying the appropriate regression equations. At the end of the year, each composite would be discharge-weighted on the basis of that portion of the annual hydrograph it represented. Finally, by summing the contributions of each composite, the annual transport of suspended sediment and associated trace elements could be estimated. Obviously, this sampling scheme could be modified, depending on individual study needs and/or financial resources; for example 1) decrease the size of each sample aliquot (e.g., <100mL) but increase the number of aliquots while maintaining the same 10-day coverage to deal with temporal variations shorter than an hour, 2) maintain the same-sized aliquot, but increase the time between aliquots, to reduce the number of samples per year (e.g., 100mL every two hours) from 36 to 18, 3) maintain the same-sized aliquot, but decrease the time between samples to one every half hour, producing a 5-day composite instead of a 10-day one, while increasing the number of samples from 36 to 72 per year, etc. After several years, a careful evaluation of the data may suggest sampling scheme modifications that could reduce the number of samples, increase the time between samples taken fo⁻ compositing, etc., while maintaining or increasing the accuracy of the estimates, as required.

CONCLUSIONS

Based on the results of the present study, it appears feasible to use data from automaticallycollected point samples (from two separate vertical points), in conjunction with site-specific regression equations, to accurately (within $\pm 20\%$) estimate cross-sectional suspended sediment and associated trace element concentrations. The equations need to be established for discharge conditions covering at least 90% of the range of the average annual hydrograph. By using automatic samplers to continuously collect a series of composite samples, it should be feasible to estimate the annual transport of suspended sediment and associated trace elements. The actual sampling scheme can be as flexible as needed, with the only constraints being the automatic sampler used, the individual study needs, and the financial resources available.

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