Chris Steller

From:	Johnson, Gregory (MPCA) <gregory.johnson@state.mn.us>
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To:	Chris Steller
Subject:	Reports
Attachments:	Statewide Sediment Network Work Order .pdf; Comparability of River Suspended-Sediment Sampling and Laboratory Analysis Methods - 2018.pdf
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I am attaching a final report and a publication for a work order project titled 'Statewide Sediment Network'. The final report is a non-published report summarizing the work completed in the work order. The publication is a U.S. Geological Survey report describing the results of one part of the project. The reports are not printed, so no print copies will be sent. The USGS report is located at https://pubs.er.usgs.gov/publication/sir20185023.

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U. S. Geological Survey
Minnesota Water Science Center
Statewide Sediment Network
Work Order #15 – Final Report
Period ending January 31, 2018

Project Name: Statewide Sediment Network

MPCA Work Order Number: Swift ID: 105428, PO # 3000018795
Begin Date: May 2017 **End Date**: Jan. 2018

Project Chief: Joel Groten **Cooperators**: Minnesota Pollution Control Agency

Objective:

The objective of this study is to improve understanding of relations among streamflow, SSC, bedload, turbidity and acoustic backscatter at existing sediment network sites.

Tasks Completed in Work Order

Task A: Develop relations between streamflow, suspended-sediment concentrations, bedload, turbidity, and acoustic backscatter at selected sites.

> 23 water samples were collected and analyzed for suspended-sediment concentration (SSC), total suspended solids (TSS), and percent fines at four monitoring sites (Minnesota River at Mankato, Knife River near Two Harbors, Blue Earth River at Hwy. 169, and Zumbro River at Kellogg). Field measurements of water temperature, specific conductance, transparency, and turbidity were made during each sample event. Lab analysis for TSS was completed by the Minnesota Department of Health lab in Minnesota and for SSC by the U.S. Geological Survey lab in Iowa. Three turbidity and SSC simple linear regressions models have been developed, reviewed, approved, and are available to the public.

Task B: Provide online web-based real-time continuous turbidity measurements at three sites (Knife River, Blue Earth River, and Zumbro River).

> Continuous data turbidimeters were operated at the Knife, Blue Earth, and Zumbro River sites. An acoustic Doppler velocity meter (ADVM) was operated at the Minnesota River at Mankato site. The data was transmitted in real-time via GOES satellite to the USGS Water Science Center in Mounds View and then posted to the USGS NWIS website.

Task C: Install and program upgraded equipment at four sites on the Minnesota and Mississippi Rivers.

> New dataloggers and antennas were installed and programmed at four sites to improve the capacity for the telemetry of Acoustic Doppler velocity meter (ADVM) data for use in providing real-time SSC monitoring from the ADVM backscatter data. The four sites included:

05355235 Mississippi River abv Red Wing blw Diamond Isl, MN
05355341 Mississippi R. (Lk Pepin) above Reads Landing
05330000 Minnesota River nr Jordan, MN
05325000 Minnesota River at Mankato, MN

Real-time monitoring was accomplished by USGS staff scripting telemetered data in the USGS database to display the explanatory variable, sediment-corrected backscatter (SCB), online. The SCB display online will eventually allow the display of real-time SSC computed from SCB.

Task D: Publish a daily suspended sediment load at the USGS stream gage on the Minnesota River at Mankato, Minnesota (station ID 05325000).

46 SSC samples were collected during scheduled visits to the Minnesota River at Mankato gage site and from daily observer samples. Daily and annual suspended-sediment loads were computed and published via NWIS for the Minnesota River at Mankato (USGS ID 05325000).

Task E: Describe differences between SSC and TSS and assign proportions attributable to differences in field data collection procedures and/or laboratory analytical methods.

Data analysis was completed for SSC and TSS data collected in 2016 to determine the effect of field sampling and laboratory analysis methods on the differences in concentration between the two variables. A draft USGS Scientific Investigations Report was written and submitted for USGS peer review in 2017. The report was published in March, 2018, and is located at https://pubs.er.usgs.gov/publication/sir20185023. The following paragraphs were excerpted from the report abstract:

> Concurrent grab and EWDI water samples were collected at eight sites in 2016 to compare SSC and TSS 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.

The work order for $200,000 (Swift ID: 105428, PO # 30000018795) was completed and ended 01/31/2018. All funds have been expended and the final invoice has been paid by MPCA.

Plans for Next Work Order

Future work will continue to focus on the development and incorporation of surrogate technology to improve understanding of sediment transport and processes and to improve the accuracy of sediment load calculations. An alternative field sampling method will also be examined as a potentially less expensive method for developing relationships between TSS and SSC for estimating SSC from graab sample TSS. A work order will be developed to continue the Statewide Sediment Network work through 2018. A focus of the work will be to establish real-time reporting of SSC using surrogate sensors on the Minnesota River at Mankato, Knife River near Two Harbors, Zumbro River near Kellogg, and Blue Earth River near Mankato. The work order will include on-going suspended sediment and particle-size sampling and analysis at the four sites along with grab sampling for TSS analysis by the MDH Laboratory.

Significant Results for Work Order #15

Data analysis of 2016 sample results affirm the differences between TSS and SSC in Minnesota reported in a USGS Scientific Investigations Report published in January 2014. A draft USGS Scientific Investigations Report was written and submitted for USGS peer review in 2017. The report was published in March, 2018, and is located at https://pubs.er.usgs.gov/publication/sir20185023.

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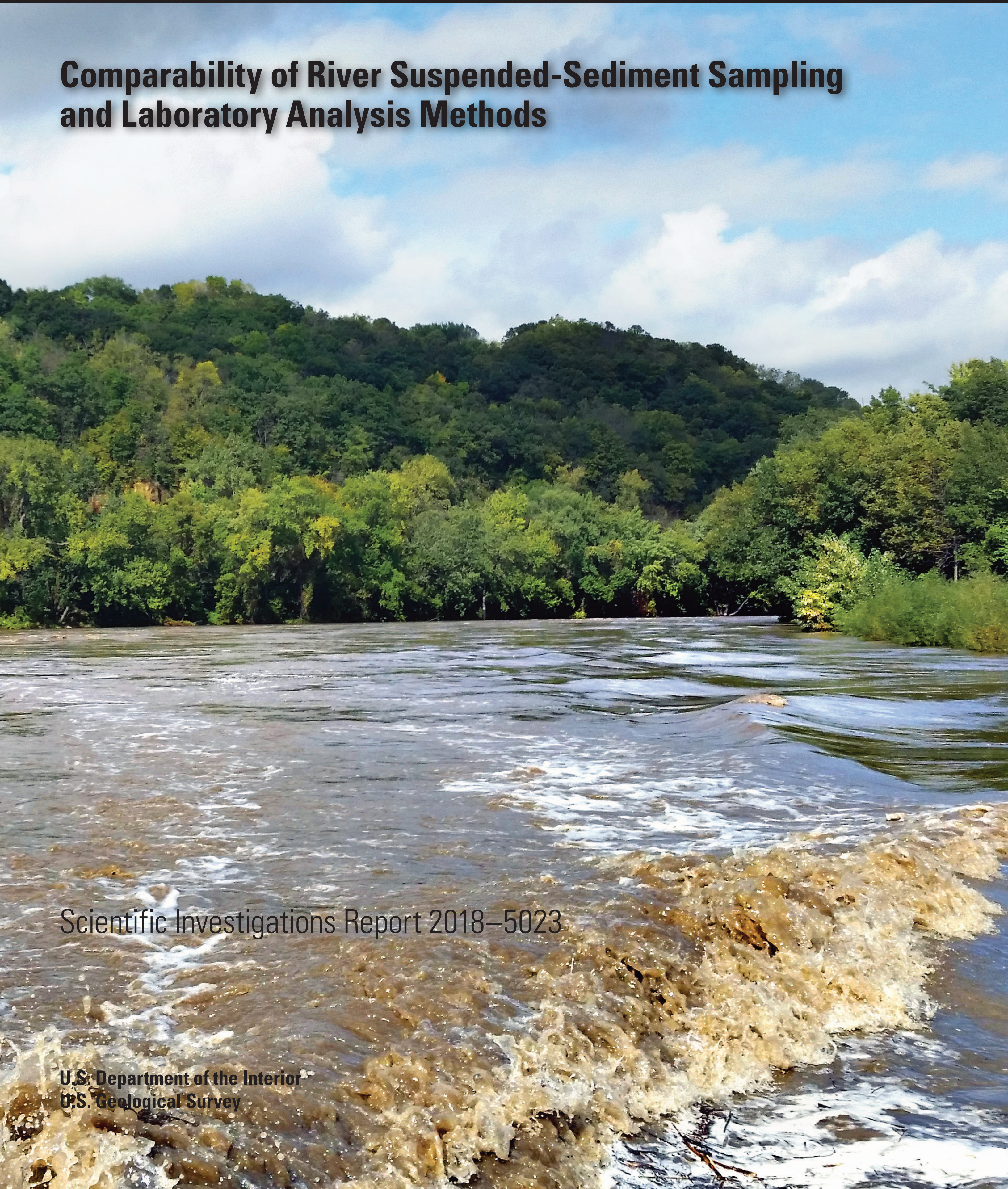
CLEAN WATER LAND & LEGACY AMENDMENT



Comparability of River Suspended-Sediment Sampling and Laboratory Analysis Methods

Scientific Investigations Report 2018–5023

U.S. Department of the Interior
U.S. Geological Survey

Cover. The Blue Earth River looking downstream at the confluence with the Minnesota River in Mankato, Minnesota (photograph by J. William Lund, U.S. Geological Survey).

Comparability of River Suspended-Sediment Sampling and Laboratory Analysis Methods

By Joel T. Groten and Gregory D. Johnson

Prepared in collaboration with the Minnesota Pollution Control Agency, Clean Water Fund

Scientific Investigations Report 2018–5023

U.S. Department of the Interior
U.S. Geological Survey

U.S. Department of the Interior
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U.S. Geological Survey
William H. Werkheiser, Deputy Director
exercising the authority of the Director

U.S. Geological Survey, Reston, Virginia: 2018

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Contents

Acknowledgments vi
Abstract 1
Introduction....1
    Purpose and Scope 2
    Description of the Study Area 2
Methods of Data Collection and Analysis 2
    Field Sampling Methods 6
        Pilot Study 6
        Grab Field Sampling 6
        Equal-Width-Increment or Equal-Discharge-Increment Field Sampling 6
    Laboratory Analysis Methods....6
        Total Suspended Solids Laboratory Analysis Method....6
        Suspended-Sediment Concentration Laboratory Analysis Method 6
    Data Analysis....6
Field Sampling and Laboratory Analysis Method Comparison 7
    Effect of Particle Size on Sampling and Laboratory Analysis Methods 15
    Quality Assurance....18
Summary....20
References Cited....21
Appendix....23

Figures

1. Map showing selected sediment monitoring sites, contributing basins, and hillshade of the landscape relief in Minnesota 3
2. Graphs showing streamflow and collection dates of suspended-sediment samples at eight sediment monitoring sites in Minnesota, water year 2016......................4
3. Infographic demonstrating five combinations of field sampling and laboratory analysis methods used to compare differences in sediment concentrations 11
4. Box plots for grab samples, equal-width-increment or equal-discharge-increment samples, total suspended solids, suspended-sediment concentrations, and percent fines data at eight sites in Minnesota, water year 2016 12
5. Graphs showing relations between different field sampling and laboratory analysis methods, field sampling methods, and laboratory analysis methods in Minnesota, water year 2016..14
6. Graphs showing sand-sized particles effect on relations between different field sampling and laboratory analysis methods, field sampling methods, and laboratory analysis methods in Minnesota, water year 2016.....................................17

Tables

1. Selected sediment monitoring sites in Minnesota, water year 2016...................................2
2. Grab, equal-width-increment or equal-discharge-increment, total suspended solids, and suspended-sediment concentration data at eight sites in Minnesota, water year 2016...8
3. Suspended-sediment concentration outliers, water year 2016..11
4. Summary statistics for grab sampling, equal-width-increment or equal-discharge-increment sampling, total suspended solids, suspended-sediment concentrations, and percent fines at eight sites in Minnesota, water year 2016..13
5. Summary of Wilcoxon signed-rank tests used to evaluate differences between field sampling and laboratory analysis method combinations in Minnesota, water year 2016 13
6. Summary of simple linear regression models to evaluate field sampling and laboratory analysis method combinations in Minnesota, water year 2016 15
7. Summary of simple linear regression models to evaluate effect of sand-sized particles on field sampling and laboratory analysis method combinations in Minnesota, water year 2016..16
8. Results of quality-assurance samples for suspended-sediment concentration for samples collected at selected sites in Minnesota, water year 2016.................................19
9. Results of quality assurance for the total suspended solids laboratory analysis method at two laboratories, water year 2016 20

Conversion Factors

International System of Units to U.S. customary units

Multiply	By	To obtain
	Length	
millimeter (mm)	0.03937	inch (in.)
centimeter (cm)	0.3937	inch (in.)
meter (m)	1.094	yard (yd)
	Area	
square kilometer (km^2)	0.3861	square mile (mi^2)
	Volume	
liter (L)	33.81402	ounce, fluid (fl. oz)

Supplemental Information

Concentrations of constituents in water are given in milligrams per liter (mg/L).

Water year (WY) is the 12-month period, October 1 through September 30, and is designated by the calendar year in which it ends.

Abbreviations

ASTM	American Society for Testing and Material
EWDI	equal-width-increment or equal-discharge-increment
MDH	Minnesota Department of Health
MNDNR	Minnesota Department of Natural Resources
MPCA	Minnesota Pollution Control Agency
PD	percent difference
p-value	probability value
RPD	relative percent difference
R^2	coefficient of determination
SLR	simple linear regression
SSC	suspended-sediment concentration
TSS	total suspended solids
USGS	U.S. Geological Survey
WY	water year

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This report presents a compilation of information supplied by many agencies and individuals. The authors would like to thank the Minnesota Pollution Control Agency, Clean Water Fund, Minnesota Department of Natural Resources, and the Environment and Natural Resources Trust Fund for their assistance with this study.

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Comparability of River Suspended-Sediment Sampling and Laboratory Analysis Methods

By Joel T. Groten[1] and Gregory D. Johnson[2]

Abstract

Accurate measurements of suspended sediment, a leading water-quality impairment in many Minnesota 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 that 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.

[1]U.S. Geological Survey.

[2]Minnesota Pollution Control Agency.

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 (2018), 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 two protocols that included different field sampling and 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 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 typically is 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. In addition, 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 demonstrated 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 study is required 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 (fig. 1; table 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.

Description of the Study Area

The eight sediment monitoring sites selected for this study represent different basins (fig. 1; table 1) and suspended-sediment characteristics present in Minnesota. A map of Minnesota shows the sediment monitoring sites, the contributing basins, and a hillshade of the landscape relief (fig. 1). Sediment monitoring sites (table 1) were collocated at either USGS streamgages, available at https://waterdata.usgs.gov/nwis (USGS, 2017a), or Minnesota Department of Natural Resources (MNDNR) and MPCA cooperative streamgages (table 1), available at http://www.dnr.state.mn.us/waters/csg/index.html (MNDNR, 2017). The MNDNR and MPCA cooperative streamgages (table 1) included in this study are part of the MPCA Watershed Pollutant Load Network (MPCA, 2017b).

Methods of Data Collection and Analysis

Water samples were collected for analyses of TSS, SSC, and particle sizes at eight sediment monitoring sites (fig. 1; table 1) in WY 2016. All samples were collected during the open-water season (March 1 through September 30; fig. 2). SSC samples were collected over a wide range of streamflow conditions (USGS, 2017a; MNDNR, 2017). The position of the samples along the streamflow hydrograph for each site is shown on figure 2.

Table 1. Selected sediment monitoring sites in Minnesota, water year 2016.

[USGS, U.S. Geological Survey; Minn., Minnesota; MNDNR, Minnesota Department of Natural Resources; MPCA, Minnesota Pollution Control Agency]

Station name	USGS station number	Responsible for streamgage operation	Latitude (North)	Longitude (West)	Drainage area (square kilometers)
Knife River near Two Harbors, Minn.	04015330	USGS	46.94694	-91.79222	218
Clearwater River at Plummer, Minn.	05078000	USGS	47.92333	-96.04611	1,434
Sauk River near St. Cloud, Minn.	05270500	USGS	45.55972	-94.23333	2,685
Redwood River near Marshall, Minn.	05315000	USGS	44.43027	-95.82937	672
Blue Earth River at Highway 169 at Mankato, Minn.	05321995	USGS	44.09156	-94.01596	9,194
Minnesota River at County Highway 22 in Saint Peter, Minn.	05325300	MNDNR/MPCA	44.30750	-93.95008	39,098
Zumbro River at Kellogg, Minn.	05374900	MNDNR/MPCA	44.31194	-92.00389	3,626
Root River at County Highway 25 near Mound Prairie, Minn.	05386070	MNDNR/MPCA	43.78136	-91.44647	4,120

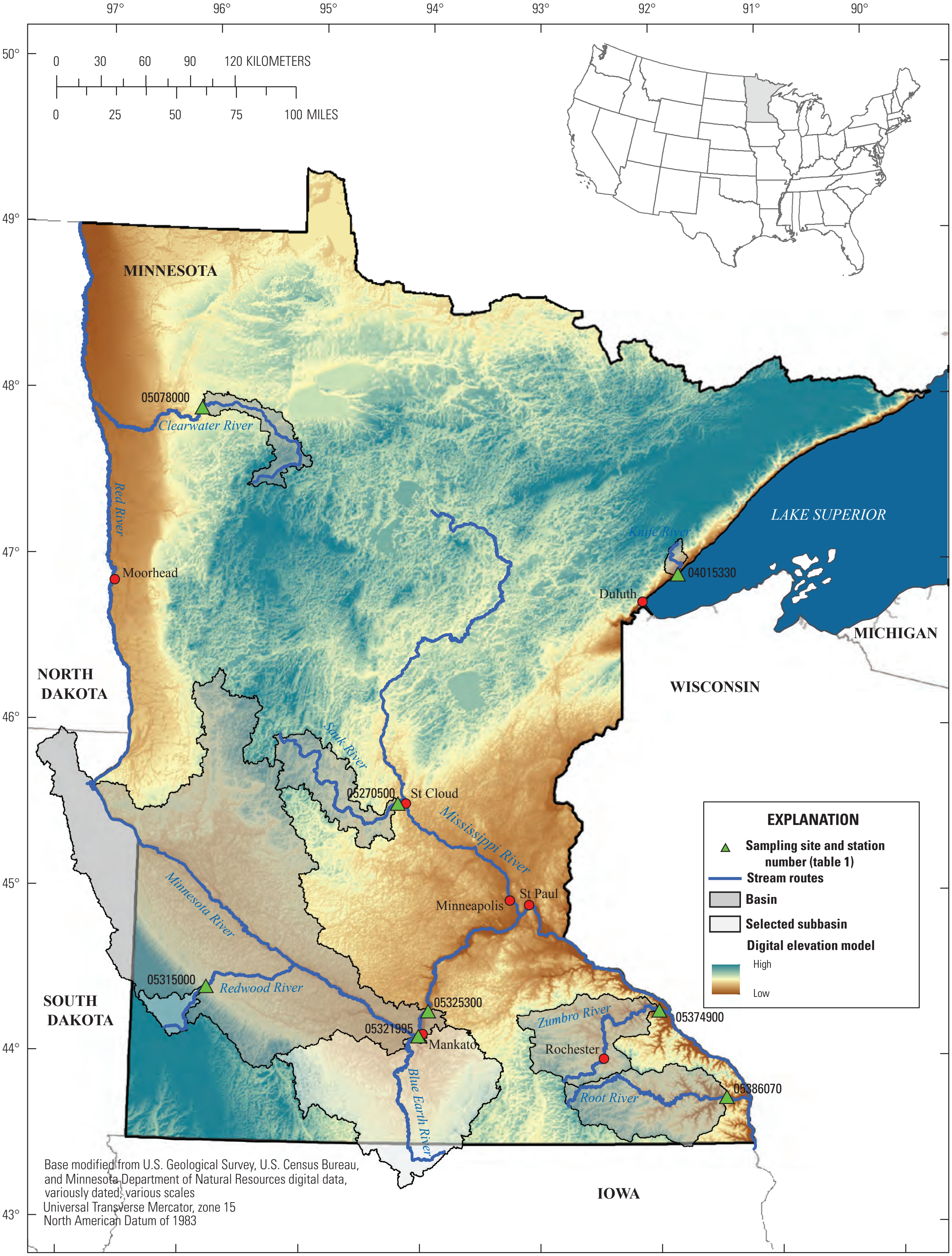

Figure 1. Selected sediment monitoring sites, contributing basins, and hillshade of the landscape relief in Minnesota.

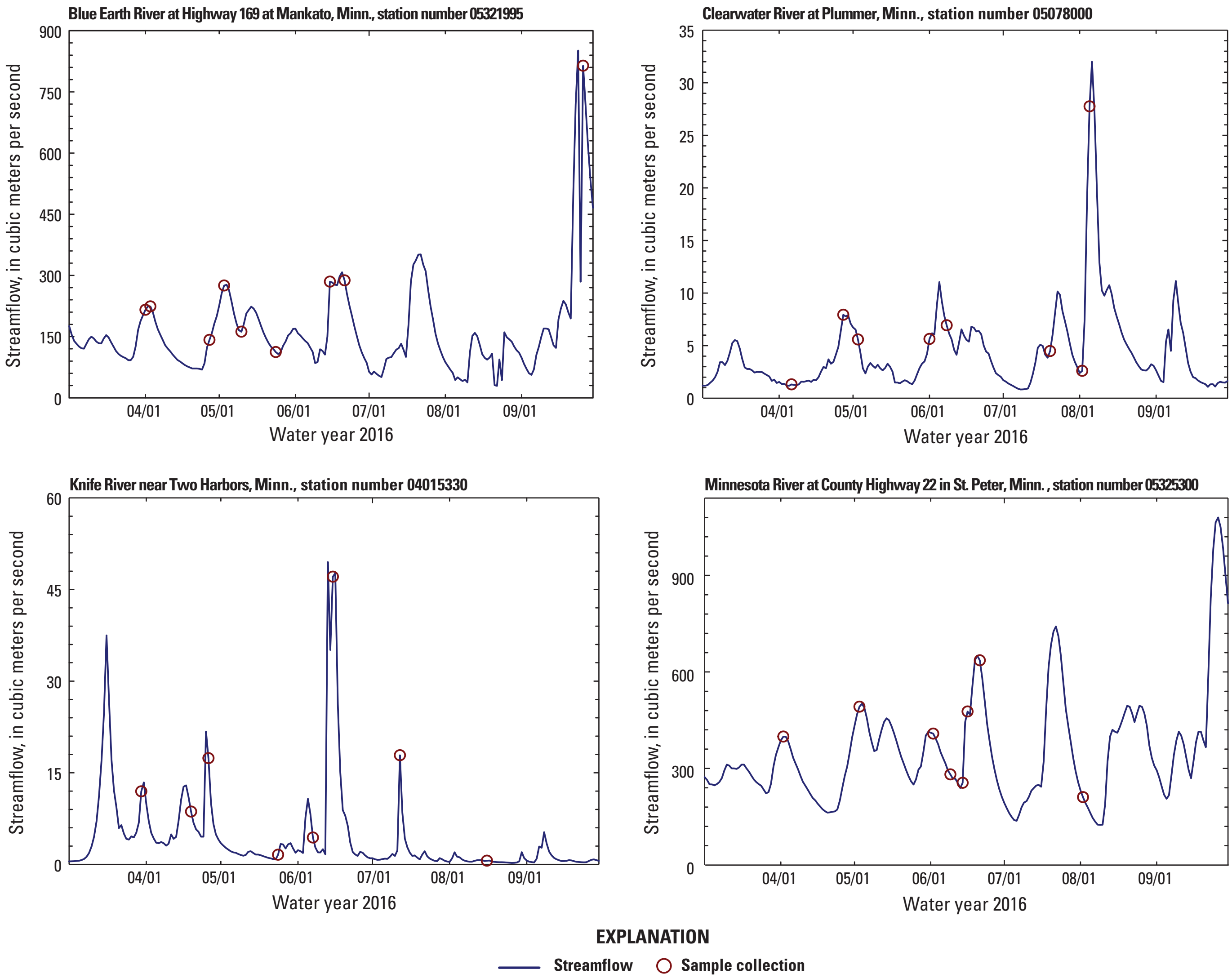

Figure 2. Streamflow and collection dates of suspended-sediment samples at eight sediment monitoring sites (fig. 1; table 1) in Minnesota, water year 2016.

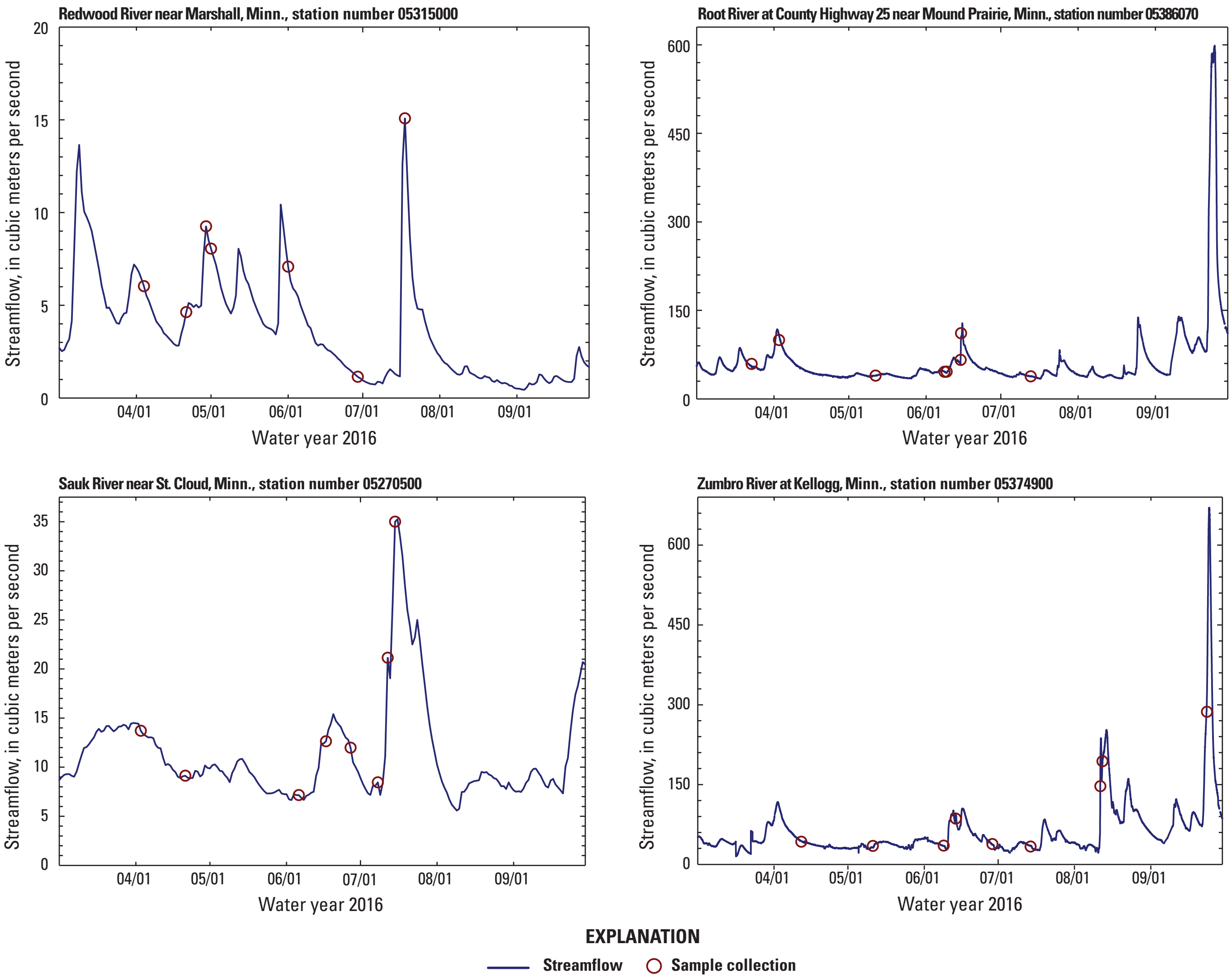

Figure 2. Streamflow and collection dates of suspended-sediment samples at eight sediment monitoring sites (fig. 1; table 1) in Minnesota, water year 2016.—Continued

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. Concurrent sample collection methods were used to eliminate concerns raised by a 2015 pilot study completed in Minnesota regarding uncertainties with using a churn splitter to provide paired subsamples for laboratory analysis.

Pilot Study

A churn splitter to field-process water samples is not recommended when SSC values are greater than 10,000 milligrams per liter (mg/L) because its usage is not representative of the stream and the sample variance is inordinately large (USGS, 1997; Wilde and others, 1999). All the samples obtained in a WY 2015 pilot study were below the 10,000 mg/L threshold; however, preliminary results have indicated that the subsample from the churn splitter is not representative of the original sample at values less than 10,000 mg/L, and a churn splitter is not recommended (Mark Landers, USGS, oral commun., March 21, 2016). The insights garnered from the 2015 pilot study led to a modified sampling plan designed to reduce potential variance, bias introduced from using the churn splitter, or both. The modification to the WY 2016 sampling plan entailed not using the churn splitter.

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). 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, percent difference (PD; Ellison and others, 2014), and relative percent difference (RPD; Ellison and others, 2014). Data used in analyses are presented in table 2; data also are available at https://waterdata.usgs.gov/nwis (U.S. Geological Survey, 2017a) and at https://www.pca.state.mn.us/environmental-data (MPCA, 2017a).

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. RPD provides a measure of the relative difference between two values when neither of the two values is representative of the true value.

Datasets were examined for outliers before doing statistical analyses. Outliers (table 3) were identified by a low percentage of fine particle sizes (less than 0.0625 mm) relative to other samples. Two outliers (table 3) were identified and removed from the dataset before doing analyses. Outliers can result from errors during data collection. Examples of data collection errors include the sampler not being raised from the streambed fast enough, which could have disrupted the streambed and contaminated the sample, or the sampler could have accidently come into contact with a sand dune and also contaminated the sample. Also, outliers could result from natural anomalies that deviate from the rest of the dataset.

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. The data used for the comparisons are listed in table 2. Visualizations of the field sampling and laboratory analysis method comparisons used in the following sections are shown in figure 3.

Mean and median values of EWDI–SSC were (fig. 4) greater than Grab–SSC, EWDI–TSS, and Grab–TSS (table 4). Also, Grab–SSC had greater mean and median values than the EWDI–TSS and Grab–TSS (table 4). Boxplots (fig. 4) showed minimal differences between methods; however, closer inspection of the differences among paired samples indicated that the differences were statistically significant.

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 values were statistically significant. Overall, the comparison of EWDI–SSC samples to Grab–TSS samples was statistically significant (probability value [*p*-value] less than 0.01; table 5). The PD in this comparison was 41 percent with the EWDI–SSC median value being greater than the Grab–TSS median value (table 5). For the two field sampling method comparisons (EWDI compared to grab), results indicated that median concentrations for EWDI samples (EWDI–SSC and EWDI–TSS) were statistically significant (*p*-value less than 0.01) being greater than the corresponding median 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 5). The analysis of the two laboratory analysis method comparisons indicated that the median concentrations were statistically significant (*p*-value less than 0.01) for SSC and TSS. The SSC laboratory analysis method yielded substantially larger median 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 5).

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 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; fig. 5) is larger than the explanatory variable (x-axis; fig. 5). 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.

Patterns among the field sampling and laboratory analysis methods are indicated on figure 5. 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 (table 6). 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

Table 2. Grab, equal-width-increment or equal-discharge-increment, total suspended solids, and suspended-sediment concentration data at eight sites in Minnesota, water year 2016.

[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; EWDI, sample collected with the equal-width-increment or equal-discharge-increment field sampling method; SSC, sample analyzed with the suspended-sediment concentration laboratory analysis method; Fines, concentration of fines in SSC; <, less than; mm, millimeter; RPD, relative percent difference; Minn., Minnesota; USGS, U.S. Geological Survey; --, unavailable]

Date	Grab–TSS (mg/L)	EWDI–TSS (mg/L)	Grab–SSC (mg/L)	Grab–SSC–Fines (percent <0.0625 mm)	EWDI–SSC (mg/L)	EWDI–SSC–Fines (percent <0.0625 mm)	Grab–SSC–Fines (mg/L)	EWDI–SSC–Fines (mg/L)	Absolute RPD[a] EWDI–TSS to Grab–SSC–Fines	Absolute RPD[a] EWDI–TSS to EWDI–SSC–Fines	Absolute RPD[a] Grab–TSS to Gab–SSC–Fines
Knife River near Two Harbors, Minn. (USGS station number 04015330)											
3/30/2016	59	93	98	87	91	90	85	82	9	13	36
4/19/2016	8	18	17	93	20	93	16	19	13	3	--
4/26/2016	37	32	58	92	56	91	53	51	50	46	36
5/24/2016	--	4	4	91	6	93	4	6	--	--	--
6/7/2016	6	20	17	96	18	97	16	17	20	14	--
6/15/2016	64	84	88	93	112	91	82	102	3	19	24
7/12/2016	40	68	59	97	57	95	57	54	17	23	35
8/16/2016	2	6	1	100	1	100	1	1	--	--	--
Clearwater River at Plummer, Minn. (USGS station number 05078000)											
4/6/2016	3	7	2	100	7	82	2	6	--	--	--
4/27/2016	15	28	12	89	18	76	11	14	90	69	34
5/3/2016	8	9	6	92	8	72	6	6	--	--	--
6/1/2016	--	20	15	96	14	87	14	12	33	49	--
6/8/2016	23	21	23	88	26	90	20	23	4	11	13
7/20/2016	10	14	9	99	11	95	9	10	--	29	--
8/2/2016	4	11	4	95	4	95	4	4	--	--	--
8/5/2016	52	62	66	68	63	72	45	45	32	31	15
Sauk River near St. Cloud, Minn. (USGS station number 05270500)											
4/3/2016	7	20	5	85	18	67	4	12	--	50	--
4/21/2016	8	10	5	86	11	62	4	7	--	--	--
6/6/2016	5	6	5	100	8	93	5	7	--	--	--
6/17/2016	5	6	4	89	6	82	4	5	--	--	--
6/27/2016	5	11	4	81	10	64	3	6	--	--	--
7/8/2016	4	10	4	79	5	94	3	5	--	--	--
7/12/2016	30	33	26	93	30	93	24	28	31	17	21
7/15/2016	28	32	20	91	39	81	18	32	55	1	42

Table 2. Grab, equal-width-increment or equal-discharge-increment, total suspended solids, and suspended-sediment concentration data at eight sites in Minnesota, water year 2016.—Continued

[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; EWDI, sample collected with the equal-width-increment or equal-discharge-increment field sampling method; SSC, sample analyzed with the suspended-sediment concentration laboratory analysis method; Fines, concentration of fines in SSC; <, less than; mm, millimeter; RPD, relative percent difference; Minn., Minnesota; USGS, U.S. Geological Survey; --, unavailable]

Date	Grab–TSS (mg/L)	EWDI–TSS (mg/L)	Grab–SSC (mg/L)	Grab–SSC–Fines (percent <0.0625 mm)	EWDI–SSC (mg/L)	EWDI–SSC–Fines (percent <0.0625 mm)	Grab–SSC–Fines (mg/L)	EWDI–SSC–Fines (mg/L)	Absolute RPD[a] EWDI–TSS to Grab–SSC–Fines	Absolute RPD[a] EWDI–TSS to EWDI–SSC–Fines	Absolute RPD[a] Grab–TSS to Gab–SSC–Fines
Redwood River near Marshall, Minn. (USGS station number 05315000)											
4/4/2016	62	89	77	72	143	60	55	86	46	4	11
4/21/2016	76	139	90	79	166	61	71	101	65	31	7
4/29/2016	180	252	192	80	332	63	154	209	49	19	16
5/1/2016	77	142	103	79	200	57	81	114	54	22	6
6/1/2016	120	154	125	86	211	73	108	154	36	0	11
6/29/2016	11	--	17	70	40	74	12	30	--	--	--
7/18/2016	240	268	317	80	336	76	254	255	6	5	6
Blue Earth River at Highway 169 at Mankato, Minn. (USGS station number 05321995)											
4/1/2016	270	324	359	83	495	61	298	302	8	7	10
4/3/2016	230	254	398	61	385	64	243	246	5	3	5
4/27/2016	190	173	214	84	253	70	180	177	4	2	6
5/3/2016	300	342	393	84	541	67	330	362	4	6	10
5/10/2016	120	142	147	77	191	64	113	122	23	15	6
5/24/2016	--	127	116	76	152	69	88	105	36	19	--
6/15/2016	1,000	989	1,400	85	1,230	76	1,190	935	18	6	17
6/21/2016	210	229	230	86	328	64	198	210	15	9	6
9/26/2016	390	--	659	--	685	--	--	--	--	--	--
Minnesota River at County Highway 22 in Saint Peter, Minn. (USGS station number 05325300)											
4/2/2016	201	254	261	84	332	67	219	222	15	13	9
5/3/2016	230	330	269	88	374	77	237	288	33	14	3
6/2/2016	180	194	202	90	240	76	182	182	6	6	1
6/9/2016	120	140	148	85	167	83	126	139	11	1	5
6/14/2016	120	136	131	87	187	80	114	150	18	10	5
6/16/2016	400	446	463	94	565	79	435	446	2	0	8
6/21/2016	220	206	247	92	324	73	227	237	10	14	3
8/2/2016	110	99	148	74	126	85	110	107	10	8	0

Table 2. Grab, equal-width-increment or equal-discharge-increment, total suspended solids, and suspended-sediment concentration data at eight sites in Minnesota, water year 2016.—Continued

[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; EWDI, sample collected with the equal-width-increment or equal-discharge-increment field sampling method; SSC, sample analyzed with the suspended-sediment concentration laboratory analysis method; Fines, concentration of fines in SSC; <, less than; mm, millimeter; RPD, relative percent difference; Minn., Minnesota; USGS, U.S. Geological Survey; --, unavailable]

Date	Grab–TSS (mg/L)	EWDI–TSS (mg/L)	Grab–SSC (mg/L)	Grab–SSC–Fines (percent <0.0625 mm)	EWDI–SSC (mg/L)	EWDI–SSC–Fines (percent <0.0625 mm)	Grab–SSC–Fines (mg/L)	EWDI–SSC–Fines (mg/L)	Absolute RPD[a] EWDI–TSS to Grab–SSC–Fines	Absolute RPD[a] EWDI–TSS to EWDI–SSC–Fines	Absolute RPD[a] Grab–TSS to Gab–SSC–Fines
Zumbro River at Kellogg, Minn. (USGS station number 05374900)											
4/12/2016	28	50	32	93	106	37	30	39	51	24	6
5/11/2016	31	29	35	72	64	40	25	26	14	12	21
6/8/2016	47	42	47	92	79	61	43	48	3	14	8
6/13/2016	170	157	193	90	--	--	174	--	8	10	--
6/28/2016	61	69	69	89	117	58	61	68	12	2	1
7/14/2016	47	55	37	97	95	50	36	48	42	15	27
8/11/2016	1,800	--	2,260	92	2,530	89	2,079	2,252	--	--	14
8/12/2016	910	--	1,040	96	1,270	86	998	1,092	--	--	9
9/23/2016	630	--	--	--	1,130	60	--	678	--	--	--
Root River at County Highway 25 near Mound Prairie, Minn. (USGS station number 05386070)											
3/23/2016	73	74	138	49	116	58.7	68	68	9	8	8
4/3/2016	180	207	217	91.1	310	74	198	229	5	10	9
5/11/2016	28	19	33	85	57	64.8	28	37	38	64	0
6/8/2016	75	92	81	91.7	--	--	74	--	20	21	--
6/9/2016	100	86	92	90.8	140	61.8	84	87	3	1	18
6/14/2016	140	144	138	92.4	299	43.8	128	131	12	9	9
6/15/2016	1,600	1,604	1,766	96.8	1,913	88.9	1,709	1,701	6	6	7
7/13/2016	27	54	38	90.9	81	55	35	45	44	19	25
							Mean absolute RPD[a]		**23**	**16**	**13**

[a]Calculation of absolute relative percent difference is $|[(x_1 - x_2)/([x_1 + x_2]/2)]| \times 100$, where x_1 is the suspended-sediment concentration of the first dataset, and x_2 is the suspended-sediment concentration of the second dataset, in milligrams per liter.

Table 3. Suspended-sediment concentration outliers, water year 2016.

[USGS, U.S. Geological Survey; EWDI, sample collected with the equal-width-increment or equal-discharge-increment field sampling method; suspended-sediment concentration; SSC, sample analyzed with the suspended-sediment concentration laboratory analysis method; mg/L, milligram per liter; <, less than; mm, millimeters; Minn., Minnesota]

Station name	USGS station number	Date	Time	EWDI–SSC (mg/L)	EWDI–SSC Fines (percent <0.0625 mm)
Root River at County Highway 25 near Mound Prairie, Minn.	05386070	6/8/2016	17:50	780	10.9
Zumbro River at Kellogg, Minn.	05374900	6/13/2016	15:25	633	30

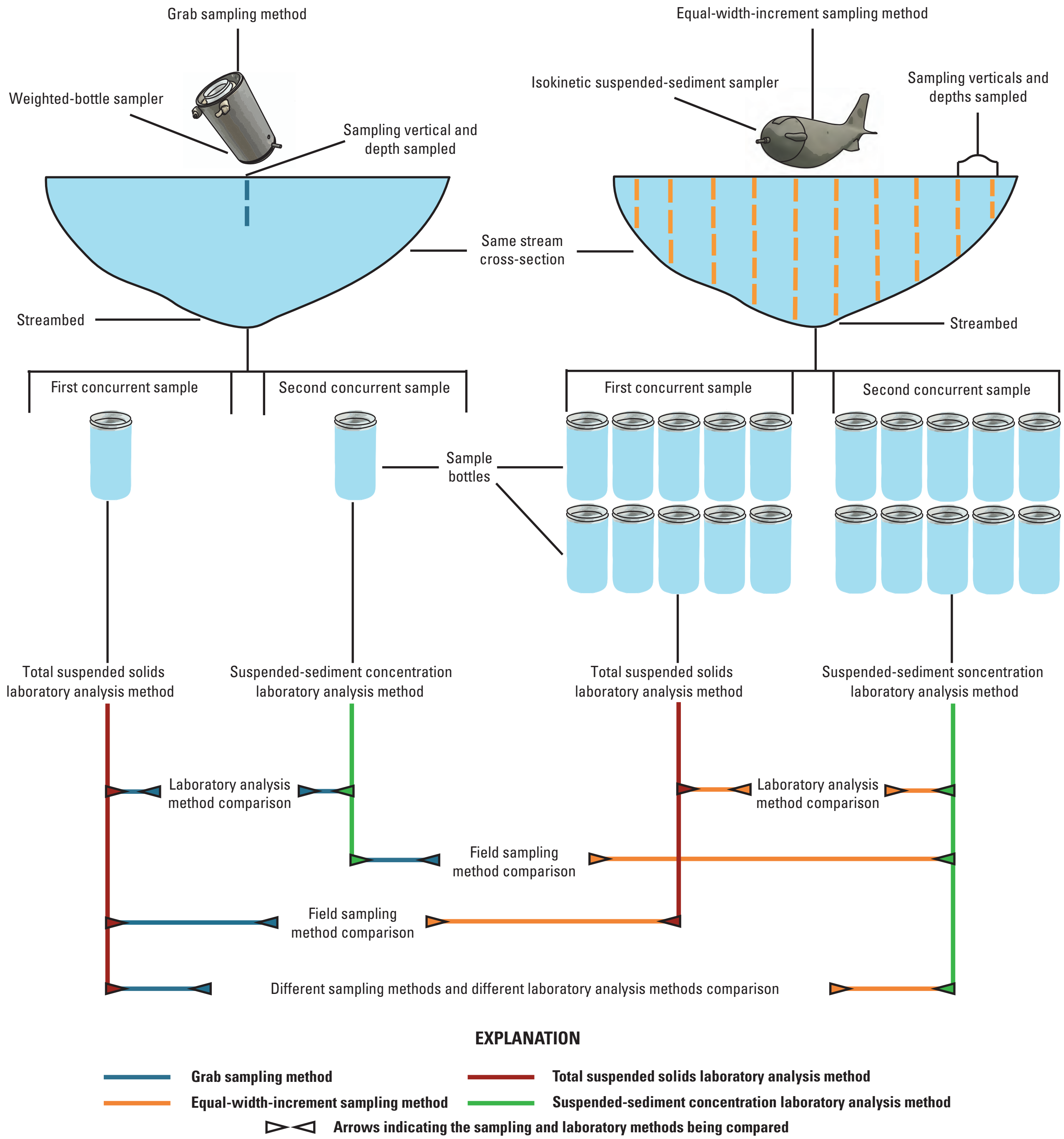

Figure 3. Infographic demonstrating five combinations of field sampling and laboratory analysis methods used to compare differences in sediment concentrations.

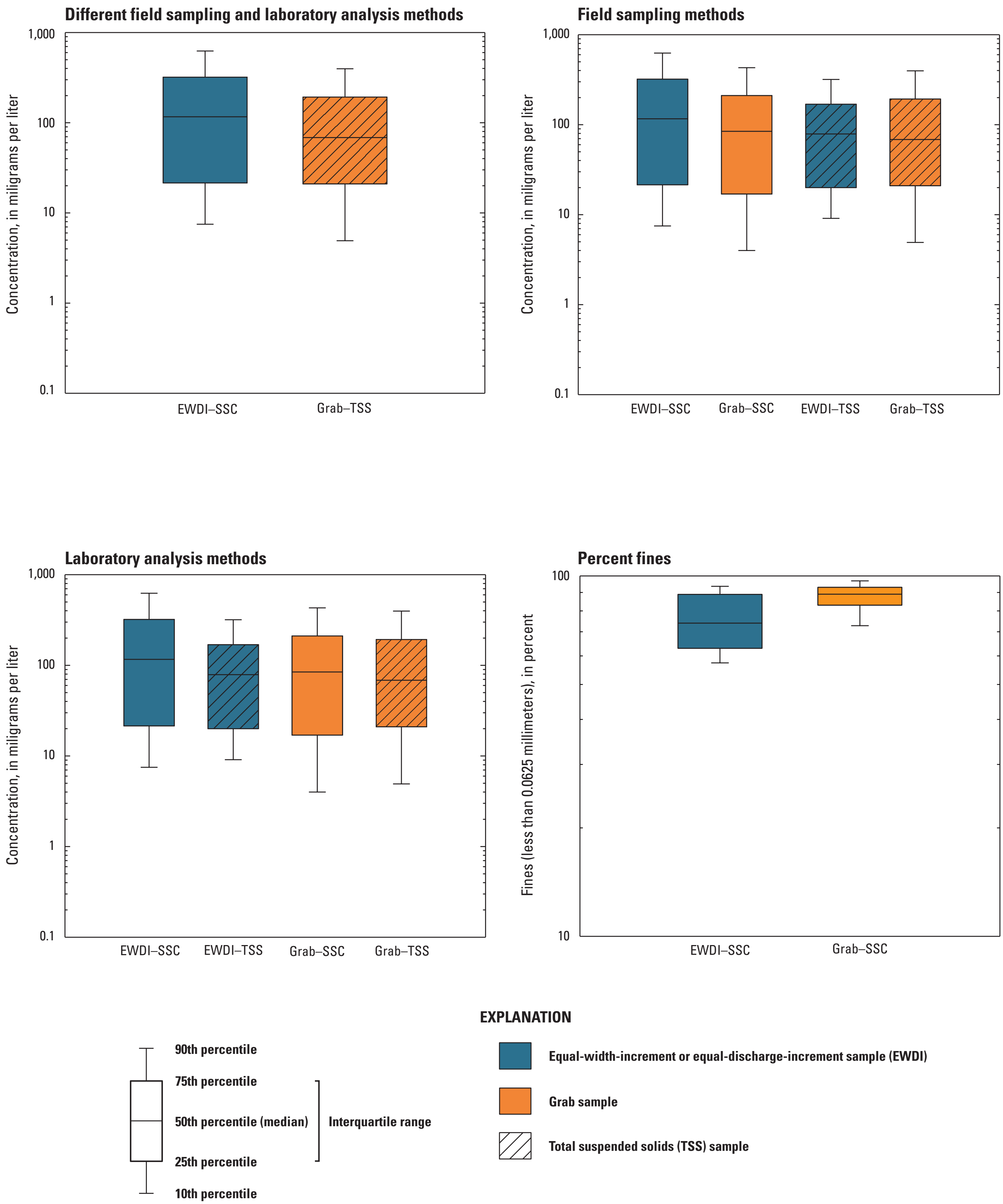

Figure 4. Box plots for grab samples, equal-width-increment or equal-discharge-increment samples, total suspended solids, suspended-sediment concentrations (SSC), and percent fines data at eight sites in Minnesota, water year 2016.

Table 4. Summary statistics for grab sampling, equal-width-increment or equal-discharge-increment sampling, total suspended solids, suspended-sediment concentrations, and percent fines at eight sites in Minnesota, water year 2016.

[*n*, number of samples; 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; EWDI, sample collected with the equal-width-increment or equal-discharge-increment field sampling method; SSC, sample analyzed with the suspended-sediment concentration laboratory analysis method; Fines, concentration of fines in SSC; <, less than; mm, millimeter]

Method combination	Minimum	Mean	Median	Maximum	Total *n*	Standard deviation
Grab–TSS (mg/L)	2	184	69	1,800	62	339
EWDI–TSS (mg/L)	4	146	79	1,604	60	245
Grab–SSC (mg/L)	1	211	85	2,260	64	405
Grab–SSC–Fines (percent <0.0625 mm)	49	87	89	100	63	10
EWDI–SSC (mg/L)	1	269	116	2,530	63	454
EWDI–SSC–Fines (percent <0.0625 mm)	37	74	74	100	62	15

Table 5. Summary of Wilcoxon signed-rank tests used to evaluate differences between field sampling and laboratory analysis method combinations in Minnesota, water year 2016.

[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]

Grab–TSS (mg/L)	Grab–SSC (mg/L)	EWDI–TSS (mg/L)	EWDI–SSC (mg/L)
Median			
69	85	79	116
Method combination comparison (x_1 to x_2[a])	**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.

the field sampling and laboratory analysis methods were different, the data plotted farthest above the 1:1 line than all the other comparisons (fig. 5*A*), indicating Grab–TSS consistently underpredicts EWDI–SSC.

For field sampling comparisons (figs. 5*B*, 5*C*), 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 (fig. 5*C*). Conversely, for TSS analyses, concentrations derived from grab samples approached the 1:1 line when sediment concentrations approached 200 mg/L (fig. 5*B*).

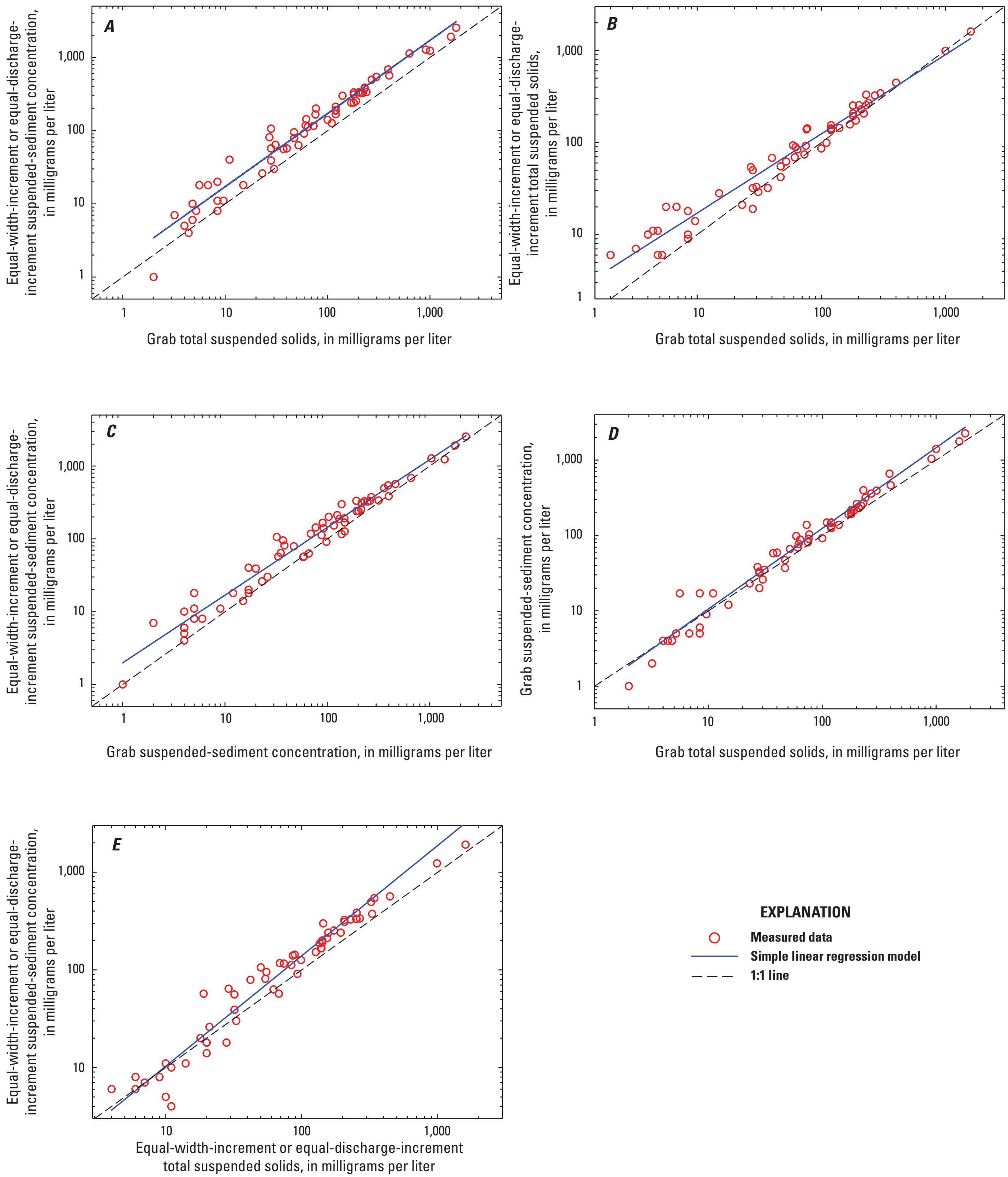

Figure 5. Relations between *A*, different field sampling and laboratory analysis methods, *B* and *C*, field sampling methods, and *D* and *E*, laboratory analysis methods in Minnesota, water year 2016.

Table 6. Summary of simple linear regression models to evaluate field sampling and laboratory analysis method combinations in Minnesota, water year 2016.

[*n*, number of samples; R^2, coefficient of determination; *p*–value, probability value; BCF, bias correction factor; EWDI, sample collected with the equal-width-increment or equal-discharge-increment field sampling method; SSC, sample analyzed with the suspended-sediment concentration laboratory analysis method; Grab, sample collected with the grab field sampling method; TSS, sample analyzed with the total suspended solids laboratory analysis method; <, less than]

Method combination comparison	*n*	Simple linear regression model	Standard error	R^2	Average model standard percentage error	*p*–value	BCF[a]
EWDI–SSC to Grab–TSS	61	$EWDI\text{–}SSC = 1.622 \times Grab\text{–}TSS^{0.999b}$	0.149	0.96	35	<0.01	1.06
Grab–SSC to Grab–TSS	61	$Grab\text{–}SSC = 0.857 \times Grab\text{–}TSS^{1.07b}$	0.123	0.97	28.7	<0.01	1.05
EWDI–SSC to EWDI–TSS	59	$EWDI\text{–}SSC = 0.714 \times EWDI\text{–}TSS^{1.13b}$	0.175	0.94	41.3	<0.01	1.07
EWDI–TSS to Grab–TSS	57	$EWDI\text{–}TSS = 2.275 \times Grab\text{–}TSS^{0.86b}$	0.125	0.95	29.2	<0.01	1.04
EWDI–SSC to Grab–SSC	63	$EWDI\text{–}SSC = 1.888 \times Grab\text{–}SSC^{0.93b}$	0.139	0.96	32.6	<0.01	1.05

[a]Bias correction factor or “smearing” estimator is used to correct retransformation bias of regression estimates (Duan, 1983).

[b]Slope coefficent.

For laboratory comparisons (figs. 5*D*, 5*E*), 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 (figs. 5*D*, 5*E*). At sediment concentrations greater than 40 mg/L, TSS concentrations were negatively biased (figs. 5*D*, 5*E*). These comparisons followed observations by Gray and others (2000) and indicated the TSS laboratory analysis methods were most likely biased because of sand-sized particles (greater than or equal to 0.0625 mm) because the SSC method measures the 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 median values (table 4) and boxplots (fig. 4) indicated that samples collected using the Grab–SSC method had a greater percentage of fines than samples collected using the EWDI–SSC method. 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 integrate the vertical water column and exclude the lowest 10 centimeters above the streambed; furthermore, samples collected using the EWDI method incorporate water from 5 to 10 locations across the horizontal stream cross section.

Gray and others (2000) stated that the difference between SSC and TSS was intensified 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.”

After the dataset was divided 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, and *p*-values were less than 0.01; table 7). The slope coefficients of the SLR models ranged from 0.84 to 1.12 (table 7). The sands plotted farthest above the 1:1 line in the comparison of EWDI–SSC to Grab–TSS (fig. 6*A*). Error was cumulative as sand increased because the grab method failed to capture sand in the sample, whereas the TSS laboratory analysis method failed to capture sand during the extraction procedure.

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

Table 7. Summary of simple linear regression models to evaluate effect of sand-sized particles on field sampling and laboratory analysis method combinations in Minnesota, water year 2016.

[≥, greater than or equal to; mm, millimeter; *n*, number of samples; R^2, coefficient of determination; *p*–value, probability value; BCF, bias correction factor; EWDI, sample collected with the equal-width-increment or equal-discharge-increment field sampling method; SSC, sample analyzed with the suspended-sediment concentration laboratory analysis method; Grab, sample collected with the grab field sampling method; TSS, sample analyzed with the total suspended solids laboratory analysis method; <, less than]

Method combination comparison	Sands (≥0.0625 mm)						
	n	Simple linear regression model	Standard error	R^2	Average model standard percentage error	*p*–value	BCF[a]
EWDI–SSC to Grab–TSS	31	$EWDI–SSC = 2.388 \times Grab–TSS^{0.942}$[b]	0.128	0.94	29.9	<0.01	1.04
Grab–SSC to Grab–TSS	30	$Grab–SSC = 0.724 \times Grab–TSS^{1.11}$[b]	0.096	0.97	22.4	<0.01	1.02
EWDI–SSC to EWDI–TSS	30	$EWDI–SSC = 1.203 \times EWDI–TSS^{1.04}$[b]	0.118	0.94	27.6	<0.01	1.04
EWDI–TSS to Grab–TSS	29	$EWDI–TSS = 1.995 \times Grab–TSS^{0.887}$[b]	0.128	0.92	30	<0.01	1.04
EWDI–SSC to Grab–SSC	31	$EWDI–SSC = 3.289 \times Grab–SSC^{0.84}$[b]	0.116	0.94	27.1	<0.01	1.03

Method combination comparison	Fines (<0.0625 mm)						
	n	Simple linear regression model	Standard error	R^2	Average model standard percentage error	*p*–value	BCF[a]
EWDI–SSC to Grab–TSS	30	$EWDI–SSC = 1.324 \times Grab–TSS^{1.01}$[b]	0.14	0.978	32.7	<0.01	1.05
Grab–SSC to Grab–TSS	31	$EWDI–SSC = 0.914 \times Grab–TSS^{1.06}$[b]	0.145	0.97	34.1	<0.01	1.06
EWDI–SSC to EWDI–TSS	29	$EWDI–SSC = 0.608 \times EWDI–TSS^{1.12}$[b]	0.194	0.94	46.1	<0.01	1.08
EWDI–TSS to Grab–TSS	28	$EWDI–TSS = 2.393 \times Grab–TSS^{0.852}$[b]	0.125	0.96	29.2	<0.01	1.04
EWDI–SSC to Grab–SSC	32	$EWDI–SSC = 1.469 \times Grab–SSC^{0.951}$[b]	0.11	0.98	25.6	<0.01	1.03

[a]Bias correction factor or “smearing” estimator is used to correct retransformation bias of regression estimates (Duan, 1983).

[b]Slope coefficent.

and fines SLR best-fit lines (figs. 6*C*). The comparisons of EWDI–SSC to Grab–SSC (fig. 6*C*) 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 (fig. 6*C*). 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 (fig. 6*B*). A possible explanation for the small separation between sand and fines SLR best-fit lines in figure 6*B* 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 (fig. 6*E*) than on the Grab–SSC to Grab–TSS comparison (fig. 6*D*). For EWDI–SSC to EWDI–TSS, the EWDI–TSS sand samples underestimated the most representative sediment concentration throughout the range of samples (fig. 6*E*). For Grab–SSC to Grab–TSS, the sands followed almost an identical pattern as the fines and had little effect (fig. 6*D*).

By comparing the concentration of fines from the SSC analysis to the TSS analysis and seeing how closely they match, understanding can be gained to determine if sand is being captured through TSS analysis. The concentration of fines in SSC was calculated from equation 1:

$$Concentration\ of\ Fines = \left(\left[\frac{PF}{100} \right] \times SSC \right) \tag{1}$$

where

PF is the percentage of fines less than 0.0625 millimeters; and

SSC is the suspended-sediment concentration, in milligrams per liter.

All values of 10 mg/L or less were not considered in these comparisons because of the high variance with laboratory analysis at low concentrations. The concentrations of fines will be combined to the field sampling and laboratory analysis method abbreviations in the following section of the report; for example, the concentration of fines will be referred to as, “Fines” and will follow an en dash (–) after the laboratory method abbreviation (TSS or SSC).

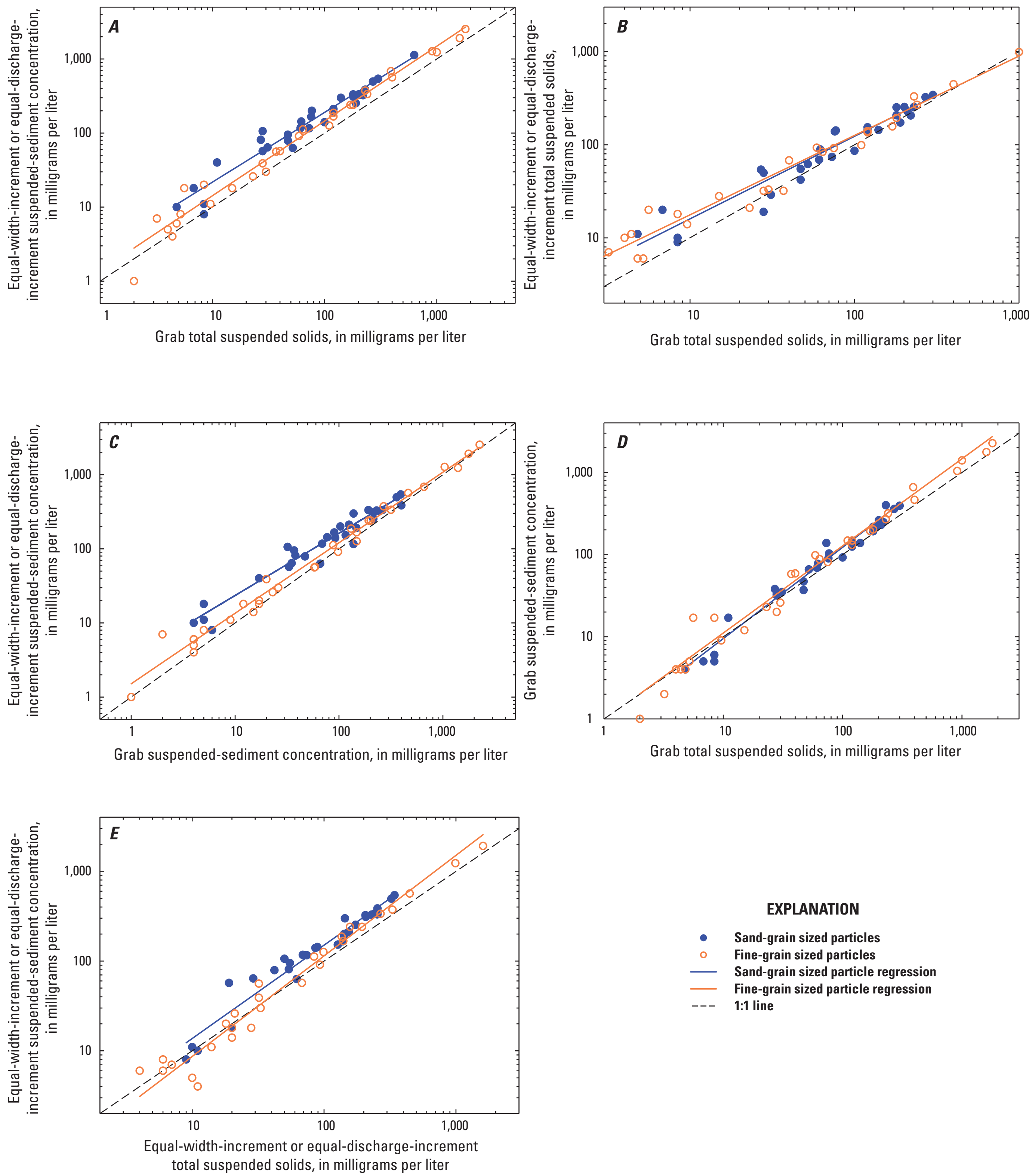

Figure 6. Sand-sized particles effect on relations between *A*, different field sampling and laboratory analysis methods, *B* and *C*, field sampling methods, and *D* and *E*, laboratory analysis methods in Minnesota, water year 2016.

Mean absolute RPDs between SSC–Fines and TSS demonstrated the substantial effect of sand on sediment concentrations (table 2). When comparing field sampling methods and laboratory analysis methods, the difference between concentrations for EWDI–TSS and Grab–SSC–Fines had a mean absolute RPD of 23 percent. When comparing laboratory analysis methods, the mean absolute RPD decreased to 16 percent when comparing EWDI–TSS and EWDI–SSC–Fines. The mean absolute RPD was 13 percent when comparing the Grab–TSS and Grab–SSC–Fines. When comparing Grab–TSS and Grab–SSC–Fines, the mean absolute RPD was the lowest indicating less sand-size particles were being captured using the grab field sampling and TSS laboratory analysis methods.

Quality Assurance

Quality-assurance replicate samples were collected to assess the variation in the reproducibility of field sampling and laboratory analysis methods (table 8). Concurrent replicate samples were collected with the EWDI field sampling method most of the time and analyzed for SSC at Knife River near Two Harbors, Minn. (USGS station 04015330), Blue Earth River at Highway 169 at Mankato, Minn. (USGS station 05321995), Minnesota River at County Highway 22 in Saint Peter, Minn. (USGS station 05325300), and Zumbro River at Kellogg, Minn. (USGS station 05374900). Overall, the mean absolute RPD of 6 percent was small, indicating that field sampling and laboratory analysis methods primarily used by the USGS are reproducible and consistent.

An exploratory comparison of the TSS analyses completed by the two different laboratories (USGS Sediment Laboratory and MDH Environmental Laboratory) was completed to provide a determination of the differences between laboratories. Samples of known sediment concentration were submitted to both laboratories and analyzed for TSS. The USGS Branch of Quality Systems prepared two samples with known concentrations (table 9) as part of the Sediment Laboratory Quality Assurance Project (USGS, 2017b). One sample was sent to the USGS Sediment Laboratory, and the other sample was sent to the MDH Environmental Laboratory. The MDH Environmental Laboratory and USGS Sediment Laboratory measured results had a RPD of 8 percent (table 9). The PDs between the known and measured concentrations were 30 and 24 percent (table 9) for the USGS Sediment Laboratory and MDH Environmental Laboratory, respectively. The PDs between the known concentration and measured concentration is most likely a result of the sand content in the sample, which was 15 percent for both samples.

Table 8. Results of quality-assurance samples for suspended-sediment concentration for samples collected at selected sites in Minnesota, water year 2016.

[EWDI, sample collected with the equal-width-increment or equal-discharge-increment field sampling method; SSC, sample analyzed with the suspended-sediment concentration laboratory analysis method; mg/L, milligram per liter; RPD, relative percent difference; Minn., Minnesota; USGS, U.S. Geological Survey]

Date	Time	EWDI–SSC primary sample (mg/L)	Time	EWDI–SSC replicate sample (mg/L)	Absolute RPD[a]
Knife River near Two Harbors, Minn. (USGS station number 04015330)					
3/30/2016	14:25	91	14:30	91	0
4/19/2016	12:30	20	12:35	19	5
4/26/2016	13:00	56	13:05	64	13
5/24/2016	12:05	6	12:10	5	18
6/7/2016	10:40	18	10:45	18	0
6/15/2016	08:15	112	08:20	113	1
7/12/2016	14:50	57	14:55	55	4
8/16/2016	09:30	1	09:35	1	0
Blue Earth River at Highway 169 at Mankato, Minn. (USGS station number 05321995)					
4/1/2016	10:45	495	10:50	471	5
4/3/2016	09:30	385	09:35	407	6
4/27/2016	14:10	253	14:15	275	8
5/3/2016	16:45	541	16:50	571	5
5/10/2016	19:05	191	19:10	187	2
5/24/2016	16:05	152	16:10	148	3
6/15/2016	17:25	1,230	17:30	1,380	11
6/21/2016	09:50	328	09:55	445	30
9/26/2016	17:20	685	17:25	680	1
Minnesota River at County Highway 22 in Saint Peter, Minn. (USGS station number 05325300)					
4/2/2016	16:30	332	16:35	333	0
5/3/2016	11:00	374	11:05	346	8
6/2/2016	11:30	240	11:35	251	4
6/14/2016	10:30	187	10:35	188	1
6/21/2016	15:05	324	15:10	340	5
8/2/2016	11:30	126	11:35	131	4
Zumbro River at Kellogg, Minn. (USGS station number 05374900)					
4/12/2016	11:55	106	12:00	111	5
5/11/2016	16:35	64	16:40	62	3
6/8/2016	13:45	79	13:50	81	3
6/28/2016	14:05	117	14:10	111	5
7/14/2016	10:55	95	11:00	94	1
8/11/2016	18:15	2,530	19:25	2,270	11
8/12/2016	06:20	1,270	07:27	1,220	4
				Mean absolute RPD[a]	**6**

[a]Calculation of absolute relative percent difference is $|[(x_1 - x_2)/([x_1 + x_2]/2)]| \times 100$, where x_1 is the suspended-sediment concentration of the first dataset, and x_2 is the suspended-sediment concentration of the second dataset, in milligrams per liter.

Table 9. Results of quality assurance for the total suspended solids laboratory analysis method at two laboratories, water year 2016.

[mg, milligram; L, liter; g, gram; mg/L, milligram per liter; PD, percent difference; USGS, U.S. Geological Survey; MDH, Minnesota Department of Health; RPD, relative percent difference]

Laboratory	Fines weight (mg)	Sand weight (mg)	Percentage of fines	Total sediment weight (mg)	Volume of water (L)	Bottle with cap weight (g)	Known sample concentration (mg/L)	Measured by lab concentration (mg/L)	PD[a]
USGS	115.88	20.29	85	136.17	0.44756	66.7	304.2	213	30
MDH	115.93	20.34	85	136.27	0.44796	67.8	304.2	230	24
								RPD[b]	**8**

[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.

[b]Calculation of absolute relative percent difference is $|[(x_1 - x_2)/([x_1 + x_2]/2)]| \times 100$, where x_1 is the suspended-sediment concentration of the first dataset, and x_2 is the suspended-sediment concentration of the second dataset, in milligrams per liter.

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) are from 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 are underrepresenting 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 field sampling and laboratory analysis methods caused grab and TSS methods to be significantly biased low, and the difference in laboratory analysis methods was slightly greater than the difference in 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. Differences between concurrent grab samples with one set being analyzed for concentration of fines in the SSCs and the other being analyzed for TSS were the smallest of all comparisons. This smaller difference suggests that grab field sampling and TSS laboratory analysis methods are not sufficiently capturing sand-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 because 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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Appendix

The final selected log-transformed simple linear regression models are included in the appendix. The files include the definitions, statistics, data, and plots for the simple linear regression models. The appendix files are available for download at https://doi.org/10.3133/sir20185023.

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