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Sediment Concentrations and Loads Upstream from and through John Redmond Reservoir, East-Central Kansas, 2010–19

Scientific Investigations Report 2021–5037

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

Cover. Photograph showing stabilized versus unstabilized reach of Cottonwood River upstream from the confluence of the Cottonwood and Neosho Rivers, taken by Tony Layzell (Kansas Geological Survey).

Back cover. Top, photograph showing flooded Neosho River near Hartford, Kansas, taken on May 22, 2019, by Ariele Kramer (U.S. Geological Survey [USGS] hydrologist).

Left, photograph showing streambank erosion between rock vanes along the Cottonwood River, taken in October 2019 by Tony Layzell (Kansas Geological Survey).

Right, photograph showing flooded Neosho River downstream from the continuous water-quality monitor installation, taken at the Neosho River at Neosho Rapids, Kansas (USGS site 07182390), on April 27, 2016, by USGS personnel.

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Conversion Factors

U.S. customary units to International System of Units

Multiply	By	To obtain
	Length	
inch (in.)	2.54	centimeter (cm)
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Area	
square mile (mi^2)	259.0	hectare (ha)
square mile (mi^2)	2.590	square kilometer (km^2)
	Volume	
cubic yard (yd^3)	0.7646	cubic meter (m^3)
acre-foot (acre-ft)	1,233	cubic meter (m^3)
acre-foot (acre-ft)	0.001233	cubic hectometer (hm^3)
	Flow rate	
ton per day (ton/d)	0.01157	kilogram per second (kg/s)
pound per year (lb/yr)	0.000124	kilogram per year (kg/yr)
acre-foot per year (acre-ft/yr)	1,233	cubic meter per year (m^3/yr)
acre-foot per year (acre-ft/yr)	0.001233	cubic hectometer per year (hm^3/yr)
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
	Mass	
pound, avoirdupois (lb)	0.4536	kilogram (kg)
ton, short (2,000 lb)	0.9072	metric ton (t)

Multiply	By	To obtain
	Pressure	
pound per square mile (lb/mi^2)	1.75133×10^{-7}	kilogram per square meter (kg/m^2)
	Density	
pound per cubic foot (lb/ft^3)	16.02	kilogram per cubic meter (kg/m^3)
pound per cubic foot (lb/ft^3)	0.01602	gram per cubic centimeter (g/cm^3)

International System of Units to U.S. customary units

Multiply	By	To obtain
	Length	
millimeter (mm)	0.03937	inch (in.)

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

$$°F = (1.8 \times °C) + 32.$$

Datum

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

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.

Supplemental Information

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

Concentrations of chemical constituents in water are given in milligrams per liter (mg/L).

Abbreviations

AEP	annual-exceedance probability
EPA	U.S. Environmental Protection Agency
FNU	formazin nephelometric units
GHCN	Global Historical Climatology Network
MSPE	model standard percentage error
n	number of samples
NWS	National Weather Service
R^2	coefficient of determination
RPD	relative percentage difference
SSC	suspended-sediment concentration
USGS	U.S. Geological Survey
±	plus or minus

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By Ariele R. Kramer, Cara L. Peterman-Phipps, Matthew D. Mahoney, and Bradley S. Lukasz

Abstract

Streambank erosion and reservoir sedimentation are primary concerns of resource managers in Kansas and throughout many regions of the United States and negatively affect flood control, water supply, and recreation. The Cottonwood and upper Neosho Rivers drain into John Redmond Reservoir, and since reservoir completion in 1964, there has been substantial conservation-pool sedimentation and storage loss in John Redmond Reservoir, causing storage capacity losses more rapidly than most other Federal reservoirs in Kansas. The U.S. Geological Survey (USGS), in cooperation with the Kansas Water Office, has monitored water quality (temperature, specific conductance, and turbidity) on the Cottonwood River (upstream from the reservoir) and Neosho River (upstream and downstream from the reservoir) since 2007 with additional sites added in 2009. The purpose of this report is to quantify suspended-sediment concentrations, loads, and yields entering and exiting John Redmond Reservoir during January 1, 2010, through December 31, 2019.

Three water-quality monitoring sites were upstream from the reservoir (Cottonwood River near Plymouth, Kansas [USGS site 07182250; hereinafter referred to as "Cottonwood"]; Neosho River at Burlingame Road near Emporia, Kans. [USGS site 07179750; hereinafter referred to as "Burlingame"]; and Neosho River at Neosho Rapids, Kans. [USGS site 07182390; hereinafter referred to as "Neosho Rapids"]), and one water-quality monitoring site was downstream from the reservoir (Neosho River at Burlington, Kans. [USGS site 07182510; hereinafter referred to as "Burlington"]). The Neosho Rapids streamgage is downstream from the confluence of the Cottonwood and upper Neosho Rivers and has a contributing drainage area accounting for 91 percent of the total contributing drainage area to John Redmond Reservoir.

Continuously measured streamflow, water quality, and discrete water-quality data were used to develop updated regression models to compute suspended-sediment concentrations, loads, and yields upstream and downstream from John Redmond Reservoir in east-central Kansas. Several turbidity sensors were deployed during the analysis period, and there are no established relations between the sensors; therefore, individual models for each sensor were developed. Model statistics for the turbidity and suspended-sediment concentration linear regression models were better (based on the coefficient of determination, root mean square error, and model standard percentage error) than the streamflow and suspended-sediment concentration linear regression models, indicating better model performance. Computed concentrations, loads, and yields do not account for the ungaged 9 percent of the drainage basin downstream from the Neosho Rapids streamgage.

Mean daily suspended-sediment loads upstream from the reservoir were largest at Neosho Rapids (2,250 tons), second largest at Cottonwood (2,180 tons), and smallest at Burlingame (624 tons). Streamflow at Burlington was predominately regulated by reservoir releases, and mean daily suspended-sediment loads were smaller (286 tons) than at upstream sites. Among the upstream sites, Cottonwood had the largest mean daily suspended-sediment concentration (179 milligrams per liter [mg/L]), followed by Neosho Rapids (162 mg/L), and Burlingame (108 mg/L). Burlington had the smallest mean daily suspended-sediment concentration of all sites (46 mg/L).

Annual reservoir trapping efficiency ranged from 82 to 94 percent, and the largest sediment mass trapped was during 2019 (2,230,000 tons). Reservoir storage decreased an estimated 7,750 acre-feet during 2010 and 2014–19. Using the mean trapping efficiency to estimate suspended-sediment loads during years with missing data (2011–13), the total estimated reservoir storage lost to sedimentation for the analysis period (2010–19) was 8,690 acre-feet, about 17 percent of the remaining storage space reported in 2007. The mean annual sedimentation rate during the analysis period (747 acre-feet per year) was about 85 percent larger than the design sedimentation rate (404 acre-feet per year) originally projected during construction. Different reservoir outflow management strategies, including operating near normal capacity as opposed to higher flood pool levels, could reduce the total reservoir storage lost by 3 percent (about 261 acre-feet), which is equal to 14 percent of the total sediment removed during the dredging operation in 2016.

During the study period, about 56 percent of the total suspended-sediment load was transported during streamflows greater than the National Weather Service flood action stage at the upstream sites (0.1–5 percent of the record; Cottonwood mean: 48 percent; Burlingame mean: 40 percent; Neosho Rapids mean: 78 percent). Disproportionately large sediment loads were delivered during short periods of time, and localized efforts of stream erosion protection (streambank stabilization, riparian buffers) were likely to be overwhelmed. Precipitation frequency and intensity are projected to continue to increase in this region; therefore, future sediment reduction strategies that account for extreme episodic events may be beneficial. Changes to reservoir outflow management could also minimize sediment accumulation while still preserving flood control. Continued investigation of sediment reduction measures is necessary for future mitigation with the understanding that sedimentation rate is largely driven by high flows. Results from this study can be used to calibrate sediment models, explore sediment reduction strategies, highlight the importance of continued water-quality monitoring to determine effectiveness and changes in sediment transport, and assess the ability of John Redmond Reservoir to support designated uses into the future.

Introduction

John Redmond Reservoir, in east-central Kansas, has a primarily agricultural drainage basin of about 3,015 square miles (mi^2) that includes the Cottonwood and upper Neosho Rivers (fig. 1). The reservoir was constructed during 1959 through 1964 for flood control, water supply, and recreation (U.S. Army Corps of Engineers, 2013). Surface water is the primary source of water in the Neosho regional planning area, which includes the Cottonwood and Neosho River Basins and accounts for 86 percent of the total reported water use (54-percent industrial, 33-percent municipal, and 13-percent agriculture and recreation; Kansas Water Office, 2018). Water management plans and systems are an integral part of Kansas water supplies where fresh surface water is predominately stored in reservoirs.

John Redmond Reservoir has a total storage capacity of 816,795 acre-feet (acre-ft) at maximum pool level; about 505,855 acre-ft are available for storage of floodwater (U.S. Army Corps of Engineers, 2016). John Redmond Dam is on the Neosho River 2 miles (mi) northwest of Burlington, Kansas. The dam is equipped with 14 40- by 35-foot- (ft) high Tainter gates with a spillway capacity at the maximum pool of 428,000 cubic feet per second (ft^3/s) at the top of the flood-control pool. There are two low-flow pipes with a discharge capacity of 130 ft^3/s at the spillway crest. Bankfull capacity of the channel below the dam site is 15,000 ft^3/s (U.S. Army Corps of Engineers, 2016).

John Redmond Reservoir is losing storage capacity more rapidly than most other Federal reservoirs in Kansas (Jakubauskas and others, 2014; Rahmani and others, 2018; Kansas Water Office, 2019). John Redmond Reservoir was designed using an estimated sedimentation rate of 404 acre-feet per year (acre-ft/yr; U.S. Army Corps of Engineers, 2016). Previously estimated reservoir sedimentation rates exceeded the designed sedimentation rate; U.S. Army Corps of Engineers (2016) estimated a sedimentation rate of 736 acre-ft/yr for 1964–2010, Jakubauskas and others (2014) estimated a sedimentation rate of 492 acre-ft/yr for 2007–14, and Lee and others (2008) estimated a sedimentation rate of 874 acre-ft/yr for 2007–8. Excess sedimentation has reduced water availability in the conservation pool by an estimated 42 percent (Kansas Water Office, 2019). A previous study estimated a reduction in water availability in the conservation pool of 41 percent through 2009 with a mean annual loss of 1 percent (Juracek, 2010). By comparison, the reported loss in 2019 indicates a much smaller storage depletion over the last 10 years; however, storage reallocation was approved in 2013, raising the conservation pool 2 ft, and the dredging operation concluded in 2016, both restoring water supply lost to sedimentation (about 17,200 acre-ft and 1,860 acre-ft, respectively; U.S. Army Corps of Engineers, 2013; Kansas Water Office, 2017). Water-storage loss affects socioeconomic and cultural resources and allocated water rights for various entities.

Reservoir sedimentation reduces storage capacity and can have lasting effects on flood control, public water supply, habitat for fish and wildlife, and recreation. Sediment and reservoir siltation are environmental concerns because they degrade habitat and water quality (Owens and others, 2005), contribute to declines in aquatic organism populations (Waters, 1995; Henley and others, 2000), and create lower light conditions in the water column, inhibiting growth of some phytoplankton and aquatic macrophytes (Wetzel, 2001; Donohue and Molinos, 2009). The transport of fine-grained sediments through the reservoir system is associated with the transport of adsorbed nutrients, metals, and several other contaminants (Owens and others, 2005; Luoma and Rainbow, 2008).

The U.S. Geological Survey (USGS), in cooperation with the Kansas Water Office, has monitored water quality on the Cottonwood River (upstream from the reservoir) and the Neosho River (upstream and downstream from the reservoir) since 2007 with additional sites added in 2009 (USGS sites 07182250, 07179750, 07182390, and 07182510; fig. 1, table 1). Streamflow at the Cottonwood River near Plymouth, Kans. (USGS site 07182250; hereinafter referred to as “Cottonwood”) and Neosho River at Burlington, Kans. (USGS site 07182510; hereinafter referred to as “Burlington”) has been continuously measured since 1963 and 1961, respectively (U.S. Geological Survey, 2020). Streamflow at the Neosho River at Burlingame Road near Emporia, Kans. (USGS site 07179750; hereinafter referred to as “Burlingame”) and the Neosho River at Neosho Rapids, Kans. (USGS site 07182390; hereinafter referred to as “Neosho Rapids”)

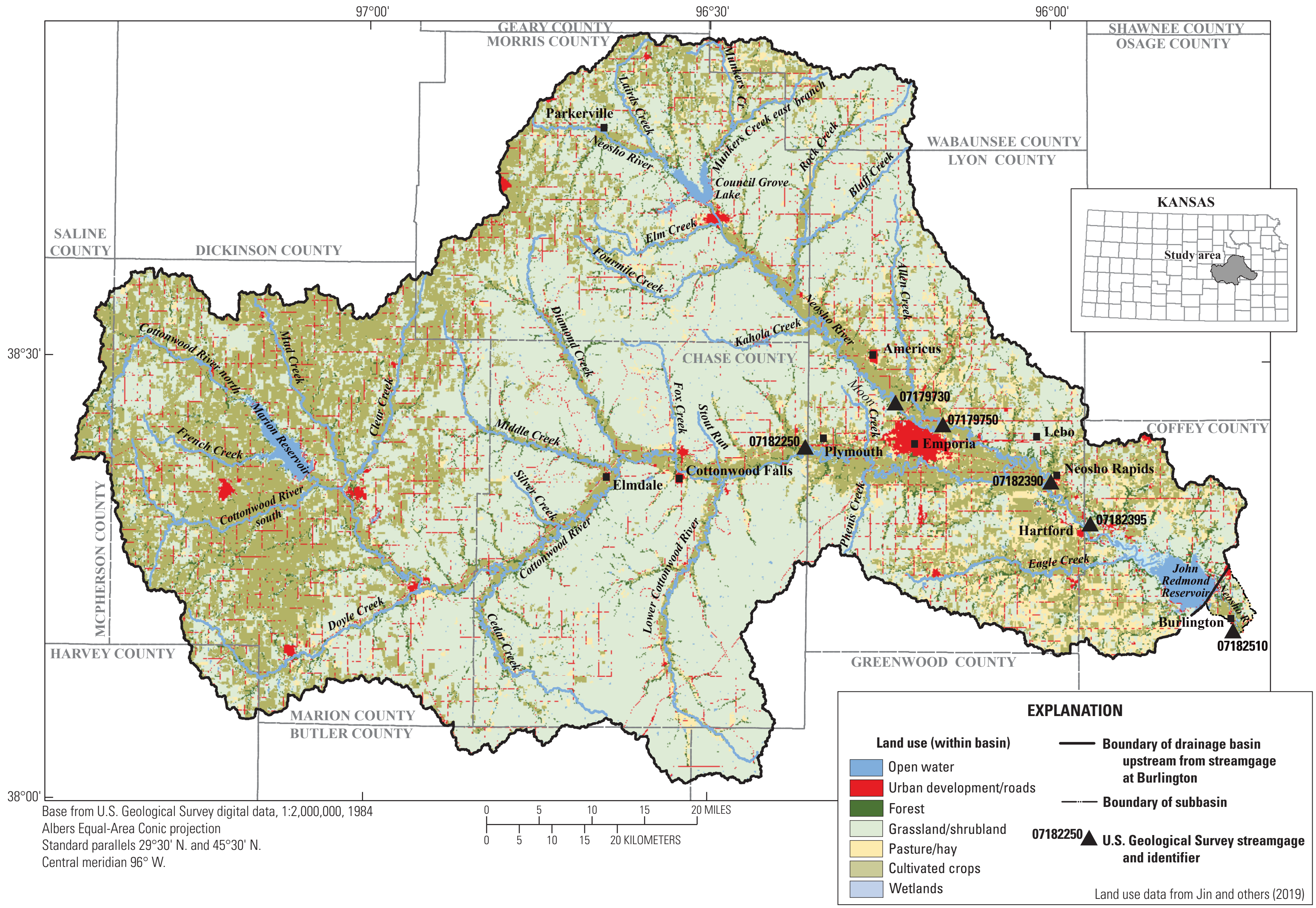

Figure 1. Location of continuous streamflow and real-time water-quality monitoring sites and land use in the John Redmond Reservoir drainage basin, Kansas.

Table 1. Periods of deployment of YSI 6600 and YSI EXO water-quality monitors at continuous water-quality monitoring sites used in this study.

[Blue shading with bold text indicates period of YSI Incorporated 6600 Extended Deployment System water-quality monitor (YSI 6600) deployment. Green shading with italic text indicates period of Xylem YSI EXO, model EXO2, continuous water-quality monitor (YSI EXO) deployment. Dates shown as month/day/year. USGS, U.S. Geological Survey]

Site (USGS site identifier)	[1]2007	[1]2008	[1]2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Cottonwood River near Plymouth, Kansas (07182250)	**10/1/2007–5/18/2009**			No data					*4/22/2015–12/31/2019*				
Neosho River at Burlingame Road near Emporia, Kansas (07179750)	No data		**8/1/2009–12/16/2012**				No data		*5/2/2015–12/31/2019*				
Neosho River at Neosho Rapids, Kansas (07182390)	No data		**8/11/2009–11/11/2015**						*11/13/2015–12/31/2019*				
Neosho River at Burlington, Kansas (07182510)	**10/1/2007–4/11/2011**				No data		**4/3/2013–10/21/2015**		*10/23/2015–9/30/2019*				No data

[1]Data during these years were used for model development but were not used for load and concentration computations in this report.

has been measured since 2009 (U.S. Geological Survey, 2020). Water-quality monitoring at these four sites provided 15-minute measures of water temperature, specific conductance, and turbidity. Discrete water-quality samples have been collected at these sites and used to develop and update regression models establishing relations between continuously monitored water-quality physical properties (turbidity) and water-quality constituents of interest that are not easily monitored (for example, suspended-sediment concentration [SSC]). These models are useful for evaluating concentrations of water-quality constituents to compare with water-quality criteria and for computing loads and yields to assess yields and fluxes.

The Kansas Water Office has identified more than 350 streambank erosion sites along the Cottonwood and Neosho Rivers above the reservoir, and nearly 12 percent of those sites have been stabilized since 2010 by rock structures, bank grading, riprap, and vegetation (Kansas Water Office, 2020). The rock structures were designed to be about 2 ft above the base-flow elevation and extend up and flush with the graded back to thwart the river from flanking the stabilization structures (Watershed Institute, Inc., written commun., 2020). The structures are intended to slow streambank erosion to allow streambank vegetation per plantings and natural regeneration.

Purpose and Scope

The purpose of this report is to quantify suspended-sediment concentrations and loads entering and exiting John Redmond Reservoir in east-central Kansas during January 1, 2010, through December 31, 2019. Study objectives were met by measuring continuous streamflow and water-quality properties (specifically turbidity) and collecting discrete suspended-sediment samples at three sites upstream from the reservoir and one downstream. Collection of concomitant continuous and discrete data allowed for development of regression models to compute continuous SSC in real time. Suspended-sediment concentrations and loads were computed at multiple locations for the analysis period and used to estimate reservoir trapping efficiency. Results from this study can be used to calibrate sediment models, explore sediment reduction strategies, highlight the importance of continued water-quality monitoring to determine effectiveness and changes in sediment transport, and assess the ability of John Redmond Reservoir to support designated uses into the future. Methods used in this study contribute to an understanding of sediment sources and quantification of reservoir sediment input, throughput, and trapping efficiency that could be applied to other reservoirs regionally, nationally, and globally.

Description of John Redmond Reservoir Drainage Basin

John Redmond Reservoir drainage basin, in the Osage Plains section of the Central Lowland Province (Schoewe, 1949), covers an area of about 3,015 mi^2 and drains a part of east-central Kansas. The drainage basin's bedrock is composed of northwesterly dipping strata of alternating limestones and shales of the Upper Pennsylvanian and lower Permian subsystems that overlap one another, tilting toward the west in a stairstep fashion to create cuestas (Buchanan, 1984). One-third of the drainage basin is within the Osage Cuesta physiographic region that is characterized as alternating hard and soft strata with tilted beds that overlap toward the west. The remaining two-thirds are mostly within the Flint Hills, which has a similar westward dipping strata as the Osage Cuesta and, as a result of weathering, sits higher than areas directly east and west (Schoewe, 1949). The Flint Hills Upland topography is characterized as gently rolling.

The Cottonwood River, the major tributary to the Neosho River, drains about 1,900 mi^2 and has a river slope of about 3.5 feet per mile (ft/mi) at its headwaters, declining to 1.5 ft/mi near Emporia (Jordan and Hart, 1985; Lee and others, 2008). The Neosho River, excluding the Cottonwood River tributary, drains about 1,110 mi^2 upstream from the reservoir with slopes ranging from 3 ft/mi near Council Grove to 1.5 ft/mi near Emporia (fig. 1; Carswell and Hart, 1985). The Neosho River and major tributaries flow through Quaternary alluvium with soils mostly classified as silty-clay loam (20–70-percent clay, 40 percent or more of silt, and 20 percent or less of sand) or silty clay (40 percent or more of clay, 40 percent or more of silt, and 20 percent or less of sand; U.S. Department of Agriculture, 2019). Erodibility of these soil classes generally is similar (Brady and Weil, 1999).

The Burlingame and Cottonwood streamgages are upstream from the confluence of the Cottonwood and Neosho Rivers. These streamgages are downstream from 2,497 mi^2 of the approximate 3,015 mi^2 that drain into the reservoir (table 2; U.S. Army Corps of Engineers, 2002). Council Grove Lake (drainage area of 246 mi^2) and Marion Lake (drainage area of 200 mi^2) regulate streamflow in the basin draining into John Redmond Reservoir. Council Grove Lake impounds 32 percent of the drainage basin upstream from the Burlingame streamgage, and Marion Lake impounds 11 percent of the drainage basin upstream from the Plymouth streamgage. The Neosho Rapids streamgage is downstream from the confluence of the Cottonwood and upper Neosho Rivers and has a contributing drainage area of 2,753 mi^2, about 91 percent of the total contributing drainage area to John Redmond Reservoir.

The Clean Water Act, section 303(d) authorizes the U.S. Environmental Protection Agency (EPA) to assist States in developing a list of impaired waters that are too degraded or polluted to meet State water-quality standards or exceed total maximum daily load regulations (U.S. Environmental Protection Agency, 33 U.S.C §1251 et seq., 1972). The

Table 2. Continuous water-quality monitoring sites in the John Redmond Reservoir drainage basin, Kansas.

[Site information and data available on the National Water Information System website (https://doi.org/10.5066/F7P55KJN; U.S. Geological Survey, 2020); USGS, U.S. Geological Survey; mi^2, square mile; °, degree; ′, minute; ″, second; N, north; W, west]

USGS site identifier	Site name	Total drainage area (mi^2)	Unregulated drainage area (mi^2)	Nearest upstream reservoir and corresponding regulated drainage area (mi^2)	Latitude	Longitude
07182250	Cottonwood River near Plymouth, Kansas	1,740	1,540	Marion Lake (200)	38°23′51″N	96°21′21″W
07179750	Neosho River at Burlingame Road near Emporia, Kansas	757	511	Council Grove Lake (246)	38°25′43″N	96°09′29″W
07182390	Neosho River at Neosho Rapids, Kansas	2,753	2,307	Marion Lake and Council Grove Lake (446)	38°22′05″N	96°00′00″W
07182510	Neosho River at Burlington, Kansas	3,042	27	John Redmond Reservoir (3,015)	38°11′40″N	95°44′40″W

Cottonwood River near the cities of Elmdale, Emporia, and Plymouth, Kans., has impaired uses for aquatic life and water supply because of total suspended solids, atrazine, sulfate, and total phosphorus (Kansas Department of Health and Environment, 2018a). The Neosho River near the cities of Americus, Neosho Rapids, and Parkerville, Kans., has impaired uses for recreation and aquatic life because of *Escherichia coli* (*E. coli*) bacteria, fecal coliform bacteria, copper, and total phosphorus (Kansas Department of Health and Environment, 2018a). John Redmond Reservoir has listed impairments for aquatic life and water supply because of eutrophication, dissolved oxygen, and siltation.

The EPA provides nonenforceable guidelines for States to assist water resource and human health protection. The Cottonwood and Neosho Rivers, upstream from the reservoir, are within level III ecoregion IV subregion 28 (Flint Hills) and ecoregion IX subregion 40b (Osage Cuestas) (U.S. Environmental Protection Agency, 2000, 2001). EPA turbidity reference conditions are 19.5 formazin nephelometric units (FNU) in ecoregion 28 and 15.5 FNU in ecoregion 40b (U.S. Environmental Protection Agency, 2000, 2001).

Land use in the study area is mostly grassland (56 percent) and agriculture, and agricultural lands are devoted to row-crop farming (26 percent) and areas reserved for pasture/hay (6 percent; fig. 1; Jin and others, 2019). During 2001 through 2016, urban development increased 2 percent and cultivated cropland increased 3 percent, whereas forest (−1 percent), grassland (−1 percent), pasture (−2 percent), and wetlands (−4 percent) land cover all decreased in the study area (Homer and others, 2004; Jin and others, 2019). Although erosion is a natural process through the actions of rain, wind, and the freezing and thawing of soil, excess erosion can result from anthropogenic activities. The effects of crop cultivation on streams include a loss of riparian vegetation and an associated increase in bank erosion that can degrade streams and reduce downstream reservoir storage capacity (Fox and others, 2016; Rahmani and others, 2018).

Daily precipitation during the analysis period was available from multiple Global Historical Climatology Network (GHCN) stations in the drainage basin including Cottonwood Falls, Kans. (GHCND:USC0141858); Emporia Automated Surface Observing Systems in Emporia, Kans. (GHCND:USW00013989); and Lebo, Kans. (GHCND:USC0144608; Menne and others, 2012b) (fig. 1). Precipitation totals can vary spatially; therefore, to better summarize precipitation in the basin, annual precipitation totals from the three GHCN stations were averaged. The mean annual precipitation during 2010 through 2019 was 35.4 inches (in.). Annual mean precipitation during the analysis period ranged from 22.4 to 49.6 in. in 2012 and 2019, respectively (table 3).

Extreme precipitation can be defined as the top 1 percent of precipitating days (Agel and others, 2018, 2019). To determine the top 1 percent of daily precipitation observations, the 100-year period from 1919 through 2019 was used for the Cottonwood Falls and Lebo GHCN stations. The top 1 percent of daily precipitation would be any 24-hour period with precipitation totals greater than or equal to 1.68 in. (hereinafter, “extreme precipitation”). During the analysis period, the annual number of days with extreme precipitation ranged from 1 to 7 at the three GHCN stations. The mean was from 2 to 6 days per year of extreme precipitation ranging from 3.9 to 14.9 in. of rain accumulated during those extreme precipitation days (table 3, fig. 2). The percentage of annual precipitation that accumulated during these extreme events ranged from 14 to 36 percent (mean: 24 percent) of the total annual precipitation. A substantial part of the total annual precipitation occurred during these extreme precipitation events over a disproportionately small amount of time when increased runoff and sediment erosion are more likely (fig. 2).

In Kansas, reservoir capacity loss because of sedimentation is dependent on three factors: reservoir age, reservoir volume, and sedimentation rate (deNoyelles and Kastens, 2016). Streambank stabilization has been used as one of the primary ameliorative strategies in an attempt to reduce reservoir sedimentation. Two of the main processes that affect incised-bank streams in this study area are hydraulic erosion by streamflow and gravitational (mass wasting) processes (Simon and others, 2000). Two ways to protect streambanks from these types of erosion are reducing the force of water against the channel bank with various rock structures and (or) planting riparian vegetation to increase resistance to address hydraulic erosion and grading the streambanks to protect against mass wasting (U.S. Army Corps of Engineers, 2002).

Streambank stabilization projects can become costly if all fluvial variables are not considered and can lead to improper implementation that can result in unnecessary loss of streambank and additional costs. The use of process-based models has been determined to be an important tool when evaluating potential streambank stabilization practices (Enlow and others, 2018). When all stream variables were considered in a process-based model and stabilization methods were implemented correctly, some areas (those where riparian vegetation is present in comparison to areas where streambanks are left unprotected) have indicated a decrease in streambank erosion by about three times (Purvis and Fox, 2016). Many factors contribute to the effectiveness of stabilization projects such as riverbank size, scour, streambank material, rate of change in streamflow, remediation type, and degree of vegetation establishment during an erosion event.

The streambank rock structures constructed along the Cottonwood and Neosho Rivers are designed to increase erosion resistance to the streambank toe by slowing water velocities in the near bank region (Watershed Institute, Inc., written commun., 2020). There are, however, no defined streamflow criteria that these structures are built to withstand, and suspended sediment transported during high flows is minimally affected by the rock structures and streambank vegetation (Watershed Institute, Inc., written commun., 2020). Another common ameliorative strategy in this drainage basin is bank grading to address mass wasting of banks. Streambank stabilization project efficiencies for reducing streambank

Table 3. Annual precipitation totals, extreme event precipitation totals, and counts of extreme precipitation days for Cottonwood Falls, Kansas; Emporia Automated Surface Observing Systems, Kans.; and Lebo, Kans., Global Historical Climatology Network stations (GHCND:USC00141858, GHCND:USW00013989, and GHCND:USC00144608).

[Menne and others, 2012a; National Oceanic and Atmospheric Administration, 2018; in., inch]

Year	Annual precipitation total (in.)	Extreme event precipitation total[1] (in.)	Count of extreme days
Cottonwood Falls, Kansas			
2010	45.2	14.3	6
2011	27.4	7.9	4
2012	22.9	1.7	1
2013	41.6	7.1	2
2014	29.4	8.4	4
2015	37.3	11.3	5
2016	41.7	13.8	5
2017	33.7	7.7	4
2018	37.0	4.1	2
2019	51.6	16.2	7
Emporia Automated Surface Observing Systems, Kansas			
2010	35.7	12.0	6
2011	26.9	2.1	1
2012	21.3	3.7	2
2013	33.4	4.0	2
2014	28.1	7.9	4
2015	35.1	8.9	4
2016	38.8	12.9	6
2017	33.2	3.1	1
2018	37.6	8.2	4
2019	43.3	10.9	5
Lebo, Kansas			
2010	39.8	17.4	7
2011	30.8	3.6	2
2012	22.9	6.5	3
2013	33.8	4.6	2
2014	30.2	7.5	3
2015	40.5	13.6	5
2016	40.6	12.2	5
2017	34.1	7.0	3
2018	33.4	3.7	2
2019	53.9	17.6	6
Basin mean[2]			
2010	40.2	14.5	6
2011	28.4	4.6	2
2012	22.4	3.9	2
2013	36.3	5.2	2
2014	29.2	8.0	4
2015	37.6	11.2	5
2016	40.4	13.0	5

Table 3. Annual precipitation totals, extreme event precipitation totals, and counts of extreme precipitation days for Cottonwood Falls, Kansas; Emporia Automated Surface Observing Systems, Kans.; and Lebo, Kans., Global Historical Climatology Network stations (GHCND:USC00141858, GHCND:USW00013989, and GHCND:USC00144608).—Continued

[Menne and others, 2012a; National Oceanic and Atmospheric Administration, 2018; in., inch]

Year	Annual precipitation total (in.)	Extreme event precipitation total[1] (in.)	Count of extreme days
Basin mean[2]—Continued			
2017	33.6	5.9	3
2018	36.0	5.3	3
2019	49.6	14.9	6

[1]Extreme event is defined as a precipitation event that exceeds the 99th percentile during the period of analysis over a 24-hour period (greater than or equal to 1.68 in.).

[2]Defined as the mean of the provided three stations.

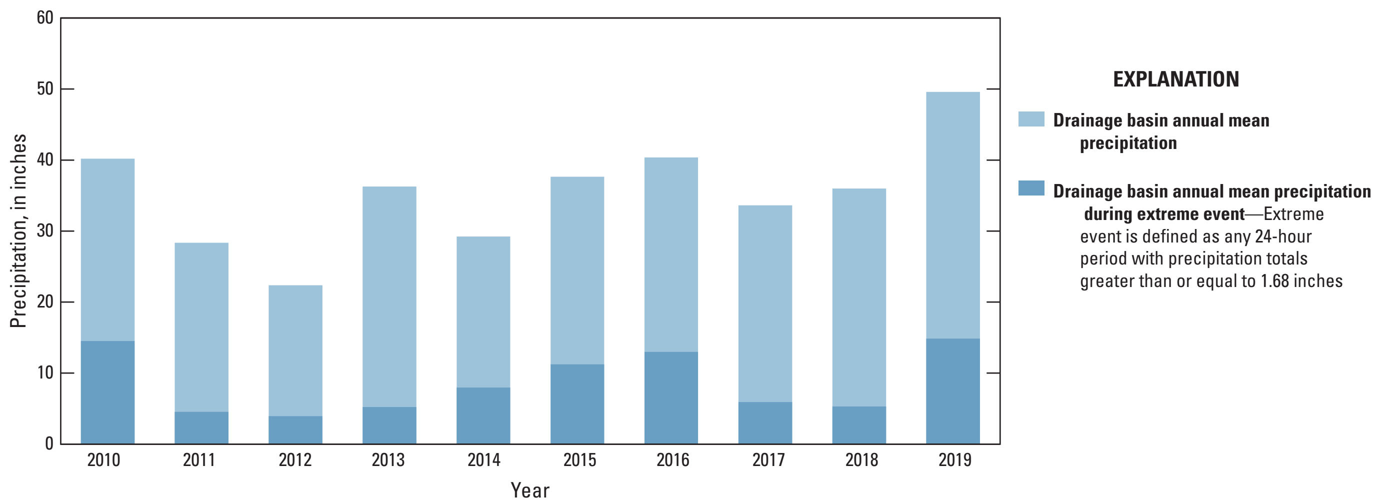

Figure 2. Annual mean precipitation and extreme event precipitation totals for the John Redmond Reservoir drainage basin, Kansas, 2010 through 2019.

erosion are difficult to quantify without accurate and representative data. An assessment using historical aerial imagery compared to postconstruction digital elevation models derived from unmanned aircraft systems flight survey data indicated erosion reduction locally at the stabilized site; however, results varied substantially between different sites (Layzell and Peterson, 2020). This study highlighted the importance of pre- and postconstruction data collection to accurately quantify the effectiveness of these projects.

Previous Investigations

Since at least the early 1960s, there has been concern regarding sediment transport and deposition from source to sink in the upper Neosho and Cottonwood River Basins. Collins (1965) estimated sediment yields and streamflow for Kansas streams. Carswell and Hart (1985) determined the magnitude of streamflow losses and gains during drought conditions in two reaches of the Neosho River. Juracek (2001) analyzed channel stability downstream from John Redmond Reservoir by assessing the pre- and postdam stability of the Neosho River channel. Lee and others (2008) characterized the suspended-sediment load to and from John Redmond Reservoir. Juracek (2010) estimated sedimentation and temporal trends in selected chemical constituents and upstream channel stability for John Redmond Reservoir. Additional studies provided precedent for approaches used in this study (Christensen and others, 2000; Putnam and Pope, 2003; Rasmussen and others, 2005; Lee and others, 2008; Foster and others, 2012; Foster, 2014, 2016). Key findings from studies in the Neosho and Cottonwood River Basins include

1. Statewide estimates of mean annual sediment yields calculated for large areas across the State indicated that soil erodibility increased from west to east. In the southwestern and south-central parts of the State, the mean annual sediment yield was less than 50 tons, whereas in the northeastern part, it was greater than 5,000 tons (Collins, 1965).

2. Using information from Council Grove Lake and John Redmond Reservoir on the duration of reservoir releases, a streamflow-routing model was developed to estimate water-wave travel times and simulate streamflow transit losses or gains while under drought conditions. Results indicated that severe drought conditions in conjunction with small reservoir-release rates over a long duration had greater total transit losses, larger channel bank storage loss, and larger losses to evapotranspiration. Shorter reservoir-release durations and larger reservoir-release rates resulted in smaller streamflow transit losses overall (Carswell and Hart, 1985).

3. Geomorphic responses were studied for river channels with streamgages 5 mi or less downstream from 24 Federal reservoirs in Kansas. There was a negative trend in channel bed elevation at 15 of 17 streamgages (for which data for the first streamgage downstream from the dam were available), including Marion Reservoir and Council Grove Lake, which was likely related to the composition of the channel bed. Downstream from John Redmond Reservoir at the Burlington site, no trend was indicated. The elevation changes observed in this study are indicative of the spatial and temporal variability associated with streams and rivers that are downstream from reservoirs (Juracek, 2001).

4. Continuous water-quality monitoring using optical turbidity sensors (YSI Incorporated 6600 Extended Deployment System water-quality monitor [hereinafter referred to as "YSI 6600"] model 6136 and optical-backscatter Hach SOLITAX SC) and ordinary-least-squares regression equations were used to characterize suspended-sediment loads (in tons) to and from John Redmond Reservoir during February 21, 2007, through February 21, 2008, at three streamgages; two upstream at the Neosho River near Americus (USGS site 07179730) and the Cottonwood site and one downstream at the Burlington site. Streamflow-derived estimates (models developed using historical discrete data) were 7 to 21 times that of turbidity-derived estimates during 2007–8 at the Burlington site. This is either the result of less sediment being eroded and transported between the reservoir and the streamgage or increased sediment trapping efficiency in the reservoir (Lee and others, 2008).

5. An investigation of sedimentation and deposition of selected chemical constituents in John Redmond Reservoir indicated that the total volume of deposited sediment occupied an estimated 41 percent of the conservation pool during 1964 through 2007 and extrapolated to 2009. This reduced the water-storage capacity of the reservoir at an annual rate of about 1 percent with a mean annual sediment deposition of about 1.24 billion pounds per year (lb/yr). Channel banks were more likely to be a source of sediment to the reservoir than channel beds. Total phosphorus was determined to be variable over time. Arsenic, chromium, and nickel concentrations detected in the bottom sediments exceeded threshold-effects guidelines for possible adverse biological effects. Overall trace element concentrations generally were uniform over time in reservoir bottom sediments (Juracek, 2010).

6. Continuous water-quality and streamflow data were coupled with a two-dimensional hydrodynamic model (CE–QUAL–W2) to assess the potential for sediment trapping reduction in John Redmond Reservoir by altering reservoir outflow management. During 2007 through 2010, an estimated 88 percent of sediment transported to John Redmond Reservoir was trapped within the reservoir. The two-dimensional model indicated smaller trapping efficiencies when mean residence times were relatively short and the reservoir was maintained near the normal operating capacity as opposed to higher flood pool levels. The idealized alternative outflow management scenario was projected to reduce sediment trapping in the reservoir by about 3 percent (Lee and Foster, 2013).

7. Linear regression models were previously developed for the Burlingame and Neosho Rapids sites using turbidity and SSC data collected during June 2009 through December 2012 (Foster, 2014). These linear models were used to describe sediment loads during large storm events during May through July 2015. During this period, about 872,000 tons of sediment entered the reservoir although only 57,000 tons of sediment were released, indicating a mean trapping efficiency of 93 percent (Foster, 2016). The computed sediment load reduced reservoir storage in the conservation pool by about 1.6 percent, indicating large infrequent inflows, coupled with minimal releases, can have substantial effects on reservoir storage and lifespan (Foster, 2016).

Methods

Continuous and discrete water-quality data were collected over a range of streamflow conditions. These data were used to update existing and develop new linear regression models, compute constituent loads and yields, and identify and examine trends during 2010 through 2019.

Continuous Water-Quality Monitoring

Continuous (15-minute interval) water-quality and streamflow data were collected at Cottonwood (USGS site 07182250), Burlingame (USGS site 07179750), Neosho Rapids (USGS site 07182390), and Burlington (USGS site 07182510; fig. 1). Streamflow has been measured since 2009 at Burlingame and Neosho Rapids, since 1963 at Cottonwood, and since 1961 at Burlington using standard USGS methods (Sauer and Turnipseed, 2010; Turnipseed and Sauer, 2010; Painter and Loving, 2015). Historical and real-time continuous and discrete water-quality data are available through the USGS National Water Information System database at https://doi.org/10.5066/F7P55KJN (U.S. Geological Survey, 2020).

All study sites were originally equipped with a YSI 6600 monitor that measured water temperature, specific conductance, and turbidity (optical model 6136) (YSI Incorporated, 2012a). The YSI 6600 monitor at Cottonwood was deployed during October 1, 2007, through May 18, 2009; the monitor at Burlingame was deployed during August 1, 2009, through December 16, 2012; the monitor at Neosho Rapids was deployed during August 11, 2009, through November 11, 2015; and the monitor at Burlington was deployed during October 1, 2007, through October 21, 2015 (table 1). The Cottonwood YSI 6600 water-quality monitor was discontinued during 2009 through 2015, the Burlingame monitor was temporarily removed because of extreme drought conditions during 2012 through 2015, and the Burlington monitor was temporarily removed during April 2011 through April 2013 because of extreme drought conditions. The Neosho Rapids water-quality monitor was deployed during the entire analysis period (table 1).

In 2015, the four study sites were equipped with Xylem YSI EXO (model EXO2, hereinafter referred to as “YSI EXO”) continuous water-quality monitors that measured the same variables as the YSI 6600 monitors (water temperature, specific conductance, and turbidity; table 1). The Cottonwood YSI EXO water-quality monitor was deployed on April 22, 2015; the Burlingame monitor was deployed on May 2, 2015; the Neosho Rapids monitor was deployed on November 13, 2015; and the Burlington monitor was deployed on October 23, 2015 (table 1). The Burlington water-quality monitor was discontinued on September 30, 2019, whereas the other three monitors were in operation through December 31, 2019. All monitors were installed near the deepest, fastest flowing section of the stream cross section, generally near the centroid, to best represent conditions across the width of the stream and were maintained in accordance with standard USGS procedures (Wagner and others, 2006; Bennett and others, 2014).

Measured water-quality properties were considered comparable between the YSI 6600 and YSI EXO monitor models during the study period except for turbidity. Different turbidity sensors can provide different readings because of differences in the optical properties of the individual sensors (Rasmussen and others, 2009). There are documented differences in the YSI 6600 model 6136 and YSI EXO turbidity sensors (Graham and others, 2018; Stone and others, 2019). Because of these differences, there can be a slight discontinuity in field readings measured with the different sensors, and readings can vary as much as 10 percent at the same site when transitioning; YSI EXO readings generally are lower in value (YSI Incorporated, 2012b). Sensor comparison studies in Kansas have indicated YSI EXO sensor readings to be 6–15 percent less on average than the YSI 6600 model 6136 turbidity sensor readings (Graham and others, 2018; Stone and others, 2019). Because of the differences in sensor readings, data from each sensor were analyzed independently and not combined. Turbidity sensors measure the optical properties of water, which can be affected by suspended and dissolved material such as silt, clay, finely eroded organic material, and microscopic organisms (ASTM International, 2003; Anderson, 2005). Turbidity concentrations experience variability in streams because of fluctuations in streamflow conditions (U.S. Environmental Protection Agency, 2000).

Time-series measurements occasionally were missing or deleted from the dataset because of equipment malfunction, excessive fouling caused by environmental conditions, extreme low- or no-flow conditions, or temporary removal of equipment because of ice. A summary of missing or deleted 15-minute and daily data is provided in table 4.

Suspended-Sediment Sample Collection and Analysis

Suspended-sediment samples were collected over a range of streamflow and turbidity conditions during February 2007 through December 2019 for the Cottonwood site, during February 2007 through September 2019 for the Burlington site, and during August 2009 through December 2019 for the Burlingame and Neosho Rapids sites using primarily depth- and width-integrated sample collection techniques (U.S. Geological Survey, 2006). During ice, extreme cold, or extreme low-flow conditions, samples were collected by other methods including single verticals, multiple verticals, or grab samples (U.S. Geological Survey, 2006). Samples collected using one of these alternative approaches were reviewed and compared to cross-section water-quality field readings measured during the sample and other samples collected during similar conditions to determine if the sample and approach were representative of the mean composition of the stream cross section. If a sample was determined to not be representative of the cross section, it was excluded from the dataset.

All samples were analyzed for total SSC, sand-fine split percentage, and in most cases of high turbidity (greater than or equal to 500 FNU), five-point grain size analysis by the USGS Iowa Sediment Laboratory in Iowa City, Iowa, according to methods described in Guy (1969).

Table 4. Summary statistics for variables measured or computed continuously at Cottonwood River near Plymouth, Kansas (U.S. Geological Survey [USGS] site 07182250); Neosho River at Burlingame Road near Emporia, Kans. (USGS site 07179750); Neosho River at Neosho Rapids, Kans. (USGS site 07182390); and Neosho River at Burlington, Kans. (USGS site 07182510), during 2010 through 2019.

[Continuous real-time water-quality data are available on the U.S. Geological Survey National Real-Time Water Quality website (https://nrtwq.usgs.gov/ks). Summary statistics were calculated using 15-minute continuous water-quality data summarized into daily mean values. *n*, number of measurements; ft^3/s, cubic foot per second; °C, degree Celsius; µS/cm, microsiemens per centimeter at 25 degrees Celsius; EXO, Xylem YSI EXO, model EXO2, continuous water-quality monitor; FNU, formazin nephelometric unit; <, less than; 6136, YSI Incorporated 6600 Extended Deployment System water-quality monitor model 6136]

Continuous variable	*n*	Minimum	Maximum	Mean	Median	Percent missing data
Cottonwood River near Plymouth, Kansas						
15-minute measurements						
Streamflow (ft^3/s)	337,570	14.8	34,700	785	187	3.8
Water temperature (°C)	155,286	−0.1	33	17	17	56
Specific conductance (µS/cm)	151,953	131	1,240	708	717	57
Turbidity (EXO, FNU)	150,136	<1.0	1,640	60	25	9
Daily mean measurements						
1963–2019 historical daily streamflow (ft^3/s)	20,759	8.7	73,500	861	246	1
Streamflow (ft^3/s)	3,652	15.3	31,500	781	185	0
Water temperature (°C)	1,621	0.0	32	16	17	56
Specific conductance (µS/cm)	1,565	174	1,160	708	717	57
Turbidity (EXO, FNU)	1,585	2.3	822	61	26	8
Neosho River at Burlingame Road near Emporia, Kansas						
15-minute measurements						
Streamflow (ft^3/s)	339,622	0.5	17,400	339	32	3
Water temperature (°C)	243,214	−0.1	38	16	17	31
Specific conductance (µS/cm)	236,684	111	699	433	436	33
Turbidity (6136, FNU)	86,365	<1.0	2,450	53	23	54
Turbidity (EXO, FNU)	138,735	2.3	2,300	51	20	15
Daily mean measurements						
2009–19 historical daily streamflow (ft^3/s)	3,800	0.48	15,100	335	35	0
Streamflow (ft^3/s)	3,652	0.48	15,100	339	33	0
Water temperature (°C)	2,619	−0.1	32	16	16	28
Specific conductance (µS/cm)	2,535	146	687	435	436	31
Turbidity (6136, FNU)	1,009	1.0	1,310	51	22	48
Turbidity (EXO, FNU)	1,493	2.6	838	51	20	12
Neosho River at Neosho Rapids, Kansas						
15-minute measurements						
Streamflow (ft^3/s)	96,661	12.9	34,100	1,790	303	72
Water temperature (°C)	308,737	−0.3	38	16	16	12
Specific conductance (µS/cm)	279,241	66	1,160	623	633	20
Turbidity (6136, FNU)	153,685	1.7	1,460	68	31	25
Turbidity (EXO, FNU)	121,810	1.8	1,190	77	27	16

Table 4. Summary statistics for variables measured or computed continuously at Cottonwood River near Plymouth, Kansas (U.S. Geological Survey [USGS] site 07182250); Neosho River at Burlingame Road near Emporia, Kans. (USGS site 07179750); Neosho River at Neosho Rapids, Kans. (USGS site 07182390); and Neosho River at Burlington, Kans. (USGS site 07182510), during 2010 through 2019.—Continued

[Continuous real-time water-quality data are available on the U.S. Geological Survey National Real-Time Water Quality website (https://nrtwq.usgs.gov/ks). Summary statistics were calculated using 15-minute continuous water-quality data summarized into daily mean values. *n*, number of measurements; ft^3/s, cubic foot per second; °C, degree Celsius; µS/cm, microsiemens per centimeter at 25 degrees Celsius; EXO, Xylem YSI EXO, model EXO2, continuous water-quality monitor; FNU, formazin nephelometric unit; <, less than; 6136, YSI Incorporated 6600 Extended Deployment System water-quality monitor model 6136]

Continuous variable	*n*	Minimum	Maximum	Mean	Median	Percent missing data
Neosho River at Neosho Rapids, Kansas—Continued						
Daily mean measurements						
2009–19 historical daily streamflow (ft^3/s)	3,542	15.5	33,200	1,220	269	7
Streamflow (ft^3/s)	3,652	15.5	33,200	1,510	296	0
Water temperature (°C)	3,353	−0.1	32	16	16	8
Specific conductance (µS/cm)	3,076	161	1,080	623	632	16
Turbidity (6136, FNU)	1,822	2.0	1,030	69	31	15
Turbidity (EXO, FNU)	1,281	1.9	877	79	28	15
Neosho River at Burlington, Kansas						
15-minute measurements						
Streamflow (ft^3/s)	337,010	5.0	36,500	1,550	183	4
Water temperature (°C)	266,425	−0.8	33	15	16	24
Specific conductance (µS/cm)	257,859	190	729	485	489	27
Turbidity (6136, FNU)	114,980	3.9	760	29	19	44
Turbidity (EXO, FNU)	126,702	3.3	1,640	28	23	14
Daily mean measurements						
1961–2019 historical daily streamflow (ft^3/s)	21,368	0.86	34,600	1,170	374	0
Streamflow (ft^3/s)	3,652	7.6	34,600	1,510	233	0
Water temperature (°C)	2,780	0.0	32	16	16	24
Specific conductance (µS/cm)	2,712	220	722	486	488	26
Turbidity (6136, FNU)	1,300	4.2	419	29	19	39
Turbidity (EXO, FNU)	1,348	3.6	161	28	24	12

Quality Control

Concurrent discrete replicate samples were collected for quality-control purposes to identify, quantify, and document potential bias and variability in data that resulted from the collection, processing, and analysis of samples in accordance with USGS standardized sampling techniques (U.S. Geological Survey, 2006). About 10 percent of discrete SSC samples collected at all sites throughout this study were replicate samples. For replicate samples collected during the analysis period, the relative percentage difference (RPD) was calculated by dividing the difference between the sample and replicate by the mean of the two results. RPD values ranged from about 0 to 44 percent and averaged about 10 percent (table 5). Cottonwood had the largest mean RPD among replicate samples (19 percent); however, samples with the largest RPD were typically storm samples when rapidly changing conditions frequently occurred. Larger RPDs could be attributed to changing streamflow conditions, poor mixing of suspended sediment in the water column, sampling techniques, or potential analysis error.

During sample collection, turbidity values were measured at every sample point across the width of the stream cross section and compared to concomitant in situ continuous turbidity sensor measurements. Comparisons between field-measured cross-sectional means and continuous turbidity measurements for YSI 6600 model 6136 and YSI EXO turbidity sensors had a near 1:1 relation in slopes (coefficient of determination

Table 5. Summary of quality-control replicate results for discretely collected suspended-sediment concentration replicate data, 2010 through 2019.

[Suspended-sediment concentration data were analyzed by the U.S. Geological Survey (USGS) Iowa Sediment Laboratory; QC, quality control; pcode, parameter code; RPD, relative percentage difference; <, less than]

QC summary statistics for suspended-sediment concentration (USGS pcode 80154)	Cottonwood River near Plymouth, Kansas (USGS site 07182250)	Neosho River at Burlingame Road near Emporia, Kansas (USGS site 07179750)	Neosho River at Neosho Rapids, Kansas (USGS site 07182390)	Neosho River at Burlington, Kansas (USGS site 07182510)
Total number of replicate pairs	5	4	3	5
Minimum RPD	0.6	1.1	0.2	<1.0
Maximum RPD	44.1	8.7	7.4	35.7
Mean RPD	19	5.4	3.7	9.6
Median RPD	13.8	5.9	3.5	2.2

[R^2]=0.96 to 0.99; fig. 3, fig. 4). Samples with turbidity measurements that plotted outside the 1:1 relation were likely due to localized differences in turbidity in the stream cross section.

Water temperature and specific conductance sensor ranges were not exceeded during the analysis period (−5 to 50 plus or minus [±] 2 degrees Celsius [°C] for water temperature and 0 to 100,000 microsiemens per centimeter [µS/cm] ± 1 percent or 2 µS/cm, whichever is greater, for specific conductance; YSI Incorporated, 2015). The YSI 6600 model 6136 optical turbidity sensor operational limit is 1,000 FNU, and the YSI EXO turbidity sensor operational limit is 4,000 FNU (YSI Incorporated, 2007, 2019). The YSI 6600 model 6136 turbidity sensor operational limit was exceeded less than 1 percent of the time at the Burlingame and Neosho Rapids sites and was never exceeded at Burlington. The YSI EXO turbidity sensor operational limit was never exceeded at any site during the analysis period.

Development of Linear Regression Models

Models for total suspended sediment were updated using data collected through March 2019. Previously published models used turbidity from YSI 6600 model 6136 optical turbidity sensors as a surrogate for SSC (table 6; Foster, 2014). These models were updated with data through the end of the deployment of the YSI 6600 model 6136 turbidity sensors, and new models were developed during the period of deployment of the YSI EXO turbidity sensors. Separate models were developed for the individual sensors during their respective periods of deployment to account for the known differences between turbidity sensors and to avoid additional bias in the SSC surrogate models.

Discrete water-quality samples were collected over a range of streamflow conditions to develop robust regression models that adequately represent conditions at each site. Models were developed using ordinary-least-squares regression analysis to relate SSC to concomitant continuously measured streamflow and instream turbidity (Rasmussen and others, 2009; Helsel and others, 2020). Concomitant continuously measured streamflow or turbidity values were time interpolated to the collection time of the associated sample. If concomitant continuous data were not available (2 or more hours of values bracketing the sample collection time were missing) because of fouling, changes in equipment, or unsuitable site conditions, the field monitor value measured during sampling was substituted.

Before developing regression models, all discrete suspended-sediment samples were analyzed for potential outliers (Rasmussen and others, 2009). Samples were not included in the dataset if the sample was affected by ice, the sample bottle was broken during shipment to the analyzing laboratory, or there were no available concomitant water-quality data associated with the sample. Regression models were evaluated using statistical significance (R^2, root mean square error, model standard percentage error [MSPE]) along with variance and distribution of discrete SSC and continuous turbidity data (Rasmussen and others, 2009; Foster, 2014; Helsel and others, 2020). For each site, a streamflow-only based model was developed to compute concentrations and loads during periods when concomitant water-quality physical properties were unavailable.

Updated models are useful for evaluating SSC to compare with water-quality criteria and for computing loads and yields to assess constituent transport through the drainage basin. The water-quality information quantifies and characterizes sediment transported into and out of the reservoir. Details of developed regression models for this report are included in appendixes 1 through 12.

Suspended-Sediment Concentrations, Loads, and Yields and Streamflow

Continuously measured turbidity and streamflow data provide accurate and reliable computations of suspended-sediment concentrations, loads, and yields (Christensen and others, 2000; Putnam and Pope, 2003; Rasmussen and others,

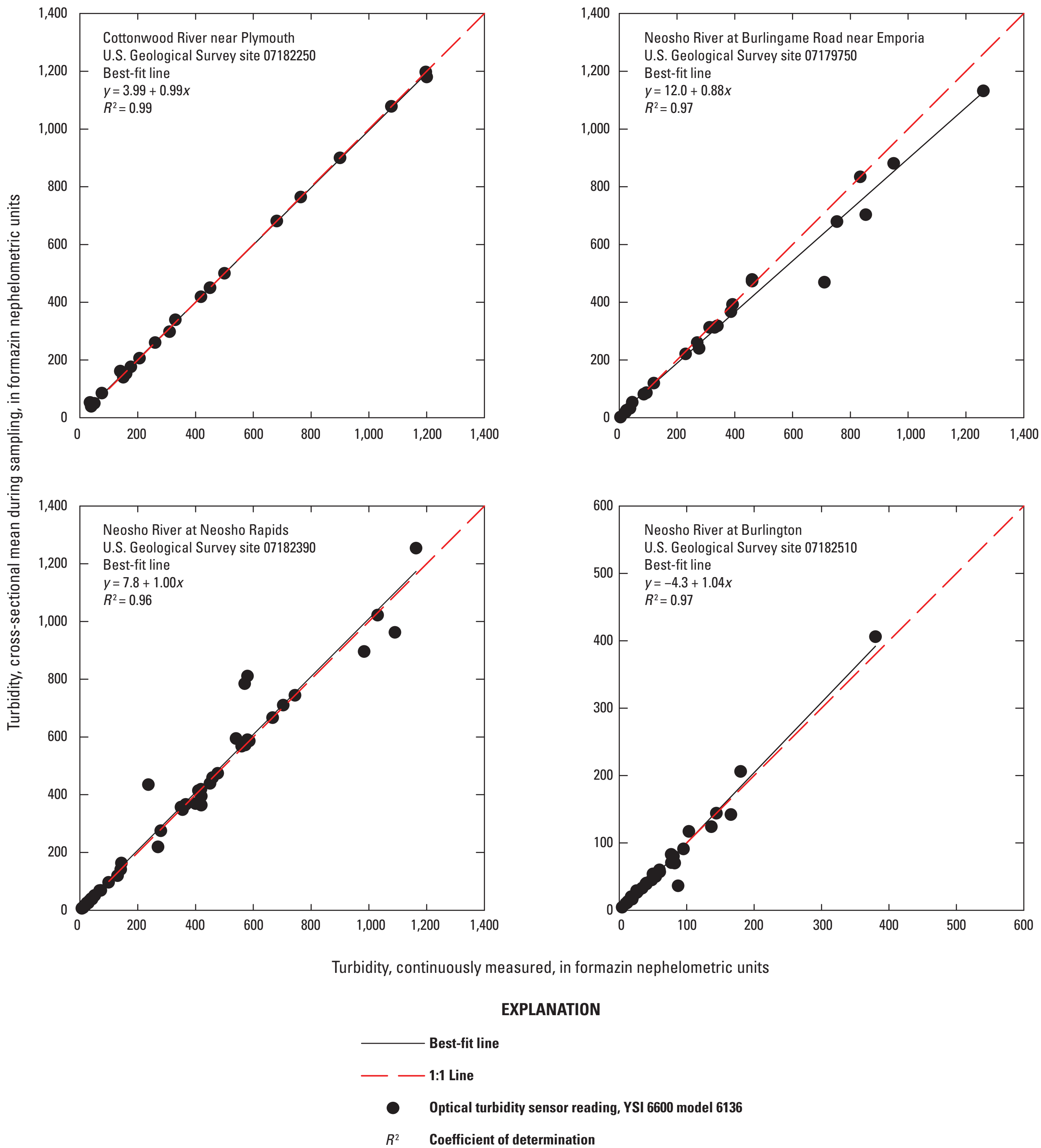

Figure 3. YSI Incorporated 6600 Extended Deployment System (YSI 6600 model 6136) turbidity sensor relation between continuously measured values and cross-sectional means during discrete sample collection for sites on the Cottonwood and Neosho Rivers, Kansas.

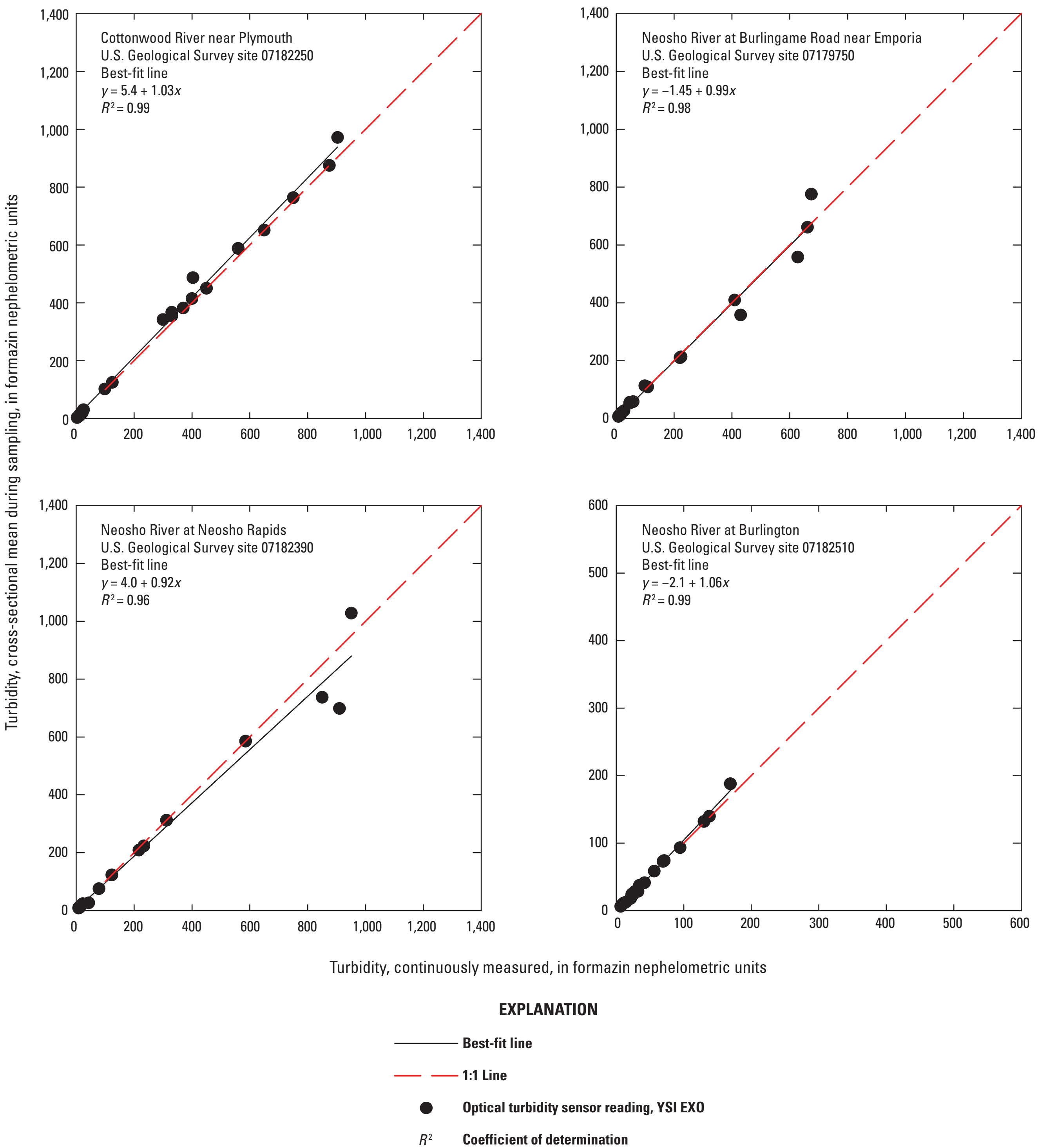

Figure 4. Xylem YSI EXO (YSI EXO), turbidity sensor relation between continuously measured values and cross-sectional means during discrete sample collection for sites on the Cottonwood and Neosho Rivers, Kansas.

Table 6. Developed regression models (Foster, 2014) and updated regression models and summary statistics for continuous suspended-sediment concentration computations (in milligrams per liter) for Cottonwood River near Plymouth, Kansas (U.S. Geological Survey [USGS] site 07182250); Neosho River at Burlingame Road near Emporia, Kans. (USGS site 07179750); Neosho River at Neosho Rapids, Kans. (USGS site 07182390); and Neosho River at Burlington, Kans. (USGS site 07182510).

[R^2, coefficient of determination; MSPE, model standard percentage error; RMSE, root mean square error; *n*, number of discrete samples; log, logarithm base 10; *SSC*, suspended-sediment concentration, in milligrams per liter; *turb*, turbidity from sensors reported in Foster (2014); --, data not available; *Q*, streamflow, in cubic feet per second; $turb_{6136}$, turbidity from YSI Incorporated 6600 Extended Deployment System water-quality monitor model 6136 turbidity sensor, in formazin nephelometric units; App., Appendix; $turb_{EXO}$, turbidity from Xylem YSI EXO turbidity sensor, in formazin nephelometric units]

Regression model	Model archive summary	Period of application	Multiple R^2	Adjusted R^2	MSPE	RMSE	Bias correction factor (Duan, 1983)	Discrete data				
								n	Range of values in variable measurements	Mean	Median	Standard deviation
Cottonwood River near Plymouth, Kansas												
Foster (2014)												
$\log(SSC)=1.02\log(turb)+0.30$	--	--	0.97	0.97	--	0.1	1.02	29	*turb*: 17–1,050	374	340	310
									SSC: 30–2,140	875	784	719
$\log(SSC)=0.742\log(Q)+0.21$	--	--	0.6	0.59	--	0.38	1.33	29	*Q*: 47–102,000	6,450	2,940	18,600
Updated												
$\log(SSC)=0.931\log(turb_{6136})+0.547$	App. 1	10/1/2007–5/18/2009	0.95	0.95	24.5	0.105	1.03	22	$turb_{6136}$: 35–1,200	421	285	373
									SSC: 78–3,500	968	746	839
$\log(SSC)=1.04\log(turb_{EXO})+0.371$	App. 5	4/22/2015–12/31/2019	0.96	0.96	34.1	0.145	1.06	23	$turb_{EXO}$: 11–903	355	333	289
									SSC: 18–3,480	1,130	987	1,030
$\log(SSC)=0.617\log(Q)+0.732$	App. 9	[1]1/1/2010–12/31/2019	0.64	0.63	95.5	0.369	1.36	47	*Q*: 48–22,400	5,700	3,700	6,110
									SSC: 18–3,960	1,150	828	1,060
Neosho River at Burlingame Road near Emporia, Kansas												
Foster (2014)												
$\log(SSC)=1.07\log(turb)+0.11$	--	--	0.95	0.95	--	0.17	1.07	27	*turb*: 2.2–1,130	343	310	309
									SSC: 4.0–2,240	747	567	738
$\log(SSC)=0.744\log(Q)+0.50$	--	--	0.54	0.52	--	0.50	2.04	27	*Q*: 18–5,320	1,300	448	1,480
Updated												
$\log(SSC)=1.10\log(turb_{6136})+0.00834$	App. 2	8/1/2009–12/16/2012	0.95	0.94	41.2	0.174	1.08	27	$turb_{6136}$: 4.3–1,260	371	313	336
									SSC: 4.0–2,240	747	567	724
$\log(SSC)=1.12\log(turb_{EXO})+0.0799$	App. 6	5/2/2015–12/31/2019	0.99	0.99	20.7	0.09	1.02	23	$turb_{EXO}$: 7.9–965	286	109	302
									SSC: 11–2,730	721	274	844
$\log(SSC)=0.707\log(Q)+0.533$	App. 10	[1]1/1/2010–12/31/2019	0.78	0.77	93.8	0.364	1.32	47	*Q*: 2.5–11,100	1,860	978	2,410
									SSC: 0.6–2,730	730	438	792

Table 6. Developed regression models (Foster, 2014) and updated regression models and summary statistics for continuous suspended-sediment concentration computations (in milligrams per liter) for Cottonwood River near Plymouth, Kansas (U.S. Geological Survey [USGS] site 07182250); Neosho River at Burlingame Road near Emporia, Kans. (USGS site 07179750); Neosho River at Neosho Rapids, Kans. (USGS site 07182390); and Neosho River at Burlington, Kans. (USGS site 07182510).—Continued

[R^2, coefficient of determination; MSPE, model standard percentage error; RMSE, root mean square error; *n*, number of discrete samples; log, logarithm base 10; *SSC*, suspended-sediment concentration, in milligrams per liter; *turb*, turbidity from sensors reported in Foster (2014); --, data not available; *Q*, streamflow, in cubic feet per second; $turb_{6136}$, turbidity from YSI Incorporated 6600 Extended Deployment System water-quality monitor model 6136 turbidity sensor, in formazin nephelometric units; App., Appendix; $turb_{EXO}$, turbidity from Xylem YSI EXO turbidity sensor, in formazin nephelometric units]

Regression model	Model archive summary	Period of application	Multiple R^2	Adjusted R^2	MSPE	RMSE	Bias correction factor (Duan, 1983)	Discrete data				
								n	Range of values in variable measurements	Mean	Median	Standard deviation
Neosho River at Neosho Rapids, Kansas												
Foster (2014)												
log(*SSC*)=1.06log(*turb*)+0.17	--	--	0.97	0.97	--	0.11	1.03	28	*turb*: 17–1,020	412	400	324
									SSC: 27–2,420	939	883	781
log(*SSC*)=0.700log(*Q*)+0.32	--	--	0.53	0.51	--	0.44	1.54	28	*Q*: 49–24,900	5,450	2,550	6,580
Updated												
log(*SSC*)=1.07log($turb_{6136}$)+0.16	App. 3	8/11/2009–11/11/2015	0.96	0.96	32.1	0.137	1.05	42	$turb_{6136}$: 6.6–1,160	374	378	320
									SSC: 14–4,230	911	707	886
log(*SSC*)=1.13log($turb_{EXO}$)+0.105	App. 7	11/13/2015–12/31/2019	0.99	0.99	21.6	0.093	1.02	17	$turb_{EXO}$: 8.3–951	343	217	339
									SSC: 17–3,570	1020	515	1,090
log(*SSC*)=0.799log(*Q*)−0.0546	App. 11	[1]1/1/2010–12/31/2019	0.71	0.70	108	0.407	1.43	56	*Q*: 48.8–30,400	5,570	2,490	6,500
									SSC: 14–4,230	953	647	971
Neosho River at Burlington, Kansas												
Updated												
log(*SSC*)=0.904log($turb_{6136}$)+0.316	App. 4	10/1/2007–10/21/2015	0.93	0.93	23.1	0.0995	1.03	34	$turb_{6136}$: 4.3–380	68	49	70
									SSC: 12–582	97	70	106
log(*SSC*)=0.896log($turb_{EXO}$)+0.382	App. 8	10/23/2015–9/30/2019	0.93	0.92	25.2	0.108	1.03	18	$turb_{EXO}$: 6.6–169	48	27	44
									SSC: 11–335	78	48	75
log(*SSC*)=0.333log(*Q*)+0.806	App. 12	[1]1/1/2010–12/31/2019	0.46	0.45	70.2	0.284	1.25	52	*Q*: 31.2–12,500	2,530	1,420	2,940
									SSC: 11–582	90	61	97

[1]Flow-based models (*Q*) are considered secondary models and were only used when primary model data (continuous water-quality data) were missing for concentration and load computation.

2005; Lee and others, 2008; Rasmussen and others, 2008). When 15-minute or hourly streamflow data were missing, daily values were estimated, reviewed, and approved following USGS methods (Turnipseed and Sauer, 2010; Painter and Loving, 2015). When continuous water-quality data were missing because of periods of extreme weather or water-quality monitor malfunction or during routine maintenance visits, daily mean values were computed by averaging hourly values and were reviewed and approved according to USGS methods (Wagner and others, 2006; U.S. Geological Survey, 2008; Bennett and others, 2014). Daily mean values (rather than 15-minute or hourly data) were used for concentration and load computation because of missing continuous streamflow data and periods of missing continuous water-quality data. Limitations of this approach include loss of intraday variability, which affects computed concentrations and thus computed loads.

When daily turbidity data were unavailable, a streamflow-based model was substituted as a secondary means of computation and provided computed SSC values. The streamflow-based SSC values were shifted to align with the next available turbidity-based SSC values based on methods described in Porterfield (1972) to align computed concentrations among model types.

Suspended-sediment concentrations and loads were calculated from January 1, 2010, through December 31, 2019, except during extended periods with missing turbidity daily values. Large gaps in water-quality data limited the ability to continuously compute suspended-sediment concentrations and loads at sites (table 1). Although the streamflow-based regression model was considered a suitable substitute for shorter periods of missing data, longer durations of missing days introduce greater uncertainty into the final concentration, load, and yield computations. Computed concentration, load, and yield data are unavailable at the Cottonwood, Burlingame, and Burlington sites for long periods of time when water-quality data were not collected. The monitor was discontinued at Burlington in 2019 at the end of September, and only streamflow data were available for concentration and load estimations for the remaining 95 days. For this period of missing turbidity data, the streamflow-based model was considered a suitable substitute, and the level of uncertainty introduced was considered minimal because of minor fluctuations in streamflow and lack of large precipitation events during the period.

Daily loads were calculated by multiplying computed daily SSC (in milligrams per liter) by daily streamflow (in cubic feet per second) and a unit conversion factor (0.0027 to calculate the load in tons per day). Annual sediment loads were estimated by summing the daily loads. Annual yields (in pounds per square mile) were calculated by dividing annual loads by the contributing drainage area (table 2). Sediment yields were computed to compare the four sites. Computed suspended-sediment concentrations, loads, and yields do not account for the ungaged 9 percent of the drainage basin. Previous studies have used different estimation methods for the ungaged part of the drainage basin, but these methods have undefined error associated with the estimates (Lee and others, 2008; Foster, 2016). The computed suspended-sediment concentrations, loads, and yields described in this report only account for the gaged 91 percent of the drainage basin.

Suspended Sediment Transported during High-Flow Events

Streambank stabilization effectiveness is difficult to assess on a drainage basin scale. During high-flow events, water can breach channel banks, resulting in erosion of lands, damage to nearby property, and subsequent destruction to the streambank stabilization project, thus reducing their effectiveness at minimizing erosion. Determining bankfull flow, or maximum streamflow without overflowing onto the floodplain, is an important step in the planning process for streambank stabilization (Baird and others, 2015). Suspended-sediment loads transported during high-flow events (greater than channel-controlled flow) were computed and compared to the total suspended-sediment load during the analysis period.

National Weather Service (NWS) flood action stages are defined for Cottonwood (30 ft) and Neosho Rapids (17 ft). In comparison with the rating curves for each site, the flood action stage is closely correlated to the point when flow transitions from channel-control flow to overbank flow; therefore, associated flow at or above the flood action stage is considered to be, for the purpose of this analysis, greater than channel-control flow. The associated streamflow for the action stages was defined by computing the mean streamflow using each stage-discharge rating developed during the analysis period (2010–19).

There is no defined NWS flood action stage for Burlingame; however, there is a defined flood action stage for the site about 13 river miles upstream (Neosho River near Americus, USGS site 07179730). The drainage-area ratio method was used to estimate the flood action stage associated streamflow equivalent from the Neosho River near Americus site to Burlingame (Southard, 2013; Eash and Barnes, 2017). To use this method, sites need to be on the same stream, and the ratio is preferred to be between 0.5 and 1.5 (the ratio between Burlingame and Neosho River near Americus is 1.2). Like Cottonwood and Neosho Rapids, the associated streamflow for the estimated flood action stage at Burlingame was defined by computing the mean streamflow using each stage-discharge rating developed during the analysis period.

Annual-exceedance probabilities (AEPs) were computed for flood action stage associated streamflows. At Cottonwood, the available period of record of streamflow daily values used to compute AEPs was 1963–2019. At Neosho Rapids and Burlingame, the available period of record of streamflow daily values used to compute AEPs was 2009–19. AEPs were calculated using the Weibull formula for computing plotting position (Helsel and others, 2020):

$$AEP = 100 \times \left(\frac{i}{n+1}\right), \quad (1)$$

where

AEP is the annual exceedance probability, or the probability that a given flow will be equaled or exceeded, (in percent);

i is the assigned rank position (dimensionless); and

n is the sample size of the daily streamflow dataset (dimensionless).

Streambank stabilization sites are implemented along many reaches of the rivers, and overbank flow conditions at these locations likely differ from overbank flow conditions at the gaged locations. There are limitations to this approach, mainly because of the dynamic nature of stream morphology, and these estimates are intended to examine the percentage of sediment transported during high-flow flooding events.

Computation of Streamflow during Backwater Conditions

A simple stage-discharge rating does not always accurately compute continuous streamflow at a streamgage. In those cases, a complex rating may be used. A complex rating consists of a stage-discharge relation, in addition to some other independent variable (Kennedy, 1984). Because of its close location to the reservoir, the Neosho Rapids site is affected by varying degrees of intermittent backwater from the reservoir. Backwater can be described as a body of water in which the flow is slowed or turned back by an obstruction (U.S. Geological Survey, 2013). Examples of obstructions are natural debris, such as leaves, logs, and sticks; a dam or bridge; and another body of water, such as a lake or river. At the Neosho Rapids site, a slope rating is used to continuously compute streamflow.

The most common method the USGS uses to compute streamflow at a streamgage is a simple stage-discharge rating (Kennedy, 1984). These ratings involve the relation of streamflow to stage and are used at the Cottonwood, Burlingame, and Burlington sites. Onsite measurements of streamflow that are made by USGS personnel are the main data source for this rating analysis. Other information that is sometimes used to improve the accuracy of a simple stage-discharge rating are a streamgage height of zero flow, dates of floods and other channel changing events, and cross-section surveys (Kennedy, 1984).

A slope rating is a complex rating that relates streamflow to stage at one gage (base gage) and to the fall in water surface elevation between the base gage and an auxiliary gage downstream (Kennedy, 1984). The slope rating at the Neosho Rapids site is composed of three parts: (1) a simple stage-discharge rating curve, (2) a fall rating curve that rates the fall between the base and auxiliary gage that varies with stage, and (3) a discharge factor rating curve that relates the ratio of measured streamflow to the rated streamflow versus the ratio of the measured fall to the rated fall. If the factor from the discharge factor curve is 1.0, then the streamgage is not affected by a backwater condition and the simple stage-discharge rating is used to compute streamflow. If the factor is less than 1.0, then the streamflow is adjusted using that factor. A more detailed explanation of simple and complex ratings is documented in Kennedy (1984).

Streamflow at the Neosho Rapids site was computed using a slope rating, and the auxiliary gage used for the slope computation was the Neosho River at Hartford, Kans. (USGS site 07182395; fig. 1). The slope rating for the Neosho Rapids site was implemented in March 2016. The slope rating computes streamflow when the stage at Neosho Rapids is between 1.53 and 23.42 ft. Since the slope rating was implemented in 2016, the streamflow at the Neosho Rapids site was affected by some degree of backwater from the reservoir a little more than one-half of the time through 2019. Before the slope rating, periods of backwater were estimated at the Neosho Rapids site using streamflow measurements made by USGS personnel more frequently and the Missing Streamflow Estimation regression tool in the HYDRA program present in the USGS Automated Data Processing System following USGS methods (Painter and Loving, 2015).

Streamflow Conditions and Continuously Monitored Water-Quality Variables

Streamflow is the major determinant of sediment fate and transport. Annual mean streamflow computed using daily mean streamflows for Cottonwood during 2010 through 2019 ranged from 226 to 2,070 ft^3/s; the smallest mean streamflow was measured in 2012 and the largest was measured in 2019. Annual mean streamflow for Burlingame during 2010 through 2019 ranged from 67 to 973 ft^3/s; the smallest mean streamflow was measured in 2014 and the largest was measured in 2019. Annual mean streamflow at Neosho Rapids ranged from 349 to 3,270 ft^3/s in 2012 and 2019, respectively. Annual mean streamflow for Burlington ranged from 414 to 4,110 ft^3/s in 2012 and 2019, respectively (table 7).

Streamflow in the drainage basin can have rapid increases and subsequent decreases with corresponding rainfall. Streamflow duration curves for each study site show the frequency of exceedance for flows of different magnitudes (fig. 5). The 1-percent exceedance flows ranged from 19,200 ft^3/s at Neosho Rapids to 5,690 ft^3/s at Burlingame. The 99-percent exceedance flows ranged from 32 ft^3/s at Neosho Rapids to 2 ft^3/s at Burlingame.

The National Integrated Drought Information System recorded the longest history of drought conditions in Kansas, which began on November 9, 2010, and ended on August 4, 2015, totaling 248 weeks. The most intense drought period

Table 7. Total annual streamflow and annual mean streamflow for study sites along the Cottonwood and Neosho Rivers, Kansas, during 2010 through 2019.

[Cottonwood, Cottonwood River near Plymouth, Kansas (U.S. Geological Survey [USGS] site 07182250); Burlingame, Neosho River at Burlingame Road near Emporia, Kans. (USGS site 07179750); Neosho Rapids, Neosho River at Neosho Rapids, Kans. (USGS site 07182390); Burlington, Neosho River at Burlington, Kans. (USGS site 07182510); AF, acre-foot; ft^3/s, cubic foot per second; --, data not available]

Year	Cottonwood		Burlingame		Neosho Rapids		Neosho Rapids (upstream loads subtracted)		Burlington		Total retained by reservoir[1] (AF)
	Total (AF)	Mean (ft^3/s)	Total (AF)	Mean (ft^3/s)	Total (AF)	Mean (ft^3/s)	Total (AF)	Mean (ft^3/s)	Total (AF)	Mean (ft^3/s)	
2010	779,000	1,080	413,000	570	1,760,000	2,430	569,000	786	1,670,000	2,300	90,000
2011	188,000	260	107,000	147	361,000	498	66,000	91	353,000	488	8,000
2012	164,000	226	64,700	89	253,000	349	24,000	34	301,000	414	−48,000
2013	623,000	860	64,200	89	1,180,000	1,630	496,000	685	792,000	1,090	388,000
2014	190,000	262	48,600	67	260,000	359	21,400	30	312,000	431	−52,000
2015	602,000	831	256,000	354	1,940,000	2,680	1,090,000	1,500	1,290,000	1,780	650,000
2016	728,000	1,000	305,000	419	1,210,000	1,670	178,000	245	1,410,000	1,940	−200,000
2017	517,000	714	270,000	372	917,000	1,270	131,000	181	1,010,000	1,390	−93,000
2018	365,000	504	227,000	313	669,000	924	77,000	106	811,000	1,120	−142,000
2019	1,500,000	2,070	704,000	973	2,360,000	3,270	158,000	219	2,980,000	4,110	−620,000
Mean	452,000	--	177,000	--	837,000	--	140,000	--	848,000	--	--
Total	5,660,000	--	2,460,000	--	10,900,000	--	2,800,000	--	10,900,000	--	--

[1]Total retained by reservoir calculated by subtracting Burlington streamflow from Neosho Rapids streamflow.

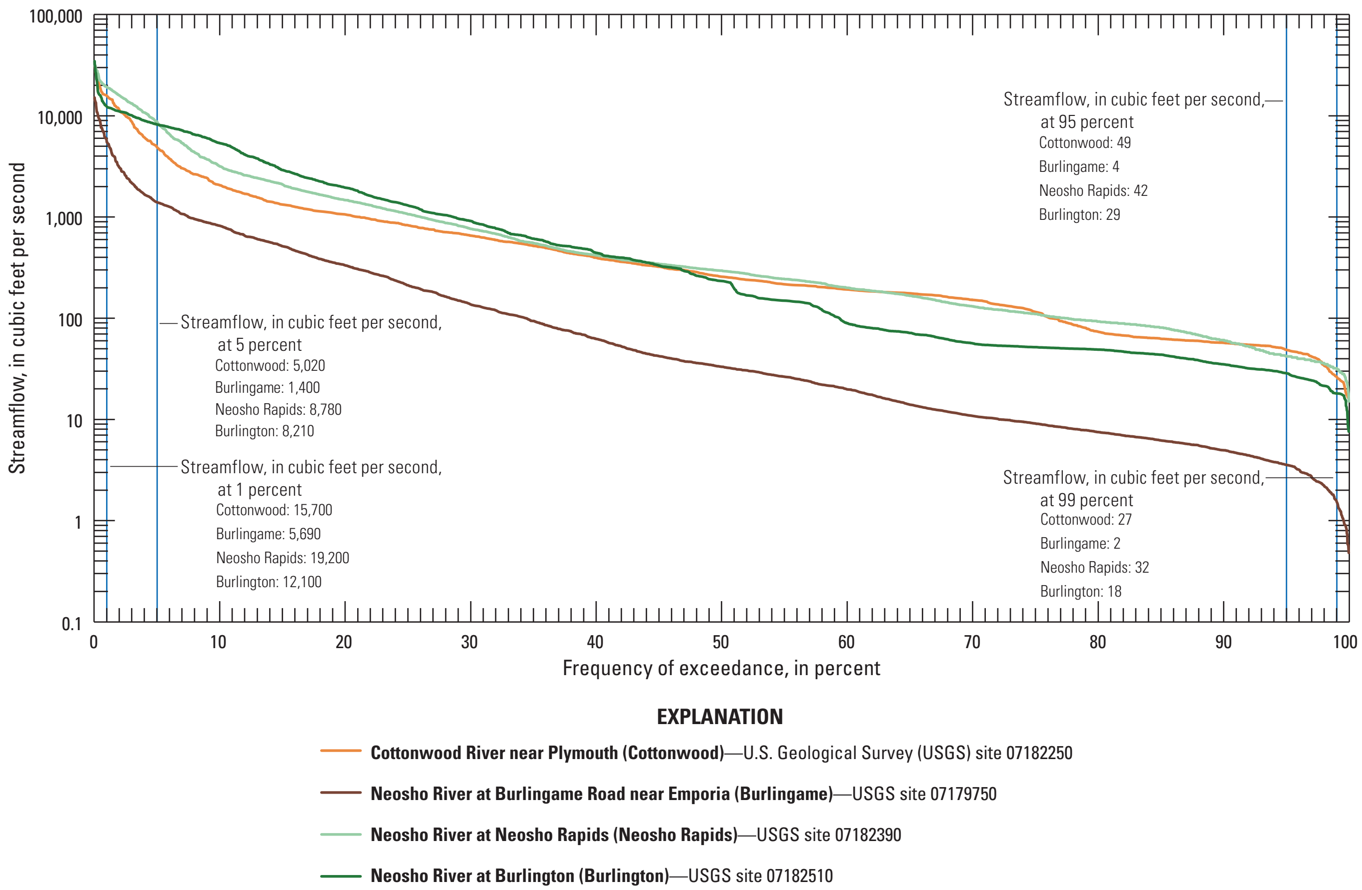

Figure 5. Streamflow duration curves with 1-, 5-, 95-, and 99-percent exceedances for the study sites along the Cottonwood and Neosho Rivers, Kansas, during 2010 through 2019.

occurred during August 2012 when nearly 67 percent of the State experienced exceptional drought including widespread crop and pasture losses and water shortages (National Integrated Drought Information System, 2020). The smallest total streamflows occurred during drought years (2011–15) for all sites. Cottonwood, Neosho Rapids, and Burlingame had the smallest annual streamflow during 2012, which also was the year with the smallest annual mean precipitation (22.4 in.) in the drainage basin (fig. 6, table 7, table 3). Streamflow at Burlingame was the smallest during 2014 (48,600 acre-ft), which had the third smallest annual precipitation (fig. 6, table 7, table 3). The largest annual streamflow for all four sites occurred during 2019 and was a result of flooding because of greater than mean rainfall totaling 49.6 in. (fig. 6, table 3). The year 2019 also had the largest number of extreme precipitation days and had a total of 14.9 in. of rain during six 24-hour periods that accounted for 30 percent of the total annual precipitation (table 3). Burlington had the largest annual streamflow in 2019 (2,980,000 acre-ft), followed by Neosho Rapids (2,360,000 acre-ft), Cottonwood (1,500,000 acre-ft), and lastly Burlingame (704,000 acre-ft; table 7).

The total streamflow at Cottonwood during 2010 through 2019 was about 5,660,000 acre-ft (mean: 452,000 acre-ft; table 7). Burlingame had a smaller total streamflow (2,460,000 acre-ft, mean: 177,000 acre-ft) than Cottonwood (table 7). Neosho Rapids includes inflow from the Cottonwood River (Cottonwood site) and upper Neosho River (Burlingame site) and had a total streamflow of 10,900,000 acre-ft (mean: 837,000 acre-ft; table 7). The Cottonwood River (streamflow estimated at Cottonwood) contributes about one-half of the computed total streamflow at Neosho Rapids (table 7). Streamflow from the upper Neosho River (streamflow estimated at Burlingame) and the contributing drainage area upstream from Neosho Rapids (Neosho Rapids [upstream loads subtracted]; table 7) make up the remaining part of the total streamflow estimated at Neosho Rapids. Despite uncertainty associated with streamflow computations, there could be other mitigating factors (natural or anthropogenically induced) that contribute to the estimated streamflow calculations. Burlington streamflow was mostly regulated by reservoir releases; therefore, the unregulated drainage area (27 mi^2) had minimal streamflow contribution. Burlington's total streamflow was 10,900,000 acre-ft (mean: 848,000 acre-ft; table 7).

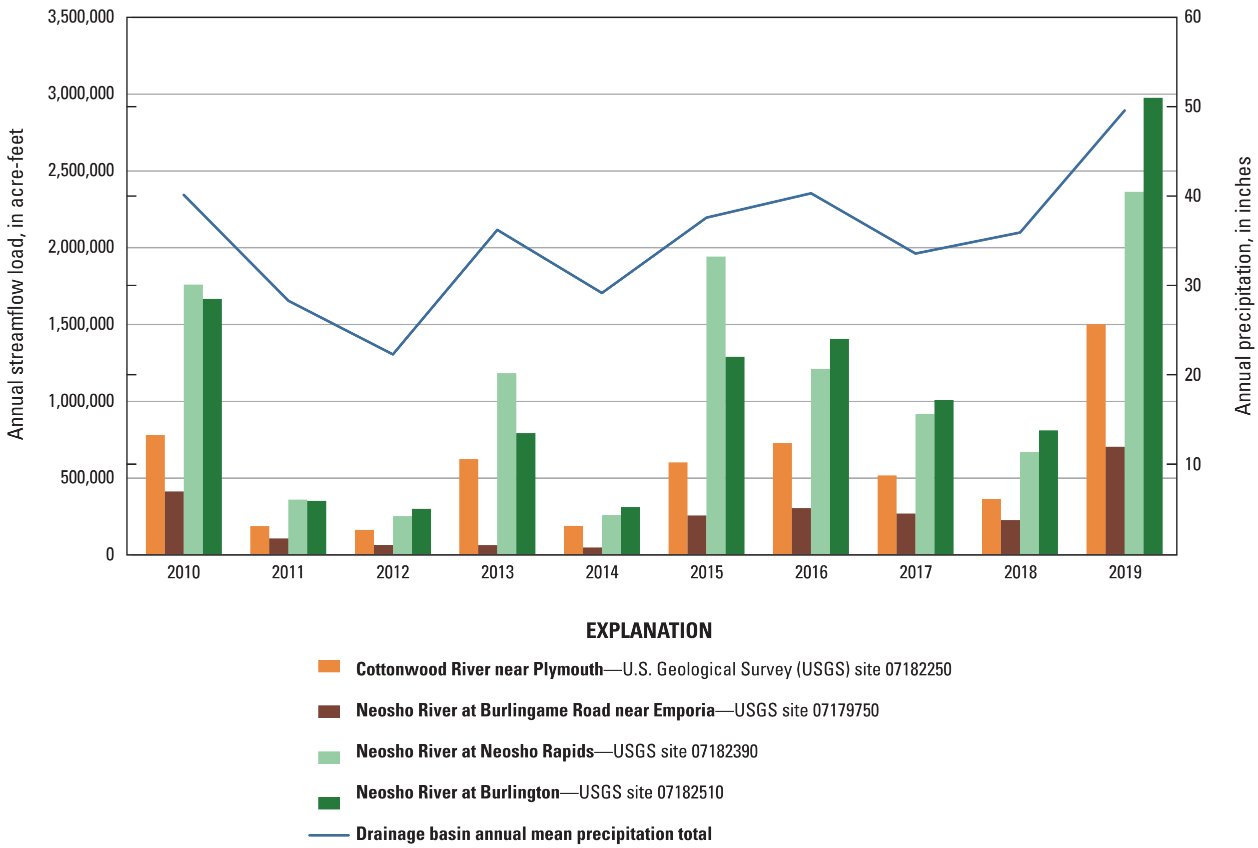

Figure 6. Annual basin mean precipitation totals and annual streamflow (in acre-feet) for study sites along the Cottonwood and Neosho Rivers, Kansas, during 2010 through 2019.

Flooding during 2019

In 2019, John Redmond Reservoir received 49.6 in. of precipitation, 38 percent more precipitation than recorded in 2018 (36.0 in.). The highest recorded precipitation totals were during the month of May (Council Grove Lake, 16.03 in.; Marion Reservoir, 9.91 in.; John Redmond Reservoir, 14.22 in.), which caused larger streamflows in the Cottonwood and upper Neosho Rivers and, in many areas, bank overflow. Mean streamflows were 2.4–3.5 times greater in 2019 than mean historical daily streamflows at all sites in the study area (tables 4, 7). As a result, many Kansas reservoirs, including John Redmond Reservoir, were filled to flood-control capacity in 2019 (U.S. Army Corps of Engineers, 2019a).

Reservoir releases increased substantially beginning in May 2019, and large streamflows continued through July 2019 (fig. 7, table 8). Total releases were largest for Council Grove Lake in May (51,910 acre-ft), Marion Reservoir in July (70,644 acre-ft), and John Redmond Reservoir in May (931,940 acre-ft) (U.S. Army Corps of Engineers, 2019b, c, d). The largest total rainfall was observed in May for all three reservoirs (16.03, 9.91, and 14.22 in., respectively). Additionally, all four sites had the largest streamflow totals in May (Cottonwood [707,000 acre-ft], Burlingame [308,000 acre-ft], Neosho Rapids [1,070,000 acre-ft], and Burlington [936,000 acre-ft]; table 8). Larger 2019 streamflows quickly decreased water-storage capacity in many reservoirs across the State, including John Redmond Reservoir, which led to forced releases and contributed to larger streamflows downstream from the reservoirs.

Continuous Water-Quality Variables

The Kansas Department of Health and Environment (2018b) established a surface water-quality standard for streamflow to a receiving water not to raise or lower the natural conditions of water temperature beyond the mixing zone more than 3 °C; however, this analysis was not included as part of this study. There are no established aquatic life criteria for specific conductance in natural waters in Kansas. Water temperature ranged from −0.8 to 38 °C at all sites (table 4). Mean water temperatures were similar at all sites (15–17 °C). The range of measured water temperatures was largest at Burlingame and Neosho Rapids, which tend to be shallower at low flows. Specific conductance ranged from 66 to 1,240 µS/cm at all sites (table 4). Specific conductance measurements typically were larger at Cottonwood and Neosho Rapids

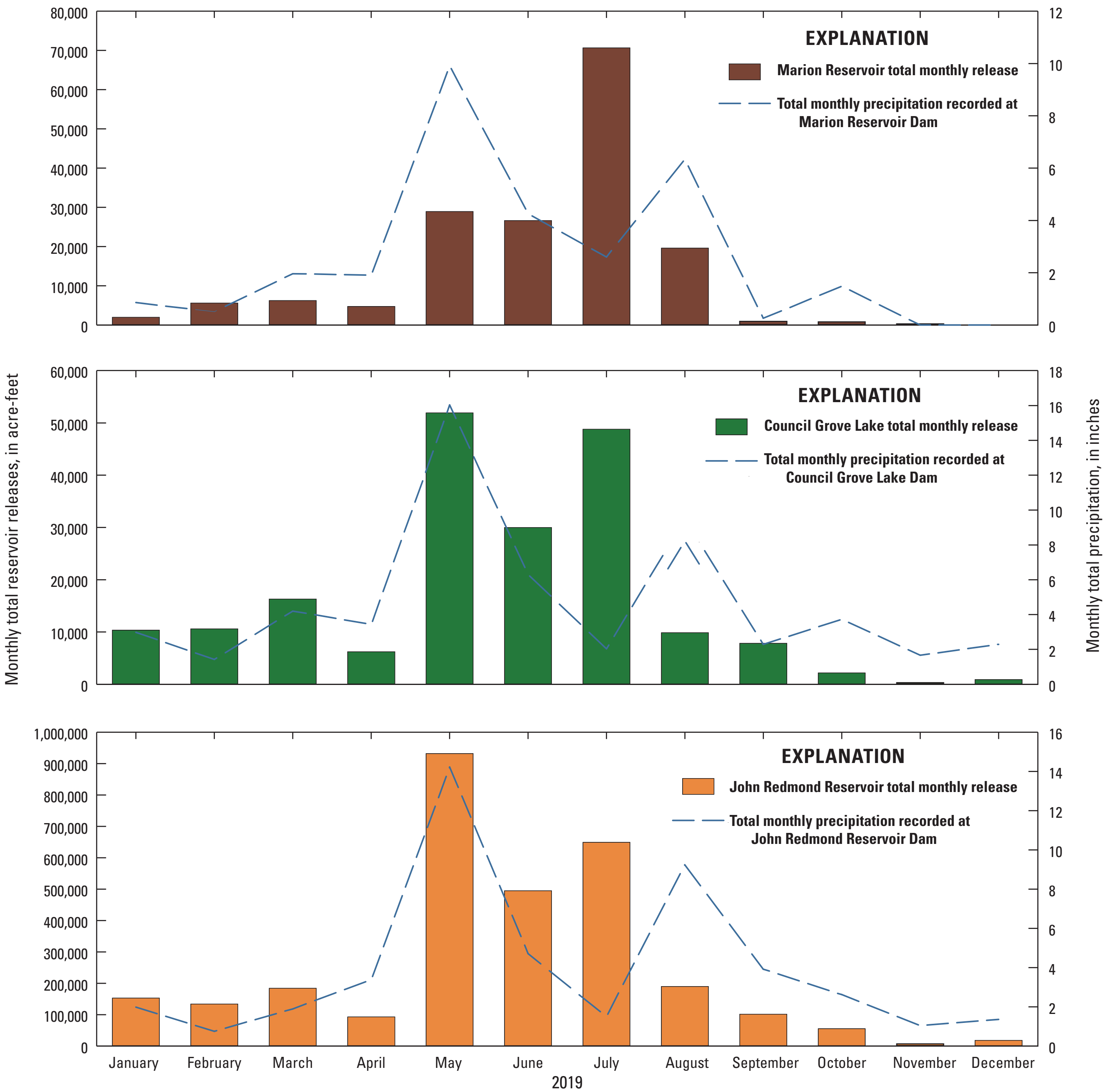

Figure 7. Monthly reservoir-release totals and rainfall totals for Marion Reservoir, Council Grove Lake, and John Redmond Reservoir, Kansas, 2019.

(mean: 708 and 623 µS/cm, respectively) and smaller at Burlingame and Burlington (mean: 433 and 485 µS/cm, respectively).

Turbidity is the measure of water clarity primarily changed by the presence of suspended material (clay, silt, and inorganic and organic matter). In addition to sediment depleting reservoir water-storage capacity, many pollutants, such as nutrients, pesticides, and metals, can adhere to sediment and can accumulate in the reservoir. The EPA established nonenforceable guidelines for turbidity in streams by region. Cottonwood and Burlingame are in level III ecoregion 28 with established nonenforceable guidelines for turbidity of 19.5 FNU (U.S. Environmental Protection Agency, 2001). Neosho Rapids and Burlington are in level IV ecoregion 40b with established nonenforceable guidelines for turbidity of 15.5 FNU.

Table 8. Monthly reservoir releases, rainfall totals, and site total streamflow computed from daily total streamflow for Council Grove Lake, Marion Reservoir, and John Redmond Reservoir, Kansas, and for each of the streamgage sites, 2019.

[Data obtained from the U.S. Army Corps of Engineers Tulsa District (U.S. Army Corps of Engineers, 2019b, c, d). Cottonwood, Cottonwood River near Plymouth (U.S. Geological Survey [USGS] site 07182250); Burlingame, Neosho River at Burlingame Road near Emporia (USGS site 07179750); Neosho Rapids, Neosho River at Neosho Rapids (USGS site 07182390); Burlington, Neosho River at Burlington (USGS site 07182510); AF, acre-foot; in., inch]

Month	Council Grove Lake		Marion Reservoir		John Redmond Reservoir		Cottonwood		Burlingame		Neosho Rapids		Burlington	
	Total release (AF)	Rainfall (in.)	Total release (AF)	Rainfall (in.)	Total release (AF)	Rainfall (in.)	Total streamflow (AF)	Contribution from upstream reservoir (percent)	Total streamflow (AF)	Contribution from upstream reservoir (percent)	Total streamflow (AF)	Contribution from upstream reservoirs (percent)	Total streamflow (AF)	Contribution from upstream reservoir (percent)
January	10,368	2.98	1,970	0.86	152,702	1.98	66,200	3	37,700	28	117,000	11	150,000	[1]102
February	10,616	1.42	5,619	0.51	133,930	0.74	48,100	12	34,900	30	91,500	18	127,000	[1]105
March	16,308	4.2	6,246	1.97	183,740	1.89	90,700	7	50,600	32	155,000	15	179,000	[1]103
April	6,222	3.43	4,756	1.91	92,758	3.38	51,800	9	25,300	25	75,400	15	87,700	[1]106
May	51,910	16.03	28,941	9.91	931,940	14.22	707,000	4	308,000	17	1,070,000	8	936,000	100
June	30,014	6.3	26,658	4.26	494,556	4.71	190,000	14	80,400	37	301,000	19	445,000	[1]111
July	48,798	2.03	70,644	2.6	648,898	1.49	175,000	40	67,300	72	254,000	47	656,000	99
August	9,860	9.49	19,621	6.34	189,781	9.24	108,000	18	51,900	19	167,000	18	202,000	94
September	7,851	2.29	952	0.26	101,073	3.92	21,900	4	21,200	37	53,100	17	101,000	[1]100
October	2,190	3.72	811	1.49	55,169	2.61	15,400	5	7,550	29	28,200	11	63,200	87
November	301	1.66	298	0.0	6,883	1.04	10,400	3	2,260	13	15,300	4	9,660	71
December	924	2.29	83	0.0	18,125	1.36	16,900	0	16,900	5	38,800	3	19,500	93

[1]Smaller total streamflow at Burlington than released from John Redmond Reservoir could be due to Wolf Creek Generating Station pumping water from the Neosho River just downstream from the reservoir to Coffey County Lake (National Regulatory Council, 2006).

Continuously measured YSI EXO turbidity ranged from less than 1 to 1,640 FNU with a mean of 60 FNU at Cottonwood (table 4), and turbidity daily values exceeded the EPA nonenforceable guideline (19.5 FNU) about 63 percent of the time (fig. 8*B*). At Burlingame, continuously measured YSI 6600 model 6136 turbidity ranged from less than 1 to 2,450 FNU with a mean of 53 FNU and YSI EXO turbidity ranged from 2.3 to 2,300 FNU with a mean of 51 FNU (table 4, fig. 8*A*, *B*). Turbidity daily values at Burlingame exceeded the EPA nonenforceable guideline (19.5 FNU) about 56 percent of the time during the analysis period. At Neosho Rapids, continuously measured YSI 6600 model 6136 turbidity ranged from 1.7 to 1,460 FNU with a mean of 68 FNU and YSI EXO turbidity ranged from 1.8 to 1,190 FNU with a mean of 77 FNU (table 4, fig. 8*A*, *B*). Turbidity daily values at Neosho Rapids exceeded the EPA nonenforceable guideline (15.5 FNU) about 74 percent of the time during the analysis period. At Burlington, YSI 6600 model 6136 turbidity ranged from 3.9 to 760 FNU with a mean of 29 FNU and YSI EXO turbidity ranged from 3.3 to 1,640 FNU with a mean of 28 FNU (table 4, fig. 8*A*, *B*). Turbidity daily values at Burlington exceeded the EPA nonenforceable guideline (15.5 FNU) about 66 percent of the time during the analysis period.

High-flow daily mean turbidity values (1–5-percent exceedance) for the YSI 6600 model 6136 turbidity sensor at Neosho Rapids were larger than the values upstream at Burlingame or downstream at Burlington (fig. 8*A*). Low-flow daily turbidity values (99-percent exceedance) were largest at Burlington and smallest at Burlingame (fig. 8*A*). High-flow daily mean YSI EXO turbidity values (1–5 percent) were largest at Neosho Rapids, whereas turbidity values at both upstream sites, Cottonwood and Burlingame, were smaller and Burlington (downstream) was the smallest (fig. 8*B*). The YSI EXO low-flow daily turbidity values (99-percent exceedance) were largest at Burlington and smallest at Neosho Rapids (fig. 8*B*). At Burlington, regulation by the reservoir and lack of contributing drainage area downstream from John Redmond Dam likely contributed to a smaller range of turbidity values.

Regression Models and Computed Concentrations, Loads, and Yields for Suspended Sediment

Turbidity has been used to compute SSC in Kansas streams when silt and clay compose most of the suspended sediment (Christensen and others, 2000; Rasmussen and others, 2005; Lee and others, 2008; Rasmussen and others, 2008; Juracek, 2011; Stone and others, 2013, 2015; Foster, 2014). In selected samples collected during high flow with large turbidity values (greater than 500 FNU), suspended sediment was measured by weight for grain sizes of 0.002, 0.004, 0.008, 0.016, 0.031, 0.065, and 1 millimeter (mm). Silt and clay (less than 0.065 mm) composed at least 85 percent of the selected samples by weight (appendix 13). Optical turbidity sensors are appropriate to compute suspended sediment because of the large percentage of fine material (silt and clay particles) present, including during high flow. Slope similarities among turbidity-SSC regression models for all four sites indicated that sediment grain size and color (the primary factors affecting those models) were similar among study sites, which coincided with findings in Lee and others (2008) and Foster (2014).

Regression models were developed using turbidity data collected during 2010 through 2019. Instream continuously measured variables for each study site included temperature, specific conductance, and turbidity. Previously published SSC models (Foster, 2014) were updated using new turbidity and SSC data (table 6).

A turbidity-SSC regression-computed time-series model is considered more reliable and reproducible than a streamflow-SSC regression-computed model (Rasmussen and others, 2009). Based on the R^2 from newly developed regression models, turbidity explained 92–99 percent of the variance in SSC and the streamflow-based regression models explained 45–77 percent of the variance (table 6). The MSPE for the turbidity-SSC regression model was 20.7–41.2 percent, and for the streamflow-SSC model, the MSPE was 70.2–108 percent (table 6). Prediction intervals (95 percent) were plotted along with regression relations among turbidity (YSI 6600 model 6136 and YSI EXO), streamflow, and SSC (figs. 9, 10, 11). The range of values within the 95-percent prediction interval for turbidity-based regressions was much smaller than the range for the streamflow-based regressions, indicating better performance.

Suspended-Sediment Concentrations, Loads, and Yields

Computed daily mean concentrations of suspended sediment at Cottonwood ranged from 6 to 2,680 mg/L (mean: 179 mg/L) during 2015 through 2019 (partial years included; table 9). Annual mean SSC was largest in 2019 (244 mg/L) and smallest in 2018 (116 mg/L; table 10). Computed daily loads for Cottonwood ranged from 1 to 176,000 tons (mean: 2,180 tons; table 9). The annual load was largest in 2019 (1,800,000 tons) and smallest in 2018 (261,000 tons; table 10). At this site, annual data were not available during 2010 through 2015.

Computed daily mean concentrations of suspended sediment at Burlingame ranged from 1 to 3,180 mg/L (mean: 108 mg/L) during 2010 through 2019 (partial years included; table 9). Annual mean SSC was largest in 2019 (178 mg/L) and smallest in 2012 (70 mg/L; table 10). Computed daily loads for Burlingame ranged from less than 1 to 75,900 tons (mean: 624 tons; table 9). The annual load was largest in 2019

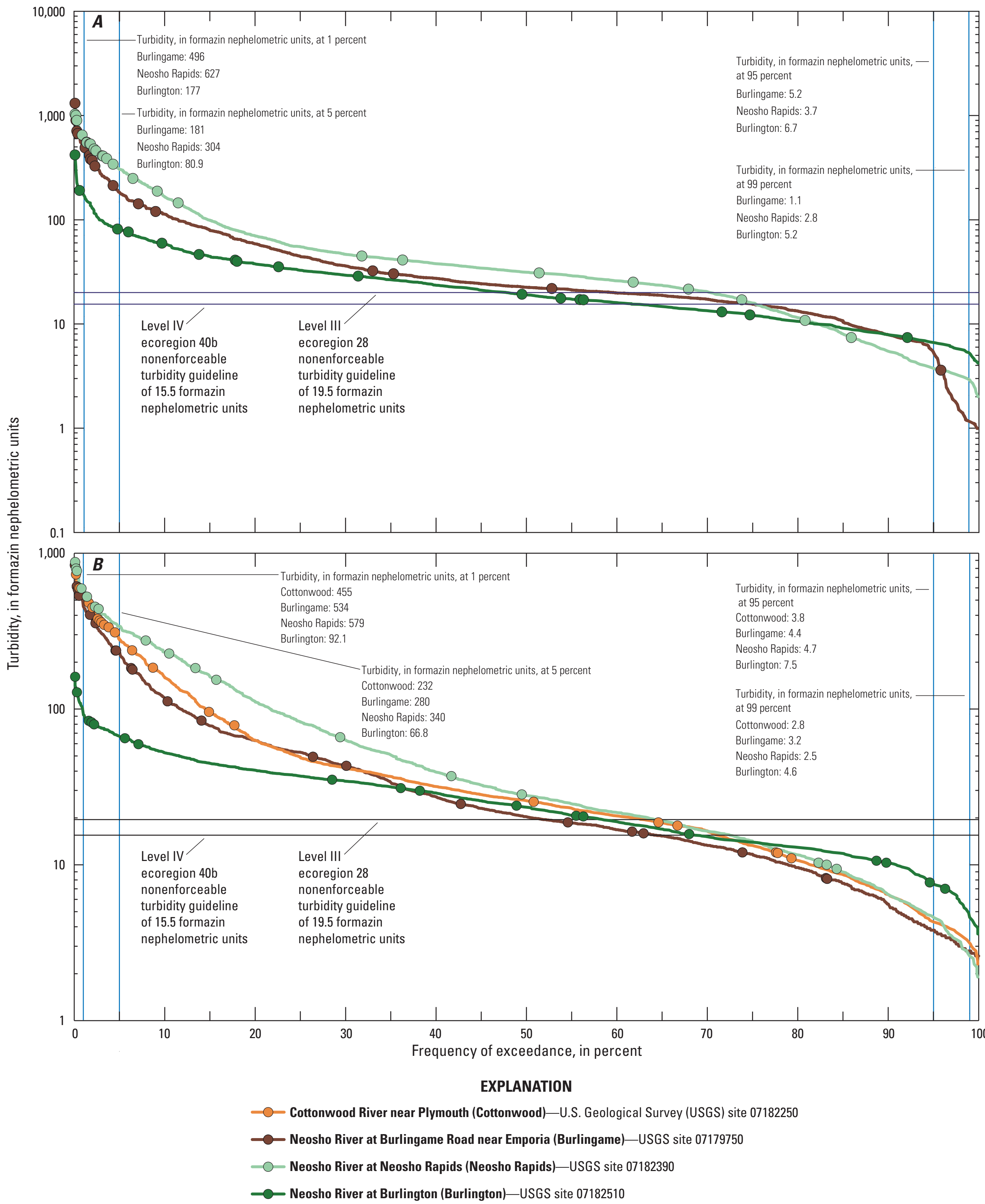

Figure 8. Duration curves of daily mean turbidity measurements for study sites along the Cottonwood and Neosho Rivers, Kansas, during 2010 through 2019. *A*, turbidity measured using YSI Incorporated 6600 Extended Deployment System monitor model 6136 turbidity sensor; *B*, turbidity measured using Xylem YSI EXO turbidity sensor.

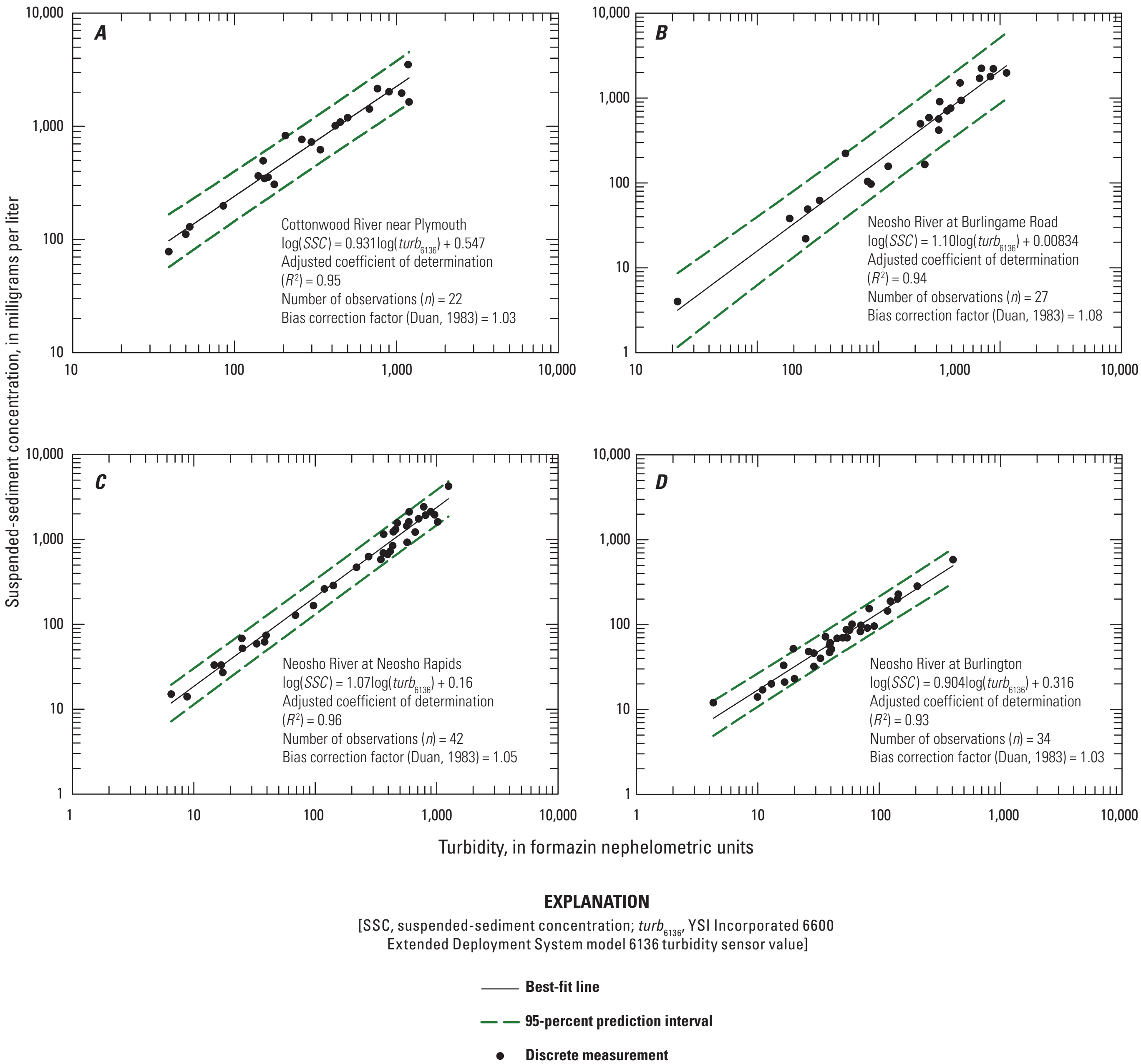

Figure 9. Regression relations between YSI Incorporated 6600 Extended Deployment System monitor model 6136 turbidity and suspended-sediment concentrations for study sites along the Cottonwood and Neosho Rivers, Kansas, during 2007 through 2015. *A*, Cottonwood River near Plymouth (U.S. Geological Survey [USGS] site 07182250); *B*, Neosho River at Burlingame Road near Emporia (USGS site 07179750); *C*, Neosho River at Neosho Rapids (USGS site 07182390); *D*, Neosho River at Burlington (USGS site 07182510).

(625,000 tons) and smallest in 2012 (37,200 tons; table 10). At this site, annual data were not available for 2013, 2014, and 2015.

Neosho Rapids was the only site with no large gaps in the continuous record for the analysis period (2010 through 2019). Computed daily mean concentrations of suspended sediment ranged from 3 to 2,750 mg/L (mean: 162 mg/L; table 9). Annual mean SSC was largest in 2019 (278 mg/L) and smallest in 2012 (107 mg/L), which corresponds to the years with the largest and smallest mean streamflow and greatest and least total annual precipitation, respectively (table 10, table 7, table 3). Computed daily loads for Neosho Rapids ranged from less than 1 to 184,000 tons (mean: 2,250 tons; table 9). The annual load was largest in 2019 (2,540,000 tons) and smallest in 2012 (173,000 tons), which corresponds to the largest and smallest annual total streamflow respectively (table 10, table 7).

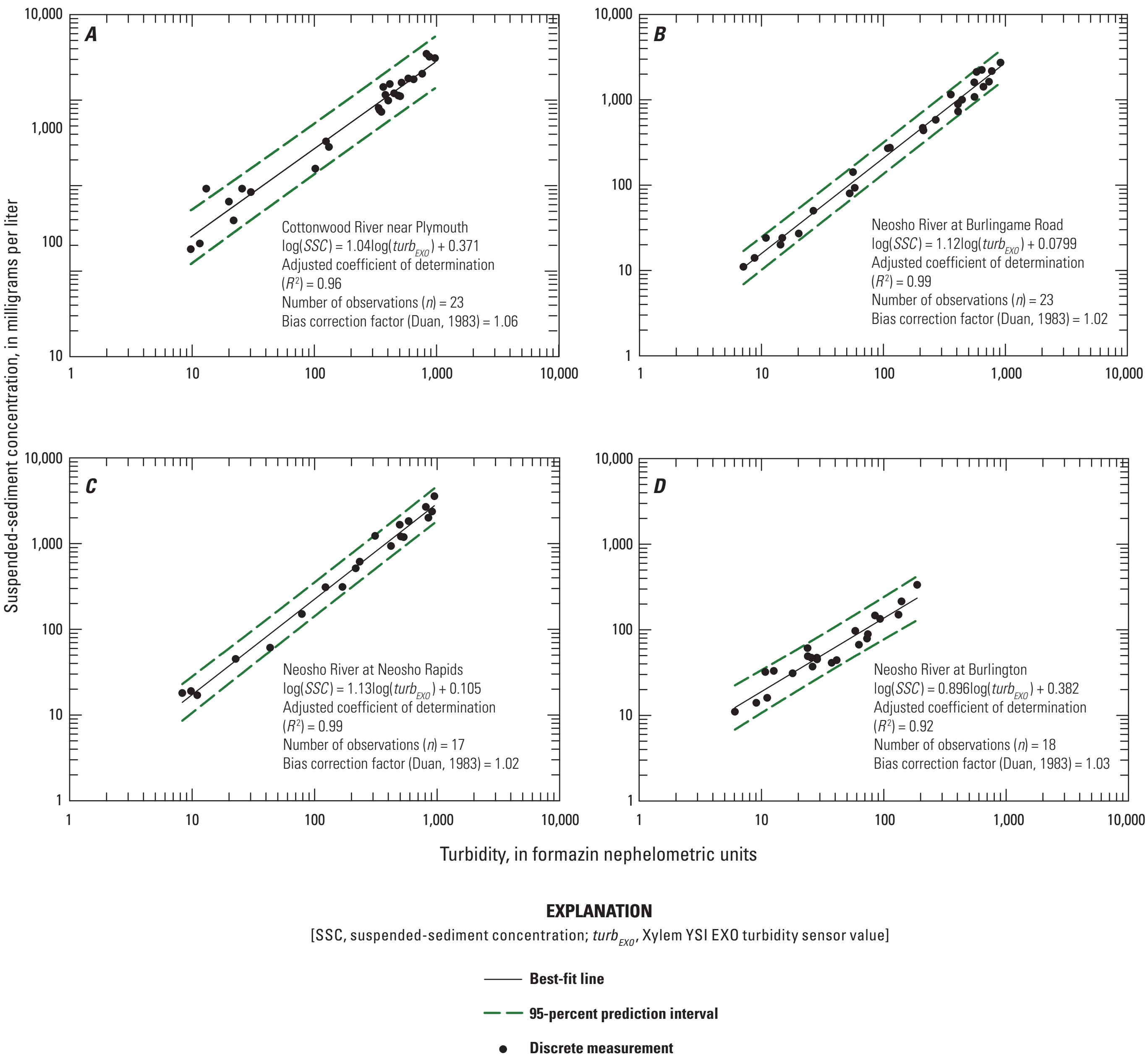

Figure 10. Regression relations between Xylem YSI EXO, model EX02, turbidity and suspended-sediment concentrations for study sites along the Cottonwood and Neosho Rivers, Kansas, during 2015 through 2019. *A*, Cottonwood River near Plymouth (U.S. Geological Survey [USGS] site 07182250); *B*, Neosho River at Burlingame Road near Emporia (USGS site 07179750); *C*, Neosho River at Neosho Rapids (USGS site 07182390); *D*, Neosho River at Burlington (USGS site 07182510).

Computed daily mean concentrations of suspended sediment at Burlington ranged from 8 to 500 mg/L (mean: 46 mg/L) during 2010 through 2019 (partial years included; table 9). Annual mean SSC was largest in 2010 (67 mg/L) and smallest in 2014 (27 mg/L; table 10). Computed daily loads for Burlington ranged from less than 1 to 9,860 tons (mean: 286 tons; table 9). The annual load was smallest in 2014 (18,800 tons) and largest in 2019 (305,000 tons; table 10). At this site, annual data were not available for 2011, 2012, and 2013.

The mean daily suspended-sediment load at Cottonwood (the Cottonwood River arm) was 3.5 times larger (2,180 tons) than at Burlingame (624 tons; the Upper Neosho arm). During the analysis period, Neosho Rapids had the largest mean daily suspended-sediment loads (2,250 tons) but was only 3 percent larger than the mean daily sediment load at Cottonwood. The mean daily sediment load at Burlington was the smallest of the four sites (286 tons), and this site consistently had the small-est annual suspended-sediment load throughout the analysis

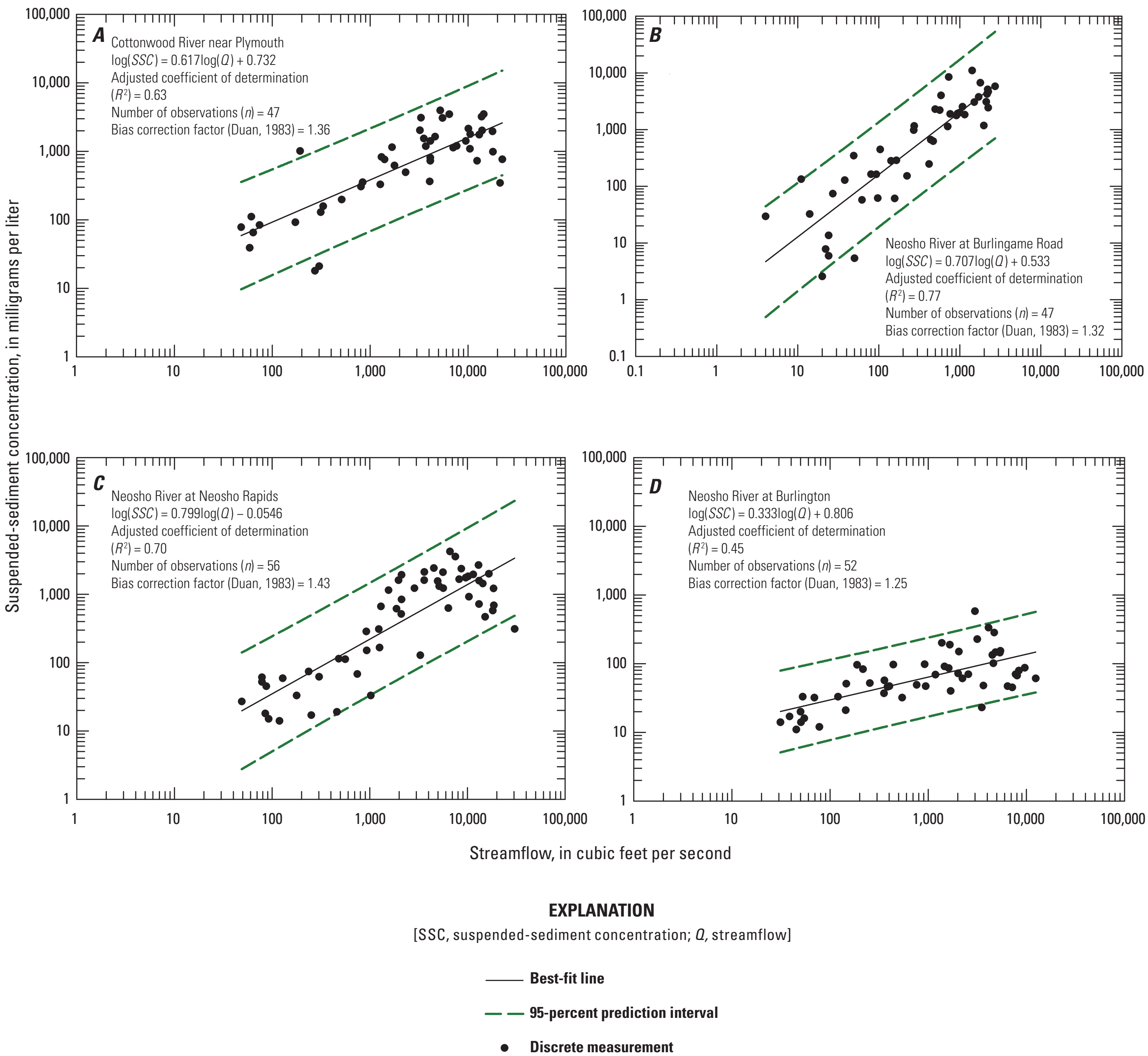

Figure 11. Regression relations between streamflow and suspended-sediment concentrations for study sites along the Cottonwood and Neosho Rivers, Kansas, during 2007 through 2019. *A*, Cottonwood River near Plymouth (U.S. Geological Survey [USGS] site 07182250); *B*, Neosho River at Burlingame Road near Emporia (USGS site 07179750); *C*, Neosho River at Neosho Rapids (USGS site 07182390); *D*, Neosho River at Burlington (USGS site 07182510).

period (table 10). Compared to Neosho Rapids (upstream from the reservoir), the mean daily load at Burlington (downstream from the reservoir) was 87 percent less.

Load duration curves were used to compare study sites. The top 1 percent of suspended-sediment daily loads, in decreasing order, were 51,500 tons at Neosho Rapids, 50,000 tons at Cottonwood, 18,500 tons at Burlingame, and 3,470 tons at Burlington (fig. 12). All sites had similar daily loads at the 99th percentile ranging from less than 1 to 1.7 tons (fig. 12). Duration curves for daily loads were comparable for Cottonwood and Neosho Rapids. Daily suspended-sediment loads at Burlingame were typically (more than about 95 percent of the time) lower than the other sites (fig. 12). The duration curve of suspended-sediment loads at Burlington has characteristics expected of a site with predominantly regulated flow, with the smaller range of loads.

Suspended-sediment yields were calculated for all sites during years for which data were available. Cottonwood had yields ranging from 299,000 lb/mi^2 in 2018 to 2,070,000 lb/mi^2 in 2019 (table 10). Burlingame yields ranged from

Table 9. Suspended-sediment concentrations and suspended-sediment loads computed using daily mean values from regulated and unregulated drainage areas at monitoring sites along the Cottonwood and Neosho Rivers, Kansas.

[mg/L, milligram per liter; Cottonwood, Cottonwood River near Plymouth (U.S. Geological Survey [USGS] site 07182250); Burlingame, Neosho River at Burlingame Road near Emporia (USGS site 07179750); <, less than; Neosho Rapids, Neosho River at Neosho Rapids (USGS site 07182390); Burlington, Neosho River at Burlington (USGS site 07182510)]

Summary statistic	Suspended-sediment concentration (mg/L)	Sediment load (ton)
	Cottonwood (2015–19)	
Minimum	6	1
Maximum	2,680	176,000
Mean	179	2,180
Median	69	41
	Burlingame (2010–19)	
Minimum	1	<1
Maximum	3,180	75,900
Mean	108	624
Median	36	4
	Neosho Rapids (2010–19)	
Minimum	3	<1
Maximum	2,750	184,000
Mean	162	2,250
Median	59	36
	Burlington (2010–19)	
Minimum	8	<1
Maximum	500	9,860
Mean	46	286
Median	35	21

98,300 lb/mi^2 in 2012 to 1,650,000 lb/mi^2 in 2019. Between the two upstream sites, Cottonwood had consistently higher yields except for 2017 when Burlingame had an estimated 1 percent higher yield than Cottonwood. Yields at Neosho Rapids ranged from 126,000 lb/mi^2 in 2012 to 1,840,000 lb/mi^2 in 2019. There were 3 years (2016, 2018, and 2019) where Cottonwood had higher estimated yields than Neosho Rapids (about 5, 1, and 12 percent higher, respectively). Burlington yields were substantially smaller than the other three sites, ranging from 12,400 lb/mi^2 in 2014 to 201,000 lb/mi^2 in 2019 (table 10).

During the analysis period, 2010 and 2019 had 6 days with extreme precipitation (defined as greater than 1.68 in. of rainfall within a 24-hour period) with a total basin mean accumulation of 14.5 and 14.9 in., respectively. These years correspond to the largest computed suspended-sediment concentrations, loads, and yields at the study sites along the Cottonwood and Neosho Rivers. Nearly 25 percent of the total precipitation during the analysis period occurred during these extreme events, which totaled only 38 24-hour periods over 10 years (1.2 percent of the analysis period).

In comparison, 45–68 percent of the total sediment load at each upstream site (Cottonwood: 68 percent; Burlingame: 62 percent; Neosho Rapids: 45 percent) was transported during the top 38 loading days. Of the top 38 loading days for each site, 21 of the days for Cottonwood, 17 of the days for Neosho Rapids, and 15 of the days for Burlingame occurred in 2019. The estimated sediment load was about 490–590 percent higher in 2019 than what was estimated for 2018 for all upstream sites and 310 percent higher in 2019 than 2018 at Burlington, downstream from the reservoir, indicating large sedimentation rates are driven by extreme events (high flow, precipitation, flooding) within this drainage basin.

Table 10. Computed annual mean concentrations, loads, and yields of suspended sediment at monitoring sites on the Cottonwood and Neosho Rivers, Kansas.

[Cottonwood, Cottonwood River near Plymouth (U.S. Geological Survey [USGS] site 07182250); Burlingame, Neosho River at Burlingame Road near Emporia (USGS site 07179750); Neosho Rapids, Neosho River at Neosho Rapids (USGS site 07182390); Burlington, Neosho River at Burlington (USGS site 07182510); mg/L, milligram per liter; lb/mi^2, pound per square mile; --, data not available]

Year	Cottonwood			Burlingame			Neosho Rapids			Burlington		
	Concentration (mg/L)	Load (ton)	Yield[1] (lb/mi^2)	Concentration (mg/L)	Load (ton)	Yield[1] (lb/mi^2)	Concentration (mg/L)	Load (ton)	Yield[1] (lb/mi^2)	Concentration (mg/L)	Load (ton)	Yield[1] (lb/mi^2)
2010	--	--	--	145	314,000	830,000	222	1,230,000	892,000	67	--	--
2011	--	--	--	88	51,200	135,000	139	256,000	186,000	--	--	--
2012	--	--	--	70	37,200	98,300	107	173,000	126,000	--	--	--
2013	--	--	--	--	--	--	125	442,000	321,000	--	--	--
2014	--	--	--	--	--	--	111	307,000	223,000	27	18,800	12,400
2015	--	--	--	--	--	--	189	1,030,000	750,000	32	76,600	50,300
2016	190	709,000	815,000	93	231,000	610,000	197	1,070,000	779,000	55	146,000	95,700
2017	126	381,000	438,000	94	167,000	442,000	143	758,000	551,000	37	82,600	54,300
2018	116	261,000	299,000	72	107,000	282,000	113	410,000	298,000	40	74,900	49,300
2019	244	1,800,000	2,070,000	178	625,000	1,650,000	278	2,540,000	1,840,000	66	305,000	201,000

[1]Yield is calculated using short tons (U.S. customary units) and the contributing drainage area in the drainage basin upstream from the location of the sites.

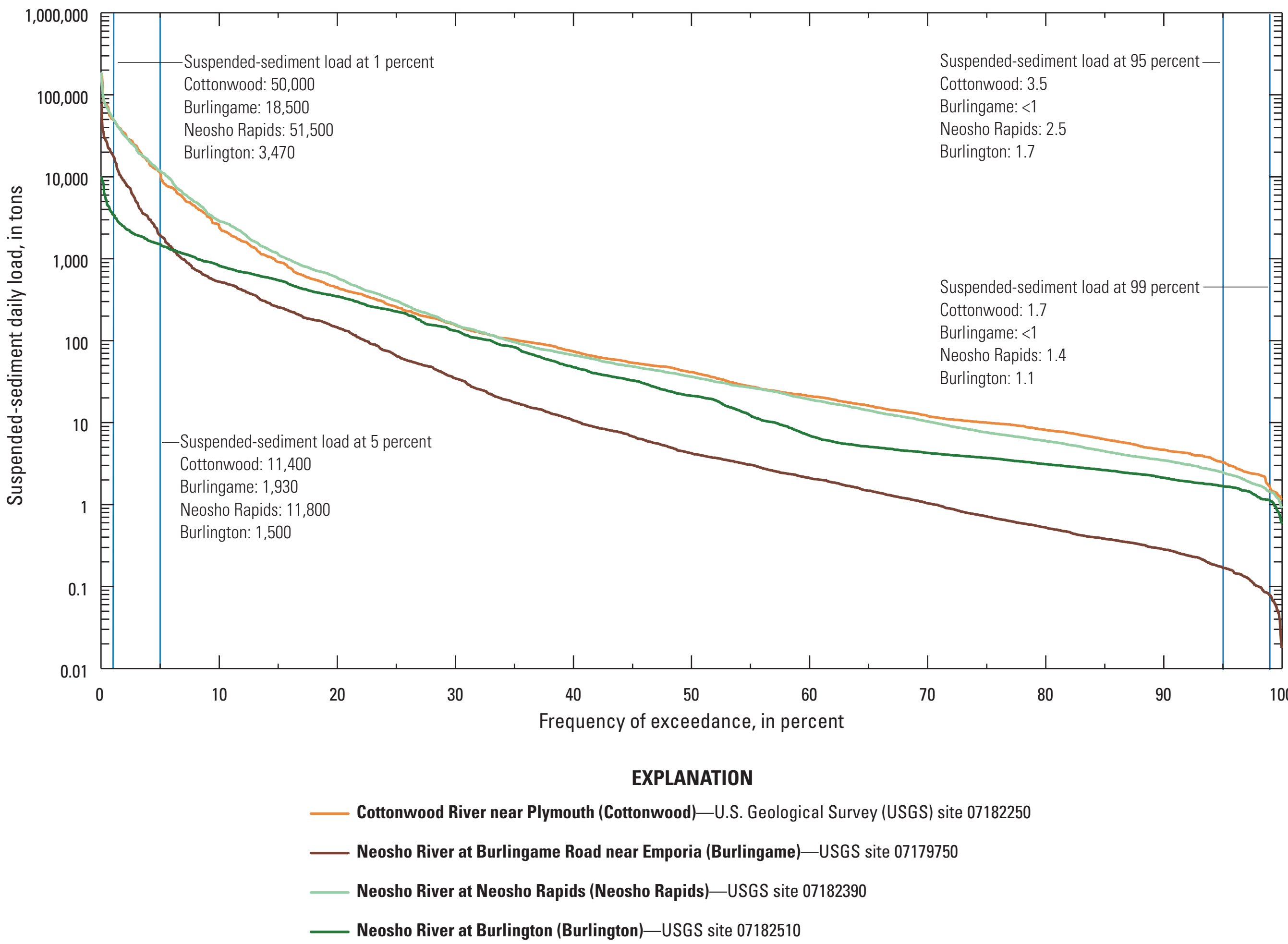

Figure 12. Duration curves of estimated daily suspended-sediment loads for study sites along the Cottonwood and Neosho Rivers, Kansas, during 2010 through 2019.

Sediment Trapping in John Redmond Reservoir

Sediment trapping efficiency, expressed as a percentage, was estimated as the total annual suspended-sediment load removed from the reservoir by releases (Burlington) subtracted from the total annual load delivered to the reservoir (Neosho Rapids). Using only years for which the Neosho Rapids and Burlington sites had continuous water-quality monitoring data (years 2010, 2014–19), estimated sediment loads were used to calculate the amount of sediment retained annually by the reservoir (table 11, fig. 13). A potential source of error in estimating sediment storage and trapping efficiency was large logjams just upstream from the reservoir, which may cause sediment to settle out of the water column before entering the reservoir (U.S. Army Corps of Engineers, 2005; Lee and others, 2008). Additional possible sources of error include the entrainment and transport of sediment from channel banks between Neosho Rapids and the reservoir and between the reservoir outflow and Burlington.

During years when concurrent load estimates were available for Neosho Rapids and Burlington (2010, 2014–19), an estimated total of 7,340,000 tons (mean: 1,050,000 tons) of sediment entered the reservoir (Neosho Rapids) and 895,000 tons (mean: 128,000 tons) were released downstream (Burlington). The difference is about 6,450,000 tons of sediment trapped in the reservoir during those 7 years, an 89-percent trapping efficiency. This compares closely with Lee and others (2008), who determined that during February 21, 2007, through February 21, 2008, an estimated 1,120,000 tons were transported into the reservoir and only 100,700 tons were transported downstream past Burlington, a 91-percent trapping efficiency. The lower trapping efficiency could be due to not including estimates for the ungaged 9 percent of the drainage basin in the computations.

The largest suspended-sediment load retained by the reservoir was during 2019 (2,230,000 tons), which corresponds to the largest annual mean streamflow for Neosho Rapids and Burlington (3,270 and 4,110 ft^3/s, respectively; table 7) and resulted in an 88-percent trapping efficiency. The largest trapping efficiency was in 2014 (94 percent) when

Table 11. Estimated annual suspended-sediment load upstream and downstream from the reservoir, amount of load retained, and trapping efficiency of John Redmond Reservoir, Kansas.

[Neosho Rapids, Neosho River at Neosho Rapids (U.S. Geological Survey [USGS] site 07182390); Burlington, Neosho River at Burlington (USGS site 07182510); --, data not available]

Year	Total sediment load (ton)		Sediment load retained by reservoir (ton)	Reservoir trapping efficiency (percent)
	Neosho Rapids	Burlington		
2010	1,230,000	191,000	1,040,000	84.4
2011	256,000	--	--	--
2012	173,000	--	--	--
2013	442,000	--	--	--
2014	307,000	18,800	288,000	93.9
2015	1,030,000	76,600	953,000	92.6
2016	1,070,000	146,000	924,000	86.4
2017	758,000	82,600	675,000	89.1
2018	410,000	74,900	335,000	81.7
2019	2,540,000	305,000	2,230,000	88.0
Total	8,220,000	895,000	6,450,000	--
Mean	822,000	128,000	921,000	89.1
Median	600,000	82,600	924,000	88.0

mean streamflow was second smallest (2012 had the smallest mean streamflow) at Neosho Rapids and Burlington because of drought conditions (mean: 359 and 431 ft^3/s, respectively). Sufficient data were not available for computations for 2012. During drought years, reservoir releases are minimal, effectively trapping most, if not all, of the suspended-sediment influx.

Suspended-sediment loads and the mean bulk density of the sediment historically deposited in the reservoir were used to estimate the storage capacity of the reservoir lost to sedimentation (Foster, 2016). Juracek (2010) used sediment cores to determine a representative bulk density for the reservoir by averaging the mean bulk density of four individual cores (38.2 pounds per cubic foot). By converting total sediment load in tons to pounds and dividing by the representative bulk density, the storage capacity lost to sedimentation can be estimated. During years with complete annual datasets at Neosho Rapids and Burlington (2010, 2014–19), about 7,750 acre-ft was lost because of sedimentation assuming all sediment was deposited in the multipurpose pool area. In 2019, the reservoir lost an estimated 2,680 acre-ft of reservoir storage to sedimentation. To obtain an estimate for the analysis period, including years with missing retained load estimations because of missing data at Burlington (2011–13; table 11), the incoming load at Neosho Rapids was multiplied by the mean reservoir trapping efficiency (89 percent) to estimate the load retained in the reservoir (230,000 tons, 155,000 tons, and 397,000 tons during 2011–13, respectively). The estimated total load retained in the reservoir during 2010–19 was about 8,690 acre-ft (mean annual load: 723,000 tons), about 17 percent of the remaining storage space (50,200 acre-ft) reported in 2007 (Juracek, 2010). The reservoir designed sedimentation rate was 404 acre-ft/yr and previous studies determined the sedimentation rate was much higher; during 1964–2010, the U.S. Army Corps of Engineers (2016) estimated a sedimentation rate of 736 acre-ft/yr, and during 2007–14, Jakubauskas and others (2014) estimated a sedimentation rate of 492 acre-ft/yr. During the analysis period, the mean annual sedimentation rate was about 747 acre-ft/yr, higher than the 1964–2010 and 2007–14 estimations and about 85 percent more than the designed reservoir sedimentation rate.

A dredging operation removed about 3 million cubic yards (yd^3; about 1,860 acre-ft) of sediment from the reservoir in 2016 (Kansas Water Office, 2017). During 2010 through 2019, about 14,000,000 yd^3 of sediment were deposited into the reservoir. In 2019, about 4.3 million yd^3 of sediment were retained in the reservoir from flooding that occurred in the drainage basin. Reservoir outflow management models indicated a 3-percent reduction in overall sediment trapping in the reservoir if mean residence times were kept short and the reservoir was operated near normal operating capacity as opposed to higher flood pool levels (Lee and Foster, 2013). During 2010 through 2019, a 3-percent reduction in the total sediment deposited to the reservoir is equal to about 261 acre-ft. That potential sediment reduction equals about 14 percent of the total sediment removed as part of the $20 million dredging project. Results from this study demonstrate that sediment deposits during large inflow events were substantially larger

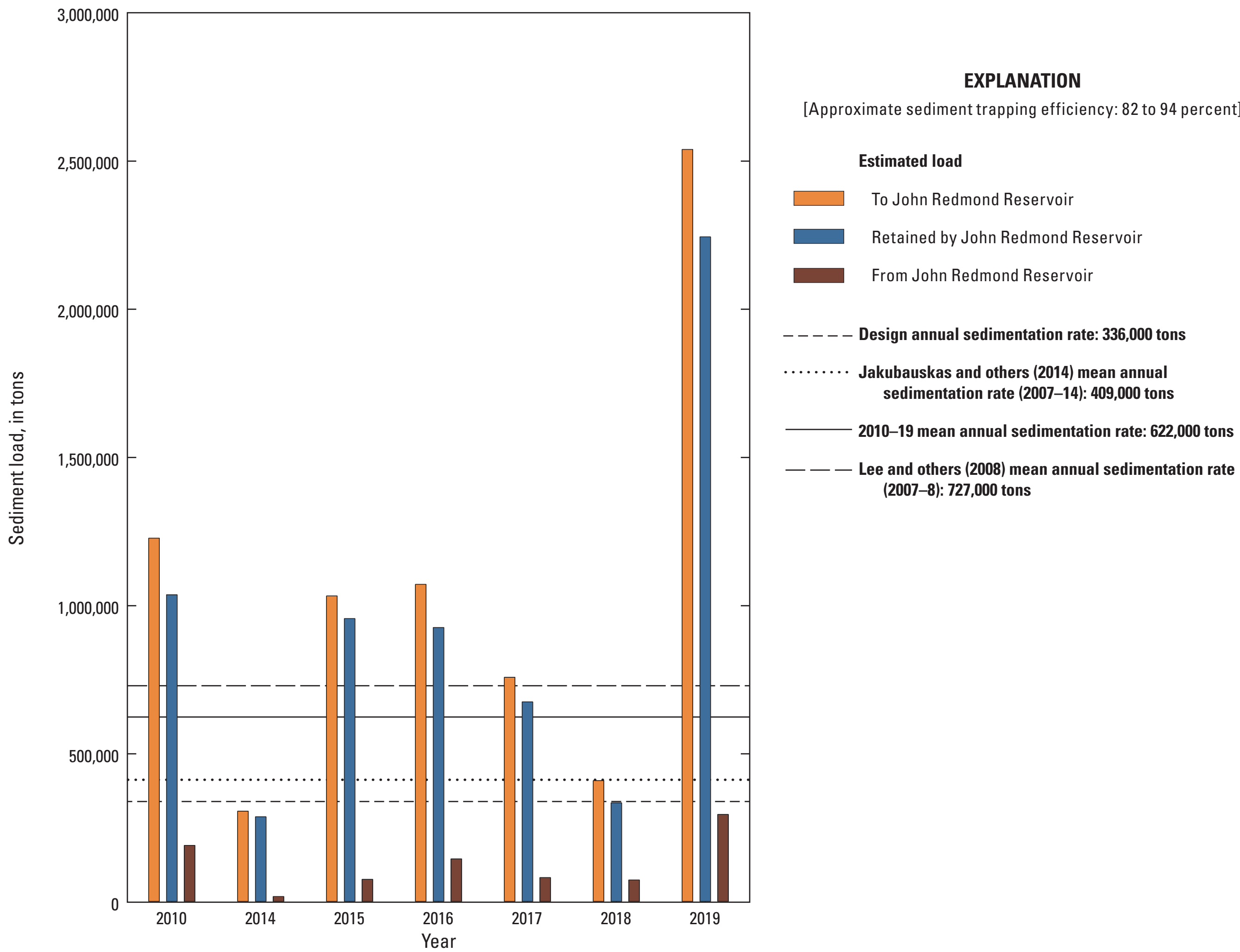

Figure 13. Estimated sediment loads into and out of John Redmond Reservoir, Kansas, and the resulting load retained in the reservoir during 2010 and 2014–19.

than previously dredged quantities of sediment and managing outflows could minimize sediment accumulation while still preserving flood control.

Suspended Sediment Transported during High-Flow Events and Relations to Streambank Stabilization

To estimate greater than channel-control streamflows, associated streamflow for the NWS flood action stage was defined at all upstream study sites. The flood action stage at Cottonwood was 30 ft; nine stage-discharge ratings during the analysis period were averaged, and the corresponding streamflow was 12,300 ft^3/s (standard deviation: 1,310 ft^3/s). At Cottonwood, this streamflow had a 1-percent AEP. The flood action stage at Neosho Rapids was 17 ft; three stage-discharge ratings during the analysis period were averaged, and the corresponding streamflow was 11,500 ft^3/s (standard deviation: 899 ft^3/s). At Neosho Rapids, this streamflow had a 2.2-percent AEP. The drainage-area ratio estimated streamflow for Burlingame was 7,010 ft^3/s (standard deviation: 515 ft^3/s) based on four stage-discharge ratings and a flood action stage of 21 ft upstream at the Neosho River near Americus. At Burlingame, this streamflow had a 0.7-percent AEP.

During 2016 through 2019 at Cottonwood, 48 percent of the total suspended-sediment load was transported when streamgage height was above the flood action stage and streamflows were greater than 12,300 ft^3/s (26 days, 1.8 percent of record). During 2010 through 2019 at Burlingame (excluding 2013–15 because of incomplete records), 40 percent of the total suspended-sediment load was transported when streamgage height was above the flood action stage and streamflows were greater than 7,010 ft^3/s (23 days, 0.1 percent of record). During 2010 through 2019 at Neosho Rapids, 78 percent of the total suspended-sediment load was transported when streamgage height was above the flood action stage and streamflows were greater than 11,500 ft^3/s

Table 12. Total suspended-sediment load and suspended-sediment load when streamflow is greater than flood action stage associated streamflow for sites upstream from John Redmond Reservoir, Kansas.

[Cottonwood, Cottonwood River near Plymouth (U.S. Geological Survey [USGS] site 07182250); Burlingame, Neosho River at Burlingame Road near Emporia (USGS site 07179750); Neosho Rapids, Neosho River at Neosho Rapids (USGS site 07182390); --, data not available]

Year	Cottonwood			Burlingame			Neosho Rapids		
	Total load (ton)	Total load above flood action stage[1] (ton)	Percent of total load	Total load (ton)	Total load above flood action stage[2] (ton)	Percent of total load	Total load (ton)	Total load above flood action stage[3] (ton)	Percent of total load
2010	--	--	--	314,000	114,000	36	1,230,000	973,000	79
2011	--	--	--	51,200	--	--	256,000	151,000	59
2012	--	--	--	37,200	--	--	173,000	86,000	50
2013	--	--	--	--	--	--	442,000	299,000	68
2014	--	--	--	--	--	--	307,000	222,000	72
2015	--	--	--	--	--	--	1,030,000	810,000	78
2016	709,000	143,000	20	231,000	142,000	62	1,070,000	808,000	75
2017	381,000	211,000	55	167,000	27,600	17	758,000	615,000	81
2018	261,000	118,000	45	107,000	24,500	23	410,000	300,000	73
2019	1,800,000	1,040,000	58	625,000	311,000	50	2,540,000	2,170,000	86
Total	3,150,000	1,510,000	48	1,530,000	619,000	40	8,220,000	6,430,000	78

[1]Daily streamflow greater than or equal to 12,300 cubic feet per second (ft^3/s).

[2]Daily streamflow greater than or equal to 7,010 ft^3/s.

[3]Daily streamflow greater than or equal to 11,500 ft^3/s.

(184 days, 5 percent of record). Annually, the percentage of total loads from greater than flood action stage streamflows ranged from 17 to 86 percent (table 12).

Stream channel banks and surrounding areas are likely a more important source of sediment to the reservoir from the upstream drainage basin compared to channel beds (Straub and others, 2006; Juracek, 2010). Linking changes in sediment loads to causal factors requires monitoring before, during, and after changes, which presents challenges related to length, frequency, and scale of data collection in addition to available streambank stabilization data. Disproportionately large sediment loads are delivered during short periods of time, and localized efforts of stream erosion protection (streambank stabilization, riparian buffers) are likely to be overwhelmed during extreme conditions. Precipitation frequency and intensity are projected to continue to increase in this region (Shafer and others, 2014; Kloesel and others, 2018); therefore, future sediment reduction strategies that account for extreme episodic events may be beneficial. Continued investigation of sediment reduction measures is necessary for future mitigation with the understanding that sedimentation rate is largely driven by high flows.

Summary

Streambank erosion and reservoir sedimentation are primary concerns of resource managers in Kansas and throughout many regions of the United States and negatively affect flood control, water supply, and recreation. John Redmond Reservoir, in east-central Kansas, has a primarily agricultural drainage basin of about 3,015 square miles that is drained by the Cottonwood and upper Neosho Rivers. Since the completion of the reservoir in 1964, there has been rapid sedimentation of its conservation pool. Channel banks and surrounding areas were more likely the source of sediment to the reservoir than channel beds. In an effort to reduce the amount of sediment transported to the reservoir, the Kansas Water Office implemented streambank stabilization projects along sections of the Cottonwood and upper Neosho Rivers. The U.S. Geological Survey (USGS), in cooperation with the Kansas Water Office, has been monitoring water quality at four sites within the drainage basin.

Daily precipitation during the analysis period was available from multiple Global Historical Climatology Network stations in the drainage basin. A mean of the annual precipitation and extreme precipitation days at three Global Historical Climatology Network stations was taken to represent a basin mean because precipitation can vary spatially. The mean annual precipitation during 2010 through 2019 was 35.4 inches (in.) and ranged from 22.4 to 49.6 in. in 2012 and 2019, respectively. The top 1 percent of daily precipitation during a 100-year period was used to define extreme precipitation (1.68 in.). During the analysis period, the annual number of days with extreme precipitation ranged from 2 to 6 days with annual precipitation totals from those events ranging from 3.9 to 14.9 in. Although the number of extreme precipitation days (38 days) only accounted for about 1 percent of the analysis period, the total accumulated precipitation during these events accounted for 24 percent of the total precipitation. A substantial part of the total annual precipitation occurred during these extreme events during a disproportionately small amount of time and can result in increased runoff and sediment erosion.

Real-time water-quality monitors, measuring water temperature, specific conductance, and turbidity, collected continuous water-quality readings every 15-minutes during January 1, 2010, through December 31, 2019. Water-quality monitors at Cottonwood River near Plymouth, Kansas (USGS site 07182250; hereinafter referred to as "Cottonwood"); Neosho River at Burlingame Road near Emporia, Kans. (USGS site 07179750; hereinafter referred to as "Burlingame"); and Neosho River at Burlington, Kans. (USGS site 07182510; hereinafter referred to as "Burlington"), were removed (various dates) during the analysis period for various reasons, including low flow from drought conditions, and then reinstalled (various dates). Three water-quality monitoring sites were upstream from John Redmond Reservoir (Cottonwood, Burlingame, and Neosho River at Neosho Rapids, Kans. [USGS site 07182390; hereinafter referred to as "Neosho Rapids"]) and one water-quality monitoring site was located downstream from the reservoir (Burlington). In 2015, the YSI Incorporated 6600 Extended Deployment System water-quality monitors (hereinafter referred to as "YSI 6600") were removed and replaced with Xylem YSI EXO, model EXO 2, continuous water-quality monitors (hereinafter referred to as "YSI EXO"). Water temperature and specific conductance are considered comparable throughout the analysis period. There are documented differences in the YSI 6600 model 6136 and YSI EXO turbidity sensors. There is no established relation between the YSI 6600 model 6136 and YSI EXO turbidity sensor models; therefore, individual models for each sensor were developed.

Discrete water-quality samples were collected during the analysis period and were analyzed for suspended-sediment concentration (SSC), sand-fine split percentage, and in most cases of high turbidity (greater than or equal to 500 formazin nephelometric units), five-point grain-size analysis. Silt and clay (less than 0.065 millimeter) composed more than 85 percent of selected high-flow samples by weight, indicating that turbidity as a surrogate for SSC was appropriate.

Regression models were updated from previous studies and developed using YSI 6600 and YSI EXO sensor turbidity data. Updated models had larger variance than previously published models but were still considered statistically similar. During the YSI 6600 deployment, low flow and drought conditions reduced available data collection, which could have contributed to the changes in variance that were observed between the previous and updated models. The new YSI EXO turbidity models, used for computations beginning in 2015 (various dates), explained 92–99 percent of the variance and included data collection over a wider range of hydrologic conditions compared to the YSI 6600 data. Compared to the streamflow-SSC linear regression models, the turbidity-SSC linear regression models explained 1.2–2.1 times more variance (adjusted coefficient of determination). Model statistics for the turbidity-SSC linear regression models were better (based on the coefficient of determination, root mean square error, and model standard percentage error) than the streamflow-SSC linear regression models, indicating better performance.

Regression-computed mean SSC was 40 percent greater at Cottonwood (179 milligrams per liter [mg/L]) than at Burlingame (108 mg/L). The mean SSC at Neosho Rapids (162 mg/L) was lower than the Cottonwood site by about 9 percent. Burlington had the smallest mean SSC among all four sites (46 mg/L).

During 2016 through 2019, there were discernible patterns in suspended-sediment concentrations, loads, and yields between the two upstream sites: Cottonwood and Burlingame. Cottonwood (the Cottonwood arm) consistently had larger estimated suspended-sediment concentrations and loads than Burlingame (the Upper Neosho arm). Suspended-sediment yields also were greater in all years, except in 2017 when Burlingame had an estimated 1 percent higher yield than Cottonwood. Cottonwood had higher yields than Neosho

Rapids for 2016, 2018, and 2019. Otherwise, Neosho Rapids had higher estimated suspended-sediment concentrations and loads than either of the two upstream sites. Sediment transported downstream from John Redmond Reservoir to Burlington had substantially smaller concentrations, loads, and yields than what was transported into the reservoir at Neosho Rapids.

The mean daily suspended-sediment load at Cottonwood was 3.5 times larger (2,180 tons) than at Burlingame (624 tons). Neosho Rapids had the largest mean daily suspended-sediment load (2,250 tons; 3 percent larger than the mean daily suspended-sediment load at Cottonwood). Streamflow at Burlington was predominately regulated by the John Redmond Reservoir outflow just upstream. The mean daily suspended-sediment load at Burlington was the smallest of the four sites (286 tons), and Burlington consistently had the smallest annual suspended-sediment load throughout the analysis period. Compared to Neosho Rapids (upstream from John Redmond Reservoir), the mean daily suspended-sediment load at Burlington (downstream from reservoir) was 87 percent less. Computed suspended-sediment concentrations, loads, and yields only account for the gaged drainage area for each site. The ungaged 9 percent of the drainage basin below the Neosho Rapids streamgage was not included in the total estimation of suspended-sediment transported to John Redmond Reservoir.

During years with a complete data record at Neosho Rapids and Burlington (2010, 2014–19), the trapping efficiency of the reservoir ranged from 82 to 94 percent (mean: 89 percent) with the largest estimated amount of sediment trapped by the reservoir in 2019 (2,230,000 tons). In 2019, a total estimated load of 2,540,000 tons was transported into the reservoir (Neosho Rapids) and only 305,000 tons of sediment was estimated to have been transported out of the reservoir downstream (Burlington). As a result of increased precipitation and flooding in 2019, the reservoir lost an estimated 2,685 acre-feet (acre-ft) of reservoir storage because of sedimentation, and for years with complete annual datasets (2010, 2014–19), a total estimated 7,753 acre-ft of reservoir storage was lost. This does not include sediment loads that were retained during 2011–13 because those years had no associated turbidity data available at Burlington to estimate sediment concentrations and loads. By multiplying the mean trapping efficiency by Neosho Rapids suspended-sediment loads during years when no load data were available at Burlington (2011–13), the total estimated reservoir storage lost to sedimentation for the analysis period (2010–19) was about 8,690 acre-ft (mean annual load: 723,000 tons), about 17 percent of the remaining storage space reported in 2007. Different reservoir outflow management strategies, including operating near normal capacity as opposed to higher flood pool levels, could reduce the total reservoir storage lost by 3 percent (about 261 acre-ft). That potential sediment reduction is equal to 14 percent of the total sediment removed during the dredging operation. The mean annual sedimentation rate during the analysis period (747 acre-feet per year) was about 85 percent more than the sedimentation rate (404 acre-feet per year) originally projected during construction.

At the three sites upstream from the reservoir, 40–78 percent (mean: 56 percent) of the total suspended-sediment load was transported during streamflows above the National Weather Service flood action stage (Cottonwood mean: 48 percent; Burlingame mean: 40 percent; Neosho Rapids mean: 78 percent). Disproportionately large sediment loads are delivered during short periods of time, and localized efforts of stream erosion protection are likely to be overwhelmed. Precipitation frequency and intensity are projected to continue to increase in this region. Continued investigation of sediment reduction strategies is necessary with the understanding that sedimentation rate is largely driven by high flows. Changes to reservoir outflow management could also minimize sediment accumulation while still preserving flood control. Results from this study can be used to calibrate sediment models, explore sediment reduction strategies, highlight the importance of continued water-quality monitoring to determine effectiveness and changes in sediment transport, and assess the ability of John Redmond Reservoir to support designated uses into the future.

References Cited

Agel, L., Barlow, M., Colby, F., Binder, H., Catto, J.L., Hoell, A., and Cohen, J., 2019, Dynamical analysis of extreme precipitation in the US northeast based on large-scale meteorological patterns: Climate Dynamics, v. 52, no. 3–4, p. 1739–1760. [Also available at https://doi.org/10.1007/s00382-018-4223-2.]

Agel, L., Barlow, M., Feldstein, S.B., and Gutowski, W.J., Jr., 2018, Identification of large-scale meteorological patterns associated with extreme precipitation in the US northeast: Climate Dynamics, v. 50, no. 5–6, p. 1819–1839. [Also available at https://doi.org/10.1007/s00382-017-3724-8.]

Anderson, C.W., 2005, Turbidity (ver. 2.1, September 2005): U.S. Geological Survey Techniques of Water-Resources Investigations, book 9, chap. 6.7, 55 p.

ASTM International, 2003, ASTM D1889–00 standard test method for turbidity of water: Conshohocken, Pa., ASTM International, v. 11.01, 6 p.

Baird, D.C., Fotherby, L., Klumpp, C.C., and Sculock, S.M., 2015, Bank stabilization design guidelines: Denver, Colo., Bureau of Reclamation, SRH–2015–25, 331 p., accessed June 2020 at https://www.usbr.gov/tsc/techreferences/mands/mands-pdfs/A-BankStab-final6-25-2015.pdf.

Bennett, T.J., Graham, J.L., Foster, G.M., Stone, M.L., Juracek, K.E., Rasmussen, T.J., and Putnam, J.E., 2014, U.S. Geological Survey quality-assurance plan for continuous water-quality monitoring in Kansas, 2014: U.S. Geological Survey Open-File Report 2014–1151, 34 p. plus appendixes, accessed May 2020 at https://doi.org/10.3133/ofr20141151.

Brady, N.C., and Weil, R.R., 1999, The nature and properties of soils 12th ed.: Upper Saddle River, N.J., Prentice-Hall, 881 p.

Buchanan, R.C., ed., 1984, Kansas geology—An introduction to landscapes, rocks, minerals, and fossils: Lawrence, Kans., University Press of Kansas, 208 p.

Carswell, W.J., and Hart, R.J., 1985, Transit losses and travel times for reservoir releases during drought conditions along the Neosho River from Council Grove Lake to Iola, east-central Kansas: U.S. Geological Survey Water-Resources Investigations Report 85–4003, 40 p. [Also available at https://doi.org/10.3133/wri854003.]

Christensen, V.G., Ziegler, A.C., and Jian, X., 2000, Regression analysis and real-time water-quality monitoring to estimate constituent concentrations, loads, and yields in the Little Arkansas River, south-central Kansas, 1995–99: U.S. Geological Survey Water-Resources Investigations Report 2000–4126, 36 p. [Also available at https://doi.org/10.3133/wri004126.]

Collins, D.L., 1965, A general classification of source areas of fluvial sediment in Kansas: Kansas Geological Survey, Kansas Water Resources Board Bulletin 8, 21 p.

deNoyelles, F., and Kastens, J.H., 2016, Reservoir sedimentation challenges Kansas: Transactions of the Kansas Academy of Science, v. 119, no. 1, p. 69–81. [Also available at https://doi.org/10.1660/062.119.0110.]

Donohue, I., and Molinos, J.G., 2009, Impacts of increased sediment loads on the ecology of lakes: Biological Reviews of the Cambridge Philosophical Society, v. 84, no. 4, p. 517–531. [Also available at https://doi.org/10.1111/j.1469-185X.2009.00081.x.]

Duan, N., 1983, Smearing estimate—A nonparametric retransformation method: Journal of the American Statistical Association, v. 78, no. 383, p. 605–610. [Also available at https://doi.org/10.1080/01621459.1983.10478017.]

Eash, D.A., and Barnes, K.K., 2017, Methods for estimating selected low-flow frequency statistics and harmonic mean flows for streams in Iowa (ver. 1.1, November 2017): U.S. Geological Survey Scientific Investigations Report 2012–5171, 99 p., accessed June 2020 at https://doi.org/10.3133/sir20125171.

Enlow, H.K., Fox, G.A., Boyer, T.A., Stoecker, A., Storm, D.E., Starks, P., and Guertault, L., 2018, A modeling framework for evaluating streambank stabilizing practices for reach-scale sediment reduction: Environmental Modelling & Software, v. 100, p. 201–212. [Also available at https://doi.org/10.1016/j.envsoft.2017.11.010.]

Foster, G.M., 2014, Relations between continuous real-time turbidity data and discrete suspended-sediment concentration samples in the Neosho and Cottonwood Rivers, east-central Kansas, 2009–2012: U.S. Geological Survey Open-File Report 2014–1171, 20 p., accessed May 2020 at https://doi.org/10.3133/ofr20141171.

Foster, G.M., 2016, Effects of May through July 2015 storm events on suspended sediment loads, sediment trapping efficiency, and storage capacity of John Redmond Reservoir, east-central Kansas: U.S. Geological Survey Scientific Investigations Report 2016–5040, 10 p., accessed May 2020 at https://doi.org/10.3133/sir20165040.

Foster, G.M., Lee, C.J., and Ziegler, A.C., 2012, Sediment transport to and from small impoundments in northeast Kansas, March 2009 through September 2011: U.S. Geological Survey Scientific Investigations Report 2012–5269, 38 p., accessed May 2020 at https://doi.org/10.3133/sir20125269.

Fox, G.A., Sheshukov, A., Cruse, R., Kolar, R.L., Guertault, L., Gesch, K.R., and Dutnell, R.C., 2016, Reservoir sedimentation and upstream sediment sources—Perspectives and future research needs on streambank and gully erosion: Environmental Management, v. 57, no. 5, p. 945–955. [Also available at https://doi.org/10.1007/s00267-016-0671-9.]

Graham, J.L., Foster, G.M., Williams, T.J., Mahoney, M.D., May, M.R., and Loftin, K.A., 2018, Water-quality conditions with an emphasis on cyanobacteria and associated toxins and taste-and-odor compounds in the Kansas River, Kansas, July 2012 through September 2016: U.S. Geological Survey Scientific Investigations Report 2018–5089, 55 p. [Also available at https://doi.org/10.3133/sir20185089.]

Guy, H.P., 1969, Laboratory theory and methods for sediment analysis: U.S. Geological Survey Techniques of Water-Resources Investigations, book 5, chap. C1, 58 p. [Also available at https://pubs.usgs.gov/twri/twri5c1/.]

Helsel, D.R., Hirsch, R.M., Ryberg, K.R., Archfield, S.A., and Gilroy, E.J., 2020, Statistical methods in water resources: U.S. Geological Survey Techniques and Methods, book 4, chap. A3, 458 p. [Also available at https://doi.org/10.3133/tm4a3.] [Supersedes U.S. Geological Survey Techniques of Water-Resources Investigations, book 4, chap. A3, ver. 1.1.]

Henley, W.F., Patterson, M.A., Neves, R.J., and Lemly, A.D., 2000, Effects of sedimentation and turbidity on lotic food webs—A concise review for natural resource managers: Reviews in Fisheries Science, v. 8, no. 2, p. 125–139. [Also available at https://doi.org/10.1080/10641260091129198.]

Homer, C., Huang, C., Yang, L., Wylie, B., and Coan, M., 2004, Development of a 2001 National Land-Cover Database for the United States: American Society for Photogrammetry and Remote Sensing, (7): p. 829–840. [Also available at https://doi.org/10.14358/PERS.70.7.829.]

Jakubauskas, M., deNoyelles, J., and Martinko, E., 2014, Bathymetric survey of John Redmond Reservoir, Coffey County, Kansas: Applied Science and Technology for Reservoir Assessment (ASTRA) Program, Report 2014–01, 17 p. [Also available at https://biosurvey.ku.edu/sites/biosurvey.ku.edu/files/publishedworks/pdfs/John%20Redmond%20bathymetric%20survey%202014.pdf.]

Jin, S., Homer, C.G., Yang, L., Danielson, P., Dewitz, J., Li, C., Zhu, Z., Xian, G., and Howard, D., 2019, Overall methodology design for the United States National Land Cover Database 2016 products: Remote Sensing, v. 11, no. 24, art. 2971, 32 p. [Also available at https://doi.org/10.3390/rs11242971.]

Jordan, P.R., and Hart, R.J., 1985, Transit losses and travel times for water-supply releases from Marion Lake during drought conditions, Cottonwood River, east-central Kansas: U.S. Geological Survey Water-Resources Investigations Report 85–4263, 41 p. [Also available at https://doi.org/10.3133/wri854263.]

Juracek, K.E., 2001, Channel-bed elevation changes downstream from large reservoirs in Kansas: U.S. Geological Survey Water-Resources Investigations Report 2001–4205, 24 p. [Also available at https://doi.org/10.3133/wri014205.]

Juracek, K.E., 2010, Sedimentation, sediment quality, and upstream channel stability, John Redmond Reservoir, east-central Kansas, 1964–2009: U.S. Geological Survey Scientific Investigations Report 2010–5191, 34 p. [Also available at https://doi.org/10.3133/sir20105191.]

Juracek, K.E., 2011, Suspended-sediment loads, reservoir sediment trap efficiency, and upstream and downstream channel stability for Kanopolis and Tuttle Creek Lakes, Kansas, 2008–10: U.S. Geological Survey Scientific Investigations Report 2011–5187, 35 p., accessed May 2020 at https://doi.org/10.3133/sir20115187.

Kansas Department of Health and Environment, 2018a, 2018 303(d) list of all impaired & potentially impaired waters: Kansas Department of Health and Environment, 56 p., accessed September 12, 2019, at https://www.kdheks.gov/tmdl/2018/Approved_2018_303_d)_List_of_All_Impaired_Waters.pdf.

Kansas Department of Health and Environment, 2018b, Kansas surface water quality standards: Kansas Department of Health and Environment, 73 p., accessed November 15, 2020, at https://www.kdheks.gov/tmdl/download/Unofficial_Copy_SURFACE_WATER_QUALITY_STANDARDS_04.11.18.pdf.

Kansas Water Office, 2017, John Redmond Reservoir dredging project—Phase I complete: Kansas Water Office, press release, June 9, 2017, accessed July 26, 2020, at https://kwo.ks.gov/news-events/press-releases/2017/06/09/john-redmond-reservoir-dredging-project--phase-i-complete-october-2016.

Kansas Water Office, 2018, State of the resource & regional goal action plan implementation—Neosho regional planning area: Kansas Water Office, 23 p., accessed on May 26, 2020, at https://kwo.ks.gov/water-vision-water-plan/state-of-the-resource.

Kansas Water Office, 2019, Kansas water supply reservoirs—Current capacity due to sedimentation: Kansas Water Office poster, 1 p. accessed January 4, 2020, at https://www.kwo.ks.gov/docs/default-source/reservoirs/current-capacity.pdf?sfvrsn=aca98514_0.

Kansas Water Office, 2020, John Redmond Reservoir watershed streambank projects: Kansas Water Office web page, accessed July 31, 2020, at https://kwo.ks.gov/projects/john-redmond-streambank.

Kennedy, E.J., 1984, Discharge ratings at gaging stations: U.S. Geological Survey Techniques of Water-Resource Investigations, book 3, chap. A10, 59 p., accessed May 26, 2020, at https://pubs.usgs.gov/twri/twri3-a10/.

Kloesel, K., Bartush, B., Banner, J., Brown, D., Lemery, J., Lin, X., Loeffler, C., McManus, G., Mullens, E., Nielsen-Gammon, J., Shafer, M., Sorensen, C., Sperry, S., Wildcat, D., and Ziolkowska, J., 2018: Southern great plains, chap. 23 *of* Reidmiller, D.R., Avery, C.W., Easterling, D.R., Kunkel, K.E., Lewis, K.L.M., Maycock, T.K., and Stewart, B.C., eds., Impacts, risks, and adaptation in the United States—Fourth National Climate Assessment, volume II: Washington, D.C., U.S. Global Change Research Program, p. 987–1035. [Also available at https://doi.org/10.7930/NCA4.2018.CH23.]

Layzell, A.L., and Peterson, A., 2020, Assessing the effectiveness of streambank stabilization projects on the Cottonwood River using Unmanned Aircraft Systems: Kansas Geological Survey Open-File Report 2020–16, 16p., accessed March 29, 2021, at http://www.kgs.ku.edu/Publications/OFR/2020/OFR2020-16.pdf.

Lee, C.J., and Foster, G.M., 2013, Assessing the potential of reservoir outflow management to reduce sedimentation using continuous turbidity monitoring and reservoir modeling: Hydrological Processes, v. 27, no. 10, p. 1426–1439. [Also available at https://doi.org/10.1002/hyp.9284.]

Lee, C.J., Rasmussen, P.P., and Ziegler, A.C., 2008, Characterization of suspended-sediment loading to and from John Redmond Reservoir, east-central Kansas, 2007–2008: U.S. Geological Survey Scientific Investigations Report 2008–5123, 25 p. [Also available at https://doi.org/10.3133/sir20085123.]

Luoma, S.N., and Rainbow, P.S., 2008, Metal contamination in aquatic environments—Science and lateral management: New York, N.Y., Cambridge University Press, 588 p.

Menne, M.J., Durre, I., Korzeniewski, B., McNeal, S., Thomas, K., Yin, X., Anthony, S., Ray, R., Vose, R.S., Gleason, B.E., and Houston, T.G., 2012a, Global Historical Climatology Network-Daily (GHCN-Daily) (ver. 3.26): National Oceanic and Atmospheric Administration, digital data, accessed March 2020 at https://www.ncdc.noaa.gov/ghcnd-data-access.

Menne, M.J., Durre, I., Vose, R.S., Gleason, B.E., and Houston, T.G., 2012b, An overview of the Global Historical Climatology Network—Daily database: Journal of Atmospheric and Oceanic Technology, v. 29, no. 7, p. 897–910. [Also available at https://doi.org/10.1175/JTECH-D-11-00103.1.]

National Integrated Drought Information System, 2020, Drought in Kansas: National Integrated Drought Information System web page, accessed June 2, 2020, at https://www.drought.gov/drought/states/kansas.

National Oceanic and Atmospheric Administration, 2018, Global Historical Climatology Network-Daily (GHCN-Daily), version 3: National Oceanic and Atmospheric Administration web page, accessed May 22, 2020, at https://doi.org/10.7289/V5D21VHZ.

National Regulatory Council, 2006, Wolf Creek Generating Station—Applicant's environmental report—Operating license renewal stage: National Regulatory Council, Docket No. 50–483, License No. NPF–42, accessed June 16, 2020, at https://www.nrc.gov/reactors/operating/licensing/renewal/applications/wolf-creek/wcnoc-er.pdf.

Owens, P.N., Batalla, R.J., Collins, A.J., Gomez, B., Hicks, D.M., Horowitz, A.J., Kondolf, G.M., Marden, M., Page, M.J., Peacock, D.H., Petticrew, E.L., Salomons, W., and Trustrum, N.A., 2005, Fine-grained sediment in river systems—Environmental significance and management issues: River Research and Applications, v. 21, no. 7, p. 693–717.

Painter, C.C., and Loving, B.L., 2015, U.S. Geological Survey quality-assurance plan for surface-water activities in Kansas, 2015: U.S. Geological Survey Open-File Report 2015–1074, 33 p., accessed March 2020 at https://doi.org/10.3133/ofr20151074.

Porterfield, G., 1972, Computation of fluvial-sediment discharge: U.S. Geological Survey Techniques of Water-Resources Investigations, book 3, chap. C3, 66 p. [Also available at https://doi.org/10.3133/twri03C3.]

Purvis, R.A., and Fox, G.A., 2016, Streambank sediment loading rates at the watershed scale and the benefit of riparian protection: Earth Surface Processes and Landforms, v. 41, no. 10, p. 1327–1336. [Also available at https://doi.org/10.1002/esp.3901.]

Putnam, J.E., and Pope, L.M., 2003, Trends in suspended-sediment concentration at selected stream sites in Kansas, 1970–2002: U.S. Geological Survey Water-Resources Investigations Report 2003–4150, 36 p. [Also available at https://doi.org/10.3133/wri034150.]

Rahmani, V., Kastens, J.D., deNoyelles, F., Jakubauskas, M.E., Martinko, E.A., Huggins, D.H., Gnau, C., Liechti, P.M., Campbell, S.E., Callihan, R.A., and Blackwood, A.J., 2018, Examining storage capacity loss and sedimentation rate of large reservoirs in central U.S. Great Plains: Water, v. 10, no. 2, art. 190, 17 p. [Also available at https://doi.org/10.3390/w10020190.]

Rasmussen, P.P., Gray, J.R., Glysson, G.D., and Ziegler, A.C., 2009, Guidelines and procedures for computing time-series suspended-sediment concentrations and loads from in-stream turbidity-sensor and streamflow data: U.S. Geological Survey Techniques and Methods, book 3, chap. C4, 54 p. [Also available at https://doi.org/10.3133/tm3c4.]

Rasmussen, T.J., Lee, C.J., and Ziegler, A.C., 2008, Estimation of constituent concentrations, loads, and yields in streams of Johnson County, northeast Kansas, using continuous water-quality monitoring and regression models, October 2002 through December 2006: U.S. Geological Survey Scientific Investigations Report 2008–5014, 104 p. [Also available at https://doi.org/10.3133/sir20085014.]

Rasmussen, T.J., Ziegler, A.C., and Rasmussen, P.P., 2005, Estimation of constituent concentrations, densities, loads, and yields in lower Kansas River, northeast Kansas, using regression models and continuous water-quality monitoring, January 2000 through December 2003: U.S. Geological Survey Scientific Investigations Report 2005–5165, 117 p. [Also available at https://doi.org/10.3133/sir20055165.]

Sauer, V.B., and Turnipseed, D.P., 2010, Stage measurement at gaging stations: U.S. Geological Survey Techniques and Methods, book 3, chap. A7, 45 p., accessed March 2020 at https://doi.org/10.3133/tm3A7.

Schoewe, W.H., 1949, The geography of Kansas—Part II, physical geography: Transactions of the Kansas Academy of Science, v. 52, no. 3, p. 261–333. [Also available at https://doi.org/10.2307/3625794.]

Shafer, M., Ojima, D., Antle, J.M., Kluck, D., McPherson, R.A., Petersen, S., Scanlon, B., and Sherman, K., 2014, Great Plains, chap. 19 *of* Melillo, J.M., Richmond, T.C., and Yohe, G.W., eds., Climate change impacts in the United States—The Third National Climate Assessment: U.S. Global Change Research Program, p. 441–461. [Also available at https://doi.org/10.7930/J0D798BC.]

Simon, A., Curini, A., Darby, S.E., and Langendoen, E.J., 2000, Bank and near-bank processes in an incised channel: Geomorphology, v. 35, no. 3–4, p. 193–217. https://doi.org/10.1016/S0169-555X(00)00036-2.

Southard, R.E., 2013, Computed statistics at streamgages, and methods for estimating low-flow frequency statistics and development of regional regression equations for estimating low-flow frequency statistics at ungaged locations in Missouri: U.S. Geological Survey Scientific Investigations Report 2013–5090, 28 p. [Also available at https://doi.org/10.3133/sir20135090.]

Stone, M.L., Graham, J.L., and Gatotho, J.W., 2013, Continuous real-time water-quality monitoring and regression analysis to compute constituent concentrations and loads in the North Fork Ninnescah River upstream from Cheney Reservoir, south-central Kansas, 1999–2012: U.S. Geological Survey Scientific Investigations Report 2013–5071, 46 p., accessed May 2020 at https://doi.org/10.3133/sir20135071.

Stone, M.L., Juracek, K.E., Graham, J.L., and Foster, G.M., 2015, Quantifying suspended sediment loads delivered to Cheney Reservoir, Kansas—Temporal patterns and management implications: Journal of Soil and Water Conservation, v. 70, no. 2, p. 91–100. [Also available at https://doi.org/10.2489/jswc.70.2.91.]

Stone, M.L., Klager, B.J., and Ziegler, A.C., 2019, Water-quality and geochemical variability in the Little Arkansas River and *Equus* Beds aquifer, south-central Kansas, 2001–16: U.S. Geological Survey Scientific Investigations Report 2019–5026, 79 p., accessed May 2020 at https://doi.org/10.3133/sir20195026.

Straub, T.D., Johnson, G.P., Roseboom, D.P., and Sierra, C.R., 2006, Suspended-sediment yields and stream channel processes on Judy's Branch watershed in the St. Louis Metro East region in Illinois: U.S. Geological Survey Scientific Investigations Report 2006–5016, 51 p. [Also available at https://doi.org/10.3133/sir20065016.]

Turnipseed, D.P., and Sauer, V.B., 2010, Discharge measurements at gaging stations: U.S. Geological Survey Techniques and Methods, book 3, chap. A8, 87 p., accessed March 2020 at https://doi.org/10.3133/tm3A8.

U.S. Army Corps of Engineers, 2002, Streambank and shoreline protection manual: U.S. Army Corps of Engineers, 23 p., accessed June 16, 2020, at https://www.lrc.usace.army.mil/Portals/36/docs/regulatory/pdf/StrmManual.pdf.

U.S. Army Corps of Engineers, 2005, Initial appraisal of the Neosho River logjam, John Redmond Reservoir, Kansas: U.S. Army Corps of Engineers, 81 p., accessed June 11, 2020, at https://kgi.contentdm.oclc.org/digital/collection/p16884coll78/id/135/.

U.S. Army Corps of Engineers, 2013, Final supplement to the final environmental statement, storage reallocation—John Redmond Dam and Reservoir, Kansas: Tulsa, Okla., U.S. Army Corps of Engineers, v. 1, [variously paged], accessed January 23, 2020, at https://www.swt.usace.army.mil/Portals/41/docs/library/john_redmond/VOL_I_JRR%20FINAL_SFES%2020130212.pdf.

U.S. Army Corps of Engineers, 2016, John Redmond Dam and Reservoir master plan—Neosho River, Coffey and Lyon County, Kansas: Tulsa, Okla., U.S. Army Corps of Engineers, [variously paged], accessed January 23, 2020, at https://www.swt.usace.army.mil/Portals/41/docs/library/john_redmond/John%20Redmond%20MP%20Revision%20(Draft)%2020160126.pdf.

U.S. Army Corps of Engineers, 2019a, Dam safety newsletter—Summer 2019: U.S. Army Corps of Engineers, 4 p., accessed July 1, 2020, at https://usace.contentdm.oclc.org/digital/api/collection/p16021coll8/id/4072/download.

U.S. Army Corps of Engineers, 2019b, Monthly charts for Council Grove Lake: U.S Army Corps of Engineers web page, accessed June 1, 2020, at https://www.swt-wc.usace.army.mil/COUNcharts.html.

U.S. Army Corps of Engineers, 2019c, Monthly charts for John Redmond Lake: U.S Army Corps of Engineers web page, accessed June 1, 2020, at https://www.swt-wc.usace.army.mil/JOHNcharts.html.

U.S. Army Corps of Engineers, 2019d, Monthly charts for Marion Lake: U.S Army Corps of Engineers web page, accessed June 1, 2020, at https://www.swt-wc.usace.army.mil/MARIcharts.html.

U.S. Department of Agriculture, 2019, Web Soil Survey home: U.S. Department of Agriculture web page, accessed December 27, 2019, at https://websoilsurvey.sc.egov.usda.gov/App/HomePage.htm.

U.S. Environmental Protection Agency, 2000, Ambient water quality criteria recommendations—Rivers and streams in nutrient ecoregion IX: Washington, D.C., U.S. Environmental Protection Agency, EPA 822–B–00–019, [variously paged], accessed March 2020 at https://www.epa.gov/sites/production/files/documents/rivers9.pdf.

U.S. Environmental Protection Agency, 2001, Ambient water quality criteria recommendations—Rivers and streams in nutrient ecoregion IV: Washington, D.C., U.S. Environmental Protection Agency, EPA 822–B–01–013, [variously paged], accessed March 2020 at https://www.epa.gov/sites/production/files/documents/rivers4.pdf.

U.S. Geological Survey, 2006, Collection of water samples (ver. 2.0, September 2006): U.S. Geological Survey Techniques of Water-Resources Investigations, book 9, chap. A4 [variously paged]. [Also available at https://doi.org/10.3133/twri09A4.]

U.S. Geological Survey, 2008, Field measurements, (edited by Wilde, F.D.): U.S. Geological Survey Techniques of Water-Resources Investigations, book 9; chap A6, [variously paged], accessed November 2019 at https://doi.org/10.3133/twri09A6.

U.S. Geological Survey, 2013, Water basics glossary: U.S. Geological Survey web page, accessed May 26, 2020, at https://water.usgs.gov/water-basics_glossary.html.

U.S. Geological Survey, 2020, USGS water data for the Nation: U.S. Geological Survey National Water Information System database, accessed January 2020, at https://doi.org/10.5066/F7P55KJN.

Wagner, R.J., Boulger, R.W., Jr., Oblinger, C.J., and Smith, B.A., 2006, Guidelines and standard procedures for continuous water-quality monitors—Station operation, record computation, and data reporting: U.S. Geological Survey Techniques and Methods, book 1, chap. D3, 51 p. [Also available at https://doi.org/10.3133/tm1D3.]

Waters, T.F., 1995, Sediment in streams—Sources, biological effects, and control—Bethesda, Md: American Fisheries Society, Monograph 7.

Wetzel, R.G., 2001, Limnology—Lake and River ecosystems (3d ed.): New York, N.Y., Academic Press, 1,024 p.

YSI Incorporated, 2007, YSI 6136 turbidity sensor specification sheet: YSI Incorporated, 2 p., accessed November 2019 at https://www.ysi.com/File%20Library/Documents/Specification%20Sheets/E56-6136-Turbidity-Sensor.pdf.

YSI Incorporated, 2012a, 6-Series multiparameter water quality sondes—User manual (revision J): YSI Incorporated, 379 p., accessed November 2019 at https://www.ysi.com/File%20Library/Documents/Manuals/069300-YSI-6-Series-Manual-RevJ.pdf.

YSI Incorporated, 2012b, EXO water quality field sensors—Features, specifications, and comparability to YSI 6-Series sensors (revision B): YSI Incorporated, 14 p., accessed November 2019 at https://www.exowater.com/media/pdfs/EXO-6Series-Sensor-Comparison.pdf.

YSI Incorporated, 2015, EXO wiped conductivity and temperature sensor, specification E113: YSI Incorporated, 2 p., accessed April 29, 2020, at https://www.ysi.com/File%20Library/Documents/Specification%20Sheets/E113_EXO-Wiped_CT-Spec-Sheet.pdf.

YSI Incorporated, 2019, Turbidity units and calibration solutions—YSI turbidity sensors: YSI Incorporated, 2 p., accessed November 2019 at https://www.ysi.com/File%20Library/Documents/Technical%20Notes/T627_Turbidity_Units_and_Calibration_Solutions.pdf.

Appendixes 1–12

Model archive summaries for suspended-sediment concentration at U.S. Geological Survey sites in Kansas are available for download at https://doi.org/10.3133/sir20215037.

Appendix 13. Suspended-Sediment Sample Grain-Size Distribution by Weight for Samples with Turbidity Measurements Greater than 500 Formazin Nephelometric Units

Generally, for water-quality samples collected when turbidity was greater than or equal to 500 formazin nephelometric units, an additional five-point grain-size analysis was requested from the laboratory. For those selected samples, suspended sediment was measured by weight for grain sizes of 0.002, 0.004, 0.008, 0.016, 0.031, 0.065, and 1 millimeter (mm; table 13.1, fig. 13.1). For suspended-sediment samples collected at Neosho River at Burlingame Road near Emporia, Kansas (U.S. Geological Survey [USGS] site 07179750) (number of samples [n] =13), silt and clay (less than 0.065 mm) composed at least 91 percent by weight of the sample concentrations, and clay-sized particles (less than 0.004 mm) composed 39–80 percent. For suspended-sediment samples collected at Cottonwood Road near Plymouth, Kans. (USGS site 07182250) (n=11), silt and clay composed at least 85 percent of the sample concentrations, and clay-sized particles composed 30–68 percent. For suspended-sediment samples collected at Neosho River at Neosho Rapids, Kans. (USGS site 07182390) (n=25), silt and clay composed at least 86 percent by weight of the sample concentrations, and clay-sized particles composed 38–80 percent. For suspended-sediment samples collected at Neosho River at Burlington, Kans. (USGS site 07182510) (n=5), silt and clay composed at least 97 percent by weight of the sample concentrations, and clay-sized particles composed 81–86 percent. Because fine particles (less than 0.065 mm) dominated the composition of the transported suspended sediment, the use of turbidity as a surrogate for suspended-sediment concentrations was appropriate.

Table 13.1. Loss on ignition, suspended-sediment concentration, and grain-size distribution of samples collected when turbidity exceeded 500 formazin nephelometric units.

[ID, identifier; Turb, field-measured turbidity; FNU, formazin nephelometric unit; LOI, loss on ignition; mg/L, milligram per liter; SSC, suspended-sediment concentration; Q, streamflow; ft^3/s, cubic foot per second; <, less than; mm, millimeter; USGS, U.S. Geological Survey; *n*, number of samples; 6136, turbidity from YSI Incorporated Extended Deployment System turbidity sensor model 6136, in formazin nephelometric units; --, no data; EXO, turbidity from Xylem YSI EXO, turbidity sensor, in formazin nephelometric units]

Sample ID	YSI model	Year	Month	Turb (FNU)	LOI (mg/L)	SSC (mg/L)	Q (ft^3/s)	Sediment size fractions, in percent, of sample per sieve diameter						
								<0.002 mm	<0.004 mm	<0.008 mm	<0.016 mm	<0.031 mm	<0.065 mm	<1 mm
Cottonwood River near Plymouth, Kansas (USGS site 07182250) (*n*=11)														
C–1	6136	2007	May	1,078	--	1,960	17,800	63	68	71	79	94	98	100
C–2	6136	2008	February	764	--	2,150	10,000	51	54	58	65	--	96	100
C–3	6136	2008	May	450	--	1,090	10,500	48	53	57	63	--	91	100
C–4	6136	2008	July	206	--	828	1,310	27	30	32	41	--	85	100
C–5	EXO	2016	April	971	406	3,100	3,300	45	51	60	72	92	98	100
C–6	EXO	2016	April	763	273	2,030	3,220	48	56	65	76	90	99	100
C–7	EXO	2016	April	651	159	1,750	13,000	46	55	62	75	91	98	100
C–8	EXO	2017	March	875	76	3,210	13,700	36	42	47	59	82	96	100
C–9	EXO	2019	March	829	262	3,480	6,440	44	47	49	61	84	97	100
C–10	EXO	2019	May	504	95	1,110	14,850	58	62	65	74	89	98	100
C–11	EXO	2019	August	517	132	1,600	5,487	39	44	53	69	88	98	100
Neosho River at Burlingame Road near Emporia, Kansas (USGS site 07179750) (*n*=13)														
B–1	6136	2009	September	703	15	2,240	2,430	40	45	47	53	87	91	100
B–2	6136	2010	July	881	5	2,210	5,120	47	49	52	65	94	98	100
B–3	6136	2012	March	1,132	2	1,980	1,090	65	73	81	92	96	99	100
B–4	6136	2012	March	392	2	760	1,890	63	63	66	76	92	98	100
B–5	6136	2012	March	313	1	567	2,200	60	66	70	78	93	97	100
B–6	EXO	2016	April	558	101	1,080	2,530	36	39	46	59	82	92	100
B–7	EXO	2016	April	661	105	1,420	11,100	52	59	67	77	92	99	100
B–8	EXO	2018	September	775	411	2,170	4,240	56	66	70	80	98	100	--
B–9	EXO	2019	February	642	192	2,240	4,663	47	52	54	66	87	98	100
B–10	EXO	2019	March	580	156	2,120	3,100	48	50	54	61	82	97	100
B–11	EXO	2019	March	914	283	2,730	5,800	51	53	61	75	92	99	100
B–12	EXO	2019	May	556	187	1,600	10,100	56	64	67	75	93	99	100
B–13	EXO	2019	May	735	133	1,630	15,400	65	80	85	91	97	99	100
Neosho River at Neosho Rapids, Kansas (USGS site 07182390) (*n*=25)														
R–1	6136	2009	June	586	2	1,110	--	53	61	61	80	90	97	100
R–2	6136	2009	July	744	2	965	--	79	80	83	91	95	98	100

Table 13.1. Loss on ignition, suspended-sediment concentration, and grain-size distribution of samples collected when turbidity exceeded 500 formazin nephelometric units.—Continued

[ID, identifier; Turb, field-measured turbidity; FNU, formazin nephelometric unit; LOI, loss on ignition; mg/L, milligram per liter; SSC, suspended-sediment concentration; Q, streamflow; ft^3/s, cubic foot per second; <, less than; mm, millimeter; USGS, U.S. Geological Survey; *n*, number of samples; 6136, turbidity from YSI Incorporated Extended Deployment System turbidity sensor model 6136, in formazin nephelometric units; --, no data; EXO, turbidity from Xylem YSI EXO, turbidity sensor, in formazin nephelometric units]

Sample ID	YSI model	Year	Month	Turb (FNU)	LOI (mg/L)	SSC (mg/L)	Q (ft^3/s)	Sediment size fractions, in percent, of sample per sieve diameter						
								<0.002 mm	<0.004 mm	<0.008 mm	<0.016 mm	<0.031 mm	<0.065 mm	<1 mm
Neosho River at Neosho Rapids, Kansas (USGS site 07182390) (*n*=25)—Continued														
R–3	6136	2009	August	896	2	2,120	3,620	48	49	50	75	94	99	100
R–4	6136	2009	September	474	7	1,560	4,960	39	41	43	55	75	87	100
R–5	6136	2010	March	784	147	2,420	4,980	39	43	46	62	87	98	100
R–6	6136	2010	June	962	7	1,950	11,500	51	54	59	61	92	97	100
R–7	6136	2010	September	141	1	286	922	45	54	57	69	90	98	100
R–8	6136	2010	September	590	3	1,610	3,610	41	46	48	66	88	97	100
R–9	6136	2011	April	1,022	1	1,610	1,970	68	80	85	96	98	100	--
R–10	6136	2012	March	811	4	1,930	2,180	53	57	65	76	94	98	100
R–11	6136	2012	March	594	21	2,110	5,620	33	38	44	57	77	86	100
R–12	6136	2012	March	710	4	1,750	9,600	52	54	56	69	91	97	100
R–13	6136	2013	August	414	1	722	13,100	42	57	63	73	86	96	100
R–14	6136	2013	August	--	2	1,580	13,200	48	53	54	72	86	97	100
R–15	6136	2014	June	1,254	265	4,230	6,630	32	38	45	56	74	88	100
R–16	EXO	2015	May	667	103	1,220	18,500	74	79	83	86	96	98	100
R–17	EXO	2015	June	568	205	1,440	10,600	48	57	63	71	92	100	--
R–18	EXO	2016	April	698	289	2,370	8,650	44	51	60	73	91	99	100
R–19	EXO	2016	April	737	135	2,000	16,600	52	60	65	77	94	98	100
R–20	EXO	2017	March	586	114	1,830	10,200	41	45	52	64	83	97	100
R–21	EXO	2018	September	1,028	310	3,570	7,517	54	58	66	75	94	99	100
R–22	EXO	2019	February	510	133	1,660	8,237	48	54	57	65	85	98	100
R–23	EXO	2019	March	817	240	2,680	13,000	48	53	60	73	94	99	100
R–24	EXO	2019	May	506	85	1,210	19,967	72	76	79	83	92	99	100
R–25	EXO	2019	May	534	118	1,190	27,100	59	73	75	86	95	99	100
Neosho River at Burlington, Kansas (USGS site 07182510) (*n*=5)														
BT–1	EXO	2019	February	28	9	45	7,190	78	81	84	88	92	98	100
BT–2	EXO	2019	February	93	26	134	4,500	81	86	89	92	96	99	100
BT–3	EXO	2019	March	188	56	335	4,120	72	81	89	92	97	99	100

Table 13.1. Loss on ignition, suspended-sediment concentration, and grain-size distribution of samples collected when turbidity exceeded 500 formazin nephelometric units.—Continued

[ID, identifier; Turb, field-measured turbidity; FNU, formazin nephelometric unit; LOI, loss on ignition; mg/L, milligram per liter; SSC, suspended-sediment concentration; Q, streamflow; ft^3/s, cubic foot per second; <, less than; mm, millimeter; USGS, U.S. Geological Survey; *n*, number of samples; 6136, turbidity from YSI Incorporated Extended Deployment System turbidity sensor model 6136, in formazin nephelometric units; --, no data; EXO, turbidity from Xylem YSI EXO, turbidity sensor, in formazin nephelometric units]

Sample ID	YSI model	Year	Month	Turb (FNU)	LOI (mg/L)	SSC (mg/L)	Q (ft^3/s)	Sediment size fractions, in percent, of sample per sieve diameter						
								<0.002 mm	<0.004 mm	<0.008 mm	<0.016 mm	<0.031 mm	<0.065 mm	<1 mm
Neosho River at Burlington, Kansas (USGS site 07182510) (*n*=5)—Continued														
BT–4	EXO	2019	April	140	19	215	311	84	85	87	92	94	99	100
BT–5	EXO	2019	May	74	7	89	16,167	85	86	87	90	91	97	100

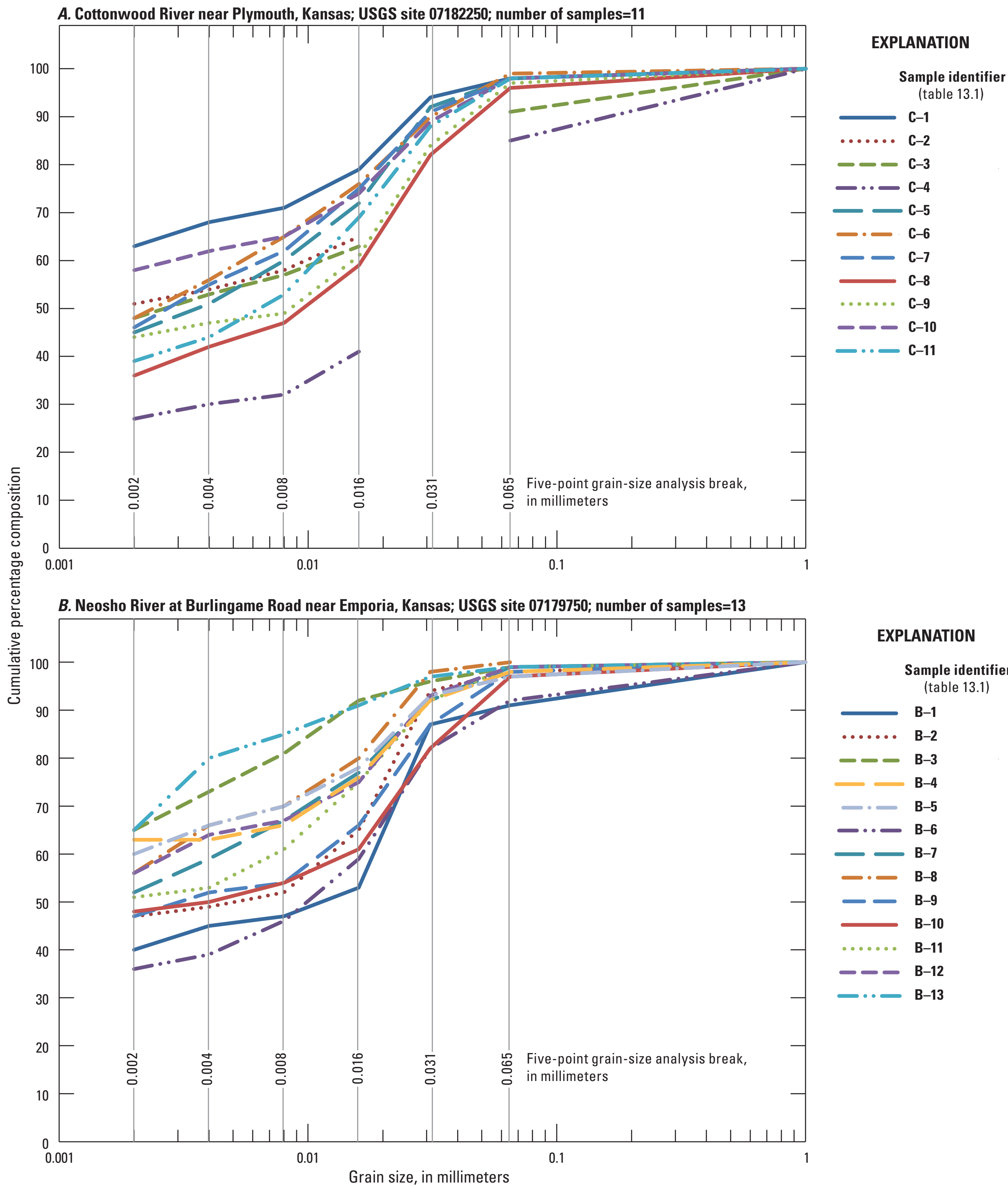

Figure 13.1. Grain size distribution for suspended-sediment samples with turbidities greater than 500 formazin nephelometric units for study sites along the Cottonwood and Neosho Rivers, Kansas, during 2007 through 2019. *A*, Cottonwood River near Plymouth (U.S. Geological Survey [USGS] site 07182250); *B*, Neosho River at Burlingame Road near Emporia (USGS site 07179750); *C*, Neosho River at Neosho Rapids (USGS site 07182390); *D*, Neosho River at Burlington (USGS site 07182510).

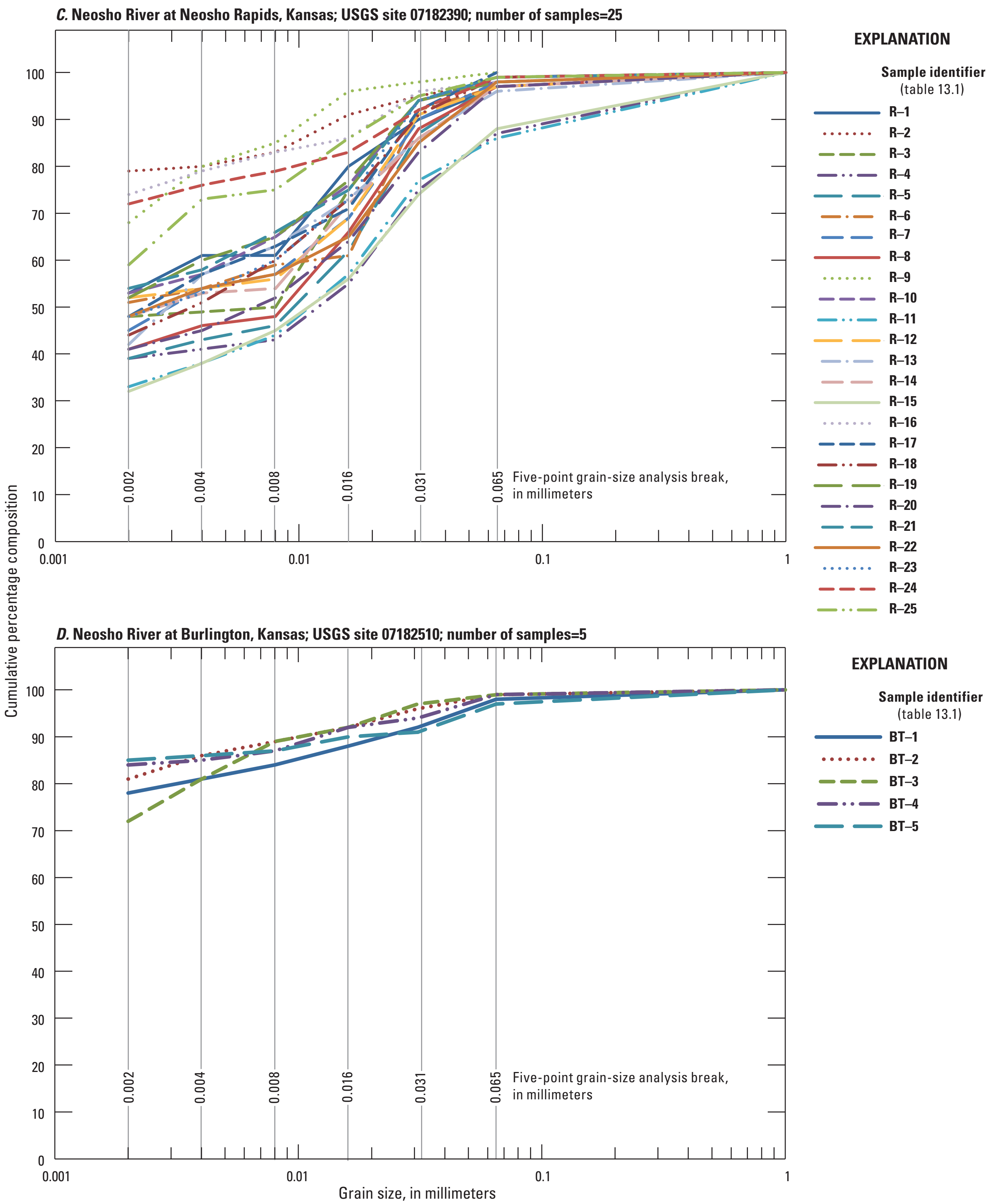

Figure 13.1. Grain size distribution for suspended-sediment samples with turbidities greater than 500 formazin nephelometric units for study sites along the Cottonwood and Neosho Rivers, Kansas, during 2007 through 2019. *A*, Cottonwood River near Plymouth (U.S. Geological Survey [USGS] site 07182250); *B*, Neosho River at Burlingame Road near Emporia (USGS site 07179750); *C*, Neosho River at Neosho Rapids (USGS site 07182390); *D*, Neosho River at Burlington (USGS site 07182510)—Continued.

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