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Documentation of Particle-Size Analyzer Time Series, and Discrete Suspended-Sediment and Bed-Sediment Sample Data Collection, Niobrara River near Spencer, Nebraska, October 2014

Data Series 1079

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

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U.S. Geological Survey
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exercising the authority of the Director

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Conversion Factors

International System of Units to U.S. customary units

Multiply	By	To obtain
	Length	
nanometer (nm)	3.93701×10^{-8}	inch (in.)
micron (µm)	0.0000393701	inch (in.)
millimeter (mm)	0.0393701	inch (in.)
centimeter (cm)	0.393701	inch (in.)
meter (m)	3.281	foot (ft)
kilometer (km)	0.6212	mile (mi)
	Volume	
liter (L)	33.82	ounce, fluid (fl. oz)
liter (L)	0.2642	gallon (gal)
	Concentration by volume	
microliter per liter (µL/L)	1	parts per million
	Concentration by weight	
milligram per liter (mg/L)	1	parts per million
milligram per liter (mg/L)	0.058	grain per gallon (gr/gal)

Temperature in degrees Celsius (°C) may be converted to degrees Fahrenheit (°F) as follows:

$$°F = (1.8 \times °C) + 32.$$

Datum

Horizontal coordinate information is referenced to the North American Datum of 1983 (NAD 83).

Abbreviations

LISST	Laser In-Situ Scattering and Transmissometry
PC_v	volumetric suspended-particle concentration
PSA	particle-size analyzer
PSD	particle-size distribution
RPD	relative percentage difference
USACE	U.S. Army Corps of Engineers
USGS	U.S. Geological Survey

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Abstract

The U.S. Geological Survey (USGS), in cooperation with the U.S. Army Corps of Engineers, monitored a sediment release by Nebraska Public Power District from Spencer Dam located on the Niobrara River near Spencer, Nebraska, during the fall of 2014. The accumulated sediment behind Spencer Dam ordinarily is released semiannually; however, the spring 2014 release was postponed until the fall. Because of the postponement, the scheduled fall sediment release would consist of a larger volume of sediment. The larger than normal sediment release expected in fall 2014 provided an opportunity for the USGS and U.S. Army Corps of Engineers to improve the understanding of sediment transport during reservoir sediment releases. A primary objective was to collect continuous suspended-sediment data during the first days of the sediment release to document rapid changes in sediment concentrations. For this purpose, the USGS installed a laser-diffraction particle-size analyzer at a site near the outflow of the dam to collect continuous suspended-sediment data. The laser-diffraction particle-size analyzer measured volumetric particle concentration and particle-size distribution from October 1 to 2 (pre-sediment release) and October 5 to 9 (during sediment release). Additionally, the USGS manually collected discrete suspended-sediment and bed-sediment samples before, during, and after the sediment release. Samples were collected at two sites upstream from Spencer Dam and at three bridges downstream from Spencer Dam. The resulting datasets and basic metadata associated with the datasets were published as a data release; this report provides additional documentation about the data collection methods and the quality of the data.

Introduction

Spencer Dam, located on the Niobrara River near Spencer, Nebraska, and operated by Nebraska Public Power District (fig. 1), typically undergoes a semiannual (spring and fall) release of accumulated sediment. In spring 2014, the Nebraska Public Power District postponed the spring release until fall. The scheduled fall sediment release would consist of a larger volume of sediment because of the additional time available for sediment to accumulate. With larger than normal sediment amounts expected, the U.S. Geological Survey (USGS) recognized an opportunity to improve the understanding of sediment transport during reservoir sediment releases. Moreover, the U.S. Army Corps of Engineers (USACE) saw this as an opportunity for validating a sediment-transport model of sediment releases for use as a sediment-management tool for operating multipurpose reservoirs (hydroelectric power and water storage) on rivers throughout the Nation (Paul Boyd, written commun., 2014). The USGS, in cooperation with USACE, collected suspended-sediment samples and bed-sediment samples and measured associated streamflows for determining suspended-sediment loads in the Niobrara River during the fall 2014 sediment release from Spencer Dam. Some additional samples (suspended and bed sediment) were collected immediately before and after the sediment release to provide sediment data during pre- and post-sediment-release conditions. The USGS also identified an opportunity for testing sediment-surrogate technologies, in this case a laser-diffraction particle-size analyzer (PSA), for use in short-duration deployments when rapidly changing channel-bed elevations and suspended-sediment concentrations are expected and detailed information about sediment particle-size distribution (PSD) is needed.

The sediment release began at approximately 08:00 on October 6, 2014, and concluded the evening of November 12. Continuous suspended-sediment data were needed during the first days of the sediment release to document rapid changes in sediment concentrations observed in previous sediment releases (Paul Spencer, Nebraska Public Power District, oral commun., 2014). The USGS deployed a laser-diffraction PSA system, the Laser In-Situ Scattering and Transmissometry StreamSide™ (Sequoia Scientific, 2011a), to provide near-continuous measured volumetric suspended-particle concentration (PC_v) at one site approximately 0.4 kilometer (km) downstream from Spencer Dam (fig. 2). The laser-diffraction PSA measured PC_v and PSD from October 1 to 2 (pre-sediment release) and October 5 to 9 (during sediment release).

The datasets produced as a result of this study were made available through a USGS data release (Schaepe and Zelt, 2018). The purpose of this report is to provide additional documentation about the collection methods and the quality of the data.

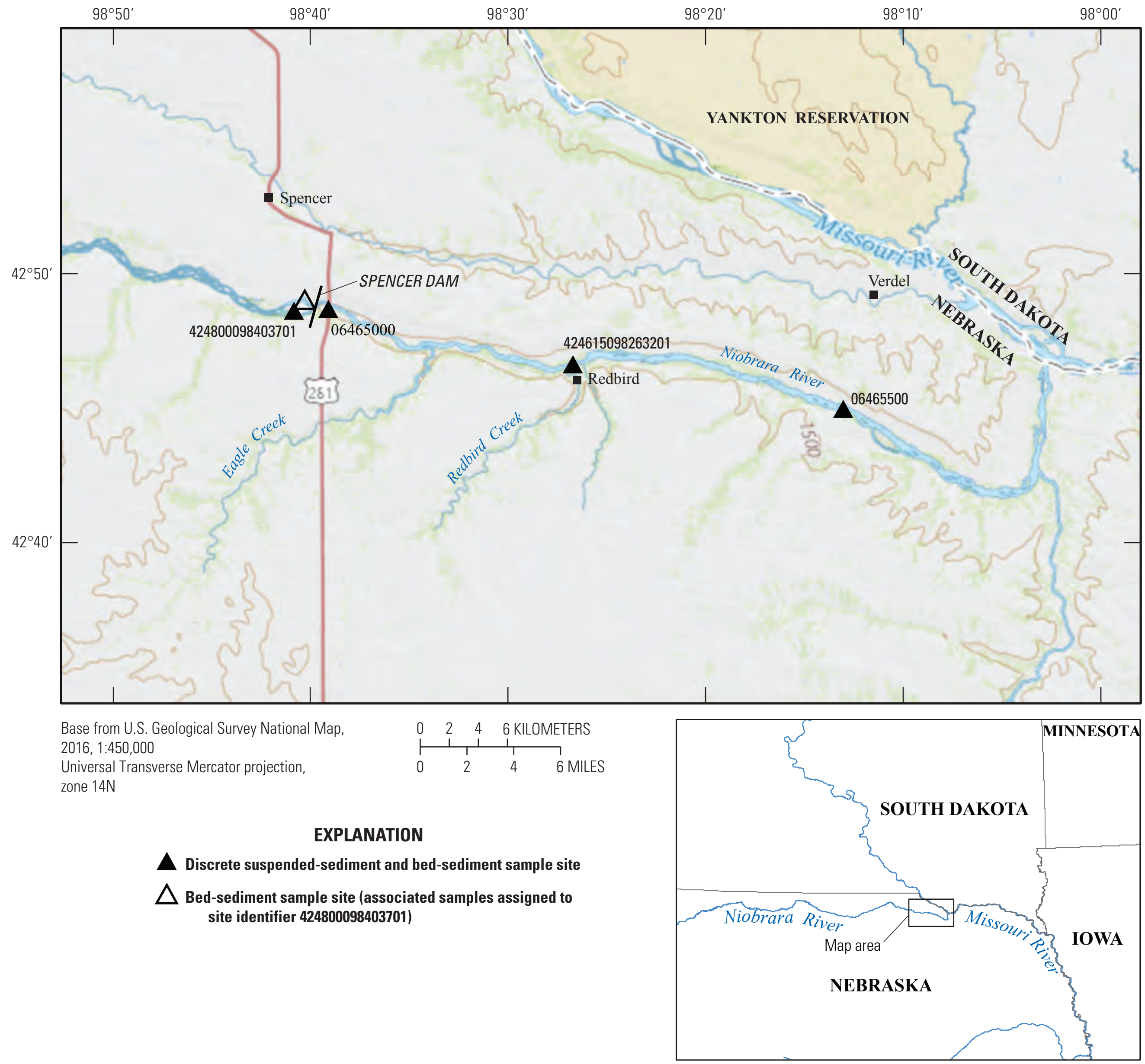

Figure 1. Study area and sampling locations along Niobrara River, Nebraska.

Figure 2. Location of sediment particle-size analyzer at Niobrara River downstream from Spencer Dam, Nebraska, October 2014.

Methodology

The methods used for this short-term study may be grouped into (1) nonstandard methods used to collect a planned near-continuous time series of suspended-particle concentration and particle-size data; and (2) standard methods used for sampling a river and determining suspended-sediment concentration. After first describing the monitored sites, subsections follow that reference or describe the nonstandard and standard methods of study, respectively.

Site Selection and Equipment

The PSA was installed in the Niobrara River at a site approximately 0.4 km downstream from Spencer Dam, about 115 meters (m) upstream from the U.S. Highway 281 bridge, near the south bank in an area of slow velocity (fig. 2). This site was selected because it was near the U.S. Highway 281 bridge where streamflow was being measured and discrete suspended-sediment concentration samples were being collected, while avoiding general channel conditions of extreme turbulence and higher velocity of flows that characterized the constricted reach near the bridge. Although the change in hydraulic conditions introduces some uncertainty in the comparability between the PSA and the suspended-sediment data collected at the bridge, the site location was chosen out of practicality for preserving the PSA equipment.

The PSA system uses a programmable pumping sampler to collect water samples for particle-size analysis. The pump was mounted in the near-bank current at a mid-depth location above the bedrock streambed. The pump was extended about 1.2 m from the stream bank, oriented transverse to flow, and angled downward at approximately the same slope as the lower bank. The pump was mounted on a sliding carriage to allow adjustments to the pump elevation. The carriage traveled along 2.5 m of metal rails, which were affixed to metal T-posts driven into the riverbank (2 posts) and streambed (2 posts).

The shelter housing the PSA, power supply, pump controller, and clear-water tank was located on the top of the high terrace bank, about 7.6 m above the river. The PSA system consists of a PSA unit, a 12-volt battery, clear water (deionized water) in a 132.5-liter (L) tank, a pump controller unit, and various power and water-tubing connections that bring the pump outflow to the PSA inflow port (fig. 3). In addition, a continuous turbidity sensor was deployed in the near-bank current, adjacent to the pump intake to aid the PSA data review.

Suspended-sediment concentrations were determined in Niobrara River water samples collected at one cross section upstream from the dam (fig. 1, station 424800098403701) and at three cross sections located at bridges downstream from the dam—U.S. Highway 281 (fig. 1; station 06465000), and county bridges near Redbird (fig. 1, station 424615098263201) and Verdel (fig. 1, station 06465500). Station 06465500 is an active USGS streamflow-gaging station and station 06465000 is a historic USGS streamflow-gaging station that was operated as recently as 2002. The site at U.S. Highway 281 (fig. 1; station 06465000) was most important for documenting sediment-transport responses to managed changes in gate positions at the dam because it was located in near proximity downstream from Spencer Dam (fig. 1).

Continuous Particle-Size Analyzer Data Collection Methods

Two time series of PC_v data were generated using the PSA system. The first data collection period, the pre-sediment-release period, ran from October 1, 2014, at 20:30 to October 2, 2014, at 21:30, and the second data collection period, immediately before and during the sediment-release period, extended from October 5 at 18:58 to October 9 at 16:00. The gap between October 2 and 5 was planned, coinciding with a period when no discrete samples were collected and no sediment was being released intentionally; however, instrumentation fouling caused two unintended gaps in the data record during the sediment-release period, from October 6 at 20:45 to October 7 at 14:45 and October 9 from 03:30 to 08:15. The reason for the first unintended data gap was discovered on the morning of October 7 when the pump that collects the stream sample was found buried below approximately 30 centimeters (cm) of sand. The reason for the second unintended data gap was discovered on the morning of October 9 when the non-operating pump was found covered with soft organic debris; the bed had aggraded, and the pump intake was at the level of streambed in the zone of bedload transport. Bed material may have entered the pump intake, eventually caused the pump impeller to jam, and consequently, the pump failed to operate.

Instrument and Instrument Settings

The PSA simultaneously measured PC_v and particle size using a laser beam (wavelength 670 nanometers [nm], red light), which passes through a sample volume that is 5 millimeters (mm) thick. The beam energy is scattered forward by particles within the water-sediment mixture and a concentric multiring detector senses the light energy. A photodiode measures the unscattered optical transmission. By means of mathematical inverse modeling, the observed multiangle scattering pattern is analyzed to calculate the PSD among 32 log-spaced size classes ranging from 1.9 to 386 microns (µm) (Sequoia Scientific, 2011a). Agrawal and Pottsmith (2000) describe the technology and its application in detail. Although 32 size-class results are provided by the PSA, because of resource constraints, the USGS limited data processing and publication to nine size classes that encompass a range from fine to coarse.

The PSA has a resolution of less than 1 milligram per liter (mg/L), using 40 measurements per second during the averaging period (Sequoia Scientific, 2011a). User settings, such as start and stop times, clean-water flush duration, stream-water intake-flush duration (intake-flush time), sampling interval, averaging period during sample collection (average duration), and interval at which a clean-water background check measurement is collected (background saved), can be programmed to ensure a more accurate sample and (or) to preserve clean water and power.

During the period prior to the sediment release, the sampling interval was set to 30 minutes, except during testing periods. The testing periods were on October 2 from 08:20 to 08:55, when the sampling interval was 5 minutes, and on October 5 from 18:58 to 19:30, when the sampling interval was approximately 10 minutes. During the sediment release, from October 6 at 08:00 until October 9 at 16:00, the sampling interval was 15 minutes. The sampling interval was generally longer before the sediment release because sediment concentrations were somewhat stable before the sediment release. Clean-water flush time (30 seconds), average duration (30 seconds), and background measurement frequency (every sample) were the same throughout the sampling period.

“Intake flush” refers to the pumping of river water through the PSA system before collection of each analyzed sample, which ensures that each sample consists of freshly collected water and allows the instrument optics to equilibrate to the temperature of the sampled water. The intake-flush interval was specified as 5 minutes until the beginning of the sediment release on October 6 at approximately 10:00, when after some testing at higher pump speeds, it was determined that even on the high-speed setting the pump was unable to maintain adequate flow to maintain suspension of all particles throughout the entire PSA system length. The impairment of pump performance was most likely related to a combination of factors, which included excessive suspended-sand concentrations and pump-speed setting. An intake-flush interval of 2 minutes was tested briefly, but then the interval was specified as 1 minute for the duration of the sampling on day 1 of the sediment release. This need for an adjustment of the intake-flush interval length may be the reason there were missing samples in the record before the Spencer Dam sediment release (see table 4 in Schaepe and Zelt, 2018).

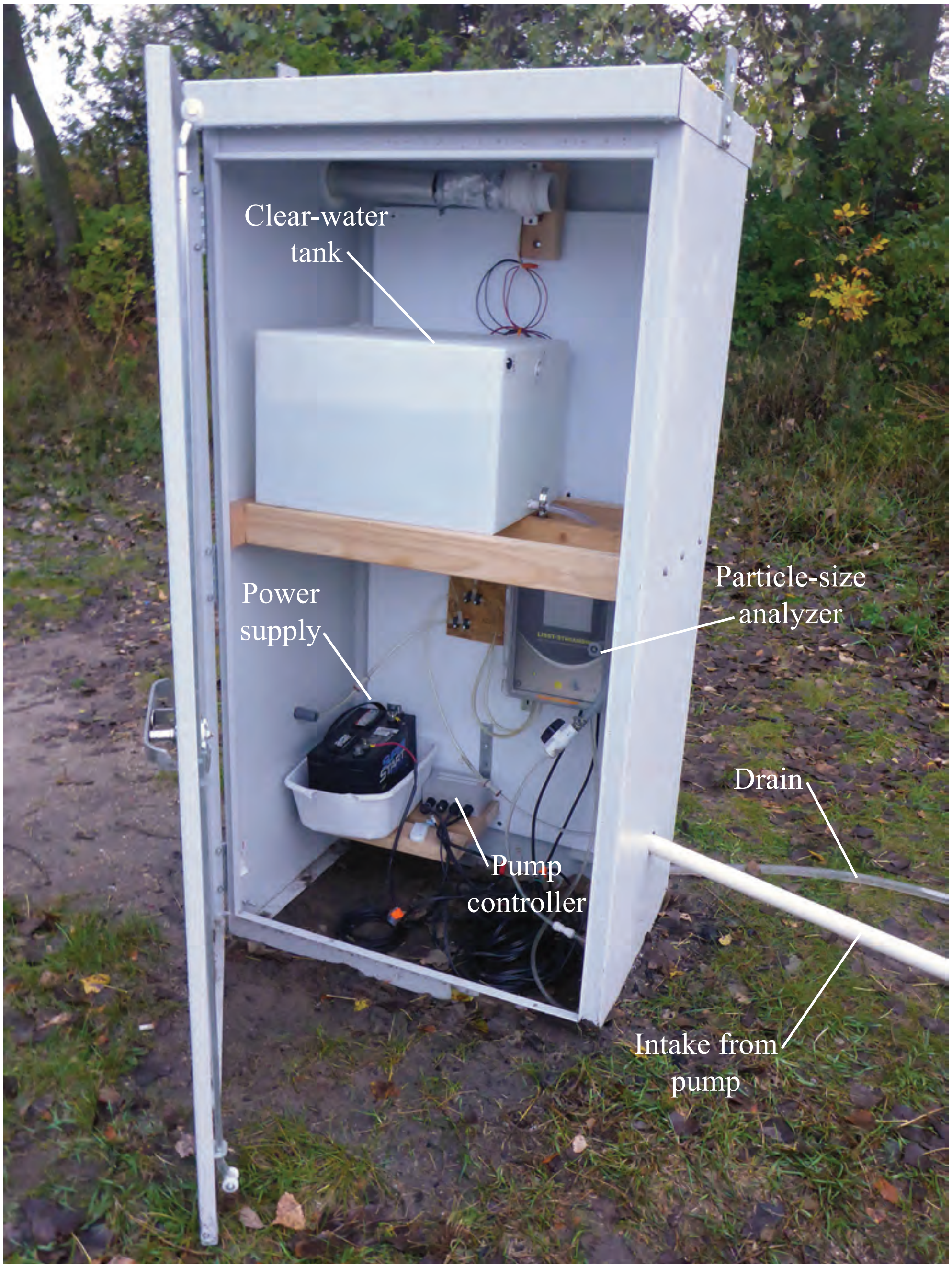

Figure 3. Sediment particle-size analyzer housing and instrumentation downstream from Spencer Dam, Nebraska.

Intake-flush interval length was reverted to 2 minutes from day 2 of the Spencer Dam sediment release through the remainder of the sampling period. The interval was lengthened because turbidity was observed to be substantially less on day 2 of the Spencer Dam sediment release relative to day 1 and to increase the time for thermal equilibration of the PSA optics to stream temperature.

Particle-Size Analyzer Calibration Verification and Checks

Before deployment, proper calibration of the PSA was verified at the USGS, Lincoln, Nebr., on September 23, 2014. Four replicate measurements were made using tap water, followed by six replicate measurements each of two standards. The tap-water measurements were made to ensure the tap water was not introducing any additional particles to the solution. The two standards were developed from mixtures of tap water and two types of Arizona Test Dust (Powder Technology Inc., Burnsville, Minnesota), one with a nominal particle size of 10–20 µm and the other with a nominal particle size of 40–80 µm (table 1). Each Arizona Test Dust reference material had a known PSD. Although the first tap-water measurement had a total particle concentration of 2.23 microliters per liter (µL/L), all subsequent tap-water measurements were 0.6 µL/L or less compared to the test-dust standard samples that ranged from 18.9 to 115.2 µL/L. The first tap-water measurement may have indicated that there were some residual particles or bubbles in the line from previous use. The results of the PSA measurements of the PSD test dust standards were compared to the known PSD to ensure proper calibration of the PSA.

On March 6, 2015, following the deployment of the PSA, a calibration check of the PSA was repeated to verify that the optics and software were not affected by the combination of field conditions and transportation to and from the field site. Seven replicate measurements were made using the 10–20-µm test dust and six replicate measurements were made using the 40–80-µm test dust. The methodology was similar to the pre-deployment calibration check; however, this time, each set of test-dust replicates was bracketed by three replicate measurements of tap water to minimize cross contamination between the two test-dust standards.

A summary of the results from the calibration checks is shown in table 1. The pre-deployment calibration results indicated that the mean of the PSA-measured median grain size agreed with those of the two types of Arizona Test Dust. Replicability, a measure of variability of replicate samples, can be measured as a relative percentage difference (RPD). The RPD between the PSA-measured median grain size and the reported median grain size was within 10 percent for all four calibration checks. The post-deployment calibration results provided no evidence of sequential drift in the PSA or other need for factory recalibration. Results for the 10–20-µm size range were remarkably consistent between the pre- and post-deployment checks. Results for the 40–80-µm size range were slightly more variable because those samples contained very fine sand that settled rapidly. Attempts to develop a precisely repeatable method for maintaining steady resuspension of particles in the standard water-sediment mixture were unsuccessful.

During the PSA deployment for the Spencer Dam sediment release, additional suspended-sediment samples were collected manually to verify the measurement results of the PSA (table 2). Stream samples were collected manually near the PSA pump intake using a U.S. DH-81 sampler (Edwards and Glysson, 1999) on October 6 at 11:00 and 16:45, October 7 at 15:30 and 19:00, October 8 at 10:00 and 16:30, and October 9 at 12:30 and 15:15. These samples were collected as point samples, where the sampler nozzle is manually covered

Table 1. Summary of calibration checks associated with particle-size analyzer, 2014–15.

[µm, micron; d_{50}, diameter of median-size particle; LCL95, lower limit of 95-percent confidence interval; UCL95, upper limit of 95-percent confidence interval; PSA, particle-size analyzer; %, percent]

Pre- or post-deployment	Test date	Test dust nominal size (µm)	Number of replicate measurements	Mean of measured d_{50} (µm)	Standard deviation of measured d_{50} (µm)	LCL95 of measured d_{50} (µm)	UCL95 of measured d_{50} (µm)	Test dust d_{50}, reported (µm)	Relative percentage difference between PSA-measured mean d50 and reported test dust d_{50} (%)
Pre	9/23/2014	10–20	6	15.2	0.4	14.8	15.6	14.2	6.8
Pre	9/23/2014	40–80	6	62.8	5.0	57.6	68.0	58.3	7.5
Post	3/6/2015	10–20	7	15.4	0.2	15.2	15.6	14.2	7.8
Post	3/6/2015	40–80	6	54.8	0.8	54.0	55.6	58.3	6.1

Table 2. Comparison of continuously collected particle-size analyzer data by the field-deployed Laser In-Situ Scattering and Transmissometry Streamside™ instrument and concurrent, manually collected point-sample data from laboratory analysis by the Laser In-Situ Scattering and Transmissometry Portable™ instrument, for samples collected near the riverbank particle-size analyzer pump intake, Niobrara River near Spencer, Nebraska (station 06465000), October 2014.

[Triplicate analyses of each sample are reported; µL/L, microliter per liter; CDT, Central Daylight Time; %, percent; µm, micron; PSA, particle-size analyzer]

Date and time (CDT)	Type	Optical transmission (%)	Volumetric suspended-particle concentration, in µL/L, for the size class indicated								
			3.7–4.3 µm	5.1–6.0 µm	7.1–8.4 µm	13.9–16.4 µm	27–32 µm	53–62 µm	102–121 µm	142–168 µm	199–235 µm
10/6/2014 11:00	Point sample	43.7	8.852	17.989	22.540	36.965	33.528	50.788	64.701	39.694	19.380
10/6/2014 11:00	Point sample	44.1	8.723	17.958	22.653	37.270	33.913	51.429	66.454	39.206	18.126
10/6/2014 11:00	Point sample	41.1	8.966	18.685	24.095	41.333	39.203	63.006	97.108	57.325	24.077
10/6/2014 11:00	PSA	15.6	12.152	26.906	33.232	47.293	45.793	39.185	30.772	32.624	14.201
10/6/2014 16:45	Point sample	41.1	8.687	17.839	22.963	39.015	35.614	44.722	90.019	89.791	62.329
10/6/2014 16:45	Point sample	45.3	7.251	15.009	19.390	33.571	30.885	41.223	90.106	91.681	65.295
10/6/2014 16:45	Point sample	36.3	10.617	21.720	27.884	46.518	41.143	50.072	92.549	90.636	65.909
10/6/2014 16:45	PSA	5.2	8.9175	25.827	61.1	89.462	66.233	52.105	49.001	52.216	28.501
10/7/2014 15:30	Point sample	73.9	1.456	2.919	3.882	6.419	5.759	5.632	26.904	66.840	150.614
10/7/2014 15:30	Point sample	74.5	1.228	2.601	3.646	6.564	5.850	5.203	26.708	72.531	172.030
10/7/2014 15:30	Point sample	75.8	1.053	2.282	3.243	5.902	5.257	4.574	24.484	70.413	169.166
10/7/2014 15:30	PSA	66.9	2.338	4.163	4.478	5.744	6.046	7.368	10.57	16.372	29.937
10/7/2014 19:00	Point sample	79.6	1.833	3.609	4.392	6.841	6.388	5.805	13.012	22.940	25.267
10/7/2014 19:00	Point sample	80.7	1.765	3.439	4.127	6.236	5.877	5.374	12.204	19.631	19.741
10/7/2014 19:00	Point sample	80.9	1.741	3.410	4.109	6.203	5.840	5.533	12.315	19.563	19.531
10/7/2014 19:00	PSA	64.8	2.829	5.076	5.485	7.102	6.394	5.641	6.717	5.3455	2.898
10/8/2014 10:00	Point sample	80.4	1.574	3.422	4.612	8.807	8.094	8.595	16.782	15.922	10.122
10/8/2014 10:00	Point sample	78.9	1.579	3.481	4.780	9.438	8.698	9.653	18.479	17.665	11.922
10/8/2014 10:00	Point sample	77.9	1.625	3.584	4.923	9.797	9.075	9.625	18.389	18.257	12.663
10/8/2014 10:00	PSA	65.7	2.77	4.942	5.384	7.373	7.174	7.67	9.874	11.716	3.8075
10/8/2014 16:30	Point sample	79.1	1.345	2.909	4.022	7.994	7.111	6.973	27.288	37.340	25.292
10/8/2014 16:30	Point sample	79.5	1.316	2.888	4.051	8.273	7.692	7.980	24.472	28.481	18.040
10/8/2014 16:30	Point sample	77.8	1.511	3.279	4.532	8.928	7.916	8.131	29.990	37.102	22.207
10/8/2014 16:30	PSA	67.7	2.546	4.448	4.753	6.213	6.028	5.923	6.977	9.616	8.491
10/9/2014 12:30	Point sample	66.3	3.166	6.372	8.038	13.521	12.490	13.746	54.444	86.738	64.682
10/9/2014 12:30	Point sample	64.1	3.405	6.821	8.608	14.612	13.680	15.247	63.117	99.042	73.822
10/9/2014 12:30	Point sample	64.6	3.315	6.668	8.328	13.549	12.651	13.977	50.925	75.645	54.257
10/9/2014 12:30	PSA	41.9	5.933	11.112	12.661	18.352	17.474	14.675	14.787	19.161	8.414
10/9/2014 15:15	Point sample	53.6	5.490	11.050	13.978	23.964	23.635	24.919	42.737	71.297	98.672
10/9/2014 15:15	Point sample	53.6	5.524	11.022	14.074	24.595	24.590	25.661	40.447	65.360	91.154
10/9/2014 15:15	Point sample	55.8	5.065	10.265	13.066	22.581	22.567	23.371	38.274	61.781	86.378
10/9/2014 15:15	PSA	32.4	3.590	7.903	9.472	12.883	11.785	0.404	1.140	4.796	0.945

until the sampler is in position, and then the nozzle intake is uncovered until a sufficient water volume (0.4–0.8 L) is collected. These samples were submitted to the USGS laboratory, Middleton, Wisconsin, for particle-size analysis, also by laser-diffraction methods; the laboratory analyzed the samples in triplicate using the Laser In-Situ Scattering and Transmissometry (LISST)-Portable™ instrument (Sequoia Scientific, 2011b).

Comparisons of the PSA results with concurrent, manually collected point samples, which were analyzed in a laboratory using the LISST-Portable™ (Sequoia Scientific, 2011b), indicate that the PSA generally overestimated material in the six fine-size classes that were evaluated and underestimated material in the three coarse-size classes that were evaluated. For the six fine-size classes, the PSA measured about 22 percent more fine material than was measured in the manually collected point samples by the laboratory. The difference in measurements in the fine-size classes ranged from 13 percent less in the 53–62-µm size material to 49 percent greater in the 3.7–4.3-µm size material measured. For the three coarse-size classes, the PSA measured about 65 percent less coarse material than what was measured in the manually collected point samples. The difference in measurements in the coarse-size classes ranged from 62 percent less in the 142–168-µm size material to 71 percent less in the 199–235-µm size material.

The discrepancy in PSD between the PSA and concurrent, manually collected point samples is likely the result of differing sample collection techniques and the effects of site conditions on the PSA. The manually collected point samples were obtained using an established isokinetic sampler to ensure that the PSD of the sample was representative of instream velocity conditions (Edwards and Glysson, 1999). The PSA has no features to measure water velocity or regulate pump speed to ensure that the sediment-water slurry pumped into the PSA is representative of the water column. Additionally, as was mentioned previously, PSA sample collection by pumping can be affected by suspended-sediment concentrations and pump-speed setting.

Six additional factors, some of which were mentioned briefly in the explanation of the two significant data gaps (in the “Continuous Particle-Size Analyzer Data Collection Methods” section), also could have contributed to reduced accuracy with the PSA method: pump-intake orientation; streambed aggradation; particles outside the measured range; foreign matter, especially organic matter or air bubbles; condensation on the PSA caused by the temperature differential between the instrument and the water intake; and biased clean-water background readings caused by bubbles within the clean-water line. The following text provides additional information about these factors.

1. The pump intake was oriented perpendicular to streamflow and angled downward. Edwards and Glysson (1999, p. 28) reported that with this orientation, sand-size particles may not be adequately sampled. Instead, a pump intake pointing directly downstream is ideal because a small eddy is formed at the intake, which envelops sand-size particles and thus allows the pump to collect a sample that is more representative of the coarse load.

2. The Spencer Dam sediment release caused the streambed to aggrade rapidly and episodically as the thalweg migrated from bank to bank on a near-hourly basis. Consequently, it was very difficult to maintain the pump intake at a consistent elevation above the streambed such that it remained submerged without sampling bedload or becoming buried by aggrading bed material. Stream depth was usually between 0.4 and 0.7 m at the pump intake, and the bed aggraded almost 1.5 m during the monitored period of the Spencer Dam sediment release, based on cumulative burial of T-posts to which the PSA’s carriage-rail frame was attached.

3. Particles outside the measured size range can distort results and cause equipment failures. Light scattered by particles outside the measured size range from 1.9 to 386 µm can distort the results in the measured range (Sequoia Scientific, 2011a). More important to continuous PSA operation, very coarse sand or fine gravel occasionally enter through the pump’s outer screen and can jam the pump impeller, which happened during the Spencer Dam sediment release, causing the pump to fail.

4. Suspended organic matter, flocculation, or precipitation of air bubbles on the particles can introduce error into the PSD measurements (Konert and Vandenberghe, 1997). Organic matter also was continually collecting on the pump during the Spencer Dam sediment release; as it became draped over the pump intake, the organic matter probably retained ambient sediment particles and may have contributed organic matter into the pump intake, thus altering the PSD of suspended particles entering the pump.

5. Temperature differences between the inflowing water and the PSA instrumentation can lead to condensation within the instrumentation. This condensation can lead to erroneous results. The temperature difference can be minimized by decreasing the time between samples and increasing the intake-flush time so that the instrument temperature can equilibrate to the water temperature. It can be concluded then that if there were condensation effects, they were more pronounced on the first day when the intake-flush time was only 1 minute as opposed to the remainder of the installation period when the intake-flush time was 2 minutes. Surface water temperatures during the sediment release portion of the PSA deployment at the Verdel site downstream from Spencer (fig. 1, station 06465500) ranged from 10.2 to 17.1 degrees Celsius (°C), with an average of 13.3 °C. Air temperature recorded in the PSA housing (fig. 2) during the same period ranged from 4.8 to 20.6 °C, with an average of 13.7 °C. There are no temperature data available for the pre-sediment-release period.

6. Bubbles within the clean-water intake can produce clean-water backgrounds with apparent particle concentrations, which could lead to negatively biased environmental sample concentrations because the instrument measures the difference in particle concentrations between the environmental sample and the clean-water background sample. This error is easier to identify because adjacently timed samples should show a natural trend, and results affected by this bias would not fit the trend. The "Procedures Used to Review Field Data" section discusses how results from adjacent times are inspected.

Validation of collected PC_v data also included the review of ancillary conditions monitored by the PSA systems for the field-deployed PSA and the laboratory tests using the LISST-Portable™. The optical transmission, which is the fraction of the transmitted laser power that was not scattered by particles (Sequoia Scientific, 2011a, 2011b), was used as a validity check of the sample data because a value greater than 100 is physically impossible; hence, sample PC_v data associated with an optical transmission value greater than 100 were considered suspect.

To aid the data review of field records collected by the PSA, a Solitax turbidity sensor (Hach Company, Loveland, Colorado) was deployed as a secondary surrogate. The collected turbidity data were not published by the USGS.

Procedures Used to Review Field Data

Graphs of PC_v from the field-deployed PSA were reviewed; these graphs displayed the concentration-by-size distribution of each sample along with those of samples at adjacent times. Graphs of PC_v from the manually collected point samples near the pump intake, also showing concentration-by-size distribution, were plotted along with the PSA data. These combined graphs aided identification of anomalous sample results from the field-deployed PSA in data review.

Any PC_v value for an individual particle-size class that was either extremely large (generally above 10 µL/L before the Spencer Dam sediment release or above 200 µL/L during the Spencer Dam sediment release) or reported as "nan" (not a number) was flagged and removed. The PC_v values that were anomalous relative to values in the same size class at adjacent sampling times, or in adjacent size classes of the same sample, were also flagged and removed. The remaining values from nine size classes (3.7–4.3, 5.1–6, 7.1–8.4, 13.9–16.4, 27–31.9, 52.5–62, 102.2–120.6, 142.5–168.2, and 198.7–234.6 µm) were further analyzed as individual time series to detect outliers and estimate replacement values. Further analysis was done using a "moving-window" neighborhood analysis along the time series by applying the two-sided median method described in Basu and Meckesheimer (2007). For this study, the size of the neighborhood window was 1 hour and the threshold departure for outlier detection was 50 percent of the neighborhood median. Threshold determination was based on review of normal quantile-quantile plots of each size class. In these diagnostic graphs, the normal-quantile values were plotted as compared to the ordered values of the square-root-transformed relative deviation of PC_v (distance of PC_v from the median of the neighborhood window), and each observation in the time series was plotted as a separate point. The outlier threshold was identified as the relative deviation where a break in slope occurred, differing from the slope through the main body of points, and because these slope breaks indicate outliers, the slope breaks identified were in the tails of the frequency distribution.

Discrete Suspended-Sediment and Bed-Sediment Sampling

Samples of discrete suspended sediment in water and bed sediment were collected using standard manual methods (Edwards and Glysson, 1999) before, during, and after the sediment release. The discrete suspended-sediment samples were collected at four sites (fig. 1). One site was approximately 1 km upstream from the dam in the south channel, and the remaining sites were at bridges downstream from the dam. The discrete suspended-sediment samples at the upstream site were collected prior to the sediment release. The discrete suspended-sediment samples from bridges were collected before, during, and after the sediment-release period at all sites but one (station 424800098403701). The water samples were analyzed for suspended-sediment concentration and percent of material finer than 62 µm. These determinations were made at the USGS Iowa City Sediment Laboratory using standard methods of Guy (1969).

Discrete bed-sediment samples were collected at five sites. One site was within the reservoir, approximately 0.5 km upstream from the dam and the other sites corresponded to sites selected for suspended-sediment sampling. For the site within the reservoir, two separate transects were sampled. Samples at the two upstream sites were collected less than a week before the sediment release. At the bridge sites, samples were collected before, during, and after the sediment release. The bed-sediment samples were dry sieved using eight different sieve sizes at the USGS Iowa City Sediment Laboratory using standard methods of Guy (1969). Results are reported as "percent smaller than the associated sieve size."

The sample period for the discrete suspended-sediment and bed-sediment samples extended from the pre-release baseline sampling on October 1 to November 13, one day after the sediment release had concluded. Forty-two suspended-sediment samples and 21 bed-sediment samples were collected, with most suspended-sediment samples (25) collected at the U.S. Highway 281 bridge. By design, the temporal distribution also was uneven, with more samples collected near the beginning of the sediment release when sediment concentrations were changing most rapidly, and fewer samples collected towards the end of the sediment release (table 3).

Table 3. Number of discrete suspended-sediment and bed-sediment samples collected during Spencer Dam sediment release on Niobrara River, October and November 2014.

[Oct., October; Nov., November; SS, suspended sediment; BS, bed sediment; Positive distances indicate downstream direction and negative distances indicate upstream direction]

Station identification number	Station name	Distance from Spencer Dam, in kilometers	Number of samples																					
			Before sediment release				During sediment release																After sediment release	
			Oct. 1		Oct. 2		Oct. 6		Oct. 7		Oct. 8		Oct. 9		Oct. 10		Oct. 11		Oct. 21		Nov. 7		Nov. 13	
			SS	BS	SS	BS	SS	BS	SS	BS	SS	BS	SS	BS	SS	BS	SS	BS	SS	BS	SS	BS	SS	BS
424800098403701	Niobrara River upstream of Spencer Dam near Spencer, Nebraska	-1.2	1	1	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
06465000	Niobrara River near Spencer, Nebraska	0.5	0	1	1	0	5	1	6	0	4	1	2	0	2	0	2	1	1	1	1	0	1	1
424615098263201	Niobrara River near Redbird, Nebraska	18.8	0	1	1	0	1	1	1	0	1	1	0	0	0	0	1	1	1	1	1	0	1	1
06465500	Niobrara River near Verdel, Nebraska	37.5	0	1	1	0	1	1	1	0	1	1	0	0	0	0	1	1	1	1	1	0	1	1

For example, at station 06465000, five suspended-sediment samples were collected on the first day of the sediment release, whereas two suspended-sediment samples were collected on the fifth day of the sediment release. One sample was collected before and after the sediment release at all sites but one, to provide pre- and post-sediment-release conditions; station 424800098403701 was not sampled after the release because of ice in the river channel. Only the downstream sites were sampled during the sediment release. Complete details of the discrete suspended-sediment and bed-sediment sampling, including the timing and number of samples, methodology, sampling conditions, and sample results, are contained within a data release (Schaepe and Zelt, 2018). The discrete suspended-sediment and bed-sediment data results are available for download from the USGS National Water Information Service online database (USGS, 2016).

Replicate results for the discrete suspended-sediment samples were used to evaluate sample result variability. Concurrent replicate samples were collected for 39 of the 42 suspended-sediment samples. Because the sediment concentrations were changing rapidly it was critical to determine the variability associated with as many samples as possible. The median RPD of all samples was 12.1 percent and it ranged from 0.1 percent to 68.1 percent. Samples collected at the Highway 281 Bridge had the highest variability, likely due to the excessive turbulence in the cross section. The average RPD of the Highway 281 Bridge (fig. 1; station 06465000) samples was 21.5 percent and ranged from 0.6 percent to 68.1 percent. The average RPD of samples collected at the two bridges downstream from the Highway 281 Bridge (fig. 1; stations 424615098263201 and 06465500) were 4.2 percent and 9.6 percent respectively, and ranged from 0.1 percent to 26.2 percent.

Replicate samples were collected for nine bed-sediment samples to evaluate sample result variability. The median difference ([percent smaller than sieve size x of sample 1A] – [percent smaller than sieve size x for sample 1B]) of replicate results for all sieve-size classes was 1 percent. The minimum difference of any one sieve-size class result for any one replicate pair was 0 percent and the greatest difference was 6 percent.

Data Release

All of the data associated with this report are provided as part of a data release by Schaepe and Zelt (2018), and the discrete suspended-sediment and bed-sediment sample results are available in the USGS National Water Information Service online database (USGS, 2016). The data release includes five tables and a geospatial dataset consisting of the location and identifying attributes for each sampling and monitoring site location. The suspended-sediment concentration results and sampling method and condition information are shown in table 1 of Schaepe and Zelt (2018). The time-series data for PC_v in nine selected size classes as determined using the PSA are shown in tables 2–4 of Schaepe and Zelt (2018). Bed sediment grain-size analysis results, sampling method, and condition information are shown in table 5 of Schaepe and Zelt (2018). Complete field definitions are in the data release metadata.

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