Investigation of Suspended-Sediment Concentration in the Mississippi River using LISST and Remote Sensing Surrogate Methods

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Abstract

Suspended sediment affects the geomorphological characteristics that maintain ecological health and river navigability. Methods for estimating suspended-sediment concentration (SSC) in fluvial systems have evolved over several decades from in-situ direct measurements to surrogate techniques including acoustic, laser diffraction, and remote sensing methods. Several versions of the Laser In Situ Scattering and Transmissometry (LISST) instrument have been used to measure volume SSC and particle size distribution (PSD) in fluvial environments. Within the past few years, remote sensing has been used as a tool to measure SSC in large rivers such as the Mississippi River and the Amazon River. Remote sensing techniques for estimating SSC use surface reflectance measured from the water surface. The objectives of this study were to compare the LISST and remote sensing surrogate methods of measuring SSC and to investigate distributions of suspended sediment in the Mississippi River to provide insight into remote sensing methods of monitoring. A LISST-200X was used to collect SSC and PSD data at two cross-sections along the Mississippi River. Vertical distributions of SSC were collected using the LISST-200X at multiple points along the cross section. The LISST-200X volume SSC and PSD were converted to mass SSC and PSD by comparing the LISST-200X data to physical water samples concurrently collected by a US D-96 and US P-6 suspended-sediment sampler. Suspended-sediment concentration was estimated using from remote sensing by using Landsat satellite surface reflectance-SSC models created for the Middle Mississippi River. The LISST-200X SSC data were compared to the Landsat satellite surface reflectance-SSC. Further, vertical SSC distribution profiles from the LISST-200X were compared to theoretical distribution profiles from the Rouse equation, which shows increasing SSC from the water surface to the channel bottom.

Introduction

Background

Suspended sediment plays a significant role in river systems. Sediment is constantly being transported and deposited, affecting the geomorphological and chemical characteristics that control river navigability and ecological health. Sediment monitoring has become increasingly important because of the necessity to measure suspended-sediment concentration (SSC) and understand sediment movement and transport. The United States Geological Survey (USGS) has several gaging stations located along the Mississippi River and its tributaries that take discrete, daily samplesof SSC. The number of gaging stations collecting daily measurements has decreased in recent years. Collecting direct daily measurements is labor intensive requiring the use of Federal Interagency Sedimentation Project (FISP) sediment samplers. These samplers collect a water sample which must be processed in a lab to quantify SSC. Surrogate methods of estimating SSC such as laser diffraction instruments require field data collection, but after initial calibration the processing time is minimal compared to processing of physical water samples. SSC estimated using remote sensing can also be a cost-effective way of measuring SSC if freely-available Landsat data are used. However, Landsat satellite surface reflectance data can be greatly affected by cloud coverage.

LISST-200X: Laser-diffraction based particle size analyzers are currently being used to measure particle sizes and concentrations in fluvial, and marine and coastal environments. Sequoia Scientific, Inc. introduced the world's first submersible commercial instruments for particle sizing based on laser diffraction. Sequoia Scientific's Laser In-Situ Scattering and Transmissometry (LISST) instrument systems are self-contained, compact, and programmable. Several versions of the LISST instrument have been used to measure SSC and particle size distribution (PSD) in fluvial environments (Topping et al., 2006; Agrawal et al., 2012; Baranya et al., 2012; Huan et al., 2015; Czuba et al., 2015; Agrawal et al., 2015). The LISST-200X measures particle size distribution (PSD) and concentration, as well as small-angle optical volume scattering function (VSF). The LISST-200X measures particle size from 1.0 to 500 micrometers and volume concentration at a 0.1 µL/L resolution.

Remote Sensing: The remote sensing method of estimating SSC uses measurements of reflectance from the water surface. Landsat satellites collect data with moderate temporal and spatial resolution and provide that data to the public to facilitate monitoring and research on the world's natural resources. The Landsat program is a joint effort between the USGS and the National Aeronautics and Space Administration (NASA). Landsat satellite data can be accessed for free through Landsat Data Access Portals. Pereira et al. (2017) created reflectance-SSC models for the Middle-Mississippi River (MMR) using surface reflectance measured by freely-available Landsat satellites. A revised version of Pereira et al. (2017) models were created using a power-regression model (Table 1). Remote Sensing detects SSC at the water surface and may not effectively represent the concentration throughout the entire water column.

Table 1. Reflectance-SSC empirical relationship created for the Middle-Mississippi River

Landsat Sensor	Reflectance-SSC Empirical Relationship	R^2
8 OLI/TIRS	$\mathrm{SSC}(\mathrm{mgL}^{-1}) = 159.9 * \left(\frac{b2}{b5}\right)^{-0.1337} * \left(\frac{b3}{b5}\right)^{-5.182} * \left(\frac{b4}{b5}\right)^{3.663} + 87.67$	0.87
7 ETM+	$\mathrm{SSC}(\mathrm{mgL}^{-1}) = 111.3 * \left(\frac{b1}{b4}\right)^{-0.2684} * \left(\frac{b2}{b4}\right)^{-6.033} * \left(\frac{b3}{b4}\right)^{5.031} + 63.84$	0.73
4-5 TM	$\mathrm{SSC}(\mathrm{mgL}^{-1}) = 74.80 * \left(\frac{b1}{b4}\right)^{-1.387} * \left(\frac{b2}{b4}\right)^{-4.639} * \left(\frac{b3}{b4}\right)^{4.227} + 80.68$	0.72

Note: b2, b3, b4 and b5 are Blue, Green, Red, and Near-Infrared band reflectance respectively for Landsat 8; b1, b2, b3, and b4 are Blue, Green, Red and Near-Infrared band reflectance respectively for Landsat 4-5 and Landsat 7 Satellites.

Suspended-Sediment Profiles: Rouse (1937) studied the vertical distribution of SSC in fluvial systems and found that for a given state of flow, the relative vertical distribution of the different particle sizes is based upon their settling velocities (Figure 1). The Rouse (1937) formula for vertical distribution of SSC is defined as the following:

$$\frac{C}{C_a} = \left(\frac{h-z}{z}\frac{a}{h-a}\right)^{P=\frac{\omega}{\kappa u_*}} \quad (1)$$

where C is suspended-sediment concentration at z (mgL^{-1}); z is elevation above the bed (m); C_a represents the reference suspended-sediment concentration at a (mgL^{-1}); a is reference elevation above the bed elevation (m); h is flow depth (m); ω is the settling velocity (ms^{-1}); κ is Von Karman's constant; u_* is shear velocity (ms^{-1}); and P is the Rouse Number. The sediment distribution curves developed from the Rouse equation show increasing SSC from the water surface to the channel bottom (Figure 1).

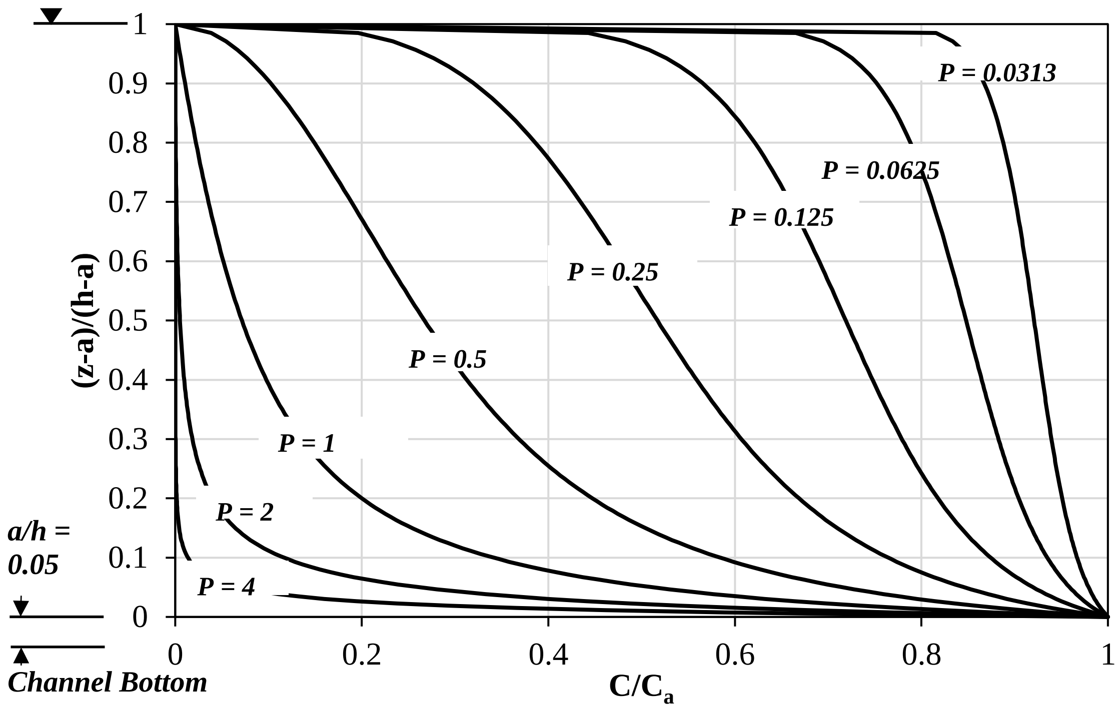

Figure 1. Rouse profile for various Rouse numbers

Methods

Data Collection

Two data collection sites along the Middle Mississippi River (MMR) were used for this study. These collection sites were located at USGS gaging stations at Chester, IL (07010000) and St. Louis, MO (07020500). Field data collection dates coincided with Landsat 8 satellite collection dates, so that LISST-200X SSC data and SSC determined from the physical water samples could be compared to SSC estimated from the reflectance-SSC models. Field data collection dates were also selected to occur during the summer months for there to be a lesser likelihood of cloud coverage since Landsat surface reflectance data are affected by clouds. The two field collection dates were on June 14th, 2018 and August 1st, 2018 for the Chester site and St. Louis site, respectively.

Data were collected at the two Mississippi River cross-sections (Chester and St. Louis gages sites) using the LISST-200X. Physical water samples were taken concurrently with the LISST -

200X using a US D-96 depth integrating suspended-sediment sampler and a US P-6 point integrating suspended-sediment sampler. LISST-200X and US D-96 depth-integrated samples were taken vertically along the Chester, IL cross-section and the St. Louis, MO cross-section. Five depth-integrated samples were collected using a US D-96 sampler at the 10%-, 30%-, 50%-, 70%- and 90%-discharge width points at Chester. The 10%-discharge width point was located at the Illinois side of the Mississippi River and the 90%-discharge width point was on the Missouri side. Ten depth-integrated samples were taken at 5%-, 15%-, 25%-, 35%-, 45%-, 55%-, 65%-, 75%-, 85%-, and 95%-discharge width points at St. Louis. The 5%-discharge width location was on the Illinois side of the Mississippi River and the 95%-discharge width location was on the Missouri side. For the LISST-200X depth-integrated data collection, the instrument was slowly lowered to the approximately 0.5 m above the channel bed and then brought back to the top of the water. The LISST-200X collects measurements at a rate of one Hz.

Point samples were taken using the US P-6 sampler at both Chester and St. Louis. Seven point samples were taken at the Chester 50%-discharge width point at five-foot depth increments from five to thirty feet (5, 10, 15, 20, 25, 30, and 35 ft). Twelve points samples were taken at the St. Louis 25%- and 75%-discharge width locations; six samples at 25%-discharge width and six samples at 75%- discharge width. The St. Louis point samples were taken at five-foot depth increments from five feet to thirty feet (5, 10, 15, 20, 25, and 30 ft) and five feet to thirty-five feet, excluding the twenty-foot point, (5, 10, 15, 25, 30 and 35 ft) at the 25%- and 75%-discharge width points respectively. The LISST-200X 'point' samples were taken by lowering and stopping the LISST-200X at five-foot increments. The LISST-200X was kept stationary at five-foot increments for one-minute periods. Since the sampling rate for the LISST-200X collection was set at 1 Hz, at least 60 measurements were made during each one-minute period. The average of the measurements was used to represent the LISST-200X 'point' samples.

Data Processing

LISST-200X: LISST-200X volume SSC was converted to mass SSC by correlating the LISST-200X data to data collected by the US P-6 and US D-96 suspended-sediment samplers for each station. Regression analysis was performed for the whole data set and for the two separate stations. The best fit regression equation was a power function. The coefficient of determination for the whole dataset, combing Chester and St. Louis data, was 0.524. When regression analysis was separated into individual stations, coefficients of determination increased from 0.5211 to 0.671 and 0.572 for Chester and St. Louis, respectively (Figure 2 and Figure 3). The LISST-200X data were converted using the individual station regression power equations.

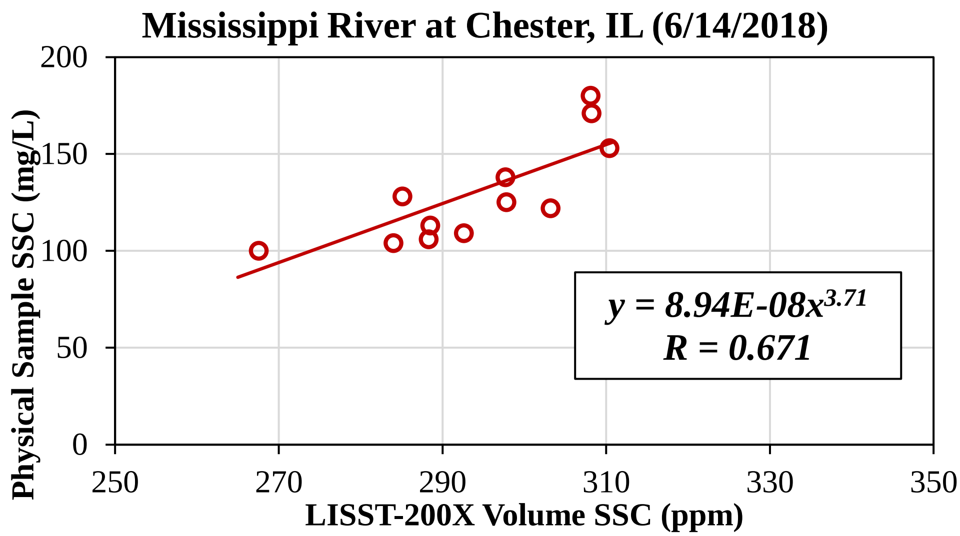

Figure 2: Physical Sample Mass SSC – LISST-200X Volume SSC Regression for Chester, IL Dataset

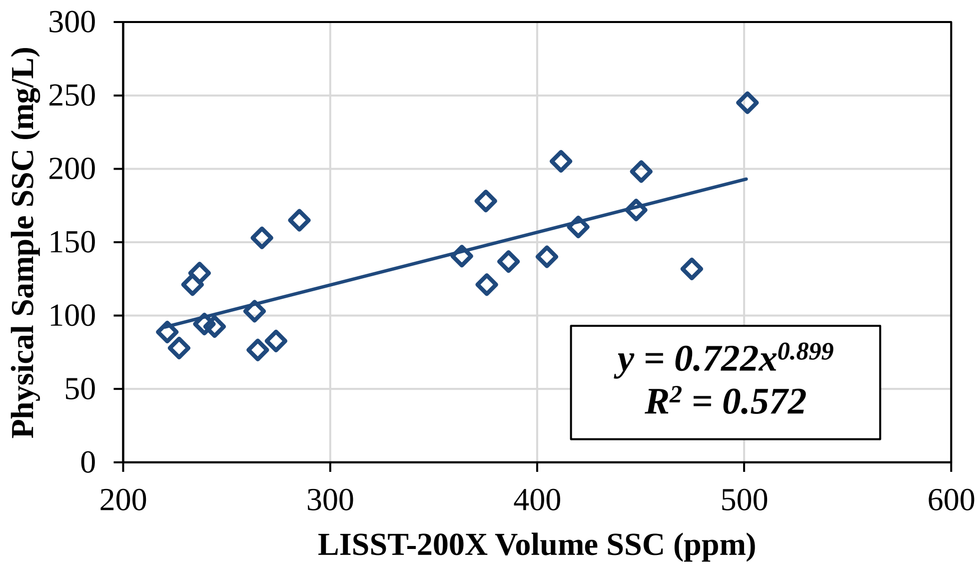

Figure 3: Physical Sample Mass SSC – LISST-200X Volume SSC Regression for St. Louis, MO Dataset

Remote Sensing: The surface reflectance-SSC model (Table 1) for Landsat 8 was used to determine SSC at Chester and St. Louis stations. Cirrus clouds were over the exact data collection location at the Chester site (Figure 4). Surface Reflectance-SSC for the Chester site was therefore taken upstream from the physical data collection points. St. Louis surface reflectance-SSC was calculated for each point that physical samples were taken (Figure 5).

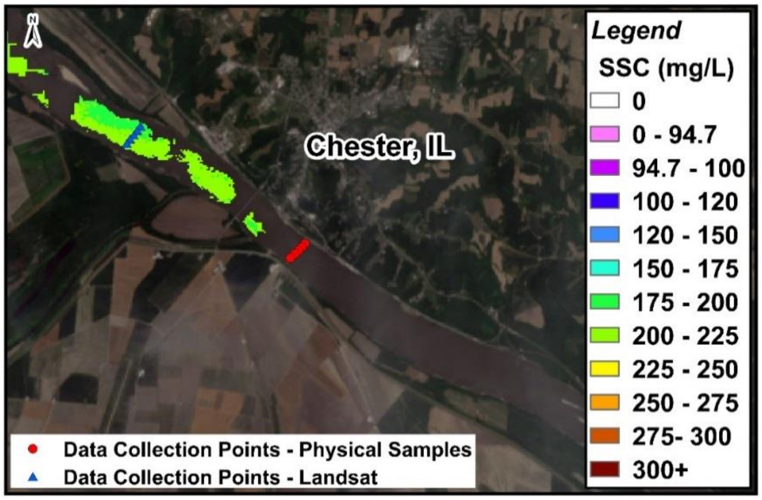

Figure 4. Surface Reflectance-SSC at Chester, IL

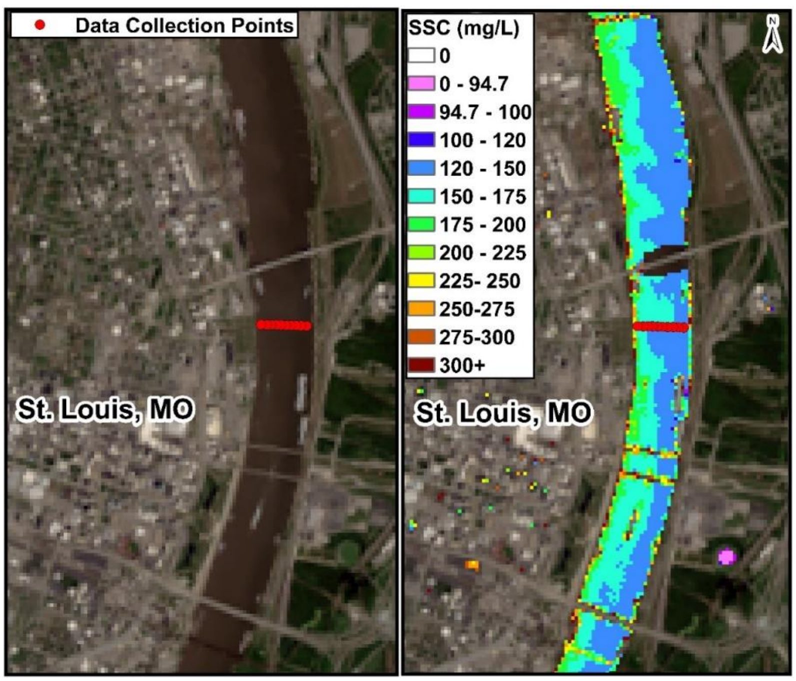

Figure 5. Surface Reflectance-SSC at St. Louis, Missouri

Results

Comparing Surrogate Methods

Depth-integrated SSC from the US D-96 sediment sampler was compared to two surrogate methods of determining SSC: the laser diffraction method using the LISST-200X instrument and surface reflectance-SSC method using Landsat 8 satellite. Ascending and descending depth-integrated SSC was calculated from LISST-200X vertical SSC profiles SSC and the average of the two depth-integrated values were used as the final depth-integrated LISST-200X SSC values.

At the Chester Landsat data collection cross-section, the SSC on the Missouri side was 204 mgL^{-1} and the Illinois side was 200 mgL^{-1}. The Missouri and Illinois sides of the river cross-section were only different by 2%. The Landsat surface-reflectance method overestimated SSC by 1.3 – 1.8 times when compared to the physical sample direct measurements at each point at Chester (Figure 6). Figure 6 shows that SSC was higher on the Missouri side of the Mississippi River for both surrogate methods but the calibrated LISST-200X predicted SSC closer to the physical samples.

The August 1st Landsat 8 SSC image at the St. Louis, MO station showed a higher SSC on the Missouri side of the Mississippi River (Figure 5). The Landsat surface reflectance-SSC at the point closest to the Missouri side was 182 mgL^{-1} and 134 mgL^{-1} at the point nearest to the Illinois side. The physical samples and the LISST-200X samples consistently showed that the Illinois side had the lower concentrations of SSC than the Missouri side of the Mississippi River (Figure 7). Sixty percent of the time, the LISST-200X predicted SSC better than Landsat surface reflectance-SSC. On the Missouri side, the LISST-200X predicted SSC the best, while one the Illinois side, Landsat surface-reflectance predicted SSC the best. Both surrogate methods were able to predict higher SSC on the Missouri side of the Mississippi River as expected. The Missouri River drains 43% of the total area of the Mississippi River basin. The Missouri river only contributes 12% of the total flow but is by far the major contributor of sediment to the Mississippi River (Meade and Moody, 2010).

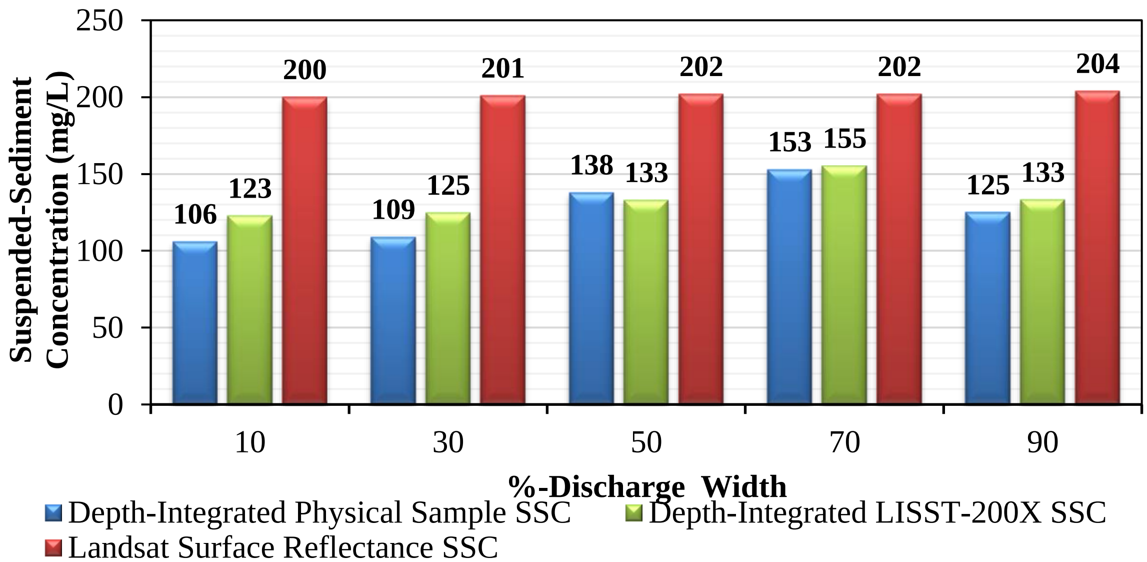

Figure 6: Comparison of SSC determined from Physical samples to surrogate methods of determining SSC (LISST-200X and Landsat Satellite) at Chester, IL on June 14, 2018

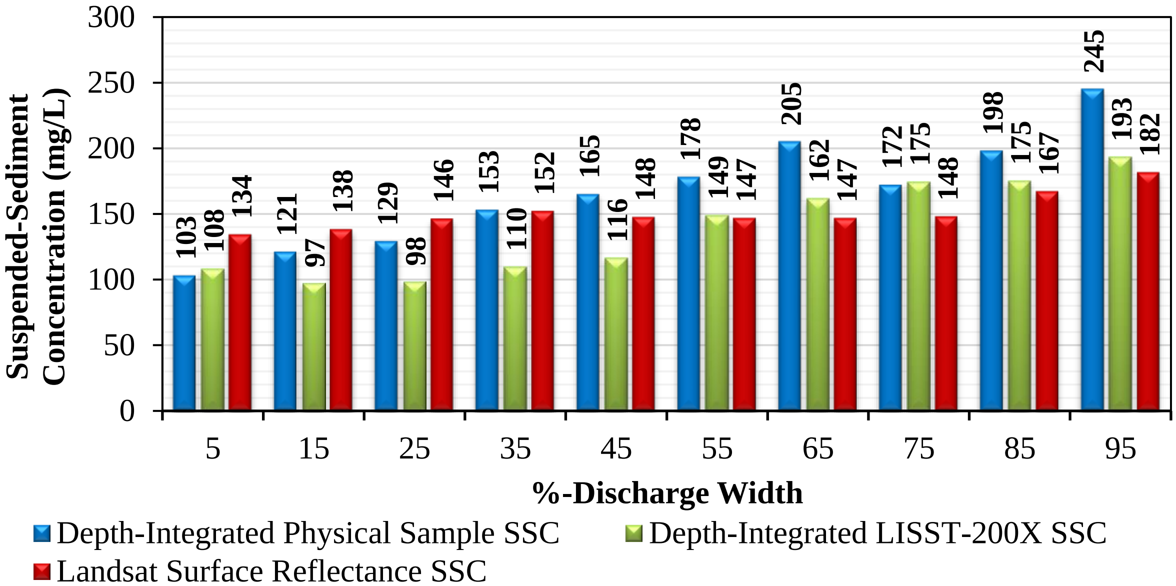

Figure 7: Comparison of SSC determined from Physical samples to surrogate methods of determining SSC (LISST-200X and Landsat Satellite) at St. Louis, MO., on August 1, 2018

SSC Vertical Profiles

Vertical SSC profiles were created using LISST-200X converted SSC data. Suspended-sediment concentration profiles were created using descending and ascending LISST-200X data. Vertical SSC profiles were also created from data when the LISST-200X was descending at five-foot increments for one minute (Figure 8 and Figure 9). The SSC data collected within the one-minute periods had a standard deviation ranging between 15.1 to 60 mg/L for Chester, IL. The averages of the SSC collected are plotted in Figure 8 for each of the one-minute periods which shows an increase of SSC with depth below water surface. Data from the vertical SSC profile created from St. Louis, MO in Figure 9 shows similar high variability within one-minute period measurements with a standard deviation ranging from 3.0 to 12.1 mg/L. The average SSC from the one-minute periods shows increases in SSC with depth for both the 25%-discharge width and 75%-discharge width locations.

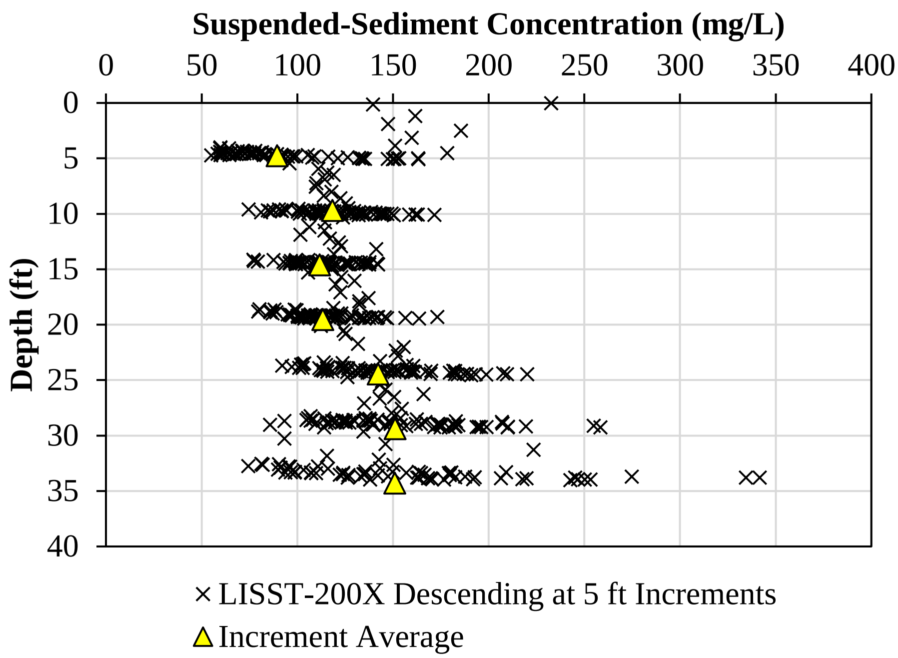

Figure 8: Vertical SSC profile from LISST-200X one-minute period measurements at five-foot increments at Chester, IL

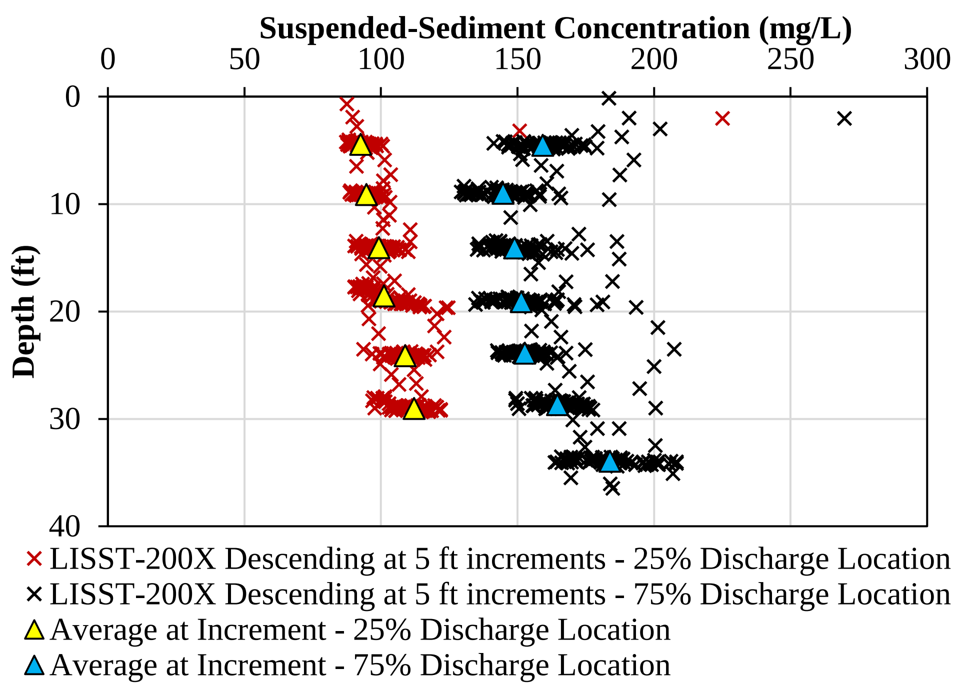

Figure 9: Vertical SSC profile from LISST-200X one-minute period measurements at five-foot increments at St. Louis, MO

The descending-ascending LISST-200X SSC profiles for 90%- and 10%-discharge width locations at Chester (Figure 10) and for 95%- and 5%- discharge width locations at St. Louis (Figure 11) show increasing SSC with depth to some degree. Although some areas of profile the

SSC would vary irregularly, each descending-ascending LISST-200X SSC profile shows a general increase in SSC with depth. The 5%-discharge width channel width location at St. Louis shows the least variability of SSC with depth. Similar trends were also observed in the 45%-, 35%-, 25%-, and 15%-discharge width locations. The profiles on the Missouri side of the Mississippi river (55%-, 65%-, 75%-, 85%-, and 95%-discharge width locations) had areas of fluctuation in their profiles. The shape of the St. Louis profiles could be due to the influx of SSC and discharge from the Missouri River. The delayed mixing of the Missouri River SSC with pre-confluence Mississippi River SSC could be the reason behind the lower SSC on the Illinois side. Therefore, the influx may not be affecting the Illinois side of the river at that location, leading to less variability in the profile and lower SSC on that side of the River.

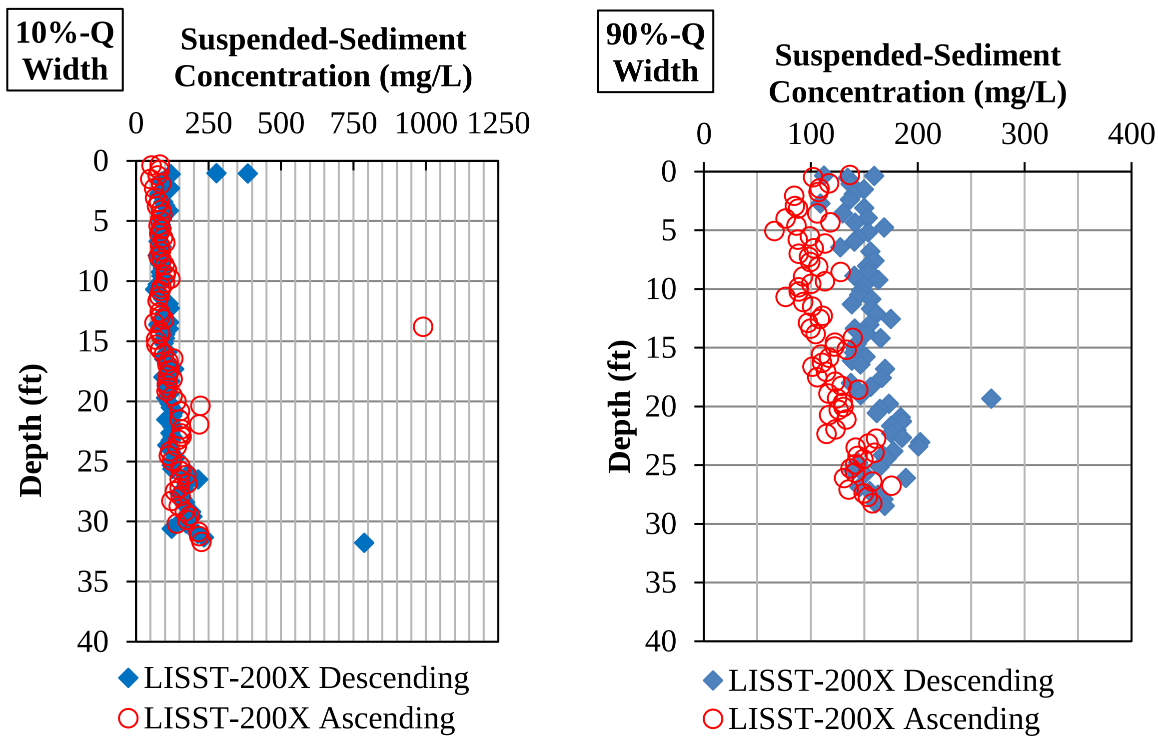

Figure 10: Chester, IL LISST-200X Vertical Profiles

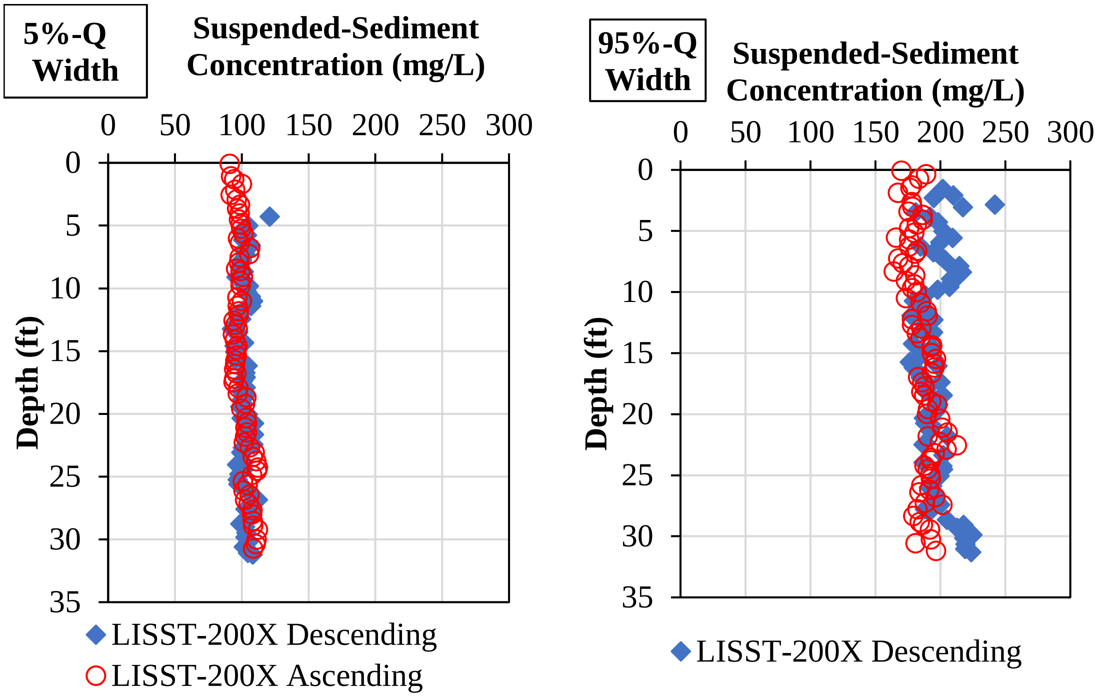

Figure 11: St. Louis, MO LISST-200X SSC Vertical Profiles

The descending-ascending LISST-200X SSC profiles plotted in Figure 11 show that at equivalent depths, SSC was not always identical. The profiles mostly indicate higher concentrations at equivalent depths when the LISST-200X was descending. The averages of the SSC collected in each one-minute increment fit in between the ascending and descending SSC profiles although the SSC collected within one-minute period was highly variable (Figure 8).

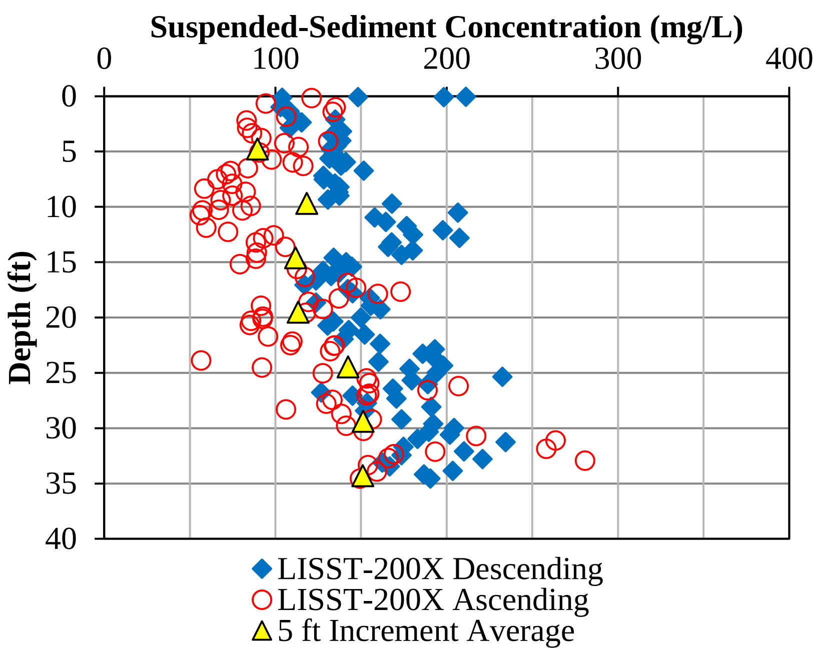

Figure 11: LISST-200X Vertical SSC profile at the 50%-Discharge width location at Chester, IL

The vertical SSC profiles from physical point samples and the LISST-200X averaged SSC from one-minute collection periods are shown in Figure 12. Both profiles exhibit an increase in SSC with depth. Although the physical sample SSC profile was not uniformly increasing at each depth increment, the profile increased from 100 mgL^{-1} at 5 ft to 180 mgL^{-1} at 35 ft. LISST-200X SSC increased from 89.5 mgL^{-1} at 5 ft to 151.1 mgL^{-1} at 35 ft.

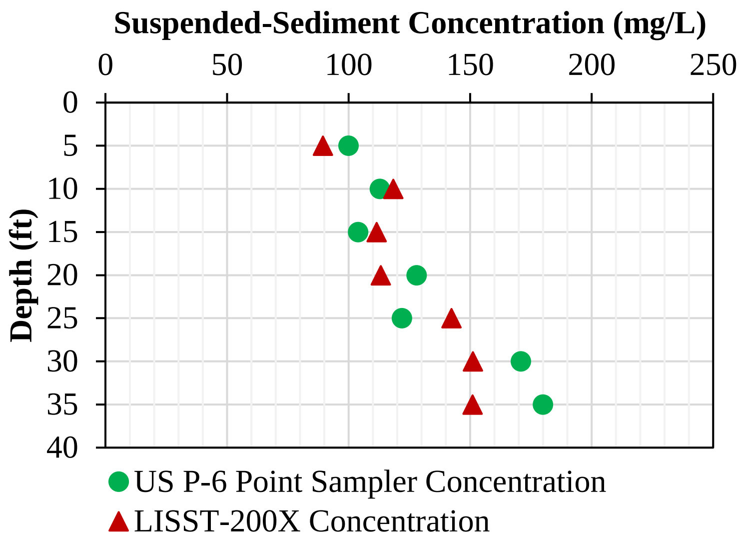

Figure 12: Vertical SSC profile at Chester, IL

Vertical SSC profiles for St. Louis are shown in Figure 13. The SSC profile at the 75%-discharge width location were on average 1.7 times higher than the SSC at the 25%-discharge width location. The profiles reflect the predicted higher SSC coming from the Missouri River. Vertical SSC profiles from the LISST-200X show a clear increasing trend in SSC with depth. The physical sample SSC vertical profiles both fluctuated irregularly and did not uniformly increase with depth. The profile at the 25%-discharge width location decreased, increased, and decreased again so that the SSC at the deepest point was lower than the SSC at the 5 ft point. The 75%-discharge width location had the same decrease, increase, and decrease pattern of SSC at the deepest point lower than at the 5 ft point.

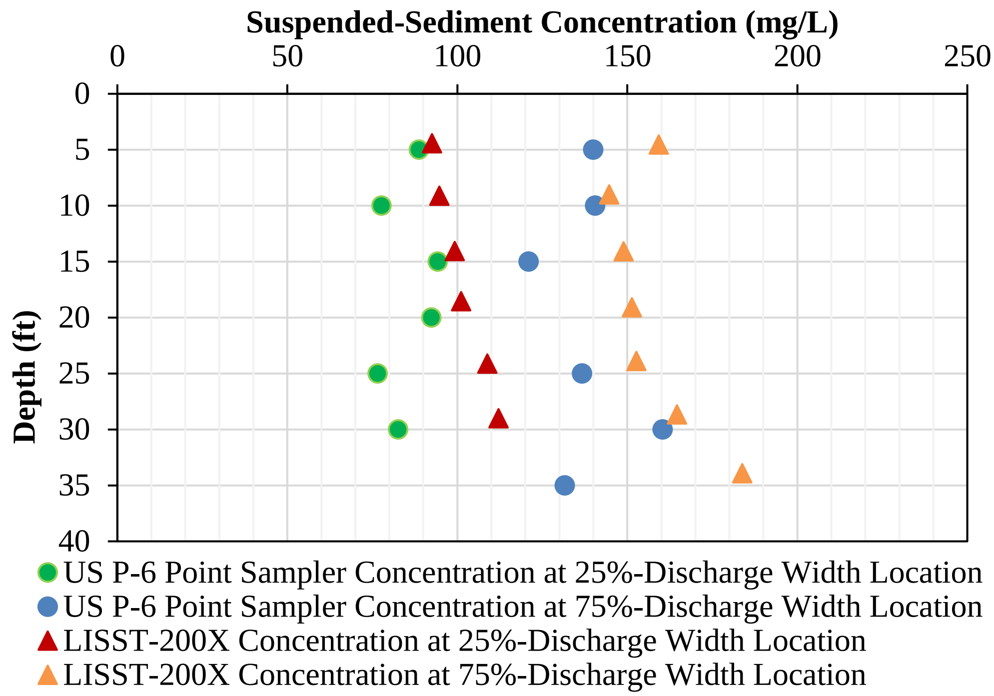

Figure 13: Vertical SSC profile for St. Louis, MO data from US P-6 Sediment Sampler and LISST-200X

Rouse Profile

A Rouse profile was created using equation (1) with data for the Chester, IL collection site. The Rouse number was calculated using Stokes settling velocity in clear water, ω_o, equation (2) and equation for shear velocity, u_*, equation (3) as follows:

$$\omega_0 = \frac{1}{18}\frac{(G-1)g}{\upsilon}{d_s}^2 \tag{2}$$

$$u_* = \sqrt{\frac{\gamma h S_0}{\rho}} \tag{3}$$

where, G is relative density, g is acceleration due to gravity (ms^{-2}); υ is kinematic viscosity of water (m^2s^{-1}); d_s is particle diameter (m); γ is specific weight of water (kgm^{-3}); h is flow depth (m); S_o is bed slope; and ρ is density of water (Nm^{-3}). The flow was assumed to be steady, and uniform, therefore the bedslope, S_o, was assumed to be equal to the water surface slope, S_w, which was calculated as 0.0001 from gaging data. Shear velocity was found to be 0.110 m/s and 0.102 m/s at Chester and St. Louis, respectively. Settling velocities were calculated using the median particle diameter, d_{50} as the particle diameter, d_s. Median particle diameters were found from the LISST-200X particle size distribution curves. The average median particle diameter for Chester, IL samples was found to be 0.034 mm. For St. Louis, the average median particle diameter was found to be 0.030 mm. The settling velocity was calculated to be 0.125 cms^{-1} for the Chester, IL dataset. Using the calculated settling velocity, the corresponding theoretical calculated Rouse number, P_t, for the Chester site was 0.0285. For St. Louis, the settling velocity was calculated to be 0.0818 cms^{-1}, The corresponding theoretical Rouse number, P_t, for St. Louis was 0.0238. The experimental Rouse number, P_e, was found by correlating LISST-200X relative SSC data, C/C_a, to $\left(\frac{h-z}{z}\frac{a}{h-a}\right)$, *z,'* to find the best fit power regression use the least-squares regression method. Experimental Rouse numbers were found for all fifteen LISST-200X vertical SSC dataset, five from Chester and ten from St. Louis shown in Table 2 and Table 3, respectively. An example of one of the fifteen best fit power curves is shown in Figure 14.

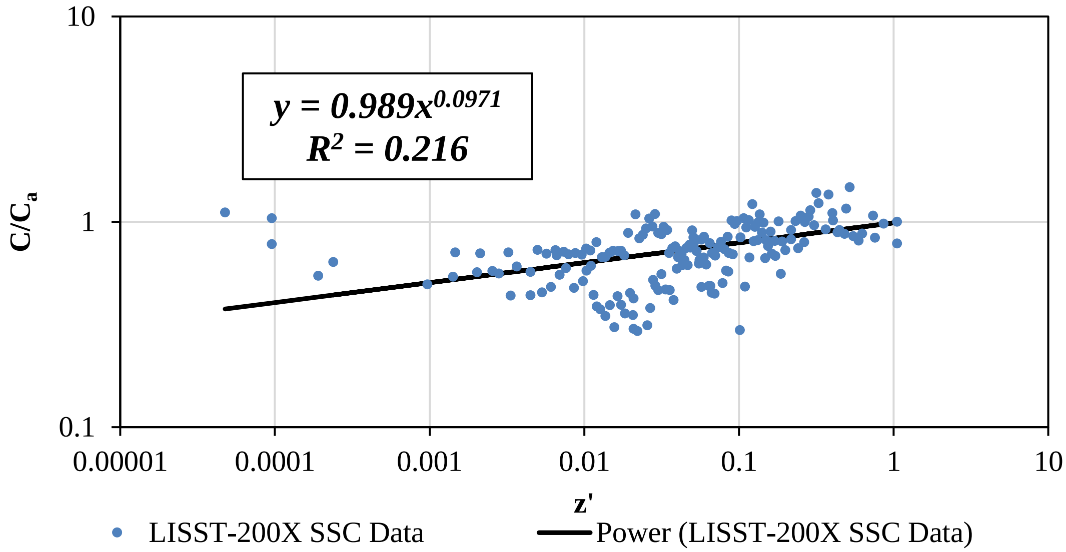

Figure 14: Best fit power regression curve for LISST-200X SSC data from the 50%-Discharge width Location at Chester, IL

An average experimental Rouse number, $P_{e,avg}$, was found for Chester and St. Louis. The experimental Rouse numbers were found to be 0.145 and 0.0253 for Chester and St. Louis respectively separately. The predicted Rouse profiles were plotted using both theoretical, experimental average, and experimental location-specific Rouse numbers (Figure 15, Figure 16, and Figure 17). The Chester predicted Rouse profiles (Figure 15) from the experimental Rouse numbers fit well with the vertical SSC profiles both physical sample and LISST-200X points. However, the St. Louis predicted Rouse profiles were not as successful at fitting the physical and LISST-200X SSC samples. The experimental Rouse profile for St. Louis overestimated SSC in both profiles (Figure 16 and Figure 17). The theoretical Rouse numbers were almost equal for Chester and St. Louis. The predicted Rouse profiles from the theoretical Rouse numbers did not fit the points from physical sample and LISST-200X data as closely as the experimental Rouse numbers.

Table 2. Experimental Rouse numbers, P_e, for Chester, IL.

%-Discharge Width	Rouse Number, P_e
10%	0.214
30%	0.223
50%	0.0971
70%	0.127
90%	0.0629
Average	*0.145*

Table 3. Experimental Rouse Numbers, P_e, for St. Louis, MO.

%-Discharge Width	Rouse Number, P_e
5%	0.0175
15%	0.0174
25%	0.0176
35%	0.0207
45%	0.0240
55%	0.0417
65%	0.0275
75%	0.0345
85%	0.0374
95%	0.0142
Average	*0.0253*

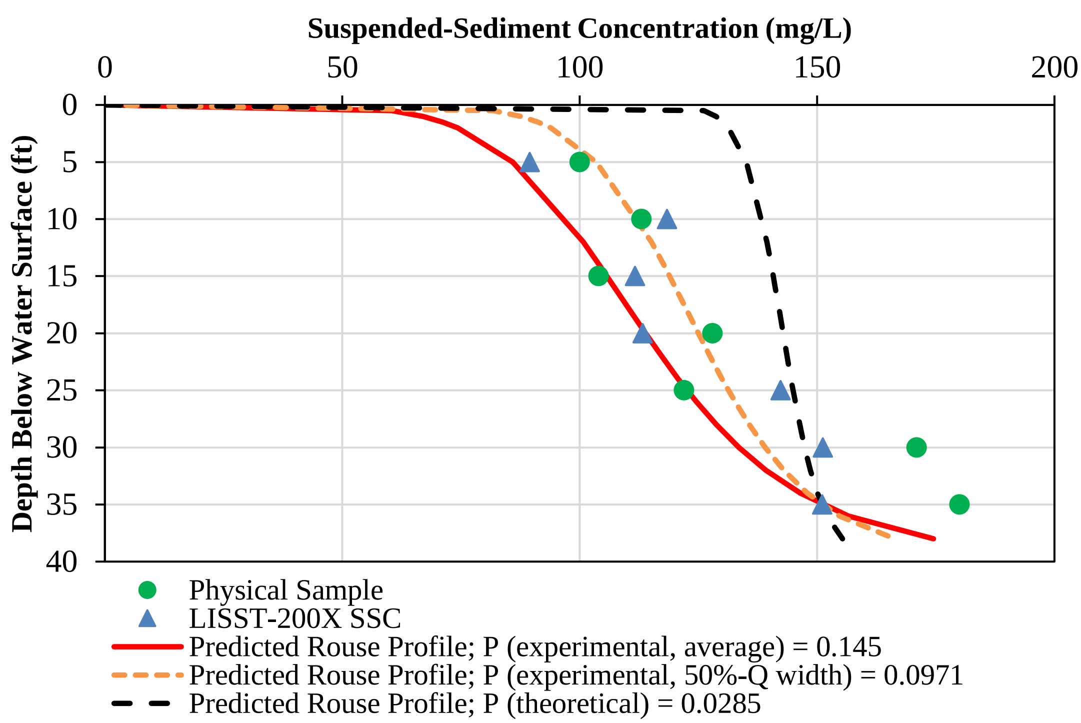

Figure 15: Predicted Rouse Profiles from Experimental and Theoretical Rouse Numbers for 50%-discharge width location at Chester

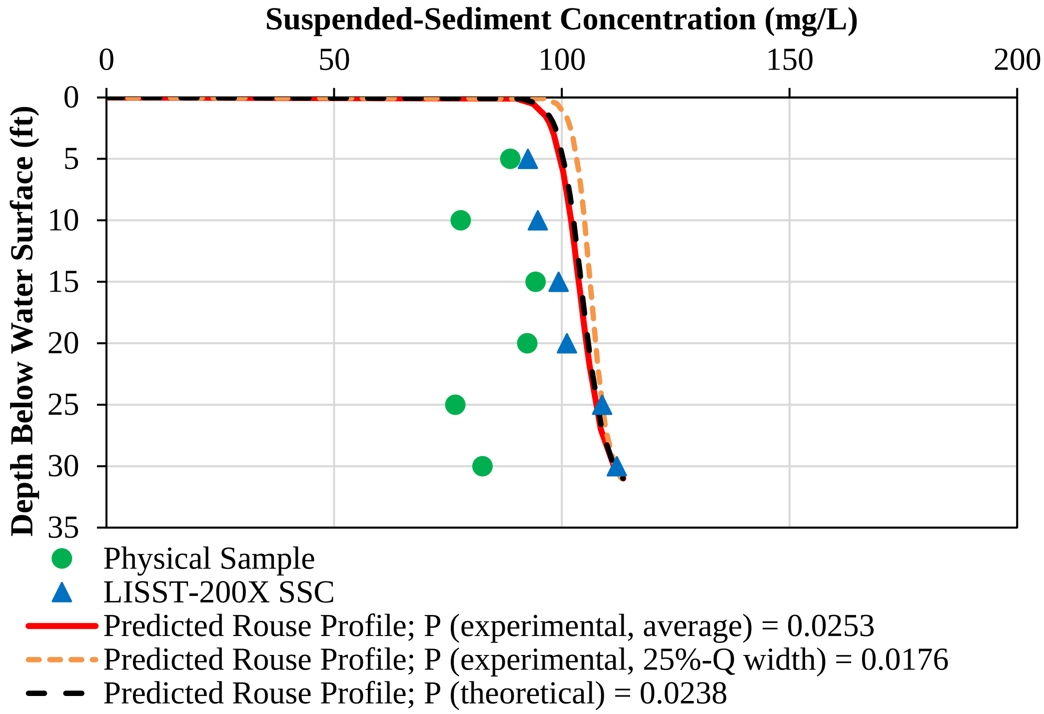

Figure 16: Predicted Rouse Profiles from Experimental and Theoretical Rouse Numbers for the 25%-discharge width location at St. Louis

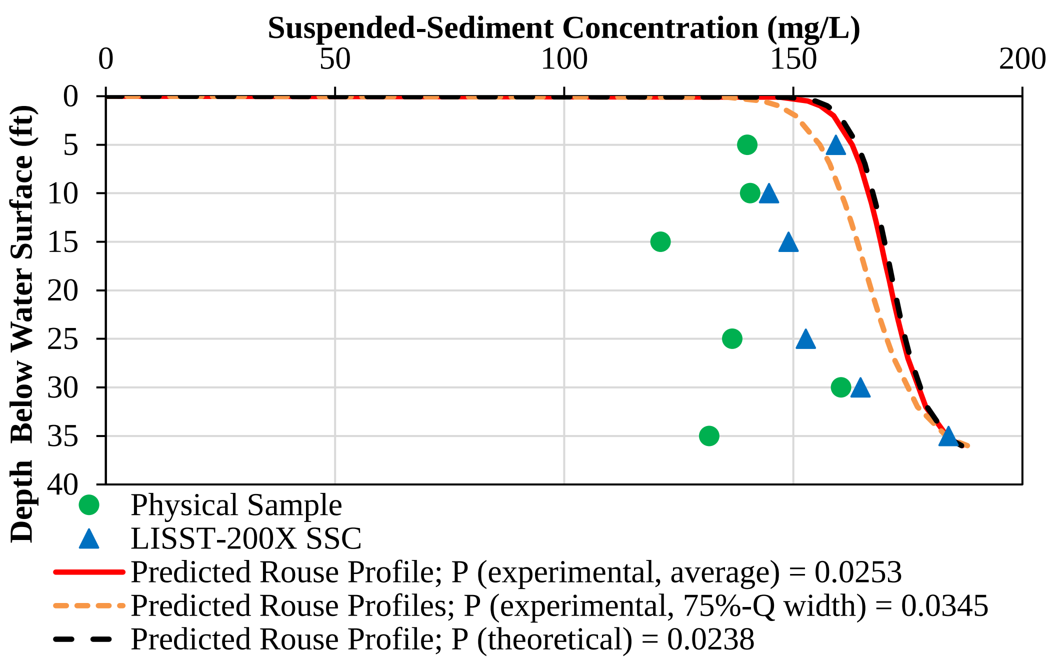

Figure 17: Predicted Rouse Profiles from Experimental and Theoretical Rouse Numbers for the 75%-discharge width location at St. Louis

Conclusions and Future Work

The following main final conclusions were made on this study:

1. laser diffraction was an effective surrogate method for measuring SSC when used in a large river such as the Mississippi River;
2. from the LISST-200X data, temporal variability was observed in SSC at stationary points in a water column (standard deviations ranging from 15.1 to 60.0 and 3.0 to 12.1 for Chester and St. Louis, respectively);
3. the LISST-200X instrument may not have been fully measuring the total SSC due to the instrument's particle measurements range;
4. the remote sensing surrogate method estimated SSC at lower concentrations best (St. Louis dataset), which supports the theory that surface-reflectance-SSC may not be fully capturing SSC in an entire water column;
5. the remote sensing surrogate method using Landsat imagery is not an ideal method for continuous SSC monitoring on the Mississippi River due its limited temporal resolution (16 days between measurements) and dependence on clear weather conditions; however, these limitations could be overcome by utilizing terrestrial-based remote sensing equipment;
6. the LISST-200X SSC (13.1%) had a lower percent error when predicting SSC than the Landsat surface-reflectance SSC (27.3%);
7. when comparing Rouse profiles created from experimentally and theoretically derived Rouse numbers, the theoretical Rouse number (P_t = 0.0285) was smaller than the experimental Rouse Numbers ($P_{e,avg}$ = 0.145 and $P_{e,50\%\text{-}Q\ width}$ = 0.0971) for Chester and the experimental Rouse number profiles matched the SSC profile the best while for St. Louis, theoretical and experimental Rouse numbers differed minimally (P_t =0.0238, $P_{e,avg}$ =0.0253, $P_{25\%\text{-}Q\ width}$ = 0.0176, and $P_{75\%\text{-}Q\ width}$ = 0.0345) but all Rouse number profiles did not match the SSC profile well.

The LISST-200X provides a time-saving surrogate method for collecting SSC with high temporal resolution. The spatial resolution can be determined by the data collector. If several vertical samples are taken to create good spatial resolution, the data could be used to create an entire cross-sectional SSC river profile. These cross-sectional SSC profiles could be helpful in studying sediment transport and aid in creating sediment transport models.

The remote sensing surrogate method provides high spatial-resolution SSC for the Mississippi River. A clear distinction in SSC contribution from the Missouri River was observed with higher SSC values on the Missouri side of the Mississippi river at the St. Louis site. The effect of cloud coverage was shown in the Chester, IL dataset. The loss of data is a disadvantage of the remote sensing surrogate method but it can still provide valuable data for large-scale monitoring of SSC with high spatial resolution.

The Rouse profiles created using the best-fit experimental Rouse number matched the measured vertical SSC profile more closely than the theoretically calculated Rouse numbers. The Rouse profile was created originally for use in streams rather than big rivers such as the Mississippi River. The poor performance of the predicted Rouse profiles could be due to the fact that in larger rivers a wide range of particle sizes are in suspension and determining a representative fall velocity for the range of sizes may not be possible.

Future research may be done to address multiple issues faced when using Landsat satellites. The effect of cloud coverage combined with the temporal resolution of Landsat could cause large gaps in the SSC dataset. To address these problems, a terrestrial multispectral camera could be used to collect images that can then be correlated to SSC, like the Landsat surface reflectance-SSC correlation. Terrestrial multispectral cameras can be either mounted at a USGS gaging station or attached to a drone for data collection. A mounted terrestrial multispectral camera would eliminate the time required for physical data collection because it could be programmed to take periodic images that could remotely accessed. Multispectral cameras as a surrogate method of estimating SSC could also provide a finer spatial resolution than Landsat's 30 m by 30 m resolution.

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