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Suspended-Sediment Budget for the North Santiam River Basin, Oregon, Water Years 2005–08

Scientific Investigations Report 2010–5038

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

Front cover photograph: Upper North Santiam River on November 6, 2006, after a debris flow on Mount Jefferson caused increased turbidity in the river.
(Photograph by Heather Bragg, USGS)

Front cover photograph (inset): Scientist collecting a sediment sample at the USGS monitoring station on the upper North Santiam River on November 6, 2006.
(Photograph by David Piatt, USGS)

Back cover photograph: Photograph showing the Little North Santiam River on November 7, 2006, during high streamflow and turbidity conditions.
(Photograph by Heather Bragg, USGS)

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Conversion Factors

Multiply	By	To obtain
	Length	
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Area	
square foot (ft^2)	0.09290	square meter (m^2)
square mile (mi^2)	2.590	square kilometer (km^2)
	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^3s)
	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:

$$°F=(1.8\times°C)+32.$$

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.

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 North American Datum of 1927 (NAD 27).

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

Conversion Factors, Datums, and Abbreviations and Acronyms—Continued

Abbreviations and Acronyms

Abbreviation/ acronym	Definition
EWI	equal-width-increment
FNU	Formazin Nephelometric Unit
MSPE	model standard percent error
N	number of samples
NWIS	USGS National Water Information System
Q	streamflow
R^2	coefficient of determination
RM	river mile
RMSE	root mean squared error
SSC	suspended-sediment concentration
SSQ	suspended-sediment discharge
SSL	suspended-sediment load
T	turbidity
USGS	U. S. Geological Survey

Suspended-Sediment Budget for the North Santiam River Basin, Oregon, Water Years 2005–08

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Significant Findings

An analysis of sediment transport in the North Santiam River basin during water years 2005–08 indicated that:

- Two-thirds of sediment input to Detroit Lake originated in the upper North Santiam River subbasin.
- Two-thirds of the sediment transported past Geren Island originated in the Little North Santiam River subbasin.
- The highest annual suspended-sediment load at any of the monitoring stations was the result of a debris flow on November 6, 2006, on Mount Jefferson.
- About 86 percent of the total sediment input to Detroit Lake was trapped in the lake, whereas 14 percent was transported farther downstream.
- More than 80 percent of the sediment transport in the basin was in November, December, and January.
- The variance in the annual suspended-sediment loads was better explained by the magnitude of the annual *peak* streamflow than by the annual *mean* streamflow.

Introduction

The North Santiam River (fig. 1) is the primary source of drinking water for more than 177,000 people in Salem, Oregon, and those in surrounding communities. The U.S. Geological Survey (USGS), in cooperation with the City of Salem, has monitored water quality in the North Santiam River basin since October 1998 (table 1). Streamflow and water-quality data are recorded, transmitted, and available in real time on the USGS National Water Information System website (http://waterdata.usgs.gov/or/nwis). The network provides advance warning of any suspended-sediment surges that may require a change of operations at the City of Salem's water treatment facility. The data also are used to compute the annual sediment loads at each of the monitoring stations and the suspended-sediment budget throughout the basin.

The North Santiam River basin encompasses 778 mi^2 on the western slopes of the Cascade Range. The basin elevation ranges from 10,497 ft at the summit of Mount Jefferson to 217 ft on the Willamette Valley floor. The City of Salem's drinking water intake is located at the Geren Island water treatment facility near Stayton, Oregon (fig. 1). Two U.S. Army Corps of Engineers dams (Big Cliff Dam at about river mile (RM) 58 and Detroit Dam at about RM 61) regulate the flow of the river. Big Cliff Dam primarily is operated as run-of-river to reregulate the flow from Detroit Dam. The two dams effectively divide the North Santiam River drainage into an "upper" basin (upstream of Detroit Dam) and a "lower" basin (downstream of Big Cliff Dam and additional unregulated tributaries).

Background and Previous Investigations

In February 1996, a week of heavy rainfall and melting snowpack resulted in some of the most severe flooding in the history of northwestern Oregon. The North Santiam River streamflow-gaging stations crested at 50- to 100-year interval flood events (Cooper, 2005). The increased suspended-sediment load during the flooding caused the City of Salem to temporarily shut down the intakes to the water treatment facility. In the following weeks, the fluvial sediment from the lower basin largely flushed out as the streamflows receded, but much of the fine-grained sediment from the upper basin was still suspended in Detroit Lake. Because the lake water was gradually released downstream, the turbidity in the lower North Santiam River basin remained elevated for months. The City of Salem was forced to implement emergency procedures to remove the sediment from the river water and maintain the supply of drinking water to the community. Since 1996, improvements at the water treatment facility enable it to handle highly turbid water for extended periods of time.

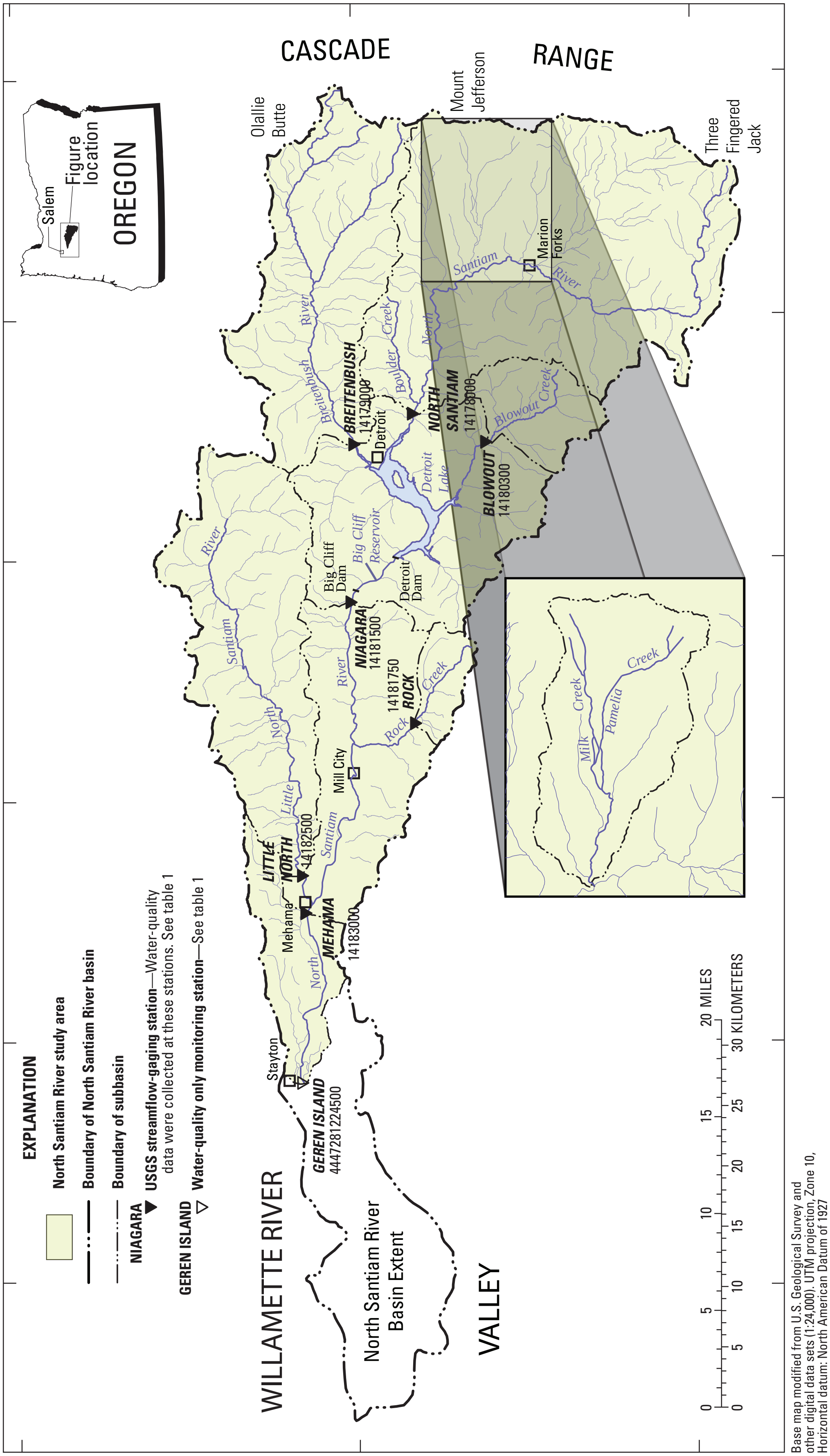

Figure 1. Location of study area and water-quality monitoring stations, North Santiam River basin, Oregon.

Table 1. Streamflow-gaging and water-quality monitoring stations, North Santiam River basin, Oregon.

[Locations of streamflow-gaging stations used for water-quality monitoring are shown in figure 1. **Abbreviations:** USGS, U.S. Geological Survey; mi^2, square miles; na, not applicable]

USGS station No.	Station name	Station reference	Drainage basin area (mi^2)	Streamflow record	
				Period of record (water year)	Years of record
Upper basin stations (upstream of Detroit Dam)					
14178000	North Santiam River below Boulder Creek, near Detroit	*North Santiam*	216	1908–1909, 1929–2008	82
14179000	Breitenbush River above French Creek, near Detroit	*Breitenbush*	108	1933–1987, 1999–2008	65
14180300	Blowout Creek near Detroit	*Blowout*	26.0	1999–2008	10
Lower basin stations (downstream of Big Cliff Dam)					
14181500	North Santiam River at Niagara	*Niagara*	453	1909–1920, 1922, 1930–2008	83
14181750	Rock Creek near Mill City	*Rock*	14.8	2006–2008	3
14182500	Little North Santiam River near Mehama	*Little North*	112	1932–2008	77
14183000	North Santiam River at Mehama	*Mehama*	655	1905–07, 1911, 1921–2008	95
4447281224500	North Santiam River at Geren Island, near Stayton	*Geren Island*	688	na	na

In an effort to understand the sources and transport of sediment in the basin, the City of Salem initiated the North Santiam River Turbidity and Suspended-Sediment Study in cooperation with the USGS. As part of the study, a continuous real-time instream monitoring network was established in 1998. Originally, three stations were installed in the upper basin. During water year 2008, the network consisted of seven stations monitoring instream water quality and streamflow, and one station (*Geren Island*) monitoring water quality only (table 1). The monitoring network provides an advance warning system for high turbidity and helps to improve the understanding of sediment transport throughout the basin.

Several USGS publications have documented the North Santiam River turbidity and suspended-sediment study. Uhrich and Bragg (2003) documented the first 2 water years of the monitoring program. The report included a detailed description of the geology, land use, climate, and hydrology of the North Santiam River basin, and also documented the methods of data collection and analysis at the three upper-basin monitoring stations (*North Santiam*, *Breitenbush*, and *Blowout*). Bragg and others (2007) updated the data analysis and reported the suspended-sediment loads for water years 1999–2004 at the three original stations, one additional upper-basin station (which is no longer in operation), and three lower-basin stations (*Niagara*, *Little North*, and *Mehama*). Sobieszczyk and others (2007) documented the major turbidity events and sediment sources associated with the highest suspended-sediment loads during water years 1999–2004. In addition, Sobieszczyk and others (2008) described a debris flow that occurred in the Milk Creek and Pamelia Creek drainage on the western slope of Mount Jefferson (figs. 1 and 2). The fluvial portion of the debris flow emptied into the upper North Santiam River, resulting in the highest turbidity and suspended-sediment concentration values at any monitoring station for the entire period of study (water years 1999–2008).

Figure 2. Mount Jefferson and the Milk Creek debris flow deposits of November 6, 2006, North Santiam River basin, Oregon.

Purpose and Scope

This report presents a summary of the suspended-sediment budget in the North Santiam River basin for water years 2005–08 with the purpose of identifying major sediment source areas that may affect water quality at the City of Salem's water treatment facility. The annual suspended-sediment loads are computed at seven monitoring stations and the historic streamflow is examined at two monitoring stations. The analysis methods involve updating the regression models annually for each station and estimating the suspended-sediment load related to the debris flow on Mount Jefferson. The sediment budget computations include the inputs to Detroit Lake, output from Big Cliff Reservoir, and additional contributions from the largest lower-basin tributaries. The combined sediment-trap efficiency of the lakes is calculated, and the seasonal transport of sediment is examined.

Methods and Data Analysis

Data Collection

Eight water-quality monitoring stations were in operation in the North Santiam River basin during water year 2008. Streamflow data were collected at seven of these monitoring stations. (The City of Salem's water treatment facility intake, located at Geren Island, is monitored for water quality only.) All preliminary data are available in near real-time on the project website (U.S. Geological Survey, 2009a). Published data are available through the USGS National Water Information System (NWIS) website (U.S. Geological Survey, 2009b).

Station Instrumentation

Water-quality data were collected in accordance with the maintenance and calibration protocols described by Wagner and others (2006) for water temperature, specific conductance, pH, turbidity, and dissolved oxygen (table 2). All water-quality monitoring stations were equipped with a YSI 6920 multi-parameter instrument. Turbidity was measured by a YSI 6026 sensor in Formazin Nephelometric Units (FNU) (Anderson, 2005). Each of these sensors has a different maximum turbidity value, ranging from 1,200 to 1,800 FNU. All parameters were recorded at 30-minute intervals by a data-logger and uploaded every 3 to 4 hours to the USGS database.

Suspended-Sediment Sampling

Suspended-sediment samples collected at the monitoring stations provided the data necessary to relate the optical property of turbidity to the concentration of sediment in the river. Suspended-sediment samples were collected at each monitoring station using standard USGS methods (Edwards and Glysson, 1999). All samples were analyzed for suspended-sediment concentration (SSC) in milligrams per liter. In addition, many samples were analyzed for percent of silt and clay and reported in percent finer than 62 µm in diameter.

The equal-width-increment (EWI) method was used to collect most cross-sectional, depth-integrated samples (Edwards and Glysson, 1999). Automatic pumping samplers were installed at the three stations in the upper basin. These samplers were programmed to collect single-point samples from a location near the in-situ water-quality instrument when the instream turbidity reached a specific threshold value (usually 20, 50, or 100 FNU). Point samples were collected at regular intervals until the turbidity was less than that same threshold value.

Quality Assurance

Cross-Sectional Samples

During the period of the North Santiam River basin study (water years 1999–2008), more than 100 replicate cross-sectional samples were collected at the seven stations to assess the precision of the sampling methods and of the laboratory results. An ordinary least-squares linear regression analysis was completed between the SSC values of pairs of concurrent samples (fig. 3). The result was a highly correlative ($R^2 = 0.98$) and close to 1:1 relation (slope = 1.07) over a wide range of SSC values (1–400 mg/L).

Table 2. Water-quality parameters measured at monitoring stations, North Santiam River basin, Oregon.

[**Station reference**: Complete station names are shown in table 1 and locations are shown in figure 1. **Water-quality parameter**: X, parameter measured. **Abbreviation:** na, not applicable]

Station reference	Instrument installation date	Water-quality parameter					Period of record for suspended-sediment sampling (water years)
		Water temperature	Specific conductance	pH	Turbidity	Dissolved oxygen	
Upper basin stations (upstream of Detroit Dam)							
North Santiam	October 1998	X	X	X	X		1999–2008
Breitenbush	October 1998	X	X	X	X		1999–2008
Blowout	October 1998	X	X	X	X		1999–2008
Lower basin stations (downstream of Big Cliff Dam)							
Niagara	April 2000	X	X	X	X		1999–2008
Rock	September 2005	X	X	X	X		2006–2008
Little North	April 2000	X	X	X	X		1999–2008
Mehama	April 2000	X	X	X	X		1999–2008
Geren Island	March 2001	X	X	X	X	X	na

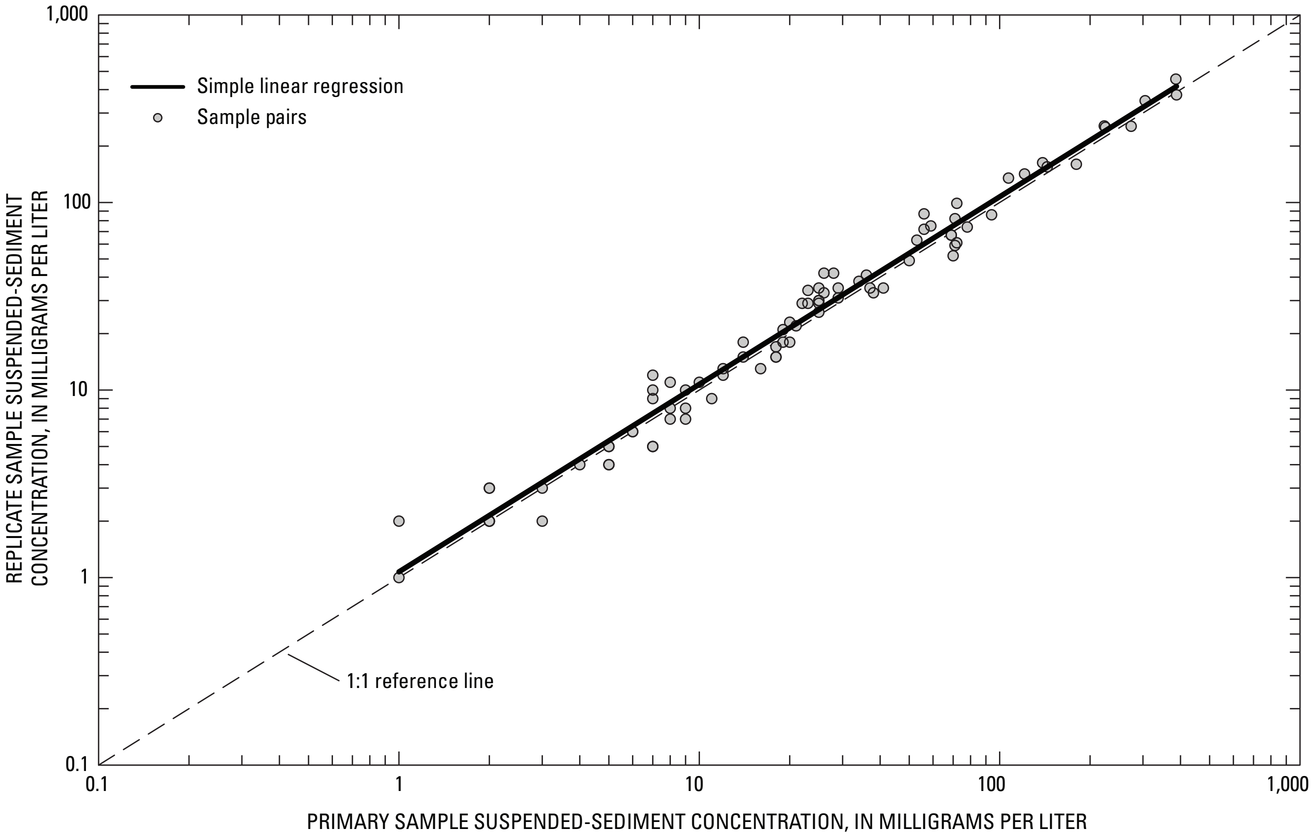

Figure 3. Correlation of replicate cross-sectional suspended-sediment samples, North Santiam River basin, Oregon, water years 1999–2008.

Point Samples

The automatic samplers at the three upper-basin stations were activated regularly before and after collection of EWI samples to assess the representativeness of single-point SSC to cross-sectional SSC. The SSC values of each pair of point samples were interpolated to the mean time of the corresponding EWI sample. An ordinary least-squares linear regression analysis was performed on the data from each monitoring station (table 3). The results show good correlation between the automatic point samples and the cross-sectional EWI samples at *North Santiam* and *Breitenbush* over the entire range of sample SSC values (10–14,500 and 2–660 mg/L, respectively). Results from *Blowout* also show good correlation, except at high SSC (greater than 400 mg/L) and high streamflow (greater than 2,500 ft^3/s). As a result, any point samples collected at *Blowout* when either of these conditions was exceeded were not included in further data analysis.

Table 3. Comparison of suspended-sediment concentrations of single-point and cross-sectional samples, North Santiam River basin, Oregon.

[**Station reference**: Complete station names are shown in table 1 and locations are shown in figure 1. R^2, coefficient of determination; N, number of samples. **Abbreviations:** ft^3/s, cubic feet per second; mg/L, milligrams per liter]

Station reference	Slope	R^2	N
North Santiam	1.04	0.999	15
Breitenbush	1.06	1.00	4
Blowout	0.819	0.962	10
Blowout[1]	1.06	0.999	7

[1]Streamflow (Q) < 2,500 ft^3/s and suspended-sediment concentration (SSC) < 400 mg/L.

Serial Correlation

The point samples at the three upper-basin stations were shown to be acceptably representative of their respective cross sections, but the large number of these samples and the timing of their collection likely would introduce serial correlation biases into the regression analyses. The vast majority of the more than 550 point samples collected by the automatic samplers during water years 2004–08 were caused by high-turbidity conditions. Once an automatic sampler was activated, samples were collected until the instream turbidity was less than the threshold value. As a result, as many as 24 samples could be collected during a single storm. In order to minimize the potential bias, one to three point samples (depending on the duration of the event) were selected randomly from any single storm or sampling event for inclusion in the model calibration datasets.

Data Analysis

Regression models were developed between sample suspended-sediment concentration (SSC) and turbidity (T) as a means of estimating continuous SSC using continuous turbidity data. The estimated SSC and streamflow (Q) were then used to compute annual suspended-sediment loads (SSL) at each of the monitoring stations for water years 2005–08. Uhrich and Bragg (2003) and Bragg and others (2007) previously reported the methods for this analysis.

Regression Models

Regression models were developed between turbidity and SSC for each of the monitoring stations. Turbidity data for the analyses were provided by the instream water-quality monitors. The 30-minute turbidity values, in FNU, recorded during the time of sample collection were averaged to produce a single turbidity value associated with each sample. The SSC values, in milligrams per liter, were provided by laboratory analysis of each sample (Guy, 1969). The pairs of turbidity and SSC data for each sample were used as the calibration dataset for the regression model.

The turbidity and SSC values were transformed to base-10 logarithmic values to improve the normal distribution of the dataset prior to ordinary least-squares linear regression analysis. The form of the regression model equation is:

$$\log_{10}(\mathrm{SSC}) = a\log_{10}(\mathrm{T}) + b, \qquad (1)$$

where

SSC is suspended-sediment concentration;

T is turbidity; and

a and b are the slope and y-intercept coefficients, respectively, obtained by the regression analysis.

The logarithmic transformation and subsequent conversion back to original form introduced a known bias, which was negated with a correction factor (Helsel and Hirsch, 2002). The predicted SSC value resulting from the model equation was multiplied by the bias-correction factor to obtain the corrected SSC value (table 4).

Table 4. Regression models for the relation of turbidity and suspended-sediment concentration, North Santiam River basin, Oregon, water year 2008.

[**Station reference**: Complete station names are shown in table 1 and locations are shown in figure 1. N, number of samples; R^2, coefficient of determination; MSPE, model standard percent error; SSC, suspended-sediment concentration; T, turbidity]

Station reference	Regression model equation	Bias-correction factor	N	R^2	Upper MSPE	Lower MSPE
North Santiam (Precipitation-driven)	$\log_{10}$ SSC = 1.12 $\log_{10}$ T + 0.224	1.12	151	0.95	60.0	37.5
North Santiam (Meltwater-driven)	$\log_{10}$ SSC = 0.898 $\log_{10}$ T + 0.0772	1.03	40	0.95	28.8	22.4
Breitenbush	$\log_{10}$ SSC = 1.06 $\log_{10}$ T + 0.215	1.09	119	0.96	50.7	33.6
Blowout	$\log_{10}$ SSC = 1.09 $\log_{10}$ T + 0.140	1.10	169	0.95	54.7	35.3
Niagara	$\log_{10}$ SSC = 0.727 $\log_{10}$ T + 0.163	1.10	78	0.84	54.1	35.1
Rock	$\log_{10}$ SSC = 1.05 $\log_{10}$ T + 0.243	1.06	27	0.94	45.3	31.2
Little North	$\log_{10}$ SSC = 1.02 $\log_{10}$ T + 0.209	1.12	131	0.92	60.9	37.8
Mehama	$\log_{10}$ SSC = 0.931 $\log_{10}$ T + 0.164	1.15	137	0.87	73.2	42.2

North Santiam Regression Models

The operation of the automatic sampler at the *North Santiam* station revealed a process of sediment transport that had not been addressed in previous analyses. Two instances of high turbidity (greater than the turbidity sensor limit of about 1,600 FNU) with no corresponding increase in streamflow were investigated by Sobieszczyk and others (2007). The sediment causing the high turbidity was associated with meltwater from the glaciers and snowfields in the Milk Creek and Pamelia Creek subbasins, located high on the slopes of Mount Jefferson (fig. 1). Analysis of the samples collected during these events revealed a relation between instream turbidity and SSC that was different from that normally measured during typical storm events, necessitating the revision of the previously published regression model (Bragg and others, 2007).

The previous model included samples collected at *North Santiam* during water years 1999–2004. For the revised analysis, all suspended-sediment samples collected during those years were categorized on the basis of the conditions during which they were collected. Typically occurring in late summer or early fall, glacial outwash events resulted when warm air temperatures rapidly melted glacial ice and snowfields, transporting newly exposed sediment downstream. These events were identified at the monitoring station by a sharp increase in turbidity but little or no increase in streamflow. The summer melting of snow and ice at high elevations also caused small-magnitude diurnal cycles of streamflow and turbidity at *North Santiam*. Samples collected during either of these conditions were classified as "meltwater-driven." During the fall and winter rainy season, increases in instream turbidity usually were accompanied by a proportional increase in streamflow. Samples collected during these conditions were classified as "precipitation-driven." The two newly classified sample sets were used to develop two new regressions to replace the single previous regression (fig. 4). The new regression models were not used to revise previous suspended-sediment load computations, but only to establish benchmark models for future analysis. Both revised *North Santiam* regression models were updated for each subsequent water year as described below.

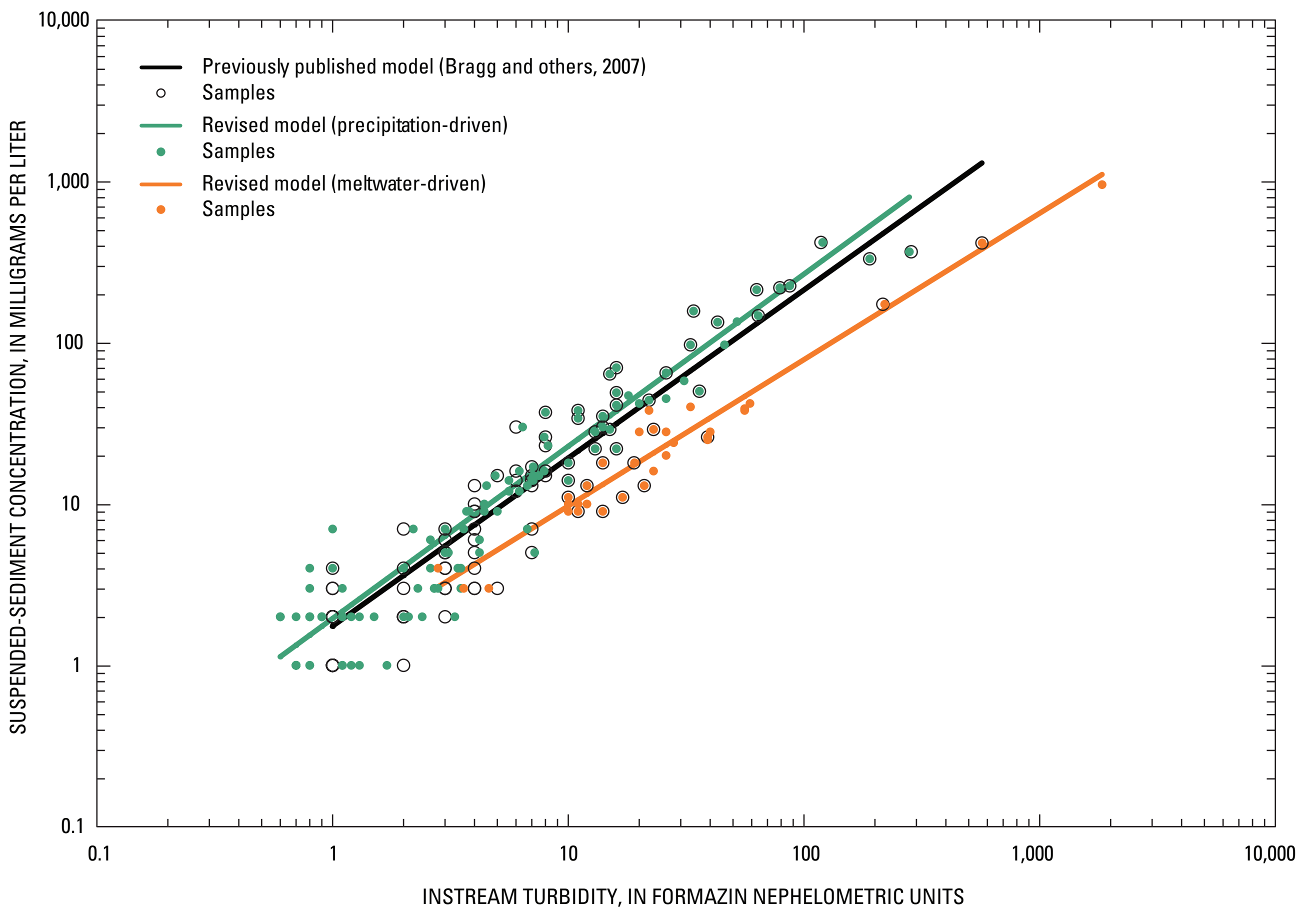

Figure 4. Regression models for the relation of turbidity and suspended-sediment concentration at *North Santiam*, North Santiam River basin, Oregon, water years 1999–2004.

Updated Regression Models

As water-quality data collection continued at all monitoring stations, the regression models required updating and verification. The regression models reported in Bragg and others (2007) were developed with suspended-sediment samples collected through water year 2004. Beginning in water year 2005, a newly established method for annually updating the regression models involved adding samples collected during each subsequent water year to the model calibration dataset (Rasmussen and others, 2009). The regression analysis at each monitoring station was repeated with the complete dataset to determine whether the coefficients (*a* and *b*, eq. 1) of the new equation had changed significantly from the equation used the previous water year. If no significant difference was detected between the two model equations, the regression model incorporating the newly collected samples was used to calculate the continuous SSC record for that water year. If the coefficients were significantly different, a new regression model could be established with either the samples collected after the date of a known change in sediment source or the samples collected during the new water year. The water year 2008 regression models (table 4) include samples collected during the entire period of suspended-sediment sampling for each station (table 2). A table of annually updated regression models for all stations for all water years (1999–2008) is available in appendix A.

The *North Santiam* regression models for precipitation-driven events demonstrated a significant change from water year 2006 to 2007 (appendix A). An analysis of the covariance between the two models indicated a significant difference in the slope (*a*; which increased) and the y-intercept (*b*; which decreased). This shift likely was a result of the inclusion of samples collected in the days and weeks following the November 2006 debris flow on Mount Jefferson. These samples reflected the documented change in available sediment in the upper elevations of the basin, which persisted through the water year. The water year 2007 model that incorporated the new samples was therefore used to calculate the precipitation-driven portions of the continuous SSC record for *North Santiam*. The water year 2008 precipitation-driven model shifted slightly in the opposite direction (the slope decreased and the y-intercept increased), indicating that the effect of the additional sediment source may have been largely temporary.

Error Analysis

Several of the summary statistics recommended by Rasmussen and others (2009) were computed to evaluate the regression models (table 4). The coefficient of determination (R^2) indicates the part of the variance explained by the regression. The root mean squared error (RMSE) of the regression was calculated in log-10 units and converted to the upper and lower model standard percent errors (MSPE). These percentages indicate the variance between the predicted and measured values and can be used to compare regression models. For example, lower magnitude MSPE values indicate less uncertainty in the predicted values. These statistics were considered when evaluating SSL computations and comparing SSL values between monitoring stations.

Regression models for water year 2008 for stations in the upper North Santiam River basin indicated high R^2 values and acceptable MSPE values. The regression models for the two lower-basin stations subject to streamflow regulation by the dams showed the most uncertainty. The R^2 value was lower at *Niagara*, but the MSPE range was comparable to the upper-basin stations. The MSPE range was greatest at *Mehama*, indicating the highest uncertainty in predicted SSC values. The greater uncertainty was attributed to the varied turbidity bias in the cross-section at *Mehama* resulting from the regulated streamflow from Big Cliff Dam and from the confluence of the Little North Santiam River less than 1 mile upstream of the station.

Estimation of Missing or Erroneous Values

Missing Turbidity Values

A complete SSC record, in 30-minute time increments, was needed to compute annual SSL. When turbidity values used to calculate SSC were missing from the record, values were estimated by several methods. Using the simplest method, the 30-minute values were estimated by interpolating between the recorded values immediately before and after the missing period. This method worked well for short time periods when streamflow conditions were steady or when turbidity consistently was increasing or decreasing. For longer periods or during changing streamflow conditions, turbidity was estimated by comparing values at adjacent monitoring stations. This method worked best when two stations had long periods of record that demonstrated a well-defined correlation between turbidity values.

The turbidity at *Rock* was estimated for several periods of missing or erroneous data. Correlation with *Little North* data was used to complete the turbidity record for December 15, 2006–January 5, 2007, which included a moderate storm event. Interpolation was used to complete the *Rock* turbidity record during the low-streamflow periods of January 26–March 5, 2008, and May 18–27, 2008. The other stations in the monitoring network had few instances of missing 30-minute turbidity values and were estimated by simple interpolation. The estimated turbidity values were used to calculate SSC at each respective monitoring station.

North Santiam Suspended-Sediment Concentration

During one major sediment transport event, the continuous SSC record was computed more directly from samples, rather than from estimated turbidity. The debris flow that occurred in the Pamelia and Milk Creek subbasin on Mount Jefferson resulted in extremely elevated turbidity and SSC at *North Santiam* on November 6–7, 2006. When the recorded turbidity values remained constant at 1,600 FNU on November 6 during 0200–0730 and 0930–1600, the instream turbidity was known to be equal to or greater than that value. During these periods, more than a dozen point and EWI samples were collected (fig. 5). On November 6 during 0800–0900, several turbidity values were recorded that were less than the sensor maximum value. The meltwater-driven regression model was used to estimate SSC during these times because no samples were collected. Using a combination of sample SSC, turbidity-estimated SSC, and interpolation, the continuous SSC record was completed for this unusual event. The estimated 30-minute SSC computations for *North Santiam* on November 6–7, 2006, are available in appendix B.

Computations of Suspended-Sediment Load

Estimated 30-minute SSC (in mg/L) and corresponding streamflow (Q) values, in cubic feet per second (ft^3/s), were used to calculate the suspended-sediment discharge (SSQ; equation 2), in tons per 30 minutes:

$$SSQ(\text{tons/30min}) = SSC(\text{mg/L}) \times Q(\text{ft}^3/\text{s}) \times c, \qquad (2)$$

where

c equals 0.0000562 to convert the units to tons per 30 minutes.

The daily SSL is computed by summing the 48 estimated SSQ values per day. The annual SSL is calculated by summing the 365 (or 366) daily SSL values.

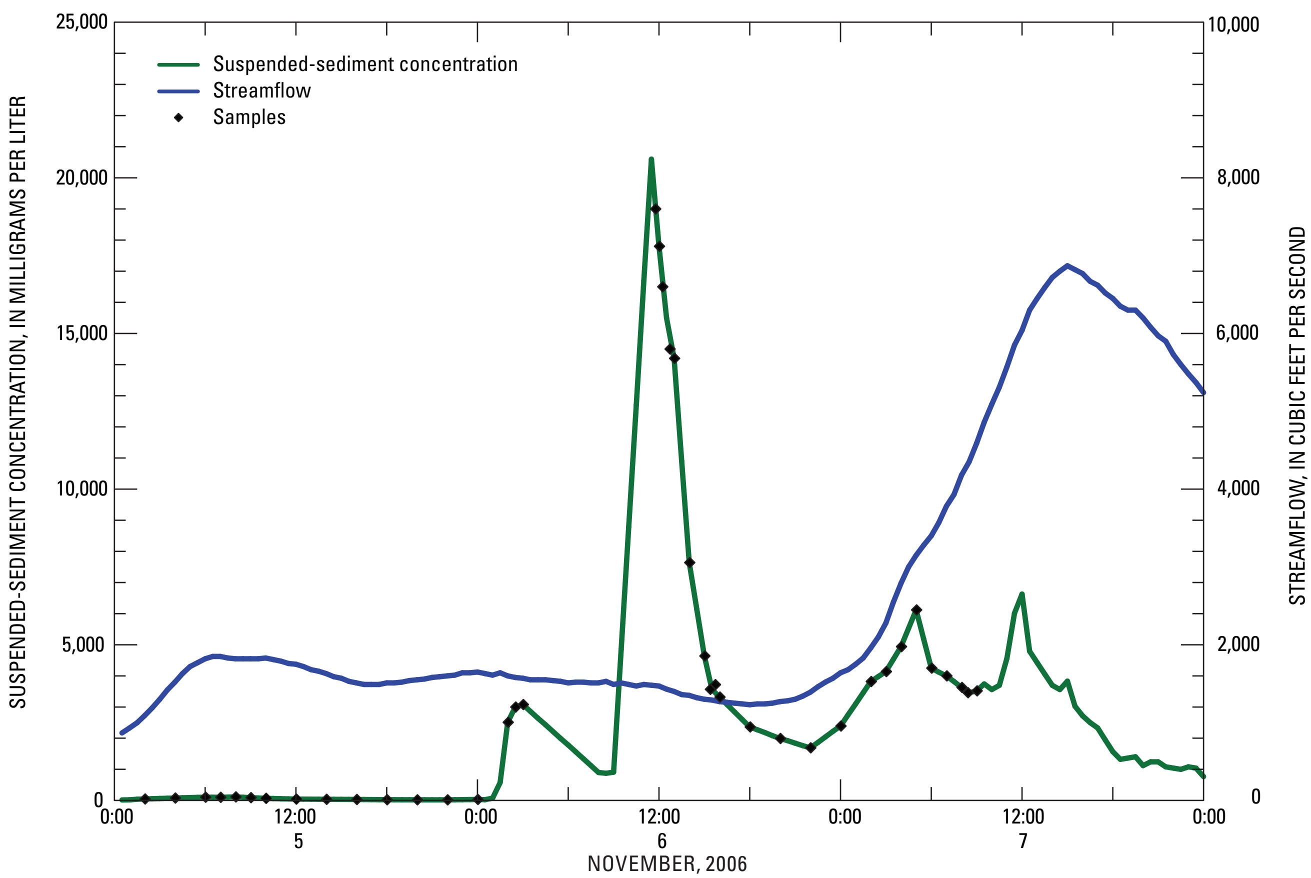

Figure 5. Suspended-sediment concentration, streamflow, and sample collection at *North Santiam*, North Santiam River basin, Oregon, November 5–7, 2006.

Prediction intervals were calculated for each of the regression models in order to provide error estimates for the annual SSL values. For each estimated 30-minute SSC value, the upper and lower predictions were calculated at 90 percent confidence. High and low annual SSL totals were calculated as described above from the continuous upper and lower SSC prediction records.

Computations of Suspended-Sediment Budget

Annual SSL totals were used to summarize the suspended-sediment budget in the North Santiam River basin for water years 2005–08 (fig. 6). The SSL from the three stations in the upper basin (*North Santiam*, *Breitenbush*, and *Blowout*) were summed to compute the sediment input to Detroit Lake. The SSL at *Niagara* represented the sediment output from Detroit Lake and Big Cliff Reservoir. The total SSL flowing past Geren Island was defined as the sum of *Niagara*, *Rock* (if data were available), and *Little North*. Although the SSL was estimated at *Mehama* for all water years, it was not used in the sediment budget because of the high uncertainty of the regression models.

The relative percent contribution of each monitoring station to each step of the suspended-sediment budget was computed for each water year. In addition, the relative percent contribution of each monitoring station was computed for the total 4-year suspended-sediment budget of water years 2005–08.

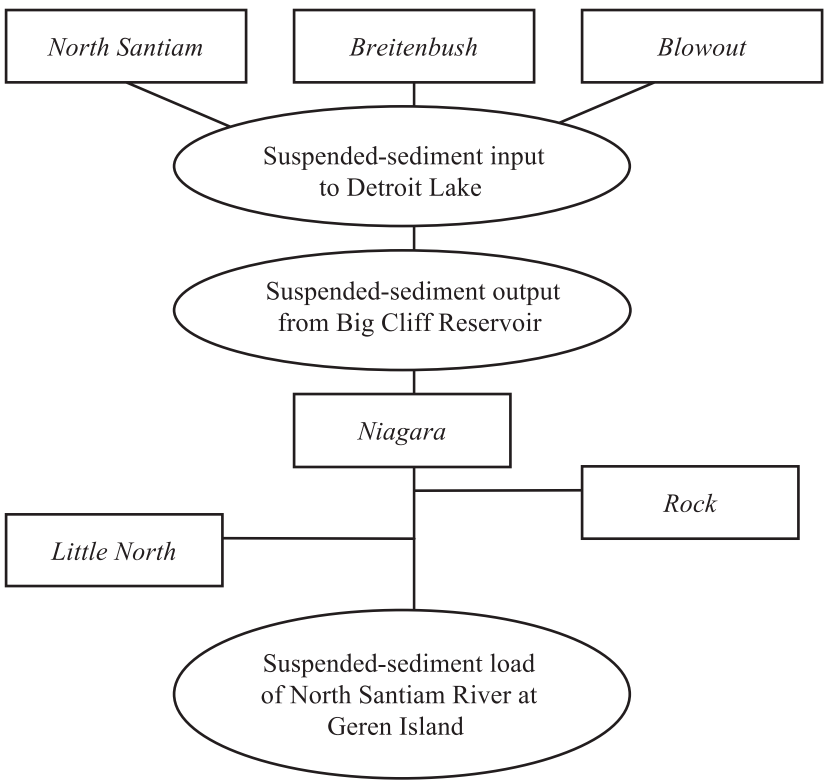

Figure 6. Sources of suspended sediment used for budget calculations, North Santiam River basin, Oregon, water years 2005–08.

The total suspended-sediment budget for water years 2005–08 also was analyzed by month to examine and quantify the season for peak sediment transport. The monthly sums for each step of the budget (input to Detroit Lake, output from Big Cliff Reservoir, and flow past Geren Island) were expressed as a percentage of the total 4-year sediment budget.

The difference between the sediment input to Detroit Lake and the sediment output from Big Cliff Reservoir (as measured at *Niagara*) was used to estimate the combined trap efficiency of the reservoirs (eq. 3).

$$\text{Trap efficiency} = (SSL_i - SSL_0)/SSL_i \, , \qquad (3)$$

where

SSL_i is total suspended-sediment load input to Detroit Lake; and

SSL_0 is total suspended-sediment load output from Big Cliff Reservoir.

About 27 percent of the water volume measured at *Niagara* during water years 2005–08 was not accounted for by the streamflow measured at the three upper-basin monitoring stations. Reservoir storage changes, groundwater input, and unmonitored tributaries could account for the water volume difference. Because the trap efficiency calculation did not account for the sediment input associated with any unmeasured streamflow entering Detroit Lake, there likely was a negative bias on the estimates. The actual annual trap efficiencies of Detroit Lake and Big Cliff Reservoir likely were higher than the calculated values.

Historic Streamflow

Streamflow data from two of the monitoring stations in the North Santiam River basin were analyzed to provide context for the suspended-sediment load and budget computations. Annual streamflow is highest at *North Santiam* in the upper basin and, for unregulated streams, at *Little North* in the lower basin. Annual mean streamflow for water years during the period of the North Santiam River study (water years 1999–2008) are shown in figure 7. The median value for each dataset was calculated from the annual mean streamflow values for the entire period of record at each station (table 1). The peak instantaneous streamflow values for the water years during the period of the study are shown in figure 8. The median value for each dataset was calculated from the annual peak streamflow values for the entire period of record at each station (table 1).

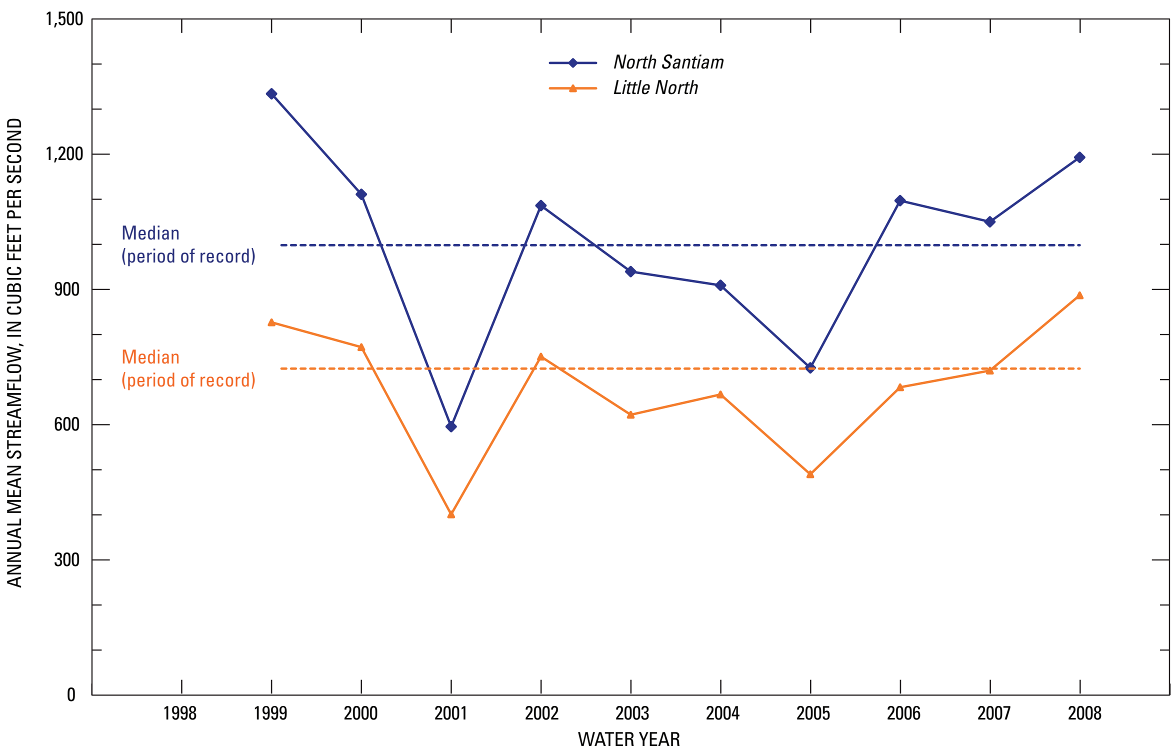

Figure 7. Annual mean streamflow at two streamflow-gaging stations, *North Santiam* (14178000) and *Little North* (14182500), North Santiam River basin, Oregon, water years 1999–2008.

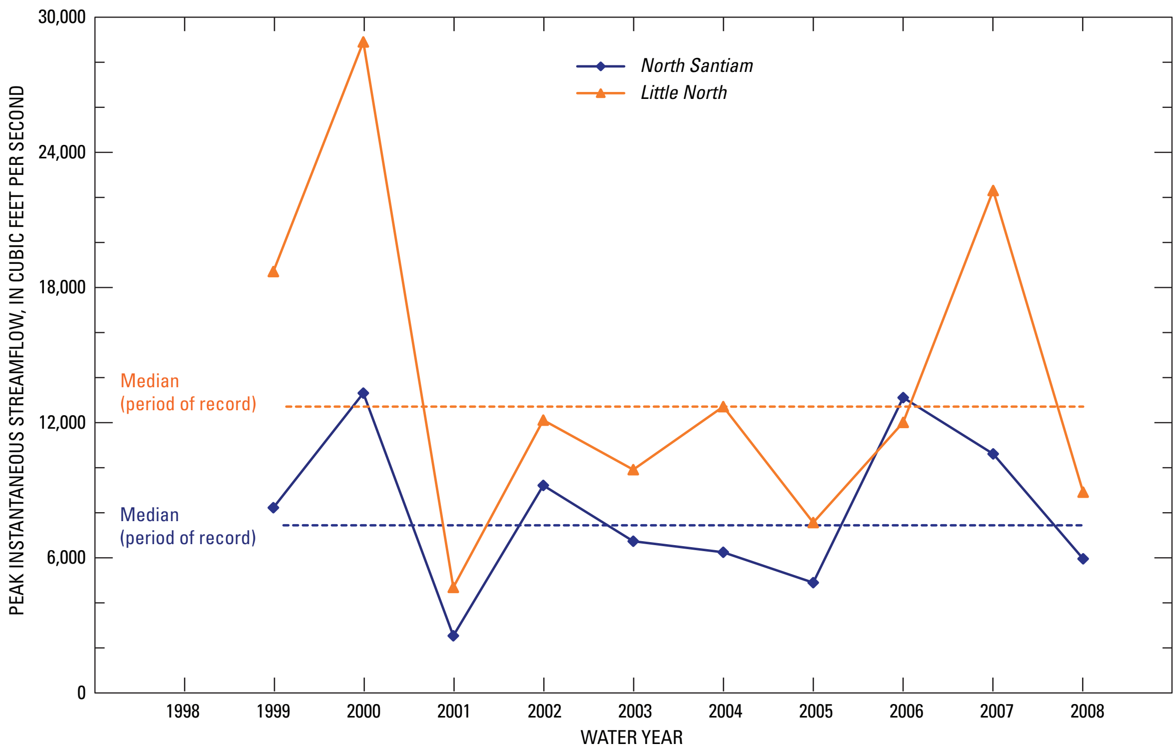

Figure 8. Annual peak streamflow at two streamflow-gaging stations, *North Santiam* (14178000) and *Little North* (14182500), North Santiam River basin, Oregon, water years 1999–2008.

Streamflow throughout the basin was less than normal for water year 2005, as demonstrated by the annual mean and peak flows at *North Santiam* and *Little North*. Streamflow for water year 2006 was slightly less than normal for *Little North* but greater than normal for *North Santiam*. In January 2006, the recurrence interval for peak streamflow at *North Santiam* was 5–10 years. Recurrence interval for peak streamflow at *Little North* during the same storm was less than 2 years. Water year 2007 included a storm in November 2006 that resulted in a peak streamflow with a 2–5 year recurrence interval at *North Santiam* and with a 5–10 year recurrence interval at *Little North*. During that year, the annual mean streamflow for *North Santiam* and *Little North* was approximately normal. Annual mean streamflow of the 4 years analyzed was highest in water year 2008, yet recurrence intervals for peak flows were less than 2 years. This was a result of the above-average, late-melting snowpack in the Cascade Range, which caused increased flows at all seven stations beginning in May 2008 and continuing into the summer.

Suspended-Sediment Loads

Annual SSL totals were computed for water years 2005–08 for each monitoring station for which streamflow and turbidity data were available (fig. 9). The error bars indicate the 90 percent prediction interval estimates for each annual SSL value.

For the low annual mean and peak streamflow in water year 2005, the SSL values were the lowest for the 4 years analyzed. In water year 2006, SSL at *Breitenbush* and *Blowout* was the highest of the 4 water years. SSL at *North Santiam* also was high in water year 2006, but was highest in water year 2007 because of the Mount Jefferson debris flow and subsequent storm event. SSL was highest during water year 2007 for all lower basin stations for the 4 water years. The streamflow conditions during water year 2008 resulted in lower SSL values than might be expected for an above-average mean flow year. The lack of significant peak streamflows resulted in SSL totals at all seven monitoring stations that were only slightly higher than those during the much lower streamflow in water year 2005.

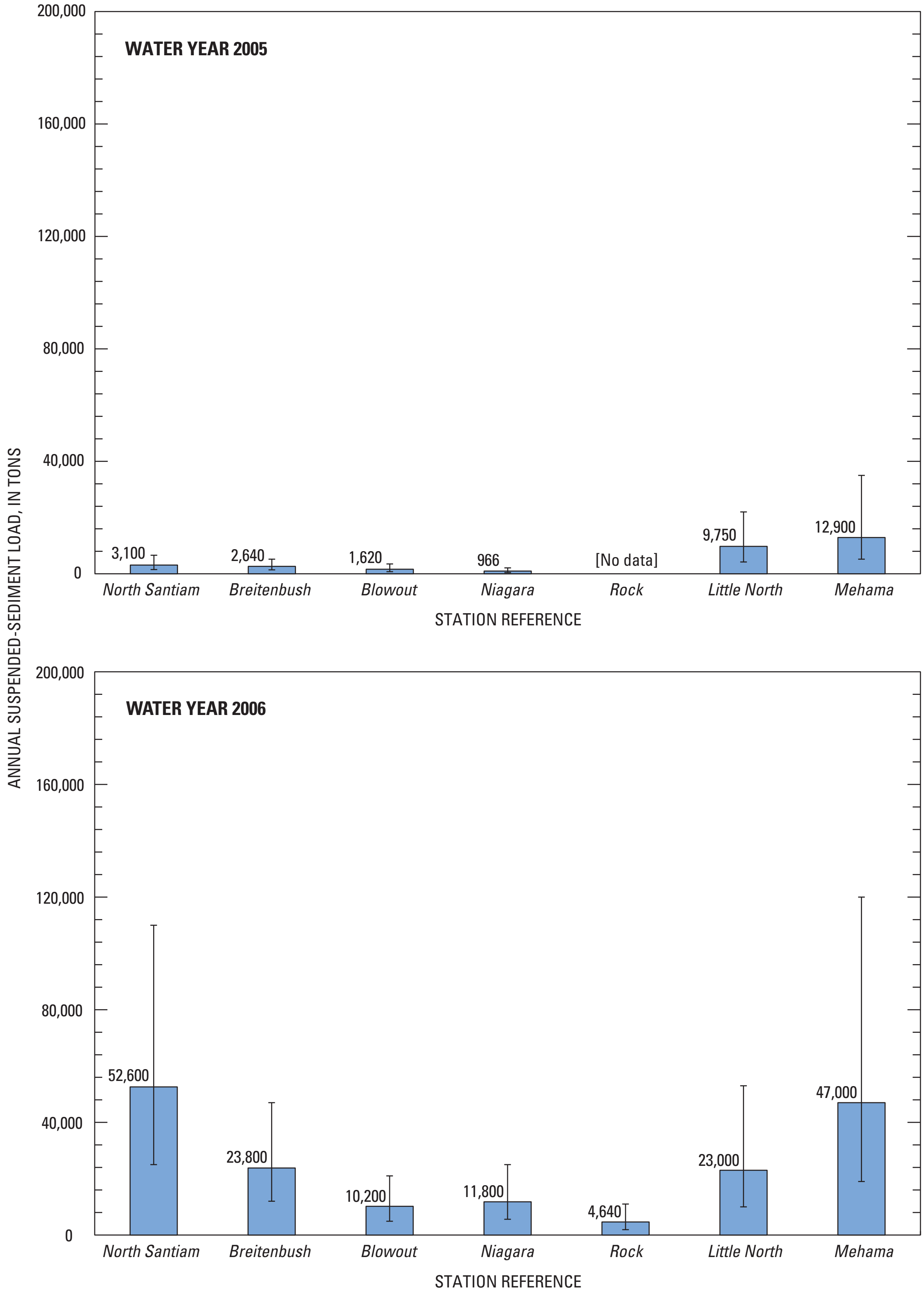

Figure 9. Suspended-sediment loads for seven monitoring stations, North Santiam River basin, Oregon, water years 2005–08. Error bar indicates 90-percent prediction interval estimate for each annual SSL value.

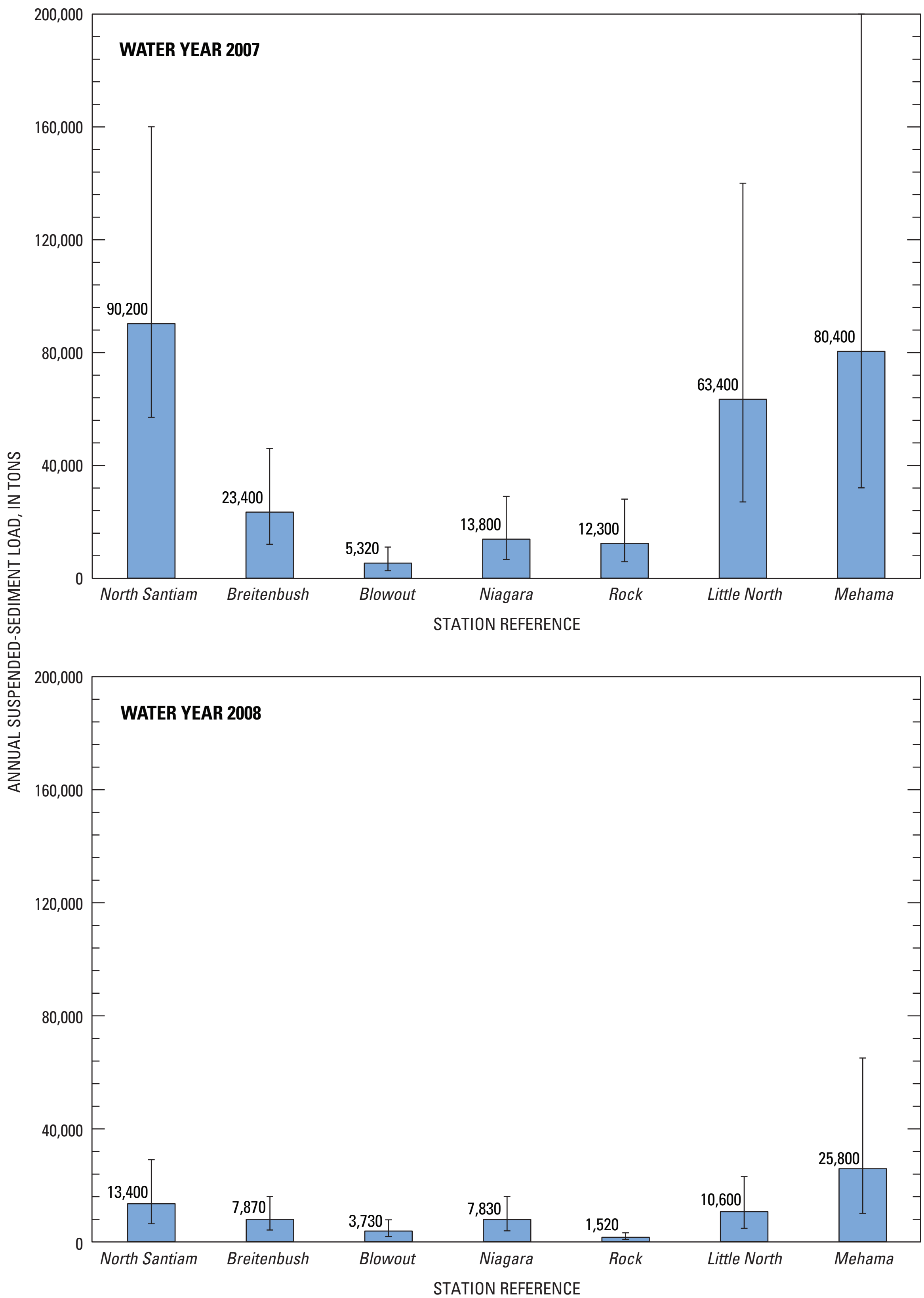

Figure 9.—Continued.

Suspended-Sediment Budget

The results of the annual suspended-sediment budget computations are presented in table 5. During water years 2005–08, the upper North Santiam River was the largest contributor of suspended sediment to Detroit Lake. The 4-year SSL total at *North Santiam* was dominated by sediment transported during the Mount Jefferson debris flow and the subsequent storm in water year 2007. The Breitenbush River was the second largest sediment contributor in the upper basin followed by Blowout Creek.

The Little North Santiam River was the largest contributor of suspended sediment to the North Santiam River at Geren Island for water years 2005–08. The highest SSL and second-highest annual percentage at *Little North* were related to the peak winter storms during water year 2007. (The highest annual proportion for *Little North* was artificially inflated because of the lack of data for *Rock* in water year 2005.) The output from Detroit Lake (*Niagara*) was the second largest sediment contributor in the lower basin followed by Rock Creek.

The computed trap efficiencies of Detroit Lake (table 6) were consistent during water years 2005–07, despite the variation in annual mean streamflow. In water year 2008, the record snowpack in the Cascade Range (more than 200 percent of the 30-year average; Natural Resources Conservation Service, 2009) increased the streamflow and suspended-sediment input to Detroit Lake into the late spring. The lake level was kept below full pool elevation by increasing the outflow from Detroit Dam throughout May and June 2008. This movement of water through the lake prevented the suspended sediment from settling and resulted in a trap efficiency value lower than the other 3 water years. The increased streamflow and SSL at *Niagara* in the spring and summer of water year 2008 also resulted in the highest proportion (39 percent) of the lower basin suspended-sediment budget for water years 2005–08 at that station. SSL inputs to the lake were higher during water years 2006 and 2007, but the suspended sediment had more time to settle, resulting in lower percentage contributions at *Niagara* to the lower basin sediment budget.

The monthly suspended-sediment budget results are presented in figure 10. Late fall and early winter were the dominant seasons for sediment transport during water years 2005–08. About 90 percent of the sediment input to Detroit Lake and 80 percent of the sediment output from Big Cliff Reservoir was in November, December, and January during the 4 years. November and December were the highest months for input to the lake, while January was the highest for output. This demonstrates the capacity of Detroit Lake to store suspended sediment and delay its release downstream. During these same months, 87 percent of the total SSL was transported past the City of Salem's Geren Island water treatment facility.

Table 5. Suspended-sediment budget computations, upper and lower North Santiam River basin, Oregon, water years 2005–08.

[**Station reference**: Complete station names are shown in table 1 and locations are shown in figure 1. **Annual SSL** is the estimated suspended-sediment load at the monitoring station. **Percentage of total** is the portion of the total SSL contribution to Detroit Lake from the basin upstream of the monitoring station. SSL, suspended-sediment load. na, not applicable]

Station reference	Water year								Total 2005–08	
	2005		2006		2007		2008			
	Annual SSL (tons)	Percentage of total	Annual SSL (tons)	Percentage of total	Annual SSL (tons)	Percentage of total	Annual SSL (tons)	Percentage of total	Annual SSL (tons)	Percentage of total
Suspended-sediment contribution to Detroit Lake										
North Santiam	3,100	42	52,600	61	90,200	76	13,400	54	159,300	67
Breitenbush	2,640	36	23,800	27	23,400	20	7,870	31	57,710	24
Blowout	1,620	22	10,200	12	5,320	4	3,730	15	20,870	9
Annual SSL for Detroit Lake (tons)	7,360		86,600		118,920		25,000		237,880	
Suspended-sediment contribution for North Santiam River at Geren Island										
Niagara	970	9	11,800	30	13,800	15	7,830	39	34,400	22
Rock	na	na	4,640	12	12,300	14	1,520	8	18,460	12
Little North	9,750	91	23,000	58	63,400	71	10,600	53	106,750	67
Annual SSL for North Santiam River at Geren Island (tons)	10,720		39,440		89,500		19,950		159,610	

Table 6. Sediment trap efficiency values for Detroit Lake and Big Cliff Reservoir, North Santiam River basin, Oregon, water years 2005–08.

	Water year				Total 2005–08
	2005	2006	2007	2008	
Input to Detroit Lake (tons)	7,360	86,600	118,920	25,000	237,880
Output from Big Cliff Reservoir (tons)	970	11,800	13,800	7,830	34,400
Reservoir trap efficiency (percent)	87	86	88	69	86

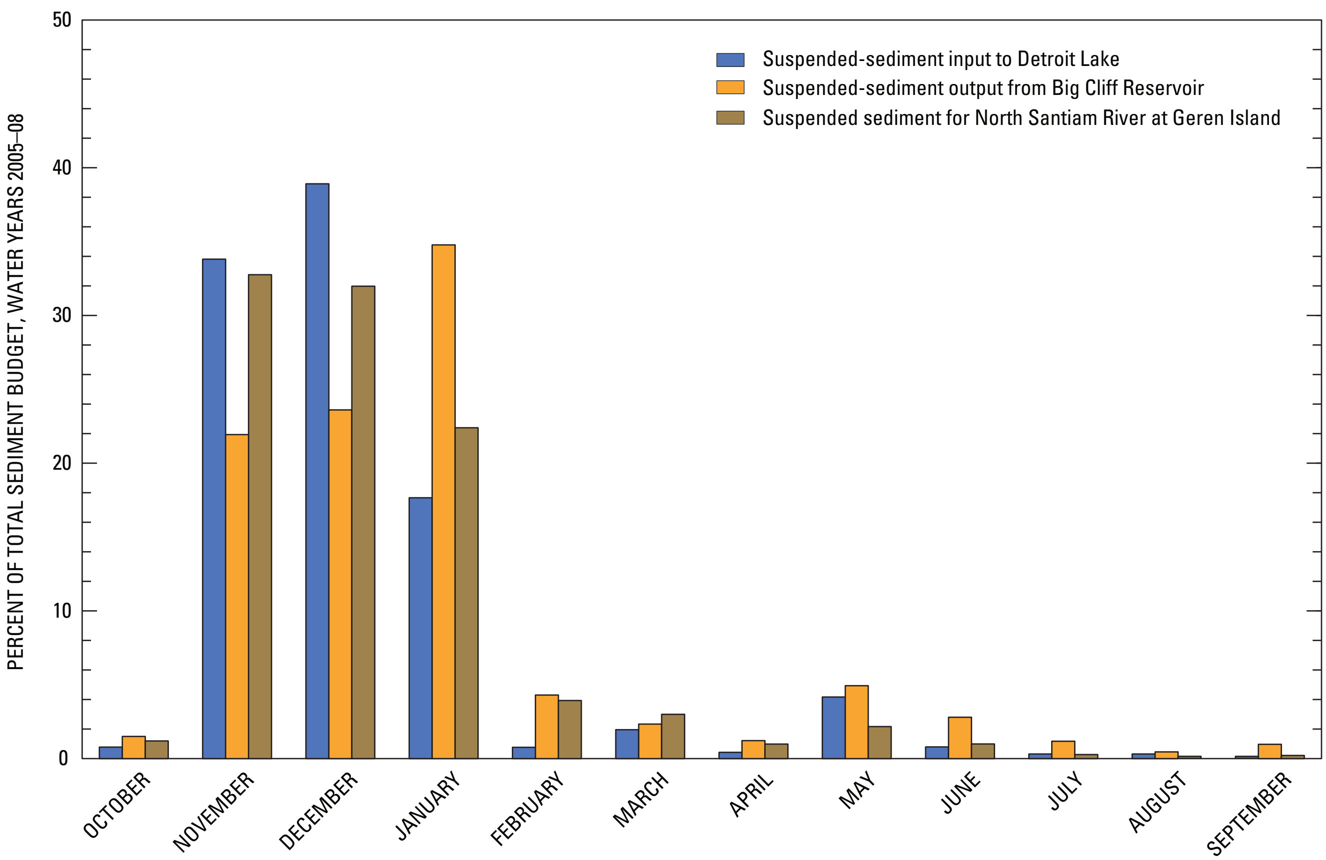

Figure 10. Total monthly suspended-sediment budget, North Santiam River basin, Oregon, water years 2005–08.

Summary and Conclusions

In cooperation with the City of Salem, the U.S. Geological Survey investigated the sources and transport of sediment in the North Santiam River basin during water years 2005–08. Seven monitoring stations were in operation throughout the basin, providing continuous streamflow and instream turbidity data. Newly collected cross-sectional and point samples were added to previously published analyses in order to verify and update the regression models relating turbidity and suspended-sediment concentration. These models were used to estimate continuous suspended-sediment concentration records and annual suspended-sediment loads at each of the monitoring stations.

The upper North Santiam River was determined to have a sediment source that required a separate regression model for estimating suspended-sediment concentration. During the summer and early fall, the melting glaciers and snowfields on Mount Jefferson transported sediment from high on the exposed mountain slopes, resulting in a distinct suspended-sediment concentration for any given turbidity. The two regression models for the upper *North Santiam* monitoring station produced better suspended-sediment concentration estimates than the previously published single regression model.

During water years 2005–08, the basin was exposed to a variety of environmental conditions, producing a wide range of suspended-sediment transport results. The low annual streamflow and lack of major storms during water year 2005 demonstrated how little sediment could be transported through the basin. A major storm during January 2006 produced the highest peak streamflows in the upper basin during the 4 years, resulting in the highest suspended-sediment loads at two of the three upper-basin stations. The upper North Santiam River had its highest sediment load following the debris flow on Mount Jefferson during November 2006 (water year 2007). This event and the subsequent storm contributed to the largest annual suspended-sediment load computed for any of the monitoring stations, as well as the largest annual suspended-sediment load to pass through Detroit Lake and Big Cliff Reservoir during the period of study. Peak streamflows in the lower basin were highest in association with the same storm of water year 2007, producing the highest suspended-sediment loads at all lower-basin stations. The annual mean streamflows in water year 2008 were the highest for the 4 years, but the peak streamflows were only slightly higher than during water year 2005. The suspended-sediment loads across the basin were similarly low during water year 2008. This indicated that suspended-sediment loads correlate better to peak streamflows, not mean streamflows, in the North Santiam River basin.

Water years 2005–08 presented examples of a wide range of sediment transport conditions in the North Santiam River basin. The 4-year total sediment budget provides a more balanced assessment. The upper basin tributaries contributed nearly 240,000 tons of sediment to Detroit Lake during the 4 years. However, only 14 percent of that sediment load was transported through the lake into the lower basin. Nearly 160,000 tons of sediment were transported by the North Santiam River as computed at Geren Island during the 4 years. Despite the massive debris flow in the upper basin, it was precipitation-driven, high-flow events in the lower basin that contributed the greatest sediment loads to the source water for the City of Salem's water treatment facility.

Acknowledgments

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Appendix A. Regression Models for Relation of Turbidity and Suspended-Sediment Concentration in the North Santiam River Basin

As explained in section "Data Analysis", the regression models required annual updating and verification. Bragg and others (2007) developed a single model for each monitoring station with samples collected during water years 1999–2004 to estimate suspended-sediment concentration from turbidity for those 5 years. The newly published method for updating the regression models (Rasmussen and others, 2009) involved adding the samples collected during each subsequent water year to the model calibration dataset and repeating the regression analysis with the new dataset. If the new model showed no significant change from the old model, the new model was used to estimate the continuous SSC record for the most recent water year. The regression models used at each monitoring station for each water year that suspended-sediment loads were computed are shown in table A1.

Table A1. Regression model equations used at each monitoring station, North Santiam River basin, Oregon, water years 1999–2008.

[**Station reference**: Complete station names are shown in table 1 and locations are shown in figure 1. N, number of samples; R^2, coefficient of determination; MSPE, model standard percent error; SSC, suspended-sediment concentration; T, turbidity]

Station reference	Regression model equation	Bias correction factor	N	R^2	Upper MSPE	Lower MSPE
Water years 1999–2004						
North Santiam	$\log_{10} SSC = 1.04 \log_{10} T + 0.188$	1.13	121	0.89	68.0	40.5
Breitenbush	$\log_{10} SSC = 1.08 \log_{10} T + 0.183$	1.18	80	0.92	71.3	41.6
French	$\log_{10} SSC = 1.01 \log_{10} T - 0.0127$	1.28	34	0.82	105	51.3
Blowout	$\log_{10} SSC = 1.18 \log_{10} T + 0.0683$	1.16	118	0.93	62.3	38.4
Niagara	$\log_{10} SSC = 0.758 \log_{10} T + 0.123$	1.12	64	0.76	63.2	38.7
Little North	$\log_{10} SSC = 1.02 \log_{10} T + 0.193$	1.14	125	0.92	66.3	39.8
Mehama	$\log_{10} SSC = 0.916 \log_{10} T + 0.170$	1.17	131	0.86	78.6	44.0
Water year 2004 (Revised)						
North Santiam (Precipitation-driven)	$\log_{10} SSC = 1.07 \log_{10} T + 0.243$	1.12	116	0.91	60.2	37.6
North Santiam (Meltwater-driven)	$\log_{10} SSC = 0.907 \log_{10} T + 0.0651$	1.04	32	0.95	31.0	23.6
Water year 2005						
North Santiam (Precipitation-driven)	$\log_{10} SSC = 1.08 \log_{10} T + 0.240$	1.11	122	0.92	58.8	37.0
North Santiam (Meltwater-driven)	$\log_{10} SSC = 0.908 \log_{10} T + 0.0690$	1.03	35	0.95	30.0	23.1
Breitenbush	$\log_{10} SSC = 1.03 \log_{10} T + 0.220$	1.08	92	0.96	48.8	32.8
Blowout	$\log_{10} SSC = 1.08 \log_{10} T + 0.150$	1.12	127	0.93	58.4	36.9
Niagara	$\log_{10} SSC = 0.718 \log_{10} T + 0.156$	1.11	62	0.79	59.3	37.2
Little North	$\log_{10} SSC = 1.03 \log_{10} T + 0.196$	1.12	123	0.91	61.9	38.2
Mehama	$\log_{10} SSC = 0.931 \log_{10} T + 0.146$	1.14	127	0.87	71.4	41.6
Water year 2006						
North Santiam (Precipitation-driven)	$\log_{10} SSC = 1.10 \log_{10} T + 0.233$	1.10	136	0.94	56.8	36.2
North Santiam (Meltwater-driven)	$\log_{10} SSC = 0.908 \log_{10} T + 0.0690$	1.03	35	0.95	30.0	23.1
Breitenbush	$\log_{10} SSC = 1.05 \log_{10} T + 0.218$	1.09	103	0.96	50.3	33.4
Blowout	$\log_{10} SSC = 1.08 \log_{10} T + 0.143$	1.11	150	0.94	56.0	35.9
Niagara	$\log_{10} SSC = 0.729 \log_{10} T + 0.153$	1.10	73	0.83	53.8	35.0
Rock	$\log_{10} SSC = 1.05 \log_{10} T + 0.241$	1.06	20	0.94	48.2	32.5
Little North	$\log_{10} SSC = 1.03 \log_{10} T + 0.195$	1.12	126	0.92	61.1	37.9
Mehama	$\log_{10} SSC = 0.937 \log_{10} T + 0.152$	1.15	133	0.87	72.5	42.0

Table A1. Regression models used at each monitoring station in the study, North Santiam River basin, Oregon.—Continued

[**Station reference**: Complete station names are shown in table 1 and locations are shown in figure 1. N, number of samples; R^2, coefficient of determination; MSPE, model standard percent error; SSC, suspended-sediment concentration; T, turbidity]

Station reference	Regression model equation	Bias correction factor	N	R^2	Upper MSPE	Lower MSPE
		Water year 2007				
North Santiam (Precipitation-driven)	$\log_{10}$ SSC = 1.12 $\log_{10}$ T + 0.222	1.12	148	0.94	60.6	37.7
North Santiam (Meltwater-driven)	$\log_{10}$ SSC = 0.898 $\log_{10}$ T + 0.0772	1.03	40	0.95	28.8	22.4
Breitenbush	$\log_{10}$ SSC = 1.07 $\log_{10}$ T + 0.213	1.09	115	0.96	50.0	33.3
Blowout	$\log_{10}$ SSC = 1.09 $\log_{10}$ T + 0.138	1.10	165	0.95	54.4	35.2
Niagara	$\log_{10}$ SSC = 0.737 $\log_{10}$ T + 0.150	1.10	76	0.84	53.7	35.0
Rock	$\log_{10}$ SSC = 1.05 $\log_{10}$ T + 0.241	1.06	25	0.95	43.8	30.5
Little North	$\log_{10}$ SSC = 1.03 $\log_{10}$ T + 0.196	1.12	129	0.92	60.3	37.6
Mehama	$\log_{10}$ SSC = 0.943 $\log_{10}$ T + 0.148	1.14	136	0.88	71.8	41.8
		Water year 2008				
North Santiam (Precipitation-driven)	$\log_{10}$ SSC = 1.12 $\log_{10}$ T + 0.224	1.12	151	0.95	60.0	37.5
North Santiam (Meltwater-driven)	$\log_{10}$ SSC = 0.898 $\log_{10}$ T + 0.0772	1.03	40	0.95	28.8	22.4
Breitenbush	$\log_{10}$ SSC = 1.06 $\log_{10}$ T + 0.215	1.09	119	0.96	50.7	33.6
Blowout	$\log_{10}$ SSC = 1.09 $\log_{10}$ T + 0.140	1.10	169	0.95	54.7	35.3
Niagara	$\log_{10}$ SSC = 0.727 $\log_{10}$ T + 0.163	1.10	78	0.84	54.1	35.1
Rock	$\log_{10}$ SSC = 1.05 $\log_{10}$ T + 0.243	1.06	27	0.94	45.3	31.2
Little North	$\log_{10}$ SSC = 1.02 $\log_{10}$ T + 0.209	1.12	131	0.92	60.9	37.8
Mehama	$\log_{10}$ SSC = 0.931 $\log_{10}$ T + 0.164	1.15	137	0.87	73.2	42.2

Appendix B. Computation of Suspended-Sediment Concentration at *North Santiam*, November 6–7, 2006

The Mount Jefferson debris flow resulted in extremely elevated turbidity and suspended-sediment concentration (SSC) at *North Santiam* on November 6–7, 2006. When the recorded turbidity remained constant at the upper limit of the sensor range (about 1,600 FNU), the samples collected at the monitoring station provided the SSC data needed to estimate the suspended-sediment load. The continuous SSC record was completed during these 2 days using a combination of sample SSC, turbidity-estimated SSC, and interpolation.

Table B1. Computations of suspended-sediment concentration at *North Santiam* (14178000), North Santiam River basin, Oregon, November 6-7, 2006.

[**Station reference**: Complete station name is in table 1 and location is in figure 1. SSC, suspended-sediment concentration; SSQ, suspended-sediment discharge; ft^3/s, cubic foot per second; FNU, Formazin Nephelometric Unit; mg/L, milligrams per liter; min, minute]

Date and Time	Streamflow (ft^3/s)	Turbidity (FNU)	SSC (mg/L)	Method of SSC estimation or computation	SSQ (tons/30min)
11/6/2006 0:00	1,650	23	31	Point sample	2.9
11/6/2006 0:30	1,630	27	24	Meltwater-driven regression	2.2
11/6/2006 1:00	1,610	92	71	Meltwater-driven regression	6.5
11/6/2006 1:30	1,640	940	575	Meltwater-driven regression	53
11/6/2006 2:00	1,600	4,970	2,510	Point sample	225.7
11/6/2006 2:30	1,580	5,980	3,000	Point sample	266.4
11/6/2006 3:00	1,570	5,630	3,080	Point sample	271.8
11/6/2006 3:30	1,550	5,220	2,860	Interpolation	249.1
11/6/2006 4:00	1,550	4,820	2,640	Interpolation	230
11/6/2006 4:30	1,550	4,410	2,430	Interpolation	211.7
11/6/2006 5:00	1,540	4,000	2,210	Interpolation	191.3
11/6/2006 5:30	1,530	3,590	1,990	Interpolation	171.1
11/6/2006 6:00	1,510	3,180	1,780	Interpolation	151.1
11/6/2006 6:30	1,520	2,770	1,560	Interpolation	133.3
11/6/2006 7:00	1,520	2,370	1,340	Interpolation	114.5
11/6/2006 7:30	1,510	1,960	1,120	Interpolation	95
11/6/2006 8:00	1,510	1,550	901	Meltwater-driven regression	76.5
11/6/2006 8:30	1,530	1,500	875	Meltwater-driven regression	75.2
11/6/2006 9:00	1,490	1,570	912	Meltwater-driven regression	76.3
11/6/2006 9:30	1,510	8,160	4,850	Interpolation	411.6
11/6/2006 10:00	1,490	14,700	8,790	Interpolation	736.1
11/6/2006 10:30	1,470	21,300	12,700	Interpolation	1,049.2
11/6/2006 11:00	1,490	27,900	16,700	Interpolation	1,398.4
11/6/2006 11:30	1,480	34,500	20,600	Point sample, Extrapolation	1,713.4
11/6/2006 12:00	1,470	26,500	17,800	Point sample	1,470.5
11/6/2006 12:30	1,430	21,800	15,500	EWI Sample	1,245.7
11/6/2006 13:00	1,400	18,200	14,200	Point sample	1,117.3
11/6/2006 13:30	1,360	13,700	10,900	Interpolation	833.1
11/6/2006 14:00	1,350	9,160	7,640	Point sample	579.6
11/6/2006 14:30	1,320	6,920	6,140	Interpolation	455.5
11/6/2006 15:00	1,300	4,680	4,640	Point sample	339

Table B1. Computations of suspended-sediment concentration at *North Santiam* (14178000), North Santiam River basin, Oregon, November 6-7, 2006.—Continued

[**Station reference**: Complete station name is in table 1 and location is in figure 1. SSC, suspended-sediment concentration; SSQ, suspended-sediment discharge; ft^3/s, cubic foot per second; FNU, Formazin Nephelometric Unit; mg/L, milligrams per liter; min, minute]

Date and Time	Streamflow (ft^3/s)	Turbidity (FNU)	SSC (mg/L)	Method of SSC estimation or computation	SSQ (tons/30min)
11/6/2006 15:30	1,290	3,300	3,570	EWI Sample	258.8
11/6/2006 16:00	1,270	2,750	3,320	Point sample	237
11/6/2006 16:30	1,260	1,570	3,080	Interpolation	218.1
11/6/2006 17:00	1,250	730	2,840	Interpolation	199.5
11/6/2006 17:30	1,240	1,320	2,600	Interpolation	181.2
11/6/2006 18:00	1,230	1,090	2,360	Point sample	163.1
11/6/2006 18:30	1,240	1,040	2,270	Interpolation	158.2
11/6/2006 19:00	1,240	890	2,180	Interpolation	151.9
11/6/2006 19:30	1,250	890	2,080	Interpolation	146.1
11/6/2006 20:00	1,270	730	1,990	Point sample	142
11/6/2006 20:30	1,280	740	1,920	Interpolation	138.1
11/6/2006 21:00	1,300	650	1,840	Interpolation	134.4
11/6/2006 21:30	1,340	650	1,760	Interpolation	132.5
11/6/2006 22:00	1,390	580	1,690	Point sample	132
11/6/2006 22:30	1,460	580	1,860	Interpolation	152.6
11/6/2006 23:00	1,520	680	2,040	Interpolation	174.3
11/6/2006 23:30	1,570	760	2,220	Interpolation	195.9
11/7/2006 0:00	1,640	710	2,390	Point sample	220.3
11/7/2006 0:30	1,680	800	2,750	Interpolation	259.6
11/7/2006 1:00	1,750	910	3,100	Interpolation	304.9
11/7/2006 1:30	1,830	1,240	3,460	Interpolation	355.8
11/7/2006 2:00	1,960	1,530	3,820	Point sample	420.8
11/7/2006 2:30	2,100	1,290	3,980	Interpolation	469.7
11/7/2006 3:00	2,280	1,080	4,140	Point sample	530.5
11/7/2006 3:30	2,550	1,560	4,540	Interpolation	650.6
11/7/2006 4:00	2,790	1,170	4,940	Point sample	774.6
11/7/2006 4:30	3,000	1,610	5,530	Interpolation	932.4
11/7/2006 5:00	3,150	3,190	6,120	Point sample	1,083.4
11/7/2006 5:30	3,280	1,620	5,180	Interpolation	954.9
11/7/2006 6:00	3,400	1,380	4,250	Point sample	812.1
11/7/2006 6:30	3,570	1,210	4,120	Interpolation	826.6
11/7/2006 7:00	3,780	1,110	4,000	Point sample	849.7
11/7/2006 7:30	3,930	980	3,820	Interpolation	843.7
11/7/2006 8:00	4,180	890	3,630	Point sample	852.7
11/7/2006 8:30	4,350	1,080	3,460	EWI Sample	845.9
11/7/2006 9:00	4,590	1,400	3,520	Point sample	908
11/7/2006 9:30	4,860	920	3,881	Precipitation-driven regression	1,060.1
11/7/2006 10:00	5,090	880	3,693	Precipitation-driven regression	1,056.3

Table B1. Computations of suspended-sediment concentration at *North Santiam* (14178000), North Santiam River basin, Oregon, November 6-7, 2006.—Continued

[**Station reference**: Complete station name is in table 1 and location is in figure 1. SSC, suspended-sediment concentration; SSQ, suspended-sediment discharge; ft^3/s, cubic foot per second; FNU, Formazin Nephelometric Unit; mg/L, milligrams per liter; min, minute]

Date and Time	Streamflow (ft^3/s)	Turbidity (FNU)	SSC (mg/L)	Method of SSC estimation or computation	SSQ (tons/30min)
11/7/2006 10:30	5,310	910	3,834	Precipitation-driven regression	1,144.1
11/7/2006 11:00	5,570	1,100	4,741	Precipitation-driven regression	1,484.1
11/7/2006 11:30	5,850	1,410	6,261	Precipitation-driven regression	2,058.4
11/7/2006 12:00	6,040	1,540	6,911	Precipitation-driven regression	2,345.9
11/7/2006 12:30	6,300	1,150	4,983	Precipitation-driven regression	1,764.3
11/7/2006 13:00	6,450	1,070	4,596	Precipitation-driven regression	1,666.2
11/7/2006 13:30	6,590	990	4,213	Precipitation-driven regression	1,560.4
11/7/2006 14:00	6,720	910	3,834	Precipitation-driven regression	1,447.9
11/7/2006 14:30	6,800	880	3,693	Precipitation-driven regression	1,411.2
11/7/2006 15:00	6,870	940	3,976	Precipitation-driven regression	1,535
11/7/2006 15:30	6,820	760	3,133	Precipitation-driven regression	1,201
11/7/2006 16:00	6,770	690	2,812	Precipitation-driven regression	1,069.9
11/7/2006 16:30	6,670	640	2,585	Precipitation-driven regression	968.9
11/7/2006 17:00	6,620	600	2,405	Precipitation-driven regression	894.6
11/7/2006 17:30	6,520	510	2,004	Precipitation-driven regression	734.5
11/7/2006 18:00	6,450	420	1,613	Precipitation-driven regression	584.6
11/7/2006 18:30	6,350	360	1,357	Precipitation-driven regression	484.3
11/7/2006 19:00	6,300	370	1,399	Precipitation-driven regression	495.4
11/7/2006 19:30	6,300	380	1,442	Precipitation-driven regression	510.4
11/7/2006 20:00	6,200	310	1,148	Precipitation-driven regression	399.9
11/7/2006 20:30	6,080	340	1,273	Precipitation-driven regression	434.9
11/7/2006 21:00	5,970	340	1,273	Precipitation-driven regression	427.1
11/7/2006 21:30	5,900	300	1,106	Precipitation-driven regression	366.8
11/7/2006 22:00	5,730	290	1,065	Precipitation-driven regression	343
11/7/2006 22:30	5,600	280	1,024	Precipitation-driven regression	322.3
11/7/2006 23:00	5,480	300	1,106	Precipitation-driven regression	340.7
11/7/2006 23:30	5,370	290	1,065	Precipitation-driven regression	321.4
11/8/2006 0:00	5,240	220	782	Precipitation-driven regression	230.2

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Bragg and others—**Suspended-Sediment Budget for the North Santiam River Basin, Oregon, Water Years 2005–08**—Scientific Investigations Report 2010–5038