Comparability of Different River Suspended Sediment Sampling and Laboratory Analysis Methods and the Effect of Sand

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Abstract

Accurate measurements of suspended sediment, a leading water-quality impairment in many rivers, are important for managing and protecting water resources; however, water quality standards for suspended sediment in Minnesota are based on grab field sampling and total suspended solids (TSS) laboratory analysis methods. These methods have underrepresented concentrations of suspended sediment in rivers compared to U.S. Geological Survey equal-width increment or equal-discharge-increment (EWDI) field sampling and suspended-sediment concentration (SSC) laboratory analysis methods. Because of this underrepresentation, the U.S. Geological Survey, in collaboration with the Minnesota Pollution Control Agency, collected concurrent grab and EWDI samples at eight sites to compare results obtained using different combinations of field sampling and laboratory analysis methods.

Study results determined that grab field sampling and TSS laboratory analysis results were biased substantially low compared to EWDI sampling and SSC laboratory analysis results, respectively. Differences in both field sampling and laboratory analysis methods caused grab and TSS methods to be biased substantially low. The difference in laboratory analysis methods was slightly greater than field sampling methods.

Sand-sized particles had a strong effect on the comparability of the field sampling and laboratory analysis methods. These results indicated that grab field sampling and TSS laboratory analysis methods fail to capture most of the sand being transported by the stream. The results indicate there is less of a difference among samples collected with grab field sampling and analyzed for TSS and concentration of fines in SSC. Even though differences are present, the presence of strong correlations between SSC and TSS concentrations provides the opportunity to develop site specific relations to address transport processes not captured by grab field sampling and TSS laboratory analysis methods.

Introduction

Excess suspended sediment can impair rivers by adversely affecting aquatic habitat, degrading water quality, transporting harmful contaminants, diminishing recreational opportunities, and depositing sediment in navigable waterways (U.S. Army Corps of Engineers, 2006; Minnesota Pollution Control Agency [MPCA], 2009). Reliable, consistent suspended-sediment data are imperative to address remediation efforts of river sediment impairments. Currently (2019), the U.S. Environmental Protection Agency and many State water-quality agencies use surface grab samples and the total suspended solids (TSS) laboratory analysis method to compare stream conditions to water-quality standards for suspended sediment (Pat Baskfield, MPCA, oral commun., May 22, 2017). However, previous studies indicated that estimates of suspended sediment obtained using these protocols substantially underestimated suspended sediment compared to standard U.S. Geological Survey (USGS) equal-width-increment or equal-discharge-increment (EWDI) and suspended-sediment concentration (SSC) laboratory analysis methods (Gray and others, 2000; Ellison and others, 2014). Because previous studies compared data obtained using several protocols that included different field sampling, the same field sampling and subsampling by use of a churn or cone splitter, and different laboratory analysis methods, the exact cause of observed differences could not be determined; therefore, the USGS, in collaboration with the MPCA, completed a study designed using multiple combinations of field sampling and laboratory analysis methods to evaluate how differences in these methods affect suspended sediment results.

Grab samples are typically collected in the centroid of a stream channel, within 1 meter of the water surface. Conversely, water samples collected by USGS methods are collected and composited from multiple locations across the stream using isokinetic samplers and depth-and-width-integration methods, as described by Ward and Harr (1990), Edwards and Glysson (1999), and Davis and the Federal Interagency Sedimentation Project (2005). The use of these data collection methods provides a vertically and laterally discharge-weighted composite sample that is intended to be representative of the entire flow passing through the cross section of a stream.

The TSS laboratory analysis method is commonly used in conjunction with a grab sample. For the TSS laboratory analysis method, a subsample of the original water sample is extracted and filtered to measure the amount of suspended material (Clesceri and others, 1998); however, according to Gray and others (2000), the subsample may not be representative of the whole water sample. Furthermore, if suspended sediment is not homogenous throughout the stream channel, the grab sample likely will not accurately represent the suspended sediment present in the entire stream channel.

In contrast, the SSC laboratory analysis method used by the USGS measures the whole water sample containing the entire amount of suspended material in the original sample (Guy, 1969; American Society for Testing and Material [ASTM], 2000; USGS, variously dated). A study comparing TSS and SSC in Minnesota streams indicated that TSS underestimated SSC median values by about 50 percent (Ellison and others, 2014). In addition, Gray and others (2000) indicated that negative biases in TSS results compared to SSC results are exacerbated when samples consist of more than 25 percent sand-sized particles (Gray and others, 2000). Therefore, additional information is needed to determine the causes and magnitudes of differences between TSS and SSC.

Purpose and Scope

The purpose of this report is to summarize and interpret river suspended-sediment data collected using different field sampling methods (grab and EWDI) and analyzed using different laboratory methods (TSS, SSC, and particle sizes) during water year (WY) 2016 at eight selected sediment monitoring sites (Figure 1) in Minnesota. Specifically, the report (1) quantifies the variation among different combinations of field sampling and laboratory analysis methods, (2) describes the effects of sand-sized particles on field sampling and laboratory analysis methods, and (3) develops relations between field sampling and laboratory analysis methods. A water year is the 12-month period October 1 through September 30 designated by the calendar year in which it ends.

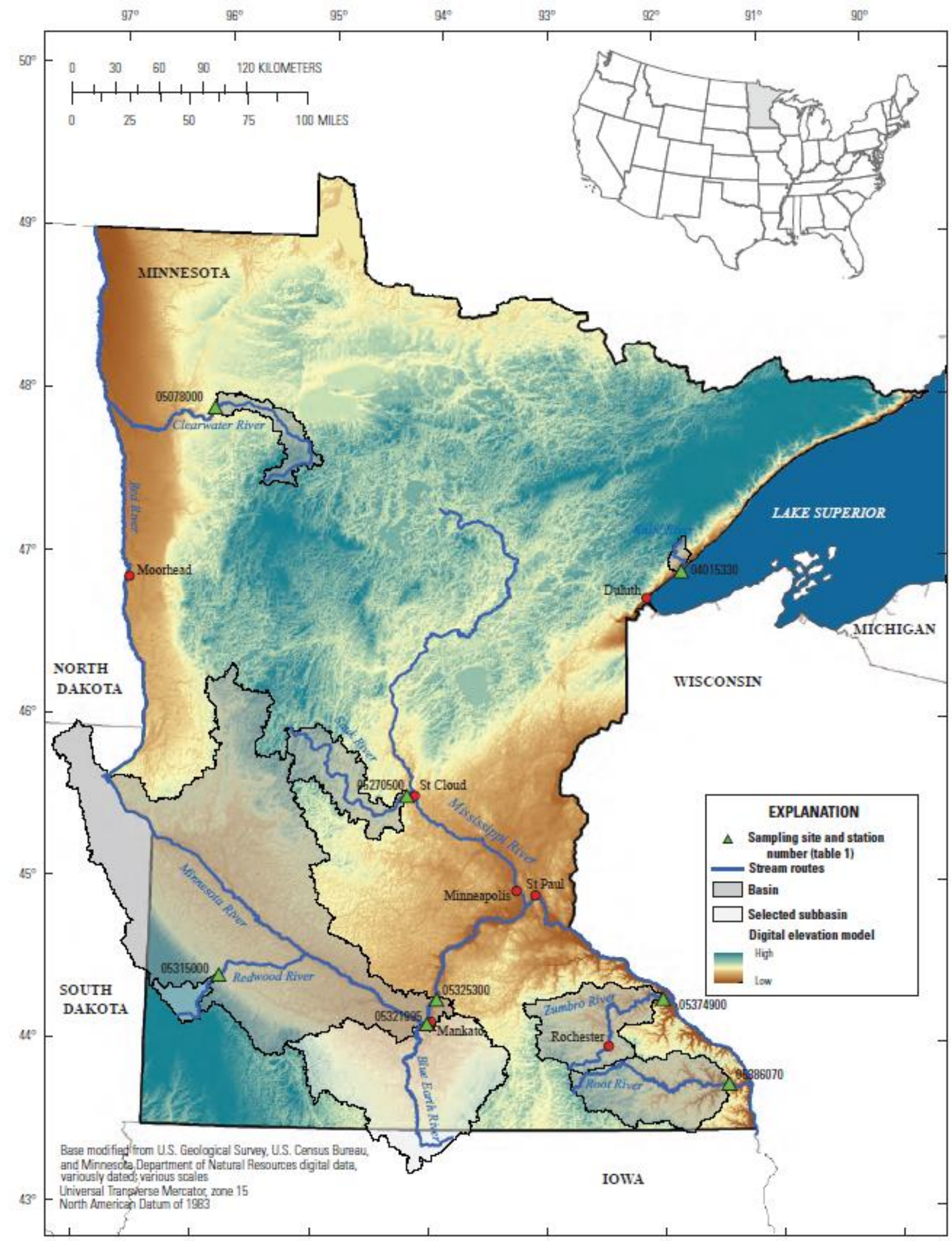

Figure 1. Selected sediment monitoring sites, contributing basins, and hillshade of the landscape relief in Minnesota.

Description of the Study Area

The eight sediment monitoring sites selected for this study represent different basins (Figure 1) in Minnesota. Sediment monitoring sites were collocated at either USGS streamgages, available at https://waterdata.usgs.gov/nwis (USGS, 2019), or the Minnesota Department of Natural

Resources (MNDNR) and MPCA cooperative streamgages, available at http://www.dnr.state.mn.us/waters/csg/index.html (MNDNR, 2019).

Methods of Data Collection and Analysis

Water samples were collected for analyses of TSS, SSC, and particle sizes at eight sediment monitoring sites (Figure 1) in WY 2016. All samples were collected during the open-water season (March 1 through September 30). SSC samples were collected over a wide range of streamflow conditions (USGS, 2019; MNDNR, 2019).

The differences attributable to field sampling methods can be determined by concurrently collecting water samples with grab and EWDI field sampling methods and analyzing those two samples with the same laboratory analysis method (SSC or TSS). This isolated the differences caused by field sampling methods. Conversely, differences in laboratory analysis methods were determined by comparing the concurrent water samples that were collected with the same field sampling method (EWDI or grab) and analyzing one sample for TSS and one sample for SSC. This isolated the difference caused by laboratory analysis methods.

Field Sampling Methods

Water samples were collected concurrently using grab and isokinetic, EWDI sampling methods (Edwards and Glysson, 1999) to provide four samples at each sampling visit. Four samples were collected at each sediment monitoring site consisting of two concurrent grab samples and two concurrent EWDI samples.

Grab Field Sampling: A grab sample was collected using a 1-liter high-density polyethylene bottle secured inside of a weighted-bottle sampler (US WBH–96, Rickly Hydrological Co., Inc., Columbus, Ohio; Any use of trade, firm, or product names is for descriptive purposes only and does not imply endorsement by the U.S. Government). The grab sample was collected from the centroid of the river channel at a depth less than 1 meter below the water surface. Two grab samples were collected concurrently at the beginning of EWDI field sampling.

Equal-Width-Increment or Equal-Discharge Increment Field Sampling: Isokinetic and depth-integrated samples were collected at EWDIs (Edwards and Glysson, 1999). Most of the samples were collected using the equal-width-increment field sampling method (Edwards and Glysson, 1999). At each sample point, two separate samples were collected concurrently. Concurrent field sampling was done at each vertical throughout the stream cross section.

Laboratory Analysis Methods

The environmental laboratory at the Minnesota Department of Health (MDH) in Saint Paul, Minnesota, and the USGS Sediment Laboratory in Iowa City, Iowa, were used to analyze collected samples. The two laboratory analysis methods were TSS and SSC.

Total Suspended Solids Laboratory Analysis Method: TSS was analyzed at two laboratories. One grab sample from each sampling event was sent to the MDH Environmental Laboratory and analyzed for TSS following method 2540 D (Clesceri and others, 1998) to determine the concentration of each sample. One EWDI from each sampling event was sent to the USGS Sediment Laboratory and analyzed for TSS following the same method (Julie Nason, USGS, oral commun., May 22, 2016).

Suspended-Sediment Concentration Laboratory Analysis Method: One grab and one EWDI sample from each sampling event were analyzed for SSC following method D3977–97 (Guy, 1969; ASTM, 2000) by the USGS Sediment Laboratory. The percentage of fines (particle sizes less than 0.0625 millimeter [mm]) also was determined for each SSC sample (Guy, 1969) at the same laboratory.

Data Analysis

Field sampling and laboratory analysis method abbreviations will be combined in the following sections of the report to describe the combined field sampling and laboratory analysis methods used for each value or group of values; for example, the field sampling method abbreviation (Grab or EWDI) describes a sample collected in the field by grab or EWDI sampling methods and will come first, followed by an en dash (–), and followed by the laboratory analysis method abbreviation (TSS or SSC), which describes the laboratory analysis method used. EWDI–SSC was considered the most representative field sampling and laboratory analysis method combination, so it was the reference value from which a result obtained from any other method would be compared.

Data analyses included the computation of summary statistics, Wilcoxon signed-rank test (Helsel and Hirsch, 2002), simple linear regression (SLR) analysis, and percent difference (PD; Ellison and others, 2014). Data used in analyses are presented in Table 2 of Groten and Johnson (2018); data also are available at https://waterdata.usgs.gov/nwis (U.S. Geological Survey, 2019) and at https://www.pca.state.mn.us/environmental-data (MPCA, 2019).

Data were normalized with a logarithm transformation (base-10 logarithms) to reduce heteroscedasticity and skewness of the residuals and meet SLR model assumptions (Helsel and Hirsch, 2002). PD provides a measure of the difference between two values when one value is assumed to be more representative of the true value.

Field Sampling and Laboratory Analysis Method Comparison

The study design allowed five sets of comparisons between field sampling and laboratory analysis method combinations. The comparison of EWDI–SSC to Grab–TSS represents the USGS and MPCA field sampling and laboratory analysis methods, respectively. This comparison has been described by Gray and others (2000) and Ellison and others (2014). The two field sampling method comparisons were EWDI–SSC to Grab–SSC and EWDI–TSS to Grab–TSS. The two comparisons for laboratory analysis methods were Grab– SSC to Grab–TSS and EWDI–SSC to EWDI–TSS. Visualizations of the field sampling and laboratory analysis method comparisons used in the following sections are shown in Figure 2.

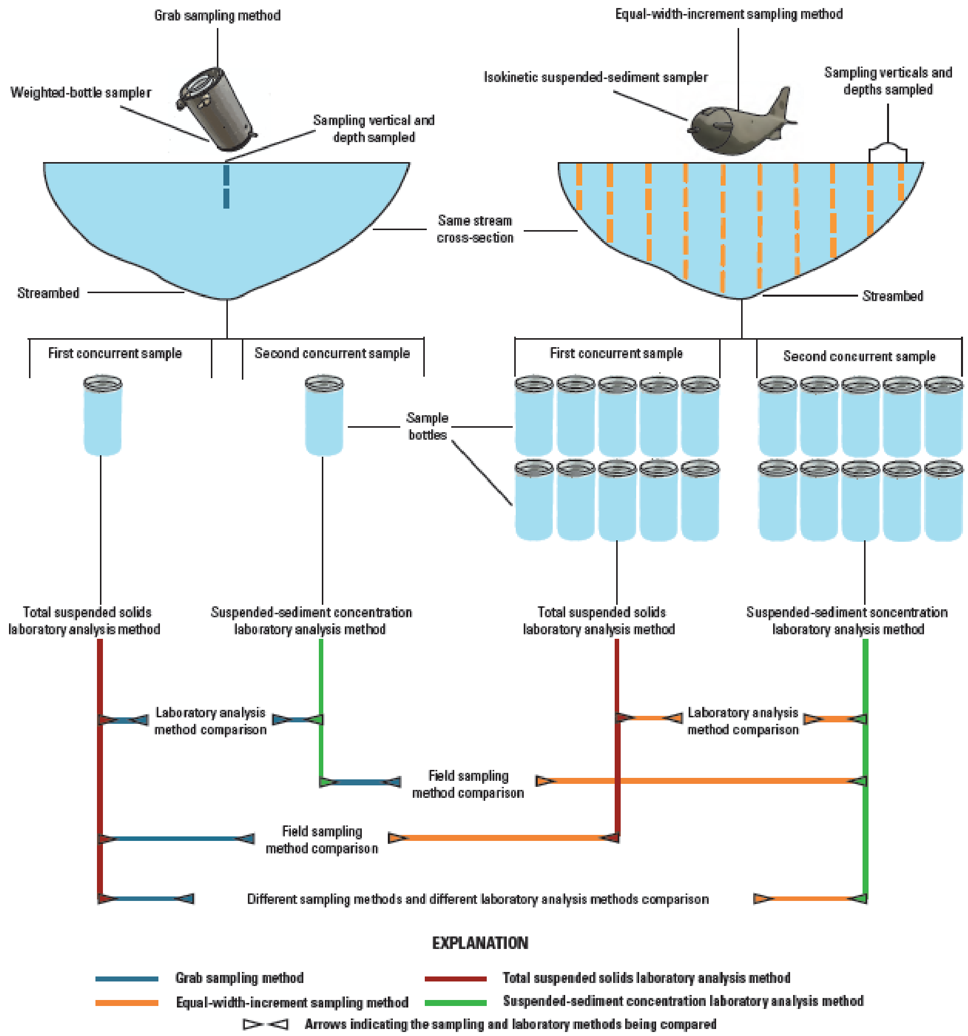

Figure 2. Infographic demonstrating five combinations of field sampling and laboratory analysis methods used to compare differences in sediment concentrations.

The median value of EWDI–SSC was greater than Grab–SSC, EWDI–TSS, and Grab–TSS median values (Table 1). Also, Grab–SSC had a greater median value than EWDI–TSS and Grab–TSS (Table 1).

Table 1. Summary of Wilcoxon signed-rank tests used to evaluate differences between field sampling and laboratory analysis method combinations in Minnesota, water year 2016.

Grab–TSS (mg/L)	Grab–SSC (mg/L)	EWDI–TSS (mg/L)	EWDI–SSC (mg/L)
Median			
69	85	79	116
Method combination comparison	**PD[a]**	**V**	**p–value**
EWDI–SSC to Grab–TSS	41	7	<0.01
Grab–SSC to Grab–TSS	19	158	<0.01
EWDI–SSC to EWDI–TSS	32	151	<0.01
EWDI–TSS to Grab–TSS	13	242	<0.01
EWDI–SSC to Grab–SSC	27	176	<0.01

[a]Calculation of percent difference is $[(x_1 - x_2)/x_1] \times 100$, where x_1 is the median concentration of the first dataset, and x_2 is the median concentration of the second dataset, in milligrams per liter.

[Grab, sample collected with the grab field sampling method; TSS, sample analyzed with the total suspended solids laboratory analysis method; mg/L, milligram per liter; SSC, sample analyzed with the suspended–sediment concentration laboratory analysis method; EWDI, sample collected with the equal–width–increment or equal–discharge–increment field sampling method; PD, percent difference; V, sum of ranks assigned to the differences with a positive sign; p–value, probability value; <, less than]

The Wilcoxon signed-rank test was used to test if differences between concurrent pairs of samples from grab and EWDI field sampling methods and laboratory analysis methods of TSS and SSC median differences were statistically significant (Table 1). Overall, the comparison of EWDI–SSC samples to Grab–TSS samples was statistically significant (probability value [p-value] less than 0.01; Table 1). The PD in this comparison was 41 percent with the EWDI–SSC median value being greater than the Grab–TSS median value (Table 1). For the two field sampling method comparisons (EWDI compared to grab), results indicated that median differences in concentrations for EWDI samples (EWDI–SSC and EWDI–TSS) were statistically significant (p-value less than 0.01) being greater than the corresponding median differences in concentrations for grab samples (Grab–SSC and Grab–TSS), respectively. The PDs between the two field sampling methods were 27 and 13 percent for EWDI–SSC to Grab–SSC and EWDI–TSS to Grab–TSS, respectively (Table 1). The analysis of the two laboratory analysis method comparisons indicated that the median difference in concentrations were statistically significant (p-value less than 0.01) for SSC and TSS. The SSC laboratory analysis method yielded substantially larger median differences in concentrations than the TSS laboratory analysis method. The PDs for the two laboratory analysis methods were 32 and 19 percent for the EWDI– SSC to EWDI–TSS and Grab–SSC to Grab–TSS comparisons, respectively (Table 1).

Scatterplots and SLR best-fit lines are presented to demonstrate the relations between each field sampling and laboratory analysis method combination. The 1:1 and SLR best-fit lines were plotted for each comparison. The 1:1 line indicates perfect agreement between the two concentration datasets being plotted, and the SLR best-fit line indicates the estimated relation between the two datasets being compared. If the data and SLR best-fit line plots are above the 1:1 line, the response variable (y-axis; Figure 3) is larger than the explanatory variable (x-axis; Figure 3). Conversely, if the explanatory variable is larger than the response variable, then the data and SLR best-fit line plots are below the 1:1 line.

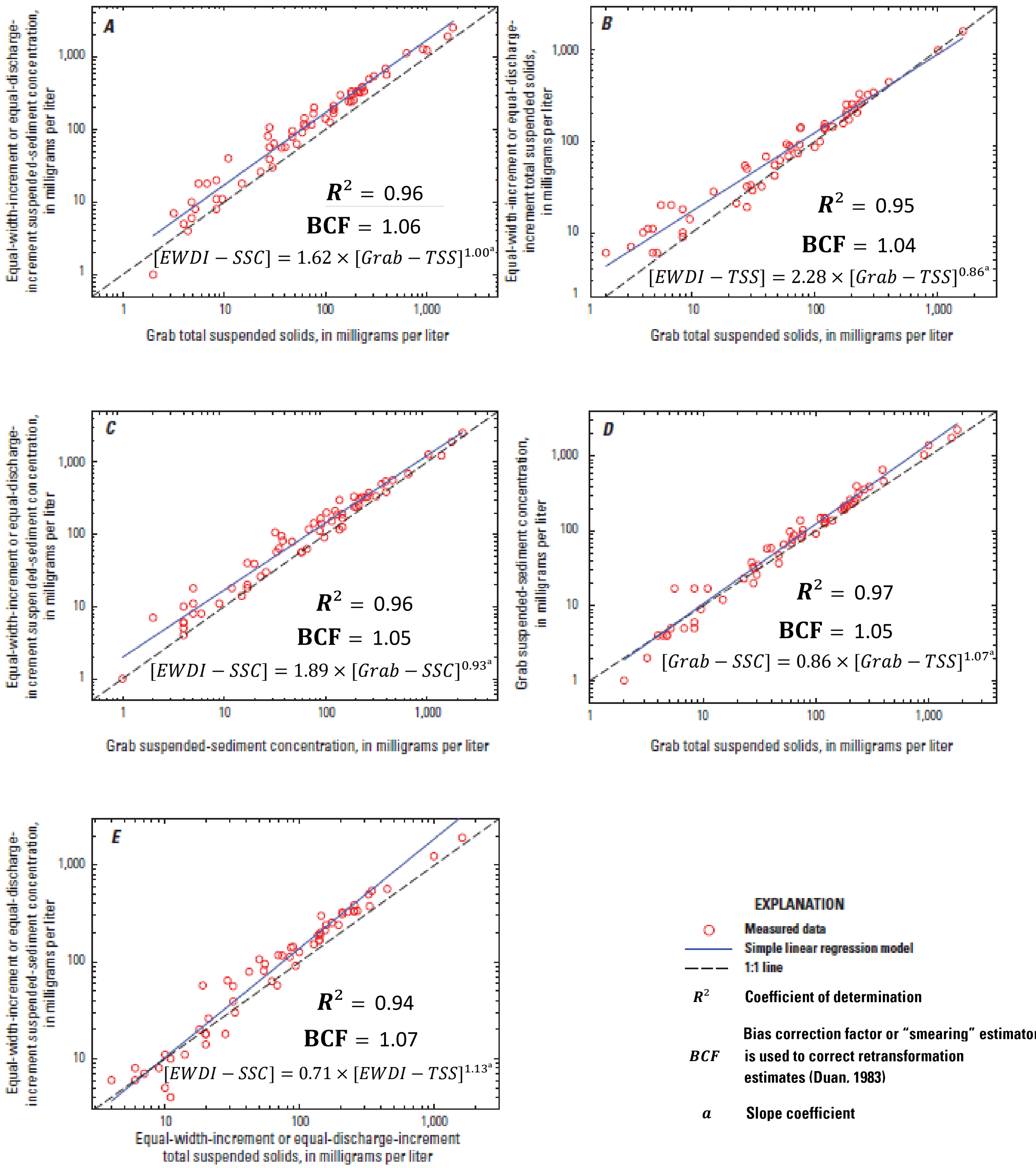

Figure 3. Relations between A, different field sampling and laboratory analysis methods, B and C, field sampling methods, and D and E, laboratory analysis methods in Minnesota, water year 2016.

Patterns among the field sampling and laboratory analysis methods are indicated on Figure 3. All the combinations had strong and significant relations with coefficients of determination (R^2) greater than or equal to 0.94 and p-values less than 0.01. Even though the grouped data have strong and significant relations, a site-specific relation between SSC and TSS should be the primary method to estimate SSC from TSS (Glysson and others, 2000). The SLR analysis indicated when field sampling and laboratory analysis methods were different, the data plotted farthest above the 1:1 line than all the other comparisons (Figure 3A), indicating Grab–TSS consistently under predicts EWDI–SSC.

For field sampling comparisons (Figures 3B, 3C), EWDI samples are assumed to be the most representative of sediment concentration in the river. When SLR best-fit lines are above the 1:1 line, this indicates that concentrations derived from grab samples underrepresent the sediment concentration (negative bias). For sediment concentrations less than 200 mg/L, concentrations derived from grab samples were negatively biased. As sediment concentrations approach 200 mg/L, this negative bias associated with grab samples decreases. This decrease in negative bias likely is the result of higher water velocities mixing suspended sediment homogenously throughout the stream channel. For SSC analyses, concentrations in grab samples were never positively biased throughout the measured range of sediment concentrations (Figure 3C). Conversely, for TSS analyses, concentrations derived from grab samples approached the 1:1 line when sediment concentrations approached 200 mg/L (Figure 3B).

For laboratory comparisons (Figures 3D, 3E), the SSC samples are assumed to be the most representative sediment concentration. SSC analyses indicated a slight positive bias at sediment concentrations less than 40 mg/L (Figures 3D, 3E). At sediment concentrations greater than 40 mg/L, TSS concentrations were negatively biased (Figures 3D, 3E). These comparisons followed observations by Gray and others (2000) and indicated the TSS laboratory analysis methods were most likely biased because the SSC method captures sand-sized particles (greater than or equal to 0.0625 mm) by measuring the entire sediment mass, whereas the TSS method was unable to capture a representative subsample because of sand settling during the extraction procedure.

Effect of Particle Size on Sampling and Laboratory Analysis Methods

The grab field sampling method may not capture sand contributions to SSCs, resulting in artificially greater percentages of fines compared to EWDI–SSC samples (Gray and others, 2000; Ellison and others, 2014). Stream velocity can affect the occurrence and distribution of sand-sized particles near the streambed or in other sections of the stream cross section. A grab sample only incorporates water from a single location near the water surface (less than 1 meter), and most paired sampling were during stream conditions where water depths exceeded 1 meter. Whereas, samples collected using the EWDI method integrates the vertical water column and excludes the lowest 10 centimeters above the streambed; furthermore, samples collected using the EWDI method incorporates water from 5 to 10 locations across the horizontal stream cross section.

Fines and sands were compared for different sampling and laboratory methods (Figure 4A). The EWDI-SSC-Sands were calculated from Table 2 in Groten and Johnson (2018) by taking EWDI-SSC-Fines (mg/L) and subtracting them from EWDI-SSC (mg/l). The EWDI-SSC-Sands were then split into four categories based on the percentage of sand in the EWDI-SSC. The percentage of sand in the EWDI-SSC was calculated from subtracting EWDI–SSC–Fines (percent less than 0.0625 mm; Table 2 in Groten and Johnson [2018]) from 100 percent. The four categories (based on the percentage of sand in the EWDI-SSC) the EWDI-SSC-Sands were split into were less than 11 percent, greater than or equal to 11 percent and less than 26 percent, greater than or equal to 26 percent and less than 41 percent, and greater than or equal to 41 percent (Figures 4B, 4C).

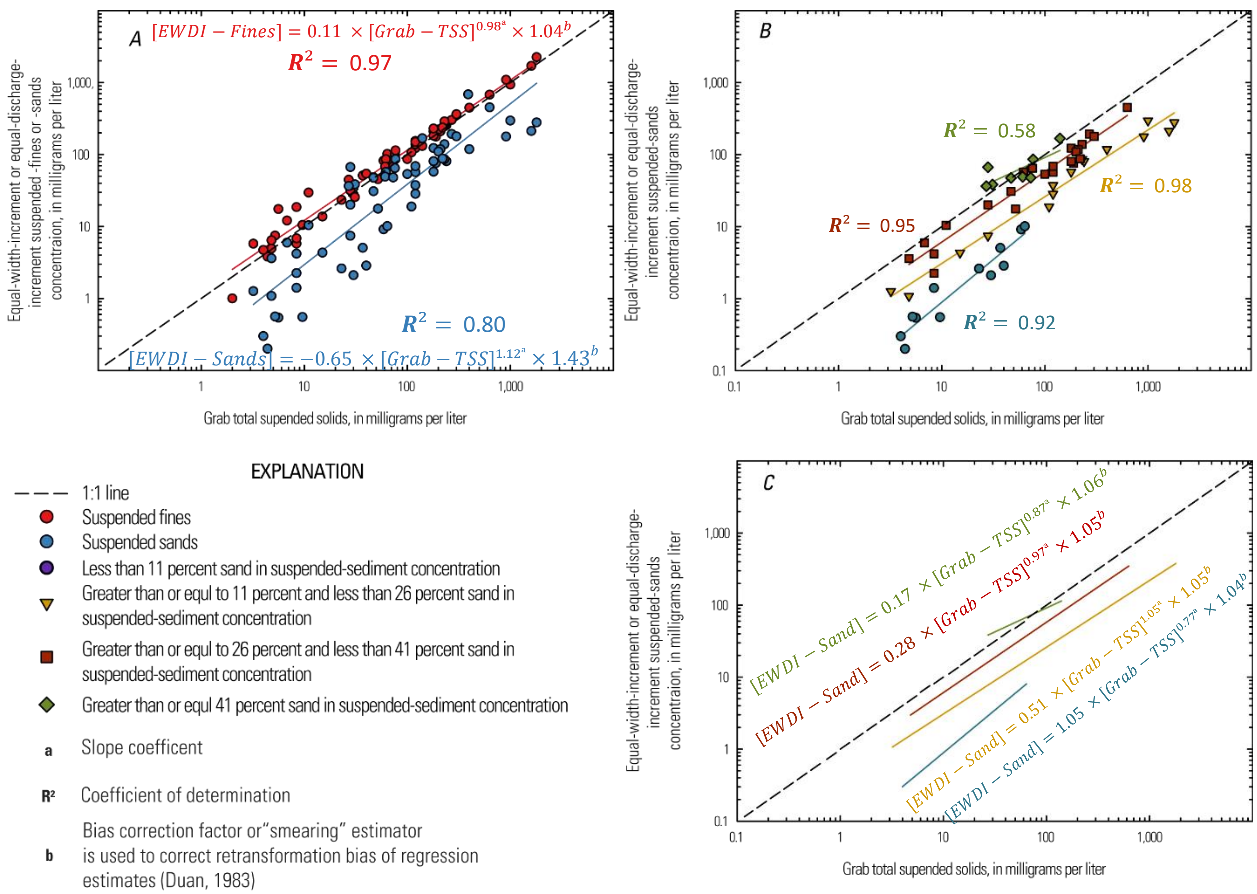

Figure 4. Sand-sized, fine-sized, and different percentages of sand-sized particles and the effect on relations between different field sampling and laboratory analysis methods in Minnesota, water year 2016.

After the dataset was divided into EWDI-SSC-Fines, EWDI-SSC-Sands, and the four categories of EWDI-SSC-Sands based on percentages of sand in the EWDI-SSC, SLR analyses were done on these datasets (Figure 4). All the comparisons had significant relations (p-values were less than 0.03). Five comparisons had strong relations (R^2 values were greater than or equal to 0.80; Figures 4A, 4B) and one did not have as strong of a relation (EWDI-SSC-Sands in the category of greater than or equal to 41 percent; R^2 of 0.58; Figure 4B). The slope coefficients of the SLR models ranged from 0.77 to 1.12 (Figures 4A, 4C).

The fines plotted on the 1:1 line above 10 mg/L in the comparison of EWDI–SSC-Fines to Grab–TSS (Figure 4A). The sands mostly plotted below the 1:1 line in the comparison of EWDI-SSC-Sand to Grab– TSS (Figure 4A) which did not have as strong of a relationship (R^2 of 0.80; Figure 4A) as the fines (R^2 of 0.97; Figure 4A). The EWDI–SSC-Sands to Grab–TSS (Figure 4A) shows that Grab-TSS underrepresents EWDI-SSC-Sands while the Grab-TSS works well to estimate EWDI-SSC-Fines.

A closer observation of the sands was done by splitting the data into four categories. Three categories plotted below the 1:1 line, and one category plotted near the 1:1 line (Figure 4B). The dataset that plotted near the 1:1 line had the highest percentage of sand in the EWDI-SSC (greater than or equal to 41 percent; Figure 4B). Below the 1:1 line plotted the next highest percentage of sand (greater than or equal to 26 percent and less than 41 percent), and then the next highest percentage of sand (greater than or equal to 11 percent and less than 26 percent) was below. The percentage with the least amount of sand (less than 11 percent) was plotted the farthest below the 1:1 line (Figure 4B). The EWDI-SSC-Sands plotted farther below the 1:1 line (Figure 4B) as the percentage of sand decreased. This indicates that Grab-SSC underrepresents EWDI-SSC-Sands more when the percentages of sand in the EWDI-SSC was less.

Gray and others (2000) stated that the divergence between SSC and TSS expanded when the contribution of sand-size particles was greater than or equal to 25 percent. For this study, the median of all the percentages of the sand in the EWDI–SSC was 26 percent and was selected as a threshold value to produce two groups of data for the dataset. One group consisted of values greater than or equal to 26 percent sands and one group less than 26 percent sands. This value of 26 percent was selected because it was close to the findings of Gray and others (2000) that indicated the differences between SSC and TSS laboratory results were exacerbated when the contribution of sand-size particles was greater than or equal to 25 percent. For the subsequent analysis investigating the effects of percentages of sand-sized particles on field sampling and laboratory analysis methods, EWDI–SSC, Grab–TSS, Grab–SSC, and EWDI–TSS paired values that had greater than 26 percent sand in the EWDI–SSC will hereafter be referred to as "sands," and values less than or equal to 26 percent sand in the EWDI–SSC will hereafter be referred to as "fines." It should be noted that even though the data will now be referenced to as "sands" and "fines", this might not accurately represent the actual fines and sands. Because EWDI-SSC are assumed to be the most representative sediment concentration in the river, it was used to group the rest of the data for the following comparisons.

After the dataset was delineated into sands and fines, SLR analyses were done on the fines and sands datasets. All the comparisons had strong and significant relations (R^2 values were greater than or equal to 0.92 [Figure 5], and p-values were less than 0.01). The slope coefficients of the SLR models ranged from 0.84 to 1.12 (Figure 5). The sands plotted farthest above the 1:1 line in the comparison of EWDI–SSC to Grab– TSS (Figure 5A). Error was cumulative as sand increased because the grab method failed to capture sand in the sample. Additionally, the TSS laboratory analysis method failed to capture sand during the extraction procedure.

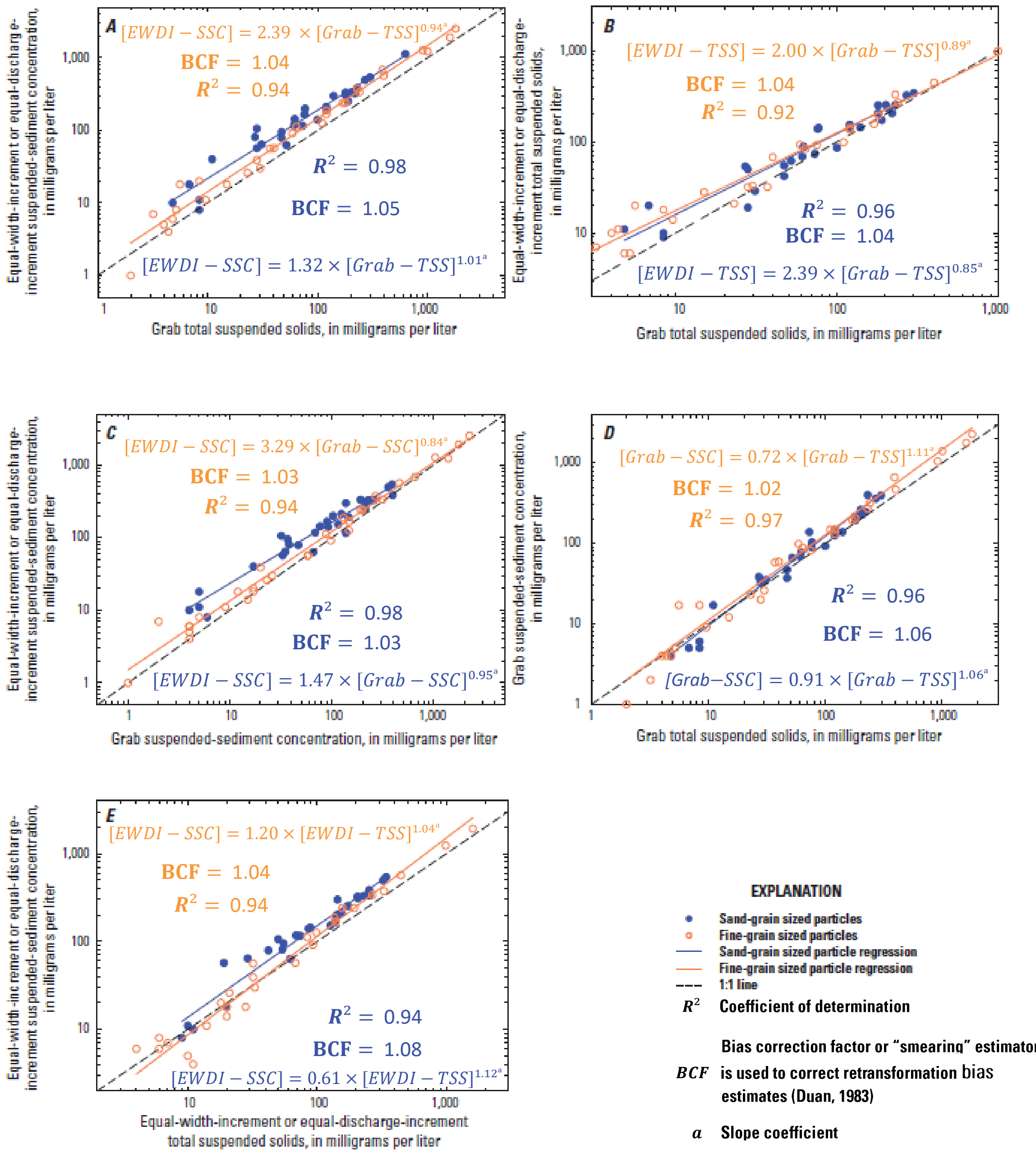

Figure 5. Sand-sized particles effect on relations between A, different field sampling and laboratory analysis methods, B and C, field sampling methods, and D and E, laboratory analysis methods in Minnesota, water year 2016.

When comparing field sampling methods, EWDI samples are assumed to be most representative of the true sediment concentration. For the two different field sampling methods (EWDI compared to grab), samples with greater percentages of sand-size particles provided a marked separation in sands and fines SLR best-fit lines (Figure 5C). The comparisons of EWDI–SSC to Grab–SSC (Figure 5C) provided further evidence that grab samples underrepresent sediment concentrations. The fines best-fit line followed a similar pattern, but the grab samples only slightly underrepresented the sediment concentration (Figure 5C). When comparing EWDI–TSS to Grab–TSS, the small separation between the sands and fines SLR best-fit lines indicated that sand-size particles had less of an effect when the TSS laboratory analysis method was used to determine concentrations (Figure 5B). A possible explanation for the small separation between sand and fines SLR best-fit lines in Figure 5B was that the TSS laboratory analysis method likely was masking the effect of sand-sized particles.

When comparing laboratory analysis methods, SSC samples are assumed to provide the most representative sediment concentration. Sands had a greater effect on the EWDI–SSC to EWDI–TSS comparison (Figure 5E) than on the Grab–SSC to Grab– TSS comparison (Figure 5D). For EWDI–SSC to EWDI–TSS, the EWDI–TSS sand samples underestimated the most representative sediment concentration throughout the range of samples (Figure 5E). For Grab–SSC to Grab–TSS, the sands followed almost an identical pattern as the fines and had little effect (Figure 5D).

Summary

Suspended-sediment monitoring entails field sampling and laboratory analysis methods to quantify how much sediment is being transported by streams. Quantitative sediment data are useful for addressing sediment impairments in rivers; however, the field sampling and laboratory analysis methods used to collect suspended sediment data can introduce error into the measured results.

This report documents findings based on river suspended sediment data collected by the U.S. Geological Survey and Minnesota Pollution Control Agency. Sediment data were collected at eight sites in Minnesota to determine if differences in concentrations between total suspended solids (TSS) and suspended-sediment concentrations (SSC) can be attributed to field sampling methods, laboratory analysis methods, or both. Grab field sampling and TSS laboratory analysis methods used by Minnesota were compared to standard U.S. Geological Survey field sampling methods and laboratory analysis methods to determine if methods used by agencies in Minnesota underrepresent the amount of suspended sediment in rivers.

Results obtained using grab field sampling and TSS laboratory analysis methods were biased low compared to equal-width-increment or equal-discharge-increment (EWDI), isokinetic, and depth-integrated field sampling and SSC laboratory analysis methods. Differences in both field sampling and laboratory analysis methods caused grab and TSS methods to be significantly biased low, and the difference between laboratory analysis methods was slightly greater than the difference between field sampling methods. The largest difference was observed when the assumed most representative field sampling (EWDI) and laboratory analysis (SSC) methods and assumed least representative field sampling (grab) and laboratory analysis (TSS) methods were compared.

Grab samples analyzed for TSS represented EWDI samples analyzed for concentration of fines well but did not accurately capture EWDI samples being analyzed for concentration of sands in the SSC. This suggests that grab field sampling and TSS laboratory analysis methods are not sufficiently capturing sand-sized particles but are capturing fine-sized particles.

Grab field sampling and TSS laboratory analyses are biased low because these methods do not effectively capture and measure sand moving through the stream channel. Grab field sampling only incorporates water from the top 1 meter of the water column at a single location in the horizontal stream cross section. In contrast, EWDI samples incorporate water throughout the vertical and horizontal water column, except the bottom 10 centimeters. The occurrence of sand is often greater near the streambed, and sand may not be evenly distributed throughout the horizontal stream cross section. The TSS laboratory analysis method also biases the sample low if the sample includes a high proportion of sand. The heavier sand-sized particles tend to fall out of suspension before a representative subsample can be collected for TSS laboratory analysis. Even though differences are present, the presence of relatively strong correlations between SSC and TSS concentrations provides the opportunity to develop site specific relations to address transport processes not captured by grab field sampling and TSS laboratory analysis methods.

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