Coastal and Marine Hazards and Resources Program

Calibrating Optical Turbidity Measurements with Suspended-Sediment Concentrations from the Herring River in Wellfleet, Massachusetts, from November 2018 to November 2019

Data Report 1180

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

Cover. Photograph of a spyder frame with a seabed altimeter, a pressure logger measuring waves and water levels, and a turbidity sensor deployed at the flank deep site in the Herring River, Wellfleet, Massachusetts, in 2019 by Steve Suttles, U.S. Geological Survey

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Conversion Factors

U.S. customary units to International System of Units

Multiply	By	To obtain
	Area	
acre	4,047	square meter (m^2)
acre	0.4047	hectare (ha)
acre	0.4047	square hectometer (hm^2)
acre	0.004047	square kilometer (km^2)

International System of Units to U.S. customary units

Multiply	By	To obtain
	Length	
millimeter (mm)	0.03937	inch (in.)
meter (m)	3.281	foot (ft)
meter (m)	1.094	yard (yd)

Datum

Horizontal coordinate information is referenced to the North American Datum of 1983 (NAD83).

Depth is referenced to the sea surface at time of sampling.

Supplemental Information

The data in this report were collected as part of a larger study, funded by the U.S. Geological Survey and National Park Service's Natural Resources Preservation Program. This study encompasses four sites within the Northeast Coastal and Barrier Network: Cape Cod National Seashore, Fire Island National Seashore, Gateway National Recreation Area, and Assateague Island National Seashore. The overarching goals of this study are to identify the dominant sources of sediment, determine how sediment transport varies over time, and analyze sediment availability to marshes at the four sites to inform management efforts.

Concentrations of suspended sediment are given in milligrams per liter (mg/L).

Abbreviations

EXOHH	YSI EXO2 sensor with a handheld display
NTU	nephelometric turbidity unit(s)
PInp	nonparametric prediction interval
SSC	suspended-sediment concentration
USGS	U.S. Geological Survey

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Abstract

The sediment budget in the tidally restricted Herring River in Wellfleet, Massachusetts, must be quantified so restoration options for the river can be evaluated. Platforms equipped with optical turbidity sensors were deployed seaward and landward of the Herring River restriction to measure a time series of turbidity, from which a time series of suspended-sediment concentration (SSC) can be estimated. Water samples were collected periodically from the Herring River from November 2018 to November 2019 and analyzed for SSC to derive a relationship to turbidity measurements given in nephelometric turbidity units. This report presents the data-collection methods used and the linear calibration model generated by repeated median regression to convert turbidity measurements to SSC.

Introduction

The Herring River estuary system, composed of several tributary streams and basins, encompasses 1,100 acres along the Cape Cod National Seashore. The estuary system has experienced ecological degradation because of the construction of a dike at Chequessett Neck Road at the mouth of the Herring River in 1909 (Smith and others, 2020). The dike restricts tidal exchange, thus reducing sediment supply to the area upstream from the dike. This lack of sediment supply may lead to marsh loss because a steady import of sediment is necessary for accretion and lateral expansion of the marsh.

Smith and others (2020) have worked with the Herring River Restoration Committee to develop a decision framework for restoration that will represent the varied interests of multiple stakeholders, including scientists, aquaculture managers, and the adjacent residents. Ultimately, restoration managers seek to restore the natural hydrology and ecological function of the estuary by building a new tide-control system that will incrementally adjust the tidal range, while minimizing the socioeconomic effects that such construction might cause. Obtaining sediment flux baseline data before restoration is important to allow future changes stemming from the restoration to be evaluated. The objective of this report is to present the calibration model (generated by repeated median regression) used to convert turbidity measurements into estimates of suspended-sediment concentration (SSC). The resulting time series of SSC can be used to calculate sediment transport flux within the system.

Sensor Deployment and Water Sample Collection

Two WET Labs ECO-NTU sensors (Sea-Bird Scientific, Bellevue, Wash.), which had been calibrated in an eight-point Formazin dilution series from 0 to 500 nephelometric turbidity units (NTU), and two multiparameter YSI EXO2 sensors (Xylem, Inc., Yellow Springs, Ohio) which were factory-calibrated, were checked before deployment with a two-point calibration in the laboratory at 0 NTU (de-ionized water) and 126 NTU (YSI 6073G turbidity standard). The sensors were mounted on platforms between 0.15 and 0.40 meter above the sediment bed from November 12–15, 2018, at three sites seaward and one site landward of the Herring River restriction (fig. 1 and table 1). Continuous turbidity measurements were taken by these sensors at 15-minute intervals for approximately 1 year until November 19, 2019, except for when the ECO-NTU sensors at the flank shallow (FS) and flank deep (FD) sites were removed from January 16, 2019, to March 27, 2019, due to ice concerns at these intertidal locations. The sensors contain integrated wipers that wiped the optical lens before sampling to prevent biofouling. During the year, the sensors were recovered three times to replace the batteries and then re-deployed. Water samples to be analyzed for SSC were collected periodically during the deployment using a Van Dorn sampler: a 1-liter horizontal point sampler that collects a sample at a specific depth (Buchanan and others, 1996). The water samples were refrigerated in the dark after collection and filtered within 1 month. Turbidity readings were taken concurrently with the water samples using a YSI EXO2 sensor with a handheld display (EXOHH).

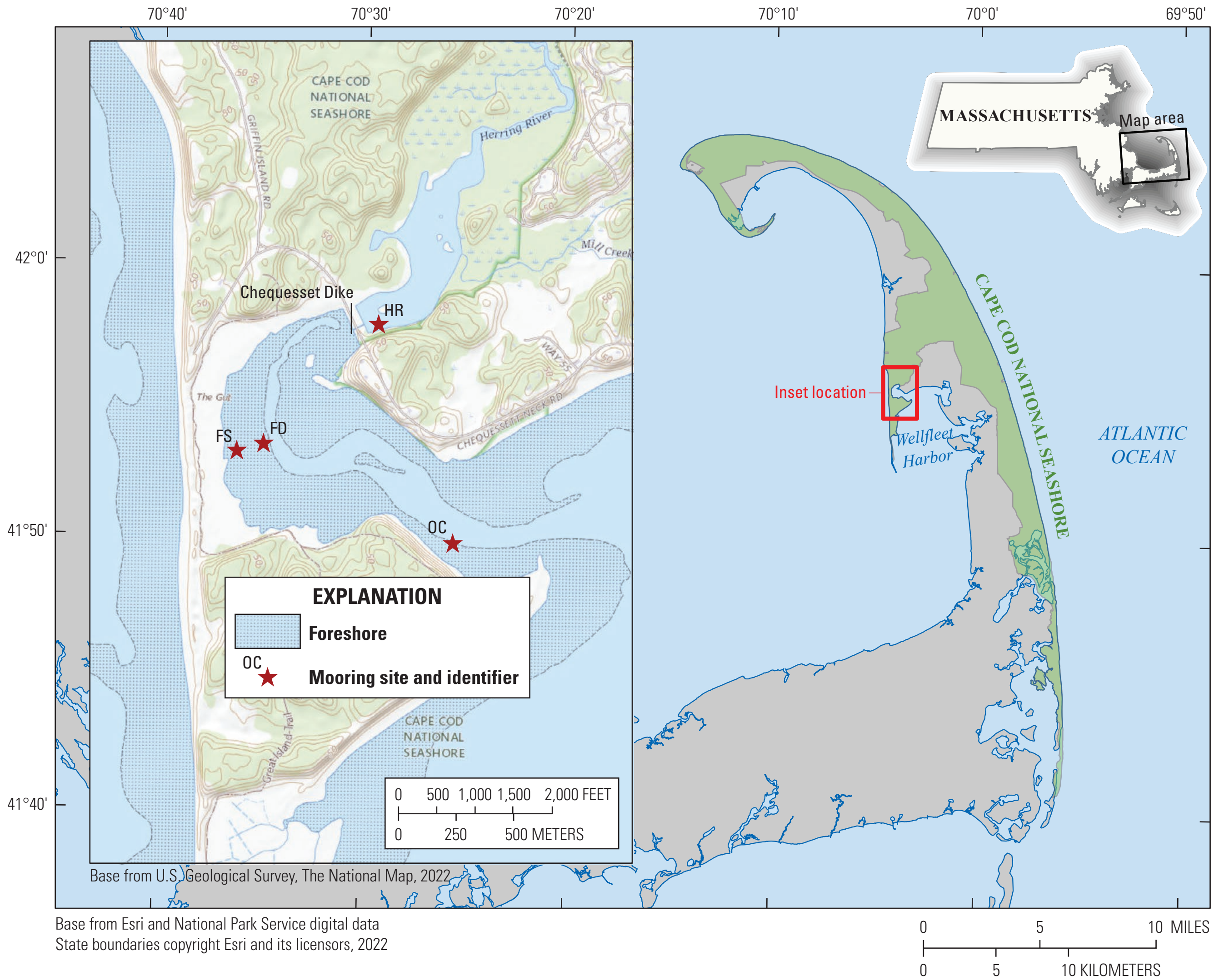

Figure 1. Map showing the Herring River turbidity sensor deployment sites.

Table 1. Site names, abbreviations, and locations of the turbidity sensors in the Herring River in Wellfleet, Massachusetts.

Site name	Site abbreviation	Latitude	Longitude
Herring River	HR	41.93094	−70.06301
Outer channel	OC	41.92262	−70.05910
Flank shallow	FS	41.92608	−70.07017
Flank deep	FD	41.92636	−70.06881

Laboratory Determination of Suspended-Sediment Concentration

Water samples were filtered at the U.S. Geological Survey Woods Hole Coastal and Marine Science Center Sediment Analysis Laboratory in Woods Hole, Massachusetts. Glass-fiber filters (47-millimeter diameter and 1.5-micron pore size) were weighed and volatilized before filtering. The full volume of each water sample was filtered to avoid subsampling errors. If the solids load from a sample was too large to be filtered by a single filter, two or more filters were used. The filtrate was rinsed with de-ionized water to wash out dissolved salts, dried at 105 °C, and weighed (Ohaus AX224 microbalance; Ohaus Corporation, Parsippany, New Jersey)—all steps followed the methods in Fishman and Friedman (1989).

Calibration of the Optical Turbidity Sensor

Turbidity sensor values were downloaded from the EXOHH, and the times of the NTU readings were matched to the time the SSC water samples were collected. Values from a 10-second burst of the EXOHH were averaged to yield a single turbidity value. If no reading was taken with the EXOHH, the value from the deployed turbidity sensor reading within 10 minutes of the sample collection time was used. Table 2 shows the paired SSC and turbidity values for each sample collected. The “Date” and “Time (UTC)” columns refer to when the water sample was collected in Coordinated Universal Time (UTC), and the “SSC” column contains the laboratory-determined suspended-sediment concentration of the water sample. The “Sensor Turbidity (NTU)” column contains the turbidity measurement. The “Sensor” column shows whether the EXOHH or the deployed turbidity sensor was used to collect the turbidity measurement. The “Flag” column indicates whether data from the EXOHH were good (flag = 0), the reason the deployed sensor was used instead of the EXOHH, or why values were excluded from the calibration. Turbidity sensor values from the deployed sensor were used if no EXOHH values were collected (flag = 1) or if the EXOHH values failed to meet quality control criteria as follows: turbidity values from the EXOHH burst were eliminated if they were greater than 100 percent of the burst median turbidity value and less than 5 readings remained (flag = 2) or the standard deviation of the turbidity value divided by the mean turbidity value was greater than 0.5 (flag = 3). In some cases, no deployed sensor values were available, for instance when sampling stopped due to battery depletion (flag = 4). Deployed sensor values were excluded from the calibration if the standard deviation of the turbidity value divided by the mean turbidity value was greater than 0.5 (flag = 5). One water sample (July 25, 2019, 19:15 UTC) was eliminated from the calibration because the water sampler hit the riverbed (flag = 6) when the sample was captured and thus was not representative of the suspended sediment in the water column.

Linear regression using a robust, nonparametric repeated median method (Siegel, 1982) was used to estimate SSC from turbidity. The repeated median estimate is less sensitive to the effect of outliers, so it was used as the regression method for the data in this study. The repeated median method first calculates the median of all possible point-to-point slopes, which results in one median slope for each data point. The final SSC versus turbidity slope is then calculated as the median of all the median data point slopes. The intercept was calculated as the median of all possible intercepts using the final slope calculation.

The nonparametric prediction interval (PInp), calculated as in Helsel and others (2020), is an error band containing one standard deviation (68 percent) of the calibration dataset. The PInp is not symmetric because it results from the distribution of the dataset. The PInp is calculated based on the residuals for each point, sorted from least to greatest. The 95-percent confidence interval of the slope was calculated as in Helsel and others (2020) by sorting all point-to-point slopes in ascending order. The ranks of the upper and lower intervals were then calculated and rounded to the nearest integer, and the slope associated with each rank was identified. See Buchanan and Lionberger (2007) for more detailed information about the PInp and confidence interval calculations that were used in this study.

Figure 2 displays the results of the repeated median regression, the nonparametric prediction interval, and the confidence interval. The calibration equation is

$$SSC = 2.5(NTU) + 6.1,$$

where

- SSC is suspended sediment concentration in mg/L, and
- NTU is nephelometric turbidity units.

Eighty data points were used to generate the equation. The nonparametric prediction interval ranged from +17 to −7, and the 95-percent confidence bounds on the slope calculation were 2.183 to 2.890. This equation will be used to derive a time series of SSC from the time series of deployed turbidity sensor data from Suttles and others (2023) to calculate sediment transport in the Herring River system.

Table 2. Suspended-sediment concentration and sensor turbidity for each water sample.

[Data from De Meo and others (2023). Dates are shown as month–day–year. Time (UTC) is given in hour:minute:second. Flag values are defined as follows: 0 equals (=) good EXOHH data, 1 = deployed sensor values used (no EXOHH data), 2 = EXOHH values eliminated if greater than 100 percent of the burst median turbidity value and less than five readings remained, 3 = EXOHH values eliminated if the standard deviation of the turbidity value divided by the mean turbidity value was greater than 0.5, 4 = no deployed sensor values available, 5 = deployed sensor values excluded from calibration if the standard deviation of the turbidity value divided by the mean turbidity value was greater than 0.5, and 6 = water sample was eliminated from the calibration because the water sampler hit the riverbed. UTC, coordinated universal time; m, meter; SSC, suspended-sediment concentration; mg/L, milligrams per liter; NTU, nephelometric turbidity unit; OC, Outer Channel; HR, Herring River; EXOHH, YSI EXO2 sensor with a handheld display; FD, flank deep; FS, flank shallow; NaN, not a number; NA, not applicable]

Site	Date	Time (UTC)	Total depth (m)	Sample depth (m)	SSC (mg/L)	Sensor turbidity (NTU)	Sensor	Flag
OC	11–12–18	17:00:00	2.3	2.0	7.6	0.5	Deployed	1
HR	11–15–18	17:45:00	0.3	0.2	122.5	NaN	NA	1,4
HR	2–13–19	17:30:30	0.9	0.5	31.4	3.6	EXOHH	0
HR	2–13–19	18:30:00	0.8	0.1	30.7	NaN	NA	1,5
HR	2–13–19	18:40:45	0.9	0.5	30.3	5.0	EXOHH	0
OC	2–15–19	13:53:59	3	2.0	17.5	0.4	EXOHH	0
HR	5–13–19	16:45:00	0.8	0.5	10.8	NaN	NA	4
HR	5–13–19	17:00:00	0.9	0.5	37.8	NaN	NA	4
HR	5–13–19	17:15:00	0.9	0.5	23.3	10.5	EXOHH	0
HR	5–13–19	17:30:00	0.7	0.5	40.7	12.2	EXOHH	0
HR	5–13–19	17:45:00	0.6	0.4	25.3	7.8	EXOHH	0
HR	5–13–19	18:00:00	0.5	0.3	30.3	NaN	NA	4
HR	5–13–19	18:15:00	0.5	0.3	26.0	NaN	NA	4
HR	5–13–19	18:30:00	0.5	0.3	33.3	7.4	EXOHH	0
OC	5–16–19	12:45:00	3.4	2.5	4.5	0.5	EXOHH	0
FD	5–16–19	13:00:00	3	2.2	6.4	1.0	EXOHH	0
FS	5–16–19	13:15:00	2.5	1.5	21.0	0.8	EXOHH	0
OC	5–16–19	13:30:00	3.8	3.0	4.5	0.5	EXOHH	0
OC	5–16–19	13:45:00	3.9	3.1	2.6	0.5	EXOHH	0
OC	5–16–19	15:30:00	3.4	2.5	5.1	0.6	EXOHH	0
FS	5–16–19	15:45:00	2	1.3	3.1	0.7	EXOHH	0
FD	5–16–19	16:00:00	2.3	1.5	2.6	0.7	EXOHH	0
OC	5–16–19	16:15:00	3	2.5	2.0	0.6	EXOHH	0
FS	5–16–19	16:29:00	1.6	1.0	3.1	0.7	EXOHH	0
FD	5–16–19	16:45:00	2.2	1.5	15.1	0.8	EXOHH	0
OC	5–16–19	17:00:00	2.4	2.0	14.0	0.6	EXOHH	0
HR	7–25–19	15:00:00	0.8	0.4	31.9	4.9	Deployed	1
HR	7–25–19	15:15:00	0.7	0.3	37.5	6.4	EXOHH	0
HR	7–25–19	15:30:00	0.7	0.3	31.8	6.7	EXOHH	0
HR	7–25–19	15:45:00	0.7	0.3	18.5	7.7	EXOHH	0
HR	7–25–19	16:00:00	0.6	0.3	25.3	7.1	EXOHH	0
HR	7–25–19	16:15:00	0.5	0.2	30.0	8.4	EXOHH	0
HR	7–25–19	16:30:00	0.4	0.2	30.1	10.1	EXOHH	0
HR	7–25–19	16:45:00	0.5	0.2	66.4	11.3	EXOHH	0
HR	7–25–19	17:00:00	0.4	0.2	57.2	11.3	EXOHH	0
HR	7–25–19	17:15:00	0.4	0.2	61.7	10.7	Deployed	0
HR	7–25–19	17:30:00	0.3	0.1	53.6	NaN	NA	5

Table 2. Suspended-sediment concentration and sensor turbidity for each water sample.—Continued

[Data from De Meo and others (2023). Dates are shown as month–day–year. Time (UTC) is given in hour:minute:second. Flag values are defined as follows: 0 equals (=) good EXOHH data, 1 = deployed sensor values used (no EXOHH data), 2 = EXOHH values eliminated if greater than 100 percent of the burst median turbidity value and less than five readings remained, 3 = EXOHH values eliminated if the standard deviation of the turbidity value divided by the mean turbidity value was greater than 0.5, 4 = no deployed sensor values available, 5 = deployed sensor values excluded from calibration if the standard deviation of the turbidity value divided by the mean turbidity value was greater than 0.5, and 6 = water sample was eliminated from the calibration because the water sampler hit the riverbed. UTC, coordinated universal time; m, meter; SSC, suspended-sediment concentration; mg/L, milligrams per liter; NTU, nephelometric turbidity unit; OC, Outer Channel; HR, Herring River; EXOHH, YSI EXO2 sensor with a handheld display; FD, flank deep; FS, flank shallow; NaN, not a number; NA, not applicable]

Site	Date	Time (UTC)	Total depth (m)	Sample depth (m)	SSC (mg/L)	Sensor turbidity (NTU)	Sensor	Flag
HR	7–25–19	17:45:00	0.3	0.1	106.0	26.9	EXOHH	0
HR	7–25–19	18:00:00	0.3	0.1	117.5	NaN	NA	3,5
HR	7–25–19	18:15:00	0.3	0.1	51.9	9.4	EXOHH	0
HR	7–25–19	18:30:00	0.3	0.1	269.0	7.2	EXOHH	0
HR	7–25–19	18:45:00	0.3	0.1	162.2	11.1	EXOHH	0
HR	7–25–19	19:15:00	0.6	0.3	NaN	10.2	EXOHH	6
HR	7–25–19	19:30:00	0.7	0.3	27.8	8.1	EXOHH	0
HR	7–25–19	19:45:00	0.7	0.3	33.5	6.3	Deployed	3
HR	7–25–19	20:00:00	0.8	0.4	17.9	4.1	Deployed	3
HR	7–25–19	20:15:00	0.8	0.4	26.3	9.0	EXOHH	0
HR	7–25–19	20:30:00	0.7	0.3	12.3	4.8	EXOHH	0
HR	7–25–19	20:45:00	0.7	0.3	11.1	4.7	EXOHH	0
HR	7–25–19	21:00:00	0.9	0.5	8.3	4.0	EXOHH	0
OC	8–7–19	12:30:00	2	1.0	9.4	3.2	EXOHH	0
OC	8–7–19	12:45:00	1.9	0.8	6.6	3.1	EXOHH	0
OC	8–7–19	13:00:00	1.8	0.8	10.8	3.8	EXOHH	0
OC	8–7–19	13:15:00	1.6	0.8	10.4	5.3	EXOHH	0
OC	8–7–19	13:30:00	1.4	0.8	15.5	6.1	EXOHH	0
OC	8–7–19	13:45:00	1.2	0.7	20.9	6.5	EXOHH	0
OC	8–7–19	14:00:00	1.1	0.5	26.4	9.7	EXOHH	0
OC	8–7–19	14:15:00	0.9	0.5	27.5	10.6	EXOHH	0
OC	8–7–19	14:30:00	0.8	0.5	26.3	11.3	EXOHH	0
OC	8–7–19	14:45:00	0.6	0.3	22.6	NaN	NA	5
OC	8–7–19	15:00:00	0.6	0.4	45.2	15.2	EXOHH	0
OC	8–7–19	15:15:00	0.5	0.2	50.4	50.7	Deployed	1
OC	8–7–19	16:00:00	0.4	0.2	27.7	12.0	EXOHH	0
OC	8–7–19	17:32:00	0.7	0.4	43.1	NaN	NA	1,5
OC	8–7–19	17:45:00	0.9	0.5	67.7	7.6	EXOHH	0
OC	8–7–19	18:00:00	0.9	0.5	53.6	6.2	EXOHH	0
OC	8–7–19	18:15:00	1.3	0.6	38.3	6.8	Deployed	1
OC	8–7–19	18:30:00	1.4	0.6	33.8	5.9	Deployed	1
OC	8–7–19	18:45:00	1.6	0.8	20.6	NaN	NA	1,5
OC	8–7–19	19:00:00	1.8	0.8	16.1	3.0	Deployed	1
FD	9–19–19	14:30:00	0.5	0.1	19.3	8.0	Deployed	1
HR	10–21–19	15:30:00	0.7	0.3	33.8	5.5	EXOHH	0
HR	10–21–19	15:45:00	0.7	0.4	22.8	5.7	EXOHH	0
HR	10–21–19	16:00:00	0.6	0.2	33.6	11.8	EXOHH	0

Table 2. Suspended-sediment concentration and sensor turbidity for each water sample.—Continued

[Data from De Meo and others (2023). Dates are shown as month–day–year. Time (UTC) is given in hour:minute:second. Flag values are defined as follows: 0 equals (=) good EXOHH data, 1 = deployed sensor values used (no EXOHH data), 2 = EXOHH values eliminated if greater than 100 percent of the burst median turbidity value and less than five readings remained, 3 = EXOHH values eliminated if the standard deviation of the turbidity value divided by the mean turbidity value was greater than 0.5, 4 = no deployed sensor values available, 5 = deployed sensor values excluded from calibration if the standard deviation of the turbidity value divided by the mean turbidity value was greater than 0.5, and 6 = water sample was eliminated from the calibration because the water sampler hit the riverbed. UTC, coordinated universal time; m, meter; SSC, suspended-sediment concentration; mg/L, milligrams per liter; NTU, nephelometric turbidity unit; OC, Outer Channel; HR, Herring River; EXOHH, YSI EXO2 sensor with a handheld display; FD, flank deep; FS, flank shallow; NaN, not a number; NA, not applicable]

Site	Date	Time (UTC)	Total depth (m)	Sample depth (m)	SSC (mg/L)	Sensor turbidity (NTU)	Sensor	Flag
HR	10–21–19	16:15:00	0.6	0.2	35.5	12.0	EXOHH	0
HR	10–21–19	16:30:00	0.5	0.2	22.4	8.2	EXOHH	0
HR	10–21–19	16:45:00	0.5	0.2	41.2	14.0	EXOHH	0
HR	10–21–19	17:00:00	0.5	0.2	34.4	14.9	EXOHH	0
HR	10–21–19	17:15:15	0.5	0.2	28.3	6.7	EXOHH	0
HR	10–21–19	17:30:00	0.6	0.2	16.8	5.7	EXOHH	0
HR	10–21–19	17:45:00	0.6	0.2	37.8	9.8	EXOHH	0
HR	10–21–19	18:00:00	0.6	0.2	21.6	11.6	EXOHH	0
OC	10–23–19	15:15:00	2	1.0	27.5	NaN	NA	1,5
OC	10–23–19	15:30:15	1.7	1.0	45.9	6.7	EXOHH	0
OC	10–23–19	15:45:00	1.6	1.0	46.4	5.4	EXOHH	0
OC	10–23–19	16:00:00	1.5	0.9	66.0	28.1	EXOHH	0
OC	10–23–19	16:15:00	1.2	0.5	57.3	21.0	EXOHH	0
OC	10–23–19	16:30:00	1.1	0.5	83.0	26.4	EXOHH	0
OC	10–23–19	16:45:00	0.8	0.3	137.1	60.8	EXOHH	0
OC	10–23–19	17:00:00	0.9	0.3	214.0	74.3	EXOHH	0
OC	10–23–19	17:15:00	0.8	0.2	108.8	45.3	EXOHH	0
OC	10–23–19	17:30:00	0.8	0.2	97.1	30.2	EXOHH	0
OC	10–23–19	17:45:00	0.7	0.2	48.6	NaN	NA	5
OC	10–23–19	18:00:00	0.8	0.2	15.9	6.9	EXOHH	0

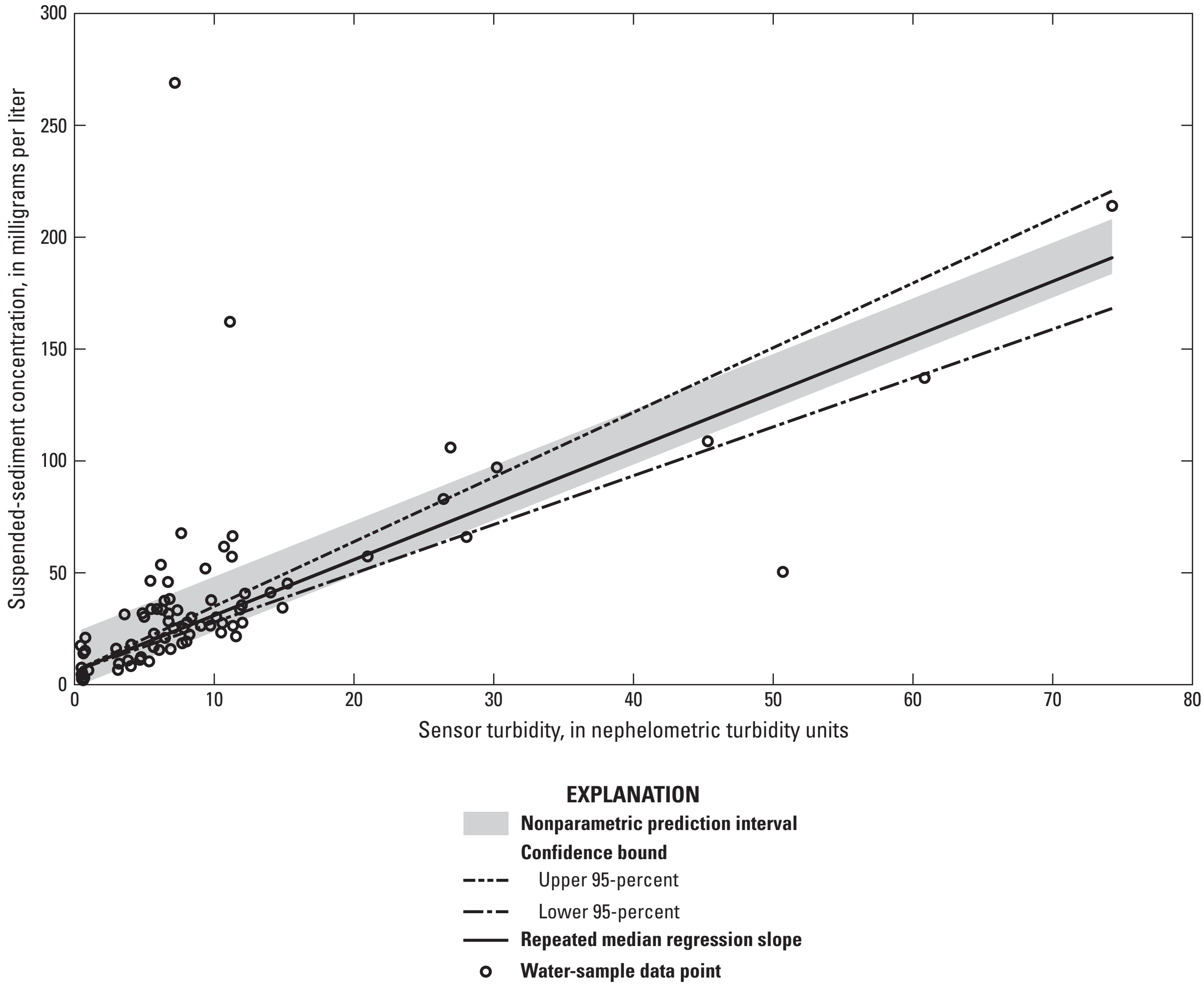

Figure 2. Graph showing the repeated median regression of suspended-sediment concentration versus sensor turbidity.

Summary

Two types of optical turbidity sensors were deployed at three sites seaward and one site landward of the Herring River restriction to monitor suspended sediment and characterize pre-restoration conditions in the river. Water samples were collected to determine suspended-sediment concentrations (SSCs) to calibrate the output of the sensors using robust, nonparameteric repeated median regression. The SSC data from the water samples and the measurements from the YSI EXO2 sensor with a handheld display are in De Meo and others (2022) and De Meo and others (2023), respectively. The resulting calibration model will be used with a time-series of deployed turbidity sensor data collected and reported by Suttles and others (2023) to derive a time series for SSC to input into sediment-flux calculations.

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