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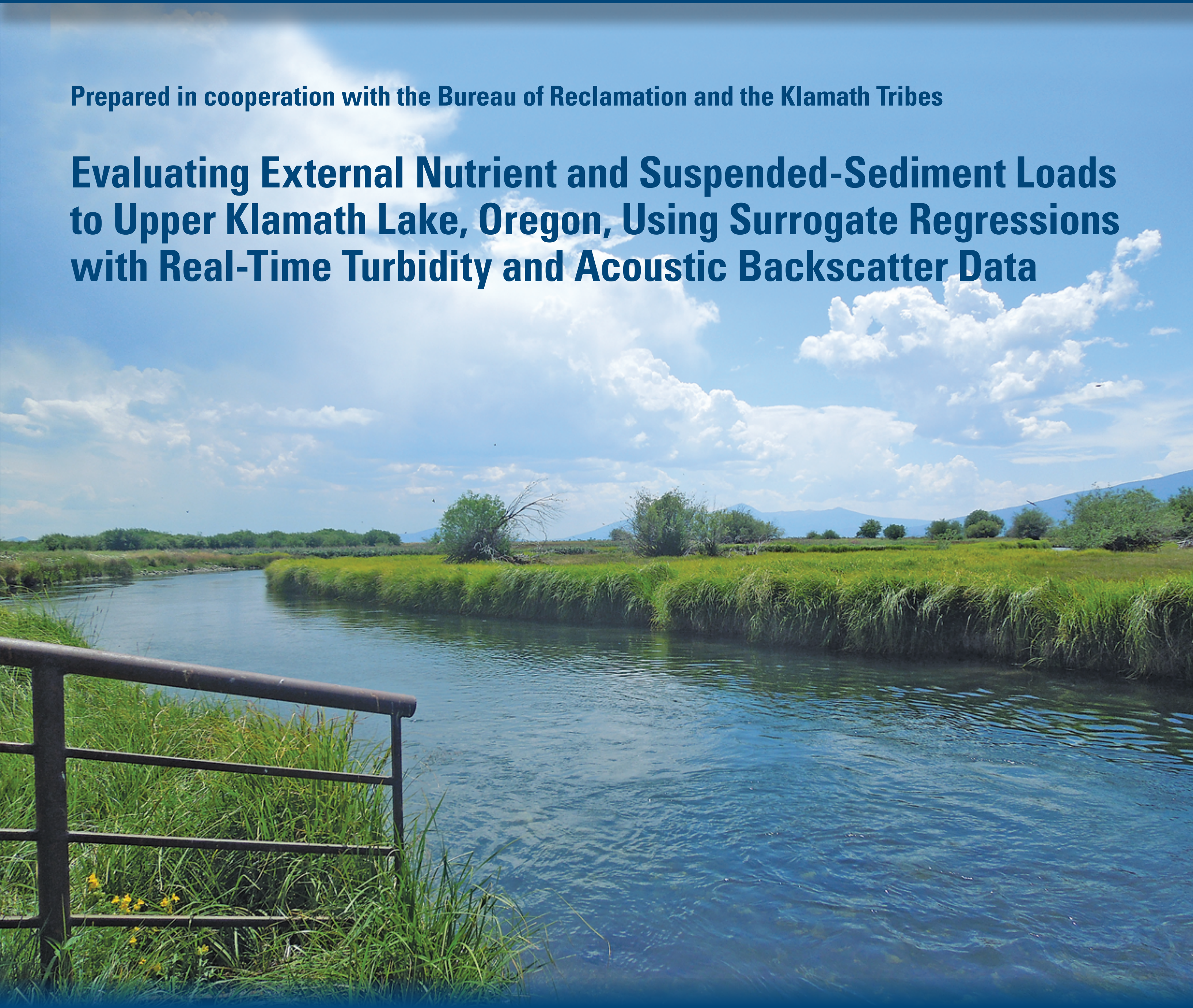
Evaluating External Nutrient and Suspended-Sediment Loads to Upper Klamath Lake, Oregon, Using Surrogate Regressions with Real-Time Turbidity and Acoustic Backscatter Data



Scientific Investigations Report 2016–5167

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

Cover: Photograph showing Wood River at Weed Road in the Wood River Valley, Oregon. Photograph by Chauncey Anderson, U.S. Geological Survey, July 8, 2014.

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SALLY JEWELL, Secretary

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

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Conversion Factors

U.S. customary units to International System of Units

Multiply	By	To obtain
	Area	
acre	0.4047	hectare (ha)
acre	0.4047	square hectometer (hm^2)
acre	0.004047	square kilometer (km^2)
square mile (mi^2)	259.0	hectare (ha)
square mile (mi^2)	2.590	square kilometer (km^2)
	Flow rate	
foot per second (ft/s)	0.3048	meter per second (m/s)
cubic feet per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
	Mass	
ton per second (ton/s)	0.9072	metric ton per second

International System of Units to U.S. customary units

Multiply	By	To obtain
	Length	
kilometer (km)	0.62137	mile (mi)
meter (m)	3.281	foot (ft)
	Volume	
milliliter (mL)	0.033814	ounce, fluid (fl. oz)
liter (L)	0.2642	gallon (gal)
	Flow rate	
centimeter per year (cm/yr)	0.393701	inch per year (in/yr)
meter per second (m/s)	3.281	feet per second (ft/s)
cubic meter per second (m^3/s)	35.315	cubic feet per second (ft^3/s)
kilogram per square kilometer (kg/km^2)	0.002855	ton per square mile (ton/mi^2)
	Mass	
microgram (µg)	2.2046×10^{-9}	pound (lb)
metric ton	1.102	ton
metric ton per year (metric ton/yr)	1.102	ton per year (ton/yr)

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

$$°F = (1.8 \times °C) + 32.$$

Concentrations of chemical constituents in water are given in micrograms per liter (µg/L), which is approximately equivalent to parts per billion (ppb) or milligrams per liter (mg/L).

Datums

Vertical coordinate information is referenced to the North American Vertical Datum of 1988 (NAVD 88) unless otherwise noted.

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

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

Abbreviations

ADAPS	Automatic Data Processing System
ADCP	acoustic Doppler current profiler
Adj R^2	adjusted coefficients of determination
ADVM	acoustic Doppler velocity meter
AFA	*Aphanizomenon flos-aquae*
ANCOVA	analysis of covariance
BCF	Duan's bias correction factor
CVO	Cascade Volcano Observatory
dB	decibel
DIN	dissolved inorganic nitrogen
DO	dissolved oxygen
EWI	equal-width-increment
HUC	Hydrologic Unit Code
FNU	Formazin Nephelometric Unit
MDL	method detection limit
MLR	multiple linear regression
MRL	method reporting limit
MSPE	model standard prediction error
N	nitrogen
NH_4^+	ammonium
$NO_2^- + NO_3^-$	nitrite plus nitrate
P	phosphorus
ppb	parts per billion
PPCC	probability plot correlation coefficient
Q	streamflow
QA	quality assurance
R^2	coefficient of determination
RPD	relative percentage difference
SAID	Surrogate Analysis and Index Developer
SCB	sediment-corrected backscatter
SLR	simple linear regression
SRWQL	Sprague River Water Quality Laboratory
SSC	suspended-sediment concentration
SSL	suspended-sediment load
TMDL	total maximum daily load
TN	total nitrogen
TP	total phosphorus (combination of dissolved and particulate phosphorus)
TSS	total suspended solids
USGS	U.S. Geological Survey
VIF	variance inflation factor
WY	water year

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Executive Summary

Suspended-sediment and total phosphorus loads were computed for two sites in the Upper Klamath Basin on the Wood and Williamson Rivers, the two main tributaries to Upper Klamath Lake. High temporal resolution turbidity and acoustic backscatter data were used to develop surrogate regression models to compute instantaneous concentrations and loads on these rivers. Regression models for the Williamson River site showed strong correlations of turbidity with total phosphorus and suspended-sediment concentrations (adjusted coefficients of determination [Adj R^2]=0.73 and 0.95, respectively). Regression models for the Wood River site had relatively poor, although statistically significant, relations of turbidity with total phosphorus, and turbidity and acoustic backscatter with suspended sediment concentration, with high prediction uncertainty. Total phosphorus loads for the partial 2014 water year (excluding October and November 2013) were 39 and 28 metric tons for the Williamson and Wood Rivers, respectively. These values are within the low range of phosphorus loads computed for these rivers from prior studies using water-quality data collected by the Klamath Tribes. The 2014 partial year total phosphorus loads on the Williamson and Wood Rivers are assumed to be biased low because of the absence of data from the first 2 months of water year 2014, and the drought conditions that were prevalent during that water year. Therefore, total phosphorus and suspended-sediment loads in this report should be considered as representative of a low-water year for the two study sites. Comparing loads from the Williamson and Wood River monitoring sites for November 2013–September 2014 shows that the Williamson and Sprague Rivers combined, as measured at the Williamson River site, contributed substantially more suspended sediment to Upper Klamath Lake than the Wood River, with 4,360 and 1,450 metric tons measured, respectively.

Surrogate techniques have proven useful at the two study sites, particularly in using turbidity to compute suspended-sediment concentrations in the Williamson River. This proof-of-concept effort for computing total phosphorus concentrations using turbidity at the Williamson and Wood River sites also has shown that with additional samples over a wide range of flow regimes, high-temporal-resolution total phosphorus loads can be estimated on a daily, monthly, and annual basis, along with uncertainties for total phosphorus and suspended-sediment concentrations computed using regression models. Sediment-corrected backscatter at the Wood River has potential for estimating suspended-sediment loads from the Wood River Valley as well, with additional analysis of the variable streamflow measured at that site. Suspended-sediment and total phosphorus loads with a high level of temporal resolution will be useful to water managers, restoration practitioners, and scientists in the Upper Klamath Basin working toward the common goal of decreasing nutrient and sediment loads in Upper Klamath Lake.

Introduction

Background

Upper Klamath Lake is a hypereutrophic lake in southern Oregon supporting large blooms of cyanobacteria during summer (typically June–October). The algal blooms cause numerous water-quality problems, including violations of the Clean Water Act and State of Oregon water-quality standards for pH, dissolved oxygen (DO), and chlorophyll-*a* (Oregon Department of Environmental Quality, 2002). In addition to violating statutory standards, the lake water-quality issues are considered a central contributor to survival problems for two species of suckers listed as endangered under the Endangered Species Act, the Lost River sucker (*Deltistes luxatus*) and the shortnose sucker (*Chasmistes brevirostris*). High pH and low DO resulting from algal productivity, among other issues, may contribute to the decrease in the recruitment of juvenile suckers into the adult populations (Hewitt and others, 2012). Although cyanobacterial biomass in Upper Klamath Lake is overwhelmingly dominated by the filamentous alga *Aphanizomenon flos-aquae* (AFA), the assemblage seasonally includes another cyanobacterium, *Microcystis aeruginosa.*

Originally identified in Upper Klamath Lake during a relatively large bloom in 1996 (Gilroy and others, 2000), *M. aeruginosa* typically proliferates in summer following large-scale bloom declines of AFA. The release of the toxin microcystin from *M. aeruginosa* also has recently been thought to contribute to the decline in endangered sucker populations (Eldridge and others, 2012). The factors affecting algal growth, decay, and successional cycles in Upper Klamath Lake, which are complex and dynamic, therefore, are crucial to understand for management of these critically endangered fish, which are culturally significant for the Klamath Tribes located near the lake.

The dominant cyanobacterium in the lake (AFA) is a diazatrophic cyanobacterium, meaning it can fix atmospheric nitrogen (N), and therefore thrive when the supply of bio-available phosphorus (P) in the lake is adequate to promote cell growth. Sources of P for AFA in the lake are both internal and external. Within a given bloom cycle, most of the P that feeds the bloom is recycled from the sediments, but the P in the sediments is a legacy of antecedent external loads and, therefore, control of external loads is a high priority for future management. Using analysis of cores from lakebed sediments, Eilers and others (2004) found that increased sediment accumulation rates in the 20th century corresponded to increases in external loading of nutrients and a change in the lake N:P ratio, and that these changes corresponded to increases in AFA dominance in the lake. Furthermore, changes in sediment composition tracked human activities in the upper watershed such as timber harvest, wetland modification, and agricultural activities (Eilers and others, 2004). Documented external sources of P to the lake include those that are transported from the upper watershed to Upper Klamath Lake by riverine inputs, primarily the Wood and Williamson Rivers (fig. 1), direct agricultural inputs from pumps and canals, and effluent pumping from drained and diked wetlands (Snyder and Morace, 1997; Kann and Walker 1999). Previous work by Kann and Walker (1999) calculated external nutrient loading using biweekly nutrient samples and streamflow, and showed that the Williamson and Wood Rivers together accounted for 67 percent of the mean annual external total phosphorus (TP, combination of dissolved and particulate P) load for water years[1] (WYs) 1992–98. Using findings from Kann and Walker (1999), a total maximum daily load (TMDL) for Upper Klamath Lake was established in 2002 by the Oregon Department of Environmental Quality (2002), and targeted a 40-percent reduction in external TP loading as the primary method of improving lake water quality. The 40-percent TP reduction corresponds to an external loading target of 109 metric tons/yr, and a long-term flow weighted mean target concentration of 66 parts per billion (ppb, or micrograms per liter).

P sources in the Upper Klamath Basin are both organic and inorganic, and in some spring-fed or wetland-dominated watersheds may be primarily in the dissolved phase. Several large groundwater sources exist in the watershed, making dissolved P, mostly as orthophosphate, an important source to the lake. However, sediment-bound P, or particulate P, is considered important, too (Walker and others, 2015), especially where it results from erosion and land-use modifications. Phosphate ions are easily adsorbed by sediments, particularly those sediments containing iron and aluminum oxide minerals (Stumm and Morgan, 1981), or are bound in rocks from the region's volcanic sources of the region. These sediments can then act as a transport mechanism for P in the fluvial environment once the sediments are entrained. Storm events are particularly prone to transporting large quantities of P from irrigated lands in the Klamath Basin (Ciotti and others, 2010). The sediment-bound P can then become bioavailable when phosphate ions are released through various biotic or abiotic mechanisms including elevated pH, reduced conditions, bioturbation, macroinvertebrate excretion, and microbial mineralization (Stumm and Morgan, 1981; Zhou and others, 2005; Wood and others, 2013). Therefore, variations and dynamics in suspended-sediment loads (SSLs), in addition to TP loads (TPLs), have important implications for resource managers.

Suspended-sediment and associated nutrient transport is affected by various factors and processes within the drainage basins of tributary rivers to Upper Klamath Lake. The underlying volcanic geology of the upper basin, which is fundamental to the availability of sediment and P, is composed of a mix of volcanic vents, pyroclastic deposits, and volcanically derived sedimentary deposits, with subsequent glaciation and stream processes modifying the river network and landscape (Gannett and others, 2007). The violent eruption of Mount Mazama roughly 6,700 years ago draped a layer of pumice and ash over much of the region, and the remnant surficial layers can be easily erodible. This is particularly true in the Sprague subbasin, which has been modified extensively by commercial forestry, agriculture, and ranching that have resulted in channel changes from straightening and diking, and riverbanks that have been exposed and trampled. Studies have shown that the South Fork Sprague River contributes more sediment to the Sprague system than the North Fork Sprague and Sycan Rivers combined (Graham Matthews and Associates, 2007; O'Connor and others, 2015) through processes of lateral channel migration and channel incision. Decreases in the frequency and extent of flood plain inundation in the Sprague River Valley have led to increased downstream sediment transport (O'Connor and others, 2015), highlighting the importance of flood plain reconnection in controlling sediment transport.

[1]The 12-month period from October 1, for any given year, through September 30 of the following year. The water year is designated by the calendar year in which it ends.

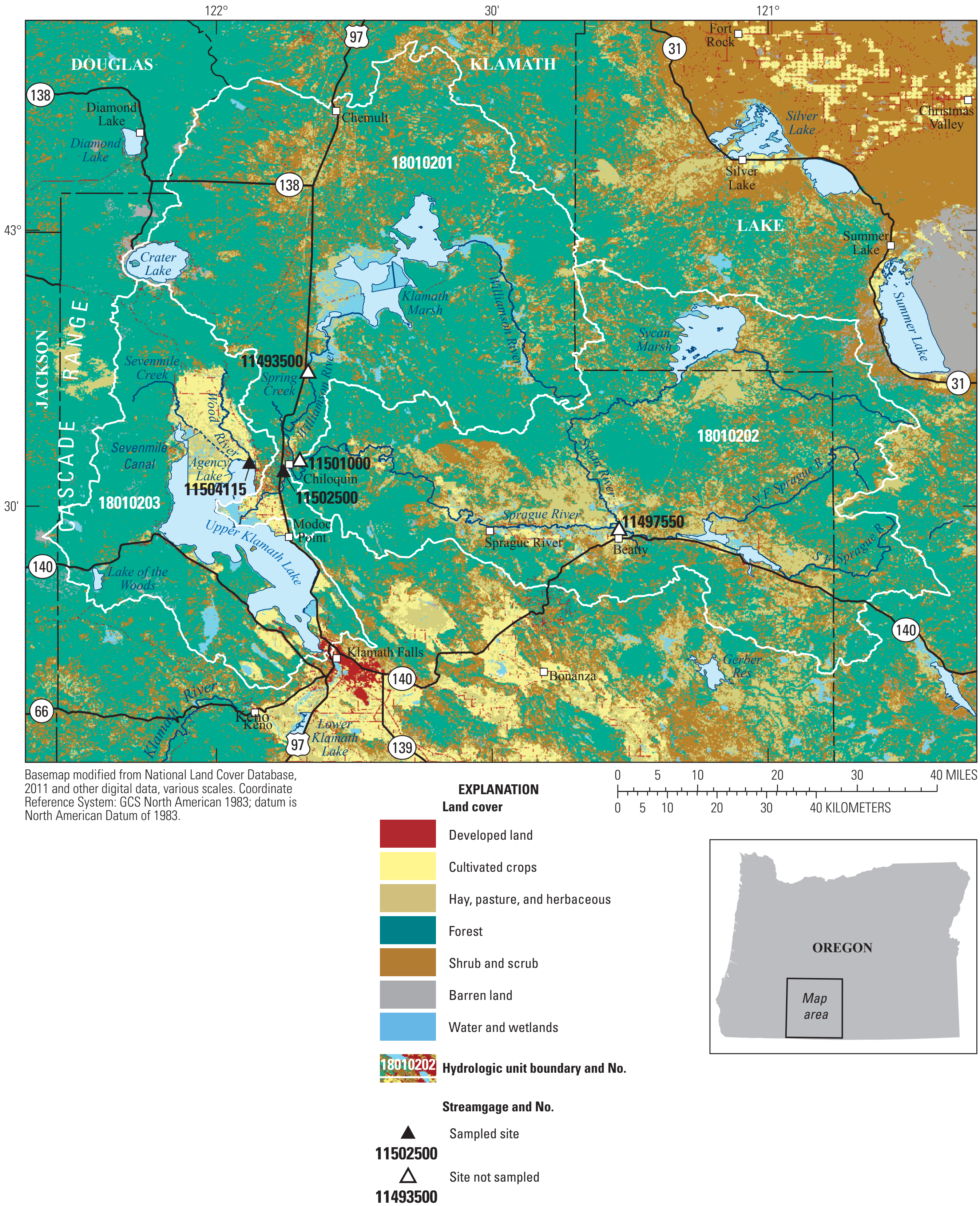

Figure 1. Area map of Upper Klamath Basin, Oregon.

Despite the importance of surficial controls on sediment and associated nutrient transport, groundwater sources also are important in many parts of the Upper Klamath Basin including the Sycan River (a tributary to the Sprague River), the upper Williamson River upstream of the Sprague River, and in the Wood River (Gannett and others, 2007), as well as numerous fringe wetlands around the lake (Synder and Morace, 1997; Carpenter and others, 2009). Nonetheless, sediment movement can occur in these groundwater-dominated systems. In the Wood River, accumulations of layers of peat soils and clays underlay pumice layers from the Mount Mazama eruption, with additional accumulations of peat and organic material sitting atop the pumice. As elsewhere in the Upper Klamath Basin, cattle grazing and channelization in the Wood River Basin, as well as wetland diking and draining, have disrupted these layers and altered the sediment and nutrient transport dynamics and loading to Upper Klamath Lake (Carpenter and others, 2009). A nearly constant supply of pumice can be visibly observed moving along the streambed at Wood River when the visibility is clear, suggesting that higher flows can access and mobilize additional pumice and other sediment types.

The local geology, land use, and surface topography all provide controlling factors in sediment transport in the tributary basins to Upper Klamath Lake, and restoration efforts have been implemented for numerous years with varying project goals. These efforts include in the fringe wetlands along the lakeshore, and in the upper basin tributaries. Wetland restoration has occurred in the Wood River wetlands and in the Williamson River Delta, with the goals of reclaiming agricultural lands and restoring seasonal and permanent wetland hydrology (Duff and others, 2009). These wetland restoration efforts have multiple objectives, but one intent is to decrease nutrient export from the wetlands transported to the larger lake ecosystem (Wong and others, 2011). Studies have shown that following wetland restoration at the Williamson River Delta, an increase in nutrient release from newly inundated sediments occurred (Wong and others, 2011), and increased nutrient flux to the overlying water column continued for at least 3 years following restoration efforts as the restored wetlands remained in a chemical transition (Kuwabara and others, 2012). However, long-term monitoring also has shown that over time, restored wetlands may retain nutrients after the initial transitional period (Pant and Reddy, 2003). Restoration efforts in the Upper Klamath Basin tributaries to Upper Klamath Lake, particularly in the Sprague and Wood River Valleys, have included goals of reducing riparian disturbances from cattle grazing, channel re-alignment, and reconnecting flood plains to main-stem channels through levee setbacks and removals, among other goals (Newfields River Basin Services, 2012).

Most of the restoration efforts in the Upper Klamath Basin generally aim to improve stream health and habitat conditions for native fish, in addition to reducing sediment and associated nutrient transport from unprotected riparian zones and modified stream channels. With the goal of reducing sediments and nutrients at the watershed scale, advanced techniques to monitor temporal variations in loads will be necessary to track the combined efficacy of restoration efforts in the Upper Klamath Basin. These advanced techniques are necessary because discrete sampling prior to this study typically has not targeted high streamflow conditions, and the variations in loads occur at time scales that cannot be captured using discrete samples alone. Additionally, streamflow data alone are often a poor predictor of nutrient and sediment concentrations, so traditional methods of assessing sediment transport may not be useful, especially in the groundwater-dominated Wood River.

The use of surrogates, such as turbidity and streamflow, in developing regression models to monitor and quantify sediment and nutrient loads in fluvial systems in near real time is an emerging technology that has proven useful nationwide, in Oregon, and in the Klamath Basin. Surrogate regressions are beneficial because they use measured high-resolution time-series (“unit”) data to compute concentrations and loads of unmeasured constituents, and allow for direct assessment of model uncertainty by computing prediction intervals around the calculated concentration (Rasmussen and others, 2009). “Daily” values, computed as the mean or median of the unit values over a given 24-hour period, generally are used to calculate loads as the product of daily concentrations and daily streamflow.

Turbidity is an expression of the optical properties of a liquid that causes light rays to be scattered and absorbed rather than transmitted in straight lines through a sample (ASTM International, 2003). As such, turbidity is not considered a direct measure of particle concentration in a water sample. However, turbidity is largely affected by particle density, size distribution, and composition, and experience has shown that it can be an excellent surrogate for suspended sediment, among other parameters (Lewis, 1996; Rasmussen and others, 2008, 2009). Turbidity as a surrogate has been used to calculate suspended-sediment concentration (SSC) in the Wilson and Trask River Basins in northwestern Oregon (Sobieszczyk and others, 2015), in the Santiam River Basin (Bragg and others, 2007), in the Middle Fork Willamette River Basin (Schenk and Bragg, 2014), and in the McKenzie River (Anderson, 2007). Similar to the use of in-place turbidity measurement as a surrogate for SSC, acoustic backscatter data collected as ancillary data for the calculation of streamflow from acoustic Doppler velocity meters (ADVMs) also have been shown to be a useful surrogate for suspended sediment and P in some systems (Medalie and others, 2014). The ancillary backscatter data must first be converted to sediment-corrected backscatter (SCB) before being evaluated as a surrogate. However, the success of surrogate regression methods is dependent on local controls including geology, hydrology, mineralogy, and land use. Some examples of local controls in the study area are the unique combinations of volcanic history and stream modification in the Williamson and Sprague Rivers (O’Connor and others, 2015), and the spring-dominated and historically modified wetland complexes in the Wood River Basin

(Duff and others, 2009), which represent new challenges for surrogate techniques, especially surrogates for P.

Water-quality improvements in Upper Klamath Lake will require a reduction in external loads of P and suspended sediment to discourage the growth of the large algal blooms that are causing poor water-quality conditions and the presence of cyanotoxins (Oregon Department of Environmental Quality, 2002). An understanding of the temporal trends in nutrient and sediment loads to the lake is important to resource managers in the Upper Klamath Basin, and for restoration practitioners attempting to improve stream health and habitat conditions for aquatic species. Walker and others (2012) produced detailed, basinwide estimates of nutrient loading from individual tributaries using biweekly, discrete sampling data collected by the Klamath Tribes. In this report, we use high temporal resolution surrogate regression models to calculate suspended-sediment and P loads to Upper Klamath Lake from two major tributaries, the Wood and Williamson Rivers. These estimates are compared to the estimates from Walker and others (2012) to assess the relative differences in the two methods and provide perspective on their respective merits.

Purpose and Scope

This report summarizes suspended-sediment and TP loads to Upper Klamath Lake, estimated at two streamgages in the Upper Klamath Basin using turbidity and acoustic backscatter data as surrogates. Study goals included the following:

1. Test the ability of high-temporal-resolution turbidity and backscatter data, combined with SSC and nutrient sampling, to successfully develop high-resolution surrogate models to estimate concentrations of suspended sediment and TP at two sites in the Upper Klamath Basin.

2. Using surrogate regression models, estimate concentrations and loads of suspended sediment and TP to Upper Klamath Lake from the Wood and Williamson River sites during short (hours to days), intermediate (days to weeks), and longer (weeks to seasons and even years) time periods.

3. Contribute to existing datasets to evaluate the efficacy of future restoration actions aimed at reducing sediment and TP loading from the Wood, Williamson, and Sprague Rivers.

4. Improve the understanding of the relative importance of particulate and dissolved P loading from the Williamson and Wood River sites, and, to the extent possible, develop an initial understanding of the reactive or bioavailable components of the TP loading including its seasonality.

Load calculations were made at two U.S. Geological Survey (USGS) streamgages in the Upper Klamath Basin on the Wood and Williamson Rivers near their discharge points to Upper Klamath Lake and, therefore, representing total SSLs and TPLs from nearly their entire respective watersheds (fig. 1). The Williamson River site is downstream of the confluence with the Sprague River and, therefore, represents SSLs and TPLs from both the Williamson and Sprague subbasins. Suspended sediment concentration and turbidity data for the Williamson and Sprague subbasins measured at the Williamson River site are available starting in WY 2008. Suspended-sediment and turbidity data for the Wood River site start in WY 2014. Nutrient data for both sites start in WY 2014. Therefore, a longer period of record exists for suspended sediment at the Williamson River site than for the Wood River site, and TPLs are reported for both sites only for WY 2014.

Description of Study Area

The Upper Klamath Basin, including the Upper Klamath Lake, Williamson, and Sprague subbasins (fig. 1), encompasses about 3,770 mi^2 (Natural Resources Conservation Service, 2005a, 2005b, 2005c). The basin is located in south-central Oregon and occupies a broad, faulted, volcanic plateau that spans the boundary between the Cascade Range and the Basin and Range geologic provinces (Gannett and others, 2007). A regional groundwater study by Gannett and others (2007) in the larger Upper Klamath Basin comprising the entire drainage basin upstream of Iron Gate Dam on the Klamath River provides detailed basin setting, regional groundwater movement, historical precipitation patterns, water budgets, and geologic framework of the basin. An additional study in the Sprague subbasin by O’Connor and others (2015) provides detailed information on geomorphologic conditions and flood-plain and near-channel vegetation. Studies in the Wood River Valley also provide information on geology and soils in that valley (Snyder and Morace, 1997; Carpenter and others, 2009).

This study used data from two USGS streamgages, each representing distinct subbasins within the Upper Klamath Basin. The streamgage on the Williamson River below Sprague River, near Chiloquin, Oregon (USGS streamgage 11502500, hereinafter referred to as the “Williamson River site”) represents streamflow, suspended-sediment, and nutrient contributions from both the Sprague (Hydrologic Unit Code [HUC] 18010202) and Williamson (HUC 18010201) subbasins and drains about 3,000 mi^2 (about 1.9 million acres), about 98 percent of the Sprague and Williamson subbasins combined. The streamgage on the Wood River near Klamath Agency (USGS streamgage 11504115, hereinafter referred to as the “Wood River site”) represents streamflow, turbidity, suspended-sediment, and nutrient contributions from the Wood River Valley, in the northern part of the Upper Klamath Lake subbasin (HUC 18010203), and drains about 80 mi^2 (51,200 acres), representing about 11 percent of the total drainage area of the Upper Klamath Lake subbasin. Additional tributaries to the lake exist, but they are smaller and were not included in this initial study for logistical reasons.

Williamson and Sprague Subbasins

The Williamson and Sprague subbasins combined constitute 79 percent of the total drainage area and about 50 percent of the streamflow to Upper Klamath Lake (Hubbard, 1970; Risley and Laenen, 1998). Forested land is the predominant land-use type in the Williamson (80 percent) and Sprague (68 percent) subbasins. Agriculture in both river subbasins is minimal in terms of overall watershed area, with about 9 and 8 percent of subbasin land use listed as pasture and grass hay for the Williamson and Sprague subbasins, respectively, and 2 percent of each of the subbasins listed as irrigated lands (tables 1 and 2). However, agricultural grazing activities that occur near the Sprague and Williamson Rivers and their tributaries reduce riparian vegetation as well as widening and shallowing the channel cross sections, which can lead to increased sediment and nutrient inputs to the fluvial systems.

On an annual basis, the Sprague River provides a substantial part of the total Williamson River streamflow measured at the Williamson River site (Hess and Stonewall, 2015). Upstream of the confluence of the Williamson and Sprague Rivers, Spring Creek provides most of the streamflow to the Williamson River at base flow, and the Williamson River between the outlet of the Williamson River canyon and the Sprague River confluence is a system with a large component of groundwater discharge that responds relatively slowly to storm events and snowmelt runoff (Gannett and others, 2007). A streamgage at the outlet of the Klamath Marsh near Kirk, above the Williamson River canyon (USGS streamgage 11493500), has an ephemeral runoff signal that remained dry for most of WYs 2014 and 2015 during the study period. WYs 2014 and 2015 were characterized by minimal snowpack and few storm events, so most of the sediment and nutrient transport measured at the Williamson River site is assumed to be comprised of inputs from the Sprague River for these years.

Table 1. Land use and land cover in the Williamson, Sprague, and Upper Klamath Lake subbasins, Oregon.

[Land use acreage values taken from Natural Resources Conservation Service (2005a, 2005b, 2005c). Totals are approximate because of rounding and small unknown acreages. **Abbreviation and Symbol:** HUC, Hydrologic Unit Code; <, less than]

8-digit HUC	Subbasin name	Public/ private/ total	Land use, in acres (percentage of total HUC acreage)			
			Forest	Grass/pasture/ hay	Shrubs/ rangelands	Water/wetlands/ developed/barren
18010201	Williamson	Public	546,200 (59)	23,500 (3)	16,000 (2)	38,200 (4)
		Private	192,200 (21)	53,400 (6)	10,600 (1)	37,600 (4)
		Total	**738,400 (80)**	**76,900 (9)**	**26,600 (3)**	**75,800 (8)**
18010202	Sprague	Public	474,000 (46)	18,900 (2)	86,400 (8)	[1] (< 1)
		Private	225,200 (22)	59,000 (6)	93,600 (9)	54,400 (5)
		Total	**699,200 (68)**	**77,900 (8)**	**180,000 (17)**	**62,500 (6)**
18010203	Upper Klamath Lake	Public	206,400 (45)	12,100 (3)	[1](< 1)	87,900 (19)
		Private	69,700 (15)	45,500 (10)	[1](< 1)	21,700 (5)
		Total	**276,100 (60)**	**57,600 (12)**	**10,700 (2)**	**109,600 (24)**

[1]Less than 1 percent of total acreage.

Table 2. Irrigated land acreage in the Williamson, Sprague, and Upper Klamath Lake subbasins, Oregon.

[Land use acreage values taken from Natural Resources Conservation Service (2005a, 2005b, 2005c). Totals are approximate because of rounding and small unknown acreages. **Abbreviation:** HUC, Hydrologic Unit Code]

8-digit HUC	Subbasin name	Land use (acres)				Total irrigated lands (percentage of HUC)
		Cultivated cropland	Uncultivated cropland	Pastureland	Total irrigated lands	
18010201	Williamson	8,200	1,200	6,600	16,000	2
18010202	Sprague	1,100	9,900	12,100	23,100	2
18010203	Upper Klamath Lake	0	8,200	34,200	42,400	9

Wood River Valley

The Wood River Valley is on the northern end of the Upper Klamath Lake subbasin (HUC 18010203), and supplies about 14 percent of the total streamflow to Upper Klamath Lake as reported by Hubbard (1970). Recent analysis by Walker and others (2012) reports the Wood River supplying about 20 percent of the total streamflow to Upper Klamath Lake, using data from 1992 to 2010. The Wood River is dominated by groundwater flows, receiving most of its streamflow from spring complexes along the fault scarp on the eastern boundary of the valley (Gannett and others, 2007). Surface drainage in the valley is heavily altered with extensive wetland draining and constructed dikes for agricultural land uses. More irrigated acreage in the Upper Klamath Lake subbasin is used as pastureland than in the Sprague and Williamson subbasins combined (table 2). Two tributaries to the Wood River (Annie and Sun Creeks) originate on the southern flanks of Crater Lake, and contribute suspended sediment to the Wood River during storm events as observed by USGS hydrologists. The Wood River site is located on the Dike Road of the Bureau of Land Management Wood River Wetlands, about 1 river mile from the point where the river discharges to Upper Klamath Lake and, therefore, represents sediment and nutrient transport from the Wood River headwaters and Annie Creek, Sun Creek, Fort Creek, and Crooked Creek. The site also has backwater effects because of its close proximity to the lake, and extreme wind events that cause short-term negative flows, complicating interpretation of streamflow and suspended-sediment and nutrient transport. Because of the backwater and wind effects, an ADVM is deployed to compute streamflow using index-velocity rating curve methods. The unique hydrology of the Wood River site results in a challenging environment for event-based sampling; at times, the turbidity response owing to storm events results in rapid rises and declines that are difficult to predict and sampling opportunities may be missed, whereas at other times the response to storms is unexpectedly delayed or minimal.

Data Collection and Methods

The USGS collected high-frequency turbidity and streamflow data at both study sites, and collected discrete suspended-sediment and nutrient samples for different periods (table 3). Data collected were used to develop site-specific SSC-turbidity and TP-turbidity regression models at the Williamson site, and SSC-SCB/turbidity and TP-turbidity regression models at the Wood River site. The models were then used to compute continuous SSC and TP data for periods determined by the availability of data at each site.

At the Williamson River site, turbidity data and suspended-sediment samples were collected starting in WY 2008 under a cooperative agreement between the Klamath Tribes and USGS. Nutrient sample collection did not start until WY 2014. As such, suspended-sediment concentrations and loads at the Williamson River site were computed for WYs 2008–14 (7 water years), and TP concentrations and loads were computed for WY 2014.

The streamgage on the Wood River was installed in August 2013. Turbidity and streamflow data have been collected since this streamgage was installed. Ancillary acoustic backscatter data were collected from the ADVM and converted to SCB, which was used in regression models. Suspended-sediment and nutrient samples were collected in WYs 2014–15. The sample set used to develop surrogate regressions was augmented with samples collected by the Klamath Tribes at the same location. Suspended-sediment and TP concentrations and loads at the Wood site were computed for November 2013–March 2015.

Table 3. Availability of streamflow and water-quality data for surrogate regressions at U.S. Geological Survey (USGS) sites on the Williamson and Wood Rivers (USGS streamgages 11502500 and 11504115), Upper Klamath Basin, Oregon, 1917–2015.

[Time-series data are monitored on a subhourly basis and telemetered for near-real time availability online. Discrete samples are collected manually and submitted to a laboratory for analysis. **Suspended sediment:** Includes concentration and percentage of particles less than 63 micrometers in diameter. **Nutrients:** Includes ammonium-nitrogen (NH_4^+ as N), nitrate plus nitrite ($NO_2^-+NO_3^-$ as N), orthophosphate-phosphorus (PO_4^{3-} as P), total nitrogen (TN), and total phosphorus (TP). **Abbreviations:** mi^2, square mile; *n*, number of samples]

USGS streamgage No.	Site name	Drainage basin area (mi^2)	Time-series data		Discrete samples	
			Streamflow	Turbidity and water temperature monitors	Suspended sediment (*n*)	Nutrients (*n*)
11502500	Williamson River	3,000	June 1917–2015	October 2007–June 2011, March 2012–15	April 2008–February 2015 (35)	November 2013–February 2015 (10)
11504115	Wood River	78.8	August 2013–15	August 2013–15	November 2013–March 2015 (14)	November 2013–March 2015 (14)

Turbidity

Time series of turbidity data were collected during the study period at both sites, using Forest Technology Systems DTS-12 turbidity sensors deployed in the water column, which report turbidity in Formazin Nephelometric Units (FNUs) (Anderson, 2005). The turbidity sensors used near-infrared light sources in the range of 780–900 mm with a single detector at 90 degrees to the light beam. Management of turbidity sensors and processing and approval of data followed USGS protocols in Wagner and others (2006) and Rasmussen and others (2009). Turbidity data were collected every 15 min at the Williamson River site and every 10 min at the Wood River site, and were stored in the USGS National Water Information System using method codes specific to the instrument type. Turbidity sensors were equipped with wipers and were programmed to wipe the sensor face prior to taking a measurement. One limitation of the DTS-12 sensors is that the wiper is not activated at temperatures less than 2 °C, a condition that often is encountered during the winter at both sites, although generally during periods when both flow and turbidity are low.

Sediment-Corrected Backscatter

Acoustic instruments are installed at many streamgages to measure velocity and compute discharge. Acoustic instruments rely on suspended particles in the water column to calculate the water velocity by measuring the Doppler shift of acoustic pulses reflected off the particles (Levesque and Oberg, 2012). One of the quality-assurance parameters from the velocity signal of the acoustic meter is backscatter intensity, which often can be related to the amount of suspended particles in the water column. Backscatter intensity has been used to estimate SSC in estuaries, rivers, and other water bodies (Gartner, 2004; Patino and Byrne, 2004; Topping and others, 2006; Wood and Teasdale, 2013). Some of the advantages of using acoustics over other types of in-place surrogate technologies are that biological fouling has little to no effect on the instrument, and acoustic data sampling volumes within the stream cross section are much larger and potentially more representative compared to point sensors (such as turbidity).

The acoustic meter installed at the Wood River site is a Sontek-SL™ Series 3.0 MHz ADVM, and is attached to a bridge piling near the right bank of the channel. The acoustic meter is configured with a blanking distance (where no data are collected) of 0.30 m from the transducer, collects acoustic data through ten 0.40-m-wide cells to within about 17 m of the left bank, and is set to average data for the first 3 min of each 10-min sample interval. The acoustic data are corrected before they can be used as an explanatory variable in regressions to estimate suspended-sediment concentration. The corrections take into account beam spreading, water absorption, and attenuation by the suspended sediment as the sound wave travels through the water. The methods used to make these corrections are documented in Landers and others (2016), Topping and others (2006), Landers (2012), and Wood and Teasdale (2013). The USGS has developed the Surrogate Analysis and Index Developer (SAID) tool to make the required corrections to acoustic backscatter data and develop regressions to estimate SSCs (Domanski and others, 2015).

The SAID program was used to make the required corrections to the backscatter data and to develop the regressions at the Wood River site for this study. The Sontek-SL™ dataset ranges from October 22, 2013, to April 30, 2015. The first cell (the one closest to the acoustic meter) was excluded from SAID because it was located in a zone of poorly mixed water and it was affected by the near field distance as described by Downing and others (1995). Within SAID, beam 2 (upstream beam) was used to correct the acoustic data, used a moving average of three acoustic values for every SSC sample, and activated the near field correction option as explained in Domanski and others (2015) even though the first cell was excluded. As a data quality check, the model was run with and without the near field correction applied, and the model results were identical.

Suspended-Sediment and Nutrient Sample Collection

This study used suspended-sediment and nutrient data collected by the USGS and the Klamath Tribes. Collection protocols differed between the two agencies.

USGS Sample Collection

Collection of SSC and nutrient samples followed USGS protocols using depth- and width-integrating (equal-width-increment [EWI]) techniques described by Edwards and Glysson (1999) and Gray and others (2008). Samples at the Williamson River site were collected from a cableway, and samples at the Wood River site were collected from a bridge. When stream velocities at the Wood River site decreased to less than 0.46 m/s (1.5 ft/s), less than the minimum velocity for most isokinetic samplers (Davis, 2005), grab samples were collected from the right bank as close to the turbidity sensor as possible.

Samples collected from the Williamson River for 2008–13 were analyzed at the USGS Cascade Volcano Observatory (CVO) sediment laboratory for SSC (in milligrams per liter) and the percentage of sediment finer than 62.5 µm. Individual sample bottles in glass pint, glass quart, or 3-L plastic bottles were sent to the sediment laboratory and composited prior to analysis. Samples collected in WY 2014 were analyzed at the Sprague River Water Quality Laboratory (SRWQL), except for one sample collected on February 19, 2014, and analyzed at CVO for SSC and the percentage of sediment finer than 62.5 µm. Samples collected in 2014 were analyzed at SRWQL for nutrients and SSC; therefore, samples for both items were subsampled from a churn splitter after an EWI sample was collected. Two 1-L bottles were filled from the churn, sent to SRWQL, and composited prior to analysis. SSC samples from the Wood River in 2014 and 2015 were analyzed at the SRWQL, and also were subsampled from a churn splitter after an EWI sample was collected.

Nutrient sample collection and processing at both sites during 2014–15 followed USGS protocols outlined in the National Field Manual for the Collection of Water-Quality Data (Wilde and others, 2004 [with updates through 2009]; U.S. Geological Survey, 2006). Clean Hands/Dirty Hands techniques were used when collecting and processing water samples. At the Williamson River site, all samples were collected from the cableway using a DH-95 isokinetic sampler suitable for collecting water-quality samples. EWI samples were composited into a 3-L, acid-washed plastic bottle protected in a plastic bag on the cableway, and transferred to the churn splitter after the sample was collected. EWI samples at the Wood River site were collected from a bridge using a three-wheel crane and a water-quality rated DH-95 isokinetic sampler when stream velocities exceeded 0.46 m/s (1.5 ft/s). Grab samples at the Wood River were collected from the right bank with gloved hands using an acid-washed plastic bottle when stream velocities were less than 0.46 m/s (1.5 ft/s). Sample water was then transferred to a churn splitter for compositing prior to subsampling. All samples were processed in the field, placed on ice, and delivered to the SRWQL on the same day the samples were collected. Samples were analyzed for total nitrogen (TN) and P, and dissolved N and P as orthophosphate, nitrite plus nitrate as N ($NO_2^- + NO_3^-$ as N), and ammonium as N (NH_4^+ as N). Samples for TP and TN were collected in 125-mL white plastic bottles and preserved with 4.5 N sulfuric acid. Samples for dissolved nutrients were filtered through a 0.45-µm in-line capsule filter using a peristaltic pump with acid-washed tubing, collected in an amber plastic bottle and stored on ice. SSC samples also were collected into two 1-L Nalgene® bottles from the same churn as the nutrient samples.

Klamath Tribes Sample Collection

The Klamath Tribes sample the Wood River site biweekly as part of an ongoing long-term water-quality monitoring program that was established in 1991. To improve model performance by increasing the number of samples used in the regression models, nutrient and total suspended solids (TSS) data that were collected by the Klamath Tribes during the study period were evaluated. Such data had the added benefit of representing base-flow hydrologic and turbidity conditions to augment the storm-event-driven sampling approach by the USGS. Prior to including these samples, comparisons of data collected on similar sampling days were evaluated to determine if differences in sampling technique compared to USGS field protocols would cause a detectable difference in analytical results. Four pairs of USGS and Klamath Tribes samples were evaluated, of which two were collected within 45 min of each other on the same day, and two were collected within 2 days of each other at base-flow conditions.

Techniques for collection of water-quality samples differ slightly between the USGS and the Klamath Tribes. The Klamath Tribes use a Van Dorn sampler to obtain point samples from middle depths at a minimum of 10 locations along the channel width, compared to the EWI sample techniques by USGS that integrate throughout the water column using isokinetic samplers, at multiple locations in the cross section. The Van Dorn sampler and the churn splitter used by the Klamath Tribes are initially acid washed in the laboratory, and between sites are field rinsed three times with environmental water before collecting water for processing. Whole water sample volumes from the churn are collected and transported back to the SRWQL on ice for processing and analysis. Laboratory analytical methods for nutrients are identical to the methods used to analyze USGS samples, but filtration and acidification occurs in the laboratory on the same day of sample collection rather than being done in the field.

There are differences in the suspended-sediment analysis used by the Klamath Tribes monitoring program, which routinely measures TSS, and the USGS protocols that measure SSC. The standard TSS method generally uses a subsample from a water sample and measures suspended material captured on a filter, whereas the SSC method measures the mass of sediment in the entire water sample. As such, TSS analysis is subject to subsampling errors that can be compounded when settleable materials (for example, sand) are present. Comparing more than 3,000 paired data points nationally, Gray and others (2000) showed that TSS commonly is biased low relative to SSC measurements, especially as the amount of sand in the samples increases, although results varied according to the sampling site and laboratory. Furthermore, TSS does not allow for measurement of grain sizes, so the fine fraction of sediment is not available with TSS data. The Klamath Tribes TSS samples are analyzed at SRWQL using Standard Method 240 D (American Public Health Association, 1998) and U.S. Environmental Protection Agency method 160.2, which uses filtration of as much as 1 L of sample through a prewashed and dried (105 °C) 1.5-µm pore-size glass fiber filter. Subsamples (about 1 L) are taken from the churn splitter prior to filtration, which is intended to minimize bias from settleable material by keeping it in suspension during subsampling. TSS samples from the Klamath Tribes were only used in regression models at the Wood River site, where the large groundwater component of streamflow and the low energy of the stream at the sampling site typically result in a suspended-sediment distribution dominated by fine-grained particles, further minimizing subsampling bias from settleable materials in the environmental samples.

Comparison of sample results shows that nutrient samples differed by 16 percent or less for all four sampling events, with the exception of NH_4^+ as N and $NO_2^- + NO_3^-$ as N results that were equal to or less than the method reporting limit (table 4), and two of the TN comparisons. The SRWQL defines the method reporting limit (MRL) as twice the value of the lowest concentration detected by analytical procedures.

The lowest concentration detected by analytical procedures is defined as the laboratory method detection limit (MDL). Concentrations less than the MRL are treated as results that are outside the capability of the laboratory to quantify. For those situations when paired results were less than the MRL, relative percentage differences (RPDs) were not calculated, and are designated as "NC" in table 4. One outlier in the comparison dataset was TN from samples collected on September 23, 2014, by the Klamath Tribes and September 25, 2014, by the USGS. TN results also differed substantially for the samples collected 50 min apart on February 18, 2015. All other nutrient parameters compared well. TSS and SSC sample pairs collected at low concentrations did not agree well, which is not surprising given the variability and comparatively low precision in analytical results at low SSCs.

A total of 6 samples collected by the Klamath Tribes were incorporated in the model calibration datasets for SSC and TP at the Wood River site, resulting in 20 total samples to inform regression models at that site. The six Klamath Tribes samples were collected during months when the USGS did not collect samples and, therefore, represented low values of turbidity and discharge that were not sampled by the USGS.

Quality Assurance

Owing to the frequently high variability in measured SSC values nationally, the USGS recommends collecting and separately analyzing replicate samples for SSC analysis, referred to as A and B sets (Nolan and others, 2005; Gray and O'Halloran, 2015). SSC samples collected at the Williamson River site during 2008–10 and 2012–13 included both A and B sets (or primary and replicate sets). For an individual sampling event, both sets were compared before being used in regression analysis. If the sample results from the two sets were different, an additional inspection was conducted to determine if one or both of the sample results were compromised because of errors during sample collection, shipping, or analysis. If results from both A and B sets were determined to be acceptable, the two SSC values were averaged to avoid serial correlation within the dataset, and the average value was used in the regression model calibration dataset. Analytical results for SSC A and B sets at the Williamson River site are available in appendix A.

SSC and nutrient samples collected at both sites for 2014–15 included additional quality-assurance (QA) samples collected as replicates periodically during the study period, representing about 20 percent of the total number of samples collected during 2014–15. Replicates were collected either as split-replicates or sequential-replicates. Split-replicate samples were collected from the same churn during sample processing, representing a split of one EWI sample, and providing an estimate of variability introduced in the laboratory analysis. Sequential-replicate samples were collected as two separate sample volumes during the EWI samples and processed separately, and provide a combined estimate of variability owing to both field and laboratory sources, similar to the A and B set sampling described in the previous paragraph. Sequential-replicate samples collected during storm events represented rapidly changing hydrologic conditions and, therefore, were more variable than the split-replicate samples because of the additional time required to collect two sample volumes, during which actual concentrations of constituents in the stream are expected to change. Three QA samples were collected during 2014–15 at the Williamson River site, and five QA samples were collected during 2014–15 at the Wood River site. Two equipment blank samples also were collected at each site to test the cleanliness of sample equipment and potential for field contamination. Blank samples were collected in the field prior to processing environmental samples. QA results are shown in appendix B.

Streamflow Methods

Instantaneous and continuously recorded streamflow at Williamson River was measured using a stage-streamflow relation, following standard USGS guidelines (Rantz and others, 1982; Kennedy, 1983; Buchanan and Somers, 1984). Streamflow measurements typically were made every 6–8 weeks, and extra measurements were made as needed at high and low flows for defining the stage-streamflow relation. This rating allows the computation of a 15-min record of streamflow at the streamgage.

Instantaneous streamflow at the Wood River site was computed using the index velocity method described in Levesque and Oberg (2012). The index velocity method commonly is used in areas where backwater is present and a stage discharge relation is not usable. The index velocity method uses an index velocity rating and a stage-area rating. The index velocity rating is developed by making discharge measurements over a range of conditions and relating the mean channel velocity derived from those measurements to the measured velocity from an in-place ADVM. The stage-area rating is a relation between channel area and water level, or stage, in the channel. The outputs from each of these ratings, mean channel velocity (V) and cross-sectional area (A), are then multiplied together to compute streamflow.

The ADVM at the Wood River site used to measure channel velocity is the same ADVM described in section, "Sediment-Corrected Backscatter," representing about 14 percent of the Wood River cross section at that site. The instrument measured and averaged velocity data over 2 out of every 10 min. The ADVM was installed such that measured velocities were aligned with downstream flows.

At both Williamson and Wood River sites, instantaneous measurements of channel streamflow were collected using an acoustic Doppler current profiler (ADCP), deployed using a tethered boat, using standard methods described in Mueller and others (2013). The Williamson River site ADCP measurements were made from the cableway 20 ft upstream of the station, and measurements at Wood River were located either upstream of the station from a rope pulley temporary cableway system or just downstream of the site tethered from the bridge with a rope.

Table 4. Nutrient, total suspended solids, and suspended-sediment concentration replicate samples collected by Klamath Tribes and the U.S. Geological Survey at Wood River near Klamath Agency, Oregon (USGS streamgage 11504115), 2014–15.

[Method reporting limit (MRL) and method detection limit (MDL) values are for the Klamath Tribes Sprague River Water Quality Laboratory, which provided analysis for all sample comparisons collected by the U.S. Geological Survey (USGS) and the Klamath Tribes (KT). **Replicate samples:** N, nitrogen; NH_4^+, ammonium; $NO_2^-+NO_3^-$, nitrite plus nitrate; P, phosphorus; PO_4^{3-}, orthophosphate; SSC, suspended-sediment concentration; TSS, total suspended solids. **Sample type:** EWI, equal-width-increment; RPD, relative percent difference. **Ammonium and nitrate plus nitrite (as N):** NC, not calculated because data less than the MRL; ND, no data. **Abbreviations and Symbol:** FNU, Formazin Nephelometric Unit; ft^3/s, cubic foot per second; mg/L, milligram per liter; %, percent]

Date	Time	Replicate samples							Instantaneous streamflow (ft^3/s)	Instantaneous turbidity (FNU)	Collecting agency
		Sample type	Total phosphorus (mg/L)	PO_4^{3-} as P (mg/L)	NH_4^+ as N (mg/L)	$NO_2^- + NO_3^-$ as N (mg/L)	Total nitrogen (mg/L)	SSC (USGS) TSS (KT) (mg/L)			
		MRL (mg/L)	**0.036**	**0.006**	**0.012**	**0.016**	**0.060**	**0.10**			
		MDL (mg/L)	**0.018**	**0.003**	**0.006**	**0.008**	**0.030**	**0.00**			
01-30-14	1233	Van Dorn	0.144	0.099	0.012	0.026	0.315	13.2	500	10	KT
01-30-14	1110	EWI	0.148	0.096	0.006	0.025	0.314	13.8	490	11	USGS
		RPD	**3%**	**3%**	**NC**	**4%**	**0%**	**4%**			
06-12-14	1200	Van Dorn	0.106	0.088	0.006	0.010	0.108	4.0	210	1.2	KT
06-11-14	1120	Grab	0.110	0.087	< 0.006	0.010	0.094	3.9	158	1.8	USGS
		RPD	**4%**	**1%**	**NC**	**0%**	**14%**	**3%**			
09-23-14	0940	Van Dorn	0.101	0.081	0.010	ND	0.080	11.0	317	3.4	KT
09-25-14	1140	EWI	0.118	0.092	0.006	0.017	0.258	10.7	363	2.7	USGS
		RPD	**16%**	**13%**	**NC**	**ND**	**105%**	**3%**			
02-18-15	0950	Van Dorn	0.114	0.095	0.014	0.018	0.188	4.0	429	3.8	KT
02-18-15	1040	Grab	0.114	0.095	0.006	0.018	0.140	2.0	421	3.6	USGS
		RPD	**0%**	**0%**	**NC**	**0%**	**29%**	**66%**			

Surrogate Regression Methods

Surrogate regression methods were evaluated at each site for each constituent of interest, and a best-fit model was selected to produce time series of SSC and nutrients where applicable. Time series of SSC and nutrients at the Williamson River site were derived using linear regression techniques as described in Rasmussen and others (2009), evaluating turbidity and streamflow as potential explanatory variables. Owing to the amount of time required for the collection of an EWI sample, multiple turbidity and streamflow values usually were recorded during the period of SSC or nutrient sample collection. In order to generate data pairs of potential explanatory variables (turbidity or streamflow) for each dependent variable (SSC or nutrient concentration), finalized unit values of turbidity and streamflow were averaged starting with the first reading prior to the start of the sample, to the last reading after the end of the sample. These averaged unit values were paired with either the individual samples or the averaged A and B sets (where applicable) to generate the calibration dataset. Methods for model selection follow those in Rasmussen and others (2009) and Schenk and Bragg (2014). Simple linear regressions (SLRs) and multiple linear regressions (MLRs) were evaluated to compute SSC, and $\log_{10}$ transformation was applied to variables where appropriate to make model residuals more symmetric, linear, and homoscedastic. Appropriate models were selected based on minimal model standard prediction errors (MSPEs), maximum coefficients of determination (R^2) or adjusted coefficients of determination (Adj R^2), depending on the number of explanatory variables, evaluation of residuals with probability plots, and the probability plot correlation coefficients (PPCCs) for log-transformed data. MSPE is the percentage expression of the root mean square error (RMSE) of a regression, which measures the variance between regression-computed and observed values, and PPCC values test the normality of residuals by plotting the residuals on a normal-probability plot (Rasmussen and others, 2009). Log-transformations that maximize PPCC values (correlation coefficient values close to 1) for regression residuals optimize the normality of the residuals (Helsel and Hirsch, 1992). For log-transformed regression equations, values of continuous SSC and nutrients were computed from the $\log_{10}$ transformation as determined from the regression after correcting for transformation bias using Duan's bias correction factor (BCF; Helsel and Hirsch, 1992). At the Wood River site, SCB was evaluated as an explanatory variable in addition to turbidity and streamflow because of the availability of ancillary backscatter data at that site.

Calculated SSC time-series records were worked, checked, and reviewed through the USGS Continuous Records Processing Implementation Plan (U.S. Geological Survey, 2008), which resulted in approved "unit" SSC data. Upon approval of SSC data for each station, time series either were uploaded directly into the USGS Automatic Data Processing System (ADAPS) database, or in the case of the Williamson River site, a separate data processor in ADAPS was used to calculate unit values of SSC in real time on an ongoing basis.

Surrogate regressions using acoustic backscatter were evaluated using the SAID program to create ordinary least squares models between SSC and SCB/turbidity. The various models were compared based on regression statistics such as low MSPE, high R^2, PPCC values close to 1, constant variance, and random patterns in residual plots.

Suspended-Sediment and Total-Phosphorus Load Calculations

Williamson River

Daily mean SSL values were computed as the product of daily mean SSC and streamflow at the Williamson River site. Daily mean SSL values were then summed for the entire water year to report a water year total SSL. For each daily mean value of SSC and streamflow, the resulting daily mean SSL was computed using equation 1:

$$\mathrm{SSL}_d = \mathrm{SSC}_d \times Q_d \times \mathrm{C}_1 \times \mathrm{C}_2 \tag{1}$$

where

SSL_d is daily mean suspended-sediment load in metric tons;
SSC_d is daily mean suspended-sediment concentration, in milligrams per liter;
Q_d is daily mean streamflow, in cubic feet per second;
C_1 is the constant 0.0027 to convert to tons; and
C_2 is the constant 0.907 to convert tons to metric tons.

Instantaneous values of TP calculated using the TP-turbidity regression were used to calculate instantaneous values of TP loads in tons per second using equation 2:

$$\mathrm{TPL}_i = \mathrm{TPC}_i \times Q_i \times \mathrm{C} \tag{2}$$

where

TPL_i is instantaneous total phosphorus load, in tons per second;
TPC_i is instantaneous total phosphorus concentration, in milligrams per liter;
Q_i is instantaneous streamflow, in cubic feet per second; and
C is the constant 3.121×10^{-8} to convert to tons per second.

Instantaneous TP loads in tons per second were aggregated monthly by summing the mean daily TP loads for each month of interest, and then were converted to metric tons. In contrast to the longer period of SSL computations at this site, only 2 days during the analysis period of November 21, 2013–February 9, 2015, were considered partial days with regard to turbidity unit values (June 2 and 3, 2014), and there were no days of completely missing turbidity data that required daily value estimation. Numerous instantaneous values were excluded during June 2–3, 2014, because of sensor fouling at low turbidities (1.2–1.6 FNUs). Unit values of TP were linearly interpolated between the deleted points, as there were no noteworthy flow events and neither streamflow nor turbidity were variable during the 2 partial days.

Wood River

Daily loads of suspended sediment at the Wood River site were computed as the product of daily median SSC and daily median streamflow, to produce daily loads in metric tons using equation 3:

$$SSL_d = SSC_d \times Q_m \times C_1 \times C_2 \times C_3 \quad (3)$$

where

- SSL_d is daily suspended-sediment load, in metric tons;
- SSC_d is daily median suspended-sediment concentration, in milligrams per liter;
- Q_m is daily median streamflow, in cubic feet per second;
- C_1 is the constant 86,400 to convert seconds to days;
- C_2 is the constant 28.3169 to convert cubic feet to liters; and
- C_3 is the constant 1×10^{-9} to convert milligrams to metric tons.

Monthly loads of suspended sediment were computed by summing the daily loads for each month of interest.

Instantaneous values of TP concentrations, calculated using the TP–turbidity regression, were used to determine daily values of TP loads in metric tons using equation 4 at the Wood River site. Daily median TP concentrations were combined with daily median streamflow to calculate the daily loads because of the highly variable streamflow and turbidity unit values that can be routinely encountered at this site. The daily loads were then summed to provide monthly loads of TP.

$$TPL_d = TP_c \times Q_m \times C_1 \times C_2 \times C_3 \quad (4)$$

where

- TPL_d is daily total phosphorus load, in metric tons;
- TP_c is daily median total phosphorus concentration, in micrograms per liter;
- Q_m is daily median streamflow, in cubic feet per second;
- C_1 is the constant 86,400 to seconds to days;
- C_2 is the constant 28.3169 to convert cubic feet to liters; and
- C_3 is the constant 1×10^{-12} to convert micrograms to metric tons.

Suspended-Sediment Surrogate Models

Williamson River

After evaluating for outliers, the final calibration dataset consisted of 35 samples and spanned the period from 2008 to 2014, excluding WY 2011, when no samples were collected and turbidity data collection lapsed between June 1 and September 30. Samples were collected to cover the range of streamflow and turbidity encountered at the site, as represented by a flow-duration curve and turbidity-duration curve for the study period (fig. 2). A station analysis that includes model development details, statistics, and evaluation of the dataset is included in appendix A.

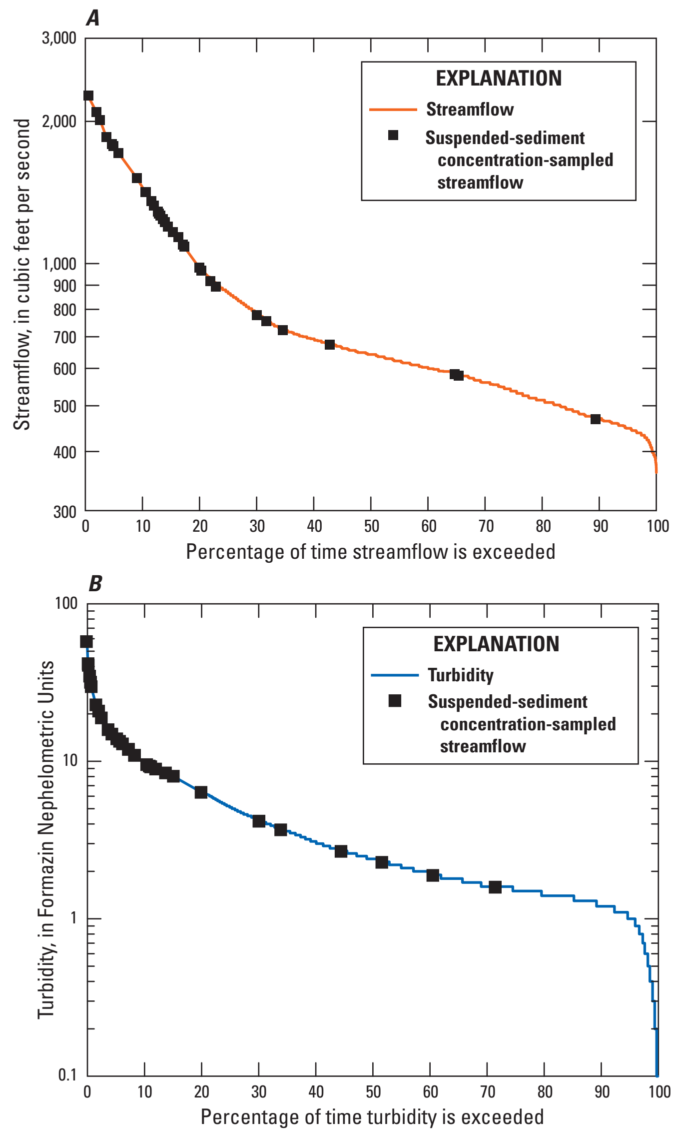

Figure 2. Duration curves for streamflow (*A*) and turbidity (*B*) for suspended-sediment samples collected at Williamson River below Sprague River, near Chiloquin, Oregon (USGS streamgage 11502500), water years 2008–10 and 2012–14.

Best-Fit Model

The best-fit surrogate model to calculate SSC at the Williamson River site for 2008–10 and 2012–14 was a $\log_{10}$-transformed SLR with turbidity as the explanatory variable (table 5, fig. 3). Streamflow (*Q*) was evaluated as a potential explanatory variable together with turbidity, and separately, and was statistically significant (p<0.05). However, adding in *Q* as an explanatory variable resulted in higher MSPE values, increasing the uncertainty of the model. PPCC values also were lower when including *Q*, so ultimately *Q* was not included in the final model. The resulting SLR model for the Williamson River site in table 5 was then retransformed and corrected for bias with the BCF value.

Unit values of SSC were calculated using corresponding unit values of turbidity to produce time series of SSC and 90-percent prediction intervals for the analysis period. An example plot for part of WY 2014 is shown in figure 4. The maximum turbidity value recorded for the analysis period was 76 FNUs, and the maximum turbidity associated with an SSC sample used in the regression equation was 58 FNUs.

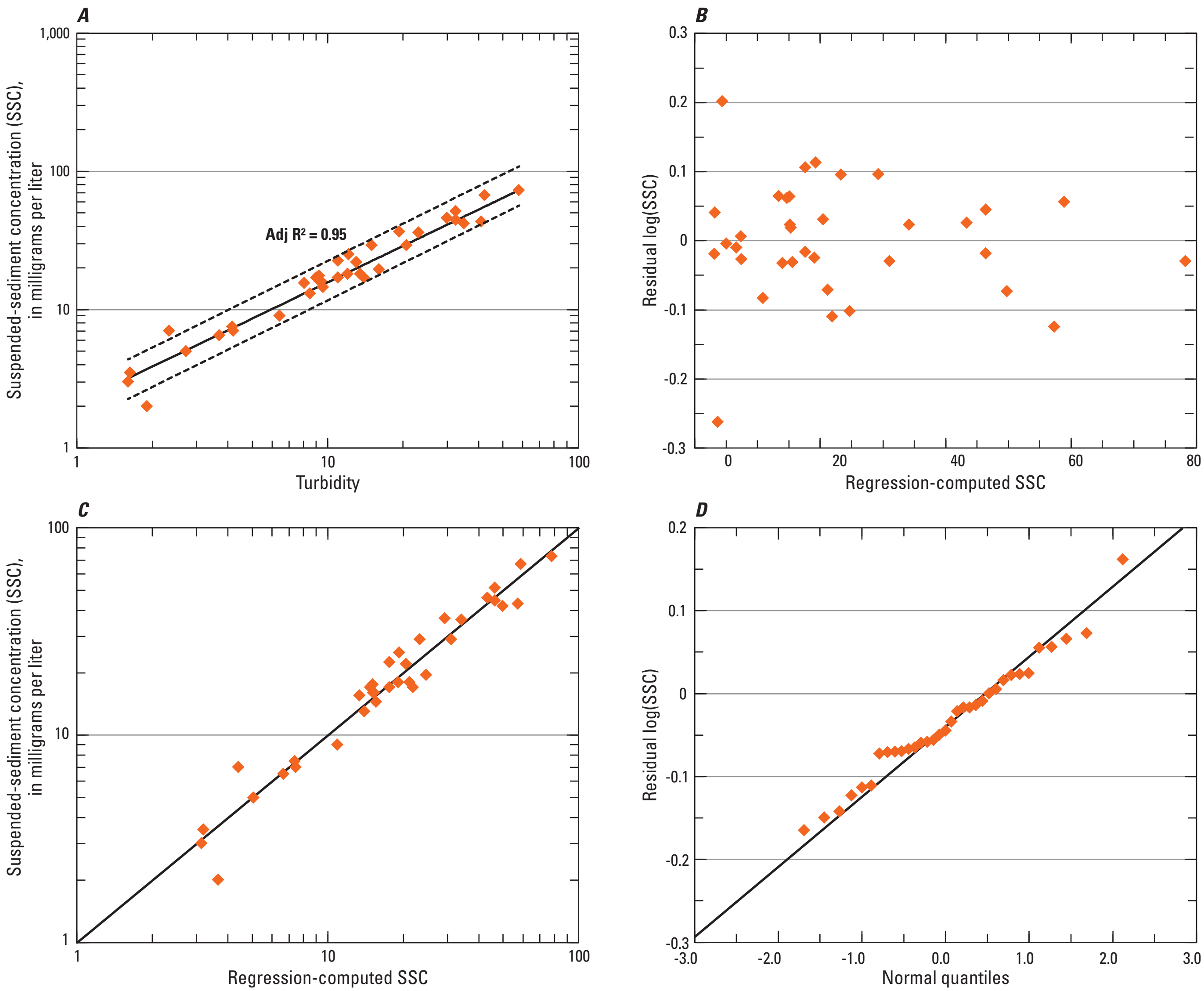

Figure 3. Results of simple linear regression analysis for (*A*) turbidity and suspended-sediment concentration (SSC) data, (*B*) residuals of the regression-computed SSC, (*C*) regression-computed and associated measured SSC, and (*D*) probability plot of residuals (normal quartiles) for the Williamson River site (USGS streamgage 11502500), Upper Klamath Basin, Oregon.

Table 5. Suspended-sediment concentration models for the Williamson and Wood River sites (USGS streamgages 11502500 and 11504115), Upper Klamath Basin, Oregon.

[Models calculate unit, or instantaneous, values of suspended-sediment concentrations from unit values of turbidity or acoustic backscatter. **Regression model equation:** SSC, suspended-sediment concentration; SCB, sediment-corrected backscatter; Turb, turbidity. **BCF:** Duan's bias correction factor (Helsel and Hirsch, 1992). **MSPE:** Model standard percentage error. **PPCC:** Probability plot correlation coefficient. **Abbreviation:** USGS, U.S. Geological Survey]

USGS streamgage No.	Site name	Regression model equation	Retransformed regression model equation
11502500	Williamson River	$Log_{10}(SSC) = 0.896 * Log_{10}(Turb) + 0.314$	$SSC = 2.102 * Turb^{0.896}$
11504115	Wood River	$Log_{10}(SSC) = 6.69 * Log_{10}(mean\ SCB) + 0.297 * Log_{10}(Turb) – 11.4$	$SSC = (4.06E\text{-}12) * SCB^{6.69} * Turb^{0.297}$

USGS streamgage No.	Site name	BCF	Adjusted coefficient of determination (Adj R^2)	MSPE (percent)	PPCC	Number of samples used in the regression equation	Computation dates
11502500	Williamson River	1.02	0.95	+21.47,-17.67	0.97	35	10-17-07 to 09-30-10, 10-01-11 to 09-30-14
11504115	Wood River	1.02	0.89	+26.5, -21.0	0.97	19	11-26-13 to 03-13-15

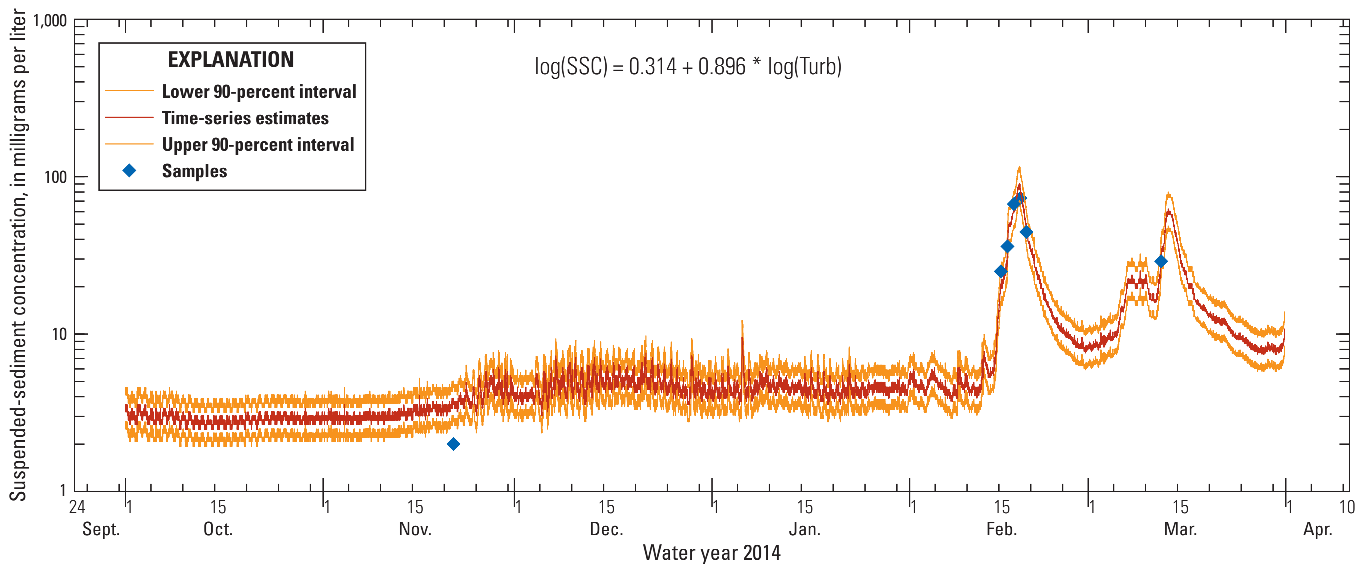

Figure 4. Time series of suspended-sediment concentration (SSC), 90-percent prediction intervals, and SSC samples at the Williamson River site (USGS streamgage 11502500), Upper Klamath Basin, Oregon, September 2013–March 2014.

As a result, 0.12 percent (232 unit values) of the computed SSC values for the analysis period (2008–10 and 2012–14) used turbidity values that exceeded the upper limit of the SSC-turbidity regression equation, and, therefore, had greater uncertainty that is not quantified. WY 2008 is considered a partial year for turbidity, with data collected starting on October 17. For WY 2012, turbidity was collected starting in March 2012 and, therefore, SSC and SSL estimates are only available for one-half of that water year.

Estimated Suspended-Sediment Concentration and Load Data

Missing values of turbidity at the Williamson River resulted in multiple days that lacked enough unit values to calculate mean daily SSC values in WYs 2008–10 and 2012–14. Many of these missing days occurred in summer during base flow, when algal growth caused excessive sensor fouling. Sediment transport during the period of missing data is assumed to be minimal; however, some of the days with missing data occurred on the rise or decline of the hydrograph during a storm event, and some data most likely were deleted from the record because of fouling from debris accumulation. There were no cases where the turbidity sensor limit (1,600 FNUs) was exceeded, causing truncated values of turbidity. To complete each individual water-year record of SSC, missing daily mean values of SSC were calculated using one of four methods, depending on the hydrologic condition as explained in appendix C. The exception was for WYs 2008 and 2012, when missing daily values could not be estimated to provide complete individual water year records. In WY 2008, the turbidity sensor was deployed on October 17, resulting in 16 days in October when SSC and SSL values could not be computed. Similarly in 2012, the sensor was deployed on March 16, resulting in 166 days when SSC and SSL could not be computed. Partial days owing to sensor deployment were not included in daily value estimates. A summary of all estimated daily values and their respective estimation methods for WYs 2008–14 is included in appendix C.

The highest measured annual SSL value was computed for WY 2008, which also had the highest mean annual streamflow for the analysis period (excluding 2011, fig. 5). WY 2012 had the second highest annual SSL and mean annual streamflow, although only 200 days of turbidity data were available to compute the annual load and an important fraction of the annual load could have occurred during the missing months of October–February; therefore, the reported value in table 6 underestimates the true annual SSL for that year. WY 2011 had the highest mean annual streamflow, but no SSC data were collected, so SSL could not be quantified during this high-streamflow year. Dry water years in 2010 and 2014 resulted in the lowest computed annual SSL.

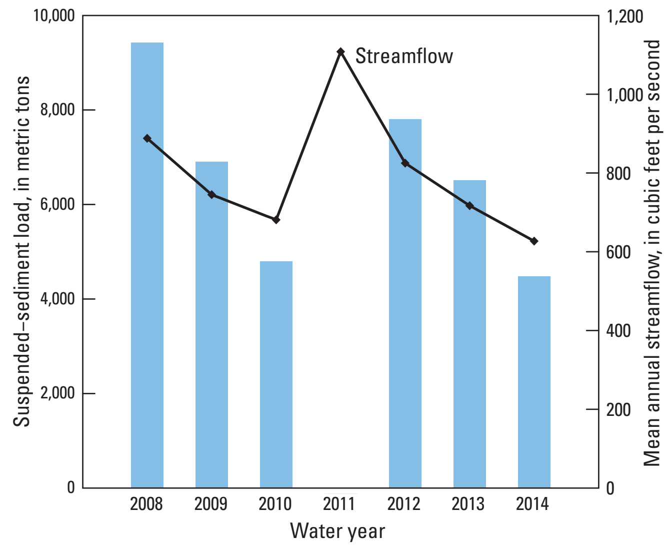

Figure 5. Annual suspended-sediment loads and mean annual streamflow for Williamson River below Sprague River, near Chiloquin, Oregon (USGS streamgage 11502500), water years 2008–10 and 2012–14. Suspended-sediment load for water year 2011 is omitted because of lack of data. Suspended-sediment load for water year 2012 is a partial year, with sediment loads computed for March–September only.

Table 6. Annual suspended-sediment loads for Williamson River site (USGS streamgage 11502500), Upper Klamath Basin, Oregon, water years 2008–10 and 2012–14.

[See appendix D for details on load estimates when input data were missing. **Abbreviation:** SSL, suspended-sediment load]

Water year	Start date	End date	Number of SSL daily values	Annual SSL (metric tons)
2008	10-17-07	09-30-08	350	9,420
2009	10-01-08	09-30-09	365	6,900
2010	10-01-09	09-30-10	365	4,800
2012	03-16-12	09-30-12	199	7,800
2013	10-01-12	09-30-13	365	6,510
2014	10-01-13	09-30-14	365	4,480

Wood River

SSC samples were collected at the Wood River site from November 2013 to March 2015, concurrent with nutrient-sample collection. Of the 14 total samples, 13 were used for the model calibration dataset after removing 1 upper outlier, in addition to 6 TSS samples collected by the Klamath Tribes, resulting in a total of 19 samples for the model calibration dataset. Turbidity, SCB, and streamflow were evaluated as explanatory variables for SSC together and separately, and as log-transformed and non-transformed variables.

Model statistics determined that streamflow was not a statistically significant explanatory variable for computing SSC, leaving SCB and turbidity as explanatory variables. Both of these explanatory variables were evaluated for multicollinearity using variance inflation factor (VIF), with a result of 1.48, much less than the VIF=10 guidance typically cited for multicollinearity (Rasmussen and others, 2009).

Best-Fit Model

An MLR model with log-transformed SSC as a function of both SCB and turbidity was selected as the best-fit model to compute unit values of SSC (table 5, fig. 6). The model in table 5 was transformed to linear space and corrected for bias using the BCF.

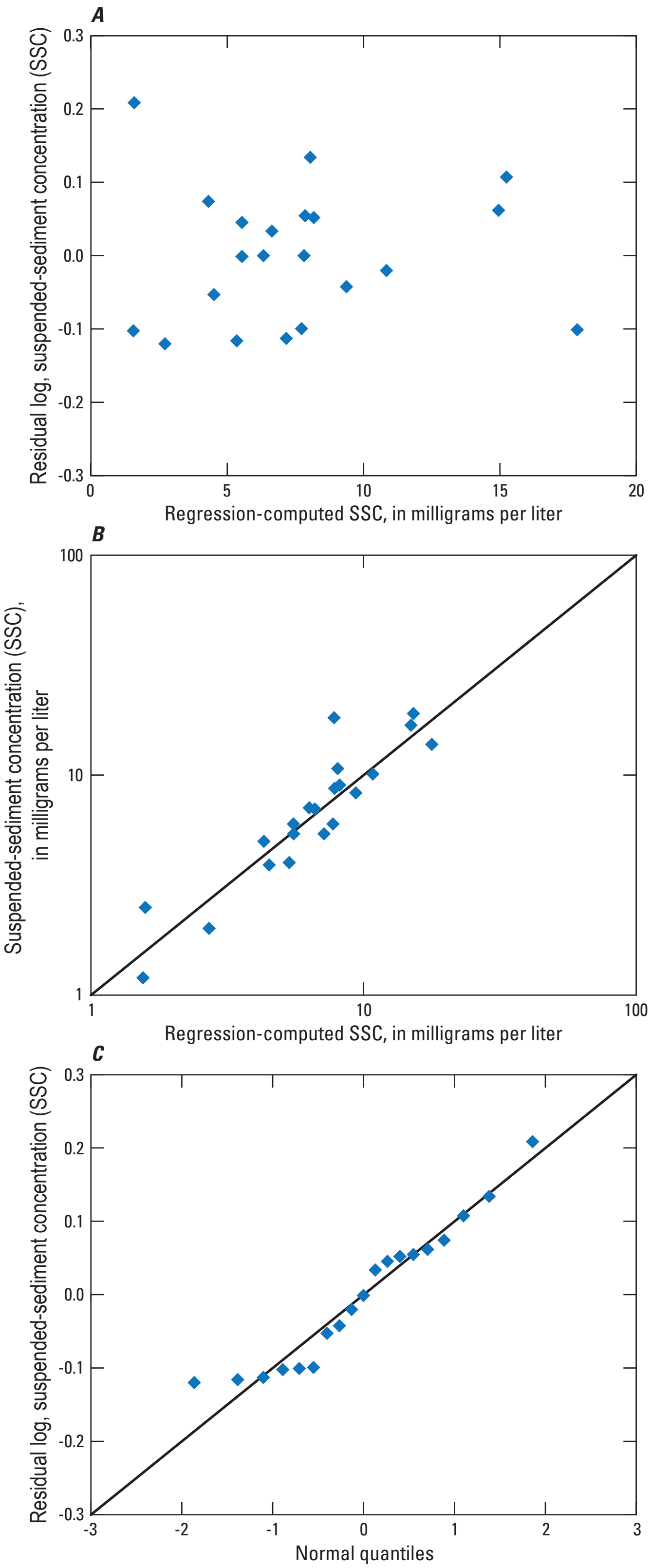

Figure 6. Results of multiple linear regression analysis for (*A*) residuals of the regression-computed suspended-sediment concentration (SSC), (*B*) regression-computed and associated measured SSC, and (*C*) probability plot of residuals for the Wood River site (USGS streamgage 11504115), Upper Klamath Basin, Oregon.

Unit values of SSC were calculated using unit values of mean SCB and turbidity to produce time series of SSC for the analysis period. The maximum SCB value observed for the analysis period was 76.4 decibels (dB), and the maximum SCB associated with an SSC sample used in the regression equation was 68.4 dB. The maximum turbidity value observed for the analysis period was 24 FNUs, which also was the maximum turbidity associated with an SSC sample, collected during the December 23, 2014, storm event. As a result, 0.8 percent of the computed SSC values for the analysis period (November 2013–March 2015) used SCB values that exceeded the upper limit of the SSC-SCB/turbidity regression equation and, therefore, are assumed to have high uncertainty that is not quantified.

Monthly loads of suspended sediment at Wood River were computed by summing the daily loads computed using equation 3 (fig. 7).

Estimated Suspended-Sediment Concentration and Load Data

Some anomalous unit values of SCB were excluded from the analysis period for various reasons, resulting in a total of 15 days of missing data. These reasons included acoustic signal interference with beam 2, which was used to compute SCB, and interferences by aquatic vegetation or other items lodged on the sensor. All the erroneous SCB data occurred during periods of low turbidity, stable streamflow, and low sediment transport. Daily median values of SCB from these periods were estimated by averaging the daily median values from 5 days before and after the missing periods, and were combined with daily median turbidity to compute daily median SSC in milligrams per liter.

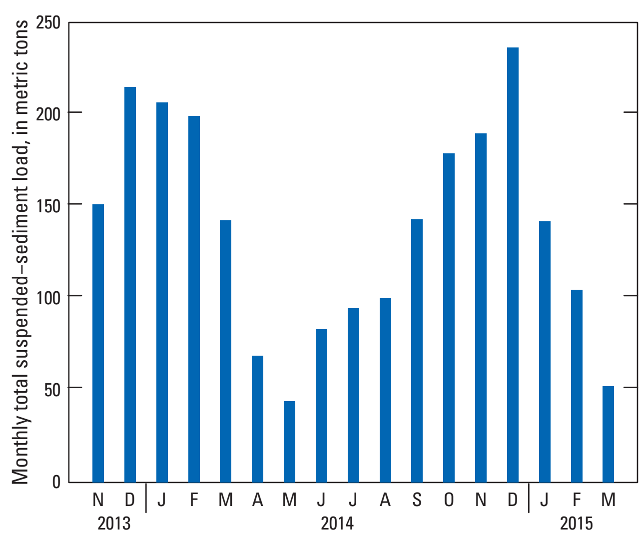

Figure 7. Monthly suspended-sediment loads for Wood River near Klamath Agency, Oregon (USGS streamgage 11504115), November 2013–March 2015.

Nutrient Sample Results

Ten nutrient samples were collected at the Williamson River, and 14 were collected at the Wood River by the USGS (table 3 and appendix D). Nutrient concentrations were then used in the development of surrogate regression models at both sites to compute time series of nutrient concentrations. Total and dissolved N and P were evaluated as dependent variables in the regression models, but only regression models with TP as a dependent variable were determined to be useful from a statistical standpoint. As a result, time series of TN, orthophosphate, ammonia, and nitrate-nitrite could not be computed with the limited available datasets at both sites.

Storm events were prioritized for sampling during the study period, with additional base-flow or moderate streamflow conditions also sampled in an attempt to represent the range of hydrologic and turbidity conditions at both sites. The two sites represent subbasins that have different hydrologic characteristics, which translated to differences in terms of turbidity and streamflow response to storm events. For example, the storm event in mid-February 2014 resulted in a peak turbidity value of 64 FNUs at the Williamson River (when SSC was greater than 70 mg/L), and the same event resulted in a peak turbidity of 7.7 FNUs at the Wood River site (when SSC was about 8 mg/L).

Williamson River Nutrient Concentrations

TN concentrations at the Williamson River site typically were low during base-flow conditions (about 0.1 mg/L) and were higher during storm events, with the maximum concentration of 0.88 mg/L on February 18, 2014, at the peak of the largest storm event of the study period (fig. 8). Dissolved inorganic N species (NH_4^+ as N and NO_2^-+NO_3^- as N,

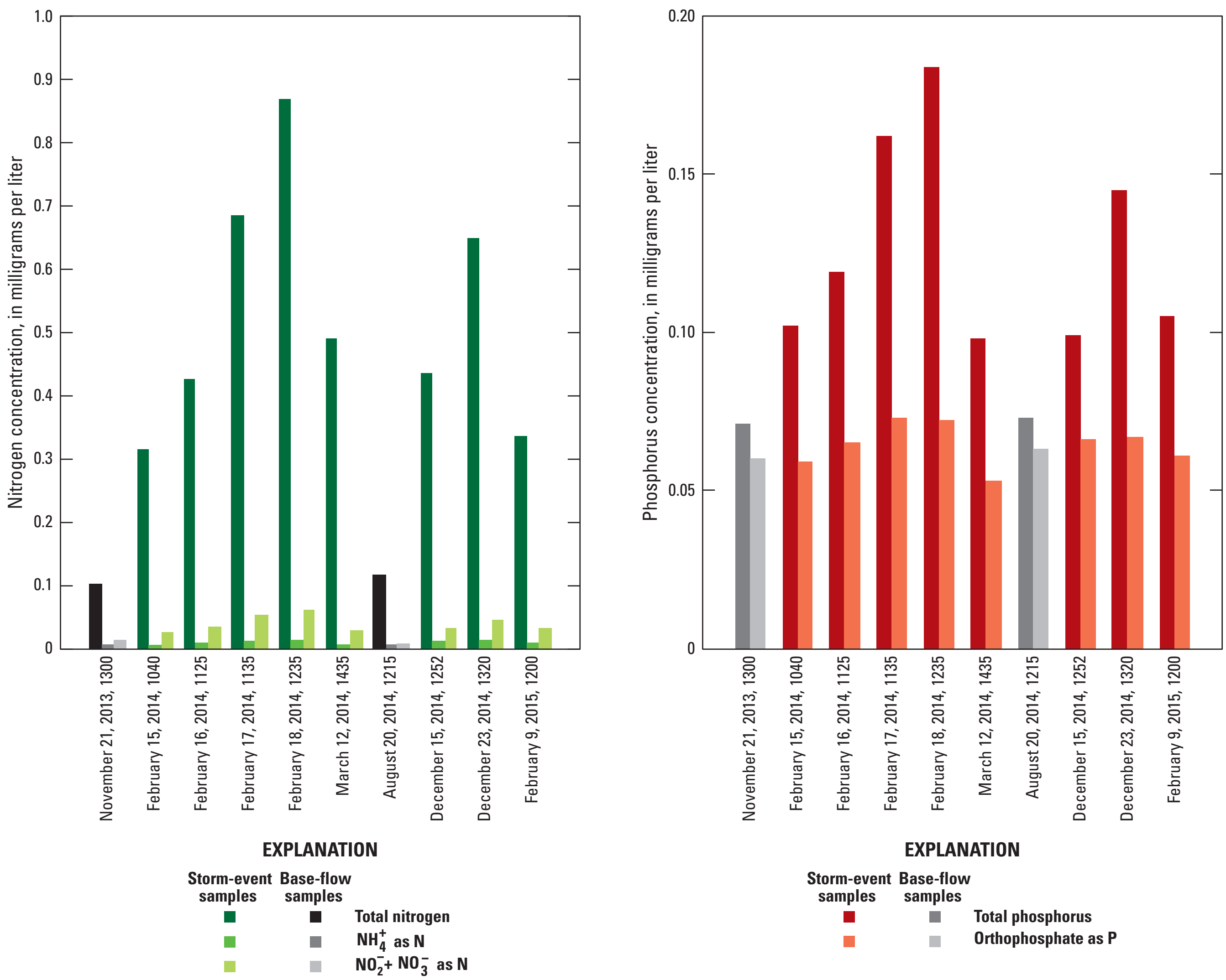

Figure 8. Nutrient concentration results from water-quality samples collected at the Williamson River below Sprague River, near Chiloquin, Oregon (USGS streamgage 11502500), November 21, 2013–February 9, 2015.

or DIN) increased slightly during storm events, although NH_4^+ as N sample results all were less than the laboratory MRL of 0.012 mg/L with the exception of one sample on February 18, 2014, at the peak of the storm event with a concentration of 0.015 mg/L. $NO_2^- + NO_3^-$ as N samples collected during base flow were less than the MRL of 0.016, with the maximum concentration also from the peak of the storm event on February 18, 2014, at a concentration of 0.061 mg/L. Particulate + organic N, represented by the difference between TN and DIN, dominated all samples during the study period, with 90 percent of the samples in particulate form for storm event samples, and 83 percent of the samples in particulate form for base-flow samples.

TP concentrations also increased during the sampled storm events, with the particulate fraction increasing markedly from base-flow conditions (fig. 8). The maximum TP concentration of 0.184 mg/L was recorded in a sample collected on February 18, 2014, at the peak of a storm event, and the minimum concentration of 0.071 mg/L was recorded in a sample collected during base flow on November 21, 2013. Dissolved inorganic P (orthophosphate) concentrations varied little regardless of the hydrologic regime during sample events, with a range of 0.053–0.073 mg/L for all samples. Dissolved P also dominated the base-flow samples, comprising an average of 85 percent of TP.

Wood River Nutrient Concentrations

TN concentrations at the Wood River site generally were lower than at the Williamson River site for storm event samples collected during the study period (figs. 8 and 9, appendix D). The highest TN concentration (0.55 mg/L) was from a storm sample on February 15, 2014, the second significant storm event of the 2014 winter

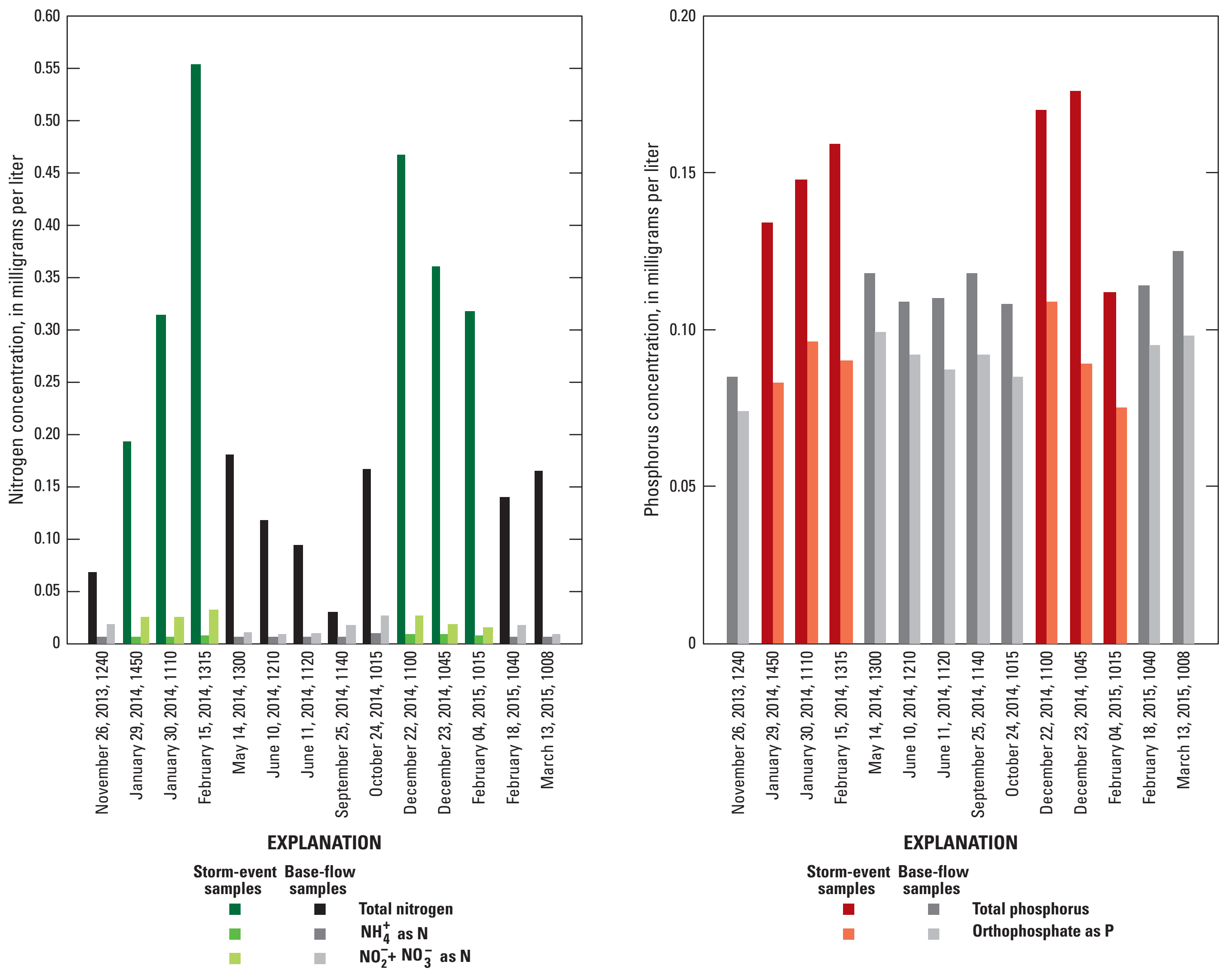

Figure 9. Nutrient concentration results from USGS water-quality samples collected at the Wood River near Klamath Agency, Oregon (USGS streamgage 11504115), November 26, 2013–March 13, 2015.

season. Turbidity at the time of sampling (7.7 FNUs) was higher than typical for this site. Prior to this storm event, a turbidity of 10.8 FNUs was sampled on January 30, 2014, but the sample had a lower TN concentration. Particulate + organic N, represented by the difference of TN and DIN, dominated all samples during the study period, similar to that of samples at the Williamson River, with 91 and 83 percent of the samples in particulate + organic form for storm-event and base-flow samples, respectively. DIN species increased with storm-event samples, but remained low during the study period. Most NH_4^+ as N samples were at or less than the MDL of 0.006 mg/L, and no samples exceeded the laboratory reporting limit of 0.012 mg/L. NH_4^+ as N increased only slightly during storm events, with a concentration of 0.007 mg/L occurring on February 15, 2014. The highest NH_4^+ as N concentration occurred on October 24, 2014, with a concentration of 0.010 mg/L, which is considered a base-flow sample at low turbidity, and still less than the laboratory reporting limit of 0.012 mg/L. Concentrations of NO_2^- + NO_3^- as N also were relatively low at the Wood River site, with most samples equal or less than the laboratory reporting limit of 0.016 mg/L for base-flow conditions. Concentrations increased during storm-event samples, with the highest concentration of 0.032 mg/L occurring on February 15, 2014.

TP concentrations on the Wood River were in the same range of values measured at the Williamson River site, but base-flow samples from the Wood River had higher concentrations of TP than base-flow samples from the Williamson River, often exceeding 0.10 mg/L (fig. 9). The highest TP sample concentration (0.176 mg/L) occurred on December 23, 2014. Dissolved P dominated the base-flow samples, comprising an average of 82 percent of the TP samples. Samples collected during storm events had a higher percentage of the P in particulate form, on average (39 percent), but still had a comparatively lower particulate fraction than in storm samples at the Williamson River site (48 percent). Orthophosphate concentrations were more variable than in the Williamson River and were higher overall, with concentrations ranging from 0.074 to 0.11 mg/L for all samples. Orthophosphate concentrations for base-flow samples ranged from 0.074 to 0.099 mg/L, higher than the Williamson River base-flow samples, suggesting a higher baseline concentration of bioavailable P on the Wood River.

Total Phosphorus Surrogate Models

Williamson River

Turbidity and streamflow were evaluated as explanatory variables for nutrients at the Williamson River. All N and P constituents were evaluated, but owing to the small sample size for Williamson River nutrients (n=10), and the N cycling processes that are not explained well by the small sample size, only TP was modeled as a dependent variable.

Best-Fit Model

A log-transformed TP–turbidity model was selected as the best-fit regression model to compute TP for the study period (fig. 10, table 7). The SLR model was applied

Table 7. Total phosphorus concentration models for the Williamson and Wood River sites (USGS streamgages 11502500 and 11504115), Upper Klamath Basin, Oregon.

[Models calculate unit, or instantaneous, values of total phosphorus from unit values of turbidity. **Regression model equation:** TP, total phosphorus, in micrograms per liter; Turb, turbidity. **BCF:** Duan's bias correction factor (Helsel and Hirsch, 1992). **MSPE:** Model standard percentage error. **PPCC:** Probability plot correlation coefficient. **Abbreviations**: NA, not applicable; USGS, U.S. Geological Survey]

USGS streamgage No.	Site name	Regression model equation	Retransformed regression model equation
11502500	Williamson River	$Log_{10}(TP) = 0.212*Log_{10}(Turb) + 1.79$	$TP = 62.3*Turb^{0.212}$
11504115	Wood River	$TP = 3.51*Turb + 103$	NA

USGS streamgage No.	Site name	BCF	Adjusted coefficient of determination (Adj R^2)	MSPE (percent)	PPCC	Number of samples used in the regression equation	Computation dates
11502500	Williamson River	1.01	0.73	+17.8, -15.1	0.99	10	11-21-13 to 02-09-15
11504115	Wood River	NA	0.51	±14	0.99	20	11-26-13 to 03-13-15

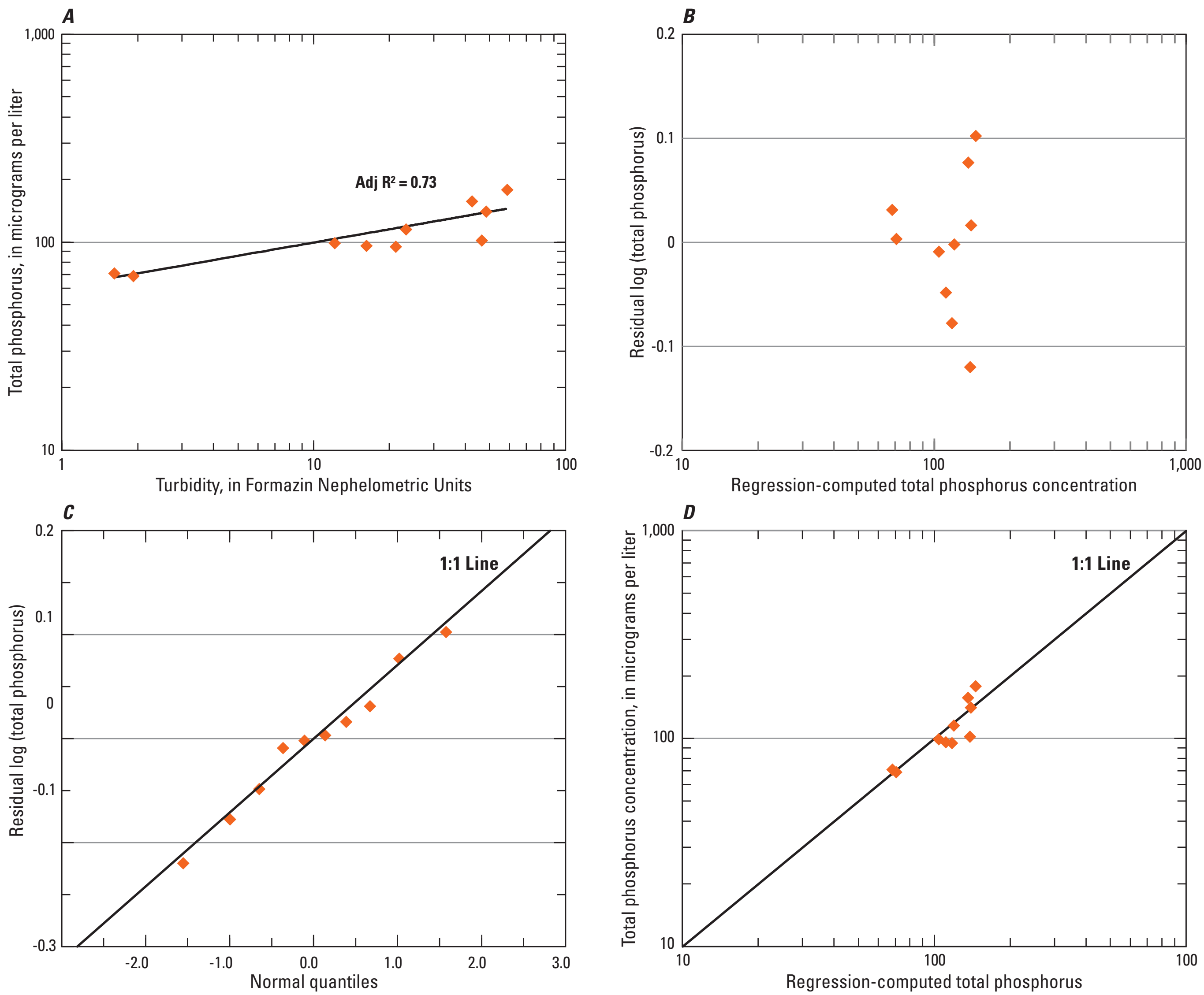

Figure 10. Results of simple linear regression analysis for (*A*) turbidity and total phosphorus (TP) concentration data, (*B*) residuals of the regression-computed TP, (*C*) probability plot of residuals, and (*D*) regression-computed and associated measured TP, for the Williamson River site (USGS streamgage 1150250), Upper Klamath Basin, Oregon, November 21, 2013–February 9, 2015.

to the time series of turbidity collected at the Williamson River site to compute time-series concentrations of TP for November 21, 2013–February 9, 2015, the analysis period when nutrient samples were collected. During this period, the maximum recorded turbidity was 67 FNUs, and the maximum turbidity sampled during sample collection was 58 FNUs on February 18, 2014. Only 0.13 percent (57 unit values) of the computed TP values were computed with turbidity values that exceeded the limits of the regression (turbidity values greater than 58 FNUs). Predicted TP concentrations and 90 percent prediction intervals (Rasmussen and others, 2009) for the time series are shown in figure 11.

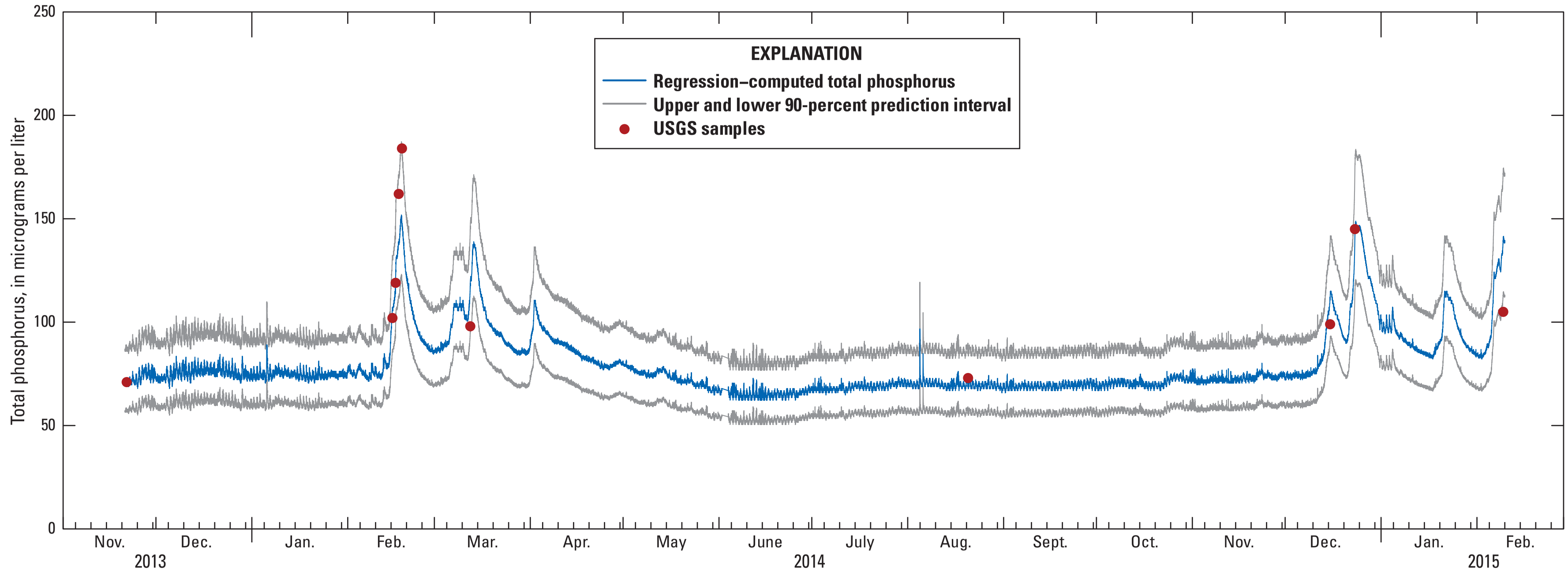

Figure 11. Time series of computed unit values of total phosphorus (TP) concentrations, associated 90-percent prediction intervals, and observed values of TP concentration from samples collected at Williamson River site (USGS streamgage 1150250), Upper Klamath Basin, Oregon, November 21, 2013–February 9, 2015.

Williamson River Total Phosphorus Loads

Instantaneous values of TP calculated using the TP-turbidity regression were used to calculate instantaneous values of TP loads in tons per second.

Monthly TP loads are shown in figure 12 for December 2013–January 2015. November 2013 and February 2015 monthly loads are omitted because only 10 and 9 days of TP loads were computed for each month, respectively. A summary of the monthly loads is shown in table 8. Because of the lack of data for October and November 2013, an annual TP load cannot be calculated for WY 2014. The sum of the monthly loads for December 2013–September 2014 was about 39 metric tons, but does not accurately represent the entire water year TP load because of the missing 2 months.

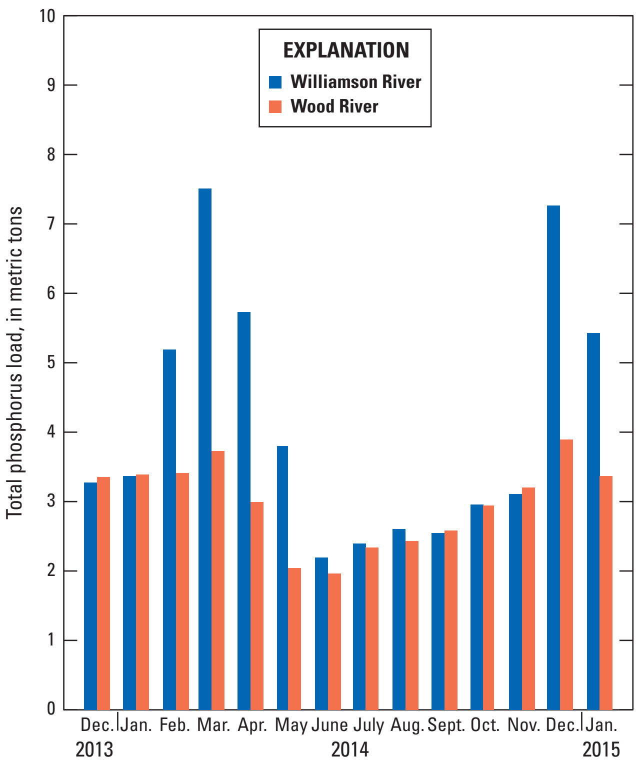

Figure 12. Monthly total phosphorus loads calculated using surrogate regression models at Williamson River below Sprague River, near Chiloquin, Oregon (USGS streamgage 11502500), December 2013–January 2015.

Table 8. Monthly total phosphorus loads at Williamson River below Sprague River, near Chiloquin (USGS streamgage 11502500) and Wood River near Klamath Agency (USGS streamgage 11504115), Oregon, December 2013–January 2015.

Water year	Year–month	Monthly total phosphorus load (metric tons)	
		Williamson River	Wood River
2014	2013–12	3.27	3.35
2014	2014–01	3.37	3.38
2014	2014–02	5.19	3.40
2014	2014–03	7.51	3.72
2014	2014–04	5.72	2.99
2014	2014–05	3.80	2.03
2014	2014–06	2.19	1.95
2014	2014–07	2.39	2.33
2014	2014–08	2.60	2.43
2014	2014–09	2.54	2.58
2015	2014–10	2.95	2.94
2015	2014–11	3.10	3.20
2015	2014–12	7.27	3.88
2015	2015–01	5.42	3.37

Wood River

Turbidity, SCB, streamflow, and water temperature were evaluated as explanatory variables for TP at the Wood River site. Samples collected by the Klamath Tribes were incorporated in the model calibration dataset to increase the sample size and to provide data for evaluating seasonal trends in TP concentrations. The addition of the samples from the Klamath Tribes resulted in 20 total samples used to develop surrogate regressions for TP at this site.

Best-Fit Model

After evaluating all explanatory variables in linear and log-transformed simple and MLR models, a non-transformed SLR with turbidity as an explanatory variable was chosen as the best-fit model (fig. 13, table 7). The model fit was poor, however, primarily because TP concentrations do not vary greatly at this site and they are largely comprised of the soluble fraction, derived mostly from the large groundwater component of streamflow in the Wood River (Gannett and others, 2007).

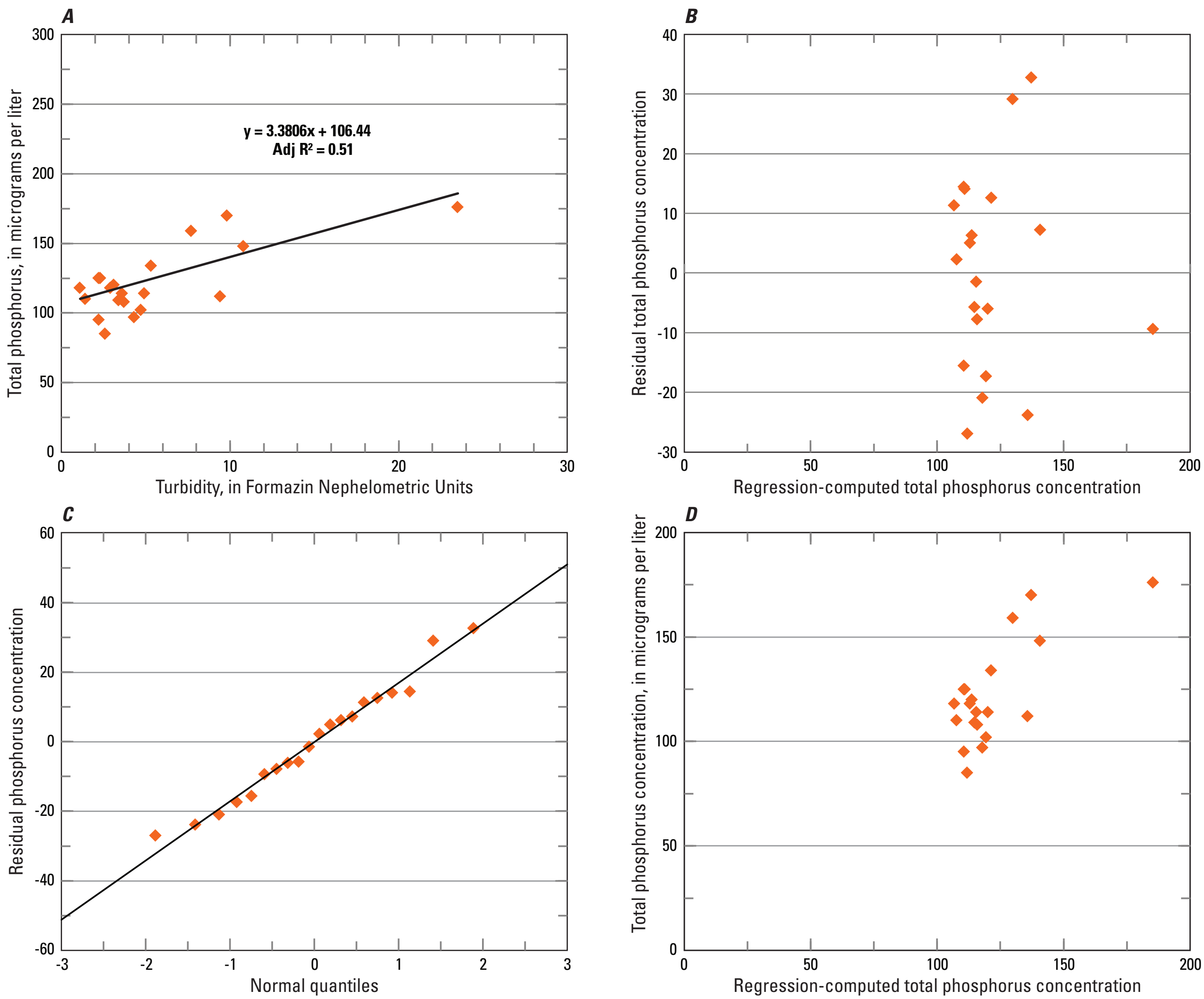

Figure 13. Results of simple linear regression analysis for (*A*), turbidity and total phosphorus (TP) concentration data, (*B*) residuals of the regression-computed TP, (*C*) probability plot of residuals, and (*D*) regression-computed and associated measured TP, for the Wood River site (USGS streamgage 11504115), Upper Klamath Basin, Oregon, November 26, 2013–March 13, 2015.

The SLR model in table 7 was applied to the time series of turbidity collected at the Wood River site to compute time series of TP in micrograms per liter for November 26, 2013–March 13, 2015, the analysis period when nutrient samples were collected. During this period, the maximum recorded turbidity was 24 FNUs, which was sampled during the storm event on December 23, 2014. Therefore, no computed TP values exceeded the limits of the regression for the analysis period. TP time series, 90-percent prediction intervals, and samples collected by USGS and the Klamath Tribes are shown in figure 14.

Wood River Total Phosphorus Loads

Monthly TP loads are shown in figure 12 for December 2013–January 2015. A summary of the monthly loads for this time period is shown in table 8. The partial WY 2014 calculations (excluding October and November) resulted in 28 metric tons at the Wood River, compared to 39 metric tons at the Williamson River. Loads from November 2013 and February–March 2015 are omitted from table 8 and figure 11 for consistency with the monthly TP loads calculated at the Williamson River site.

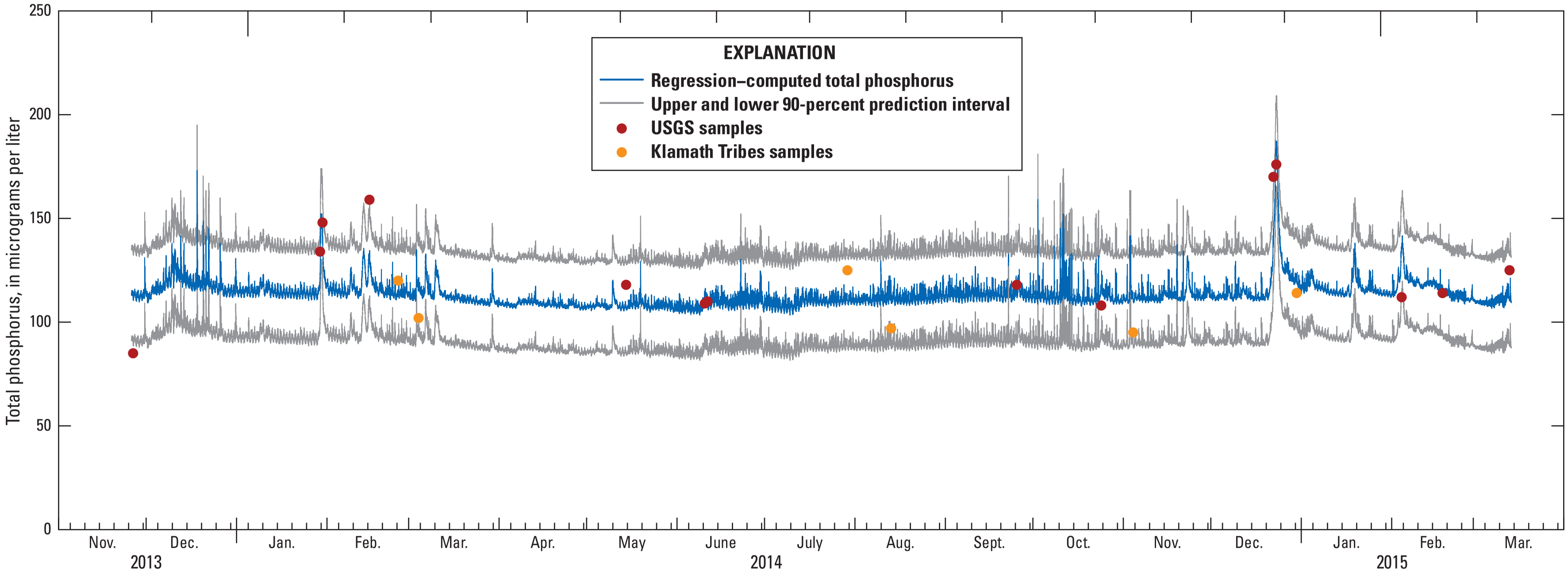

Figure 14. Time series of computed unit values of total phosphorus (TP) concentrations, 90-percent prediction intervals, and observed values of TP concentration from samples collected at the Wood River site (USGS streamgage 11504115), Upper Klamath Basin, Oregon, November 26, 2013–March 13, 2015.

Discussion

Total Phosphorus and Sediment Loads to Upper Klamath Lake

TP loads to Upper Klamath Lake from the Wood and Williamson Rivers were computed from December 2013 to January 2015. Overall, TP loads were larger at the Williamson River site than at the Wood River site, especially during winter and spring (December–May), when streamflows typically are higher on the Williamson River. TP loads were similar for months without storm events at the two sites, suggesting similar base-flow loading of TP to Upper Klamath Lake from the Williamson and Wood Rivers (fig. 12). The influence of storm events in TP transport from the Williamson River is evident in the elevated turbidity and streamflow values during the events. TP loads for the partial WY 2014, excluding October and November, were 39 and 28 metric tons for the Williamson and Wood Rivers, respectively. Earlier studies by Walker and others (2012) used biweekly nutrient data collected by the Klamath Tribes, and reported a TP annual load range of about 40–120 metric tons/yr at the Klamath Tribes site on the Williamson River for WYs 1992–2010 (about 6 river miles downstream of the USGS site sampled for this study), and about 20–50 metric tons/yr at Wood River, using the same site as the USGS. The partial water year 2014 Williamson River and Wood River TP loads from this study are on the low end of the range reported by Walker and others (2012), and are assumed to be biased low because of the absence of data from the first 2 months of WY 2014 and the drought conditions that were prevalent in the Upper Klamath Basin during WY 2014. Therefore, TP and SSLs in this report should be considered as representative of low-water years for the two study sites.

In terms of watershed yields of TP for the Wood and Williamson Rivers for the partial WY 2014, the Wood River and its tributaries delivered proportionately higher amounts of TP to Upper Klamath Lake, with a yield of 137 kg/km^2 [1.37 (kg/ha)/yr], compared to 5 kg/km^2 [0.05 (kg/ha)/yr] at the Williamson River site, which includes both the Williamson and Sprague subbasins. The watershed yields include important groundwater components of P loading to both systems in addition to overland flow during storm events. For this study, there were few storm events to sample, so the difference in watershed yield likely is affected by differences in the P component of groundwater discharge (dissolved P), which seems to be higher on the Wood River compared to the Williamson River based on nutrient sample results (figs. 7 and 8). Watershed yields likely would have been higher at the Williamson River site if there were more storm events transporting nutrients and sediment from the Sprague subbasin during the study, as has been characterized by Walker and others (2015). Individual storm events at the Williamson River site in the partial WY 2014 accounted for 13 percent of the annual TP load, whereas smaller storm events on the Wood River accounted for 3 percent of the annual TP load. Walker and others (2015) calculated a 23 percent anthropogenic contribution (the difference between total load and total background load) to the TP load at a site on the Sprague River just upstream of the Sprague-Williamson River confluence (USGS streamgage 14151000, Klamath Tribes site ID “Power”) for WYs 2010–14. WY 2014 was a drought year with minimal snowpack and, thus, with minimal snowmelt response in both drainage basins, so a normal water year likely would result in more TP being transported with suspended sediments during more intense and frequent storm events, particularly in the Williamson River.

The Wood and Williamson Rivers have differing turbidity responses to storm events, with the Williamson River indicating a classic rise and recession response, and the Wood River characterized by short-duration, or “flashy” responses that can rise and fall within hours, but with a very consistent base-flow dominated by groundwater. Large storm events recorded at the Williamson River site in WY 2014 did not result in similar responses at the Wood River, and relatively small storm events on the Wood River were not observed at the Williamson River site. The TP loading data from these sites suggest that, although the Sprague and Williamson drainages can contribute substantial amounts of TP to the lake during storm events, in low-water years when storm events are few and mild, most of the annual TP load from the Williamson River occurs during moderate- or low-flow conditions, as in 2014, and primarily is in the dissolved phase. The Wood River site contributed substantially more P load than the Williamson site during moderate-to-low streamflow conditions in 2014, with 97 percent of the annual load occurring during moderate- and low-flow conditions. This is owing to the high concentrations of TP when the system is dominated by groundwater inputs.

SSLs are an important contributing factor in TP loading dynamics in the Upper Klamath Basin, consistent with other studies such as Walker and others (2015). Dissolved P reacts strongly with fine-grained sediments, particularly clays and iron and aluminum metal oxides and hydroxides (Zhou and others, 2005; Withers and Jarvie, 2008). When suspended in water, these fine-grained sediments act as transport mechanisms of P from a watershed to a terminus—in this case, Upper Klamath Lake. Sedimentation occurs in the middle-northern part of Upper Klamath Lake at an average rate of 0.172 cm/yr (Colman and others 2004), and various biological and physical processes can then cause dissolved P to desorb from the sediments into the overlying water column, enhancing cyanobacterial blooms (Jacoby and others, 1982; Sondergaard, 1988; Fisher and Wood, 2004; Simon and others, 2009). A comparison of loads from the two sites for November 2013–September 2014 shows that the Williamson and Sprague Rivers combined, as measured at the Williamson River site, contributed substantially more suspended sediment to Upper Klamath Lake than the Wood River, with 4,360 and 1,450 metric tons measured, respectively (fig. 15). Most of the suspended-sediment load difference occurred during high-flow events on the Williamson River during February–April 2014, whereas base-flow conditions seemed to transport similar quantities of suspended sediment from both systems. The gradually decreasing suspended-sediment load at the Wood River during March–May likely represents reduced streamflow owing to the backwater effect caused by increasing lake elevations leading up to the irrigation season beginning in June (fig. 16). Another important source of sediment loads and associated particulate-bound nutrients to the lake from the Wood River Valley is Sevenmile canal (not sampled for this study), which is west of the Wood River site, and transports return water from agricultural fields west of the Wood River to Upper Klamath Lake (Walker and others, 2012).

Limitations of Wood River Surrogate Regressions

Streamflow measured at the Wood River site is highly variable on a seasonal scale because of backwater effects of Upper Klamath Lake, at times resulting in negative flows reported at the streamgage during strong southerly winds. The site is close to the Wood River terminus in Upper Klamath Lake and typically enters backwater in December or January when the lake reaches full pool, and stays in that state until irrigation season starts in June, reducing lake elevations and increasing stream velocities (fig. 16). The highly variable streamflow conditions resulting from these external factors complicate interpretations of streamflow, and sediment and nutrient loads. Turbidity values also are highly variable at this site, with small turbidity events indicated as spikes in the data. However, close examination of these patterns shows that they are in fact short-term rise and recession events that can occur on hourly time scales (fig. 17). The cause of these small events is unknown, but the turbidity is low during these events, typically 3–5 FNUs. True storm-event responses at the site result in less variable turbidity data, suggesting that some of the low-end variability could be background noise in the sensor itself. Because of the variable streamflow, turbidity, and SCB data at the Wood River site, daily median values were used in calculating loads of TP and suspended-sediment. Ultimately, the models for SSC and TP at the Wood River site had somewhat poor, although statistically significant, performance with broad prediction uncertainty. Refining and improving these models should be possible with additional sample collection including during higher flows than those measured in this study, and continued improvement in techniques for measuring streamflow, velocity, and backscatter under backwater conditions.

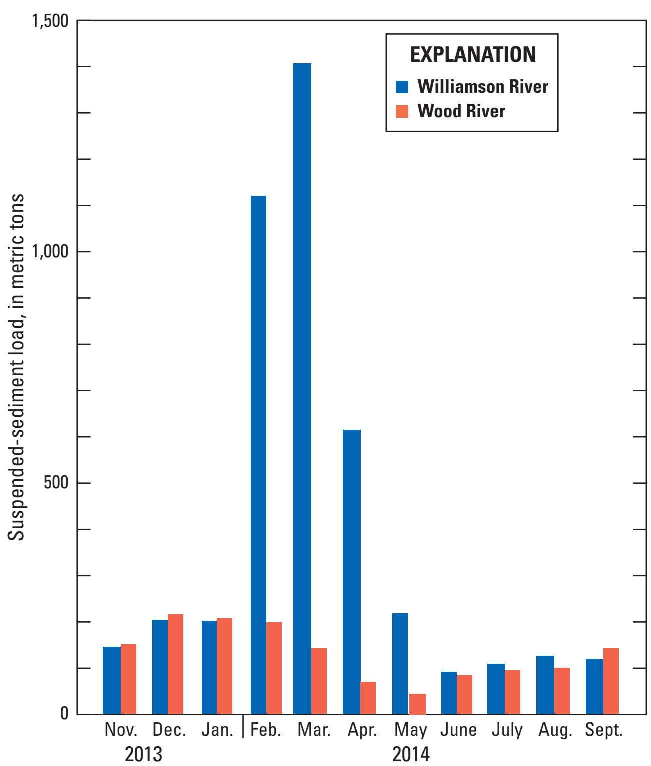

Figure 15. Monthly suspended-sediment loads at the Wood and Williamson River sites (USGS streamgages 11504115 and 11502500), Upper Klamath Basin, Oregon, November 2013–September 2014.

Application of Methods to the Upper Sprague River

The positive results of the surrogate techniques in this report show that high temporal resolution of sediment and nutrient concentrations and loads can be obtained at the Williamson River site. Applying the surrogate techniques to streamgages on the Sprague River could provide high-temporal-resolution sediment and nutrient-load data from subbasin areas to the Sprague River. On the basis of available data, these techniques would be most applicable to the two USGS streamgage locations (USGS streamgages 11501000 and 11497550, fig. 1) near the towns of Chiloquin and Beatty, Oregon. Such efforts would complement recent efforts by the Klamath Tribes to determine subbasin contributions of sediment and nutrient loads using biweekly data collected at numerous sites distributed upstream in the Sprague subbasin (Walker and others, 2015), and would provide higher spatial resolution of loads along the river network than the two USGS streamgages used herein that are located close to Upper Klamath Lake. The surrogate techniques outlined in this report, which require storm-event focused sampling, could help refine nutrient loading estimates, especially during high-flow events when much of the suspended-sediment and TP loads occur.

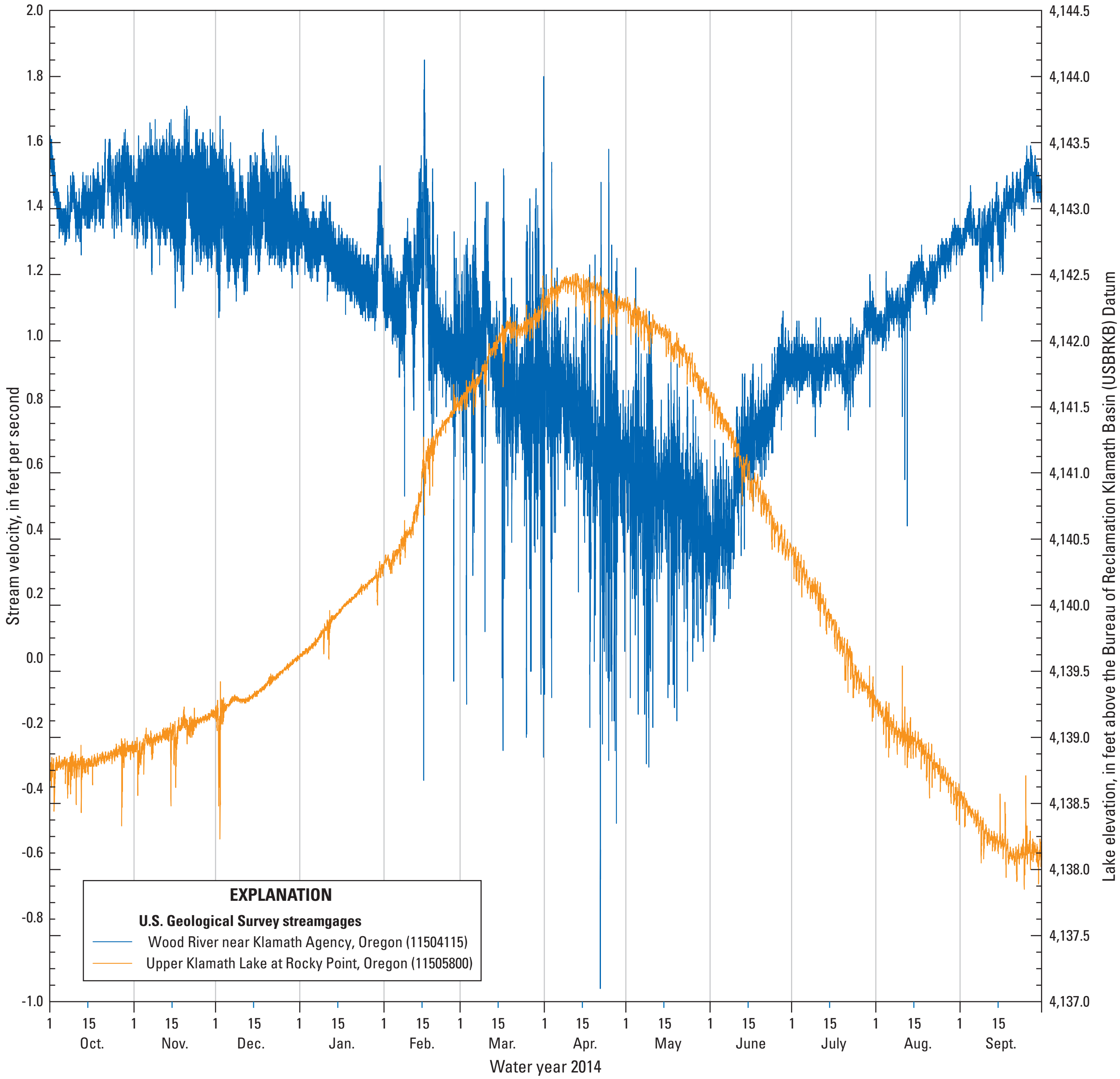

Figure 16. Stream velocity at the Wood River near Klamath Agency (USGS streamgage 11504115) and elevation of Upper Klamath Lake, Oregon, water year 2014.

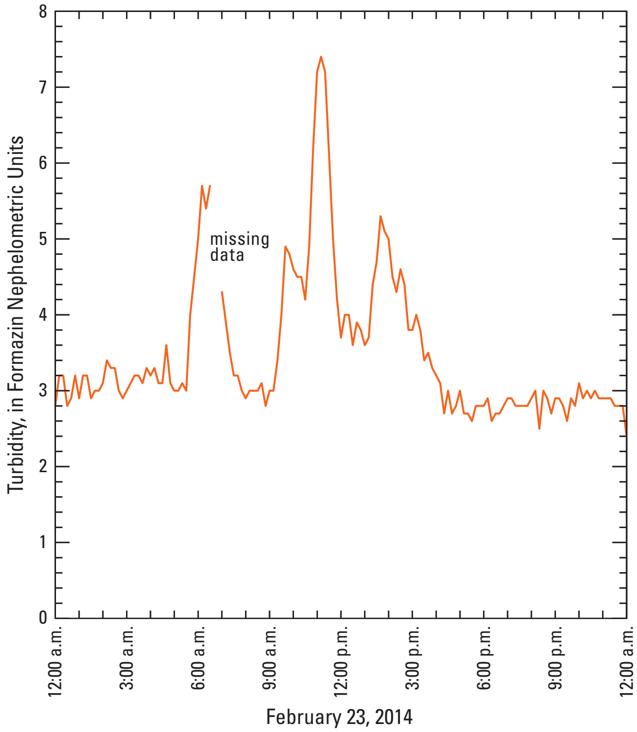

Figure 17. Variable turbidity at Wood River near Klamath Agency (USGS streamgage 11504115), Oregon, February 23, 2014.

Suitability of Surrogate Methods for Water Resource Management

Monitoring nutrient and sediment loads to Upper Klamath Lake is important to basinwide efforts to reduce external P loading and improve water quality in the lake. A TMDL model for Upper Klamath Lake was completed in 2002, and recent reviews and improvements to the model have shown that a 40-percent reduction in external P loads to the lake (the designated external P load reduction in the 2002 TMDL) could result in lower long-term-averaged water column total P concentrations in 20–75 years (Wood and others, 2013; Wherry and others, 2015). Rapid and accurate assessment of basinwide contributions of nutrients and sediment will help to assess the cumulative efficacy of restoration efforts in the Williamson and Sprague subbasins, and the Wood River Valley, and is complementary to effectiveness monitoring of individual restoration projects.

Surrogate techniques have proven useful at the two study sites, particularly in using turbidity to compute SSC at the Williamson River site. The proof-of-concept efforts for computing TP and SSLs using turbidity at the Williamson and Wood River sites also have shown that with an extended dataset, high temporal resolution loads and associated uncertainties can be assessed on a daily, monthly, and annual basis. The use of SCB at the Wood River site to compute SSC is a useful surrogate to compute SSL contributions from that site as well. Suspended-sediment and TP loads with a high level of temporal resolution will be useful to water managers, restoration practitioners, and scientists in the Upper Klamath Basin working toward the common goal of decreasing nutrients and sediment loads in Upper Klamath Lake.

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Appendix A. Suspended-Sediment Concentration Station Analysis for Williamson River below Sprague River, near Chiloquin, Oregon, 2008–10 and 2012–14

WATER YEARS 2008–14
SUSPENDED-SEDIMENT RECORD
USGS Streamgage 11502500—Williamson River below Sprague River, near Chiloquin, Oregon

MODEL CALIBRATION DATASET. The model calibration dataset includes samples collected from water years (WYs) 2008–14, excluding WY 2011 when no samples were collected due to a temporary lapse in study funding. For samples where both A and B sets were collected, the two suspended-sediment concentration (SSC) values were averaged to avoid serial correlation within the dataset. Approved unit values of turbidity and streamflow were averaged starting with the first punch prior to the start of the sample, to the last punch after the end of the sample. These averaged unit values were paired with either the individual samples or the averaged A and B sets (where applicable) to generate the calibration dataset.

The final initial calibration dataset included 36 samples. Of the 36 samples, three B set samples were deemed erroneous due to high percentages of sand in the sample and high SSC values. Over-sampling of the streambed was assumed to have caused these high values, and only the A-set samples were used in these cases. One outlier was removed from the dataset (sample collected on April 19, 2009) after the initial regression model analysis. This sample reported a low SSC value (11 mg/L) associated with a moderate turbidity value (21 Formazin Nephelometric Units [FNUs]). Database entry was evaluated with this sample, along with information recorded on field sheets. Nothing obvious was identified to cause this extreme lower outlier. Samples collected in the range of 19–32 FNUs were then evaluated to put the lower outlier sample into hydrological context for this site. SSC samples within this moderate range of turbidity consistently produced results that were much higher than the outlier sample (table A1). For example, a sample collected on March 12, 2014, at 21 FNUs resulted in an SSC of 29 mg/L. As such, this sample was determined to be biased low for unknown reasons, and removal of the sample from the calibration dataset resulted in improved model statistics. After removal of this outlier, the final model calibration dataset consisted of 35 samples.

All SSC samples were collected using U.S. Geological Survey (USGS) equal-width-increment (EWI) protocols. Individual bottles were sent to the sediment laboratory and composited prior to analysis. Samples collected during WYs 2008–13 were analyzed at the USGS Cascade Volcano Observatory (CVO) sediment laboratory, providing the SSC value (in milligrams per liter) for each sample, as well as the percentage of values finer than 62.5 µm. Samples collected in WY 2014 were analyzed at the Sprague River Water Quality Laboratory (SRWQL), except for one sample on February 14, 2014, analyzed at the CVO, providing the SSC value (in milligrams per liter) for each sample, as well as mass of sediment in the sand and fines size fraction, which were used to calculate the percentage of samples finer than 62.5 µm. Samples analyzed at the SRWQL in 2014 were processed in a churn-splitter after the EWI sample was collected. Two 1-L bottles were filled from the churn and composited prior to analysis. Analytes for total and dissolved nutrients also were analyzed along with the SSC samples from the churn as part of a nutrient loading study in WY 2014. A list of samples used in the calibration dataset is included at the end of this station analysis.

Table A1. Results of analysis of turbidity and suspended-sediment concentrations justifying removal of lower outlier sample dated April 14, 2009, Williamson River site (USGS streamgage 11502500), Upper Klamath Lake, Oregon, 2009–14.

[**Abbreviations:** FNU, Formazin Nephelometric Unit; mg/L, milligram per liter]

Date	Time	Turbidity (FNU)	Suspended-sediment concentration (mg/L)	
03-04-09	1010	19	37	
03-20-09	1012	30	46	
04-02-12	1545	32	52	
02-16-14	1125	23	36	
03-12-14	1435	21	29	
04-14-09	1230	21	11	(lower outlier)

MODEL DEVELOPMENT. Regression analyses were conducted using the Turbidity Sediment Spreadsheet following methods described in the USGS Techniques and Methods Report, book 3, chap. C4 (Rasmussen and others, 2009). Turbidity and streamflow were evaluated together and separately as possible surrogates. The log-10 transformations of each parameter also were evaluated together and separately as possible surrogates.

Although SSC samples and turbidity data have been collected at this site since WY 2008, no sediment records have been computed to date. A limited number of samples were collected in the first 2 years of data collection (WYs 2008 and 2009), leading to the combination of samples from both water years for use in the first regression analysis. Samples in subsequent years were evaluated against the previous model to determine if model statistics improved with the addition of more SSC samples. This process was repeated until the final year of analysis, WY 2014, when all samples collected from 2008 to 2014 were included in the analysis. Model selection was based on analysis of residual plots, probability plot correlation coefficient (PPCC), model standard prediction error (MSPE), and the adjusted coefficient of determination (Adj R^2) value.

Initial model analysis resulted in a simple linear regression (SLR) with turbidity as the explanatory variable being the best-fit model for WYs 2008–10. Analyses for WYs 2012 and 2013 resulted in a deviation from the non-transformed SLR to a $\log_{10}$-transformed multiple linear regression (MLR) with turbidity and streamflow as the explanatory variables (table A2). However, only three samples were collected in 2012, and one sample in 2013. With so few samples collected in those 2 water years, it is unclear if the hydrologic conditions changed enough to warrant a change to the model. The addition of samples from WY 2014 resulted in switch back to a non-transformed SLR, similar to the 2008–10 models. As such, initial analysis resulted in the application of one SLR non-transformed model using all of the samples collected from 2008 to 2014 in the calibration dataset (table A3), and applied to all water years. However, calculation of the 90-percent prediction intervals resulted in many negative unit values of SSC in the lower prediction intervals from the non-transformed model. Accordingly, then next best-fit model was chosen to calculate time series of SSC, which was a log-10 transformed SLR with turbidity as the explanatory variable. As with the non-transformed model, the 2014 model that incorporated samples from 2008 to 2014 was chosen and applied to all water years to compute SSC time series. Rejected models can be viewed in the attached sediment spreadsheet for data collected between 2008 and 2014.

Statistical analysis of the models using analysis of covariance (ANCOVA) shows that the log-10 transformed 2008–14 combined model was not statistically different from the models using samples from 2008 to 2010 and 2012 to 2013. As such, the log-10 transformed SLR with turbidity as an explanatory variable using samples from 2008 to 2014 was used for all WYs 2008–14.

Table A2. Simple linear regression model output from water years 2008–10 and 2012–14.

[**Regression model:** Adj R^2**,** adjusted coefficients of determination. **PRESS**, predicted residual error sum of squares. **PPCC**, probability plot correlation coefficient. **Upper MSPE**, upper model standard prediction error. **Lower MSPE**, lower model standard prediction error]

Water years	Model type	Number of samples	Slope	Intercept	Adj R^2	Standard error	PRESS	PPCC	Upper MSPE	Lower MSPE
2008–09	SLR $\log_{10}$-transformed	13	0.80	0.42	0.94	0.081	0.10	0.97	20.4	-16.9
2008–10	SLR $\log_{10}$-transformed	23	0.83	0.38	0.94	0.070	0.13	0.97	17.7	-15.0
2008–12	SLR $\log_{10}$-transformed	26	0.85	0.37	0.94	0.071	0.15	0.99	17.9	-15.2
2008–13	SLR $\log_{10}$-transformed	27	0.83	0.39	0.94	0.073	0.16	0.98	18.3	-15.4
2008–14	SLR $\log_{10}$-transformed	35	0.90	0.31	0.95	0.084	0.28	0.97	21.5	-17.7

Table A3. Model calibration dataset, 2008–14.

[**Abbreviations:** FNU, Formazin Nephelometric Unit; ft^3/s, cubic foot per second; mg/L, milligram per liter]

Date	Time	Turbidity (FNU) (DTS-12 turbidity sensor)	Streamflow (ft^3/s)	Suspended-sediment concentration (mg/L)	Percentage of suspended sediment finer than 62 micrometers
04-24-08	10:09:30	9.4	2,020	16	89
05-02-08	10:20:00	11	1,860	17	93
05-20-08	10:27:30	9.0	1,720	17	94
07-03-08	09:39:00	1.6	580	3.5	80
01-08-09	12:34:30	3.7	780	6.5	85
02-23-09	14:15:00	2.3	757	7.0	73
02-25-09	12:38:00	8.5	921	13	92
02-26-09	12:36:00	13.5	970	18	89
02-27-09	11:38:00	14	897	17	89
03-04-09	10:10:00	19	1,170	37	91
03-20-09	10:12:30	30	1,420	46	89
04-13-09	11:22:00	35	1,523	42	96
05-12-09	12:05:00	11	1,780	23	95
01-13-10	14:38:30	2.7	675	5.0	80
02-19-10	11:41:00	4.2	780	7.0	90
03-09-10	14:43:30	4.2	724	7.5	80
04-30-10	09:48:00	12	1,200	18	94
05-03-10	11:58:00	16	1,245	20	96
05-13-10	09:55:30	9.3	1,140	18	79
05-18-10	13:45:00	9.3	1,170	16	88
05-26-10	12:26:00	6.4	1,100	9.0	92
06-07-10	11:03:00	9.6	1,227	15	95
06-09-10	12:00:00	13	1,360	22	96
04-02-12	15:45:00	32	2,098	52	90
05-01-12	13:30:00	15	2,272	29	84
05-10-12	13:12:30	8.1	1,797	16	89
12-06-12	11:42:00	41	1,330	43	96
11-21-13	12:40:00	1.9	585	2.0	91
02-15-14	10:40:00	12	982	25	84
02-16-14	11:25:00	23	1,090	36	89
02-17-14	11:35:00	42	1,280	67	91
02-18-14	12:35:00	58	1,420	73	92
02-19-14	10:30:00	32	1,268	45	93
03-12-14	14:35:00	21	1,293	29	94
08-20-14	12:15:00	1.6	470	3.0	79

MODEL SUMMARY. Summary of final regression analysis for SSC at Williamson River below Sprague River, near Chiloquin, Oregon.

$$\log_{10}(SSC) = [0.896 \times \log_{10}(Turb) + 0.314] \times BCF \text{ ~or~ } SSC = 2.102 \times (Turb)^{0.896} \tag{A1}$$

where

SSC is suspended-sediment concentration, in milligrams per liter,
Turb is turbidity (DTS-12), in Formazin Nephelometric Units, and
BCF is Bias Correction Factor.

Bias Correction Factor = **1.02**
Adjusted coefficient of determination (Adj R^2) = **0.95**

RECORD. SSC unit values were computed every 15 min, similar to turbidity and streamflow at this site. During short periods of missing or deleted turbidity data, SSC was estimated in the Automatic Data Processing System (ADAPS) by interpolating between the computed SSC values.

SSC unit values from WY 2011 were computed using the 2008–14 regression, but no samples were collected to verify the unit values or 90-percent confidence intervals. The WY 2011 SSC record was computed using an incomplete turbidity record due to lack of funding. The SSC record for 2011 begins in October 2010 and ends in June 2011.

SSC RECORD. The record is computed using the regression model and ADAPS database. A parameter-dependent rating in ADAPS is used to compute time series of SSC. Data are computed at 15-min intervals. The records are complete for the water years analyzed except as noted in section, “Discussion.”

MISSING/PARTIAL DAYS.

WY 2008

Instrumentation was installed and data collection began on October 16, 2007, which is flagged as a partial day with only 35 unit values recorded. Partial days also were recorded from July 21 to 23, and July 29 to 30 due to deleted turbidity data. No turbidity data were recorded from July 24 to 28. A station analysis for the turbidity record could not be located, so the causes of turbidity data deletions are unknown.

WY 2009

Missing SSC data are the result of turbidity data marked erroneously on October 16 and June 28.

WY 2010

Partial days on February 16 and 17 due to missing transmits, and July 3 from deleted erroneous data.

WY 2011

Data were collected from the beginning of the water year until June 1, 2011. No samples were collected in WY 2011 due to a lapse in funding. The turbidity sensor was maintained for a part of the water year, and the regression equation was applied to the turbidity time series to compute SSC. The only partial day occurred on June 1, 2011, when turbidity data ceased to be collected at this site.

WY 2012

Turbidity data were collected in WY 2012 beginning on March 16, 2012. Partial days for SSC include March 16 due to sensor deployment, June 29, July 12, and July 18 due to erroneous turbidity data.

WY 2013

Multiple partial days of SSC data occurred in 2013 due to deletion of turbidity data: December 13; January 2, 4, and 15; February 11–13; May 6 and 31; June 2–4; July 21–25.

WY 2014

Partial days of SSC data on June 2 and 3 due to deletion of turbidity data.\

EXTREME VALUES.

WY 2008

Maximum Instantaneous SSC: 72.4 mg/L on March 14 @ 0630 and 0830
Minimum Instantaneous SSC: 0.00 mg/L on various dates

WY 2009

Maximum Instantaneous SSC: 71.2 mg/L on March 6 @ 0145 and 0315
Minimum Instantaneous SSC: 1.3 mg/L on various dates

WY 2010

Maximum Instantaneous SSC: 41.6 mg/L on May 1 @ 1100, 1215, 1600
Minimum Instantaneous SSC: 2.3 mg/L on various dates

WY 2011

Maximum Instantaneous SSC: 72.4 mg/L on March 9 @ 2315
Minimum Instantaneous SSC: 2.5 mg/L on October 5 @ 1345

WY 2012

Maximum Instantaneous SSC: 102 mg/L on March 19 @ 0500
Minimum Instantaneous SSC: 1.7 mg/L on various dates

WY 2013

Maximum Instantaneous SSC: 69.9 mg/L on December 6 @ 0300
Minimum Instantaneous SSC: 1.9 mg/L on June 21 and 22

WY 2014

Maximum Instantaneous SSC: 90.9 mg/L on February 18 @ 0815
Minimum Instantaneous SSC: 2.1 mg/L on various dates

Worked: lschenk, June 8, 2015
Checked: cboudrea, June 10, 2015
Reviewed: mastewar

Statistical Analysis of Regression Models

An ANCOVA was run in R comparing the slopes of the log-transformed SSC-turbidity relations of the following five datasets to determine if there is a statistically significant difference between the model slopes:

WYs 2008–09, 13 samples
WYs 2008–10, 23 samples
WYs 2008–12, 26 samples
WYs 2008–13, 27 samples
WYs 2008–14, 35 samples

An “aov” command was used to determine if the SSC-turbidity relation was different due to the year the data were collected. In the following script the YR.Group variable is a factor with five levels;

2009 (includes 2008–09 samples)
2010 (includes 2008–10 samples)
2012 (includes 2008–12 samples, excluding WY 2011)
2013 (includes 2008–13 samples, excluding WY 2011)
2014 (includes 2008–14 samples, excluding WY 2011)

The turbidity and SSC variables are numeric, with SSC modeled as the dependent variable. The ANCOVA resulted in the following output:

```
mod3 <- aov(Log10SSC~Log10Turbidity*YR.Group, data=lmdata.stat)
summary(mod3)
                         Df Sum Sq Mean Sq F value Pr(>F)
Log10Turbidity            1 11.953 11.953 1945.623 <2e-16 ***
YR.Group                  4  0.003  0.001    0.140  0.967
Log10Turbidity:YR.Group   4  0.019  0.005    0.779  0.541
Residuals               114  0.700  0.006
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

The results show a significant relation between turbidity and SSC, but not year, and no significant interaction between turbidity and year, suggesting the slopes of all of the five regression lines are similar.

A second model was run to remove the interaction term and test if there are significant differences in the slopes of the five regression lines, resulting in the following:

```
mod4 <- aov(Log10SSC~Log10Turbidity+YR.Group, data=lmdata.stat)
summary(mod4)
                  Df Sum Sq Mean Sq F value Pr(>F)
Log10Turbidity     1 11.953 11.953 1960.295 <2e-16 ***
YR.Group           4  0.003  0.001    0.142  0.966
Residuals        118  0.720  0.006
---
Signif. codes:   0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

The results show no significant effect of year on the dependent variable (SSC). Therefore, the 2008–14 combined model was used as the best-fit model for all water years.

Appendix B. Quality-Assurance Results for Replicate and Blank Samples at Wood and Williamson River Sites, Oregon

Precision of the combined sampling and analysis, as measured with field replicate samples, generally was good and suggests that surrogate regressions in this study are largely unaffected by variability associated with sample processing and laboratory analysis (table B1). Of the 10 replicate samples collected, most relative percentage differences (RPDs) for suspended-sediment concentration (SSC) samples were less than or equal to 10 percent. Three samples for total phosphorus (TP) had RPDs greater than or equal to 10 percent, with one sample (a concurrent replicate) having 19 percent variability between the individual samples. Concurrent replicate samples are collected separately from each other (as compared to being subsampled from the same churn splitter), so increased variability is expected and likely indicates natural variability in aquatic concentrations. Total nitrogen (TN) samples had higher variability, with one-half of the samples having more than 10 percent RPD, and two having more than 40 percent RPD. For this study, which focuses on TP and not TN, the variability in TN measurements is not problematic. The dissolved nutrient analyses had good precision—most had RPDs less than 10 percent but the few that had greater than 10 percent (notably for NH_4^+ as N) were all at low concentrations near their respective method reporting limits, in the range where relatively high variability is common.

Results of equipment blank samples indicate that field techniques generally were clean and contamination was minimized, particularly for phosphorus (both total and dissolved) and dissolved nitrite plus nitrate as nitrogen (N) (NO_2^- +NO_3^- as N), which had no detections in blank samples (table B2). One field blank had a detection of TN (0.083 mg/L), which is less than 95 percent of the detected TN concentrations. Ammonium as N (NH_4^+ as N), typically the nutrient analyte most susceptible to contamination, did have detected concentrations in two of the five blank samples (0.006 and 0.015 mg/L) at or about double the method detection limit, in the same range as most of the detected concentrations from environmental samples shown in appendix D. In this report, the NH_4^+ as N data are not used for surrogate purposes so potential NH_4^+ as N contamination does not affect the findings, but future data analysis should carefully consider the blank results when using the environmental data from this study. Whether the NH_4^+ as N contamination resulted from contaminated blank water, or improper field techniques, cannot be discerned from the available data.

Table B1. Quality-assurance results for nutrient and suspended-sediment samples, Williamson and Wood River sites (USGS streamgages 11502500 and 11504115), Upper Klamath Basin, Oregon, 2013–15.

[Method reporting limit (MRL) and method detection limit (MDL) values are for the Klamath Tribe Sprague River Water Quality Laboratory, which provided analysis for all sample comparisons collected by the U.S. Geological Survey (USGS) and the Klamath Tribes (KT). **Replicate samples:** N, nitrogen; NH_4^+, ammonium; NO_2^-+NO_3^-, nitrite plus nitrate; P, phosphorus; PO_4^{3-}; SSC, suspended-sediment concentration. **Sample type:** RPD, relative percent difference. **Ammonium and nitrate plus nitrite (as N):** E, estimated. **Abbreviations and Symbols:** NA, not applicable; mg/L, milligram per liter; <, less than; %, percent]

Date	Time	Replicate samples						
		Sample type	Total phosphorus, as P (mg/L)	PO_4^{3-} as P (mg/L)	NH_4^+ as N (mg/L)	NO_2^- +NO_3^- as N (mg/L)	Total nitrogen, as N (mg/L)	SSC (mg/L)
		MRL (mg/L)	**0.036**	**0.006**	**0.012**	**0.016**	**0.060**	**0.100**
		MDL (mg/L)	**0.018**	**0.003**	**0.006**	**0.008**	**0.030**	**0.000**
Williamson River below Sprague River, near Chiloquin, Oregon, USGS streamgage 11502500								
11-21-13	1300	Split-Replicate	0.071	0.060	< 0.006	E 0.015	0.102	2.4
11-21-13	1301	Split-Replicate	0.064	0.060	< 0.006	E 0.013	0.062	ND
		RPD	**10%**	**0%**	**0%**	**14%**	**49%**	**NA**
02-17-14	1135	Split-Replicate	0.162	0.073	0.012	0.054	0.684	67.1
02-17-14	1136	Split-Replicate	0.164	0.073	E 0.010	0.053	0.712	65.6
		RPD	**1%**	**0%**	**18%**	**2%**	**4%**	**2%**
12-15-14	1252	Split-Replicate	0.099	0.066	0.012	0.032	0.436	18.52
12-15-14	1253	Split-Replicate	0.095	0.066	0.015	0.032	0.355	19.35
		RPD	**4%**	**0%**	**22%**	**0%**	**20%**	**4%**
02-09-15	1200	Concurrent-Replicate	0.105	0.061	0.011	0.033	0.336	35.71
02-09-15	1202	Concurrent-Replicate	0.127	0.059	0.013	0.035	0.527	37.39
		RPD	**19%**	**3%**	**17%**	**6%**	**44%**	**5%**
Wood River near Klamath Agency, Oregon, USGS streamgage 11504115								
01-30-14	1110	Split-Replicate	0.148	0.096	0.006	0.025	0.314	13.8
01-30-14	1111	Split-Replicate	0.164	0.097	< 0.006	0.025	0.356	14.2
		RPD	**10%**	**1%**	**0%**	**0%**	**13%**	**3%**
05-14-14	1300	Split-Replicate	0.118	0.099	< 0.006	E 0.011	0.180	2.50
05-14-14	1301	Split-Replicate	0.116	0.101	< 0.006	E 0.010	0.148	2.50
		RPD	**2%**	**2%**	**0%**	**10%**	**20%**	**0%**
08-19-14	1222	Split-Replicate	0.097	0.082	< 0.006	< 0.008	0.073	7.04
08-19-14	1224	Split-Replicate	0.098	0.091	< 0.01	< 0.01	0.082	ND
		RPD	**3%**	**10%**	**0%**	**0%**	**9%**	**NA**
12-22-14	1100	Split-Replicate	0.170	0.109	E 0.009	0.027	0.467	16.83
12-22-14	1101	Split-Replicate	0.176	0.109	E 0.008	0.027	0.485	18.42
		RPD	**3%**	**0%**	**12%**	**0%**	**4%**	**9%**
02-04-15	1015	Concurrent-Replicate	0.112	0.075	0.007	0.015	0.318	8.69
02-04-15	1017	Concurrent-Replicate	0.112	0.075	E 0.006	0.017	0.312	9.60
		RPD	**0%**	**0%**	**15%**	**13%**	**2%**	**10%**
03-13-15	1008	Concurrent-Replicate	0.125	0.098	0.006	0.009	0.165	1.2
03-13-15	1009	Concurrent-Replicate	0.122	0.010	0.006	0.010	0.153	< 0.8
		RPD	**2%**	**2%**	**0%**	**11%**	**8%**	**NA**

Table B2. Blank sample results for nutrient samples, Williamson and Wood River sites (USGS streamgages 11502500 and 11504115), Upper Klamath Basin, Oregon, 2013–14.

[Method reporting limit (MRL) and method detection limit (MDL) values are for the Klamath Tribe Sprague River Water Quality Laboratory, which provide analysis for all sample comparisons collected by the U.S. Geological Survey (USGS) and the Klamath Tribes (KT). **Blank samples:** N, nitrogen; NH_4^+, ammonium; NO_2^-+NO_3^-, nitrite plus nitrate; P, phosphorus; PO_4^{3-}, orthophosphate. **Ammonium (as N):** E, estimated. **Abbreviations and Symbol:** mg/L, milligram per liter <, less than]

Date	Time	Blank samples					
		Sample type	Total phosphorus, as P (mg/L)	PO_4^{3-} as P (mg/L)	NH_4^+ as N (mg/L)	NO_2^- + NO_3^- as N (mg/L)	Total nitrogen, as N (mg/L)
		MRL (mg/L)	**0.036**	**0.006**	**0.012**	**0.016**	**0.060**
		MDL (mg/L)	**0.018**	**0.003**	**0.006**	**0.008**	**0.030**
Williamson River below Sprague River near, Chiloquin, Oregon, USGS streamgage 11502500							
03-12-14	1439	Blank	< 0.018	< 0.003	E 0.006	< 0.008	0.083
08-20-14	1219	Blank	< 0.018	< 0.003	< 0.006	< 0.008	< 0.030
Wood River near Klamath Agency, Oregon, USGS streamgage 11504115							
11-26-13	1244	Blank	< 0.018	< 0.003	< 0.006	< 0.008	< 0.030
06-11-14	1134	Blank	< 0.018	< 0.003	< 0.006	< 0.008	< 0.030
12-22-14	0800	Blank	< 0.018	< 0.003	0.015	< 0.008	< 0.030

Appendix C. Missing Unit Values and Methods for Estimating Daily Suspended-Sediment Concentration at the Williamson River Site, Oregon

Methods for estimating daily suspended-sediment concentration (SSC) for periods of missing data are shown in table C1 and explained here.

Method 1: During two periods at base-flow or low-flow conditions, all the unit values for turbidity were deleted because of fouling and macrophyte growth. For these periods, mean daily, “estimated” SSCs were generated using measured daily streamflow as the independent variable. As a dependent variable we used daily SSCs, for the 10 days prior to and 10 days following the missing period, that had themselves been previously calculated from the unit value regression of turbidity and SSC. This regression of daily streamflow and daily SSC was applied to daily streamflow during the period of missing turbidity unit values to estimate daily SSCs for that period. We rejected a different, more direct streamflow-SSC regression that used the unit values from the calibration dataset and SSC sample data because it resulted in daily SSC values significantly higher than the surrounding periods that had intact records for instantaneous turbidity.

Method 2: During base-flow or low-flow conditions where the streamflow and turbidity were not changing, and relatively few turbidity values were deleted because of fouling, the remaining unit values of SSC for the day of interest were averaged to provide a daily mean SSC value. In most cases, this method was applied to 88 or more unit values of turbidity in a single day and the resulting daily values are considered “estimated.” In some cases, about one-half of the unit values for the day were used to compute the daily average, but only if the hydrologic conditions were not changing (for example, during periods of low turbidities and near-constant streamflow). This method also was applied to 4 days in December 2012 and January 2013 when the streamgage was ice-affected. During these periods, the existing data were determined to be representative of the daily values because streamflow and turbidity were not changing during those time periods.

Method 3: During the rise or recession of a hydrograph, turbidity data were linearly interpolated over the interval of the missing data, the log(turb)-log(SSC) equation was applied to the interpolated turbidity values, and individual unit values of SSC were computed. The SSC values from the interpolated period were combined with the computed SSC values (that used measured turbidity data) to generate a complete daily record of SSC. Those values were averaged, and only a daily mean SSC value was reported.

Method 4: Data deleted between July 21 and 25, 2013, and occurred at nearly unchanging streamflow, making the use of any type of regression unusable. As such, daily mean SSC values were interpolated for those days, and represented very low daily concentrations (about 3 mg/L).

Table C1. Methods for estimating daily mean suspended-sediment concentration at Williamson River site (USGS streamgage 11502500), Upper Klamath Basin, Oregon.

[**Abbreviations:** mg/L, milligram per liter; SSC suspended-sediment concentration]

Water year	Date	Number of computed unit values SSC	Number of missing SSC unit values	Resulting estimated daily mean SSC (mg/L)	Method of estimating daily mean SSC (mg/L)
2008	07-21-08	24	72	1.19	Method 1
	07-22-08	65	31	1.40	Method 1
	07-23-08	32	64	1.44	Method 1
	07-24-08	0	96	1.70	Method 1
	07-25-08	0	96	1.52	Method 1
	07-26-08	0	96	1.19	Method 1
	07-27-08	0	96	0.99	Method 1
	07-28-08	0	96	0.81	Method 1
	07-29-08	38	58	0.80	Method 1
2009	10-16-08	88	8	2.90	Method 2
	06-28-09	88	8	3.84	Method 2
2010	02-16-10	52	44	5.29	Method 2
	02-17-10	46	50	5.85	Method 2
	07-03-10	88	8	5.08	Method 2
2012	06-29-12	68	28	3.31	Method 2
	07-12-12	83	13	2.34	Method 2
	07-18-12	78	18	2.14	Method 2
2013	12-31-12	72	24	8.34	Method 2
	01-02-13	62	34	7.2	Method 2
	01-04-13	82	14	7.44	Method 2
	01-15-13	67	29	7.42	Method 2
	02-11-13	58	38	12.51	Method 3
	02-12-13	0	96	10.96	Method 3
	02-13-13	63	33	9.03	Method 3
	05-06-13	87	9	6.66	Method 2
	05-31-13	78	18	5.34	Method 2
	06-02-13	17	79	4.79	Method 1
	06-03-13	0	96	4.02	Method 1
	06-04-13	51	45	3.65	Method 1
	07-21-13	0	96	3.2	Method 4
	07-22-13	0	96	3.2	Method 4
	07-23-13	0	96	3.2	Method 4
	07-24-13	0	96	3.1	Method 4
	07-25-13	53	43	3.1	Method 4
2014	06-02-14	53	43	2.83	Method 2
	06-03-14	89	7	2.62	Method 2

Appendix D. Nutrient-Concentration Results from Water Samples Collected at Wood and Williamson River Sites, Oregon

Table D1. Nutrient sample results from Wood and Williamson River sites (USGS streamgages 11502500 and 11504115), Upper Klamath Basin, Oregon, 2013–15.

[Method reporting limit (MRL) and method detection limit (MDL) values are for the Klamath Tribes Sprague River Water Quality Laboratory (SRWQL), which provided analysis for all sample comparisons collected by the U.S. Geological Survey (USGS) and the Klamath Tribes (KT). **Primary samples:** N, nitrogen; NH_4^+, ammonium; $NO_2^-+NO_3^-$, nitrite plus nitrate; P, phosphorus; PO_4^{3-}, orthophosphate. **Ammonium and nitrate plus nitrite (as N):** E, estimated. **Abbreviations and Symbol:** mg/L, milligram per liter; <, less than]

Date	Time	Primary samples						Analyzing entity
		Sample type	Total phosphorus, as P (mg/L)	PO_4^{3-} as P (mg/L)	NH_4^+ as N (mg/L)	$NO_2^- + NO_3^-$ as N (mg/L)	Total nitrogen, as N (mg/L)	
		MRL (mg/L)	**0.036**	**0.006**	**0.012**	**0.016**	**0.060**	
		MDL (mg/L)	**0.018**	**0.003**	**0.006**	**0.008**	**0.030**	
Williamson River below Sprague River, near Chiloquin, Oregon, USGS streamgage 11502500								
11-21-13	1300	Primary	0.07	0.060	<0.006	E0.015	0.10	SRWQL
02-15-14	1040	Primary	0.10	0.059	<0.006	0.027	0.31	SRWQL
02-16-14	1125	Primary	0.12	0.065	E0.010	0.035	0.43	SRWQL
02-17-14	1135	Primary	0.16	0.073	0.012	0.054	0.68	SRWQL
02-18-14	1235	Primary	0.18	0.072	0.015	0.061	0.87	SRWQL
03-12-14	1435	Primary	0.10	0.053	<0.006	0.029	0.49	SRWQL
08-20-14	1215	Primary	0.07	0.063	<0.006	E0.009	0.12	SRWQL
12-15-14	1252	Primary	0.10	0.066	0.012	0.032	0.44	SRWQL
12-23-14	1320	Primary	0.14	0.067	0.014	0.046	0.65	SRWQL
02-09-15	1200	Primary	0.10	0.061	0.011	0.033	0.34	SRWQL
Wood River near Klamath Agency, Oregon, USGS streamgage 11504115								
11-26-13	1240	Primary	0.09	0.074	<0.006	0.019	0.07	SRWQL
01-29-14	1450	Primary	0.13	0.083	<0.006	0.025	0.19	SRWQL
01-30-14	1110	Primary	0.15	0.096	E0.006	0.025	0.31	SRWQL
02-15-14	1315	Primary	0.16	0.090	E0.007	0.032	0.55	SRWQL
05-14-14	1300	Primary	0.12	0.099	<0.006	E0.011	0.18	SRWQL
06-10-14	1210	Primary	0.11	0.092	<0.006	E0.008	0.12	SRWQL
06-11-14	1120	Primary	0.11	0.087	<0.006	E0.010	0.09	SRWQL
09-25-14	1140	Primary	0.12	0.092	<0.006	0.017	<0.03	SRWQL
10-24-14	1015	Primary	0.11	0.085	E0.010	0.027	0.17	SRWQL
12-22-14	1100	Primary	0.17	0.109	E0.090	0.027	0.47	SRWQL
12-23-14	1045	Primary	0.18	0.089	E0.090	0.019	0.36	SRWQL
02-04-15	1015	Primary	0.11	0.075	E0.007	E0.015	0.32	SRWQL
02-18-15	1040	Primary	0.11	0.095	0.006	0.018	0.14	SRWQL
03-13-15	1008	Primary	0.12	0.098	0.006	0.009	0.17	SRWQL

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