Adjustment of Total Suspended Solids Data for Use in Sediment Studies

G. Douglas Glysson (1), John R. Gray (2), and Lisa M. Conge (2)

(1) U.S. Geological Survey, 412 National Center, Reston, VA 20192; PH (703)648-5019; FAX (703)648-5722; email gglysson@usgs.gov
(2) U.S. Geological Survey, 415 National Center, Reston, VA 20192; PH (603)648-5318; FAX (703)648-5295; email jrgray@usgs.gov; lmconge@usgs.gov

Abstract: The U.S. Environmental Protection Agency identifies fluvial sediment as the single most widespread pollutant in the Nation's rivers and streams, affecting aquatic habitat, drinking water treatment processes, and recreational uses of rivers, lakes, and estuaries. A significant amount of suspended-sediment data has been produced using the total suspended solids (TSS) laboratory analysis method. An evaluation of data collected and analyzed by the U.S. Geological Survey and others has shown that the variation in TSS analytical results is considerably larger than that for traditional suspended-sediment concentration analyses (SSC) and that the TSS data show a negative bias when compared to SSC data.

This paper presents the initial results of a continuing investigation into the differences between TSS and SSC results. It explores possible relations between these differences and other hydrologic data collected at the same stations. A general equation was developed to relate TSS data to SSC data. However, this general equation is not applicable for data from individual stations. Based on these analyses, there appears to be no simple, straightforward way to relate TSS and SSC data unless pairs of TSS and SSC results are available for a station.

Introduction: The importance of fluvial sediment in the quality of aquatic and riparian systems is well established. The U.S. Environmental Protection Agency (EPA) identifies sediment as the single most widespread pollutant affecting the beneficial uses of the Nation’s rivers and streams (EPA, 1998). TSS data are often the only source of sediment data available to engineers and scientists who estimate sediment loads for a variety of purposes, including EPA’s total maximum daily load program.

Reliable, quality-assured sediment and ancillary data are the underpinnings for assessment and remediation of sediment-impaired waters. The U.S. Geological Survey (USGS has established protocols for sediment data collection (Edwards and Glysson, 1999) and for laboratory analysis of suspended-sediment samples (Guy, 1969; Matthes and others, 1991; Knott and others, 1992 and 1993; USGS, 1998; USGS, 1999a). Most of the analytical methods were developed by the Federal Inter-Agency Sedimentation Project, approved by the Technical Committee (Glysson and Gray, 1997) and used by most Federal agencies that analyze fluvial sediment data.

Data collected, processed, and analyzed using consistent methods are comparable in time and space. Conversely, data obtained using different methods may not provide comparable results. The focus of a previous study (Gray, Glysson, and Conge, 2000) was the comparability of suspended-sediment concentration (SSC) and total suspended solids (TSS) data. The terms SSC and TSS are often used interchangeably in the literature to describe the concentration of suspended solid-phase material in a water-sediment mixture, usually measured in milligrams per liter (mg/L). However, the analytical procedures for SSC and TSS differ and at times can produce considerably different results, particularly when sand-size material composes a significant percentage of the sediment in the sample (Gray, Glysson, and Conge, 2000). An evaluation of data collected and analyzed by the U.S. Geological Survey and others has shown that the variation in TSS analytical results is considerably larger than that for traditional suspended-sediment concentration analyses (SSC) and that the TSS data show a negative bias when compared to SSC data. (USGS, 1999b).

This paper presents the initial results of a continuing investigation into the differences between SSC and TSS results and explores possible relations between these differences and other hydrologic data collected at the same stations.

Differences Between the SSC and TSS Analytical Methods. The fundamental difference between SSC (ASTM, 1999) and TSS (APHA and others, 1995) analytical methods arises during the preparation of the sample for subsequent filtering, drying, and weighing. A TSS analysis generally entails withdrawal of an aliquot of the original sample for subsequent analysis, although as determined in a previous study, there may be a lack of consistency in methods used in the sample preparation phase of the TSS analyses (Gray, Glysson, and Conge, 2000). The SSC analytical method uses the entire water-sediment mixture to calculate SSC values.

Subsampling in itself can introduce error into the analysis. Also, if a sample contains a significant percentage of sand-size material, stirring, shaking, or otherwise agitating the sample before obtaining a subsample will rarely produce an aliquot representative of the sediment concentration and particle-size distribution of the original sample. This is a by-product of the relatively rapid settling properties of sand-size material, compared to those for silt- and clay-size material, as described by Stokes Law. Aliquots obtained by pipette might be withdrawn from the lower part of the sample where the sand concentration tends to be enriched immediately after agitation, or from a higher part of the sample where the sand concentration is rapidly depleted. Because the fine material concentration will not normally be altered by the removal of an aliquot, the differences between the two methods will tend to be more pronounced as the percent of sand in the sample increases (Gray, Glysson, and Conge, 2000).

Data: All 14,466 pairs of sample pairs analyzed using the SSC and TSS methods are available in electronic files of the USGS and were used for this analysis. Data were available from 48 states and Puerto Rico. Samples that are collected sequentially in-stream may have different concentrations and size characteristics of solid-phase material. This may be due to natural variations in amounts and the composition of solid-phase material in transport and to variance and (or) bias introduced by sampling procedures. Likewise, a subsample may contain an amount and size distribution of sediment atypical of that of the source. However, any bias in individual sediment-concentration and size-distribution data resulting from in-stream variations would likely occur randomly in this paired sample data base.

Figure 1A shows the relation between SSC and TSS for the 14,466 pairs of environmental SSC and TSS data, along with a line of equal value and an ordinary least-squares regression line. A large scatter between the results of the two analyses is shown in Figure 1A; the majority of the TSS analyses results are less than the SSC results for the paired data. The percent differences between the TSS and SSC data below 500 mg/L (fig. 1B) are greater than the percent differences below 5,000 mg/L (fig. 1C) because of the effect of the relatively large average initial difference of 126 mg/L SSC value at the TSS value of zero (fig. 1B). A t-test statistical analysis as part of a previous study using a smaller subset (3,235 sets of paired samples) of the total data base (14,466 pairs), indicated that, at the 95% confidence level, the relation between SSC and TSS described by the regression equation was significantly different from that for the line of equal values of SSC and TSS (Gray, Glysson, and Conge, 2000). Data summaries for seven individual stations are listed in Table 1.

Estimating SSC from TSS data: The inability to obtain a representative amount of sand in an aliquot is one reason why TSS values differ from SSC values. The use of this knowledge may help to evaluate the amount of error in the TSS values and to correct these errors. The percent sand in the SSC samples was plotted against the water discharge of the SSC samples for the seven test stations. The results of the linear regression analysis performed on the test stations are given in Table 2. None of the data for the seven stations show a strong correlation between the percent sand and water discharge. Percent sand as a function of water discharge for station 07381590 had a R^2 value of 0.50 and had a considerable scatter around the regression line. The analysis of TSS and SSC as a function of percent difference and water discharge values and percent sand as a function of water discharge were also investigated but showed no strong linear correlation.

Based on the assumption that the fine material in the sample would be represented accurately in the aliquot taken for the TSS analysis, the relation between the concentration of fine material in the SSC values and the TSS samples was investigated. There were 6,050 pairs of samples available in which the percentage of sand in the sample was determined. The regression analysis of TSS and concentration of fine material (less than 0.062 mm) in the SSC samples resulted in the equation SSC = 0.8059TSS + 128 and a R^2 = 0.80. This same analysis was preformed for the seven test stations and the results of the regression analyses are given in Table 2. TSS values start to deviate from the line of equal value at a value of about 100 mg/L of fine material. However, there is a large amount of scatter in the data. Table 2 indicates that for all of the stations except 05599500, the relations between TSS and fine concentration of fine material have an R^2 value above 0.76. SSC samples collected at stations 014635000, 07381590, and 8188500 have very low percentages of sand (median less than 15%) and samples form stations 09520500 and 12200500 have relatively high concentrations of sand (median greater than 24%) but relatively low sediment concentrations. TSS values and the concentration of fines in the SSC samples from station 05599500 have a poor correlation and have very low percent sand (median of 1%) and relatively low suspended-sediment concentrations (table 1).

The results of the regression analysis of the complete data set (14,466 pairs of samples) indicated a fairly good relation with an R^2 of 0.54, intercept of 126 mg/L, and a slope of 1.0857 (table 2). This indicates that as a general rule, if no other data are available, the use of the formula SSC = 126 + 1.0857 (TSS) might give a better estimate of SSC in the stream. However, caution should be used in using this equation, especially to correct TSS values less that about 500 mg/L. The relatively high intercept value of 126 for the general equation is not supported by the regression analyses for the seven test stations individually. The intercept for these stations ranged from –12.4 to 103 mg/L. The R^2 values for five of the seven stations were greater than the 0.54 for the overall data set (table 2). Stations 05599500 and 12200500 had R^2 below that of the entire data set. At three of the stations (01463500, 05599500, and 0818850) the slope of the regression line is less than 1.00. At stations 0866500, 09520500, and 12200500, the slopes of the regression line are significantly greater than about 1.10; at these stations, about 30, 69, and 80% would have to be added, respectively, to the TSS values to better estimate the SSC concentrations.

Summary:

1. An analysis of 14,466 paired SSC and TSS environmental samples from 48 states showed that the TSS tended to be smaller than SSC throughout the observed range of suspended-sediment concentrations encountered in this study. This is consistent with the assumption that most of the subsamples used to produce the TSS data were obtained by pipette, or by pouring from an open container. Subsampling by pipette or by pouring will tend to produce a sand-deficient subsample.

2. No consistent relation between either the percent sand or percent difference between TSS and SSC, and water discharge or sediment concentration was identified for the stations used in this investigation.

3. Although TSS and concentration of fines from SSC samples are generally in better agreement than TSS and SSC whole-sample concentrations, the degree of agreement can vary appreciably between stations (even stations with low sediment concentrations and low sand content.)

4. The relation between SSC and TSS at a station will give a better estimate of the conversion factor needed to correct TSS data at that station than simply using the general equation of SSC = 126 + 1.0857(TSS). Caution should be exercised before relating SSC and TSS using this general equation because of the potentially large errors involved.

Conclusions: The differences between TSS and SSC analyses of paired samples can be significant. If TSS and SSC paired samples exist or can be collected, it might be possible to develop a relation between SSC and TSS. It appears from the results of this study so far, that in order to attempt to adjust TSS data, one would have to have a significant number of paired data sets from the station of interest. Even then, this method may not be a guaranteed way to adjust the TSS data accurately. There appears to be no simple, straightforward way to adjust TSS data to estimate suspended-sediment concentrations if paired samples are not available. Additional work needs to be done before any definite procedure can be recommended to adjust TSS data to better estimate SSC values.

REFERENCES CITED

American Public Health Association, American Water Works Association, and Water Pollution and Control Federation, 1995, Standard Methods for the Examination of Water and Wastewater, 1995, Total Suspended Solids Dried at 103°-105° C, Washington, D.C., American Public Health Association, Method 2540D, p. 2-56.

ASTM, 1999, Standard Test Method for Determining Sediment Concentration in Water Samples: American Society of Testing and Materials, D 3977-97, Vol. 11.02, pp. 389-394.

Edwards, T.K., and Glysson, G.D., 1999, Field Methods for Measurement of Fluvial Sediment: U.S. Geological Survey Techniques of Water-Resources Investigations, Book 3, Chapter C2, 89 p.

Glysson G.D., and Gray, J.R., 1997, Coordination and Standardization of Federal Sedimentation Activities - Expanding Sediment Research Capabilities in Today's USGS, accessed July 6, 1999, at URL http://wwwrvares.er.usgs.gov/osw/workshop/

Gray, J.R., Glysson, G.D., and Conge, L.M., 2000, Comparability of Total Suspended Solids and Suspended-Sediment Concentration Data, approved for publication, U.S. Geological Survey.

Guy, H.P., 1969, Laboratory Theory and Methods for Sediment Analysis: U.S. Geological Survey Techniques of Water-Resources Investigations, Book 5, Chapter C1, 58 p.

Knott, J.M., Sholar, C.J., and Matthes, W.J., 1992, Quality Assurance Guidelines for the Analysis of Sediment Concentration by U.S. Geological Survey Sediment Laboratories: U.S. Geological Survey Open-File Report 92-33, 30 p.

Knott, J.M., Glysson, G.D., Malo, B.A., and Schroder, L.J., 1993, Quality Assurance Plan for the Collection and Processing of Sediment Data by the U.S. Geological Survey, Water Resources Division: U.S. Geological Survey Open-File Report 92-499, 18 p.

Matthes, W.J., Jr, Sholar, C.J., and George, J.R., 1991, A Quality-Assurance Plan for the Analysis of Fluvial Sediment by Laboratories of the U.S. Geological Survey: U.S. Geological Survey Open-File Report 91-467, 31 p.

U.S. Environmental Protection Agency, 1998, Report of the Federal Advisory Committee on the Total maximum Daily Load (TMDL) Program: The National Advisory Council for Environmental Policy and Technology, EPA 100-R-98-006, 97 p., 7 appendixes.

U.S. Geological Survey, 1998, A National Quality Assurance Program for Sediment Laboratories Operated or Used by the Water Resources Division: U.S. Geological Survey, Office of Surface Water Technical Memorandum No. 98.05, accessed July 6, 1999, at URL http://water.usgs.gov/admin/memo/SW/sw98.05.txt.

U.S. Geological Survey, 1999a, Guidelines from the 1998 Sediment Laboratory Chiefs Workshop: Office of Surface Water Technical Memorandum 99.04 accessed July 6, 1999, at URL http://water.usgs.gov/admin/memo/SW/sw99.04.txt.

U.S. Geological Survey, 1999b, Sediment Laboratory Quality Assurance Project: U.S. Geological Survey, Office of Water Quality, Branch of Quality Systems, accessed January 27, 2000, at URL http://sedserv.cr.usgs.gov/.

Table 1: Data summaries for seven stations used to show relation between suspended-sediment (SSC) and total suspended solids (TSS) analysis.

Station number	Station name	Drainage area in square miles	Number of sample pairs	SSC mg/L Minimum / Median / Maximum	TSS mg/L Minimum / Median / Maximum	Q m^3/s Minimum / Median / Maximum	% Sand Minimum / Median / Maximum
01463500	Delaware River at Trenton, NJ	6,780	39	1	0	84	0
				12	21	306	7
				309	289	2,150	43
05599500	Big Muddy River nr Murphysboro, IL	2,169	26	35	11	2.8	0
				86	51	18	1
				319	269	199	34
07381590	Wax Lake Outlet at Calumet, LA	indeterminate	180	11	1	315	0
				260	131	2,500	4
				854	548	6,150	56
08066500	Trinity River at Romayor, TX	17,186	111	5	2	15	1
				25	30	87	14
				1,270	436	1,390	95
08188500	San Antonio River at Goliad, TX	3,921	103	15	9	4.1	0
				138	124	15	5
				2,450	2,860	298	64
09520500	Gila River near Dome, AZ	57,850	111	9	1	24	1
				45	21	73	24
				4,622	3,600	738	92
12200500	Skagit River near Mount Vernon, WA	3,093	83	8	0	121	7
				52	10	412	74
				800	321	1,200	100

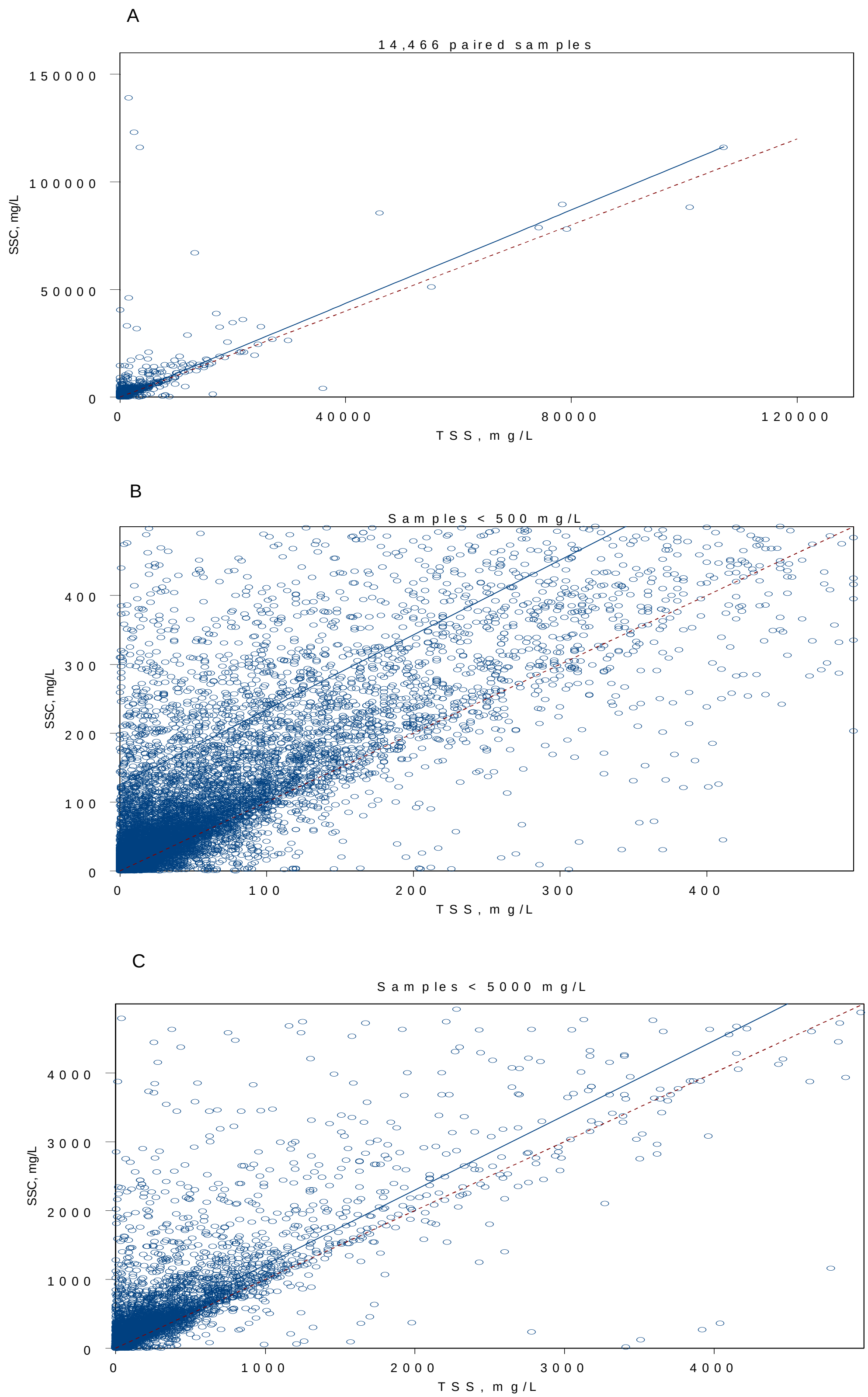
mg/L = milligrams per liter; Q = water discharge; m^3/s = cubic feet per second; % = percent

Table 2: Linear regression statistics for seven stations and the full data set used to define the suspended-sediment concentration (SSC) and the total suspended solids (TSS) relation. (First parameter is dependent variable)

Station number	Station name	TSS vs Q[1]	% Sand vs Q[1]	TSS vs fine concentration	SSC vs TSS
01463500	Delaware River at Trenton, NJ				
	Intercept	-15.5	1.60	-1.07	5.96
	Slope	0.0024	0.0006	1.017	0.9838
	R^2	0.51	0.39	0.76	0.79
05599500	Big Muddy River near Murphysboro, IL				
	Intercept	52.9	4.00	23.3	51.6
	Slope	0.0096	-0.0005	0.4263	0.8121
	R^2	0.14	0.02	0.36	0.32
07381590	Wax Lake Outlet at Calumet, LA				
	Intercept	63.6	-6.89	-32.3	103
	Slope	0.0010	0.0002	0.7677	1.0995
	R^2	0.15	0.50	0.76	0.74
08066500	Trinity River at Romayor, TX				
	Intercept	23.9	14.9	14.9	-12.4
	Slope	0.0022	0.0011	0.7462	1.6889
	R^2	0.14	0.23	0.76	0.59
08188500	San Antonio River at Goliad, TX				
	Intercept	144	6.17	-14.6	40.8
	Slope	0.1332	0.0010	1.103	0.8776
	R^2	0.18	0.03	0.91	0.92
09520500	Gila River near Dome, AZ				
	Intercept	-6.94	23.2	1.46	81.2
	Slope	0.0351	0.0029	0.5369	1.3128
	R^2	0.12	0.30	0.80	0.89
12200500	Skagit River near Mount Vernon, WA				
	Intercept	-37.7	74.0	0.69	49.6
	Slope	0.0041	-0.0004	0.7558	1.8033
	R^2	0.37	0.02	0.79	0.39
Full Data Set					
	Intercept			128	126
	Slope			0.8059	1.0857
	R^2			0.80	0.54

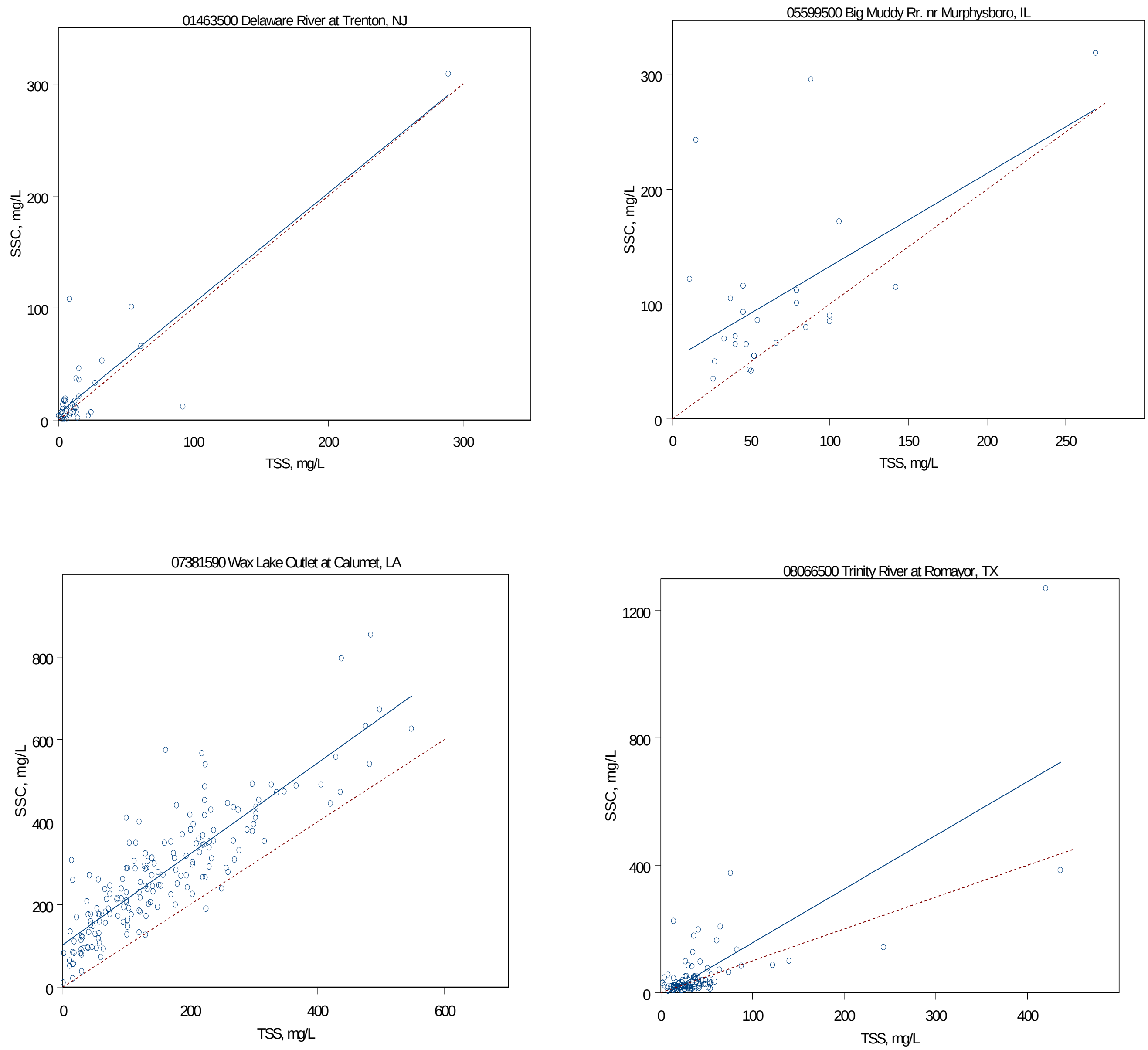
[1] Water discharge, Q, is in cubic feet per second in these regression analyses; % = percent; R = correlation coefficient

Figure 1. Suspended-sediment concentration (SSC) as a function of total suspended solids (TSS). (A = 14,466 paired samples; B = Samples < 500 mg/L; C= Samples < 5000 mg/L)



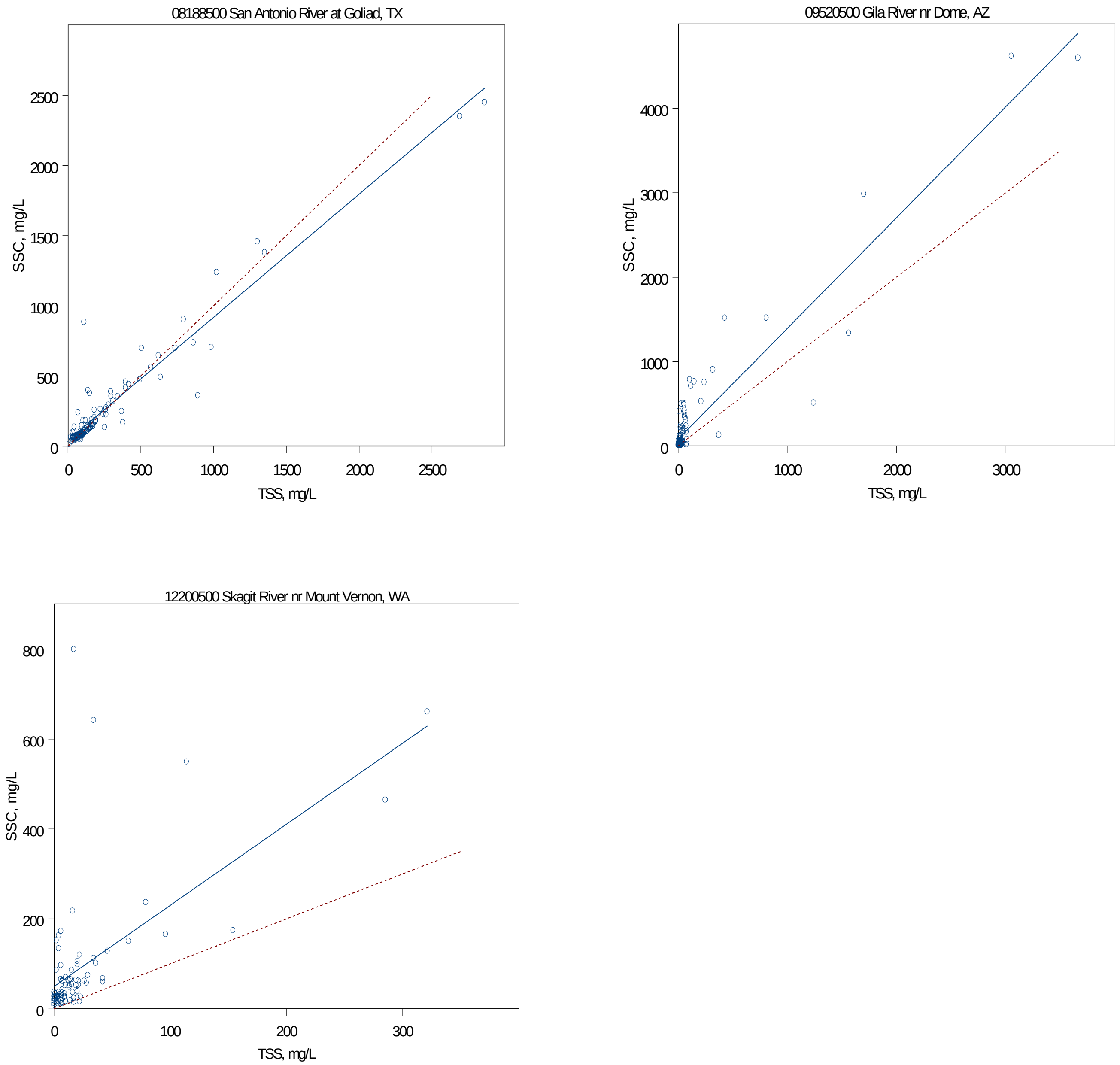
Explanation ______ Linear regression line based on all samples --------- Line of equal value

Figure 2. Suspended-sediment concentration (SSC) as a function of total suspended solids (TSS) for the seven test stations.



Explanation ______ Linear regression line --------- Line of equal value

Figure 2. Suspended-sediment concentration (SSC) as a function of total suspended solids (TSS) for the seven test stations (cont.).



Explanation ______ Linear regression line --------- Line of equal value