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Water-Quality Conditions and Suspended-Sediment Transport in the Wilson and Trask Rivers, Northwestern Oregon, Water Years 2012–14

Scientific Investigations Report 2015–5109

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

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By Steven Sobieszczyk, Heather M. Bragg, and Mark A. Uhrich

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SALLY JEWELL, Secretary

U.S. Geological Survey
Suzette M. Kimball, Acting Director

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Conversion Factors

Inch/Pound to International System of Units

Multiply	By	To obtain
Length		
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
Area		
square mile (mi^2)	2.590	square kilometer (km^2)
square mile (mi^2)	640	acre
Volume		
gallon (gal)	3.785	liter (L)
cubic foot (ft^3)	0.02832	cubic meter (m^3)
Flow Rate		
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^{3}s)
Mass		
ton, short (2,000 lb)	0.9072	megagram (Mg)
ton per day per square mile [(ton/d)/mi^2]	0.3503	megagram per day per square kilometer [(Mg/d)/km^2]

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

$$°F=(1.8×°C)+32.$$

Supplemental Information

Specific conductance is given in microsiemens per centimeter at 25 degrees Celsius (μS/cm at 25°C).

Suspended-sediment concentrations are reported in milligrams per liter (mg/L). Sediment loads are reported in tons.

Turbidity is given in formazin nephelometric units.

Dissolved oxygen is reported in milligrams per liter (mg/L).

A water year is the 12-month period from October 1 through September 30 of the following calendar year. The water year is designated by the calendar year in which it ends. For example, water year 2008 is the period from October 1, 2007, through September 30, 2008.

Datums

Vertical coordinate information is referenced to the National Geodetic Vertical Datum of 1929 (NGVD 29).

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

Elevation, as used in this report, refers to distance above the vertical datum.

Abbreviations and Acronyms

BCF	bias correction factor
DO	dissolved oxygen
EWI	equal-width-increment
FNU	Formazin Nephelometric Unit
MSPE	model standard percent error
NWIS	U.S. Geological Survey National Water Information System
OLS	ordinary least-squares
PPCC	probability plot correlation coefficient
PRESS	predicted residual sum of squares
Q	streamflow
R^2	coefficient of determination
RMSE	root mean squared error
SC	specific conductance
SSC	suspended-sediment concentration
SSL	suspended-sediment load
ST	stage
TB	turbidity
USGS	U.S. Geological Survey
VIF	variance inflation factor
WT	water temperature
WY	water year

Water-Quality Conditions and Suspended-Sediment Transport in the Wilson and Trask Rivers, Northwestern Oregon, Water Years 2012–14

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Abstract

In October 2011, the U.S. Geological Survey began investigating and monitoring water-quality conditions and suspended-sediment transport in the Wilson and Trask Rivers, northwestern Oregon. Water temperature, specific conductance, turbidity, and dissolved oxygen were measured every 15–30 minutes in both streams using real-time instream water-quality monitors. In conjunction with the monitoring effort, suspended-sediment samples were collected and analyzed to model the amount of suspended sediment being transported by each river. Over the course of the 3-year study, which ended in September 2014, nearly 600,000 tons (t) of suspended-sediment material entered Tillamook Bay from these two tributaries.

Each year of the study, the Wilson River transported between 80,300 and 240,000 t of suspended sediment, while the Trask River contributed between 28,200 and 69,900 t. The suspended-sediment loads observed during the study were relatively small because streamflow conditions were routinely lower than normal between October 2011 and September 2014. Only one storm had a recurrence interval between a 2- and 5-year event. Every other storm produced streamflows equivalent to what would be classified as a 1- or 2-year event. Because most sediment moves during high flows, the lack of heavy rainfall and elevated streamflows muted any high sediment loads.

Along with assessing suspended-sediment transport, the U.S. Geological Survey also monitored instream water quality. This monitoring was used to track instream conditions and relate them to water temperature, dissolved oxygen, and sedimentation issues for the Wilson and Trask Rivers. Stream temperatures in the Wilson and Trask Rivers exceeded the temperature standard for cold-water habitat. Water temperatures at both streams exceeded the standard for more than 30 percent of the year, as stream temperatures increased above the seasonal 13 degrees Celsius (°C) (seasonal core cold-water habitat) and 16 °C (salmon and steelhead [*Oncorhynchus mykiss*] spawning) thresholds. Conversely, dissolved oxygen concentrations rarely decreased to less than the absolute water-quality criterion of 8 milligrams per liter for cold-water streams.

Results from this study will provide resource managers insight into the seasonality of water-quality conditions and the extent of suspended-sediment transport in the Wilson and Trask Rivers. The data are useful for establishing a baseline and for maintaining best-use land management practices and possibly for aiding in prioritization of restoration actions for both rivers and their respective watersheds.

Introduction

Background

Water-quality impairments in the Tillamook Bay watershed (fig. 1) threaten native fish species, such as coho salmon (*Oncorhynchus kisutch*) and cutthroat trout (*Oncorhynchus clarkii*). Recent studies (Tillamook Estuaries Partnership, 1999; Oregon Department of Environmental Quality, 2001; Demeter Design, 2009; Johnson and Drake, 2011; Reiter and others, 2013) have identified the primary water-related issues for Tillamook Bay and its tributaries as (1) warming stream temperatures, (2) increased sedimentation and associated point and nonpoint source pollution, such as nutrients and toxics, (3) low dissolved oxygen concentrations, and (4) altered or modified channels. Each of these conditions greatly affects the overall health and quality of aquatic habitats.

Over the last few decades, landscape changes such as large forest fires, removal of riparian vegetation, and engineered channel modifications have greatly degraded the water quality of many of Oregon's northern coastal streams (Oregon Department of Environmental Quality, 2001). These degraded conditions have led to increases in fine-sediment transport, scouring of stream channels, decreases in suitable streambed habitat, and increases in stream temperatures resulting from increased exposure to direct sunlight (Demeter Design, 2009). High stream temperatures are especially problematic in summer and autumn, when above-average water temperatures can stress spawning fish populations (Oregon Department of Environmental Quality, 2001). In October 2011, the U.S. Geological Survey (USGS), in cooperation with the Tillamook Estuaries Partnership, began investigating and monitoring water-quality conditions and suspended-sediment transport in the Wilson and Trask Rivers, northwestern Oregon.

Purpose and Scope

The purpose of this report is to summarize suspended-sediment transport and continuously monitored water-quality data for the Wilson (USGS streamgage 14301500) and Trask (USGS streamgage 14302480) Rivers. This study addressed a deficiency in long-term monitoring of local streams by establishing a water-quality and suspended-sediment monitoring network for two major tributaries to Tillamook Bay. This study provided water-resource managers with continuous real-time data of water temperature, specific conductance, turbidity, and dissolved oxygen concentrations. USGS researchers provided estimates of suspended-sediment loads for the two rivers during the 3-year study period (October 1, 2011–September 30, 2014; water years 2012–14). This study did not address issues of *Escherichia coli*, fecal coliform bacteria, or other contaminants that are common water-quality issues in the two streams and in Tillamook Bay. Archived data can be accessed through the USGS National Water Information System database (U.S. Geological Survey, 2015a, 2015b).

Along with monitoring instream conditions and providing estimates for suspended sediment, specific objectives also included:

- Publishing site-specific regression models that estimate suspended-sediment concentrations using continuous turbidity and (or) streamflow data as surrogates;

- Evaluating stream conditions for water temperature, dissolved oxygen, turbidity, and sedimentation; and

- Evaluating future effects of sediment on potential downstream restoration projects, such as the Southern Flow Corridor Project (Northwest Hydraulic Consultants, 2011).

Description of Study Area

Studies in Tillamook Bay (Oregon Department of Environmental Quality, 2001; Mico and Mico, 2009; Tillamook Estuaries Partnership, 2010; Johnson and Drake, 2011) have provided detailed basin setting and ecological characterization of the Wilson River watershed (Sullivan and others, 2001; Duck Creek Associates, 2008) and the Trask River watershed (Follansbee and Stark, 1998; Snyder and others, 2003). For this study, the combined drainage area for the two monitoring sites accounts for approximately 60 percent of the total contributing area to Tillamook Bay. Typical rainfall for the Wilson and Trask River watersheds is about 123 in/yr (Follansbee and Stark, 1998).

Wilson River Watershed (USGS Streamgage 14301500)

The Wilson River begins in the Coast Range of northwestern Oregon, approximately 45 mi west of Tillamook Bay (fig. 1). Although the river flows into the bay, the Wilson River streamgage is 10.2 mi upstream of the delta (table 1). From that monitoring location, the river drains 161 mi^2 of mostly forested land (about 80 percent of the basin; Risly and others, 2008). Terrain in the watershed varies from peak elevations of higher than 3,620 ft in the Coast Range to a valley floor where elevations are at or just above sea level. Most of the watershed is within the Tillamook State Forest. In the upper watershed, the Wilson River flows through wide gravel-rich areas and through stable confined basalt gorges (Jones and others, 2012). Near the streamflow gage along the lower parts of the watershed, the Wilson River meanders as a wide channel with abundant large gravel bars.

Trask River Watershed (USGS Streamgage 14302480)

Similar to the Wilson River, the Trask River headwaters originate along the Coast Range in the Tillamook State Forest. Geographically, the Trask River watershed is the next Tillamook Bay tributary south of the Wilson River (fig. 1); therefore, they share very similar physiographic and geologic settings. For this study, water quality was monitored on the Trask River at USGS streamgage 14302480 (table 1). From this location, the river drains 156 mi^2 of mostly forested land (about 78 percent of the basin; Risly and others, 2008). Unlike the Wilson River, the Trask River sampling occurred at a different location than the monitoring. Suspended-sediment samples were collected at the Long Prairie Road Bridge, 4.0 mi downstream of the streamgage. This sampling site was used because there was not a cableway located at the streamgaging site (fig. 1).
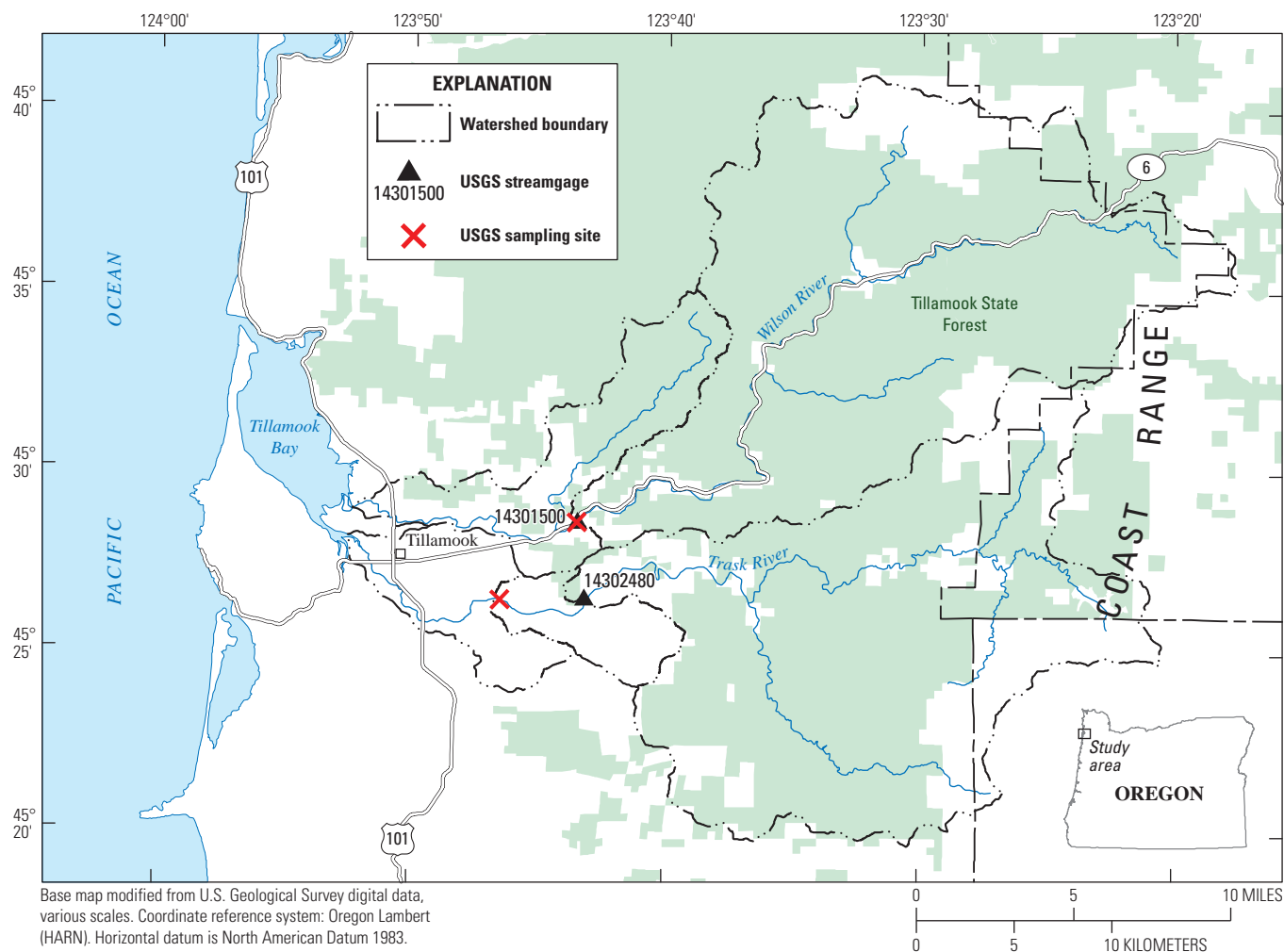
Figure 1.   Location of the Wilson and Trask Rivers, northwestern Oregon.

Table 1.   Streamflow and water-quality monitoring information for the Wilson and Trask Rivers, northwestern Oregon.

[**Parameters:** DO, dissolved oxygen concentration; SC, specific conductance; TB, turbidity; WT, water temperature. **Abbreviations:** USGS, U.S. Geological Survey. mi^2, square miles]

USGS streamgage No.	USGS streamgage name	Drainage basin area (mi^2)	Water-quality record			Streamflow record	
			Parameters	Period of record (water year)	Years of record	Period of record (water year)	Years of record
14301500	Wilson River near Tillamook	161	DO, SC, TB, WT	2012–2014	3	1915–1916, 1931–present	85
14302480	Trask River above Cedar Creek, near Tillamook	156	DO, SC, TB, WT	2012–2014	3	1996–present	18

Data Collection

Data were collected using a combination of instream water-quality monitoring and suspended-sediment sampling. More details about the sediment collection and processing are provided in appendixes A and B.

Instream Monitoring

Water temperature, specific conductance, and turbidity data were collected in near-real-time at the Wilson and Trask River streamgaging locations between October 2011 and September 2014 (water years 2012–14) (table 2). Dissolved oxygen concentration also was monitored at both rivers; however, it was only measured during the warmer months (May–June through October). Water-quality conditions were monitored using YSI, Inc. 6920-V2 multiparameter instruments. Sensors were checked and calibrated monthly using protocols described by Wagner and others (2006). Streamflow was computed from stage using USGS protocols (Rantz and others, 1982; Sauer and Turnipseed, 2010; Turnipseed and Sauer, 2010). At the Wilson River streamgage, all parameters were recorded at 15-minute intervals. At the Trask River streamgage, parameters were logged at 30-minute intervals from October 1, 2011 to May 22, 2012, after which the interval was changed to 15 minutes. All data were recorded on Sutron Satlink datalogger-transmitters and uploaded to the online National Water Information System database every 2 hours.

Suspended-Sediment Sampling

USGS personnel collected suspended-sediment samples during calibration-site visits and during storm-related events. An equal-width-increment (EWI) method (Edwards and Glysson, 1999; U.S. Geological Survey, 2006) was used to collect cross-sectional, depth-integrated samples from a bank-operated cableway at the Wilson River site. EWI samples were collected from the Long Prairie Road Bridge downstream of the Trask River site. All samples were analyzed at the USGS Cascade Volcano Observatory sediment laboratory based on procedures described in Guy (1969) for suspended-sediment concentration in milligrams per liter (mg/L), and most were analyzed for percent silt and clay (fine sediment), as reported in percentage of samples finer than 63 μm.

During the study, 93 EWI samples were collected, 45 at the Wilson River and 48 at the Trask River. Suspended-sediment samples were collected over nearly the entire range of hydrologic conditions for both rivers. Figure 2 shows the distribution of sample collection over the range and duration of instantaneous turbidity values at each streamgage. Most samples were collected during the less-frequent high turbidity events. These conditions were targeted for sampling because they were indicative of the greatest potential suspended-sediment transport. Only a few samples were collected when turbidity was less than 5.0 Formazin Nephelometric Units (FNU), when suspended-sediment transport conditions were greatly reduced.

Quality Assurance and Review

For quality assurance, sequential replicate sample pairs were compared individually to validate the reproducibility of the sampling method (Rasmussen and others, 2009). An ordinary least-squares (OLS) linear regression analysis was completed between the sample pairs at both monitoring sites. The OLS regression was useful because it formulated an equation that most closely approximated the sampled data. The results showed that the suspended-sediment concentration values for all sample pairs at both sites were highly correlated (coefficient of determination [R^2] = 0.98) and close to a 1:1 relation (slope = 1.01) over a range of 1–1,730 mg/L.

Table 2.   Water-quality parameters measured at the Wilson and Trask Rivers, northwestern Oregon, water years 2012–2014.

[**Units:** ft³/s, cubic feet per second; ft, feet; °C, degrees Celsius; μS/cm, microsiemens per centimeter; FNU, Formazin Nephelometric Unit; mg/L, milligrams per liter]

Parameter	Units	Description
Streamflow (Q)	ft³/s	Stream velocity over a given area
Stage (ST)	ft	Height of water based off a known datum
Water temperature (WT)	°C	
Specific conductance (SC)	μS/cm	Water, unfiltered, microsiemens per centimeter at 25 °C
Turbidity (TB)	FNU	Monochrome near infra-red LED light, 780–900 nanometers, detection angle 90 ± 2.5 degrees
Dissolved oxygen concentration (DO)	mg/L	Optical dissolved oxygen concentration

A. Wilson River (USGS streamgage 14301500)

EXPLANATION

o **Suspended-sediment samples**

B. Trask River (USGS streamgage 14302480)
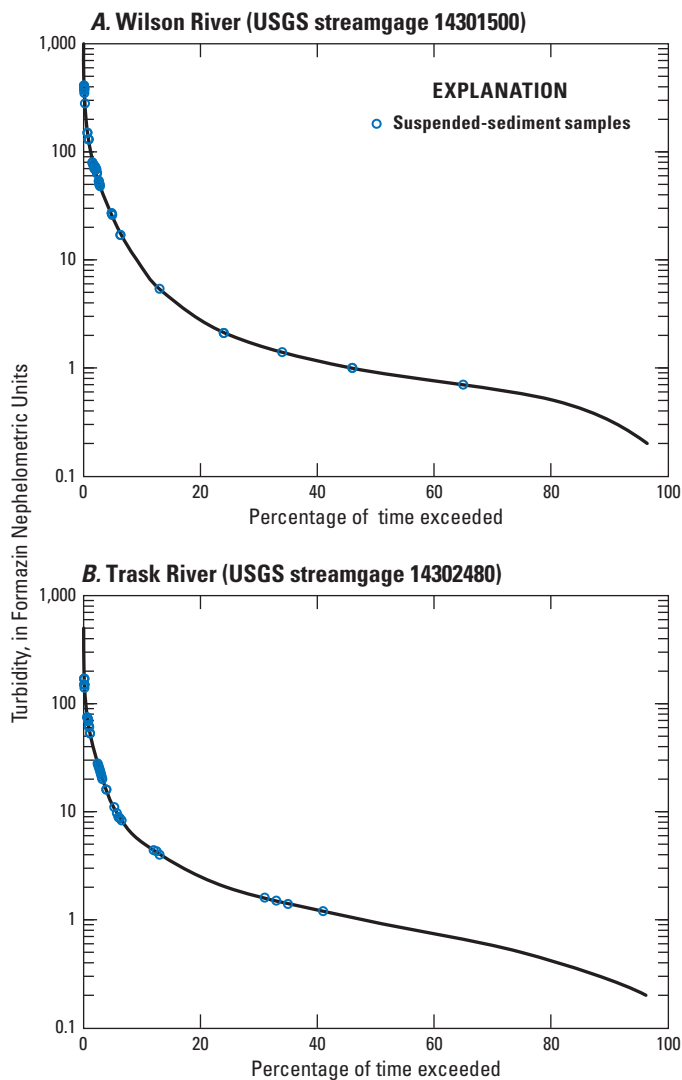
Figure 2. Instantaneous turbidity duration curves for suspended-sediment samples collected at (*A*) Wilson River and (*B*) Trask River streamgage locations, northwestern Oregon, water years 2012–2014.

Data Analysis

Model Calibration Dataset

Each suspended-sediment concentration (SSC) sample was assigned a discrete turbidity and streamflow value from the continuous water-quality monitoring record (15- or 30-minute data). For each sample, turbidity was computed as an average of the instantaneous sensor readings, beginning with the value logged immediately before the start time of the sample collection and ending with the value logged immediately after the end time. Because EWI samples could take as long as an hour to complete, there were usually 3–4 turbidity readings recorded during the sampling period. The

streamflow was interpolated between the instantaneous values to the mean time of the sample collection (see appendixes A and B for more detail).

The collection times for the Trask River EWI samples were adjusted to account for the distance between the streamgage and the sampling site. The time-of-travel correction ranged from 55 to 150 minutes, depending on the streamflow at the time of sample collection (see appendix B for more detail). The time differences were subtracted from the actual beginning, mean, and ending sample times before assigning discrete turbidity and streamflow values to the samples. No obvious outliers were identified in the initial graphical analysis of the sample datasets. However, three EWI samples collected in November 2011 at the Trask River had to be excluded from analysis because the associated turbidity values were removed because of sensor fouling. When EWI sample pairs were collected, the associated SSC, turbidity, and streamflow values of the individual samples were averaged over the sampling period and used for the regression analysis. As a result, the final model calibration dataset included 25 sampling events for the Wilson River and 23 for the Trask River. Additional information concerning the development of the regression models and computation of the continuous SSC record is available in appendixes A and B.

Suspended-Sediment Concentration Regression Models

Using the final sample datasets, OLS regression analyses were completed with the SSC sample data and the instream turbidity and streamflow data for both the Wilson and Trask Rivers. All calculations were computed with a standardized USGS spreadsheet tool designed specifically for surrogate regressions for SSC (Rasmussen and Gray, 2014) using methods described in Rasmussen and others (2009). Turbidity and streamflow were evaluated individually using simple linear regressions and together using multiple linear regressions. They also were evaluated using $\log_{10}$-transformed and untransformed data, as possible independent variables. At both sites, turbidity and streamflow were too highly correlated to use both parameters, so single linear regressions were chosen.

Several summary statistics recommended by Rasmussen and others (2009) were computed to evaluate the appropriateness of the regression models (table 3). These included the coefficient of determination (R^2), which was used to explain variance of predicted versus observed; the root mean squared error (RMSE), which was converted to the upper and lower model standard percent errors (MSPE); the probability plot correlation coefficient (PPCC), which was used to indicate improved normality of the residuals by data transformations; and the predicted residual sum of squares (PRESS), which was used to check the fit of observations that were not used in the model. Residual plots for evaluating variance, normality, homoscedasticity, and curvature are provided in appendixes A and B.

Table 3.   Suspended-sediment concentration regression models for the Wilson and Trask Rivers, northwestern Oregon.

[**Regression model equation:** SSC, suspended-sediment concentration; TB, turbidity. **BCF:** bias correction factor. **R²:** coefficient of determination. **MSPE:** model standard prediction error. **PPCC:** probability plot correlation coefficient. **PRESS:** predicted residual sum of squares. USGS, U.S. Geological Survey]

USGS streamgage No.	USGS streamgage name	Regression model equation	BCF	Adjusted R²	MSPE (percent)	PPCC	PRESS
14301500	Wilson River near Tillamook	$\log_{10}\text{SSC} = 0.361 + 1.05\,\log_{10}\text{TB}$	1.11	0.95	57.2 -36.4	0.97	1.17
14302480	Trask River above Cedar Creek, near Tillamook	$\log_{10}\text{SSC} = 0.331 + 1.06\,\log_{10}\text{TB}$	1.06	0.96	42.6 -29.9	0.94	0.60

The $\log_{10}$-transformed models using turbidity as the explanatory variable were chosen for both sites based on residual plots, adjusted R², MSPE, PPCC, and PRESS statistics. The final form of the regression model was:

$$\log_{10}\text{SSC} = b + a*\log_{10}\text{TB} \qquad (1)$$

where

    SSC is suspended-sediment concentration, in milligrams per liter;
    TB   is turbidity, in Formazin Nephelometric Units; and
    a and b are the slope and y-intercept coefficients, respectively, obtained by the OLS regression analysis.

The logarithmic transformation and subsequent conversion back to original form introduced a known bias, which was addressed with a bias correction factor (BCF) as outlined in Helsel and Hirsch (2002).

Continuous Computation of Suspended-Sediment Concentrations

A complete SSC record was needed to compute the annual suspended-sediment loads (SSL) for the Wilson and Trask Rivers. When turbidity values were missing from the records, instantaneous SSC values were estimated by different methods, depending on streamflow conditions. For the simplest method, SSC values were estimated by interpolating between the model-computed SSC values immediately before and after the missing turbidity data. This method worked well for short time periods when streamflow conditions were steady or when turbidity was consistently increasing or decreasing. For longer periods, or during changing streamflow conditions, SSC was estimated by developing an OLS regression model of SSC using streamflow, rather than turbidity, as an explanatory variable. This method worked best when SSC and streamflow were strongly correlated. Prediction intervals were calculated for each of the regression models to provide error estimates for the continuous SSC. For each computed SSC, the upper and lower predictions were calculated at 90-percent confidence intervals (appendixes A and B).

Wilson River Suspended-Sediment Concentration Record

For most of the 3-year period, continuous SSC at the Wilson River was computed using the $\log_{10}$-transformed turbidity regression model and 15-minute turbidity data. Simple interpolations were used to estimate 11.0, 6.9, and 11.5 percent of the annual records for water years 2012–14, respectively. Most of these estimates were during low-flow, low-turbidity, and low-sediment transport conditions when there were issues with algal biofouling of the optical turbidity sensor (appendix C). During water years 2012 and 2013, several storms produced turbidity values greater than the maximum (410 FNU) included in the model calibration dataset. Therefore, the computed SSCs were designated as "estimated" in the SSC record. These estimated values comprised 0.05 and 0.14 percent of the annual records for water years 2012 and 2013, respectively.

Trask River Suspended-Sediment Concentration Record

For the Trask River, continuous SSCs were computed using a similar $\log_{10}$-transformed turbidity regression model, but with both 30- or 15-minute turbidity data. Simple interpolations were used to estimate 7.3, 4.3, and 15.8 percent of the annual records for water years 2012–14, respectively. Similarly, most of these estimates were during low-flow and low-turbidity conditions. As with the Wilson River, several storms produced turbidity values for the Trask River greater than the maximum 170 FNU included in the model calibration dataset. For these periods, the computed SSCs were described as "estimated," as well, and comprised 0.02, 0.07, and 0.13 percent, respectively, of the annual records for water years 2012–14. Excessive leaf compaction and siltation during a storm in November 2011 resulted in the need to remove 12 days of instream turbidity data. SSC values during this period were computed with a separate streamflow OLS regression model. The resulting computed SSC values were considered "estimated" and comprised 2.2 percent of the annual SSC record for water year 2012.

Suspended-Sediment Load Calculations

The computed and estimated SSC values and corresponding streamflow data were used to calculate continuous SSL for the Wilson and Trask Rivers. The instantaneous SSL values were used to calculate daily SSL, which were then summed to calculate monthly and annual SSL. SSL was calculated as:

$$SSL = SSC*Q*c \qquad (2)$$

where

  SSL is suspended-sediment load, in pounds per second,
  SSC is suspended-sediment concentration, in milligrams per liter,
  Q   is streamflow, in cubic feet per second, and
  c   is the conversion coefficient to convert values to pounds per second (equal to 0.00006242).

The instantaneous SSL values were multiplied by the appropriate time interval and summed to compute total daily SSL. The monthly and annual SSL values were calculated by summing the daily SSL values and converting to tons.

Water-Quality Conditions and Suspended-Sediment Transport

Water Temperature

Between water years 2012 and 2014, there were long periods when the Wilson and Trask Rivers did not meet the water temperature standard (fig. 3) established for cold-water habitat streams in Oregon (Oregon Department of Environmental Quality, 2005a, 2005b, 2014). Each year, between July and October, stream temperatures increased to at least 20 °C in both streams, well above the 7-day average maximum temperature criterion of 16 °C for summer seasonal periods or the 13 °C criterion for the remainder of the year (Oregon Department of Environmental Quality, 2014). High stream temperatures were likely exacerbated by the relatively low baseflow conditions observed each summer during the study period. Each year, 35 percent of the Wilson River temperature readings exceeded the established threshold, and about 33 percent of Trask River temperature readings exceeded the criteria.
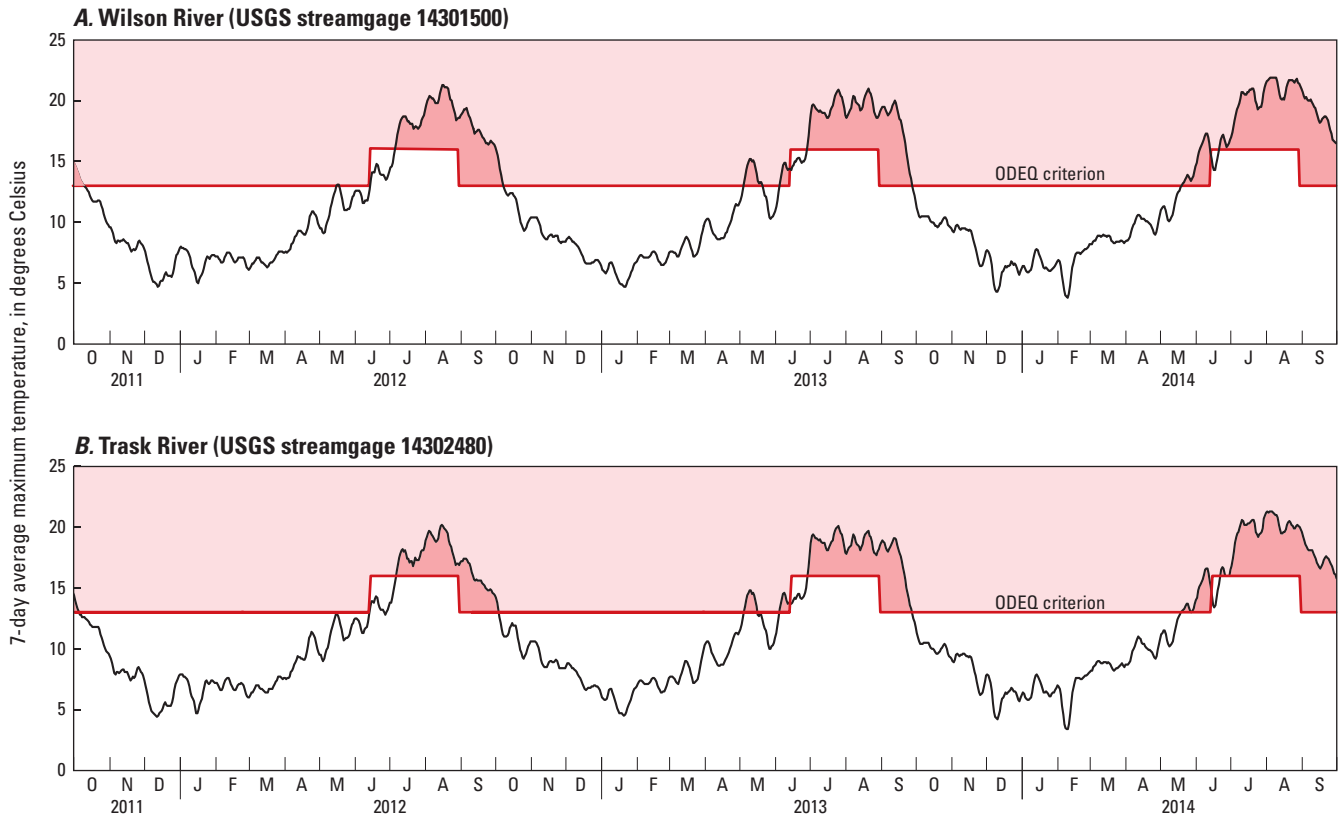
Figure 3. 7-day average maximum water temperature for the Wilson and Trask Rivers, northwestern Oregon, water years 2012–2014. ODEQ Criterion line corresponds to Oregon Department of Environmental Quality water temperature criterion for seasonal core cold-water habitat (13 °C) and salmon and steelhead spawning (16 °C) designated streams. Shaded areas represent times when ODEQ Criterion was not met.

Dissolved Oxygen Concentration

Dissolved oxygen concentrations in the Wilson and Trask Rivers (fig. 4) consistently met the minimum 8.0 mg/L criterion for cold-water habitat streams in Oregon (Oregon Department of Environmental Quality, 2005a, 2005b, 2014). Dissolved oxygen concentrations in the Trask River never decreased to less than the 8.0 mg/L criterion. Dissolved oxygen concentrations in the Wilson River remained greater than the threshold for all but a small fraction of time in the summer of 2014, when a few isolated readings decreased to 7.9 and 7.8 mg/L. There were 16 days with instantaneous readings less than 8.0 mg/L. Concentrations decreased to less than the criterion for less than 1 hour on 8 of those days. The longest period of concentrations less than 8.0 mg/L was on July 20, 2014, when readings did not meet the established criterion for about 6 hours.

Turbidity

Turbidity is an important water-quality indicator of sediment issues and can act as a surrogate for fine sediment transport (Bragg and Uhrich, 2010). The current Oregon Department of Environmental Quality standard for turbidity indicates that "turbidity causing activities" should not increase downstream turbidity by more than 10 percent (Oregon Department of Environmental Quality, 2014). However, it does not detail criteria for baseline stream conditions using turbidity as a water-quality impairment metric.

The turbidity record for the Wilson and Trask Rivers for water years 2012–14 demonstrates periods of intermittently turbid water and increased suspended-sediment transport (fig. 5). However, given the previous history of flooding (National Weather Service, 2014) and the potential for future flooding, the turbidity observed during the study was likely low compared to each river's potential. Between the two

rivers, the Wilson River was consistently more turbid than the Trask River during storms, largely because of the higher streamflow conditions. During the study period, the highest daily median turbidity at both sites was recorded in water year 2012 (fig. 5).

Suspended-Sediment Loads

Daily, monthly, and annual SSL were computed for each monitored watershed. Mean annual streamflows also were referenced to provide context for the annual SSL values. An estimated 597,000 t of suspended sediment entered Tillamook Bay during water years 2012–14. For both the Wilson and Trask Rivers, annual SSL was highest during water year 2012 (240,000 and 69,900 t, respectively; table 4). Mean annual streamflow also was highest during water year 2012. At the Wilson River streamgage, most of the annual SSL in water year 2012 occurred from November 2011 to January 2012 (65 percent of the total annual SSL), but the highest single month was March 2012 (34 percent; fig. 6). Similarly, for the Trask River, the SSL in November 2011 through January 2012 comprised 58 percent and March 2012 comprised 36 percent of the annual SSL in water year 2012.

About one-half the annual SSL was produced in water year 2013 compared to water year 2012 for both rivers. Mean streamflow also was lower for the Wilson and Trask Rivers in water year 2013 compared to the previous year, as well. The only significant autumn or winter storm during water year 2013 occurred in November 2012, although there were several smaller storms in December 2012 that added to the annual SSL. November and December 2012 accounted for 70 percent of the annual SSL at the Wilson River and 73 percent at the Trask River. A late summer/early autumn storm in September 2013 contributed to the annual SSL at the end of water year 2013.
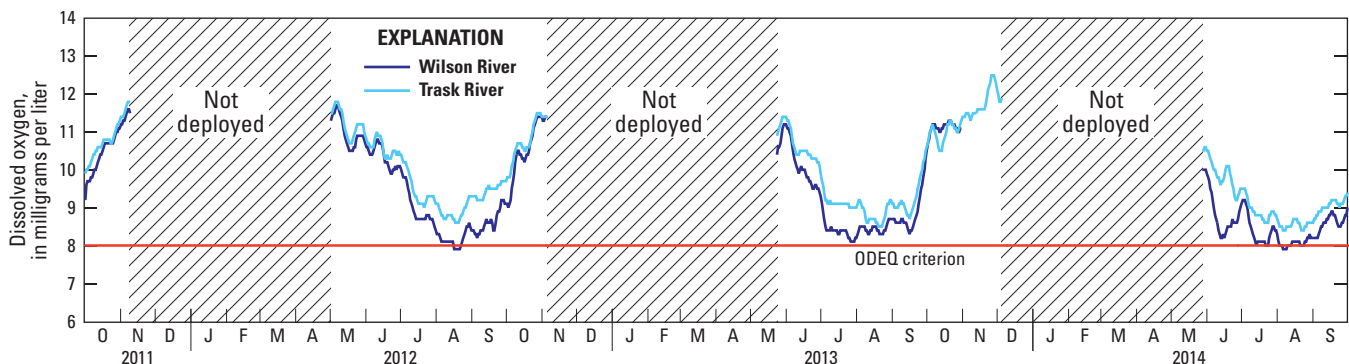
Figure 4. Dissolved oxygen data for the Wilson and Trask Rivers, northwestern Oregon, water years 2012–2014. ODEQ Criterion line corresponds to Oregon Department of Environmental Quality dissolved oxygen criterion for cold-water streams based on 30-day mean minimum daily concentration (8.0 milligrams per liter).
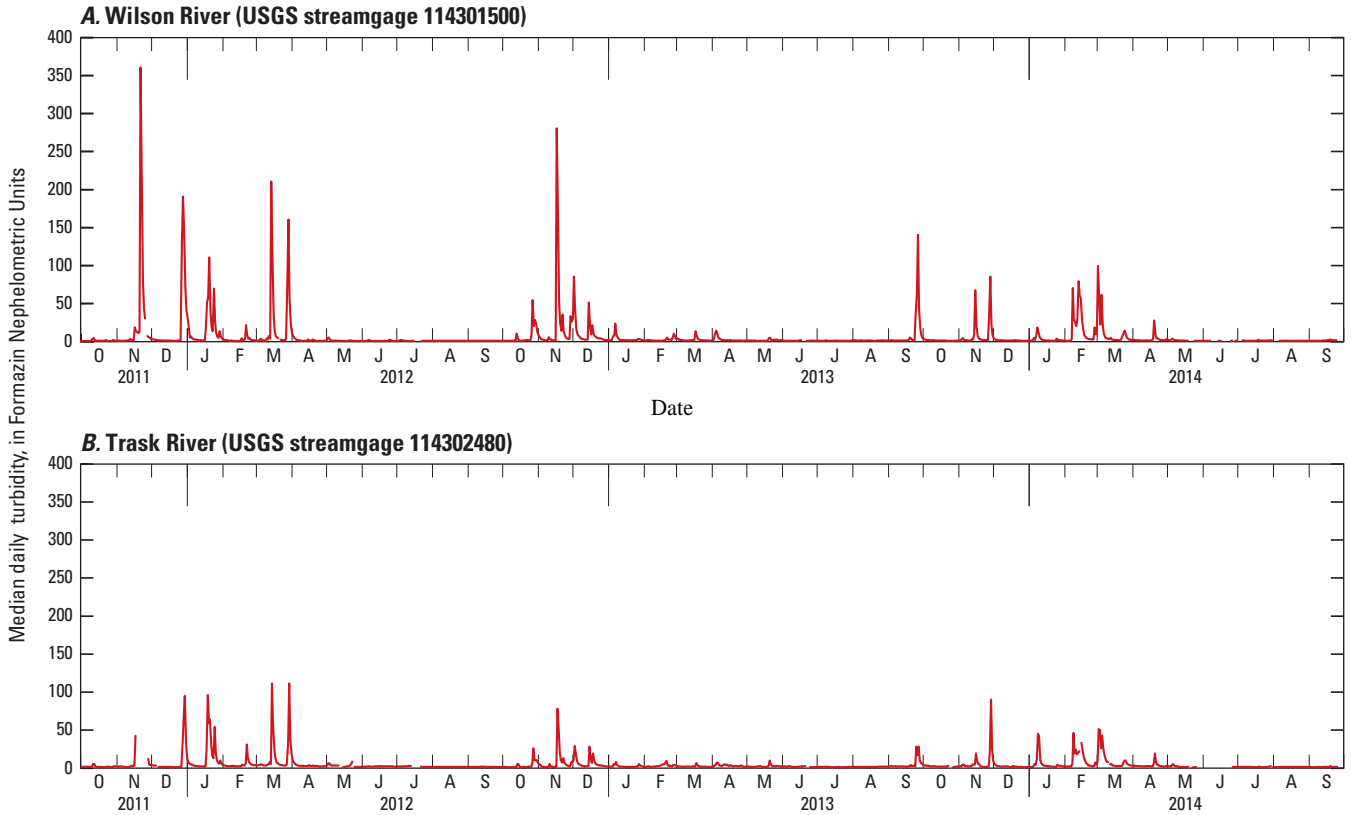
Figure 5.   Daily median turbidity data for the Wilson and Trask Rivers, Oregon, water years 2012–2014.

Table 4.   Annual suspended-sediment loads for the Wilson and Trask Rivers, northwestern Oregon, water years 2012–2014.

[USGS, U.S. Geological Survey; WY, water year]

USGS station No.	USGS station name	Annual suspended-sediment load (tons)		
		WY2012	WY2013	WY2014
14301500	Wilson River near Tillamook	240,000	129,000	80,300
14302480	Trask River above Cedar Creek, near Tillamook	69,900	28,200	49,700

Annual SSL for the Wilson River was lower in water year 2014 than for the two prior water years. There were no significant autumn or winter storms, so only the minor storms in February and March supplied any sizable amount of sediment to the annual SSL (combined 67 percent). At the Trask River, annual SSL for water year 2014 ranked between the other two water years. The storms in December 2013 contributed more to the annual SSL at the Trask River than at the Wilson River (30 and 17 percent, respectively). SSL in February (32 percent) and March (25 percent) were comparable at the Trask River. Both locations had their lowest mean annual streamflow during water year 2014.

Historical Streamflow Record

During the study, weather conditions were calm and peak annual streamflows were minimal compared to prior years. Between the autumn of 2011 and the autumn of 2014, peak streamflows in neither the Wilson nor Trask Rivers exceeded a 5-year recurrence interval, and the Trask River streamflow never exceeded a 2-year event (fig. 7). Because heavy rainfall and high streamflow are required to transport large sediment loads, the SSL calculated for this study did not represent the full sediment transport capacity by either system. Therefore, the regression models developed for this study better reflect
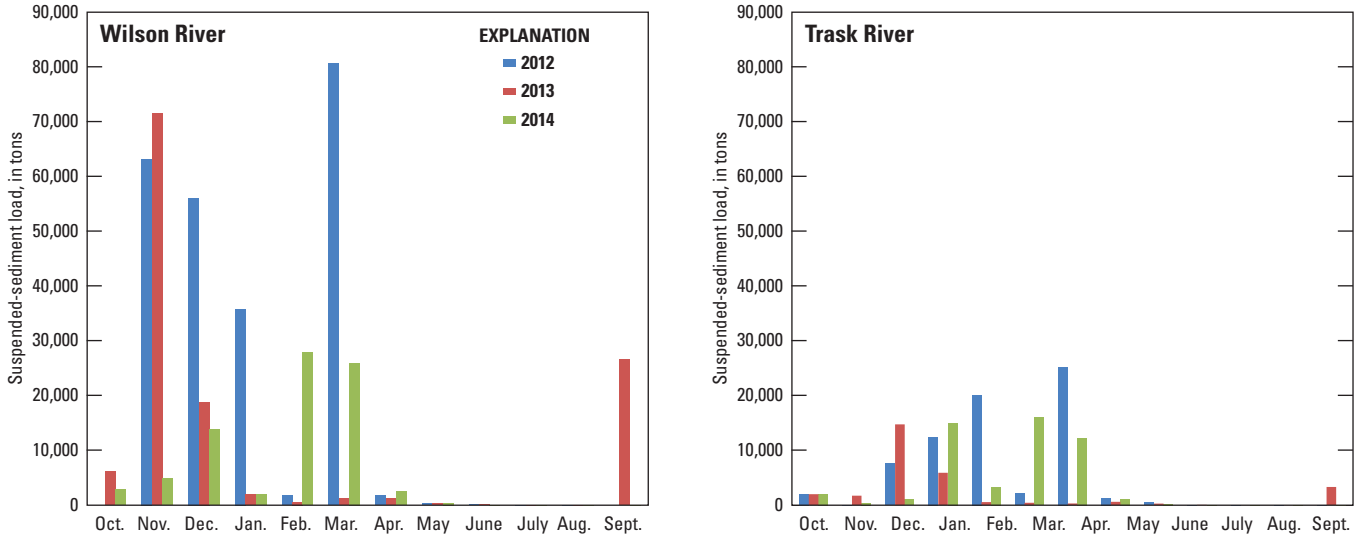
Figure 6.   Monthly suspended-sediment loads for the Wilson and Trask Rivers, northwestern Oregon, water years 2012–2014.
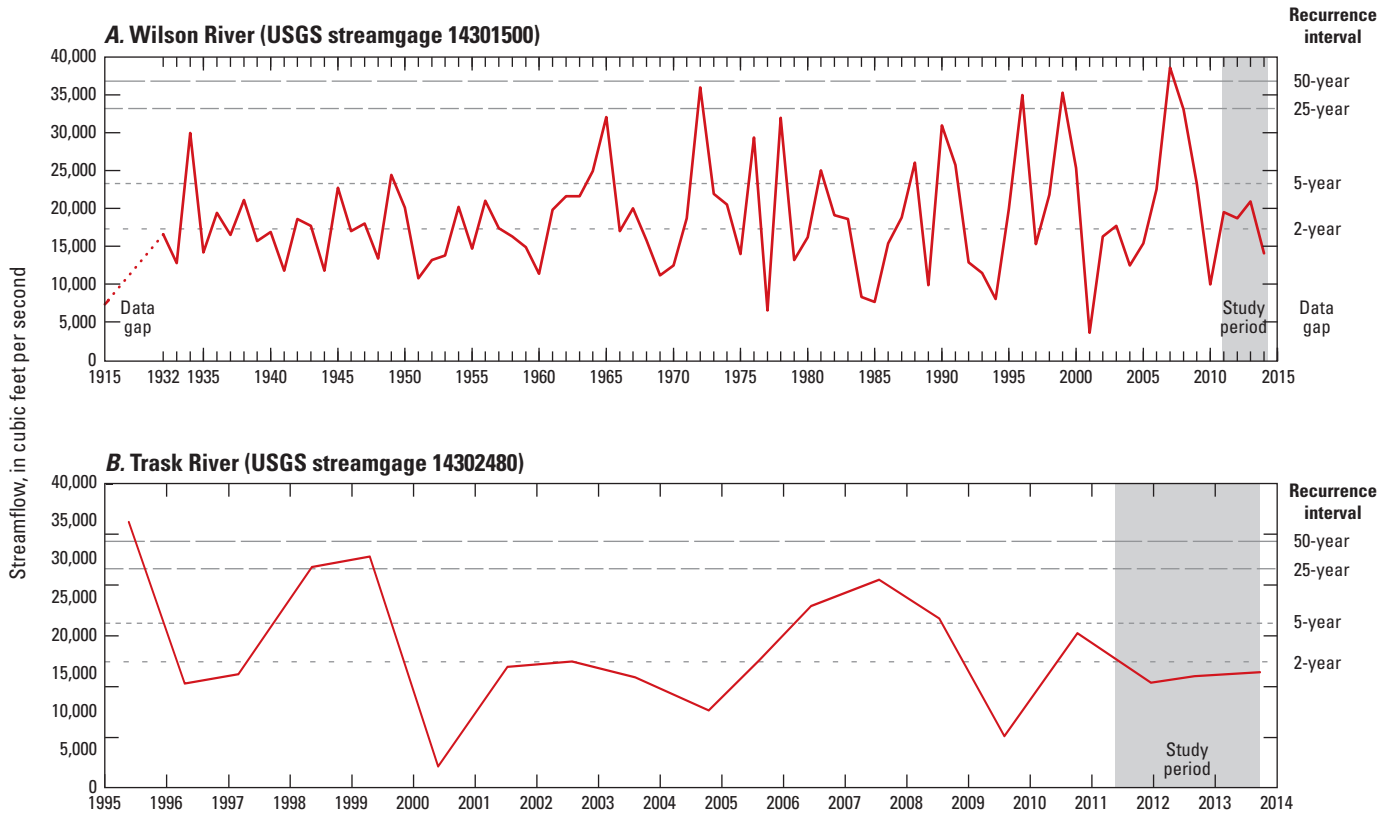
Figure 7.   Peak annual streamflow for the period of record for the (*A*) Wilson and (*B*) Trask Rivers, northwestern Oregon. Shaded area corresponds to 3-year study period. Dashed lines indicate streamflow recurrence intervals for 2-year, 5-year, 25-year, and 50-year type events (Cooper, 2005).

the lower range and magnitude of potential SSL in the Wilson and Trask Rivers. Given the consistency of the streamflow conditions during the study, the models presented do provide a strong baseline for SSL transported by a typical storm in a given year. To retain validity, the regression models should be revisited every few years to ensure that discrete sediment sources, such as landslides or changing channel conditions, have not altered the previously observed sediment transport conditions.

Implications for Stream Conditions for Wilson and Trask Rivers

Water-Quality Status of Wilson and Trask Rivers

The Oregon Department of Environmental Quality (2012) has listed segments of the Wilson and Trask Rivers for a variety of constituent impairments, including water temperature, dissolved oxygen, *E. coli*, fecal coliform, and other toxics and pollutants. Between water years 2012–14, the USGS continuously monitored water temperature, specific conductance, turbidity, and dissolved oxygen in the Wilson and Trask Rivers. Both rivers showed periods when established criterion were not met for water temperature. For example, water temperature routinely exceeded the temperature threshold each summer and remained so for the months leading into the autumn. Temperature in the Wilson and Trask Rivers exceeded the cold-water-habitat temperature criterion for about one-third of the year. Both streams did maintain compliance with the dissolved oxygen standard, as neither showed prolonged periods of low dissolved oxygen. However, summer conditions in both streams were near the dissolved oxygen threshold set by the State, including a brief period of slightly less than the 8.0 mg/L criterion for the Wilson River for parts of a few days in summer 2014. Sampling for other water-quality impairments, such as *E. coli* and nutrients, was beyond the scope of this project.

Along with monitoring water-quality conditions, the USGS sampled and modeled suspended-sediment transport. Sedimentation was identified as one of the greatest basin-wide concerns for Tillamook Bay and has been a focal point for monitoring and management in the past (Tillamook Estuaries Partnership, 1999; Johnson and Drake, 2011). Although many North Coast rivers are considered as being in good condition, some water-quality constituents like biochemical oxygen demand (BOD) and phosphorus have shown a downward trend in recent years (Johnson and Drake, 2011). During this study, normal to less than normal precipitation limited the amount of erosion and subsequent suspended-sediment transport throughout the area. The annual transported totals were likely only a fraction of the material that would be transported during prolonged high streamflow or flooding conditions.

Watershed Characteristics That Influence Sediment Production

Historically, sedimentation issues have influenced much of the resource planning and land management practices in the Tillamook Bay area (Duck Creek Associates, 2008; Johnson and Drake, 2011). As such, there is a continuing desire to better understand sediment sources and transport. Currently, there are no defined criteria because there is a lack of sufficient sediment data (Oregon Department of Environmental Quality, 2012). Data from this study can be used to supplement previous datasets from the State.

Sediment affects many things, including fish populations, water-quality impairment, contaminant transport, efficacy of restoration projects, and shipping and navigation. Previous studies (Duck Creek Associates, 2008) have demonstrated that undisturbed soil erosion in the Wilson and Trask River watersheds does not produce excessive sedimentation because native soils are sufficiently permeable. However, issues arise when soils become compacted or when drainage from roads augments sediment production. Thus, potential processes for increased sediment production in the Tillamook Bay watershed would include runoff from logging roads, storm-driven debris flows, erosion of freshly harvested timber plots, and other disruptive land use and development practices (Follansbee and Stark, 1998; Komar and others, 2004; Duck Creek Associates, 2008; Arismendi and others, 2013; Hatten and others, 2013). Therefore, any effort to impede excessive sedimentation and limit sediment transport relates directly to the reduction of soil disruptions in the Wilson and Trask River watersheds.

Trask River Watershed—Integrating Science

The Trask River watershed is heavily studied because resource agencies, universities, and timber companies are interested in how the basin is managed. In any area where landscape disturbance may occur, such as with active logging, there is always a potential for impacts to stream health. Recent studies (Arismendi and others, 2013) have begun to analyze what impact forest practices have on turbidity, SSC, and SSL. Early results indicate a possible increase in turbidity and SSC from roads used to access the new timber areas. In addition to assessing sediment, other studies like Reiter and others (2013) have explored the effect canopy shading and other thermal processes have on stream temperatures and how conditions may change because of changing climate or continued landscape alterations. Linking upstream landscape activity and water quality to lower watershed conditions would be a valuable next step for integrating science and better understanding stream functions in the Trask River.

Tillamook Southern Flow Corridor Project

One aspect of ecosystem health that benefits from stream monitoring is local restoration projects. At the confluence of the Wilson and Trask Rivers near Tillamook Bay, there is a proposed plan to reduce flood damage and restore habitat along the Tillamook Southern Flow Corridor (Federal Emergency Management Agency, 2014). The current proposal has undergone an environmental impact assessment and five restoration alternatives have been proposed for the area. The favored alternative focuses on the removal of 7–10 mi of levees to allow flood waters to flow across the project area, restoring 526 acres of mostly farmland back to tidal wetlands (Northwest Hydraulic Consultants, 2011). Monitoring SSL on the Wilson and Trask Rivers can help planners determine how much new material will enter the project area, when it will be entering, and how it might affect fluvial and tidal flow dynamics of the restored area. Long-term data collection also helps identify any temporal trends in water temperature or dissolved oxygen, components necessary for maintaining a healthy aquatic habitat.

Summary and Conclusions

The U.S. Geological Survey (USGS) investigated and monitored water-quality conditions and suspended-sediment transport in the Wilson and Trask Rivers, northwestern Oregon. The study established a water-quality and suspended-sediment monitoring network for the two rivers, which are major tributaries to Tillamook Bay. The purpose of the study was to provide water-resource managers with continuous real-time water temperature, specific conductance, turbidity, and dissolved oxygen data for the Wilson and Trask Rivers. In addition, USGS researchers provided estimates of suspended-sediment loads for the two rivers during a 3-year study period (October 2011–September 2014; water years 2012–14).

Four main conclusions can be drawn from this USGS monitoring and modeling effort for the Wilson and Trask Rivers:

1. During years when conditions were typical (no drought or flooding), water temperature did not meet established criterion for cold-water habitat. These conditions will likely be exacerbated during drought years or during months with periods of prolonged hot weather.

2. During the study, dissolved oxygen generally met the criterion for migrating or spawning salmonids. Given the standard set by the State of Oregon, there were very few instances during the study when dissolved oxygen concentrations decreased to less than the established threshold.

3. Suspended-sediment transport likely remains an issue to fish populations, restoration efforts, and even navigation; however, given the average rainfall observed during the study, low streamflow conditions did not mobilize and transport significant amounts of sediment to Tillamook Bay. Nonetheless, baseline characterization did provide context for expected suspended-sediment loads in a given year.

4. Instream monitoring provides data to assist land and resource managers make informed decisions. For example in this study, water temperature was shown to still be a potential concern for spawning and migrating fish. As restoration efforts continue in the Wilson and Trask Rivers, monitoring can be instrumental in the management of stream temperature and sedimentation.

Acknowledgments

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Appendix A. Wilson River Suspended-Sediment Concentration Record

Model Calibration Dataset

Suspended-sediment concentration (SSC) samples were collected using U.S. Geological Survey (USGS) protocols and were stored online in the National Water Information System database. Samples were collected over nearly the entire range of turbidity and streamflow conditions for the 3 years analyzed (water years 2012–14). The ordinary least-squares regression model was based on 25 equal-width-increment (EWI) sampling events where concurrent instream turbidity and streamflow data were available. The model inputs were either the event averages of multiple sample sets (EWI-A and EWI-B) or from single samples (EWI, table A1).

Methods for Assigning Turbidity and Streamflow

To assign turbidity values to discrete SSC samples, continuous (15-minute) instream turbidity data were averaged over the period of EWI sample collection. Turbidity values were averaged starting with the data value immediately before the start of the EWI collection period and ending with the data value immediately after the end of the EWI collection period. Streamflow values were time-weighted between the two 15-minute data values before and after the mean time of the SSC sample. For mean samples times collected on a 15-minute mark, single unit values of streamflow were used (table A1).

Model Development

All regression analyses were done with the "Turbidity Sediment Spreadsheet" using the methods described in Rasmussen and others (2009). Turbidity and streamflow were evaluated separately and together, $\log_{10}$-transformed and untransformed, as possible surrogates. Turbidity and streamflow were too highly correlated to one another (high variance inflation factor; VIF = 13) to use both parameters. The $\log_{10}$-transformed turbidity model was chosen on the basis of residual plots, adjusted coefficient of determination, model standard percent error,

probability plot correlation coefficient, and prediction error sum of squares statistics. Residual plots for evaluating variance, normality, homoscedasticity, and curvature are provided (fig. A1). For the $\log_{10}$-transformed model, computed SSC values were multiplied by a retransformation bias correction factor.

Model Information

The model used for the Wilson River is represented as:

$$\log_{10}\text{SSC} = 0.361 + 1.05 \log_{10}\text{TB} \tag{A1}$$

–See equation 1 and table 3
–Number of measurements = 25
–Standard error (SE) = 0.20
–Upper model standard percent error (MSPE) = +57.2 percent
–Lower model standard percent error (MSPE) = -36.4 percent
–Adjusted coefficient of determination (Adj R^2) = 0.95
–Probability plot correlation coefficient (PPCC) = 0.97
–Prediction error sum-of-squares (PRESS) = 1.17
–Duan bias correction factor (BCF) = 1.11

Suspended-Sediment Concentration Record

SSC time-series data were computed from the 15-minute turbidity data. During short periods of missing or deleted turbidity data, the SSC unit values were estimated by interpolating between the computed SSC values. The daily mean SSC estimated dates were:

Nov. 22, 2011	Jan. 3–5, 2012	Mar. 16, 2013	Jan. 22, 2014
Nov. 26–28, 2011	Mar. 12–13, 2012	June 5–6, 2013	Mar. 14, 2014
Dec. 24–25, 2011	Mar. 21–23, 2012	June 20–25, 2013	May 23–29, 2014
	Apr. 25, 2012	July 14, 2013	June 12–July 10, 2014
	May 16–17, 2012		July 17, 2014
	June 26, 2012		Aug. 5–11, 2014
	July 2–3, 2012		Aug. 24–26, 2014
	July 5, 2012		
	July 7, 2012		
	July 17–24, 2012		
	Aug. 19, 2012		
	Nov. 3–5, 2012		
	Nov. 19, 2012		
	Mar. 2–3, 2012		

Summary statistics for the regression model dataset and the continuous turbidity and SSC records are provided in table A2. The continuous SSC data and 90-percent prediction intervals are shown in figures A2–A4.

Table A1. Suspended-sediment sample and model calibration data for the Wilson River, northwestern Oregon.

[**Sample type/set:** EWI is a single sample; EWI-A/B/C are consecutive samples and are averaged into an event average. **Abbreviations:** EWI, equal-width-increment; FNU, Formazin Nephelometric Unit; ft³/s, cubic feet per second; mg/L, millligrams per liter; μm, micrometers]

Date and time (local Pacific time)		Sample type/set	Turbidity (FNU)	Streamflow (ft³/s)	Suspended-sediment concentration (mg/L)	Sediment finer than 63 μm (percent)	Record No.
11-14-2011	10:55	EWI-A	2.1	556	2	–	1200045
	11:02	EWI event average	2.1	556	2	–	1201907
	11:10	EWI-B	2.1	556	2	–	1200046
11-22-2011	15:48	EWI	380	16,300	966	73	1200030
11-29-2011	13:10	EWI	5.4	1,860	8	79	1200065
12-07-2011	16:20	EWI	1.4	715	2	–	1200090
01-19-2012	13:35	EWI-A	68	9,070	618	20	1200136
	14:05	EWI-B	71	9,360	446	30	1200137
	14:08	EWI event average	71	9,440	527	27	1201908
	14:45	EWI-C	75	9,900	516	32	1200140
01-24-2012	16:43	EWI	26	5,200	115	38	1200149
01-25-2012	11:00	EWI-A	76	9,630	245	52	1200152
	11:09	EWI event average	74	9,560	260	48	1200153
	11:18	EWI-B	72	9,500	276	45	1200153
02-06-2012	16:05	EWI	0.7	1,140	4	50	1200205
03-15-2012	12:50	EWI-A	350	18,500	1,530	56	1201909
	13:05	EWI event average	370	18,600	1,630	55	1200225
	13:20	EWI-B	390	18,700	1,730	54	1201910
	13:47	EWI-A	390	18,800	1,690	54	1201911
	14:01	EWI event average	380	18,800	1,680	54	1200231
	14:14	EWI-B	380	18,700	1,660	54	1201912
	18:14	EWI	280	17,500	1,090	51	1200235
03-16-2012	10:58	EWI	130	9,980	359	59	1200240
05-23-2012	15:50	EWI-A	1	1,170	4	–	1200333
	16:06	EWI event average	1	1,160	4	–	1201913
	16:22	EWI-B	1	1,160	3	–	1200334
10-29-2012	11:55	EWI-A	69	7,740	216	48	1300124
	12:20	EWI event average	66	7,520	220	46	1300127
	12:35	EWI-B	64	7,390	225	43	1300125
	12:55	EWI-C	63	7,200	223	44	1300126
10-30-2012	12:35	EWI-A	17	3,880	46	39	1301527

Table A1. Suspended-sediment sample and model calibration data for the Wilson River, northwestern Oregon.—Continued

Date and time (local Pacific time)		Sample type/set	Turbidity (FNU)	Streamflow (ft³/s)	Suspended-sediment concentration (mg/L)	Sediment finer than 63 µm (percent)	Record No.
	12:55	EWI event average	17	3,960	44	42	1300134
	13:15	EWI-B	17	4,040	42	44	1301528
10-31-2012	11:51	EWI-A	27	5,400	60	52	1300141
	12:08	EWI event average	27	5,400	60	52	1301529
	12:25	EWI-B	27	5,400	60	–	1300143
11-19-2012	12:59	EWI-A	380	18,400	929	65	1300063
	13:26	EWI Event Average	375	18,800	950	70	1301530
	13:53	EWI-B	370	19,200	971	74	1301531
	14:35	EWI-A	410	19,700	1,030	77	1300072
	14:42	EWI event average	410	19,800	1,060	76	1301532
	14:50	EWI-B	410	19,900	1,100	74	1300074
11-20-2012	13:24	EWI-A	150	8,920	295	76	1300085
	13:29	EWI event average	150	8,900	295	76	1301533
	13:34	EWI-B	150	8,890	295	75	1300087
11-21-2012	12:14	EWI-A	50	5,470	106	66	1300101
	12:22	EWI event average	50	5,450	110	62	1301534
	12:31	EWI-B	50	5,430	114	58	1300102
12-05-2012	10:35	EWI-A	51	6,600	110	58	1300184
	10:46	EWI event average	50	6,580	110	56	1301535
	10:55	EWI-B	48	6,570	110	55	1300186
09-29-2013	10:24	EWI-A	53	6,550	127	59	1301536
	10:38	EWI event average	54	6,620	126	57	1300854
	10:59	EWI-B	54	6,690	124	55	1301537
11-19-2013	09:52	EWI-A	80	6,840	180	60	1400037
	10:06	EWI event average	80	6,830	185	58	1400040
	10:20	EWI-B	79	6,820	190	55	1400042
12-02-2013	14:05	EWI-A	72	7,130	156	62	1400077
	14:19	EWI event average	71	7,040	150	66	1400775
	14:34	EWI-B	70	6,950	143	69	1400080
02-12-2014	11:03	EWI-A	130	10,100	333	66	1400254
	11:19	EWI event average	130	9,790	322	65	1400776
	11:35	EWI-B	130	9,480	312	64	1400255

Table A2.   Summary statistics for model calibration and continuous turbidity and suspended-sediment concentration for the Wilson River, northwestern Oregon.

[**Continuous data:** SSC, suspended-sediment concentration; WY, water year. **Abbreviations:** FNU, Formazin Nephelometric Unit; mg/L, millligrams per liter]

Summary statistic	Model calibration data (number of sampling events = 25)		Continuous data (15-minute interval)					
			WY2012		WY2013		WY2014	
	Turbidity (FNU)	SSC (mg/L)	Turbidity (FNU)	SSC (mg/L)	Turbidity (FNU)	SSC (mg/L)	Turbidity (FNU)	SSC (mg/L)
Minimum	1	2	0	0	0.2	0.5	0.1	0.2
Maximum	410	1,680	600	2,110	540	1,890	250	843
Median	128	411	0.6	1.5	1.1	2.8	1	2.5
Mean	71	185	8.2	25.7	5.6	16.9	4.6	13.7
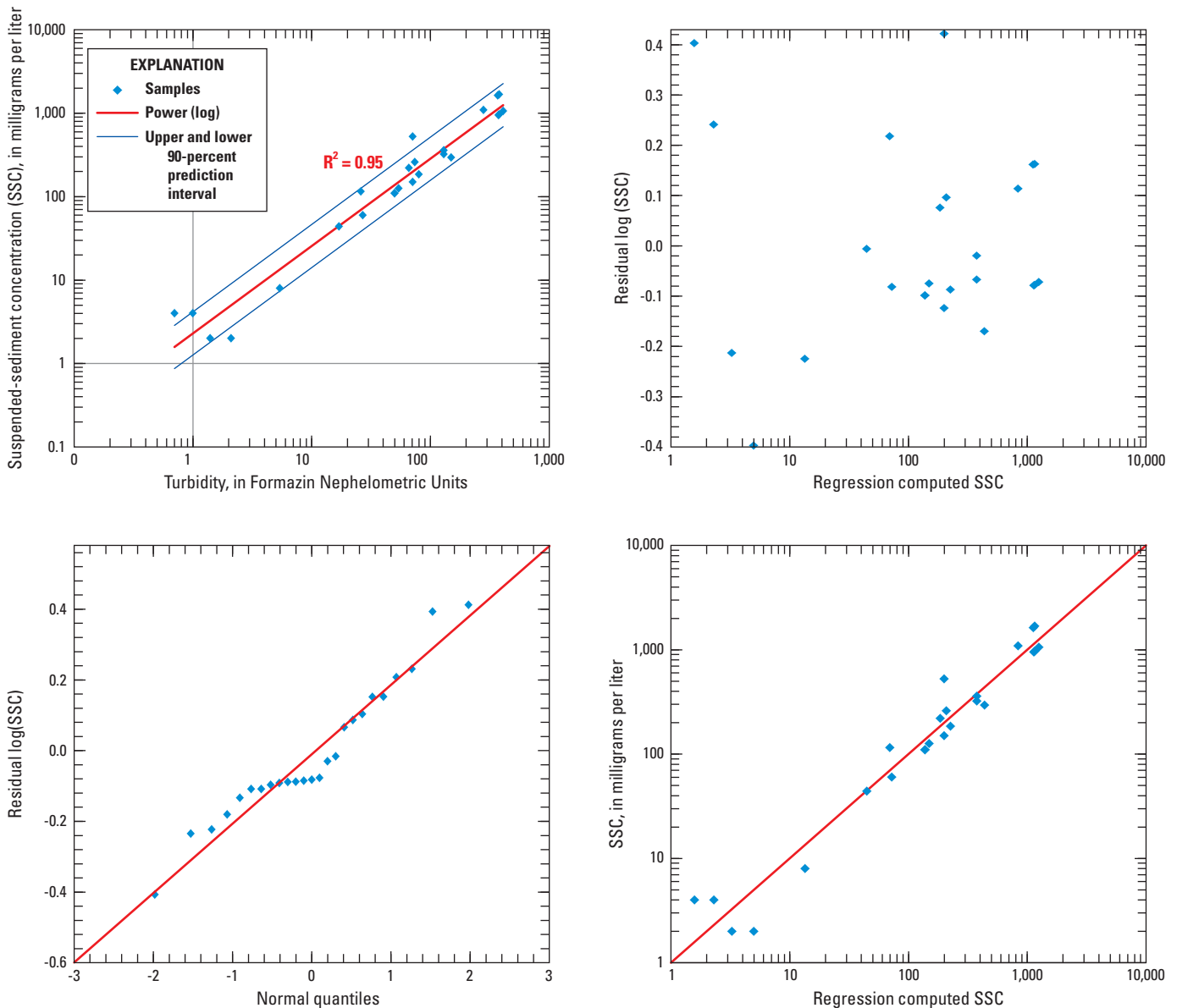
Figure A1.   Ordinary least-squares regression model plots for the Wilson River, northwestern Oregon.
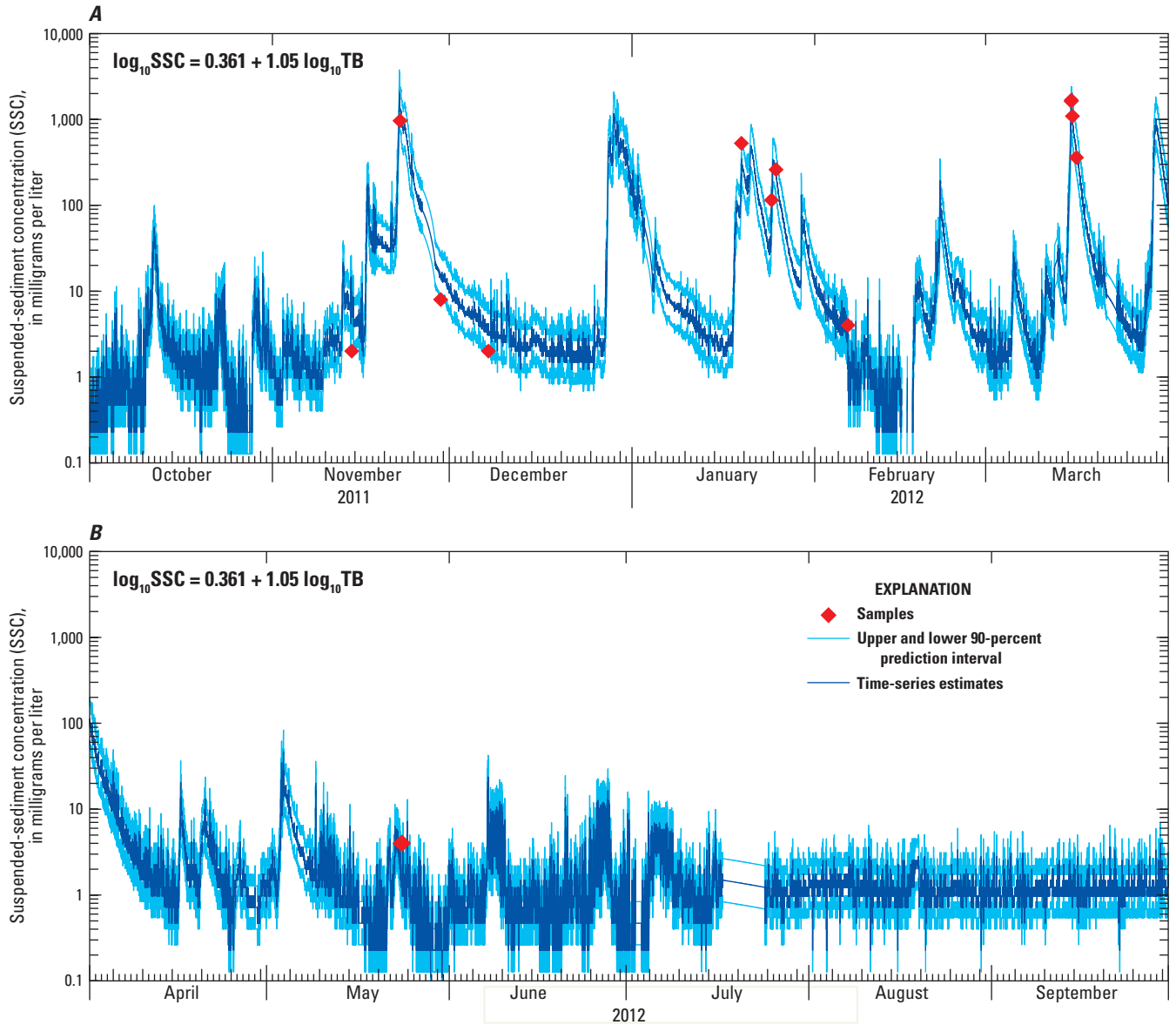
Figure A2. Suspended-sediment concentration (SSC) data, 90-percent prediction intervals, and sample data at the Wilson River, northwestern Oregon, October 2011–March 2012 and April–September 2012.
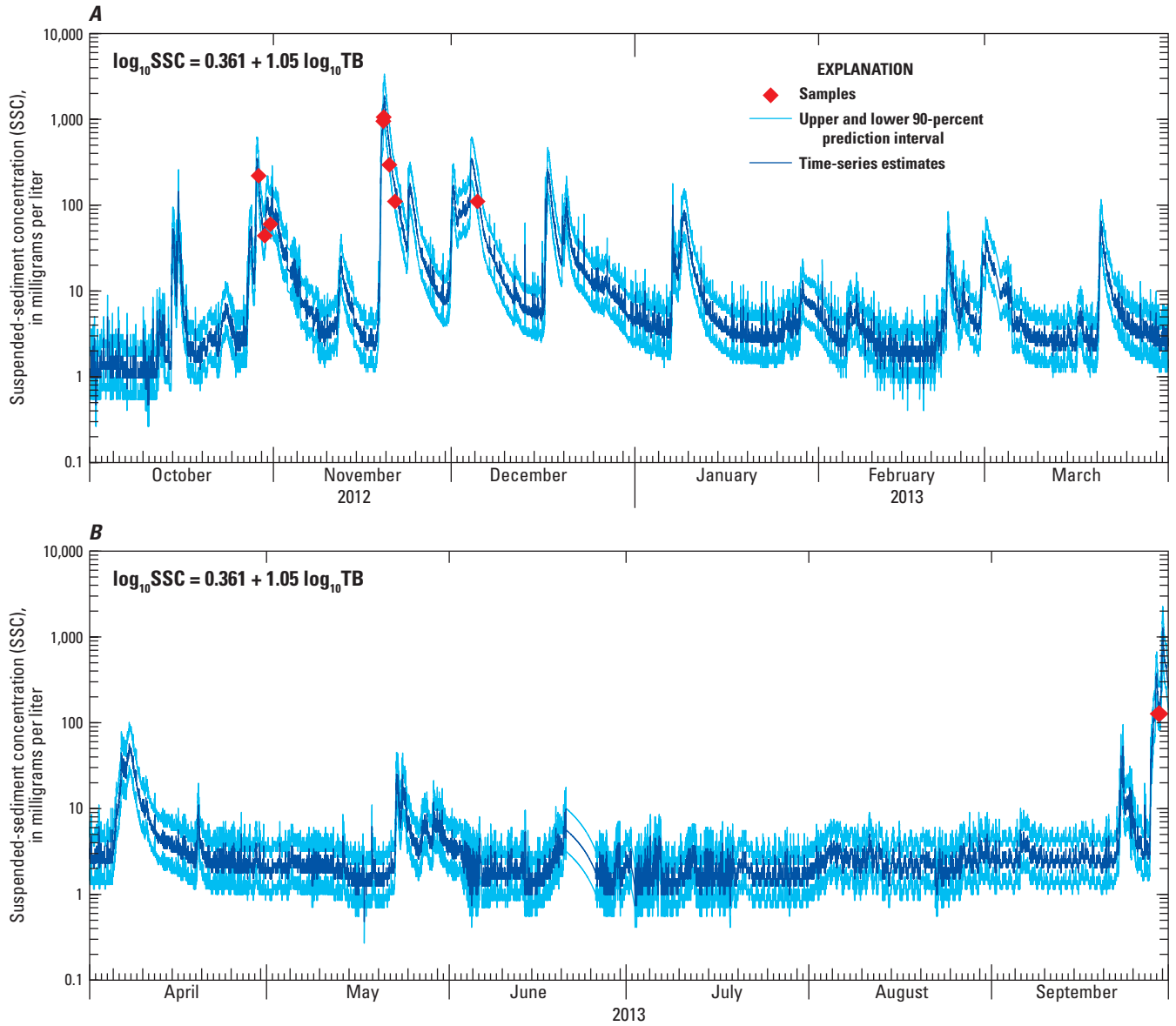
Figure A3.   Suspended-sediment concentration (SSC) data, 90-percent prediction intervals, and sample data at the Wilson River, northwestern Oregon, October 2012–March 2013 and April–September 2013.
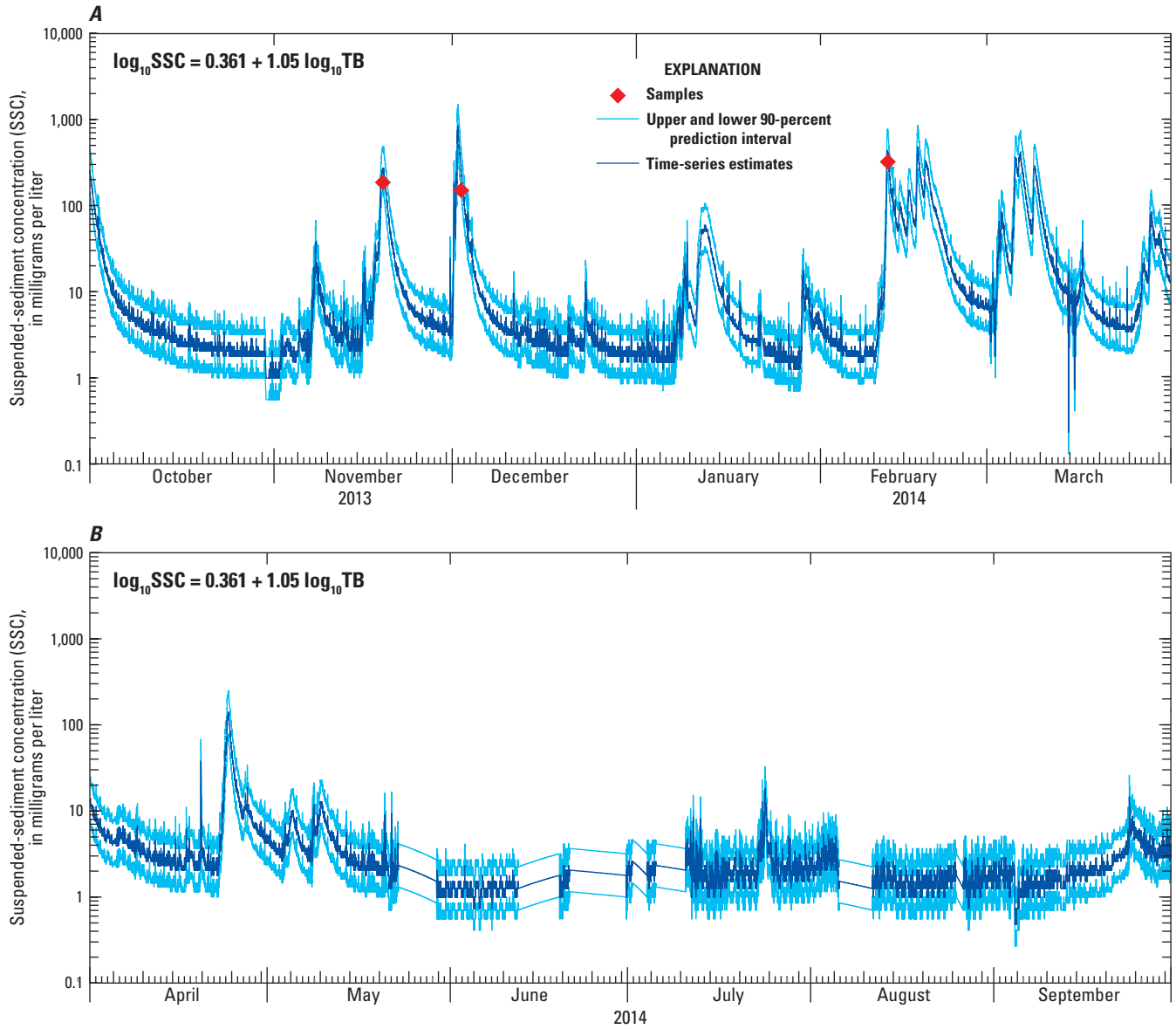
Figure A4.   Suspended-sediment concentration (SSC) data, 90-percent prediction intervals, and sample data at the Wilson River, northwestern Oregon, October 2012–March 2013 and April–September 2013.

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Appendix B. Trask River Suspended-Sediment Concentration Record

Model Calibration Dataset

All suspended-sediment concentration (SSC) samples were collected using USGS protocols and are stored in the U.S. Geological Survey National Water Information System database. Samples were collected over nearly the entire range of turbidity and streamflow conditions for the 3 years analyzed (water years 2012–14). The ordinary least-squares regression model was based on 23 equal-width-increment (EWI) sampling events where concurrent instream turbidity and streamflow data were available. The model inputs were either the event averages of multiple sample sets (EWI-A and EWI-B) or from single samples (EWI, table B1).

Time-of-Travel Correction

The location of the water-quality monitor and streamgage was about 4 river miles (21,120 ft) upstream of the sampling location on the Long Prairie Road Bridge. To account for this difference, all suspended-sediment sample times were adjusted for time-of-travel. The computation used the mean velocity of all streamflow measurements from water years 2008–2014 and two high-streamflow measurements from water years 1998 and 1999 (47 measurements total). The time-of-travel during the streamflow measurements was computed using:

$$t = \frac{\dfrac{d}{1.3 * v}}{c} \tag{B1}$$

where

> t is time-of-travel (hr),
> d is the distance (ft),
> v is the mean velocity (ft/s), and
> c is a conversion constant to convert seconds to hours (equal to 3,600 s/hr).

The discrete measured streamflow and associated time-of-travel values were plotted and a power function trend line was fit to the data. The resulting equation was used to determine the time-of-travel correction for each suspended-sediment sample based on the streamflow at the actual mean sample time:

$$t = 14 * Q^{-0.294} \tag{B2}$$

where

> t is time-of-travel (hr), and
> Q is streamflow (ft^3/s).

The time-of-travel adjustment was subtracted from the actual mean sample times for each sample for assigning streamflow values. Adjusted begin and end sample times also were used for computing average turbidity values for the samples (table B1).

Methods for Assigning Turbidity and Streamflow

To assign turbidity values to discrete SSC samples, continuous (30- or 15-minute) instream turbidity data were averaged over the period of EWI sample collection. Turbidity values were averaged starting with the data value immediately before the start time (adjusted for time-of-travel) of the EWI and ending with the data value immediately after the end time (adjusted for time-of-travel) of the EWI. Streamflow values were time-weighted between the two 30- or 15-minute data values before and after the mean time (adjusted for time-of-travel) of the SSC sample. For mean samples times on a 30- or 15-minute mark, single unit values of streamflow were used (table B2).

Model Development

Regression analyses were done with the "Turbidity Sediment Spreadsheet" using the methods described in the Rasmussen and others (2009). Turbidity and streamflow were evaluated separately and together, log$_{10}$-transformed and untransformed, as possible surrogates. The log$_{10}$-transformed turbidity model was chosen on the basis of residual plots, adjusted coefficient of determination, model standard percent error, probability plot correlation coefficient, and prediction error sum of squares statistics. Residual plots for evaluating variance, normality, homoscedasticity, and curvature are provided in figure B1. For the log$_{10}$-transformed model, computed SSC values were multiplied by a retransformation bias correction factor.

Model Information

The model used for the Trask River site is represented as:

$$\log_{10}\text{SSC} = 0.331 + 1.06 \log_{10}\text{TB} \qquad \text{(B3)}$$

–See equation 1 and table 3
–Number of measurements = 23
–Standard error (SE) = 0.15
–Upper model standard percent error (MSPE) = +42.6 percent
–Lower model standard percent error (MSPE) = -29.9 percent
–Adjusted coefficient of determination (Adj R^2) = 0.96
–Probability plot correlation coefficient (PPCC) = 0.94
–Prediction error sum-of-squares (PRESS) = 0.60
–Duan bias correction factor (BCF) = 1.06

Suspended-Sediment Content Record

SSC time-series data were computed from the 15-minute turbidity data. During short periods of missing or deleted turbidity data, the SSC unit values were estimated by interpolating between the computed SSC values.

The daily mean SSC estimated dates were:

Nov. 17–28, 2011	May 11–16, 2012	Apr. 28–29, 2013	Jan. 13–14, 2014
Dec. 4–7, 2011	May 24–26, 2012	May 15, 2013	Feb. 6–7, 2014
	July 3, 2012	May 20, 2013	Feb. 12–15, 2014
	July 14–23, 2012	June 5–7, 2013	Feb. 17–19, 2014
	Oct. 24, 2012	June 23–27, 2013	Feb. 22–25, 2014
	Oct. 29, 2012	Oct. 4, 2013	Mar. 14–16, 2014
	Nov. 1–4, 2012	Oct. 8, 2013	May 23–27, 2014
	Nov. 19–21, 2012	Oct. 24–30, 2013	May 30–July 1, 2014
	Nov. 26–29, 2012	Nov. 19, 2013	Aug. 3–5, 2014
		Nov. 22–23, 2013	
		Dec. 2, 2013	
		Dec. 6, 2013	
		Dec. 9, 2013	
		Dec. 19, 2013	

Summary statistics for the regression model dataset and the continuous turbidity and SSC records are provided in table B2. The continuous SSC data and 90-percent prediction intervals are shown in figures B2–B4.

Table B1. Suspended-sediment sample and model calibration data for the Trask River, northwestern Oregon.

[**Sample type/set:** EWI is a single sample; EWI-A/B/C are consecutive samples and are averaged into an event average. **Abbreviations:** EWI, equal-width-increment; FNU, Formazin Nephelometric Unit; ft³/s, cubic feet per second; mg/L, millligrams per liter; μm, micrometers]

| Date and time (local Pacific time)	Date and time (time-of-travel adjusted)	Sample type/set	Turbidity (FNU)	Streamflow (ft³/s)	Suspended-sediment concentration (mg/L)	Sediment finer than 63 μm (percent)	Record No.
11-14-2011 13:15	11-14-2011 10:44	EWI-A	1.6	342	3	–	1200066
13:27	11-14-2011 10:57	EWI event average	1.6	342	3	–	1201914
13:40	11-14-2011 11:09	EWI-B	1.5	342	2	–	1200067
11-29-2011 10:18	11-29-2011 08:37	EWI	4	1,390	10	50	1200069
12-07-2011 13:55	12-07-2011 11:49	EWI	1.2	651	3	–	1200103
01-19-2012 11:22	01-19-2012 10:19	EWI-A	61	6,010	474	29	1200158
11:35	01-19-2012 10:38	EWI event average	66	6,160	368	45	1200160
12:00	01-19-2012 10:57	EWI-B	71	6,330	261	60	1200161
16:05	01-19-2012 15:06	EWI-A	150	8,740	410	62	1200162
16:17	01-19-2012 15:19	EWI event average	150	8,750	413	65	1200163
16:30	01-19-2012 15:32	EWI-B	150	8,770	416	67	1200164
01-24-2012 15:30	01-24-2012 14:16	EWI-A	16	3,760	74	37	1200165
15:37	01-24-2012 14:25	EWI event average	16	3,810	71	39	1200166
15:47	01-24-2012 14:34	EWI-B	16	3,850	67	40	1200167
01-25-2012 08:42	01-25-2012 07:38	EWI-A	71	6,840	177	72	1200168
08:55	01-25-2012 07:52	EWI event average	70	6,820	180	70	1200169
09:09	01-25-2012 08:05	EWI-B	69	6,790	182	67	1200170
02-07-2012 13:01	02-07-2012 11:07	EWI	1.4	882	5	33	1200206

Table B1.   Suspended-sediment sample and model calibration data for the Trask River, northwestern Oregon.—Continued

| Date and time (local Pacific time)		Date and time (time-of-travel adjusted)		Sample type/set	Turbidity (FNU)	Streamflow (ft³/s)	Suspended-sediment concentration (mg/L)	Sediment finer than 63 μm (percent)	Record No.
03-15-2012	15:59	03-15-2012	15:03	EWI-A	170	10,400	463	64	1200243
	16:08	03-15-2012	15:13	EWI event average	170	10,400	448	68	1200244
	16:17	03-15-2012	15:23	EWI-B	170	10,500	433	71	1200245
	16:40	03-15-2012	15:44	EWI-A	170	10,300	417	72	1200246
	16:50	03-15-2012	15:54	EWI event average	170	10,200	415	70	1200247
	17:01	03-15-2012	16:05	EWI-B	170	10,200	412	67	1200248
03-16-2012	09:10	03-16-2012	08:06	EWI-A	71	6,860	195	65	1200249
	09:25	03-16-2012	08:21	EWI event average	70	6,780	191	67	1200250
	09:40	03-16-2012	08:36	EWI-B	69	6,700	186	69	1200251
05-23-2012	10:31	05-23-2012	08:37	EWI-A	4.3	904	3	–	1200335
	10:42	05-23-2012	08:48	EWI event average	4.4	905	4	–	1201915
	10:53	05-23-2012	08:59	EWI-B	4.4	909	5	–	1200336
10-29-2012	14:40	10-29-2012	13:27	EWI-A	27	4,270	58	69	1300144
	15:15	10-29-2012	14:01	EWI event average	25	4,200	58	69	1301544
	15:20	10-29-2012	14:06	EWI-B	25	4,180	54	67	1300145
	15:45	10-29-2012	14:30	EWI-C	24	4,100	62	70	1300146
10-30-2012	15:06	10-30-2012	13:48	EWI-A	8.3	3,100	21	67	1300147
	15:20	10-30-2012	14:02	EWI event average	8.6	3,140	21	68	1301545
	15:35	10-30-2012	14:17	EWI-B	8.9	3,160	21	68	1300148
10-31-2012	09:33	10-31-2012	08:17	EWI-A	8.7	3,360	17	73	1300149
	09:47	10-31-2012	08:31	EWI event average	8.8	3,370	18	73	1301546
	10:02	10-31-2012	08:45	EWI-B	8.9	3,400	18	72	1300150
11-19-2012	10:17	11-19-2012	09:16	EWI-A	74	7,260	217	76	1300089
	10:31	11-19-2012	09:31	EWI event average	74	7,330	202	77	1301547
	10:45	11-19-2012	09:45	EWI-B	75	7,450	186	78	1300090
11-20-2012	11:09	11-20-2012	10:04	EWI-A	62	6,460	242	38	1300091
	11:26	11-20-2012	10:21	EWI event average	62	6,460	233	41	1301548
	11:43	11-20-2012	10:38	EWI-B	61	6,330	223	43	1300092
11-21-2012	10:29	11-21-2012	09:17	EWI-A	21	4,360	47	67	1300104
	10:42	11-21-2012	09:30	EWI event average	20	4,350	52	60	1301549
	10:55	11-21-2012	09:43	EWI-B	20	4,360	57	52	1300105
12-05-2012	08:25	12-05-2012	07:17	EWI-A	23	5,300	54	64	1300189
	08:49	12-05-2012	07:41	EWI event average	22	5,250	52	67	1301550
	09:14	12-05-2012	08:05	EWI-B	22	5,240	49	70	1300190
09-29-2013	12:50	09-29-2013	11:31	EWI-A	11	3,210	19	71	1300870
	13:00	09-29-2013	11:46	EWI event average	10	3,220	21	68	1300872
	13:20	09-29-2013	12:01	EWI-B	9.7	3,230	22	65	1300873
11-19-2013	11:39	11-19-2013	10:23	EWI-A	28	3,610	50	75	1400048
	11:50	11-19-2013	10:35	EWI event average	27	3,630	61	64	1400050
	12:02	11-19-2013	10:47	EWI-B	26	3,630	72	52	1400051
12-02-2013	11:30	12-02-2013	10:29	EWI-A	150	7,880	317	83	1400083
	12:03	12-02-2013	11:02	EWI event average	150	7,800	302	84	1400780
	12:05	12-02-2013	11:03	EWI-B	150	7,780	303	84	1400084
	12:35	12-02-2013	11:33	EWI-C	140	7,630	287	84	1400085
02-12-2014	14:24	02-12-2014	13:14	EWI-A	53	4,940	274	33	1400259
	14:34	02-12-2014	13:24	EWI event average	53	4,880	242	43	1400781
	14:45	02-12-2014	13:35	EWI-B	53	4,850	151	52	1400260

Table B2.   Summary statistics for model calibration and continuous turbidity and suspended-sediment concentration for the Trask River, northwestern Oregon.

[**Continuous data:** SSC, suspended-sediment concentration; WY, water year. **Abbreviations:** FNU, Formazin Nephelometric Unit; mg/L, millligrams per liter]

| Summary statistic | Model calibration data (number of sampling events = 23) | | Continuous data (15-minute interval) | | | | | |
| | | | WY2012 | | WY2013 | | WY2014 | |
	Turbidity (FNU)	SSC (mg/L)	Turbidity (FNU)	SSC (mg/L)	Turbidity (FNU)	SSC (mg/L)	Turbidity (FNU)	SSC (mg/L)
Minimum	1	3	0	0	0	0	0	0
Maximum	170	448	180	558	302	966	342	1,100
Median	52	147	1.2	3	1	2.3	1	2.3
Mean	25	61	4.7	14.1	2.8	7.4	4	11
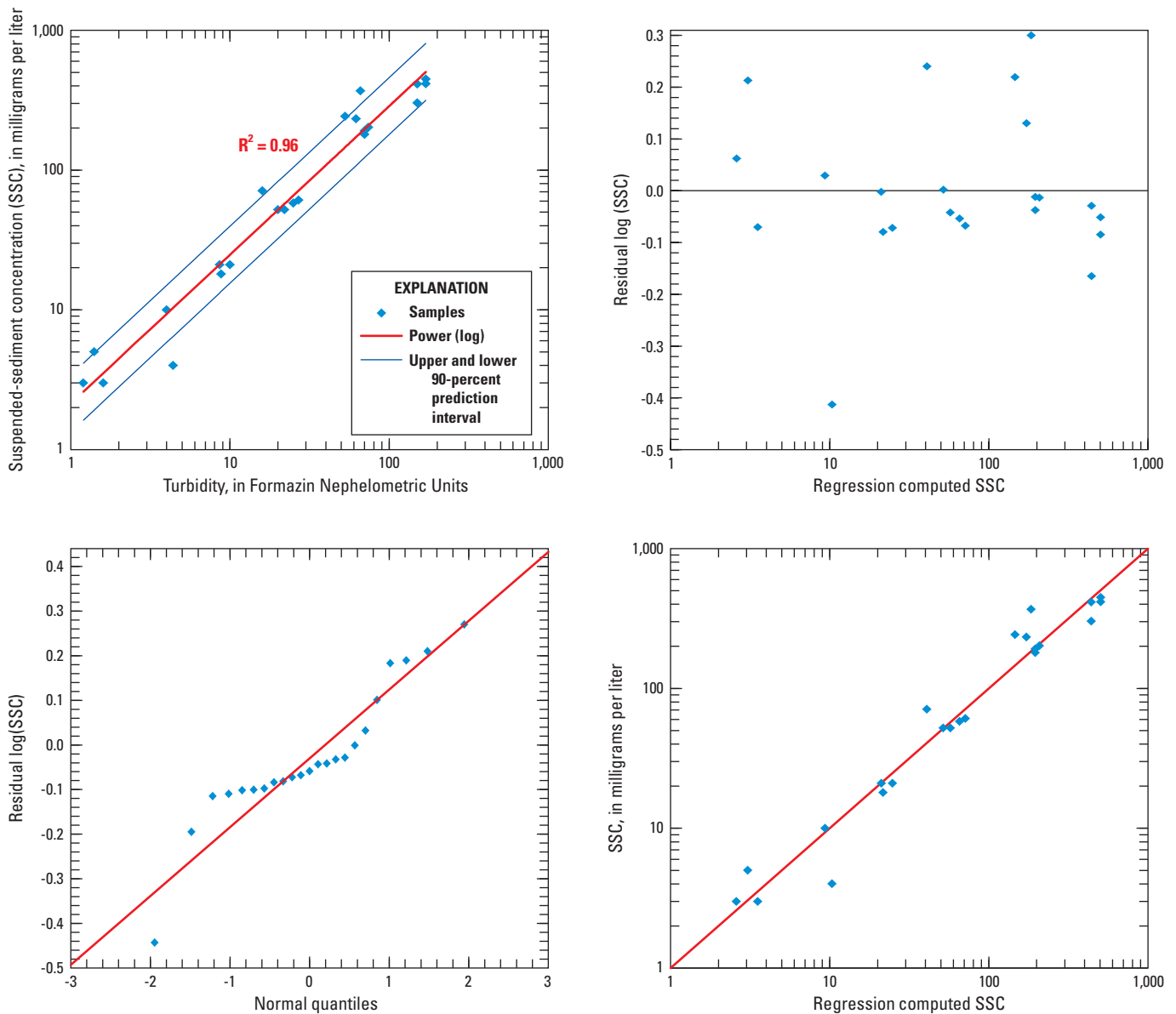
Figure B1.   Ordinary least-squares regression model plots for the Trask River, northwestern Oregon.
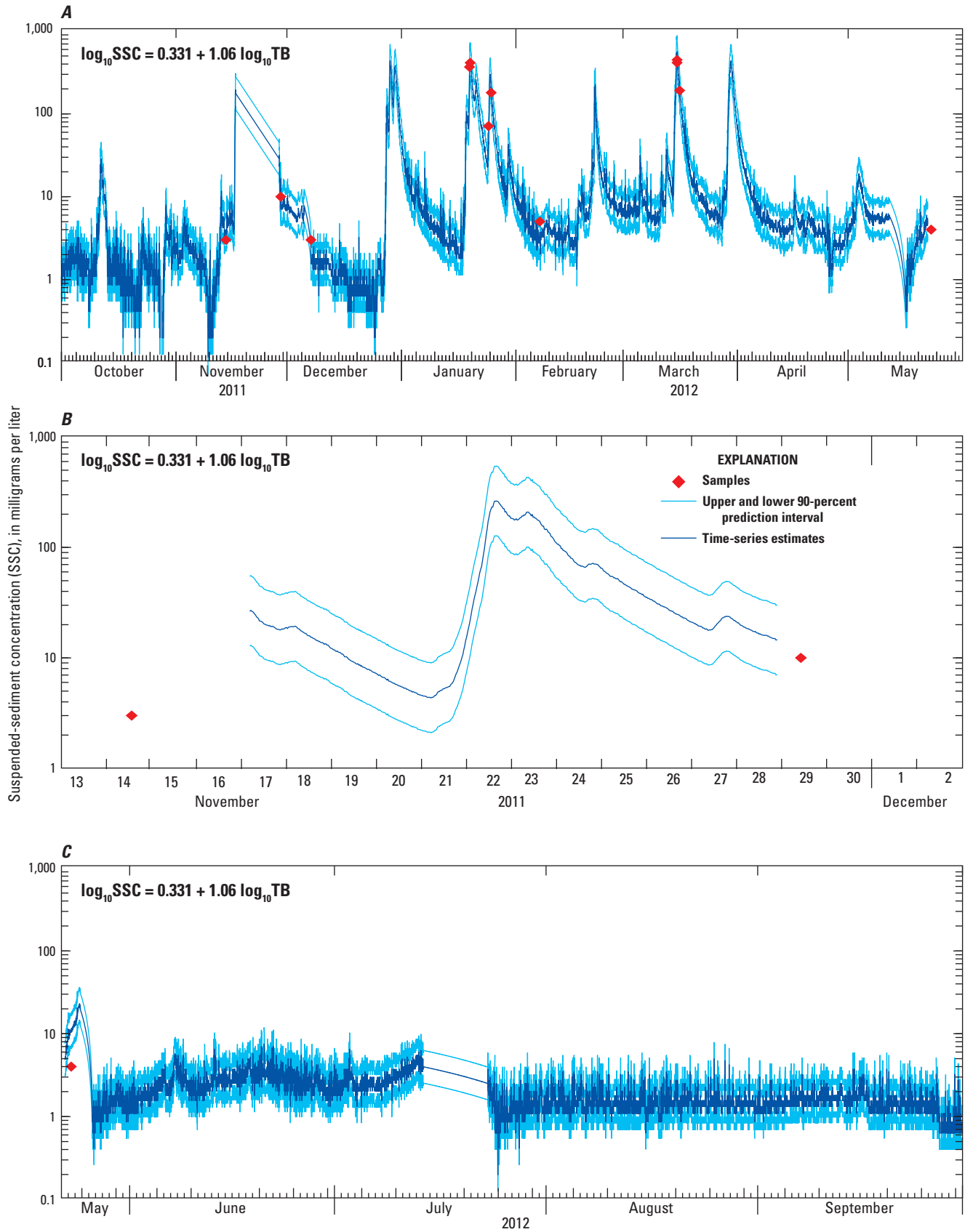
Figure B2. Suspended-sediment concentration (SSC) data, 90-percent prediction intervals, and sample data at the Trask River, northwestern Oregon, October 1, 2011–May 22, 2012, November 18–28, 2011, and May 22–September 30, 2012.
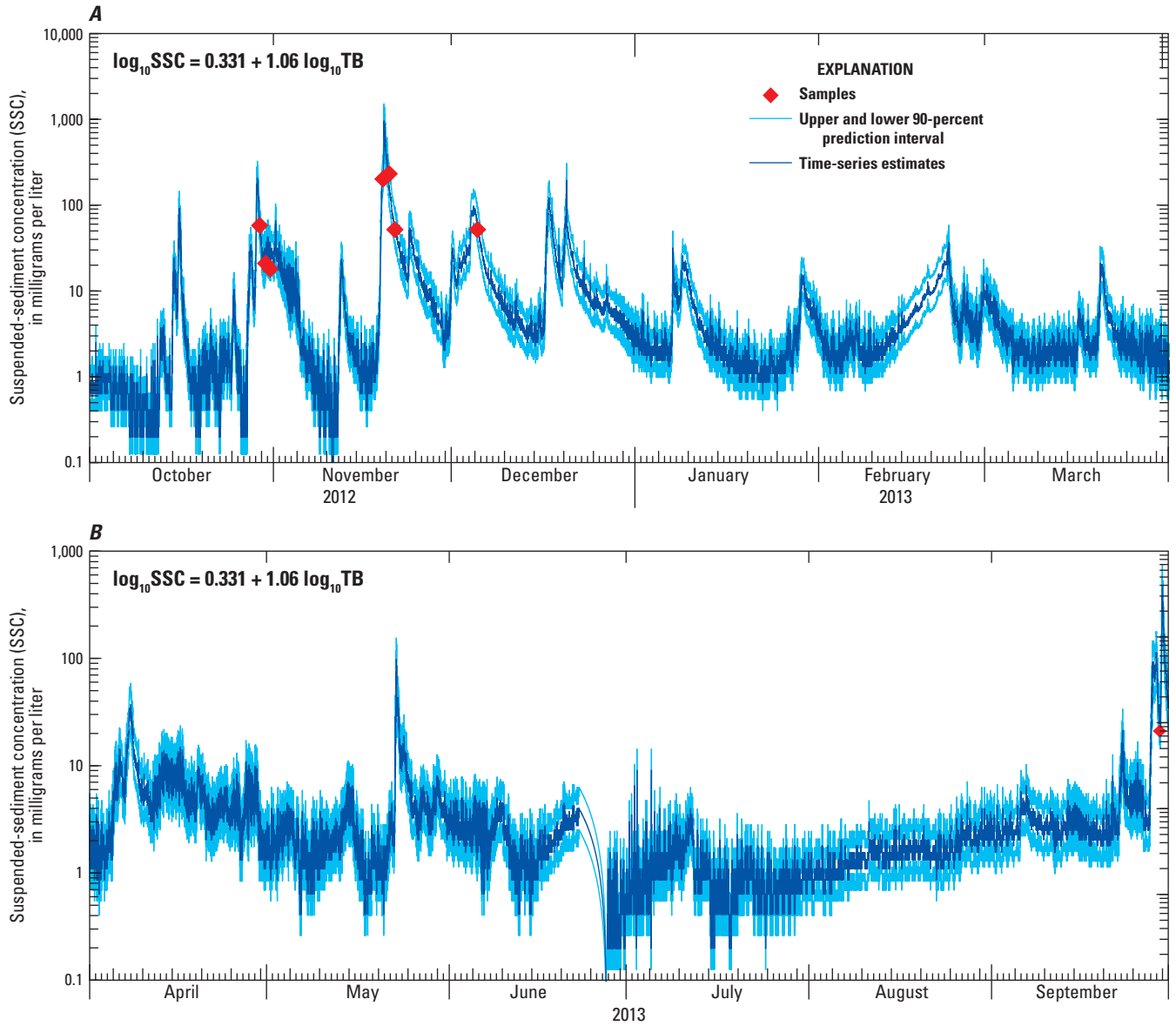
Figure B3.   Suspended-sediment concentration (SSC) data, 90-percent prediction intervals, and sample data at the Trask River, northwestern Oregon, October 2012–March 2013 and April–September 2013.
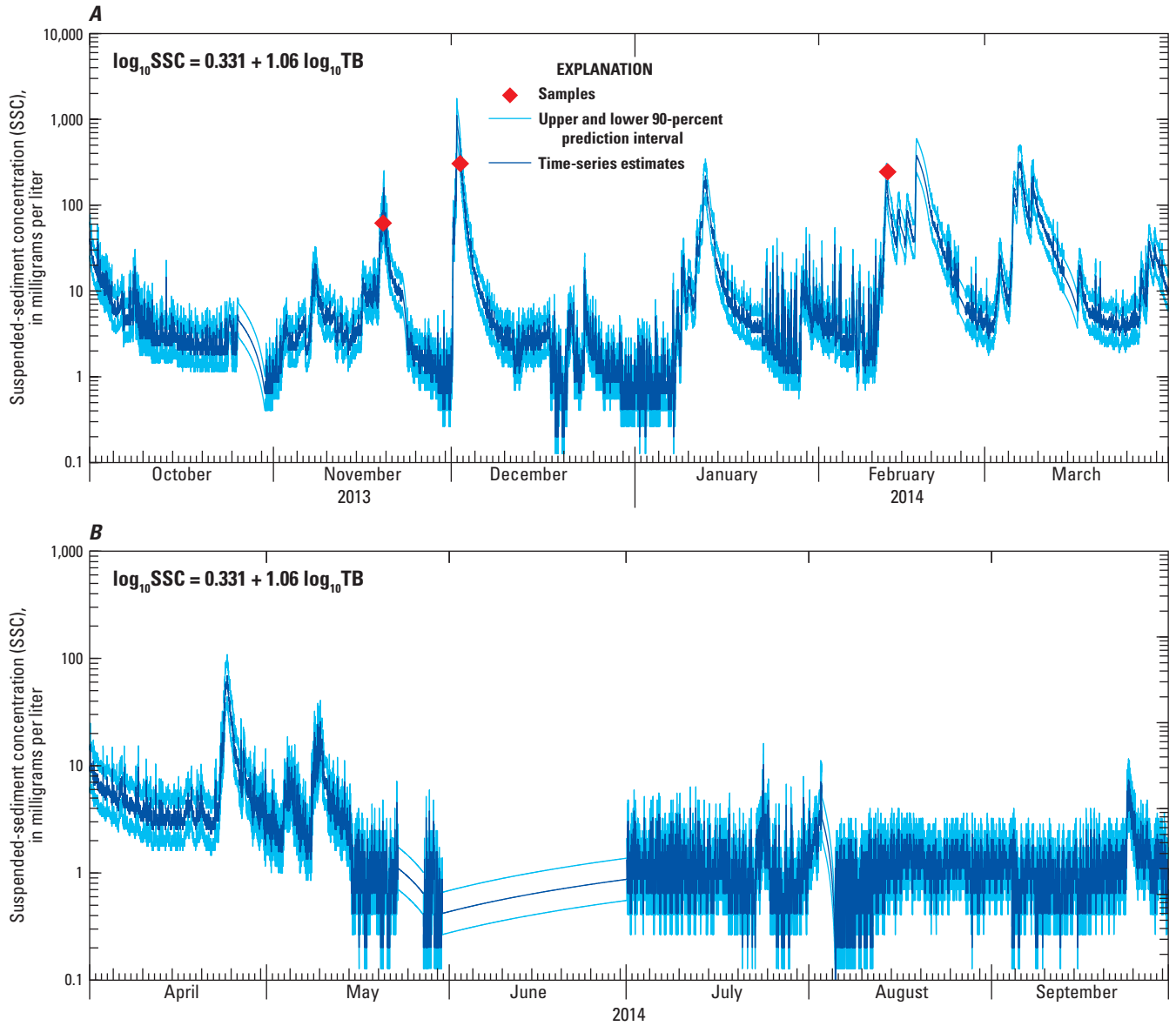
Figure B4. Suspended-sediment concentration (SSC) data, 90-percent prediction intervals, and sample data at the Trask River, northwestern Oregon, October 2013–March 2014 and April–September 2014.

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# Appendix C. Troubleshooting Instream Monitors

During deployment, instrument sensors at both stations occasionally experienced temporary periods of data that did not meet established calibration specifications (Wagner and others, 2006). Measures were taken to minimize common problems of sensor deployment in high gradient mountain streams, including seasonal issues such as clogging by leaf litter (fig. C1) or accumulated fine sediment, biofouling, or sensor calibration drift.

During autumn, additional site visits were made by U.S. Geological Survey staff and volunteers to clean leaves and sediment buildup from the deployment pipes and instruments. Other chemical and mechanical solutions also were tested.

One of the simpler solutions was to increase the wiping interval for the optical sensors (turbidity and dissolved oxygen). This helped, but it did not eliminate the issues entirely. A non-toxic, anti-fouling nanopolymer C-spray (YSI, 2013) was used successfully for reducing the summer algal fouling issues, albeit for the short term (about 7–10 days). The most successful solution was the deployment of an aquarium pump attached to the instrument (fig. C2). The pump supplied a repetitive jet of water for 1 minute every 2 hours to clean the optical turbidity sensors. This worked extremely well, especially from July to October 2014.

Figure C1.   Siltation and leaf compaction clogging the pipe and instrumentation at the Trask River site, northwestern Oregon. Photograph by Mark Uhrich, U.S. Geological Survey, November 2012.
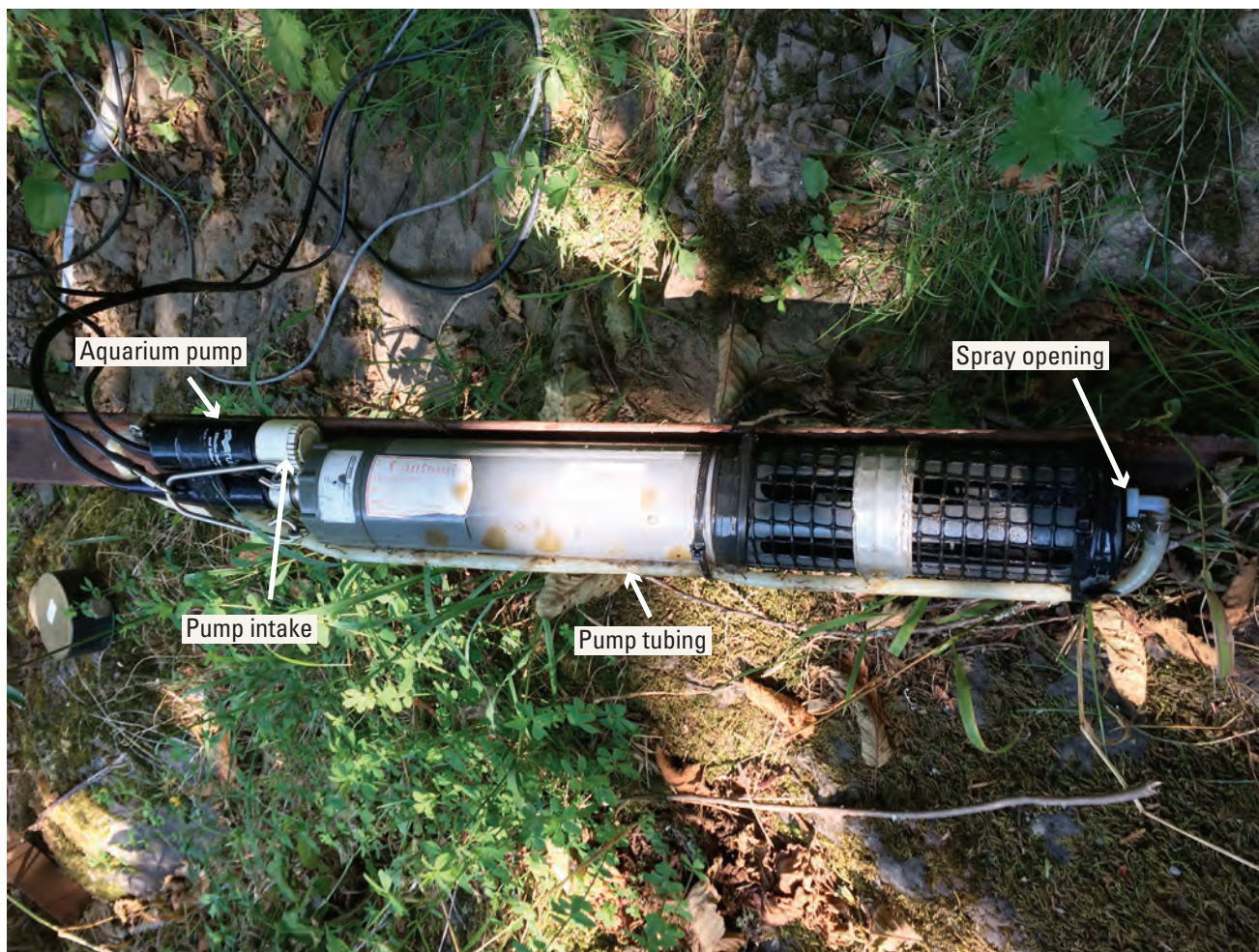
Figure C2.   Aquarium pump installed on water-quality monitoring instrumentation at Trask River site, northwestern Oregon. The pump successfully eliminated bio-fouling issues during low-streamflow summer months. Photograph by Heather Bragg, U.S. Geological Survey, August 2014.

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