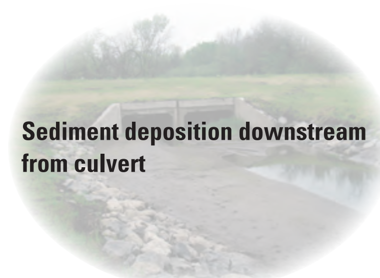
Prepared in cooperation with the Johnson County Stormwater Management Program

Effects of Urbanization, Construction Activity, Management Practices, and Impoundments on Suspended-Sediment Transport in Johnson County, Northeast Kansas, February 2006 through November 2008

Scientific Investigations Report 2010–5128

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



Cover photographs. Photographs taken after a storm in the headwaters of Clear Creek, Lenexa, Kansas, April through May 2007. Photographs courtesy of Dale Clark, City of Lenexa.

Effects of Urbanization, Construction Activity, Management Practices, and Impoundments on Suspended-Sediment Transport in Johnson County, Northeast Kansas, February 2006 through November 2008

By Casey J. Lee and Andrew C. Ziegler

Prepared in cooperation with the Johnson County Stormwater Management Program

Scientific Investigations Report 2010–5128

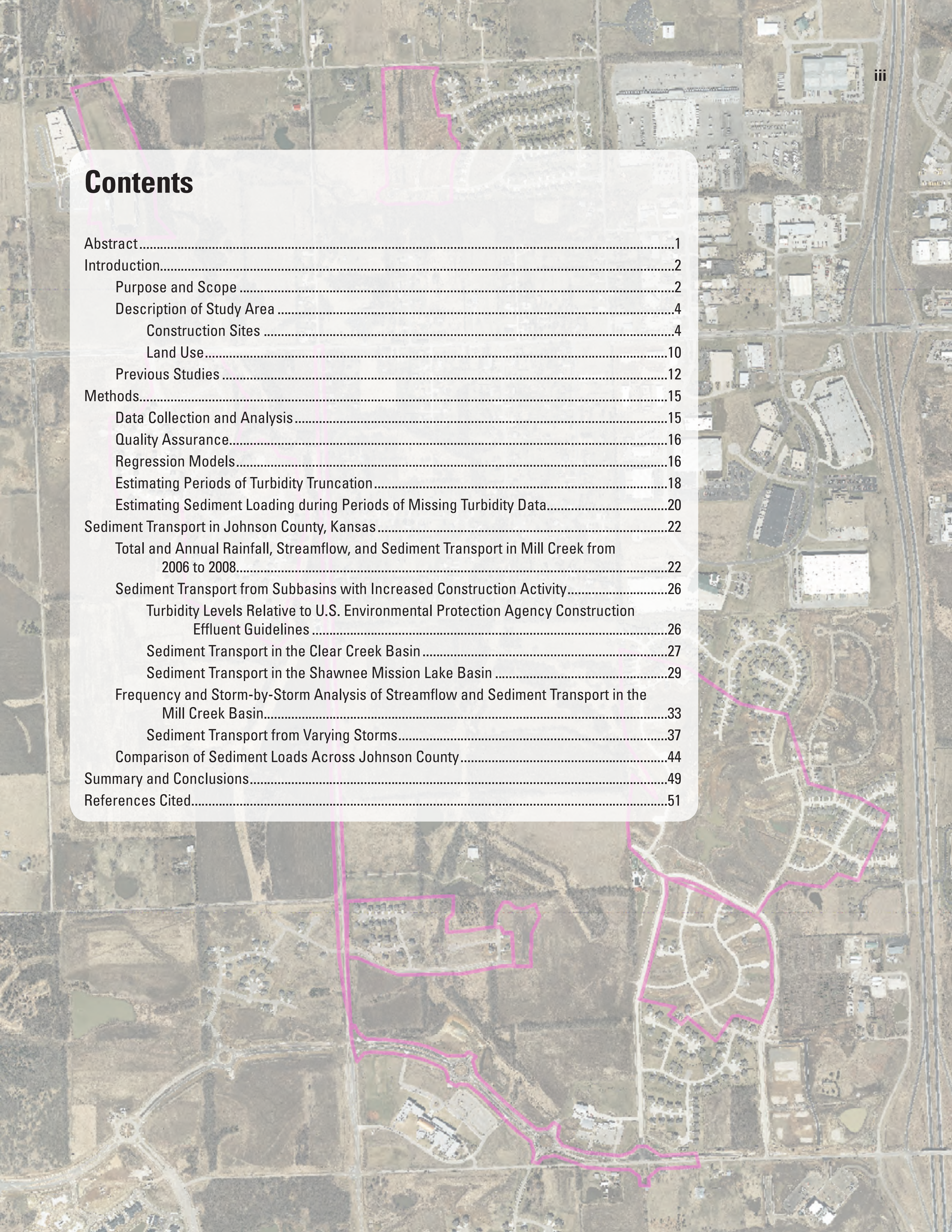
U.S. Department of the Interior
U.S. Geological Survey

U.S. Department of the Interior
KEN SALAZAR, Secretary

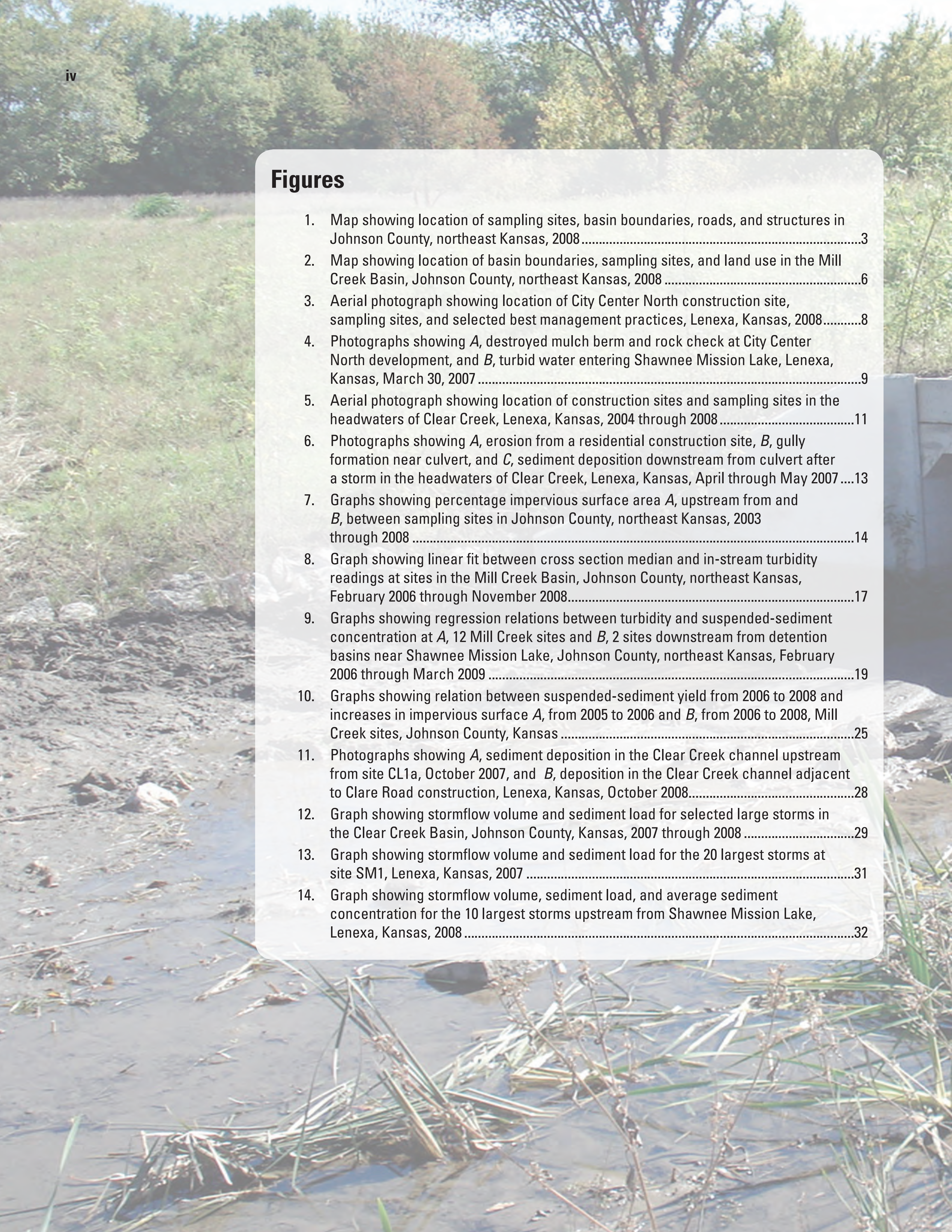
U.S. Geological Survey
Marcia K. McNutt, Director

U.S. Geological Survey, Reston, Virginia: 2010

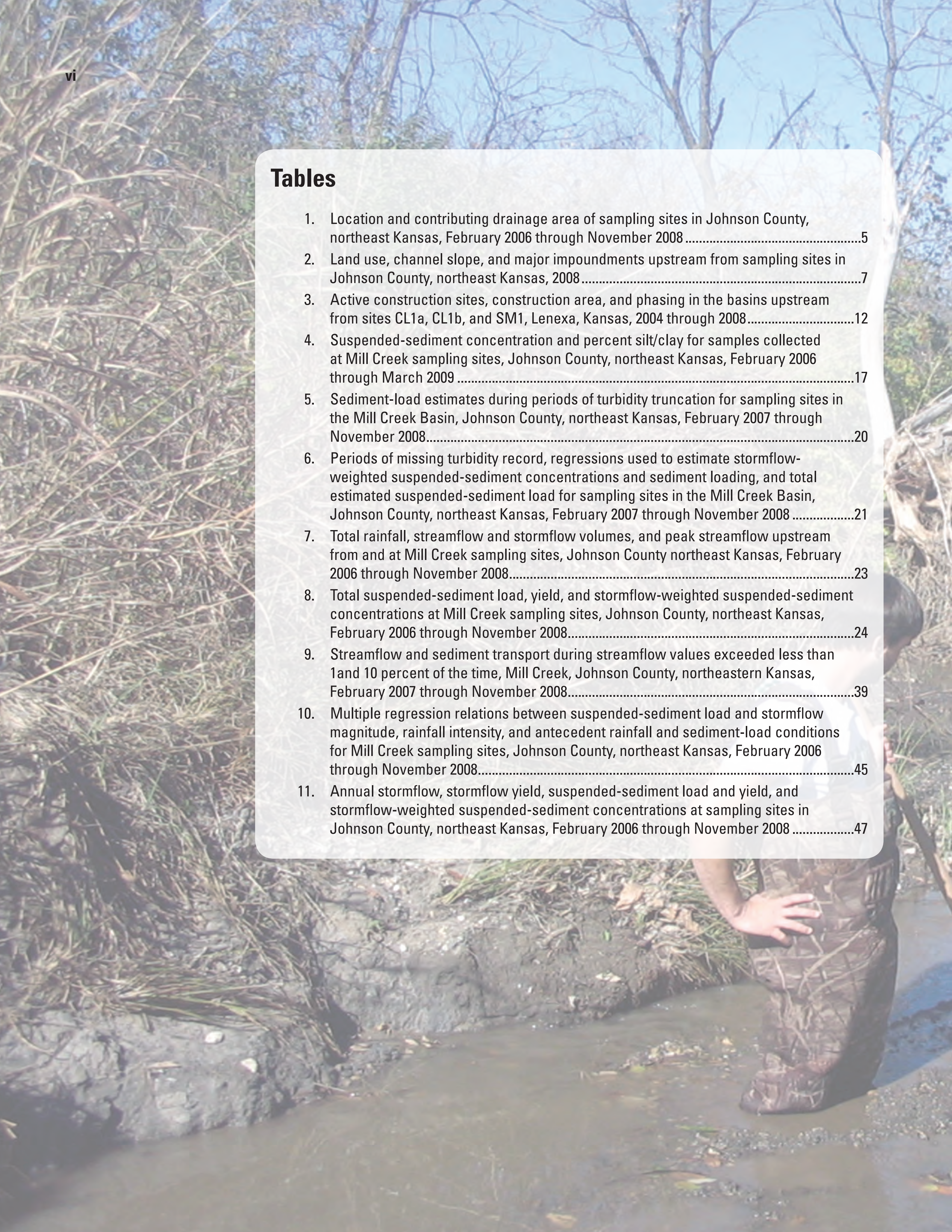
Suggested citation:
Lee, C.J., and Ziegler, A.C., 2010, Effects of urbanization, construction activity, management practices, and impoundments on suspended-sediment transport in Johnson County, northeast Kansas, February 2006 through November 2008: U.S. Geological Survey Scientific Investigations Report 2010–5128, 54 p.



Contents



Figures



Tables

Conversion Factors and Datums

Multiply	By	To obtain
	Length	
centimeter (cm)	0.3937	inch (in.)
inch (in.)	2.54	centimeter (cm)
foot (ft)	0.3048	meter (m)
micrometer (µm)	0.00003937	inch (in.)
mile (mi)	1.609	kilometer (km)
	Area	
acre	4,047	square meter (m^2)
square mile (mi^2)	2.590	square kilometer (km^2)
	Volume	
gallon (gal)	3.785	liter (L)
gallon (gal)	0.003785	cubic meter (m^3)
acre-foot (acre-ft)	1,233	cubic meter (m^3)
	Flow rate	
acre-foot per square mile (acre-ft/mi^2)	476.25	cubic meter per square kilometer (m^3/km^2)
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
cubic foot per second (ft^3/s)	1.9835	acre-feet per day (acre-ft/d)
cubic foot per second per square mile [($ft^3/s/mi^2$])	0.01093	cubic meter per second per square mile [$m^3/s)/km^2$]
foot per mile (ft/mi)	0.1894	meter per kilometer (m/km)
million gallons per day (Mgal/d)	0.04381	cubic meter per second (m^3/s)
inch per hour (in/h)	25.4	millimeter per hour (mm/h)
	Mass	
gram (g)	0.03527	ounce (oz)
pound per second (lb/s)	43.2	ton per day (ton/d)
ton	2,000	pound (lb)
	Yield	
ton per square mile (ton/mi^2)	0.3503	tonne per square kilometer (tonne/km^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)
	Hydraulic gradient	
foot per mile (ft/mi)	0.1894	meter per kilometer (m/km)

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

$$°C=(°F-32)/1.8$$

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).

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

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

Suspended-sediment loads are reported in tons.

Effects of Urbanization, Construction Activity, Management Practices, and Impoundments on Suspended-Sediment Transport in Johnson County, Northeast Kansas, February 2006 through November 2008

By Casey J. Lee and Andrew C. Ziegler

Abstract

The U.S. Geological Survey, in cooperation with the Johnson County, Kansas, Stormwater Management Program, investigated the effects of urbanization, construction activity, management practices, and impoundments on suspended-sediment transport in Johnson County from February 2006 through November 2008. Streamgages and continuous turbidity sensors were operated at 15 sites within the urbanizing 57-square-mile Mill Creek Basin, and 4 sites downstream from the other largest basins (49 to 66 square miles) in Johnson County.

The largest sediment yields in Johnson County were observed downstream from basins with increased construction activity. Sediment yields attributed to the largest (68 acre) active construction site in the study area were 9,300 tons per square mile in 2007 and 12,200 tons per square mile in 2008; 5 to 55 times larger than yields observed at other sampling sites. However, given erodible soils and steep slopes at this site, sediment yields were relatively small compared to the range in historic values from construction sites without erosion and sediment controls in the United States (2,300 to 140,000 tons per square mile). Downstream from this construction site, a sediment forebay and wetland were constructed in series upstream from Shawnee Mission Lake, a 120-acre reservoir within Shawnee Mission Park. Although the original intent of the sediment forebay and constructed wetland were unrelated to upstream construction, they were nonetheless evaluated in 2008 to characterize sediment removal before stream entry into the lake. The sediment forebay was estimated to reduce 33 percent of sediment transported to the lake, whereas the wetland did not appear to decrease downstream sediment transport. Comparisons of time-series data and relations between turbidity and sediment concentration indicate that larger silt-sized particles were deposited within the sediment forebay, whereas smaller silt and clay-sized sediments were transported through the wetland and into the lake. Data collected at sites up and downstream from the constructed wetland indicated that hydraulic retention alone did not substantially reduce sediment loading to Shawnee Mission Lake.

Mean-daily turbidity values at sampling sites downstream from basins with increased construction activity were compared to U.S. Environmental Protection Agency turbidity criteria designed to reduce discharge of pollutants from construction sites. The U.S. Environmental Protection Agency numeric turbidity criteria specifies that effluent from construction sites greater than 20 acres not exceed a mean-daily turbidity value of 280 nephelometric turbidity units beginning in 2011; this criteria will apply to sites greater than 10 acres beginning in 2014. Although numeric criteria would not have been applicable to data from sampling sites in Johnson County because they were not directly downstream from construction sites and because individual states still have to determine additional details as to how this criteria will be enforced, comparisons were made to characterize the potential of construction site effluent in Johnson County to exceed U.S. Environmental Protection Agency Criteria, even under extensive erosion and sediment controls. Numeric criteria were exceeded at sampling sites downstream from basins with increased construction activity for multiple days during the study period, potentially indicating the need for additional erosion and sediment controls and (or) treatment to bring discharges from construction sites into compliance with future numeric turbidity criteria.

Among sampling sites in the Mill Creek Basin, sediment yields from the urbanizing Clear Creek Basin were approximately 2 to 3 times those from older, more stable urban or rural basins. Sediments eroded from construction sites adjacent to or surrounding streams appear to be more readily transported downstream, whereas sediments eroded from construction sites in headwater areas are more likely to be deposited locally on land surfaces or within the stream network. Comparison of sediment yields among headwater and downstream sites in the Clear Creek Basin indicated that factors such as site and stream slope, the current phase of construction, management practices, and site location relative to streams affect the amount and length of time it takes eroded

sediment to be transported downstream. Sediment concentrations in Mill Creek tributaries downstream from increased construction activity were larger than other sites for a much longer period of time, likely decreasing light penetration and increasing fine sediment deposition on streambeds. Subbasins partially regulated by impoundments and those with stable urban land use had the smallest sediment concentrations and loads in the Mill Creek Basin.

The most extreme streamflows transported the most sediment throughout the Mill Creek Basin. Streamflows that occurred less than 1 percent of the time transported 73 to 91 percent of sediment loads, whereas streamflows that occurred less than 10 percent of the time transported 93 to 100 percent of sediment loads. Multiple regression analysis of the factors affecting sediment transport indicated the largest, most intense storms transport substantially larger sediment loads at all sampling sites. Large storms decreased sediment supplies available for transport by subsequent storms.

Contrary to results observed from smaller subbasins within the Mill Creek Basin, sediment yields from the predominantly mature, urban Indian Creek Basin were more than double those from other large urbanizing and rural (49 to 66 square miles) basins in Johnson County from 2006 through 2008. Larger sediment loads in the Indian Creek Basin likely originate from frequent stormflows that erode streambed and streambank sediments. Variation in sediment yields among other large basins in Johnson County are likely related to differences in the number and location of large impoundments and the magnitude and location of urban construction.

Introduction

Urban development causes substantial change to the form, flow, and ecology of streams. The removal of surface vegetation and excavation of soils for building and road foundations increase soil erosion during rainfall events (Wolman and Schick, 1967). These soils are transported downgradient and can be redeposited on land surfaces, floodplains, and streambeds. When the construction phase is finished, impervious surfaces route rainwater directly to streams, resulting in larger, faster streamflows that can transport deposited sediments and incise or widen stream channels (Wolman, 1967; Wolman and Schick, 1967; Leopold and others, 2005). Changes to natural streams as a result of urbanization can result in property loss, reduction in biological diversity (Wood and Armitage, 1997), siltation of downstream reservoirs (Morris and Fan, 1997), and increased water treatment costs (Osterkamp and others, 1998).

Urban growth has negatively affected streams in Johnson County, located in the southwest corner of the Kansas City metropolitan area (fig. 1). Sampling sites downstream from urban areas of the county have decreased macroinvertebrate diversity (Poulton and others, 2007; Rasmussen and others, 2009b) and transport more water, sediment, nutrients, and bacteria than streams draining rural areas (Rasmussen and others, 2008). Streambed sediments in urbanized basins have among the largest concentrations of selected metals, polycyclic aromatic hydrocarbons, phthalates, and other organic compounds (Lee and others, 2005). All of these negative effects can, in part, be related to changes in streamflow and sediment transport resulting from urbanization. Nutrients, indicator bacteria, trace elements, and organic contaminants often are transported while adsorbed to sediment. Increased water routing to streams from impervious surfaces in urban basins facilitates the transport of sediments (and associated contaminants) downstream. Increased sediment deposition and (or) changes to natural streamflow conditions have been linked to decreased diversity of macroinvertebrate and fish communities (Walters and others, 2003; Freeman and Schorr, 2004; Poff and others, 2006).

To improve the understanding of the effects of urbanization on streamflow and sediment transport, from 2006 to 2007 the U.S. Geological Survey (USGS) in cooperation with the Johnson County Stormwater Management Program, studied streamflow and sediment transport at nine sampling sites with varying upstream land use in the urbanizing Mill Creek Basin, and at four sampling sites in larger basins throughout Johnson County (Lee and others, 2009). That study reported increased sediment transport from subbasins with more active construction sites, and decreased sediment transport from smaller, completely urbanized basins within the Mill Creek Basin. Continued study of streamflow and sediment transport conducted by the USGS and the Johnson County Stormwater Management Program involved data collection at previously studied sampling sites (through November 2008), and new data collection at sampling sites more directly downstream from active construction sites, as well as from one sampling site downstream from a small, undisturbed “reference” basin with grassland/forest cover. New sampling sites were installed to better quantify sediment loading downstream from differently sized construction sites with varied erosion and sediment controls, and to better understand how these sediments are transported downstream.

Purpose and Scope

The purpose of this report is to describe the effects of urbanization, construction activity, management practices, and impoundments on sediment transport in Johnson County, Kansas, based on data collected from February 2006 through November 2008. This report describes data collected using continuously recording stage and water-quality sensors at nine sites previously monitored within the urbanizing Mill Creek Basin, and at the outlets of the four other largest basins in Johnson County. Six additional sites were operated within the Mill Creek Basin from February 2007 to December 2008 to assess sediment transport from active construction sites, through a sediment forebay, and a constructed wetland upstream from one of Johnson County’s largest reservoirs

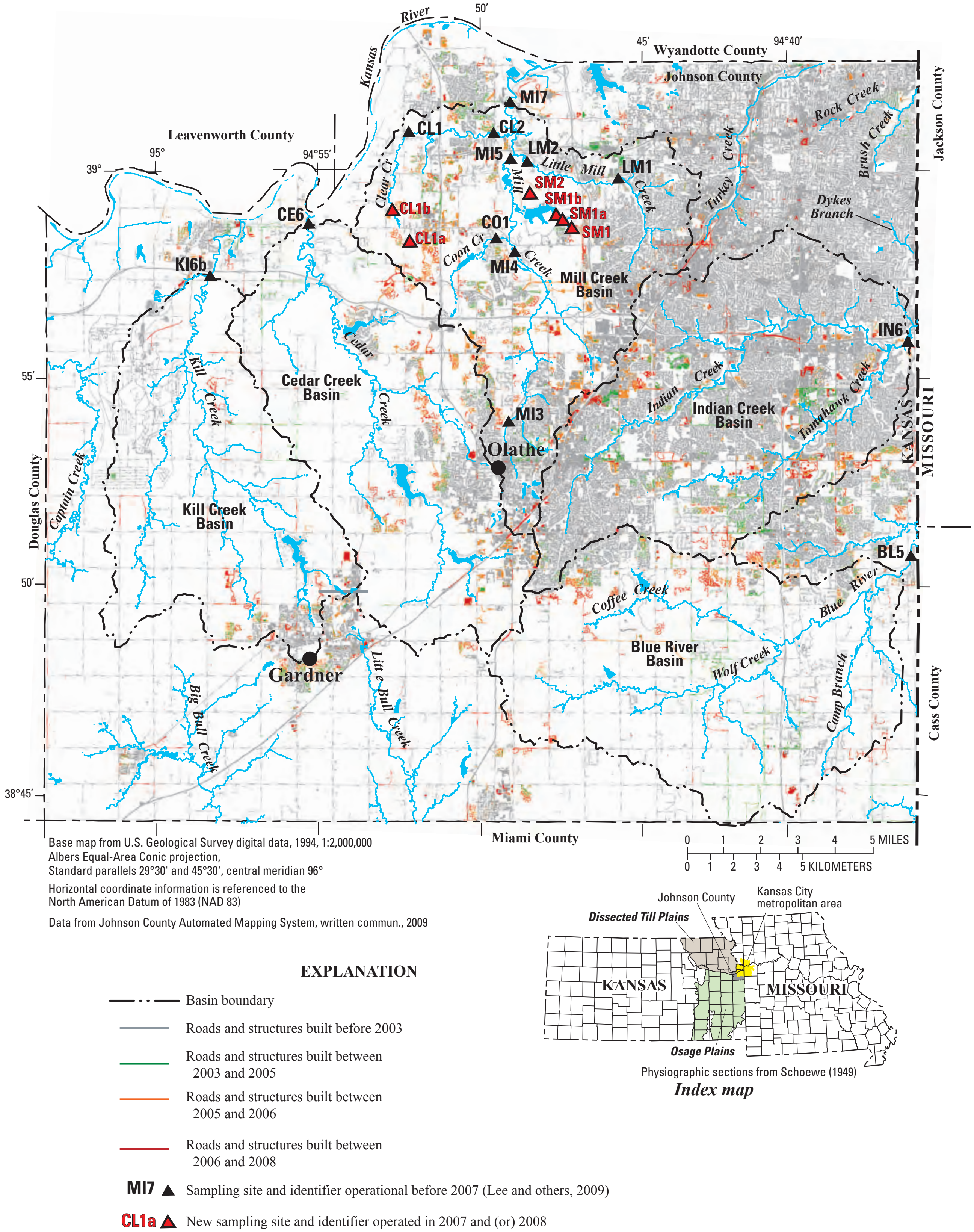


Figure 1. Location of sampling sites, basin boundaries, roads, and structures in Johnson County, northeast Kansas, 2008.

(Shawnee Mission Lake), and from a small, undeveloped basin. Data collected from this study can be used by local officials to help develop effective strategies to mitigate sediment-related impairments. These results support Federal, state, and local efforts to improve water quality and identify processes affecting the transport of fluvial sediment.

Description of Study Area

Johnson County, Kansas, consists of 477 square miles (mi^2) of surface area located in the western part of the Kansas City metropolitan area (U.S. Census Bureau, 2008). Sites were located at the most feasible downstream point in the 5 largest basins (Blue River, Cedar Creek, Indian Creek, Kill Creek, and Mill Creek) in Johnson County and at 14 additional sites (during various times) within the urbanizing Mill Creek Basin (fig. 1; table 1). Physiographic regions of Johnson County include the Osage Plains in the central and southern parts of the county and the Dissected Till Plains along the northern part of the county (fig. 1) (Schoewe, 1949). The county is underlain by sedimentary rock characterized by alternating layers of limestone and shale, and smaller amounts of fine-grained sandstone. Soils primarily consist of loess, and to a lesser degree, glacial till (Evans, 2003).

The Mill Creek Basin is located in the north-central part of the county and includes a large percentage of the cities of Lenexa, Olathe, and Shawnee (fig. 2). One municipal wastewater-treatment facility (Mill Creek Regional) discharges to Mill Creek, directly upstream from sampling site MI3 (fig. 2). Percolation of rainfall to groundwater is limited because of relatively impermeable limestone and shale bedrock. Wells in the county commonly yield less than 10 gallons per minute (gal/min) (O'Connor, 1971). Because of limited groundwater capacity, most of the streamflow likely originates from overland or shallow subsurface flow. Most of Mill Creek and its tributaries flow through alternating layers of limestone and shale; streambeds primarily are composed of gravel, cobble, rock, and bedrock. Entrainment of large-grained streambed material is not considered a substantial part of the stream-sediment load. Soils and stream-channel banks within the Mill Creek Basin generally consist of erosive to moderately erosive silt and silty-clay loams; channel-banks have occasional limestone and shale outcrops (Evans, 2003).

Channel slope was determined upstream from and among sites using methods described in Lee and others (2008). Among large basins in the county, slopes were steepest among north flowing streams [Cedar Creek, 14.6 feet per mile (ft/mi); Kill Creek, 17.1 ft/mi; and Mill Creek, 14.6 ft/mi] relative to east-flowing streams (Blue River, 9.6 ft/mi; Indian Creek, 11.8 ft/mi). Among Mill Creek sampling sites, channel slope was steepest among headwater sampling sites (SM2, 210 ft/mi; SM1, 112 ft/mi; SM1a, 102 ft/mi; SM1b, 96.0 ft/mi; CL1a, 53.7 ft/mi; table 2) and decreased downstream. Channel slope was smallest between downstream sites MI5 and MI7 (5.9 ft/mi), sites MI4 and MI5 (13.1 ft/mi), and sites CL1 and CL2 (17.6 ft/mi).

The mean annual temperature (1931–2008) in Olathe, Kansas (located in the center of the county; fig. 1), is 55.2 degrees Fahrenheit (°F), with a mean monthly range of 29.4°F in January to 78.8°F in July (National Oceanic and Atmospheric Administration, 2009). Mean annual rainfall (1931–2008) is 39.0 inches (in.), with 68 percent of the rainfall occurring during the growing season from April through September (National Oceanic and Atmospheric Administration, 2009). Storms with more than 1 in. of rainfall occur an average of 10.7 days per year (1948–2008; National Oceanic and Atmospheric Administration, 2009).

Construction Sites

Active construction sites in the study area typically undergo three phases before completion. Grading consists of excavation (cut) and filling of soils to provide level, stable foundations for buildings and roads. This phase is likely to produce the most surface erosion because of widespread destabilization of surface soils and removal of surface vegetation. Roads and storm sewer construction typically succeed cut and fill activities, followed by building construction. Phase II National Pollution Discharge Elimination System regulations require operators of separate municipal storm sewer systems to enforce best management practices (BMPs) during and after construction activities at sites disturbing greater than 1 acre of land (U.S. Environmental Protection Agency, 2005). These BMPs include erosion controls (early seeding, erosion control blankets/mats) and sediment controls (mulch/earth berms, silt fences, rock checks, swales, and settling basins).

Sampling sites SM1, SM1a, and SM1b were installed to assess sediment transport from a large, 68-acre multi-use construction site (City Center North; City of Lenexa) and through a sediment forebay and constructed wetland to Shawnee Mission Lake (fig. 3). Shawnee Mission Lake is a 150-acre reservoir constructed in 1962, and primarily is used for swimming, boating, and fishing. The basin upstream from the lake has had some residential development from 2000 to 2006, but remained primarily undeveloped until the City Center North construction site broke ground in March 2007. At the City Center North construction site, steep slopes required extensive cut and fill to bring the site to final grade (R. Beilfuss, City of Lenexa, written commun., 2008). Mulch berms and silt fences (not visible on aerial photography) were installed in series along each slope, along with three rock checks in the central channel (fig. 3). Silt fences also were installed around fill piles on site. After a 1.2-in. rain on March 29, 2007 (slightly larger than the average storm in terms of amount and intensity), inspections conducted by the City of Lenexa indicated that storm runoff had compromised perimeter mulch berms and a rock check, runoff from the central stream eroded beneath rock checks, sediment-laden water was discharging from the main settling basin, and a large sediment plume was observed leaving the site and entering Shawnee Mission Lake (fig. 4). After this event, existing sediment-control practices were strength-

Table 1. Location and contributing drainage area of sampling sites in Johnson County, northeast Kansas, February 2006 through November 2008.

[mi^2, square mile; mm, month; yr, year]

Sampling site (fig. 1)	U.S. Geological Survey identification number	Site name	Contributing drainage area (mi^2)	Latitude (degrees, minutes, seconds)	Longitude (degrees, minutes, seconds)	Period of streamflow/ sediment record (excluding periods of freezing) (mm/yr–mm/yr)
		Mill Creek sites				
CL1a	385818094520300	Clear Creek at 86th Terrace, Lenexa	0.7	38°58'18"	94°52'03"	02/07–11/08
CL1b	385922094485500	Clear Creek at 79th Street, Lenexa	2.8	38°59'22"	94°48'55"	02/07–11/07
CL1	390051094522200	Clear Creek at Clare Road, Shawnee	5.5	39°00'51"	94°52'22"	02/06–11/08
CL2	390056094493200	Clear Creek at Woodland Road, Shawnee	10.9	39°00'56"	94°49'32"	02/06–11/08
CO1	385826094491700	Coon Creek at Woodland Road, Lenexa	5.1	38°58'26"	94°49'17"	02/06–11/08
LM1	385952094454000	Little Mill Creek at Lackman Road, Shawnee	8.8	38°59'52"	94°45'40"	02/06–11/08
LM2	390010094482100	Little Mill Creek at Warwick Lane, Shawnee	12.1	39°00'10"	94°48'21"	02/06–11/08
MI3	385404094485800	Mill Creek at Woodland Road, Olathe	2.8	38°54'04"	94°48'58"	02/06–11/08
MI4	385800094485300	Mill Creek at 87th Street Lane, Lenexa	19.7	38°58'00"	94°48'53"	02/06–11/08
MI5	390026094485800	Mill Creek upstream from Shawnee Mission Parkway, Shawnee	31.7	39°00'26"	94°48'58"	02/06–11/08
MI7	06892513	Mill Creek at Johnson Drive, Shawnee	57.4	39°01'46"	94°49'03"	09/02–11/08
SM1	385835094471300	Unnamed tributary at Barkley Drive, Lenexa	.6	38°58'35"	94°47'13"	02/07–11/08
SM1a	385910094474400	Unnamed tributary into Shawnee Mission Lake Wetland	1.3	38°59'10"	94°47'44"	02/08–11/08
SM1b	385859094473700	Unnamed tributary into Shawnee Mission Lake, Lenexa	1.4	38°58'59"	94°47'37"	02/08–11/08
SM2	385922094485500	Unnamed tributary near Shawnee Mission Lake, Lenexa	.2	38°59'22"	94°48'55"	02/07–11/07
		Additional Johnson County sites monitored during study period				
BL5	06893100	Blue River at Kenneth Road, Overland Park	65.7	38°50'32"	94°36'44"	02/04–11/08
CE6	06892495	Cedar Creek near DeSoto	58.5	38°58'41"	94°55'20"	09/02–01/08
IN6	06893390	Indian Creek at State Line Road, Leawood	63.1	38°56'15"	94°36'30"	02/04–11/08
KI6b	06892360	Kill Creek at 95th Street near DeSoto	48.6	38°57'28"	94°58'30"	02/04–01/08

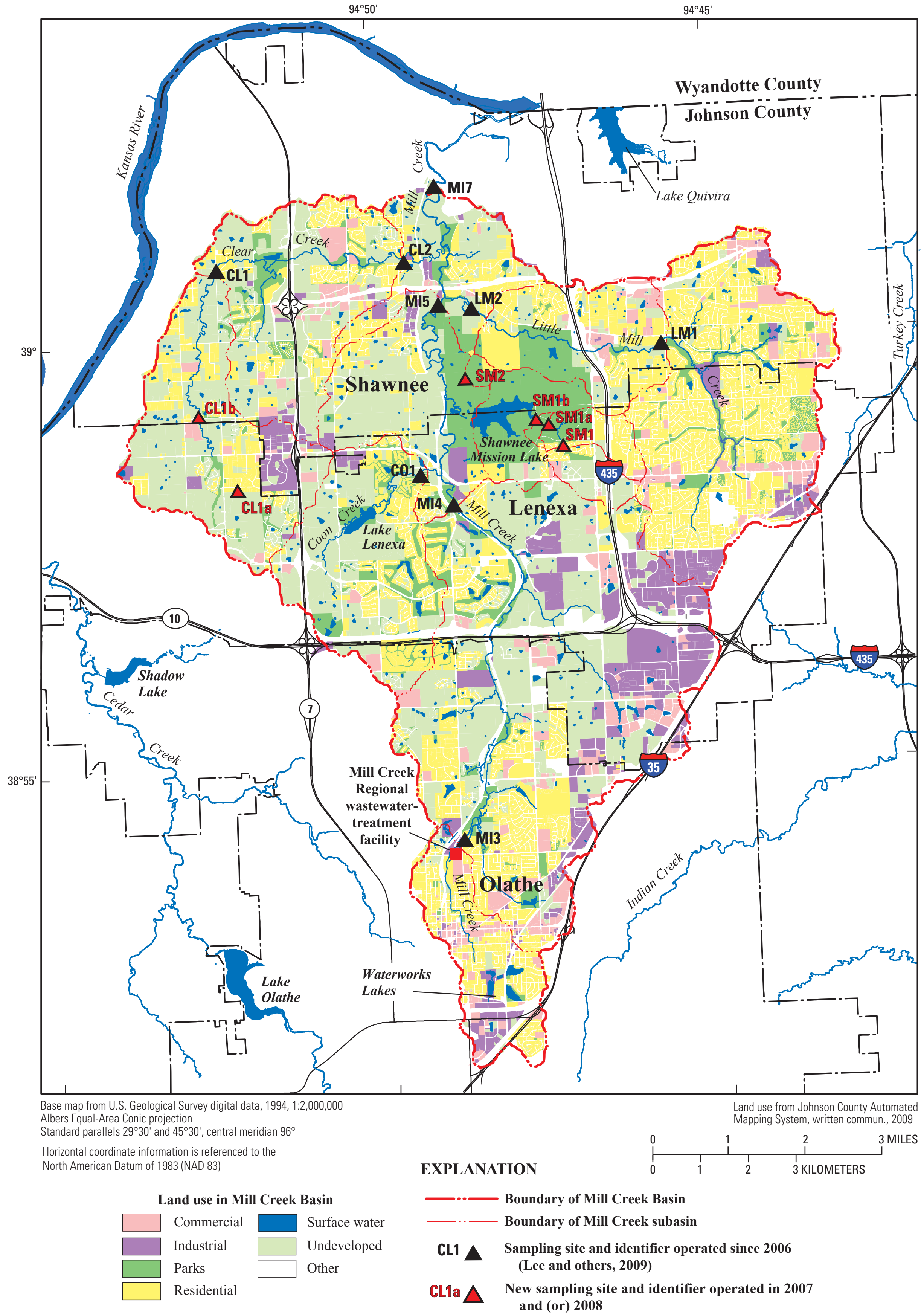


Figure 2. Location of basin boundaries, sampling sites, and land use in the Mill Creek Basin, Johnson County, northeast Kansas, 2008.

Table 2. Land use, channel slope, and major impoundments upstream from sampling sites in Johnson County, northeast Kansas, 2008.

[mi^2, square mile; ft/mi, foot per mile; --, not applicable; data from S. Porter, Johnson County Automated Information Mapping System, written commun., 2009]

Sites immediately upstream (fig. 1)	Down-stream sites (fig. 1)	Estimated drainage area (mi^2)	Percentage of basin area affected by impoundments	Channel slope (ft/mi)	Percentage land use								Percentage impervious surface (change in percentage from 2006 to 2008)
					Residential	Commercial	Industrial	Right of way	Parks	Water	Undeveloped[a]	No data[b]	
Basin upstream from sampling sites													
--	CL1a	0.7	--	53.7	9.8	3.3	0.6	1.3	6.7	0.5	68.4	9.4	10.9 (3.1)
--	CL1b	2.8	--	39.5	16	4.3	14.5	4.7	4.3	.4	47.7	8.1	18.8 (1.9)
--	CL1	5.5	--	28.3	18.6	3.1	7.8	2.6	2.6	1.0	58.5	5.8	11.3 (1.0)
--	CL2	10.9	--	20.0	19.9	5.5	4.8	4.3	5.6	1.1	51.5	7.3	13.1 (0.9)
--	CO1	5.1	40 (Lake Lenexa)	43.1	23.2	1.6	2.1	8	13.5	1.5	44	6.1	10.8 (.5)
--	LM1	8.8	--	29.2	52.6	9.9	7.3	2.4	7.3	.8	3.5	16.2	30.7 (.8)
--	LM2	12.1	--	22.8	51	9.7	5.5	4.6	9.8	1.0	4.3	14.1	27.1 (.7)
--	MI3	2.8	36 (Waterworks Lakes)	22.9	37.6	11.6	13.0	9.2	1.3	2.4	7.4	17.5	35.1 (2.2)
--	MI4	19.7	5	21.6	21.5	7.9	15.2	8.9	4.1	1.6	29.8	11.0	24.8 (1.6)
--	MI5	31.7	19	18.2	22.1	5.8	10.6	8.7	12.9	2.2	28.1	9.6	17.8 (1.0)
--	MI7	57.4	10	14.6	27.8	6.3	8.2	6.9	10.7	1.7	28.5	9.9	18.8 (1.0)
--	SM1	.6	--	112	15.6	5.0	.1	16.9	5.5	.5	46.6	9.8	27.7 (2.5)
--	SM1a	1.3	--	102	27.2	3.9	.1	13.1	21.8	.4	23.5	10.0	26.5 (1.5)
--	SM1b	1.4	--	96.0	25.7	3.7	.1	12.4	26.0	.4	22.2	9.5	25.8 (1.4)
--	SM2	.2	--	210	18.7	0	0	0	81.0	.3	0	0	1.5 (.0)
Basins between sampling sites													
CL1a	CL1b	2.1	--	27.1	18.3	4.7	19.4	5.9	3.5	.3	40.3	7.6	21.7 (1.4)
CL1b	CL1	2.7	--	22.2	21.1	1.8	1.3	.5	.8	1.5	68.9	4.1	4.0 (.1)
CL1	CL2	5.4	--	17.6	21.3	8.1	1.7	6.1	8.9	1.2	44.2	8.5	15.0 (.9)
LM1	LM2	3.3	--	23.1	41.5	8.0	.1	10.2	15.5	1.5	15.8	7.4	17.3 (.3)
MI3	MI4	16.9	--	24.0	18.5	7.3	15.6	8.8	4.6	1.5	33.9	9.8	22.9 (1.4)
CO1, MI3, MI4	MI5	5.3	42 (Shawnee Mission Lake)	13.1	12.5	.6	3.9	2.3	33.4	5.1	38.2	7.0	6.2 (.3)
CL2, LM2, MI5	MI7	2.7	--	5.9	26.2	1.3	4.9	5.9	8.8	2.4	45.5	5.0	10.5 (.2)
SM1	SM1a	.7	--	77.5	37.7	2.9	.1	9.7	36.5	.4	2.7	10.0	25.5 (.5)
SM1a	SM1b	.1	--	63.6	0	0	0	0	96.6	.6	0	2.7	13.3
Other monitored basins in Johnson County (Rasmussen and others, 2008)													
--	BL5	65.7	--	9.6	15.7	2.2	3.1	2.0	5.0	2.2	65.5	4.3	4.4 (0.5)
--	CE6	58.5	18 (Olathe Lake)	14.6	12.5	2.8	8.4	3.5	4.0	2.1	61.6	5.1	7.6 (.6)
--	IN6	63.1	--	11.8	45.0	15.3	2.4	4.4	8.3	1.0	8.5	15.1	30.1 (1.3)
--	KI6b	48.6	11 (Gardner City Lake)	17.1	6.7	2.4	5.2	.7	3.6	1.9	76.8	2.7	4.1 (.5)

[a] Undeveloped land use includes agricultural land use and land not under production.

[b] No data land use includes untaxed land uses (such as government property and public roads).

Figure 3. Location of City Center North construction site, sampling sites, and selected best management practices, Lenexa, Kansas, 2008.

Figure 4. *A,* Destroyed mulch berm and rock check at City Center North development, and *B*, turbid water entering Shawnee Mission Lake, Lenexa, Kansas, March 30, 2007. Photographs by Dale Clark, City of Lenexa.

ened, and two main sedimentation basins were added in early June 2007.

A constructed wetland and sediment forebay were completed in February 2008 immediately upstream from Shawnee Mission Lake and downstream from the City Center construction site (fig. 3). The wetland was constructed to augment a wetland that was naturally developing on the southeast arm of the lake, with the goal of increasing habitat diversity, providing educational opportunities to local citizens, and improving the water quality of Shawnee Mission Lake (T. Stanton, Olsson Associates, written commun., 2009). A 1.8-acre-foot (acre-ft) sediment forebay was installed upstream to maintain and extend the life of the wetland. Wetland/forebay construction was initiated in response to lake-water quality concerns present before City Center North construction, and thus were not implemented to specifically reduce sediment accumulation as a result of these projects. The wetland was designed to facilitate flow (as well as fish and canoes) into the lake, and thus was not constructed to maximize hydraulic retention for the purpose of reducing sediment accumulation in the lake. Additionally, although the construction of the sediment forebay and wetland were completed before site installation in 2008, wetland vegetation will not be fully established (and thus best able to filter sediment) for 3 to 4 years (T. Stanton, Olsson Associates, written commun., 2009). Nonetheless, sediment sampling was initiated to assess the ability of the forebay/wetland to reduce sediment accumulation in Shawnee Mission Lake.

Sampling site SM1 was located 1,400 feet (ft) downstream from the City Center North construction site and operated from February 2007 through November 2008 to estimate the amount of sediment transported from the site (fig. 3). Sites SM1a and SM1b were operated from February 2008 through November 2008 after construction of a sediment forebay and constructed wetland. Site SM1a was installed directly downstream from the forebay; site SM1b was installed downstream from the constructed wetland to characterize sediment transport from the subbasin containing the construction site through the forebay and wetland into Shawnee Mission Lake.

Site SM2 was operated from February through November 2007 and was downstream from undeveloped parkland. Site SM2 was discontinued in November 2007 and equipment was relocated to monitor sediment removal at the sediment forebay and constructed wetland.

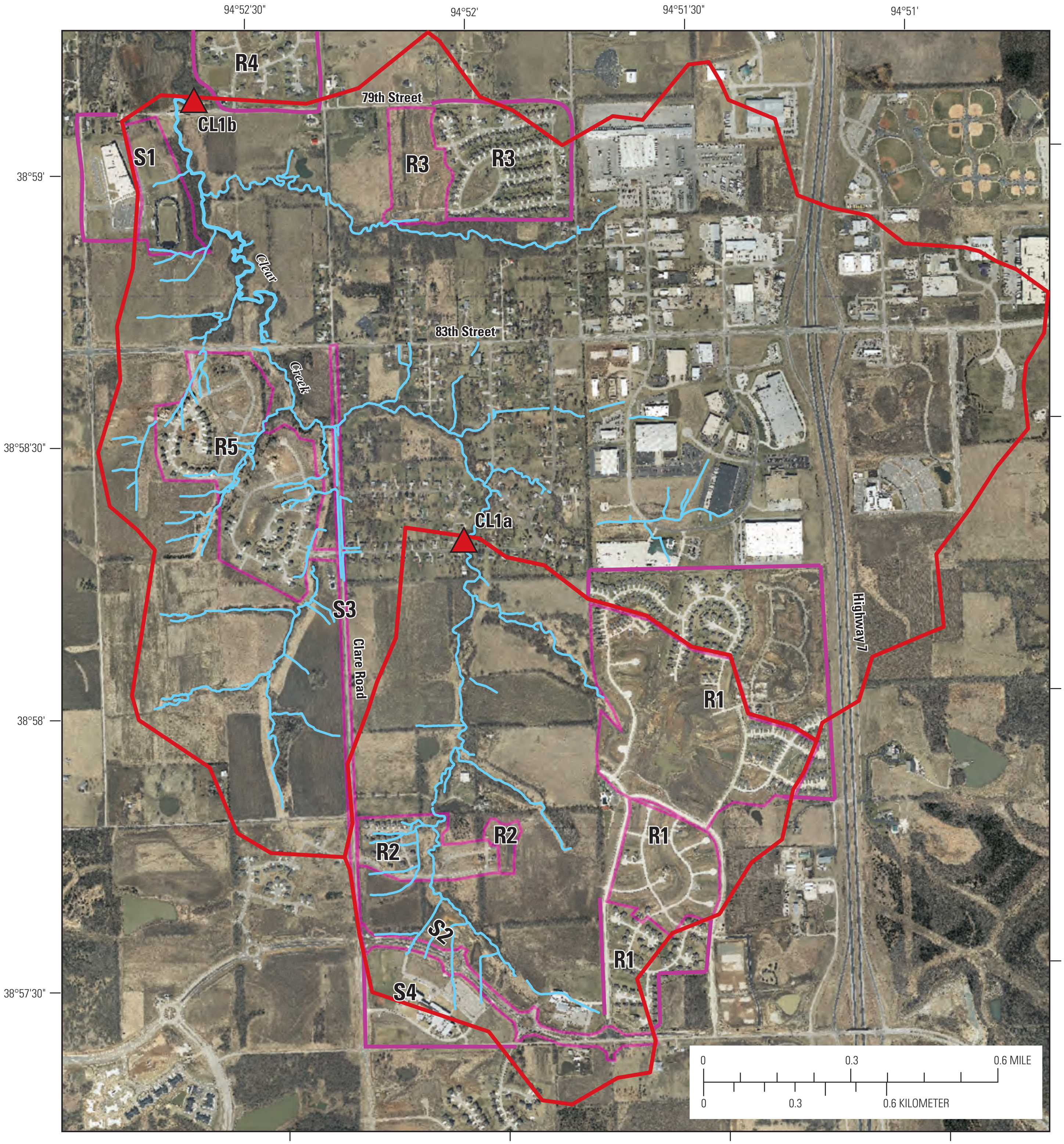
Because the headwaters of the Clear Creek Basin [upstream from site CL1, (fig. 1)] transported the most sediment to Mill Creek (per unit area) from February 2006 through June 2007 (Lee and others, 2009), sampling sites CL1a and CL1b were installed in the headwaters of the Clear Creek Basin to better characterize predominant sediment-source areas (fig. 5). Site CL1a was operated from February 2007 through November 2008; site CL1b was operated from February through November 2007. Site CL1b was discontinued in December 2007, and equipment was relocated to monitor sediment removal at a sediment forebay and constructed wetland during 2008. Several construction sites were active in the Clear Creek Basin during and immediately before the study period (fig. 5; table 3), including several large housing developments, a school, and road construction. Sediment controls at construction sites generally consisted of silt fences and rock checks at locations where flows were concentrated. Although City of Lenexa erosion control inspections generally documented that on-site erosion controls were functioning correctly, examples of their failure were documented (fig. 6).

Land Use

Property tax data were used to distinguish land use among various types [residential, commercial, industrial, right of way, parks, water, undeveloped, and "no data" (S. Porter, Johnson County Automated Information Mapping System, written commun., 2009)]. The "no data" category consists of untaxed land-use parcels. Among the five large basins in Johnson County, Indian Creek is almost completely urbanized (as defined by residential, commercial, and industrial land use; fig. 1; table 2), Mill Creek is mixed between urban and rural, and Blue River, Cedar Creek, and Kill Creek predominantly are rural. The amount of urban construction (defined by the change in percentage of impervious surface from 2006 to 2008; table 2) were largest in the Indian (1.3 percent) and Mill Creek (1.0 percent) basins and much less (0.5 to 0.6 percent) in the other large basins (table 2). Urbanization in the northeast part of Johnson County is beginning to expand into the predominantly rural Blue River and Cedar Creek Basins.

Urbanization in the Mill Creek Basin has been concentrated in the eastern and northern sections of the basin (fig. 1; table 2). Subbasins upstream from site LM1 (City of Lenexa) and site MI3 (City of Olathe) were the only subbasins with more than 60 percent (72 and 71 percent, respectively) urban land use (residential, commercial, industry, and right of way) and greater than 30 percent impervious surface (30.7 and 35.1 percent, respectively). These basins also had the smallest amount of land classified as parks or as undeveloped (10.8 and 8.7 percent, respectively). Undeveloped areas (such as agricultural land, forests, and grassland) and parks are the predominant land use in the central and western parts of the basin, primarily in the Clear Creek and north-central Mill Creek subbasins (table 2).

Because property tax data indicate the primary use of a parcel of land rather than the actual building or road area, these data may not accurately characterize the effects of land use on streams. For this reason, changes in impervious surface (defined as building and pavement area obtained from aerial photography) are used to define changes for various periods from 2003 to 2008 (fig. 7). Subbasins upstream from sampling sites LM1 and LM2 had relatively small increases in impervious surfaces (table 2), indicating relatively little new urban construction (fig. 1). The largest increases in impervious surface from 2003 to 2008 generally occurred upstream from sites CL1, CL2, MI3, MI4, and SM1, indicating that new urban construction primarily is occurring in the central and western parts of the Mill Creek Basin (Clear Creek and



Aerial photography taken March 2008 (Johnson County Automated Information Mapping System, written commun., 2009)

Data from Johnson County Automated Information Mapping System, written commun., 2009

EXPLANATION

Construction site boundary

Subbasin boundary

County defined drainage line

CL1b Sampling site and identifier (table 1)

R4 Construction site and identifier (table 3)

Figure 5. Location of construction sites and sampling sites in the headwaters of Clear Creek, Lenexa, Kansas, 2004 through 2008.

Table 3. Active construction sites, construction area, and phasing in the basins upstream from sites CL1a, CL1b, and SM1, Lenexa, Kansas, 2004 through 2008.

[mi²; square mile]

Site designation (fig. 5)	Area (mi^2)	Sampling site identifier immediately downstream	Phases and timing of construction (D. Clark, City of Lenexa, written commun., 2009)
Residential construction sites			
R1	0.34	CL1a/CL1b	Mass graded in 2004, houses built through 2008.
R2	.04	CL1a	Mass graded in 2005, paved in 2006, houses built through 2008.
R3	.12	CL1b	Construction from 2004 to 2008.
R4	.06	CL1	Construction from 2004 to 2008.
R5	.11	CL1b	Mass graded and paved in 2006, houses built through 2008.
Road/School/Commercial construction sites			
S1 (Public school)	0.05	CL1b/CL1	Building construction through 2006.
S2 (Prairie Star Parkway)	.02	CL1a	Graded in 2007, paved in 2008.
S3 (Clare Rd)	.02	CL1a/CL1b	Mass graded and storm drainage began in spring 2008.
S4 (Private school)	.06	CL1a	Completed in 2005.
City Center North	.11	SM1	Grading from spring-summer 2007, storm sewers and roads in fall 2007, building construction through 2008.

central Mill Creek subbasins). Parking lot and building construction in the far southern, industrial part of the urbanized basin upstream from sampling site MI3 caused a substantial increase (32.9 to 35.1 percent) in impervious surface from 2006 to 2008 (table 2); however, these developments were upstream from a series of impoundments (Waterworks Lakes), and thus may not affect sediment transport at downstream sampling sites.

Three, relatively large (greater than 30-acre) surface-water impoundments are present within the Mill Creek Basin. The largest impoundment (in terms of surface area—impoundment volumes generally are unknown) is Shawnee Mission Lake, which has a surface area of 120 acres, an estimated contributing drainage area of approximately 2.9 mi^2, and affects 42 percent of the basin area between sampling sites MI4 and MI5 (fig. 2). Waterworks Lakes have a combined surface area of 32 acres (volume unknown), an estimated contributing drainage area of 1.0 mi^2, and affect 36 percent of the basin area upstream from site MI3 (fig. 2; table 2). Lake Lenexa is a 30-acre, 550-acre-ft, impoundment constructed from 2005 to 2006, which has an estimated contributing drainage area of 2.0 mi^2, and affects 40 percent of the basin area upstream from site CO1 (R. Beilfuss, City of Lenexa, written commun., 2007). Large impoundments generally retain incoming stormflows longer, allowing more time for sediment to deposit to the impoundment bottom, thus decreasing sediment loads at downstream sampling sites. Smaller farm ponds and sediment-control structures present in the Mill Creek Basin and other basins (fig. 2) also likely remove suspended sediment from fluvial transport (Renwick and others, 2005).

Previous Studies

Rasmussen and others (2008) used continuous water-quality monitoring to estimate constituent concentrations and loads in the five largest Johnson County streams, including Mill Creek. That study determined that most streamflow and sediment were transported from the most urbanized basin (Indian Creek; Rasmussen and others, 2008). Suspended-sediment yields from Mill Creek were smaller than yields from Indian Creek, but larger than those from the more rural Cedar and Kill Creeks (fig. 1).

A report on sediment sources and transport in the Mill Creek Basin from February 2006 through June 2007 was published in 2009 (Lee and others, 2009). That report described streamflow and sediment transport at nine sites in the Mill Creek Basin and four sites at the outlet of the other largest basins in Johnson County. The initial study determined that construction sites were the largest source of sediment to Mill Creek, whereas mature, urban subbasins within the Mill Creek Basin had substantially smaller sediment yields. These findings served as the impetus for continued study described in this report focusing on sediment transport with respect to construction sites. Slightly smaller sediment yields in larger basins were attributed to sediment deposition in larger, less sloping stream channels. Streamflow and sediment transport were enumerated for individual storms and analyzed in relation to measurements of storm intensity, antecedent rainfall, and sediment transport conditions. Storms with increased rainfall intensity resulted in increased sediment transport at eight of the nine sampling sites, whereas storms that follow periods of increased sediment loading transported substantially less sediment at two of the nine sampling sites. Methods of data collection and analysis from the study by Lee and others (2009) are used as a template for those in this report. This study served as the impetus for continued monitoring and further focus on sediment transport with respect to construction sites.

Construction has been shown to cause substantial sediment deposition in stream channels resulting in erosion of channel banks, obstruction of flow and increased flooding, blanketing of stream life, changes in light transmission through the water column, and alteration of fish species (Wolman and Schick, 1967; Guy, 1970). Several, primarily older (1960s to 1980s) studies have characterized the effect of urban

Figure 6. *A*, Erosion from a residential construction site, *B*, gully formation near culvert, and *C*, sediment deposition downstream from culvert after a storm in the headwaters of Clear Creek, Lenexa, Kansas, April through May 2007. Photographs by Dale Clark, City of Lenexa.

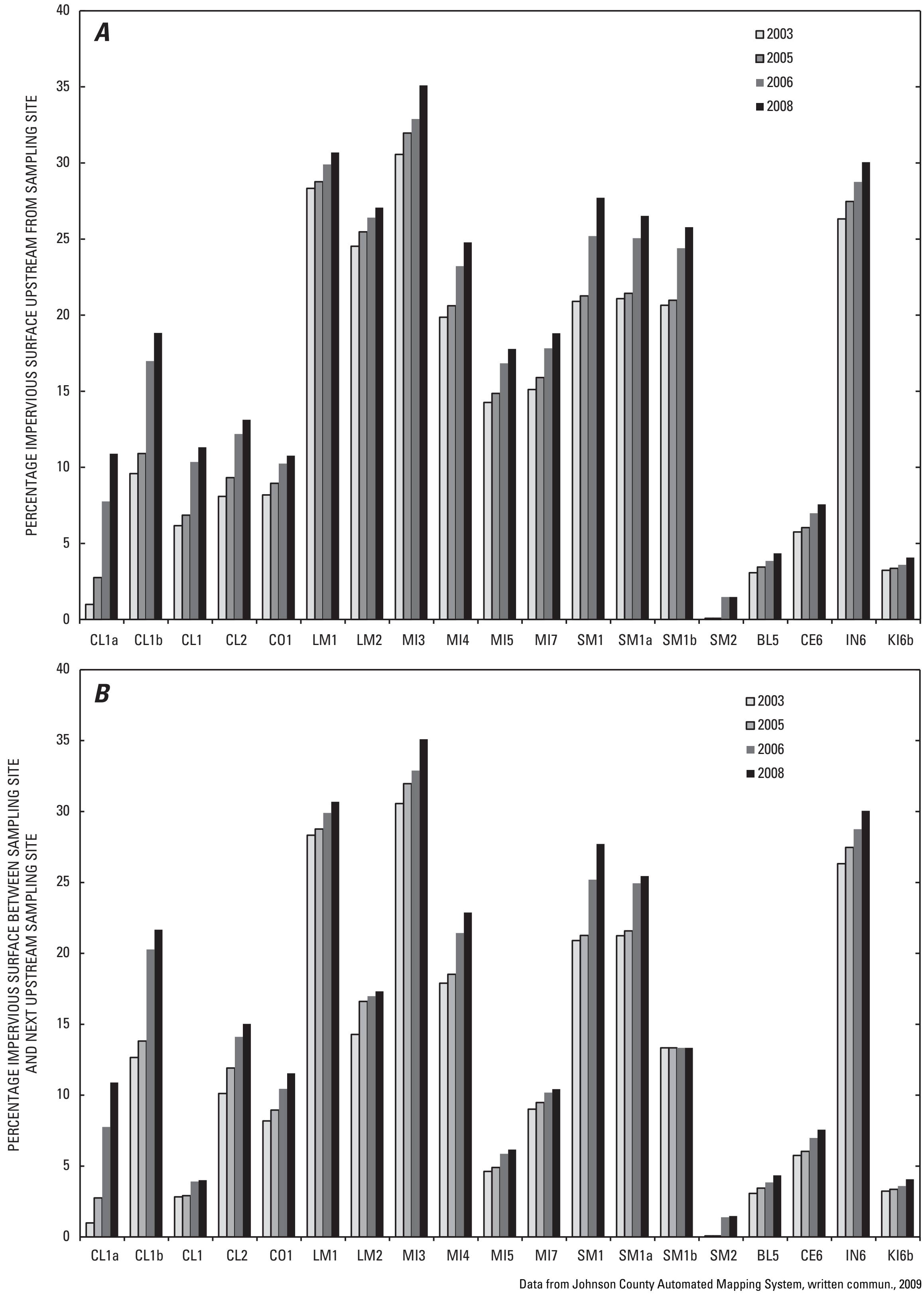


Figure 7. Percentage impervious surface area *A*, upstream from and *B*, between sampling sites in Johnson County, northeast Kansas, 2003 through 2008.

construction on sediment transport in the United States. These studies indicated widespread erosion and sediment transport during urban construction relative to agricultural, urban, or undisturbed land. Historical sediment yields from construction sites without sediment-control measures ranged from 2,300 to 140,000 tons per square mile per year (tons/mi^2/yr), compared to agricultural (420 to 2,750 tons/mi^2/yr) or forest land (15 to 110 tons/mi^2/yr; Wolman and Schick, 1967; Vice and others, 1969; Guy, 1970; Walling and Gregory, 1970; Yorke and Herb, 1978; Helsel, 1984; and Owens and others, 2000). The principal factors affecting the transport of sediment from sites are basin size, soil type, rainfall amount and intensity, length of time the sites were unvegetated, slope, site proximity to stream channels, soil compaction from heavy equipment, and the use of erosion and sediment-control measures (Wolman and Schick, 1967; Yorke and Herb, 1978). Erosion and sediment-control measures at construction sites have been shown to decrease sediment yields by 60 to 80 percent (Yorke and Herb, 1978).

Methods

Data Collection and Analysis

Eight sampling sites were installed in the Mill Creek Basin in February 2006 (in addition to site MI7, operated since October 2002). Four additional sites were installed in February 2007 (CL1a, CL1b, SM1, SM2), two of these sites (CL1b, SM2) were removed in December 2007 and equipment reinstalled to monitor sediment removal at a sediment forebay and constructed wetland at sites SM1a and SM1b in February 2008. All monitors in the Mill Creek Basin were removed from November 30 to December 1, 2008 (table 1). YSI Incorporated (YSI) water-quality monitors equipped with specific conductance, water temperature, and model 6136 turbidity sensors were operated at each site. Suspended-sediment concentration (SSC) and the percentages of sediment greater and less than 63 micrometers (µm) in diameter were determined at the USGS Sediment Laboratory in Iowa City, Iowa, using methods from Guy (1969).

YSI water-quality monitors were installed in streams and were housed in polyvinyl chloride pipes with holes drilled to facilitate flow through the installation. Monitors were installed at the stream edge, approximately 0 to 2 ft above the streambed depending upon stream depth. Site locations were chosen to divide the study area into equally sized subbasins and to characterize sediment transport from construction sites, while accounting for site suitability and attempting to avoid backwater conditions. Data were collected every 5 or 15 minutes (15-minute data were collected at basin outlets); real-time data are available on the USGS Kansas Water Science Center Web page (*http://nrtqw.usgs.gov/ks/*). Monitor maintenance and data reporting generally followed procedures described in Wagner and others (2006) with the exception of increased length between calibration checks (approximately 2 to 3 months). Length between calibration checks was extended beyond the recommended monthly frequency because of the absence of pH and dissolved oxygen sensors, which are most prone to calibration drift. Turbidity records generally were rated good (error of 5 to 10 percent) and occasionally fair (10 to 15 percent) on the basis of guidelines developed by Wagner and others (2006).

Solinst Levellogger (Ontario, Canada) sensors and (or) radar gage sensors were installed to monitor gage height. Streamflow was measured and calculated using methods described in Kennedy (1983, 1984). Rating curves comparing gage height and streamflow were developed using streamflow measurements and the slope-conveyance method (Kennedy, 1984). Streamflow records were compiled without regular streamflow measurements during low-flow conditions, which have a negligible effect on sediment loads. Nonstandard development of streamflow record required a “poor” rating, implying that 95 percent of daily flows could be in error by more than 15 percent. Streamflow was not estimated at site SM1b because of consistent backwater conditions. Backwater conditions also were present during base-flow conditions at site SM1a, but because stormflow peaks were much larger than at site SM1b, backwater was not apparent during observed stormflow conditions, and streamflow estimates compared favorably to upstream site SM1, streamflow conditions were estimated at site SM1a. Streamflow values and interpretations are considered more uncertain at site SM1a because of periodic backwater conditions.

With the exception of site MI7, streamflow and water-quality data were not collected from November 30 to December 18, 2006; January 10 to February 20, 2007; and December 7, 2007 to February 16, 2008, because of freezing conditions. Sensors were removed during these periods because stream ice expansion can potentially crush monitoring equipment (site MI7 is located at a deep pool below ice). Precipitation during the winter of 2006–07 generally consisted of snow, and thus streamflow and sediment concentrations observed at site MI7 generally were at (or near) base-flow conditions. Four storms occurred during the winter of 2007–08 that resulted in increased streamflow at site MI7 while sensors were removed at other sites. Storms occurred from December 11 to 13, 2007 [peak streamflow, 530 cubic feet per second (ft^3/s)], January 8 to 9, 2008 (peak streamflow, 260 ft^3/s), January 10 to 11, 2008 (peak streamflow, 560 ft^3/s), and February 5 to 7, 2008 (peak streamflow, 1,790 ft^3/s). For purposes of comparing streamflow and sediment loading between sampling sites, computations of streamflow and sediment loading exclude these periods from analysis. Because aggregate measures of streamflow were similar between sites LM1 and LM2, total flow and the flow volume of two small storms missing at site LM1 from April 6 to 16, 2007, were estimated using data from site LM2.

Individual storms were delineated based on observed rainfall and streamflow conditions as described in Lee and others (2009). Base flow (defined as wastewater discharge and groundwater flow) and stormflow (defined as overland flow and interflow) parts of the streamflow record were separated using the base-flow index program (BFI; Wahl and Wahl, 2006). Storms in which more than 0.5 in. of rain occurred on the Mill Creek Basin were assigned a whole number (1–63) starting at the beginning of the study period. Storms in which streamflow increased relative to base-flow conditions in response to less than 0.5 in. of rainfall on the basin were assigned a decimal dependent upon the whole-numbered storms they fell between. The beginning and end of stormflow periods were assigned from the first few values before an observed rise in streamflow after a period of rainfall, until streamflow values were not consistently decreasing as a result of the previous storm (or beginning of the next storm).

Stormflow volumes were determined by subtracting the volume of base flow from the volume of streamflow transported during the storm. A consistent criteria was not used to determine the beginning and end times of storms because back-to-back rainfall periods occasionally increased streamflows before a complete return to base-flow conditions, multiple storms at headwater sampling sites often could not be isolated at downstream sites (and thus were combined into one storm), and data analysis indicated that a small percentage of stormflow volume and sediment loads occurs during the beginning and end of stormflow periods, and that minor changes in storm beginning and end times have a negligible effect on the computed cumulative stormflow volume and sediment load. The gage and water-quality monitor installation at site CL1a was destroyed by storm debris on September 13, 2008, and was replaced on September 24, 2008. Total stormflow for the storm during this period was estimated by multiplying the stormflow for the same storm at site CL1 by the percentage of total stormflows at CL1a compared to site CL1 (9.4 percent).

Rainfall data were collected and analyzed from 18 tipping-bucket rain gages located in and around the Mill Creek Basin from February 2006 through November 2008 (Overland Park Stormwatch, 2009; Lee and others, 2009). Data from the rain gages were combined and weighted using Thiessen polygons (Thiessen and Alter, 1911) to estimate rainfall characteristics for basins upstream from sampling sites.

Suspended-sediment-concentration samples generally were collected at a minimum of five locations equally distributed across the stream cross section according to methods described in Nolan and others (2005). At riffles less than 3 ft wide and 0.5 ft deep, samples were collected by dipping a bottle in the center of the cross section. All other samples were collected through equal-width increment sampling methodologies, using USGS-approved samplers (Nolan and others, 2005).

Quality Assurance

Median values of cross-section turbidity measurements were used to compute SSC using regression analysis. Cross-section turbidity measurements were used in regression analysis (as opposed to values from in-stream monitors) because in-stream values were not collected in real-time, and thus occasionally were malfunctioning or were subject to environmental fouling during sample collection. To ensure that the values of the cross-section turbidity readings represent those recorded by in-stream continuous water-quality sensors, comparisons of turbidity values were made between in-stream sensors and the median of cross-section measurements. Samples from all sampling sites were aggregated to determine if consistent bias existed between cross-section and point-turbidity data among sampling sites. Relations between turbidity readings were accurate ($R^2 = 0.98$) and had a near 1:1 relation (slope = 1.01; fig. 8). These data verify that continuous water-quality-sensor readings generally were representative of stream-water quality across the width of the stream cross section under a variety of streamflow conditions (0.98 to 1,190 ft^3/s) and that in-stream sensor values were reproducible by an independently calibrated sensor. Replicate samples were not collected for SSC samples because random errors in laboratory analysis contribute to error observed within regression analyses with turbidity (see “Regression Models” section in this report).

Regression Models

Regression analysis was used to develop statistical models relating SSC from in-stream samples to the median of turbidity values collected across the stream cross section. Suspended-sediment-concentration and turbidity values were log-transformed to better approximate normality and homoscedasticity in the data distribution. After development of the regression relation, variables were retransformed back to a linear scale. Because this retransformation can cause bias when adding load estimates with time, a bias-correction factor (Duan’s smearing estimator; Duan, 1983) was used to correct for potential bias (Helsel and Hirsch, 2002). Uncertainty of regression estimates were determined by the 95-percent prediction intervals (Helsel and Hirsch, 2002). Regression methods used in this study generally follow guidelines described in Rasmussen and others (2009a). Continuous SSC and load computations, uncertainty, and duration curves are available on the World Wide Web at URL *http://nrtqw.usgs.gov/ks/*. With the exception of sampling site SM2, 5 to 14 samples were collected at newly installed sampling sites in an attempt to represent the range of turbidity values observed at each site (table 4). Selected samples were collected in 2009 to verify patterns in regression relations observed at sites SM1a and SM1b. Site SM2 had fewer samples because of difficulty of manually sampling stormflow conditions in the small basin. Maximum SSCs ranged from 160 milligrams per liter (mg/L) at sampling site SM2 to 3,300 mg/L at site SM1 (table 4). Site CO1 had smaller maximum and mean SSC values likely because of sediment trapping by Lake Lenexa and several additional small impoundments within the basin (fig. 2; table 4). Mean SSC values were smaller at site MI5 because

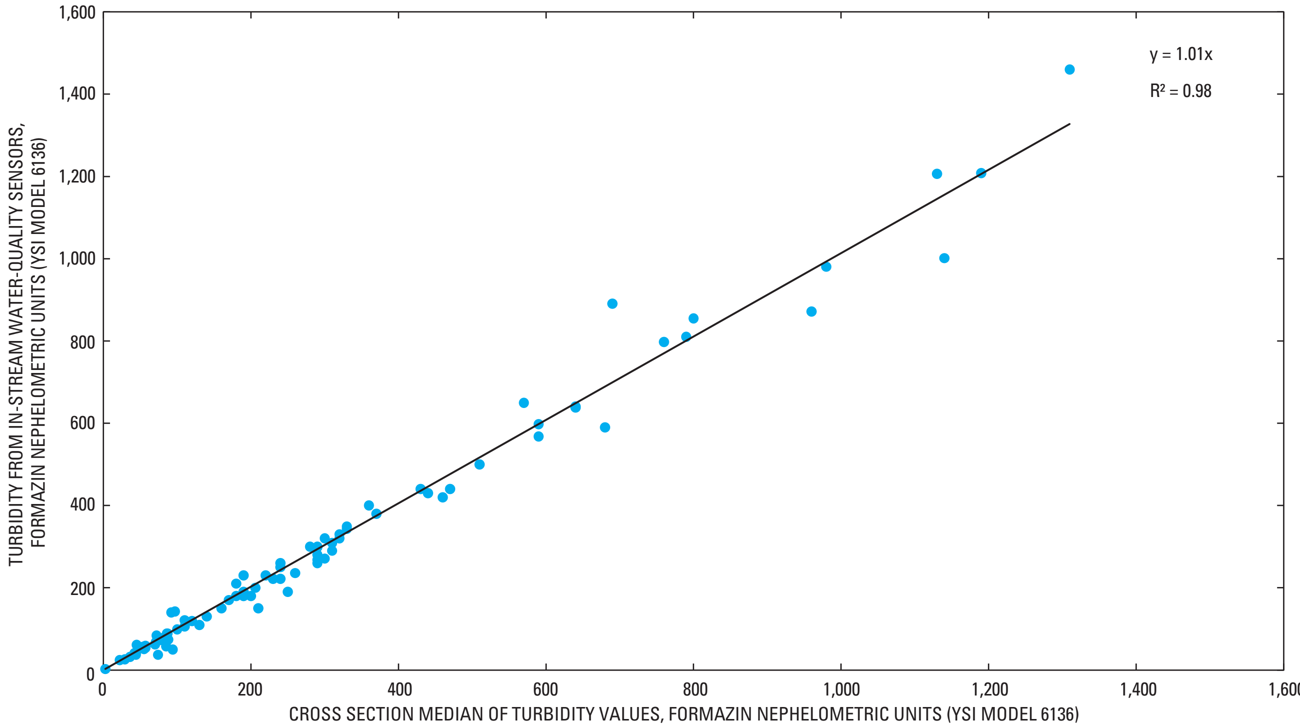


Figure 8. Linear fit between cross section median and in-stream turbidity readings at sites in the Mill Creek Basin, Johnson County, northeast Kansas, February 2006 through November 2008.

Table 4. Suspended-sediment concentration and percent silt/clay (less than 63-micrometer diameter) for samples collected at Mill Creek sampling sites, Johnson County, northeast Kansas, February 2006 through March 2009.

[mg/L, milligrams per liter; µm, micrometer]

Sampling site (fig. 1)	Number of samples	Maximum suspended-sediment concentration (mg/L)	Minimum suspended-sediment concentration (mg/L)	Mean suspended-sediment concentration (mg/L)	Standard deviation (mg/L)	Maximum percentage of sediment less than 63 µm	Minimum percentage of sediment less than 63 µm	Mean percentage of sediment less than 63 µm
CL1a	5	1,960	100	600	770	100	84	96
CL1b	6	2,280	63	780	780	100	95	98
CL1	14	1,920	49	650	550	100	91	98
CL2	13	1,530	110	660	470	100	69	96
CO1	8	510	59	240	150	99	93	97
LM1	7	760	55	370	290	100	96	98
LM2	10	1,530	50	490	520	100	91	98
MI3	8	910	130	360	270	97	89	93
MI4	10	1,150	94	510	340	100	73	94
MI5	6	410	130	220	110	99	97	98
SM1	8	3,300	110	1,210	1,190	100	93	99
SM1a	5	950	15	480	400	100	95	98
SM1b	6	710	26	340	260	100	93	98
SM2	2	160	105	130	36	93	79	86

the site was not located at a bridge, and samples could not be collected during increased flow conditions. Sediment concentrations at sites CL1a, CL1b, CL1, CL2, and SM1 often were increased for prolonged periods during stormflow conditions, providing more opportunity to collect larger maximum and mean SSC values than other sampling sites.

In addition to the distribution of SSC values, the grain size and color of suspended sediment are the primary factors that affect the turbidity/SSC regression (Downing, 2006). Turbidity has been shown to accurately estimate SSC in northeast Kansas streams with a preponderance of silt- and clay-sized sediment (Christensen and others, 2000; Rasmussen and others, 2005, 2008; Lee and others, 2008, 2009). Silt- and clay-sized sediment composed the vast majority of suspended-sediment samples at all Mill Creek sampling sites, as only 3 of 108 samples (sites CL2, MI4, and SM2) had less than 89 percent silt/clay particles. Sand did not comprise a larger part of the sediment-grain-size distribution during increased flow conditions, indicating that sand-sized material generally was not suspended within stream channels. All three of the samples with less than 89 percent silt/clay particles were collected during medium- to low-flow conditions when sediment concentrations were relatively small. Laboratory analysis indicated that sediment concentrations for two of these samples were biased by insect parts (site MI4) and sand-sized precipitate (site CL2).

Two linear regression relations (as opposed to multiple, site-specific relations) were developed between turbidity and SSC data for 14 sampling sites (fig. 9). Two samples were collected during conditions in which in-stream turbidity values were greater than the sensor limit [approximately 1,200 formazin nephelometric units (FNU)]. These samples were not included because the use of the maximum turbidity value would bias the regression relation (methods to estimate SSC during periods of turbidity maxima are described later in this report). Regression relations were aggregated among sites because soils in the Mill Creek Basin are similar in terms of particle size, mineralogy, and organic content (Lee and others, 2009). One regression relation was developed for sites SM1a and SM1b, and one for the remaining 12 sampling sites. An analysis of covariance (ANCOVA) test was performed to test whether or not regression relations were significantly different (Helsel and Hirsch 2002). ANCOVA results indicated a statistically significant [p-value less than 0.01] difference in y-intercept values between the aggregate regression relation from sites SM1a and SM1b and from the remaining 12 sites. Differences are likely because larger-grained sediments settled out in the sediment forebay (upstream from sites SM1a and SM1b). Turbidity sensors are known to exhibit increased response to fine particles (approximately 1 µm; Sadar, 1998), thus finer grain-size distributions of suspended sediment at sites SM1a and SM1b resulted in a turbidity/SSC regression relation with a smaller slope (0.916) than the relation at the other 12 sites (0.982). Although two samples from site SM1b (turbidity values of 22 and 117) plotted beneath the established relation, larger turbidity samples at site SM1b had a similar relation with SSC values compared to those at SM1a, indicating that there is not a large difference in the turbidity/SSC relation during the periods when sediment concentrations are the largest (fig. 9). Relations at sites directly downstream from reservoirs (sites CO1 and MI3) were not significantly different from the overall relation because reservoirs only affected 40 percent of the basin, and outflows from Lake Lenexa lagged storms, and thus did not affect sediment grain-size distributions during storms.

Despite the addition of 30 samples at existing and new sites, the regression relation (slope of 0.982, y-intercept 0.28) was similar to the relation established for the eight sampling sites in 2007–08 (slope of 0.969, y-intercept 0.32) (fig. 9; Lee and others, 2009). Turbidity explained 93 percent of the variability in SSC values at the 12 Mill Creek sites. Residuals from each regression relation generally were distributed evenly around the best-fit line; individual sampling sites did not exhibit consistent bias in relation to the regression line (fig. 9). Relations were aggregated because turbidity/SSC relations were similar among sampling sites because soils in the Mill Creek Basin are similar in terms of particle size, mineralogy, and organic content (Evans, 2003), and data analyzed among multiple sites (Lee and others, 2009) indicated consistent relations and estimates of sediment loading.

Estimating Periods of Turbidity Truncation

YSI model 6136 turbidity sensors can record values from 0 to 2,000 FNU—the maximum recordable value varies among individual sensors (YSI Inc., 2010). When in-stream turbidity values are larger than maximum sensor values, sensors record the maximum value, resulting in underestimation of actual in-stream turbidity. Turbidity truncation measurements for only minutes can bias results because typically it occurs when sediment concentrations and loads are largest. Varying turbidity maxima and amounts of truncated data among sampling sites also bias comparisons of sediment loads and yields between sites. Estimates of turbidity during periods of truncation are performed as described and evaluated in Lee and others (2009). If turbidity and streamflow covary before and after the truncation period, the turbidity/streamflow ratio before and after sensor truncation is multiplied by continuous streamflow data during the period of sensor truncation to obtain a time-series estimate of turbidity. If turbidity and streamflow do not covary, the slope of turbidity measurements are interpolated for the period of sensor truncation (similar to methods described in Bragg and others, 2007).

Estimating data during periods of truncation increased sediment loads at sampling sites from 0 to about 24 percent (table 5). Truncated data at sites CL1, CL2, CO1, LM1, LM2, MI3, MI4, MI5, and MI7 were estimated from June 2007 to November 2008 (February 2006 to June 2007 are described in Lee and others, 2009); data considered from newly installed sites were from the entire period of sensor operation. Other than sites SM1 (24.3 percent), SM2 (11.3 percent), and SM1a (10.0 percent), estimates of sensor truncation increased sediment transport by less than 10 percent. Sites SM1 and SM1a

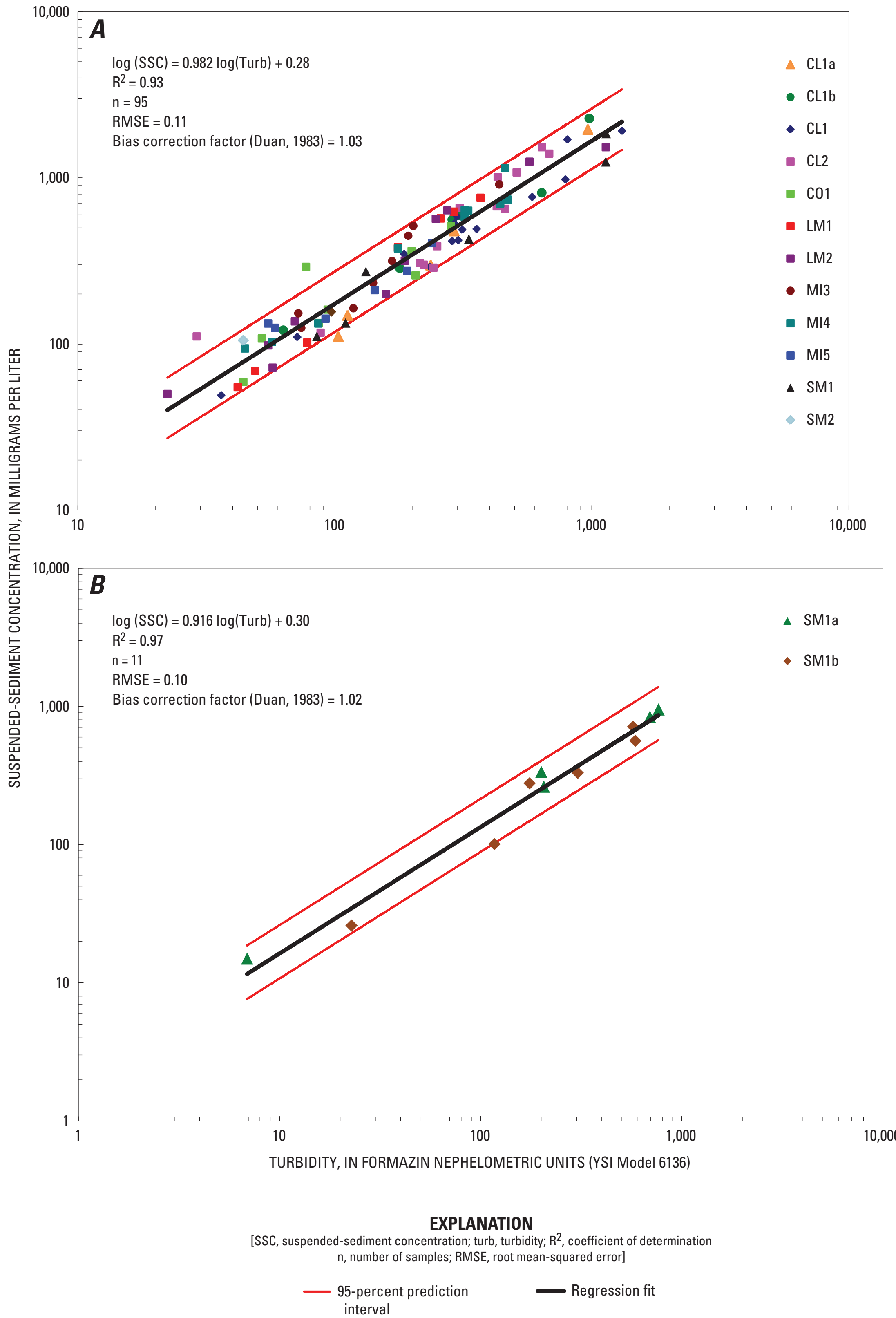


Figure 9. Regression relations between turbidity and suspended-sediment concentration at *A*, 12 Mill Creek sites and *B*, 2 sites downstream from detention basins near Shawnee Mission Lake, Johnson County, northeast Kansas, February 2006 through March 2009.

Table 5. Sediment-load estimates during periods of turbidity truncation for sampling sites in the Mill Creek Basin, Johnson County, northeast Kansas, February 2007 through November 2008.

[mm, month; yr, year; --, no data]

Sampling site (fig. 1)	Period of streamflow/ sediment record (excluding periods of freezing; (mm/yr–mm/yr)	Hours of truncated turbidity data	Sediment load without estimation during turbidity truncation (tons)	Sediment load with truncated periods estimated (tons)	Percentage increase
CL1a	02/07–11/08	7.8	900	910	1.1
CL1b	02/07–11/07	10.8	3,000	3,200	6.7
CL1	06/07–11/08	4.0	10,400	10,700	2.9
CL2	06/07–11/08	5.5	16,300	16,500	1.2
CO1	06/07–11/08	0	2,200	2,200	0
LM1	06/07–11/08	.7	6,600	6,700	1.5
LM2	06/07–11/08	.7	11,400	11,400	0
MI3	06/07–11/08	.6	1,400	1,400	0
MI4	06/07–11/08	3.4	17,800	18,100	1.7
MI5	06/07–11/08	2.7	25,200	26,900	6.7
MI7	06/07–11/08	8.2	48,900	49,100	.4
SM1	02/07–11/08	112	1,770	2,200	24.3
SM1a	02/08–11/08	21.7	1,000	1,100	10
SM1b	02/08–11/08	9.7	--	--	--
SM2	02/07–11/07	1.5	18	20	11.3

had extensive truncation because of upstream construction; sediment loading estimates from this site are considered more uncertain than estimates from other sites. Larger percentage increases at site SM2 were caused by relatively little flow and smaller sediment load. Turbidity truncation at other sites occurred either rarely or during smaller flows, and thus did not substantially affect sediment loading estimates.

Estimating Sediment Loading during Periods of Missing Turbidity Data

Data occasionally are missing from the continuous turbidity record because of environmental fouling or turbidity-sensor malfunction. When sensors malfunction during storms, sediment transport is unaccounted for, biasing computations of sediment load. Sediment loading estimates during periods of turbidity-sensor malfunction are performed as described in Lee and others (2009). If turbidity sensors failed during low-flow periods, turbidity values were interpolated using data before and after the missing period. If the turbidity sensor at a site failed during a storm, sediment loads were estimated by establishing relations in stormflow-weighted suspended-sediment concentrations (SWSCs) between that site and a nearby sampling site. Stormflow-weighted suspended-sediment concentrations are the average sediment concentration for a given volume of stormflow. Stormflow-weighted suspended-sediment concentrations from sites within the same basin are useful in estimating storm-sediment loads because they incorporate factors (such as soils, rainfall intensity, and antecedent conditions) that are similar between sites and storms. Stormflow-weighted suspended-sediment concentrations are calculated by dividing the turbidity-predicted sediment load (in tons) by the total stormflow volume (in acre-feet) of an individual storm and multiplying by a unit conversion [x 907.2 kilograms per ton (kg/ton) x 1,000,000 milligrams per kilograms (mg/kg) x 1,233,482 liters per acre-feet (L/acre-ft)] to obtain the storm SWSC in milligrams per liter. Regression relations are then established between the logarithm of SWSCs for sites immediately upstream or downstream to estimate SWSCs for storms with missing turbidity data. Estimated SWSCs (in milligrams per liter) were multiplied by the total stormflow (in acre-feet) observed during the missing storm (and a unit conversion, 0.00136) to derive an estimate of suspended-sediment load (in tons) for the missing storm. If storms were not observed at nearby sampling sites because of too little streamflow or malfunctioning sensors, regression relations developed between stormflow volume and sediment load among individual storms at each sampling site were used to estimate sediment load (denoted by superscript “a”; table 6).

Data considered at sites CL1, CL2, CO1, LM1, LM2, MI3, MI4, MI5, and MI7 were from June 2007 to November 2008 (February 2006 to June 2007 were described in Lee and others, 2009); data considered from other sites are for the entire period of sensor operation. Debris destroyed the streamgage and turbidity sensor at site CL1a in September 2008, and thus no streamflow or turbidity-sensor data were measured during storm events 58 and 59 (table 6). Total stormflow at site CL1a was estimated by computing the percentage of total stormflow transported by these events at downstream site CL1, and multiplying the percentage by the total stormflow observed at site CL1a for the same study period. Stormflow/sediment load regression relations were then used to estimate sediment loading for each storm. Sediment loading was not computed at site SM1b because persistent backwater conditions precluded estimation of continuous streamflow.

Five of the 15 sites did not have missing turbidity data during any storm, and only 3 of the sites had missing turbidity data that resulted in estimation of 10 percent or more of total sediment loading (MI5, 10 percent; MI3, 18 percent; CL1b, 40 percent). Aggregate measures of sediment loading at these sites (especially site CL1b) are more uncertain than other sites.

Table 6. Periods of missing turbidity record, regressions used to estimate stormflow-weighted suspended-sediment concentrations and sediment loading, and total estimated suspended-sediment load for sampling sites in the Mill Creek Basin, Johnson County, northeast Kansas, February 2007 through November 2008.

[mi^2, square mile; mm, month; yr, year; SWSC stormflow-weighted suspended-sediment concentration, in milligrams per liter; R^2, coefficient of determination; RMSE, root mean-squared error; @, at; SSL, suspended-sediment load; Q, total stormflow; --, no data]

Sampling site (fig. 1)	Basin drainage area (mi^2)	Period of streamflow/sediment record (excluding periods of freezing) (mm/yr–mm/yr)	Missing storms	SWSC regression relation/R^2	Duan's bias correction (Duan, 1983)	RMSE	Estimated storm suspended-sediment load (tons)	Suspended-sediment load at upstream/downstream site during same period (tons)	Suspended-sediment load without estimated storm loads (tons)	Suspended-sediment load with estimated storm loads (tons)	Percentage of load estimated
CL1a	0.7	02/07–11/08	[a]41 41.1 [b]58 [b]59	Log(SWSC@CL1a) = 0.52logSWSC@CL1 + 1.39 (.75) Log(SSL) = 1.21logQ - .32 (.83)	1.10 1.29	0.19 .34	8.6 .96 1.9 6.2	-- 3.4 (CL1) 25.8 (CL1) 931 (CL1)	910	1,000	9
CL1b	2.8	2/07–11/07	12 13 13.1 14.1 [a]14.2	Log(SWSC@CL1a) = 0.62logSWSC@CL1 + 1.22 (.85) Log(SSL) = 1.57logQ - 1.02 (.90)	1.10 1.33	.20 .36	711 1,060 216 131 15.7	2,060 (CL1) 1,770 (CL1) 475 (CL1) 131 (CL1) --	3,200	5,300	40
CL1	5.5	06/07–11/08	40.1 41	Log(SWSC@CL1) = 1.11logSWSC@CL2 - .31 (.86)	1.2	.29	50.9 3.4	71.4 (CL2) 6.8 (CL2)	10,700	10,700	0
CL2	10.9	06/07–11/08	--	--	--	--	--	--	16,500	16,500	0
CO1	5.1	06/07–11/08	--	--	--	--	--	--	2,200	2,200	0
LM1	8.8	06/07–11/08	--	--	--	--	--	--	6,700	6,700	0
LM2	12.1	06/07–11/08	45.1 45.2	Log(SWSC@LM2) = 1.18logSWSC@LM1 - .35 (.85)	1.19	.29	5.0 2.3	4.6 (LM1) 2.2 (LM1)	11,400	11,400	0
MI3	2.8	06/07–11/08	25 41 41.1 45.1 45.2 58 59	Log(SWSC@MI3) = 0.48logSWSC@MI4 +1.23 (.72)	1.51	.26	1.7 37.4 7.5 3.3 1.9 1.4 245	2.0 (MI4) 189 (MI4) 24.0 (MI4) 15.5 (MI4) 4.5 (MI4) 6.6 (MI4) 1,810 (MI4)	1,400	1,700	18
MI4	19.7	06/07–11/08	--	--	--	--	--	--	18,100	18,100	0
MI5	31.7	06/07–11/08	20.2 20.3 21 22 23 38 41 41.1 59	Log(SWSC@MI5) = .95logSWSC@MI4 + .10 (.89)	1.09	.19	4.2 9.1 49.8 79.9 261 313 192 27.5 2,170	3.8 (MI4) 10.3(MI4) 44.8 (MI4) 77.8 (MI4) 231 (MI4) 251 (MI4) 189 (MI4) 24.0 (MI4) 1,810 (MI4)	26,900	30,000	10
MI7	57.4	06/07–11/08	27 28 30 30.1	Log(SWSC@MI7) = 1.01logSWSC@MI5 - .06 (.92)	1.09	.17	3,760 561 287 40.0	1,640 (MI5) 257 (MI5) 178 (MI5) 28.4 (MI5)	49,100	53,700	9
SM1	.6	02/07–11/08	[a]20	Log(SSL) = 1.57logQ - .64 (.87)	1.49	.42	.34	--	2,300	2,300	0
SM1a	1.3	02/08–11/08	--	--	--	--	--	--	1,100	1,100	0
SM1b	1.4	02/08–11/08	45.1 45.2 52 58.1	--	--	--	--	--	--	--	--
SM2	.2	02/07–11/07	[a]14.2	Log(SSL) = 0.78logQ - .23 (.60)	1.35	.72	1.6	--	20	21.9	7

[a] Estimated from total stormflow/sediment load equation.

[b] Stormflow estimated by comparison with same storm at site CL1, sediment load then estimated from total stormflow/sediment load equation.

Sediment Transport in Johnson County, Kansas

Study results for sediment transport in Johnson County, Kansas consider data collected from 2006 through 2008 and are organized into four sections. Sections are organized by discussion of (1) total and annual rainfall, streamflow, and sediment transport in the Mill Creek Basin from 2006 to 2008, (2) sediment transport from subbasins with increased construction activity, (3) frequency and storm-by-storm analysis of streamflow and sediment transport in the Mill Creek Basin from 2006 to 2008, and (4) a comparison of streamflow and sediment among the five largest basins in Johnson County from 2006 to 2008.

Total and Annual Rainfall, Streamflow, and Sediment Transport in Mill Creek from 2006 to 2008

Annual average rainfall from 1931 to 2008 in Olathe, Kansas (excluding 1950 because of data error), was 39.0 in. Rainfall during 2006 (36.4 in.) and 2007 (44.5 in.) was between the 25th and 75th percentile of annual rainfall, whereas 2008 (49.5 in.) was greater than the 75th percentile of annual rainfall (National Oceanic and Atmospheric Administration, 2009). The maximum observed rainfall during the study period for a single day in Olathe, Kansas (central to the study area), was 5.8 in. on July 30, 2008 (National Oceanic and Atmospheric Administration, 2009); larger than the 10-year daily recurrence interval (5.29 in.), but smaller than the 25-year recurrence interval (6.27 in.) estimated for Johnson County (Overland Park Stormwatch, 2009).

Rainfall volume was quantified for each subbasin in Mill Creek, and streamflow and stormflow volume were computed at each sampling site in the basin during the periods of streamgage/water-quality monitor operation from 2006 to 2008 (Overland Park Stormwatch, 2009; table 7). Stormflow comprised most of the flow at each sampling site from 2006 to 2008, from 56 percent of the total streamflow at site MI3 to 96 percent of observed flow at site CL1b. Base- and low-flow periods were not computed at sampling sites CL1a and SM2 because too few measurements were made to characterize the low-flow portion of the streamflow record. Base-flow volumes were not estimated at sampling sites SM1a or SM1b because of backwater conditions. Sites SM1 (50 percent), SM1a (48 percent), CL1b (41 percent), MI3 (39 percent), CO1 (36 percent) and LM1 (33 percent) had the most stormflow as a percentage of rainfall in the basin. All of these sites are headwater sites, and are thus less influenced by groundwater contributions than lower elevation downstream sampling sites. Additionally, increased impervious surface area upstream from sites SM1, SM1a, LM1, and MI3 route more rainfall directly to streams. Site CO1 has substantially less upstream impervious surface (10.8 percent); however, relatively steep slopes (table 2) in this subbasin may have led to increased stormflows relative to the amount of rainfall.

A storm on June 4, 2008, resulted in the largest peak flow during the period of record for all sites except site CL1a (and for sites out of operation in 2008). Peak-flow values from this storm at sites CL2 (2,400 ft^3/s) and MI7 (8,800 ft^3/s) were larger than 2-year recurrence intervals (2,030 and 7,770 ft^3/s, respectively) but less than 5-year recurrence intervals (4,200 and 13,630 ft^3/s, respectively) estimated by Perry and others (2004). Peak-streamflow values at sites LM2 (5,180 ft^3/s) and MI5 (7,320 ft^3/s) were larger than 5-year recurrence intervals (4,180 and 5,860 ft^3/s, respectively) but less than 10-year recurrence intervals (5,990 and 8,430 ft^3/s, respectively).

The turbidity/SSC model was applied to continuous turbidity data (fig. 9) to obtain continuous, 5-minute estimates of SSC at each sampling site. Time-series (5 minute) streamflow values (in cubic feet per second) were multiplied by 5-minute computations of SSC and by a unit-conversion factor [x 1/1,000 milligram per gram (mg/g), x 1/453.6 gram per pound (g/lb), and x 28.32 liter per cubic foot (L/ft^3)] to compute time-series suspended-sediment discharge in pounds per second. Five-minute sediment discharge computations are summed and multiplied by a unit conversion factor [x 300 seconds x 1 ton/2,000 pounds (lbs)] to compute sediment loads (in tons) for periods of interest. Sediment loads, yields, and SWSCs were calculated for each sampling site by calendar year (2006–08, table 8). Periods when monitors were removed during freezing conditions (January 1 to February 20, 2006; December 1 to December 18, 2006; January 10 to February 20, 2007; and December 6, 2007 to February 20, 2008) were excluded from this analysis. Stormflow-weighted suspended-sediment concentrations were computed to characterize average sediment concentrations for a given volume of stormflow. Stormflow-weighted suspended-sediment concentrations are computed by dividing the sediment load (in tons) by the total stormflow (in acre-feet) for a period of interest and multiplied by a conversion factor [x 907.2 kg/ton x 1,000,000 mg/kg x 1,233,482 L/acre-ft], to report data in milligrams per liter.

Among the sites monitored continuously from 2006 to 2008 (CL1, CL2, CO1, LM1, LM2, MI3, MI4, MI5, and MI7) sediment yields were substantially larger in the Clear Creek Basin [CL1; 3,400 tons per square mile (tons/mi^2); CL2, 2,600 tons/mi^2; table 8]. Subbasins partially regulated by impoundments (site CO1, 640 tons/mi^2; site MI3, 950 tons/mi^2) and those with stable urban land use (site LM1, 1,200 tons/mi^2; site LM2, 1,300 tons/mi^2; site MI3, 950 tons/mi^2) had the smallest sediment yields in the Mill Creek Basin. Sediment yields from the Clear Creek Basin were approximately 2 to 3 times those from the more rural (and impounded) Coon Creek Basin and the older, stable urban Little Mill Creek and upper Mill Creek Basins (table 8).

Cumulative sediment yields from 2006 to 2008 increased coincidental with increases in impervious surface from 2005 to 2006 (fig. 10*A*), but were unrelated to increases in impervious surface from 2006 to 2008 (fig. 10*B*). This is potentially

Table 7. Total rainfall, streamflow and stormflow volumes, and peak streamflow upstream from and at Mill Creek sampling sites, Johnson County northeast Kansas, February 2006 through November 2008.

[mi^2, square mile; ft^3/s, cubic feet per second; --, no data; rainfall data from Overland Park Stormwatch Program, 2009]

Sampling site (fig. 1)	Basin area (mi^2)	Percent impervious surface, 2008	Total rainfall (acre-feet)			Total streamflow (acre-feet)			Total stormflow (acre-feet)			5-minute peak streamflow (ft^3/s)
			2006	2007	2008	2006	2007	2008	2006	2007	2008	
CL1a	0.7	10.9	--	1,500	1,600	--	340	470	--	340	470	160
CL1b	2.8	18.8	--	6,300	--	--	2,700	--	--	2,600	--	1,910
CL1	5.5	11.3	8,400	12,500	12,500	1,200	4,100	4,900	1,100	4,000	4,500	2,630
CL2	10.9	13.1	16,800	24,800	24,900	4,400	9,000	10,700	3,000	7,800	9,900	2,400
CO1	5.1	10.8	8,100	11,100	11,800	1,700	4,800	6,800	1,400	3,900	6,000	430
LM1	8.8	30.7	14,400	20,600	21,400	4,000	9,000	10,500	3,500	7,100	8,200	3,350
LM2	12.1	27.1	19,800	28,300	29,400	3,900	9,000	9,200	3,300	8,000	8,200	5,180
MI3	2.8	35.1	4,800	6,800	6,900	3,200	4,700	5,000	1,600	2,600	3,000	680
MI4	19.7	24.8	32,200	44,500	47,700	10,900	21,200	25,700	7,300	15,700	17,400	4,840
MI5	31.7	17.8	51,600	72,100	76,500	12,700	25,100	16,900	8,900	18,100	21,200	7,320
MI7	57.4	18.8	92,600	132,000	136,700	17,800	43,600	53,800	14,200	34,100	40,400	8,800
SM1	.6	27.7	--	1,300	1,500	--	600	910	--	540	860	250
SM1a	1.3	26.5	--	--	3,100	--	--	--	--	--	1,500	290
SM2	.2	1.5	--	500	--	--	40	--	--	40	--	21

Table 8. Total suspended-sediment load, yield, and stormflow-weighted suspended-sediment concentrations at Mill Creek sampling sites, Johnson County, northeast Kansas, February 2006 through November 2008.

[mi², square mile; tons/mi², tons per square mile; mg/L, milligrams per liter; --, no data]

Sampling site (fig. 1)	Basin area (mi²)	Increase in percentage of impervious surface from 2005 to 2006	Increase in percentage of impervious surface from 2006 to 2008	Suspended-sediment load (tons)			Suspended-sediment yield (tons/mi²)			Stormflow-weighted suspended-esdiment concentration (mg/L)			Total suspended-sediment load from 2006 to 2008 (tons)	Total suspended-sediment yield from 2006 to 2008 (tons)
				2006	2007	2008	2006	2007	2008	2006	2007	2008		
CL1a	0.7	5.0	3.1	--	570	440	--	810	630	--	1,220	690	--	--
CL1b	2.8	6.1	1.9	--	5,300	--	--	1,900	--	--	1,500	--	--	--
CL1	5.5	3.5	1.0	1,100	10,100	7,500	200	1,800	1,400	740	1,800	1,200	18,700	3,400
CL2	10.9	2.9	.9	2,000	14,800	11,900	180	1,400	1,100	490	1,400	890	28,700	2,600
CO1	5.1	1.3	.5	280	1,200	1,800	60	230	350	150	220	220	3,300	640
LM1	8.8	1.1	.8	1,400	4,900	4,200	160	550	470	290	500	370	10,500	1,200
LM2	12.1	.9	.7	1,600	7,000	7,600	130	570	620	350	640	680	16,200	1,300
MI3	2.8	.9	2.2	620	1,100	930	220	380	330	290	290	230	2,650	950
MI4	19.7	2.6	1.6	5,800	14,300	12,800	300	730	650	590	670	540	32,900	1,700
MI5	31.7	2.0	1.0	6,100	16,900	23,100	190	530	730	500	690	800	46,100	1,500
MI7	57.4	1.9	1.0	10,400	36,200	39,500	180	630	690	540	750	700	86,100	1,500
SM1	.6	3.9	2.5	--	990	1,300	--	1,700	2,200	--	1,200	1,100	--	--
SM1a	1.3	3.6	1.5	--	--	1,100	--	--	850	--	--	580	--	--
SM2	.2	1.4	0	--	20	--	--	100	--	--	370	--	--	--

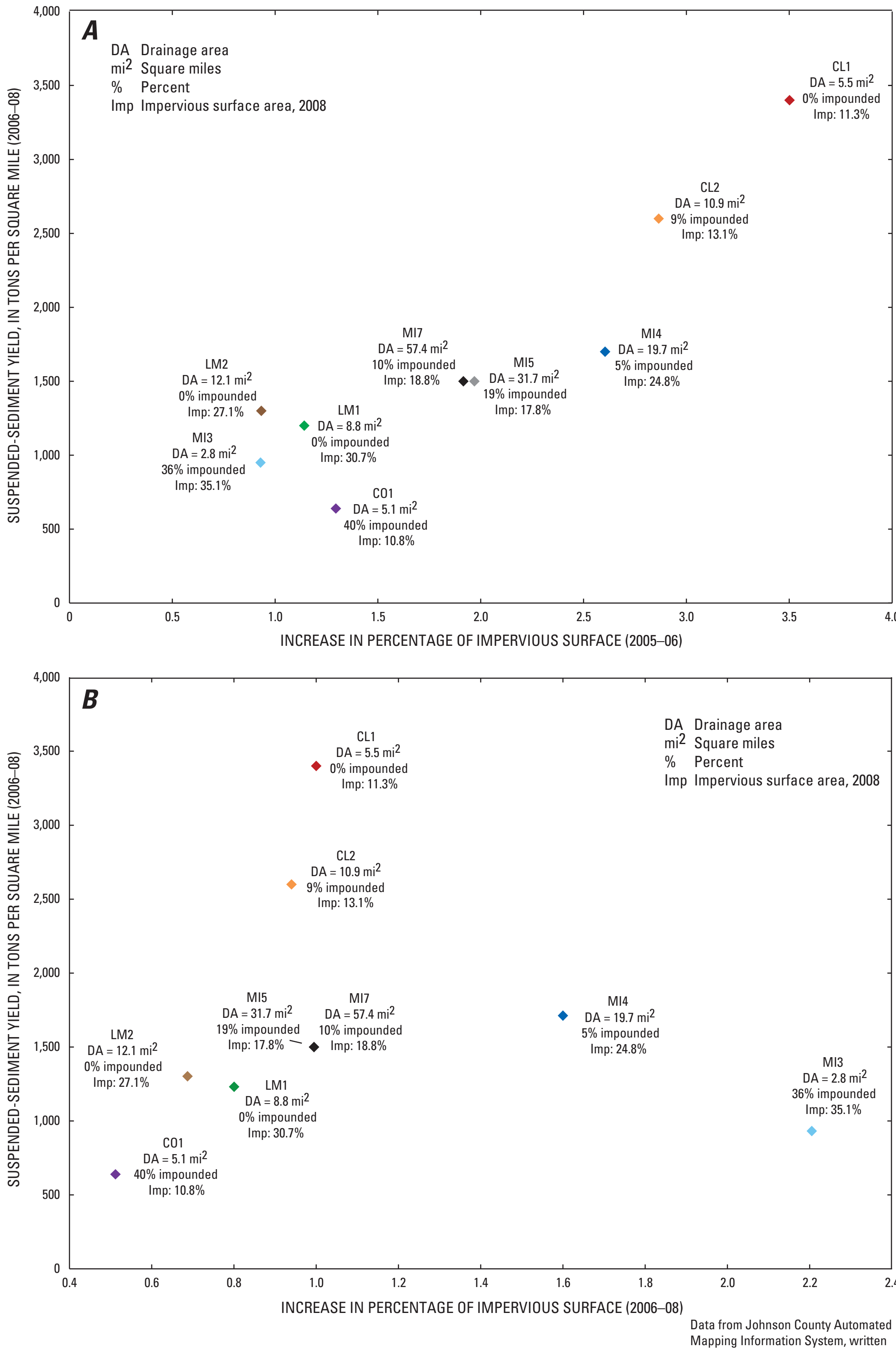


Figure 10. Relation between suspended-sediment yield from 2006 to 2008 and increases in impervious surface *A*, from 2005 to 2006 and *B*, from 2006 to 2008, Mill Creek sites, Johnson County, Kansas.

because there was more construction (and thus soil disturbance) from 2005 to 2006, and relatively little stormflow during 2006 to transport sediment through the stream network. Although general patterns appear to exist between construction activity and sediment transport on a basin scale, several site-specific factors, such as management practice, impoundments, construction-site slope, site proximity to streams, sediment deposition and resuspension, and stream-channel erosion complicate relations between landscape activities and sediment yield.

Because of smaller amounts and less intense rainfall, 2006 typically had less than one-half of the stormflow, and one-third of the sediment load compared to 2007 and 2008. Larger stormflows in 2007 and 2008 resulted in substantially larger sediment loading at sites affected by urban construction. Site CL1 had nearly 4 times the flow in 2007 than in 2006, but more than 9 times the sediment transport, whereas site CL2 had 2.6 times more flow in 2007 than in 2006, but 7.8 times the sediment transport. Predominantly urban and rural sites had 1.7 to 2.7 times the flow in 2007 than in 2006, but only 1.7 to 4.1 times the sediment transport. These comparisons indicate that at sites with substantial soil disturbance, the amount of flow is the predominant factor limiting sediment transport. Smaller supplies of sediment available for transport in urbanized basins limit increases in sediment transport as a result of a wetter year. Site SM2, downstream from a predominantly undeveloped, parkland basin had less than one-half the sediment yield (100 tons/mi^2) and generally smaller SWSC values (370 mg/L) than other basins in Mill Creek; however, data at site SM2 may be biased because of difficulty measuring flashy flow conditions (and thus inability to verify theoretical streamflow ratings). Relatively small sediment yields and SWSC values in 2007 at site SM2 (table 8) indicate that sediment yields from small, unimpacted subbasins likely are similar (or less than) those from predominantly established urban basins.

Although stormflows were slightly larger at all sampling sites (1.0 to 1.6 times) in 2008 than in 2007, sediment loads decreased at sites CL1a, CL1, CL2, LM1, MI3, and MI4. Decreases in sediment transport may be related to transport of readily erodible sediment supplies in 2007 and (or) less active construction area upstream from these sites from 2006 to 2008. With the exception of site MI3, impervious surfaces upstream from these sites increased more in 1 year from 2005 to 2006 (0.9 to 5.0 percent) than during the subsequent 2 years from 2006 to 2008 (0.8 to 2.2 percent). Sampling sites in the Clear Creek Basin had nearly triple the increase in impervious surface area from 2005 to 2006 (site CL1, 3.5 percent; site CL2, 2.9 percent), than during the subsequent 2 years (site CL1, 1.0 percent; site CL2, 0.9 percent; table 8; fig. 10).

Increases in stormflow from 2007 to 2008 resulted in increases in sediment transport at sites CO1, LM2, MI5, MI7, and SM1. Construction in the Coon Creek Basin from 2006 to 2008 was concentrated along an unregulated tributary in the northern part of the subbasin, possibly enabling eroded soils to be readily transported downstream. Construction upstream from SM1 (described in “Land Use” and subsequent parts of this report) was ongoing throughout 2007 to 2008, but was not paved at the time aerial photography was taken (March 2008; fig. 3) and, therefore was not accounted for in impervious surface estimates. Visual observations were made of commercial construction contributing excess sediment to a tributary 1,300 ft from Little Mill Creek between sites LM1 and LM2, but the magnitude of the sediment contribution is unknown. Continued increases in sediment loading from 2007 to 2008 at downstream sites MI5 and MI7 may be related to either sediment contributions from sediments deposited in (or near channels) or from streambank erosion.

Sediment Transport from Subbasins with Increased Construction Activity

Streamflow and (or) sediment concentrations were computed in the headwaters of the Clear Creek Basin (CL1a and CL1b) and upstream from Shawnee Mission Lake (SM1, SM1a, SM1b) in 2007 and (or) 2008 to better understand the effects of construction sites on sediment transport in Johnson County, Kansas.

Turbidity Levels Relative to U.S. Environmental Protection Agency Construction Effluent Guidelines

Beginning on February 1, 2010, the U.S. Environmental Protection Agency (USEPA) required all construction sites greater than 1 acre to obtain permit coverage to meet guidelines designed to limit discharge of pollutants (primarily sediment) as a result of construction activity (U.S. Environmental Protection Agency, 2009). Initial implementation of the guidelines required all construction sites to implement pollution prevention measures, erosion and sediment controls, and soil stabilization measures (U.S. Environmental Protection Agency, 2009). Beginning August 1, 2011, all sites that disturb greater than 20 acres of land at once will be required to monitor discharges and comply with a mean-daily turbidity criteria of 280 nephelometric turbidity units (NTU; U.S. Environmental Protection Agency, 2009). Monitoring and numeric criteria will be extended to all sites greater than 10 acres at once on February 1, 2014 (U.S. Environmental Protection Agency, 2009). Although storms with rainfall greater than the 2-year, 24-hour storm (3.6 inches in Johnson County) will be exempt from USEPA criteria, the cumulative 24-hour rainfall did not exceed 3.6 inches in either of the monitored basins with increased construction activity.

To evaluate the applicability and potential effect of new USEPA construction guidelines, mean-daily turbidity values at sites in the construction-impacted Clear Creek and Shawnee Mission Lake Basins were compiled in 2007 and 2008 and compared to numeric criteria. However, these comparisons are not applicable to construction guidelines because sampling sites were not directly downstream from construction sites, and because turbidity measurements made by YSI model 6136 sensors may or may not be applicable to future criteria, as individual states will determine how to measure turbidity (U.S Environmental Protection Agency, 2009). Monitoring downstream from areas under construction likely underestimate actual turbidity from construction sites, but because of additional stormflow, downstream sites could also overestimate the duration in which turbidity values are elevated. The results of comparing different turbidity units are less certain. Because turbidity is the measurement of an apparent physical property, different turbidity units only distinguish various measurement methods, and thus do not assure consistent reporting. Additionally, comparisons among instruments generally are not consistent across variation in the particle size, color, and concentration of suspended sediments (Pavelich, 2002).

Mean-daily values downstream from the City Center North construction site exceeded the 280 NTU criteria during 17 days in 2007, and during 15 days in 2008. Actual values from the City Center North construction site may exceed criteria more frequently, as runoff from this site was diluted by runoff from park and residential land between the construction and sampling site. Sites SM1a and SM1b exceeded criteria less frequently than site SM1 (9 and 8 days, respectively) because of further dilution of stormflows by runoff from parkland, and because of sediment deposition in the upstream sediment forebay. Mean-daily turbidity values at site SM2 did not exceed turbidity criteria during 2007, an indication that background daily turbidity values are less than the numeric criteria. Because dry conditions were present for much of 2007 at site SM2, turbidity values observed during low-flow conditions were interpolated during dry periods to allow comparison of turbidity conditions with other sampling sites. Regular exceedance of criteria 1,400 ft downstream from a construction site with extensive erosion and sediment controls (such as those implemented on the City Center North site) may indicate the need for additional erosion and sediment controls and (or) treatment to bring discharges from construction sites into compliance with future numeric turbidity criteria.

Mean-daily turbidity values at site CL1a exceeded USEPA criteria during 6 days, and site CL1b exceeded USEPA criteria during 7 days in 2007, and turbidity levels did not reach criteria at site CL1a in 2008. However, similar to site SM1, turbidity values at sampling sites are likely smaller than in discharges directly downstream from construction sites. Turbidity values were smaller at sampling sites CL1a and CL1b compared to those observed at site SM1 because less of the upstream basin was occupied by construction activities.

Sediment Transport in the Clear Creek Basin

In addition to sampling sites CL1 and CL2 (operated from 2006 to 2008) site CL1a was installed and operated from February 2007 to November 2008, and site CL1b was installed and operated from February through November 2007. Sites were installed to characterize predominant sediment sources and transport from the subbasin upstream from site CL1 (which had the largest documented sediment yields in Johnson County from February 2006 to June 2007; Lee and others, 2009). Several construction sites were active in the headwaters of Clear Creek from 2005 to 2008 including several housing developments, two areas of road construction, and two schools (fig. 5; table 3). Sites downstream from increased recent and active construction sites in the headwaters of the Clear Creek Basin had among the largest annual sediment yields in the Mill Creek Basin during 2007 and (or) 2008 (630 to 1,900 tons/mi^2).

Although the subbasin upstream from CL1a had the most construction activity from 2005 to 2008 and multiple failures of sediment controls were observed (fig. 6), sediment yields and SWSCs were smaller than those observed at downstream Clear Creek sites with less construction (table 8). This may have been because most construction sites upstream from site CL1a were distant from streams (S4, R1, and S2; fig. 5), and thus sediments eroded from these sites are more likely to deposit on land surfaces and within stream channels. Substantial sediment deposition observed in Clear Creek upstream from site CL1a (fig. 6*C*) after spring storms in 2007 indicate that relatively smaller sediment transport capacities in the headwaters of the basin may not effectively transport sediments through the stream network. Sediments observed to have been deposited in the stream network upstream from site CL1a in May 2007 (fig. 6*C*) were still present on October 25, 2007, despite several large storm events (fig. 11), indicating the potential for more extended or permanent storage of eroded sediments in headwater drainages.

Sediment yields from the subbasins between sites CL1a and CL1b (obtained by subtracting the sediment load observed at site CL1a from sediment loads observed at site CL1b and dividing by the intermediate drainage area; 2,250 tons/mi^2; table 8) and between CL1b and CL1 (1,780 tons/mi^2; table 8) were more than double the sediment yields of other subbasins (excluding site SM1 upstream from Shawnee Mission Lake) within Mill Creek in 2007. Large yields at these sites likely are related to increased active construction directly adjacent to the stream channel between these sites (fig. 5). Sediment eroded from construction sites adjacent to stream channels have less distance to travel before being transported by stormflows in Clear Creek. Additionally, sediments eroded from construction sites before the study period may have been deposited within the stream network (figs. 6*C* and 11) and resuspended by storms in 2007 and 2008. Visual observation of the stream channel in October 2008 (fig.11*B*) indicated substantial sediment deposition throughout the stream reach as a result of construction activities on Clare Road (fig. 5). Large increases in sediment yield between sites CL1a and CL1 (table 8) likely result from a combination of previously eroded, deposited, and resuspended sediments from upstream construction sites, and recently eroded sediments from construction activities adjacent to the stream channel.

Figure 11. *A*, Sediment deposition in the Clear Creek channel upstream from site CL1a, October 2007, and *B*, deposition in the Clear Creek channel adjacent to Clare Road construction, Lenexa, Kansas, October 2008. Photograph *A* by Dale Clark, City of Lenexa and photograph *B* by Patrick P. Rasmussen, U.S. Geological Survey.

Stormflow volume, sediment load, and sediment yield were computed for the five largest storms at all Clear Creek sampling sites in 2007 (in which sites CL1a and CL1b were operational), as well as the largest storm in 2008 (in which site CL1b was no longer operational; fig. 12). During the first two large storms of 2007, sediment yields were much larger at site CL1 (150 and 280 tons/mi^2) than at upstream sites CL1a (49 and 73 tons/mi^2) and CL1b (69 and 170 tons/mi^2); however, during the next three storms in the fall of 2007, sediment yields were larger at site CL1b with respect to the amount of stormflow (indicated by larger SWSC values), and with respect to drainage area (indicated by larger sediment yields) compared to other sites in the basin. Larger sediment yields observed at site CL1b during storms in the late summer and fall of 2007 may be related to increased sediment contributions from recent and ongoing upstream construction activity adjacent to Clear Creek (table 3). Stormflow and sediment yields and SWSC values for storms at site CL1a generally were smaller than other sites in the basin, likely because construction sites were relatively distant from streams most able to convey eroded sediments. Site CL2 had smaller sediment yields and SWSCs compared to sites CL1b and CL1 for individual storms and annually (fig. 12; table 8). Smaller sediment yields at site CL2 are likely related to less construction activity in the basin between sites CL1 and CL2, and potentially related to sediment deposition in the less sloping stream channel between sites CL1 and CL2. Comparison of sediment yields among headwater and downstream sites in the Clear Creek Basin indicated that factors such as site and stream slope, the current phase of construction, management practices, and site location relative to streams affect the amount and length of time it takes eroded sediment to be transported downstream.

Sediment Transport in the Shawnee Mission Lake Basin

Sampling site SM1 was installed 1,400 ft downstream from the 68-acre City Center North residential and commercial construction site in February of 2007 to characterize sediment transport from the construction site to Shawnee Mission Lake (fig. 3). Because this was the only construction site upstream from site SM1 during the study period, and the rest of the subbasin consists of park and residential land (and thus would only marginally increase downstream sediment loads), sediment loads at this site were completely attributed to the City Center North site. Sampling sites SM1a and SM1b were

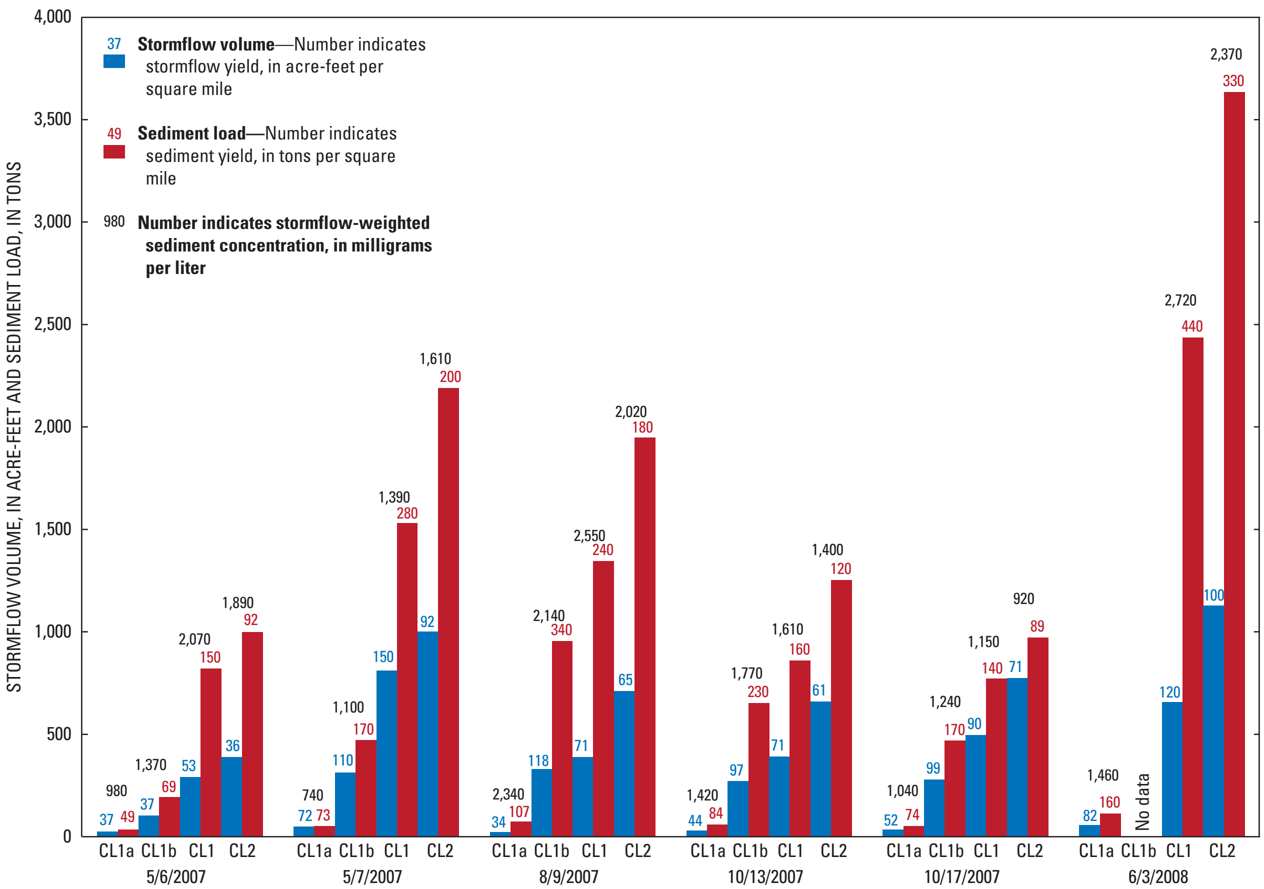


Figure 12. Stormflow volume and sediment load for selected large storms in the Clear Creek Basin, Johnson County, Kansas, 2007 through 2008.

installed in February 2008 to monitor sediment concentrations and loading through a sediment forebay (directly upstream from site SM1a) and a wetland (directly upstream from site SM1b) constructed in winter 2007–08 and planted in the spring of 2008. Because of backwater conditions, only streamflow conditions deemed unaffected by backwater were estimated at site SM1a, and continuous streamflow was not computed at site SM1b. Changes in sediment concentration during storm events were used to characterize wetland effects on sediment transport to the lake. At normal pool levels, total storage in the forebay is 1.8 acre-ft, and storage in the wetland is approximately 7 acre-ft (T. Stanton, Olsson Associates, written commun., 2009). Sediments were not dredged from either the settling basin or the wetland during the study period (T. Stanton, Olsson Associates, written commun., 2009). The sediment forebay was constructed to protect wetland vegetation from heavy sediment loads (T. Stanton, Olsson Associates, written commun., 2009), whereas the wetland was constructed to provide aquatic habitat and educational and recreational activities to the public, and to treat post-construction runoff through filtration and nutrient uptake by wetland vegetation (T. Stanton, Olsson Associates, written commun., 2009). The constructed wetland was designed to enable connectivity between the lake and wetland for fish and canoes, and thus provides only minimal detention of flows during storms (T. Stanton, Olsson Associates, written commun., 2009).

Mass grading was undertaken at the City Center North construction during the spring and summer of 2007; steep slopes resulted in extensive cut and fill (R. Beilfuss, City of Lenexa, written commun., 2008). The entire site was disturbed throughout this period and large fill piles were located on the northeast and southwest corners of the site. Initial sediment controls included 5-ft high mulch berms along the northern border of the site, and silt fences around the fill piles, the entire site perimeter, and downgradient toward the central tributary on site. Three rock check dams were installed along the central tributary, and a small sediment-control pond was installed in an east-central location on the construction site (three planned sediment ponds were not installed until June 2007 because sanitary sewer lines intersected a pond location; R. Beilfuss, City of Lenexa, written commun., 2008). City of Lenexa erosion-control inspectors noticed extensive failures of mulch berms and rock checks after an approximate 1.6-in. storm March 29–30, 2007. City staff mandated mulch berm replacement and improved maintenance and repair of existing mulch berms and sediment-control fences, gravel facement and installation of an additional rock-check dam, dredging the existing sediment pond, and installation of three additional ponds with skimmers, and added flocculants to outflow pipes. Other than an additional sediment discharge noted in mid-August 2007 (because of a contractor dumping sediment pond deposits along a tributary on the northeast corner of the site), inspections indicated the site had good erosion and sediment-control practices through the remainder of the study.

Sediment yields at sampling site SM1 in 2007 (1,700 tons/mi^2) and 2008 (2,200 tons/mi^2) were among the largest in the county (only sites CL1 and CL1b in 2007 were larger; 1,800 tons/mi^2 and 1,900 tons/mi^2, respectively). Assuming all of the sediment transported past sampling site SM1 originated from the construction site, yields from the City Center North site were 9,300 tons/mi^2 in 2007 and 12,200 tons/mi^2 in 2008. Annual sediment yields attributed to the construction site were 5 to 55 times those from other sampling sites in the Mill Creek Basin (table 8). Although these yields are much larger than other subbasins in the county with mixed land uses, sediment yields were small relative to yields observed from historical construction sites without erosion and sediment controls in the United States (2,300 to 140,000 tons/mi^2/yr; Wolman and Schick, 1967; Yorke and Herb, 1978). Given erodible soils, steep slopes, and the relatively large size of this construction site, as well as relatively wet years in 2007 and 2008, annual sediment yields were relatively small compared to the range of historically observed values. Thus, extensive on-site erosion and sediment-control practices likely are responsible for the relatively small sediment yields compared to historical unregulated sites.

Stormflow volume, sediment load, SWSC, and rainfall amount and intensity were defined for the 20 largest storms in 2007 to characterize factors affecting sediment transport from the City Center North construction site (fig. 13). Sediment loading at site SM1 primarily was related to the amount and intensity of rainfall and antecedent rainfall conditions. The largest storm, in terms of rainfall amount (October 13, 2007), had the fourth-most intense rainfall, and transported the most sediment. Although the storm on August 9, 2007, had the second-most rainfall and second-highest rainfall intensity, dry conditions preceding the storm resulted in less runoff and consequently, resulted in less sediment transport (but still relatively large SWSCs). Storms that occurred immediately after another large storm (May 7, October 15, and October 17, 2007) had smaller SWSCs than preceding storms. Thus, the most sediment transport with respect to drainage area (sediment yields) or with respect to flow (SWSCs) would be expected from large, intense rainstorms that were preceded by relatively small storms that saturate surface soils. Despite observed improvements in sediment-control practices and installation of additional sediment-control ponds (fig. 13), decreases in the amount of sediment transported during storms were not apparent relative to the larger effects of storm magnitude, rainfall intensity, and antecedent rainfall. Despite having caused failure of multiple sediment controls on-site, the storm on March 29, 2007, had smaller SWSC values than many subsequent storms. A lack of substantial change in sediment loading from storms through 2007 indicated that improved erosion and sediment-control measures could not be credited with immediate changes in downstream sediment loading.

Stormflow volume and sediment load were computed at sampling sites SM1 and SM1a, and average sediment concentrations were computed at sites SM1, SM1a, and SM1b for the 10 largest storms in 2008 (fig. 14). Sediment yields and SWSC values observed at sampling site SM1 were relatively smaller during storms in 2008 than in 2007. A comparison of similar

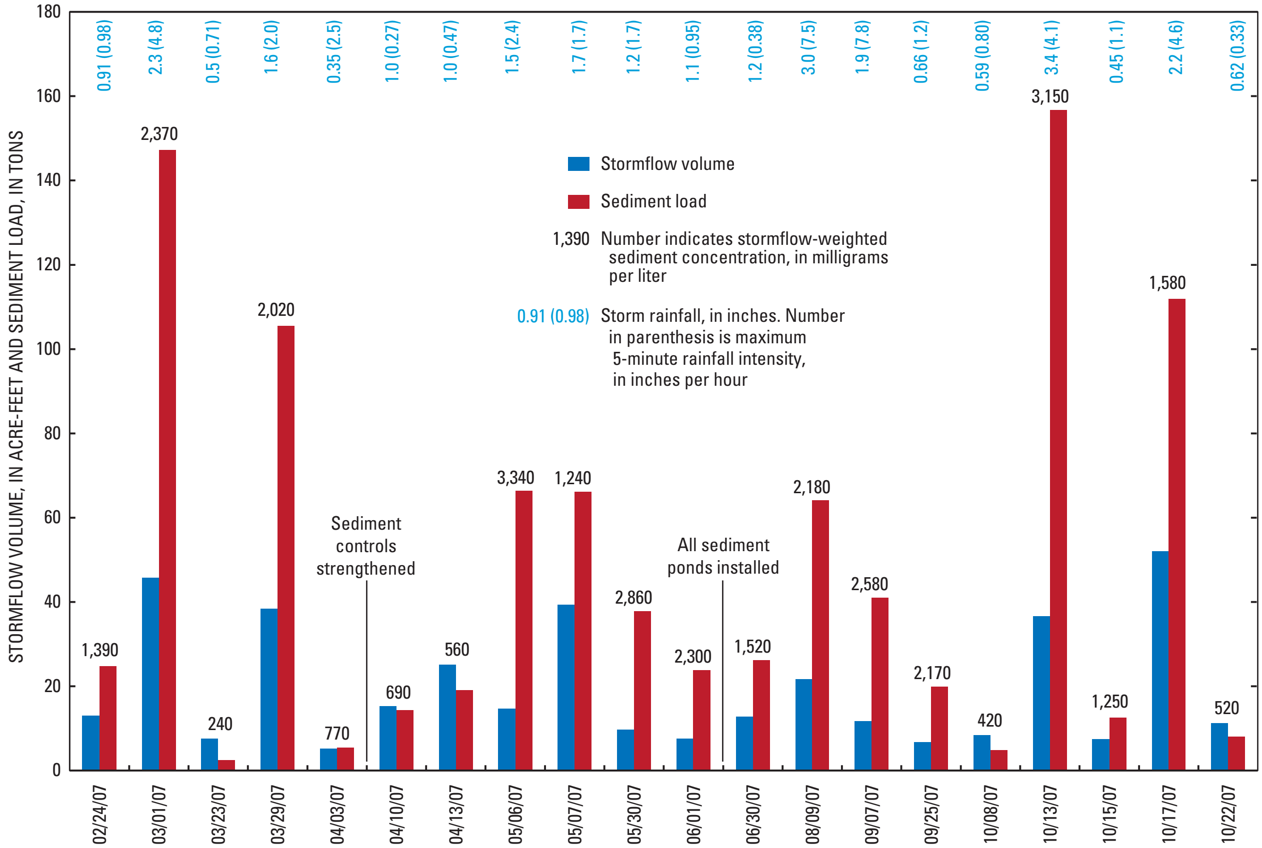


Figure 13. Stormflow volume and sediment load for the 20 largest storms at site SM1, Lenexa, Kansas, 2007.

storms on June 12, 2008 [stormflow volume, 58 acre-ft; rainfall intensity, 5.6 inches per hour (in/h); fig. 14] and October 17, 2007 (52 acre-ft and 4.6 in/h, respectively; fig. 13), indicated that the storm in 2008 transported a much smaller sediment load (75 tons compared to 112 tons) and had a much smaller SWSC (950 mg/L compared to 1,580 mg/L) relative to 2007. A storm on October 15, 2008, had substantially more flow (25 acre-ft) than a storm observed on the same date in 2007 (7.4 acre-ft) but transported only 21 tons of sediment (compared to 13 tons in 2007) thus having a SWSC about one-half (620 mg/L) of the 2007 storm (1,250 mg/L). Smaller sediment loading (relative to streamflow) at this site may because of changes in construction phasing (from mass grading to building construction) and (or) a lag between decreases in sediment loading and improved management practices at the construction site.

Annual sediment loads were slightly larger at sampling site SM1 (1,300 tons) than those estimated downstream at site SM1a (1,100 tons) during 2008, despite nearly double the drainage area at site SM1a (table 8). However, sediment transport from the basin between sites SM1 and SM1a is expected to be small because the basin is occupied by established residential (built primarily from 1988 to 1999) and park land uses (table 2). The sediment yield from the adjacent, predominantly residential basin LM1 in 2008 (470 tons/mi^2; table 8), was used (after being multiplied by the basin areas between sites SM1 and SM1a; 0.7 mi^2) to estimate a contribution of 330 tons of sediment from the basin between sites SM1 and SM1a. Under this assumption, approximately 530 tons of sediment are estimated to have been deposited (33 percent of the incoming load) within the sediment forebay (and the upstream channel) during 2008. Assuming a bulk density of 18 pounds per cubic foot (lb/ft^3); (as observed in the top 1 to 2 in. of the Shawnee Mission Lake sediment core collected in 2007; Lee and others, 2007), 1.4 acre-ft of sediment is estimated to have been deposited in or upstream from the sediment forebay. Observations at the site indicated sediment deposition in the sediment forebay at normal pool levels, as well as on the streambed upstream from the forebay. Thus the 1.4 acre-ft of sediment estimated to have been deposited in the 1.8-acre-ft forebay likely is distributed upstream, in, and around the normal pool volume of the forebay; however, given the compounding error from streamflow and sediment concentration estimates, estimates of sediment loads from the basin between sites SM1 and SM1a, and uncertainty regarding the bulk density of deposited material, these estimates are considered uncertain.

Average sediment concentrations (as opposed to SWSCs) were computed for individual storms to enable comparison of sediment transport from sampling sites SM1 and SM1a through the constructed wetland to site SM1b (downstream from the wetland in backwater conditions; fig. 14).

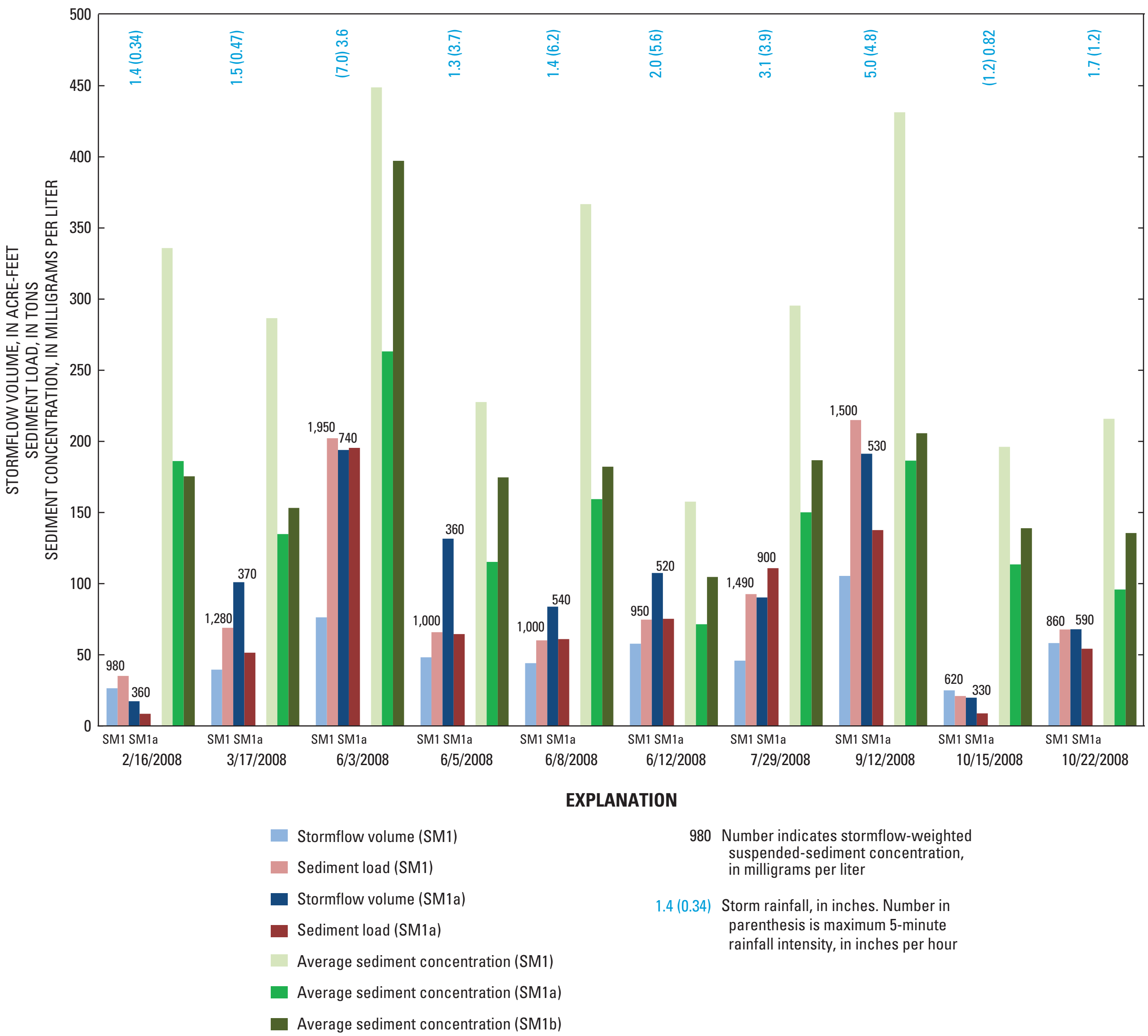


Figure 14. Stormflow volume, sediment load, and average sediment concentration for the 10 largest storms upstream from Shawnee Mission Lake, Lenexa, Kansas, 2008.

Comparison of average sediment concentrations between individual storms can effectively evaluate sediment deposition in the wetland because contributing basin areas upstream from sites SM1a and SM1b were approximately the same (table 1), storage in the sediment forebay and wetland were small relative to large storms, and the timing of rising, peak, and recessions in gage height during storms were nearly (less than 5 minutes difference) identical between sampling sites.

Site SM1 had approximately double (2.2 to 1.7 times) the average sediment concentrations of site SM1a during the largest storms, because of the influx of less turbid water from the intervening residential and parkland part of basin, and because of sediment deposition in and upstream from the sediment forebay between the sites. Average storm-sediment concentrations were larger at sampling site SM1b (downstream from the wetland) than sampling site SM1a (upstream from the wetland) for 9 of the 10 largest storms (ranging from 1.5 to 0.9 times; fig. 14). Examination of time-series turbidity data indicate nearly identical patterns of turbidity among the two sites during most storms, whereas turbidity values occasionally remained larger during the falling limb of the storm at sampling site SM1b. Suspended organic matter in the lake may result in increased turbidity values at site SM1b toward the end of storms. Similar turbidity values among sites during the largest storms indicated little reduction in sediment loading to the lake through the wetland. Increased sediment deposition in the sediment forebay relative to the wetland likely is caused by deposition of larger silt-sized particles in and upstream from the settling basin, and continued transport of clays through the wetland and into Shawnee Mission Lake.

Sediment trapping by the wetland could increase as vegetation planted in spring 2008 becomes more fully established. Thus, the pertinent conclusion of comparisons between sites up and downstream from the constructed wetland is that before the establishment of wetland vegetation, hydraulic retention by the wetland did not substantially reduce sediment loading to Shawnee Mission Lake.

Frequency and Storm-by-Storm Analysis of Streamflow and Sediment Transport in the Mill Creek Basin

Frequency analysis of continuous streamflow and sediment concentration values was conducted to better understand the magnitude and timing of streamflow and sediment transport in the Mill Creek Basin. Duration plots display how frequently a given continuous streamflow value (reported in cubic feet per second) is exceeded during the study period (fig. 15), the total amount of streamflow transported past site MI7 was also computed for each year (and reported below). Duration plots are displayed annually since the first full year of record (2003) at sampling site MI7 to compare the study period to all previously observed conditions (fig. 15). Calendar year 2008 recorded the most total flow (61,100 acre-ft) during the period of record, and the most flow exceeded less than 10 percent of the time (38,400 acre-ft), but had slightly smaller peak-flow values (8,800 ft^3/s) than during calendar year 2004 (9,700 ft^3/s; fig. 15). Calendar year 2006 had the least amount of streamflow on record (19,500 acre-ft) and calendar year 2007 had the third-most flow on record (47,500 acre-ft).

To facilitate site-to-site comparisons in the Mill Creek Basin during similar hydrologic conditions, only data from calendar years 2007 and 2008 (February 2007 through November 2008) were considered for frequency analysis. Data from site CL1a was not included because low-flow parts of the streamflow record were not computed. Streamflow-duration curves were calculated at Mill Creek sampling sites to compare the timing and magnitude of continuous streamflow data among sites. Because the number of sampling sites inhibit the display of duration curves at all nine sites, statistics derived from the flow-duration curves (streamflow values at 1-, 5-, 10-, 25-, 50-, 75-, 90-, 95-, and 99-percent exceedance) are compared among sites (fig. 16). Sites with larger drainage area had larger streamflows for more prolonged periods relative to headwater sites. Wastewater discharge increased base-flow values at sites MI3, MI4, MI5, and MI7, decreasing the range of low-flow conditions relative to sites without wastewater discharge (fig. 16*A*). To better distinguish potential effects of land use on streamflow distribution, streamflow statistics were normalized by upstream basin area (fig. 16*B*). After normalization, 1-percent streamflow exceedance values were largest at sites MI3 [37 cubic feet per second per square mile ($ft^3/s/mi^2$)], SM1 (31 $ft^3/s/mi^2$) and MI4 (29 $ft^3/s/mi^2$). Sites MI3, SM1, and MI4 had relatively large areas of impervious surface (35.1, 27.7, and 24.8 percent impervious, respectively), which routed more rainfall directly to streams. Additionally, construction and steep slopes upstream from site SM1 likely led to compacted soils and increased overland flow. Sites LM1 and LM2 had similarly large areas of impervious surface (30.7 and 27.1 percent impervious, respectively) but had smaller 1-percent exceedance levels, potentially because of the estimated 120 stormwater detention basins in the headwaters of the basin (L. Kellenberger, Johnson County Stormwater Management Program, written commun., 2007).

Duration statistics for SSC values computed from continuous turbidity measurements (for sampling sites operated from February 2007 through November 2008) are displayed on a log-10 scale to compare the frequency of SSC values observed among sampling sites (fig. 17). One-percent (2,130 mg/L, site SM1; 990 mg/L, site CL1; 1,040 mg/L, site CL2), 5-percent (390 mg/L, site SM1; 250 mg/L, site CL1; 250 mg/L, site CL2) and 10-percent (200 mg/L, site SM1; 97 mg/L, site CL1; 120 mg/L, site CL2) SSC exceedance values indicated that sites SM1, CL1, and CL2 had the largest SSC values for the longest period of time. Basins upstream from these sites had the most land surface under construction from 2005 to 2008 (figs. 1, 3, and 5; tables 2 and 3) without the presence of large (greater than 30 acre) upstream impoundments. One-, 5-, and 10-percent exceedance intervals were smallest at sites CO1, LM1, and MI3. Impervious surfaces and relatively stable vegetation in suburban basins LM1 and MI3 decrease the potential for surface-soil erosion, thus limiting the duration of large sediment concentrations at these stations. Lake Lenexa (upstream from site CO1; fig. 2) and Waterworks Lakes (upstream from site MI3; fig. 2) and storm-detention basins (upstream from site LM1) also slow water velocities and trap suspended sediment upstream from their respective dams. Suspended-sediment-concentration values were larger at more frequently exceeded intervals (50 to 99 percent exceedance) at site MI3 likely because of consistent sediment discharge (likely organic material) from the upstream Mill Creek Regional wastewater-treatment facility. These sediments are deposited in the streambed between sampling sites, as shown by smaller SSC values at 50 to 99 percent exceedance intervals at downstream sites MI4, MI5, and MI7.

Understanding when and how sediments are transported can help resource managers implement practices targeted to storms that transport the most sediment. Additionally, fine sediment deposition in streambeds has been linked to decreases in the diversity of fish and macroinvertebrate communities (Walters and others, 2003; Freeman and Schorr, 2004; U.S. Environmental Protection Agency, 2006). Fine sediments are most prone to deposit on streambeds when upstream soil disturbance results in prolonged, large sediment concentrations during relatively low-flow conditions. To compare the magnitude and duration of sediment concentrations relative to streamflow conditions and among sampling sites, 5- or 15-minute estimates of sediment loading were sorted by the streamflows in which they occurred, and then summed (along with streamflow) for streamflow values exceeded less than 0.1 percent of the time, between 0.1 and 0.5 percent of

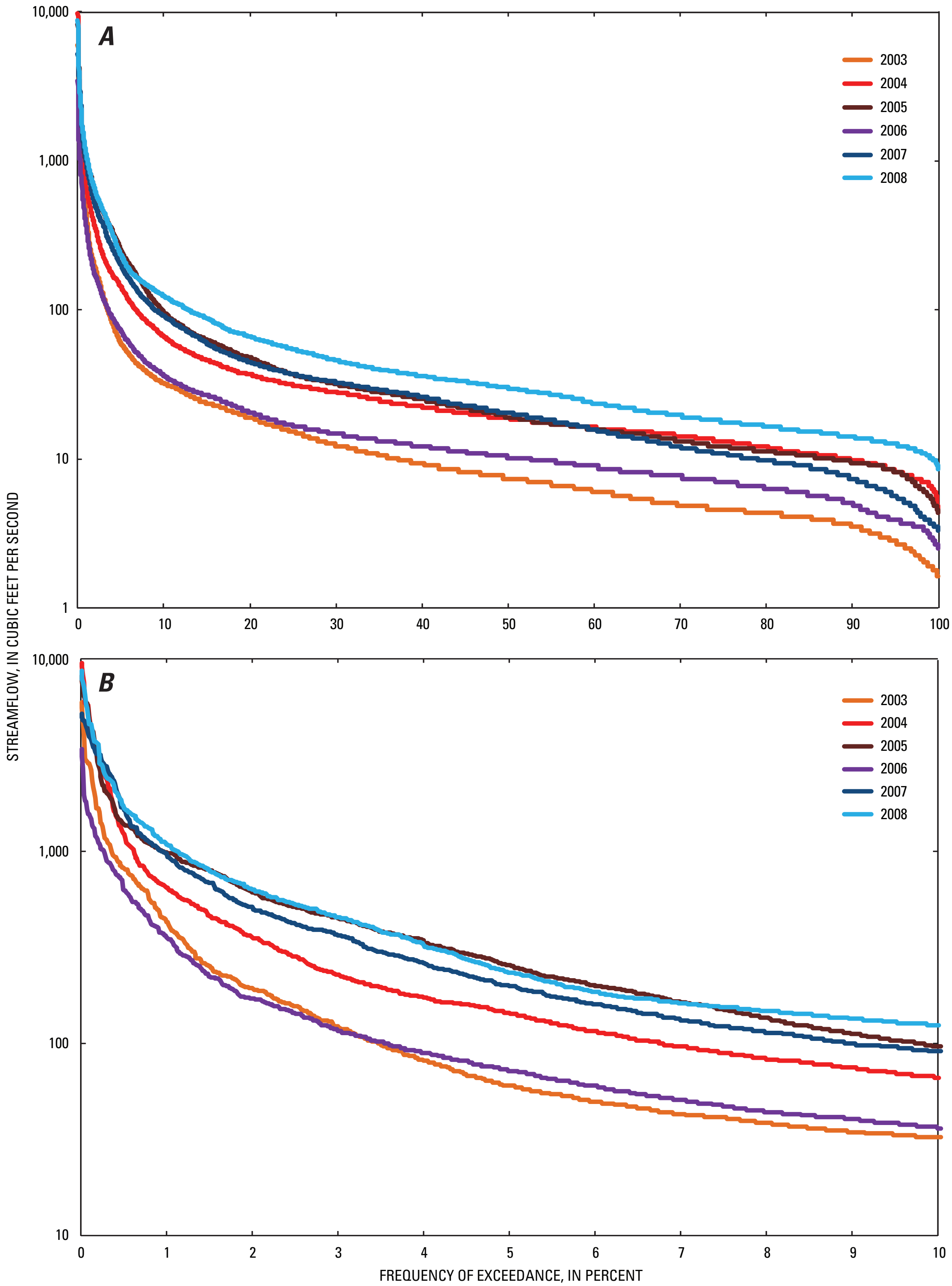


Figure 15. Streamflow exceedance for *A*, hourly streamflow values and *B*, the top 10 percent of hourly streamflow values at Mill Creek at Johnson Drive (sampling site MI7; fig. 1), Johnson County, northeast Kansas, 2003 through 2008.

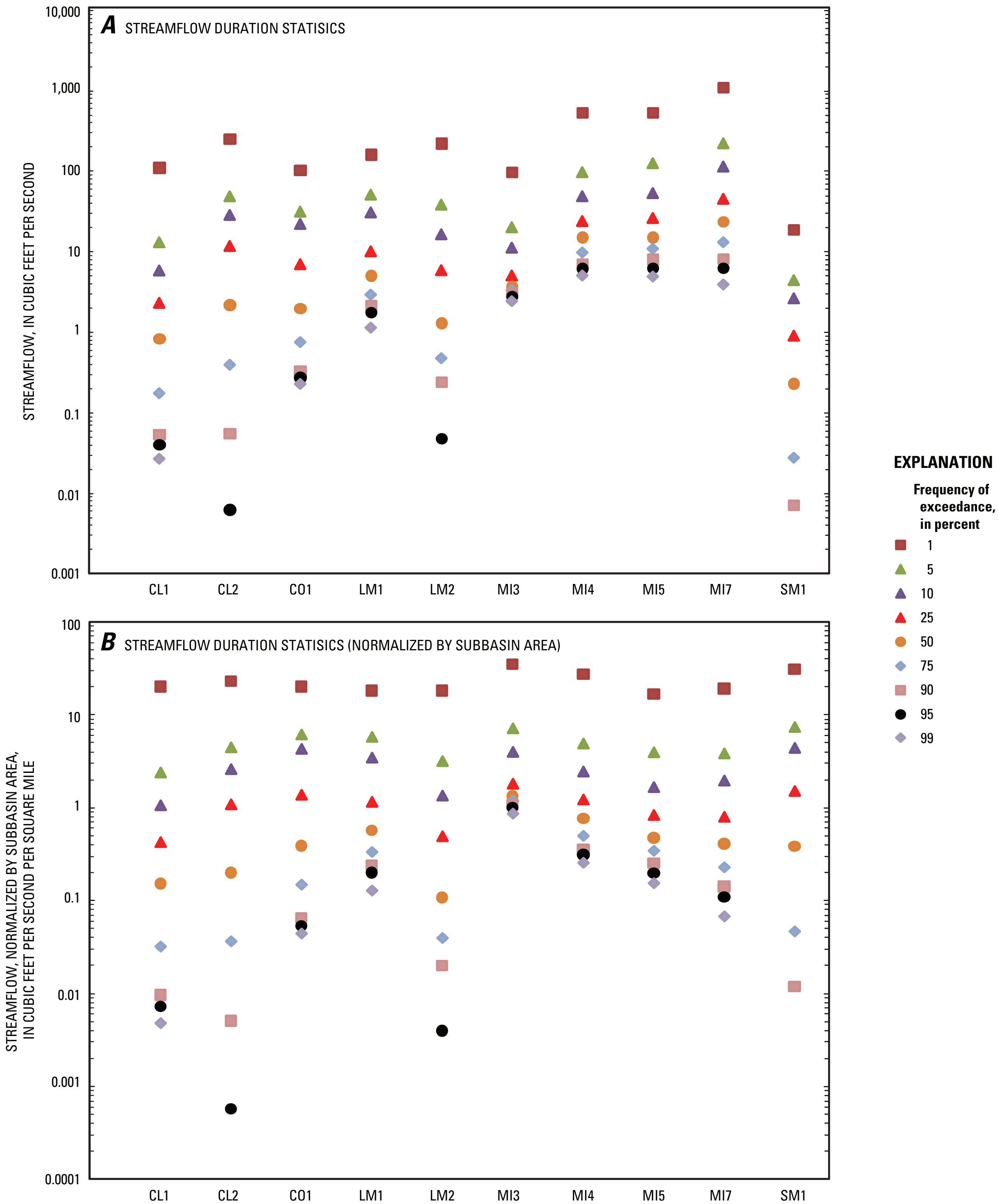


Figure 16. Duration statistics for *A*, streamflow and *B*, streamflow normalized by subbasin area for Mill Creek sampling sites operated from February 2007 through November 2008, Johnson County, northeast Kansas.

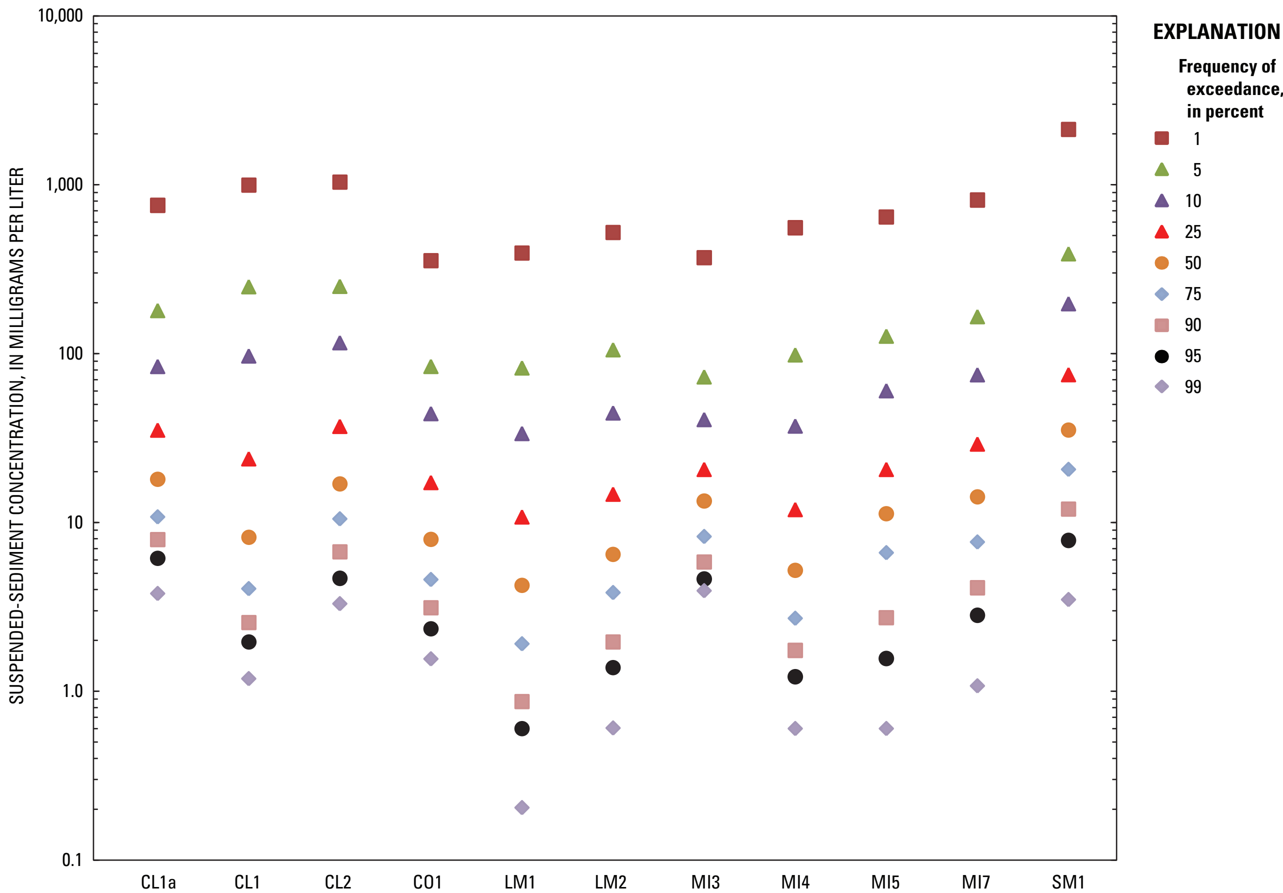


Figure 17. Duration statistics for suspended-sediment concentrations at Mill Creek sampling sites, February 2007 through November 2008, Johnson County, northeast Kansas.

the time, between 0.5 and 1 percent of the time, and then for every half percentage of time up to 100 percent. Sediment loading data summed for each streamflow exceedance interval were then divided by the total streamflow (for the same streamflow exceedance interval) to produce a flow-weighted suspended-sediment concentration (FWSC) for each interval of streamflow exceedence. Flow-weighted suspended-sediment concentrations (x-axis) are then compared to the percentage of the time streamflow values are exceeded (log-scale; y-axis) to best display the frequency of sediment concentrations among sites (fig. 18).

Streamflows exceeded less than 1 percent of the time generally consist of much of the large storms (greater than 2 in. of rainfall; fig. 19), approximately the peak of average sized storms (generally between 1 to 2 in. of rainfall), and transported between 73 and 91 percent of sediment among sampling sites (table 9). Streamflows exceeded between 1- and 10-percent of the time generally contained the initial rising limb, and end of the falling limb of stormflow hydrographs during large (greater than 2 in. of rainfall) storms, and nearly all of the average (and smaller) sized storms (approximatey1 in. of rainfall; fig. 19). Streamflow exceeded less than 10 percent of the time transported nearly all (93 to 100 percent; table 9) of the sediment load at sampling sites in the Mill Creek Basin. The largest streamflow conditions generally had the largest FWSCs (table 9; fig. 18), indicating that sediment loads generally increased exponentially with increasing flow at Mill Creek sampling sites. The largest storms come into contact with more surface and channel soils, and once these soils are suspended, larger flows have an increased capacity to transport sediments downstream. However available sediment supplies can become limited at the largest streamflows, and thus FWSC values decreased at the largest streamflow values (exceeded less than 0.1 percent of the time) relative to more frequently exceeded streamflow values at site CL2, and relatively smaller increases in FWSC values were observed at many sampling sites.

Other than in the construction-affected Clear Creek and Shawnee Mission Lake Basins, FWSCs were generally larger during streamflows exceeded 1 and 10 percent of the time at downstream (sites LM2, MI5, MI7) relative to upstream (LM1, MI3, MI4) sites (table 9). Larger average FWSCs during stormflow conditions at downstream sites generally did not correspond to larger sediment yields, but were more indicative of less episodic streamflow conditions downstream from larger basins. Increased duration of sediment transporting flows at sites with larger drainage areas is, therefore, an important

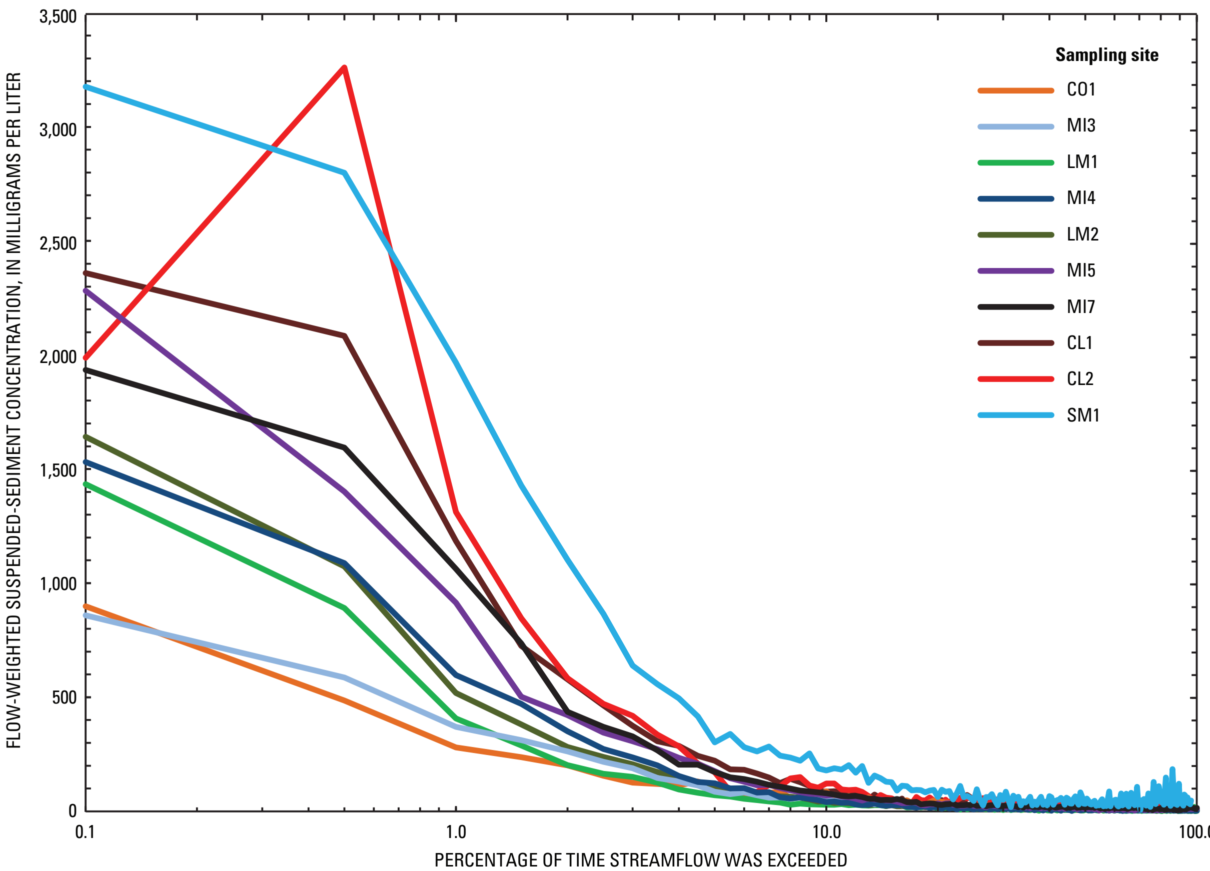


Figure 18. Flow-weighted suspended-sediment concentrations compared to streamflow exceedance at Mill Creek sampling sites, Johnson County, northeast Kansas, February 2007.

consideration when comparing SSC among sites with varying basin size.

Average FWSC values at 0.1 to 1 percent streamflow exceedance intervals were smallest at sites CO1 and MI3 because of sediment deposition in upstream reservoirs. Flow-weighted suspended-sediment concentrations during peak flow (0.1 to 1 percent exceedance) conditions from the unimpounded, established urban basin in the headwaters of the Little Mill Creek Basin (site LM1) were approximately double that observed from the partially impounded, established, urban basin in the headwaters of Mill Creek (station MI3). However, FWSCs were similar among these sites during smaller streamflow conditions, indicating that the uncontrolled impoundments in the headwaters of the Mill Creek Basin primarily decreased sediment concentrations during peak-flow conditions.

Soil disturbance from construction sites upstream from sites SM1, CL1, and CL2 resulted in the largest FWSCs during nearly all stormflow conditions (0.1 to 10 percent streamflow exceedance; fig. 18). As shown previously, streamflow value exceeded less than 1 percent of the time contribute most of the annual sediment loads; however, increased FWSCs during smaller flows at these sites may have detrimental effects on stream biota because of decreased light penetration and increased fine sediment deposition in streambeds. Larger SSC values at site SM1 during both stormflow and base-flow conditions were coincident with several inches of fine sediment deposition observed on the streambed, and indicate decreased light penetration at this site throughout the study.

Sediment Transport from Varying Storms

Sixty-three storms with rainfall more than 0.5 in. were observed in the basin upstream from sampling site MI7 (fig. 20); 34 storms with less than 0.5-in. rainfall resulted in stormflow at one or more of the other sampling sites in the Mill Creek Basin. These storms were summarized and designated decimal numbers depending on the whole numbered storms they fell between. Occasionally multiple, separate rainfall periods occurred during a single day, and therefore cumulative daily rainfall values sometimes were greater than 0.5 in., whereas values for individual storms were less than 0.5 in. (fig. 20).

Stormflow periods defined in this study from February 2006 through November 2008 occurred approximately 29 percent of the time, and transported nearly all (97 to 100 percent) of the sediment load at sampling sites. The 10 largest storms transported 63 percent of the total sediment load at site MI7 (fig. 21). The two storms, which transported the most sediment

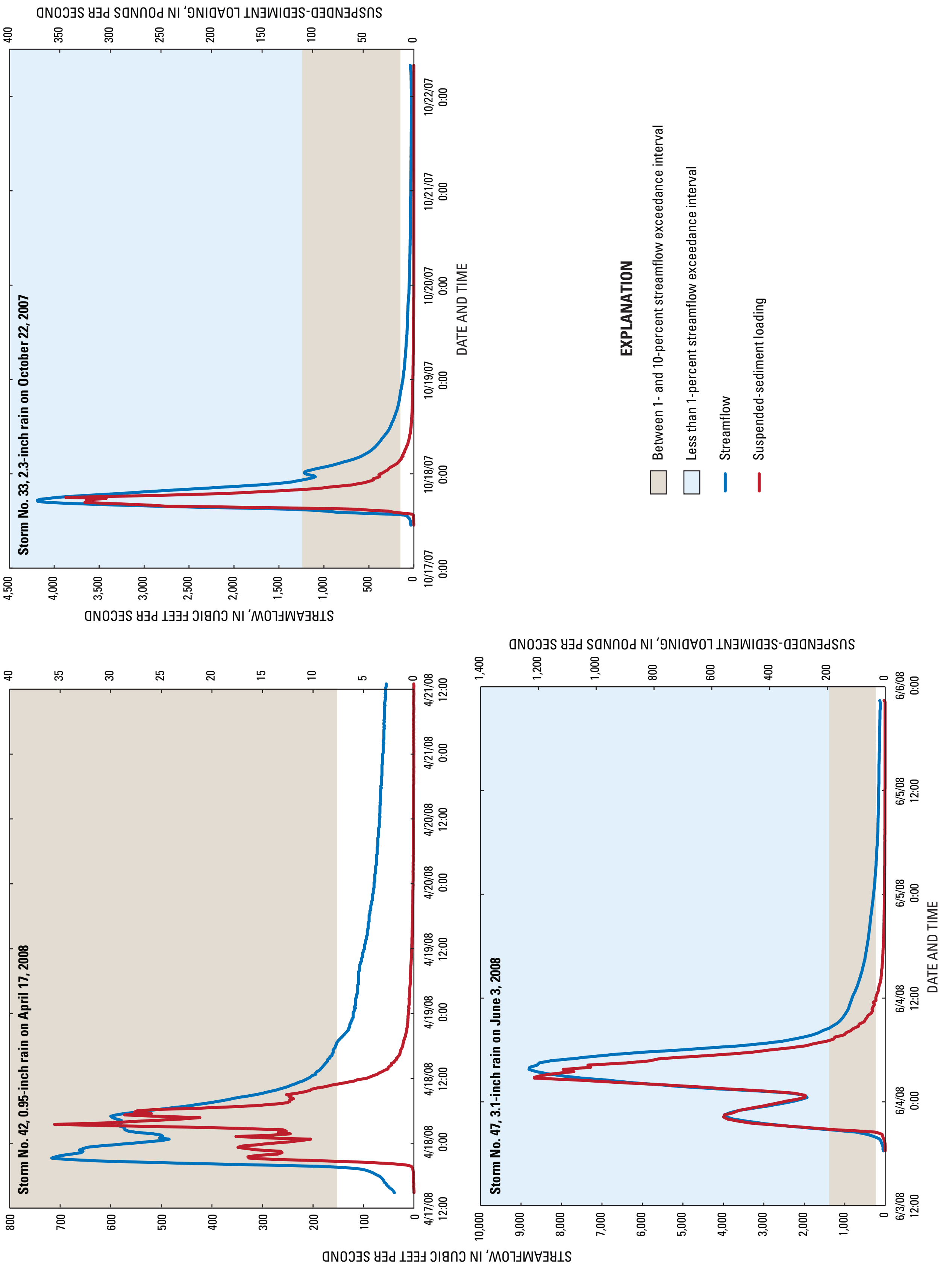


Figure 19. Streamflow and suspended-sediment loading at less than 1-percent streamflow exceedance intervals and between 1- and 10-percent exceedance intervals for three storms at site MI7, Johnson County, northeast Kansas, 2007 through 2008.

Table 9. Streamflow and sediment transport during streamflow values exceeded less than 1and 10 percent of the time, Mill Creek, Johnson County, northeastern Kansas, February 2007 through November 2008.

[mi², square mile; ft³/s, cubic feet per second; mg/L, milligrams per liter]

			Streamflow value exceeded less than 1 percent of the time						Streamflow value exceeded less than 10 percent of the time					
Sampling site (fig. 1)	Basin area (mi²)	Peak flow (ft³/s)	Streamflow (ft³/s)	Total flow less than 1 percent exceedance level (acre-feet)	Percentage of total flow	Total suspended-sediment transported at flows exceeded less than 1 percent of the time[a] (tons)	Percentage of total sediment load[a]	Flow-weighted suspended-sediment concentration (mg/L)	Streamflow (ft³/s)	Total flow less than 10 percent exceedance level (acre-feet)	Percentage of total flow	Total suspended-sediment transported at flows exceeded less than 10 percent of the time[a] (tons)	Percentage of total sediment load[a]	Flow-weighted suspended-sediment concentration (mg/L)
CL1	5.5	2,630	120	5,400	60	14,700	91	2,010	6	7,800	87	16,000	99	1,510
CL2	10.9	2,400	270	7,900	41	23,000	87	2,140	28	14,500	75	26,100	99	1,320
CO1	5.1	430	110	2,800	24	1,800	73	480	23	7,000	61	2,300	93	250
LM1	8.8	3,350	160	5,400	29	7,400	87	1,000	32	11,500	61	8,400	99	540
LM2	12.1	5,180	230	7,700	43	12,400	88	1,180	21	14,100	78	14,100	100	730
MI3	2.8	680	100	2,200	23	1,600	73	520	13	5,100	53	2,100	95	300
MI4	19.7	4,840	580	14,600	31	20,800	81	1,050	52	29,300	63	25,500	99	640
MI5	31.7	7,320	570	16,600	31	31,900	86	1,410	59	34,400	63	36,700	99	780
MI7	57.4	8,800	1,180	30,000	31	62,100	79	1,520	124	64,900	67	77,400	98	880
SM1	.6	250	19	460	30	1,700	75	2,670	2.5	1,000	66	2,200	97	1,550

[a]Sediment load does not include estimates of missing values.

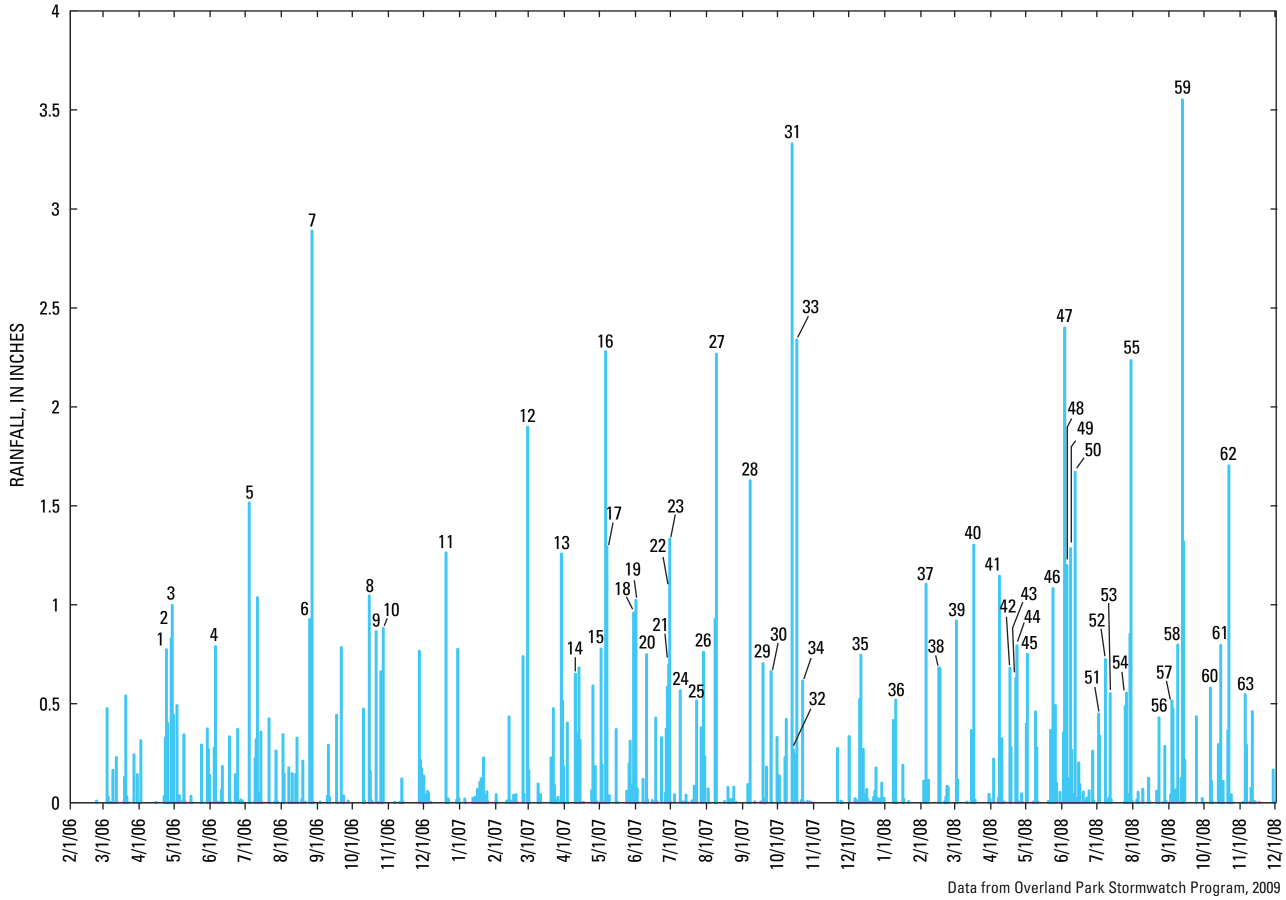


Figure 20. Daily rainfall in the basin upstream from site MI7 (fig. 1) and numbered storms with more than 0.5 inch of rainfall, Johnson County, northeast Kansas, February 2006 through November 2008.

(June 4, 2008, and March 1, 2007; fig. 21), were the first storms in each calendar year with more than 1.5 in of rainfall and maximum rainfall intensities of more than 1.1 in/h. Despite having only the fifth-most rainfall (3.07 in.) and the second-most intense maximum hourly rainfall (2.05 in/h), the storm on June 4, 2008, had the highest peak flow (8,800 ft^3/s) and transported the largest sediment load among storms at 11 of the 14 sampling sites (fig. 21). Despite having only the seventh-most rainfall (2.04 in.) and the ninth-most intense maximum hourly rainfall (1.40 in/h), the first, large storm in 2007 (March 1) transported the largest sediment load at 3 of the 14 sampling sites, sediment loads among the other 11 sites were only marginally less than those observed during the storm on June 4, 2008 (fig. 21).

Storms on August 9, 2007, October 13, 2007, and September 13, 2008, had similar or larger rainfall amounts (3.30, 3.32, and 5.04 in., respectively) and maximum rainfall intensities (5.4, 1.85, and 2.03 in/h, respectively) than storms on June 3, 2008, and March 1, 2007, but transported substantially less sediment among sampling sites. The storm on September 13, 2008, transported the most streamflow at nearly all sampling sites, but moved a substantially smaller sediment load than storms on June 4, 2008, and March 1, 2007. Increased sediment transport from the first, large storm of each calendar year indicate increased runoff and erosion during storms that occur before vegetation is fully established, and may indicate that excess sediment supplies are eroded or disaggregated by the freeze/thaw processes during fall/winter months.

Antecedent rainfall conditions also affected flow and sediment loading conditions observed during storms. Peak flows for stormflows observed at sampling site MI7 were largest on June 4, 2008 (8,800 ft^3/s), and September 13, 2008 (7,300 ft^3/s), partially because of smaller storms that saturated soil conditions before larger rainfall events. Although storms on August 9, 2007, and October 13, 2007, had similar rainfall volumes and intensities to the storm on June 3, 2008, they were not preceded by recent rainfall, and thus initial rainfall was likely absorbed by soils, resulting in smaller peak flows and smaller sediment-transport capacities.

Examination of patterns of streamflow and sediment transport among headwater and downstream sampling sites help illustrate how sediment is transported through basins. Storms were grouped by the amount of stormflow transported (less than 1 acre-ft, between 1 and 10 acre-ft, between 10 and 100 acre-ft, between 100 and 1,000 acre-ft, and more than 1,000 acre-ft) and the total sediment load and SWSCs were computed for storms within each group (fig. 22). Headwater sites generally transported much more sediment (per

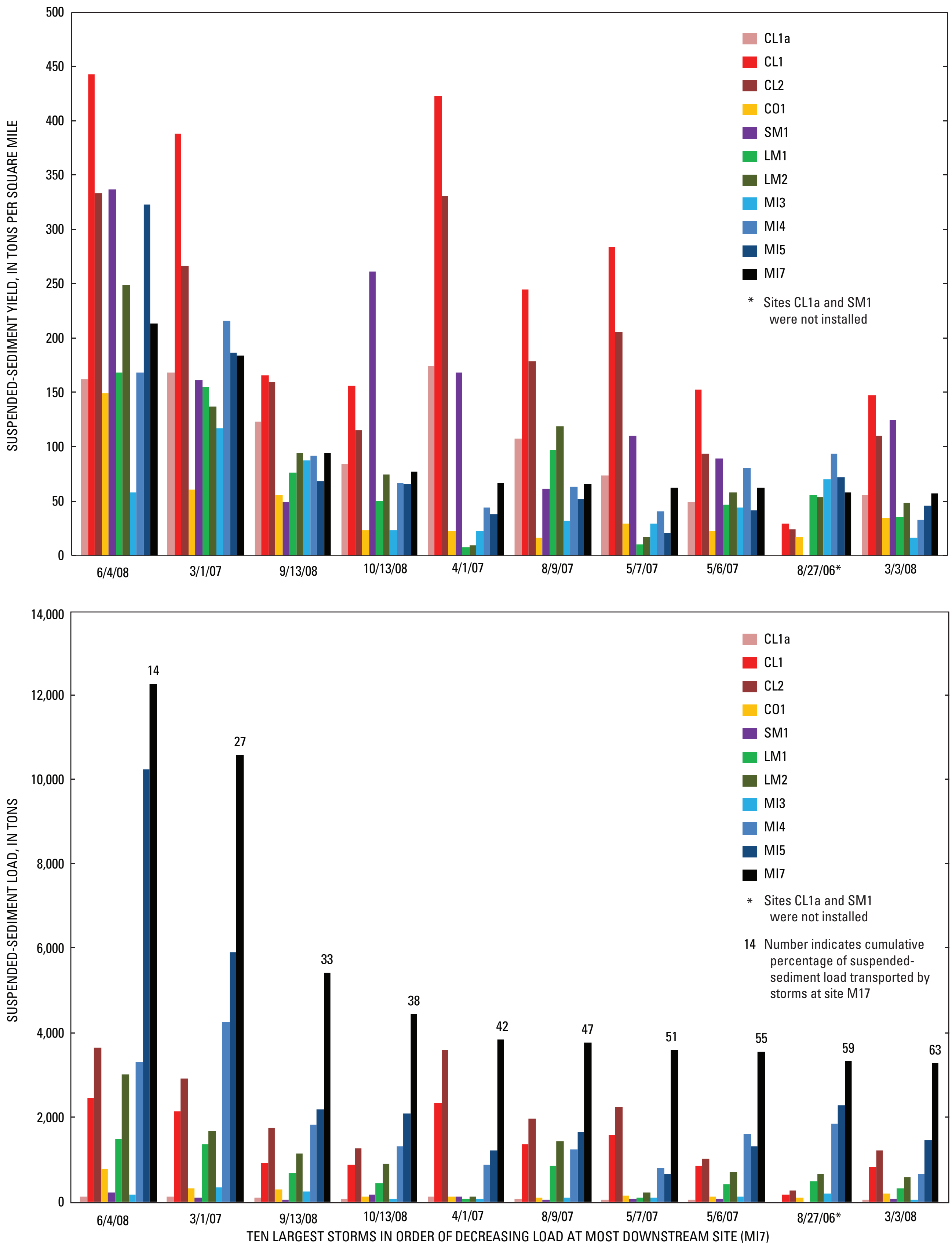


Figure 21. Suspended-sediment load and yield for the 10 largest storms in the Mill Creek Basin, Johnson County, northeast Kansas, February 2006 through November 2008.

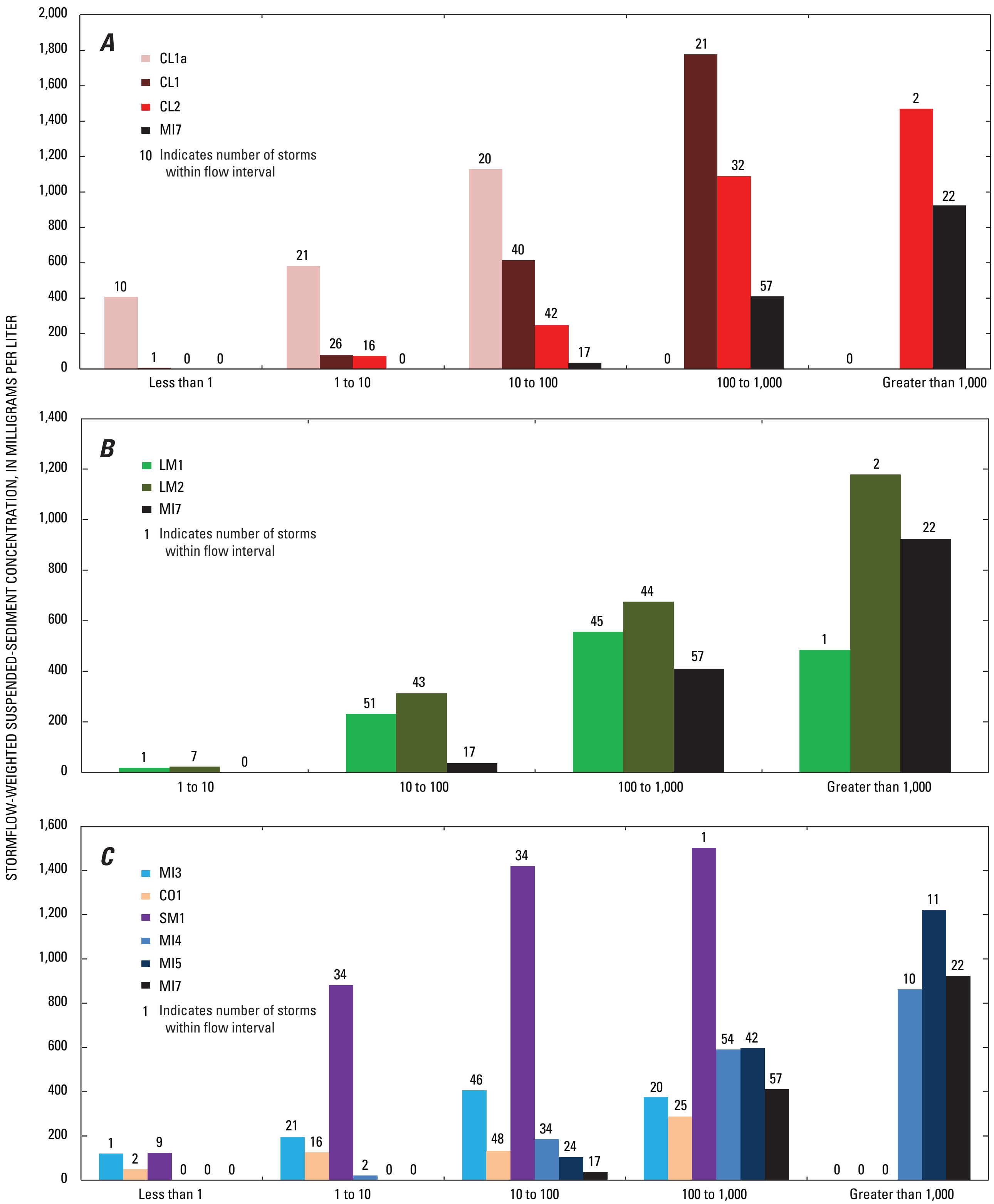


Figure 22. Stormflow-weighted suspended-sediment concentrations for groups of storms in the *A*, Clear Creek, *B*, Little Mill Creek, and *C*, mainstem Mill Creek subbasins, Johnson County, northeast Kansas, February 2006 through November 2008.

stormflow volume) than downstream sites during smaller storms (generally less than 100 acre-ft). Stormflow-weighted suspended-sediment concentrations for storms at sampling site CL1a in the Clear Creek Basin were more than double that of downstream sites within the same stormflow interval, likely a result of comparing larger intense storms at headwater sites (thus with more erosive power and more overland flow) to smaller, less intense storms at downstream sites. This also is because headwater streams with steeper slopes (table 2) have more ability to transport and suspend sediments (for the same flow volume) than larger, less-sloping downstream channels.

The most downstream sampling site in Little Mill Creek (LM2) had larger SWSCs than the upstream sampling site (LM1) throughout the range of flow values (fig. 22*B*), indicating additional sources of sediment contributing to the stream between sampling sites. Sediment yields were smaller at site LM2 than at site LM1 from February 2006 through June 2007 (Lee and others, 2009), potentially indicating either that new sediment sources began contributing to the stream between sampling sites, or decreased sediment transport upstream from site LM1 during the study period. To further analyze when the additional source(s) of sediment became available in the basin, SWSCs were computed for storms of varying magnitudes (less than 50 acre-ft, between 50 and 100 acre-ft, between 100 and 500 acre-ft, and greater than 500 acre-ft) in each of calendar years 2006, 2007, and 2008 (fig. 23). During 2006, SWSCs were slightly larger at site LM2 than at site LM1 during small (50 to 100 acre-ft) and medium (100 to 500 acre-ft) size storms, but no storms occurred greater than 500 acre-ft. During 2007, SWSCs were slightly larger at site LM1 than site LM2 during small (less than 50 acre-ft), storms, but generally were similar during larger storms. However, during 2008, SWSCs were larger at site LM2 than at site LM1 during all storms. Compared to large storms in 2007, approximately 20 percent more sediment was transported (per stormflow) for the largest storms at site LM2 during calendar year 2008, whereas approximately 22 percent less sediment was transported (per stormflow) at site LM1 during 2008 than in 2007. This analysis indicates an increase in sediment supplies available between sites LM1 and LM2, and a decrease in sediment supply upstream from site LM1.

Stormflow-weighted suspended-sediment concentrations are compared among storm categories at sites SM1, CO1, and sites on the mainstem of Mill Creek to illustrate the effect of drainage area and construction on sediment transport (fig. 22*C*). During small storms (less than 1 acre-ft), SWSCs were similar among sites SM1, CO1, and MI3 (50 to 120 mg/L). However, during small (1 to 10 acre-ft), moderate

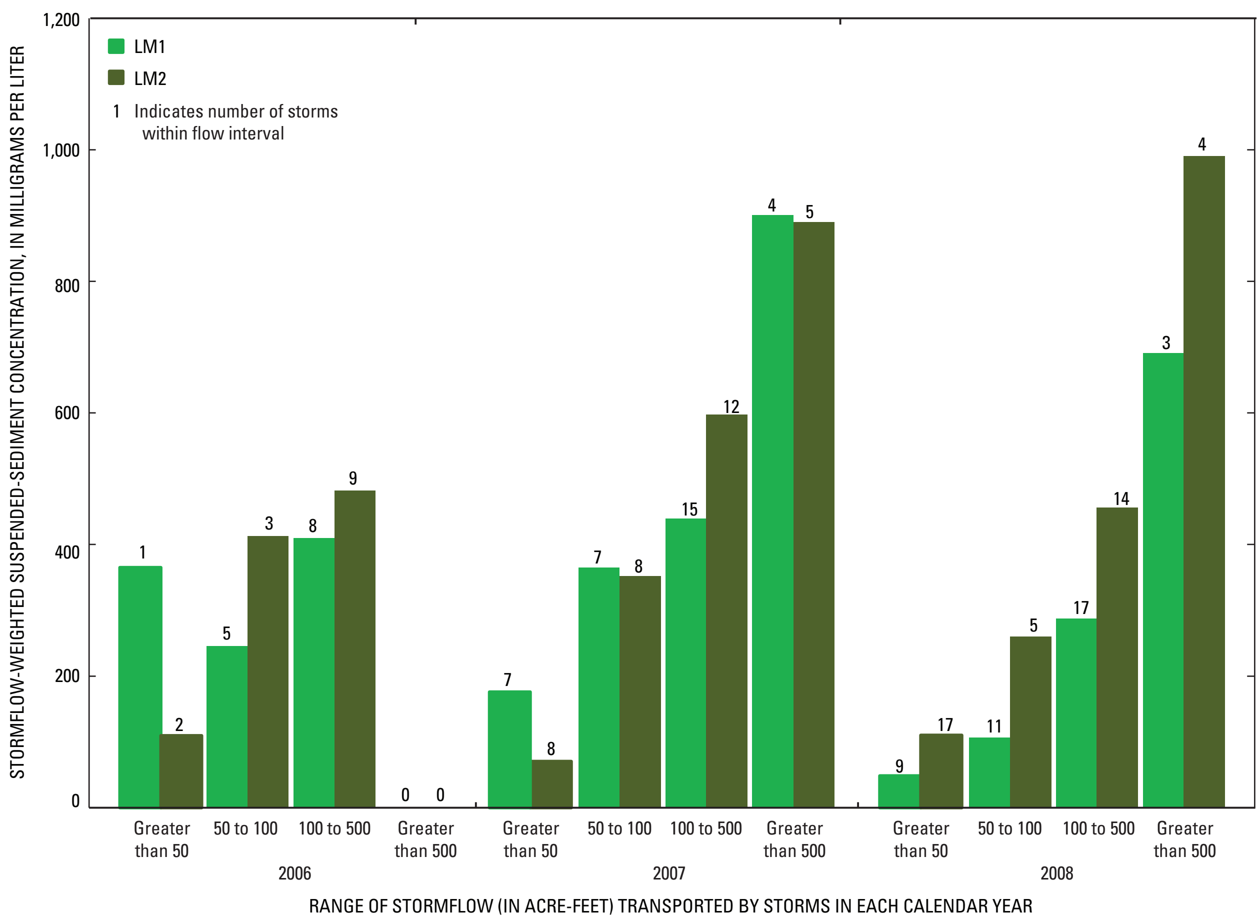


Figure 23. Stormflow-weighted suspended-sediment concentrations by year for storm ranges at sites in the Little Mill Creek Basin, Johnson County, northeast Kansas, February 2006 through November 2008.

(10 to 100 acre-ft), and larger (more than 100 acre-ft) storms, SWSCs from site SM1 were more than 5 times that of site CO1, and more than 2.5 times the SWSCs of sites on the mainstem of Mill Creek (MI3, MI4, MI5, and MI7). Although SWSCs increase with larger storms, the rate of increase is less in the smallest basins, while the rate of change continues to increase in larger basins, indicating that during progressively larger storms, sediment transport may continue to increase, but at smaller rates relative to stormflow.

Sediment loading for individual storms was evaluated against storm-specific factors, such as the amount of stormflow, rainfall amount and intensity, and antecedent streamflow and sediment transport. Characteristics of storm intensity include maximum rainfall intensity at 5, 15, 30, and 60 minutes, and the total kinetic energy of the storm (Brown and Foster, 1987). Measures of antecedent conditions include the total stormflow volume and sediment load transported in the past 15, 30, 60, and 90 days. Antecedent conditions data were tabulated for the first storm at sampling sites using data acquired since site installation. Although peak streamflow typically was better related with sediment loading than total stormflow, it was not considered because it encapsulated (and obscured) variability associated with total flow and rainfall intensity.

Stepwise multiple regression analysis was performed on log-transformed variables representing these factors, as was done in Lee and others (2009). All regression variables were log-transformed to approximate homoscedasticity and normality in regression residuals. Independent variables were added to regression equations if data distributions generally were normal and homoscedastic with respect to regression residuals. Independent variables also had to significantly improve (defined as a p-value less than 0.05) the regression relation and result in a decreased prediction error sum of square (PRESS) statistic, an indication that the independent variables added to the regression equation had the smallest amount of error when making new predictions (Helsel and Hirsch, 2002). Because of multicollinearity among measures of rainfall intensity and antecedent conditions, one variable from each category that most improved the fit of the regression equation was included in the analysis; thus, a maximum of three independent variables (total flow, a measure of rainfall intensity, and a measure of antecedent rainfall, streamflow, or sediment-load conditions) were included in the regression equations (table 10). Variance inflation factors among independent variables in regression relations were all less than 2.0, indicating that independent variables generally were uncorrelated (Helsel and Hirsch, 2002).

At all sites, storm-sediment loads were best explained by stormflow volume and secondarily by some measure of rainfall intensity. Intense rainfall increases erosion from land surfaces, the volume of overland flow (relative to subsurface flow), and the flow velocity (and thus sediment transport capacity) in rills, gullies, and stream channels. Recent, large storms immediately prior to observed storms or sediment transport resulted in significantly less sediment transport at all but one sampling site.

The y-intercept and slope of streamflow/sediment loading of the log-log regressions (first regression for each site in table 10) exhibited patterns corresponding to basin size and upstream land use. Smaller sites (fig. 24) generally had larger y-intercept values than larger sites, indicating that they transported larger sediment loads (per streamflow volume) during smaller storms. Streamflows from small storms take longer to move through the basin, providing more time for suspended sediments to deposit on the streambed, especially as channels become larger and less steep downstream. With the exception of construction-affected sites CL1 and SM1, smaller basins generally had smaller slopes between sediment load/storm flow volume relations than larger sites. Smaller sites likely have less sediment available for transport than larger sites during the largest storms. Sites CL1 and SM1 have much more sediment available for transport because of soil disturbance resulting in easily moveable sediment on soil surfaces and in streams.

Comparison of Sediment Loads Across Johnson County

Total stormflow and suspended-sediment loads and yields were compared among sampling sites operated downstream from the five largest basins (Blue River at Kenneth Road, site BL5; Cedar Creek near DeSoto, site CE6; Indian Creek at State Line Road, site IN6; Mill Creek at Johnson Drive, site MI7; and Kill Creek at 95th Street, site KI6b), in Johnson County (excluding identical periods in which sensors were removed because of freezing conditions) in 2006, 2007, and 2008 (table 11). Mill Creek sites were included for the same period of record for comparative purposes. Turbidity sensors were removed at the end of 2007 at Cedar and Kill Creek sites, and thus sediment loading estimates were not available for calendar year 2008 (Rasmussen and others, 2008). Regression relations between turbidity and SSC were used from a previous study of these sites (Rasmussen and others, 2008), and any periods of missing record or turbidity truncation were estimated using methods described in “Estimating Periods of Turbidity Truncation” and “Estimating Sediment Loading during Periods of Missing Turbidity Data” sections in this report. Sediment loads increased by less than 0.3 percent for the Cedar Creek sampling site, and by 15.2 percent for the Kill Creek sampling site after estimating truncated and missing turbidity values from February 2006 to December 2007. Sediment loads increased by 1.2 percent for the Blue River sampling site and by 37 percent in the Indian Creek sampling site after estimating truncated and missing turbidity values from February 2006 through November 2008. The water-quality sensor at Indian Creek malfunctioned during an approximately 25-year stormflow event (17,900 ft^3/s; Perry and others, 2004) on July 30, 2008. Sediment loading estimated for this storm was 62 percent of the load for 2008 (94,300 tons) using stormflow/SSL relations for storms at Indian Creek. Because of the importance of this storm and lack of sediment data at this site

Table 10. Multiple regression relations between suspended-sediment load and stormflow magnitude, rainfall intensity, and antecedent rainfall and sediment-load conditions for Mill Creek sampling sites, Johnson County, northeast Kansas, February 2006 through November 2008.

[R^2, coefficient of determination; RMSE, root mean-squared error; PRESS, prediction error sum of squares statistic; SSL, suspended-sediment load; Qtotal, total stormflow, in acre-feet; <, less than; P5, maximum rainfall intensity over 5 minutes, in inches per hour; P15, maximum rainfall intensity over 15 minutes, in inches per hour; Sed60, sediment load transported 60 days prior to event, in tons; P60 maximum rainfall intensity over 60 minutes, in inches per hour; Q15, stormflow during the past 15 days; Q60, stormflow during the past 60 days; Q90, stormflow during the past 90 days]

Sampling site (fig. 1)	Regression relation	Number of independent variables	Number of storms	Adjusted R^2	RMSE	PRESS statistic	p-value of new independent variable
CL1a	Log(SSL) = 1.22log(Qtotal) - 0.31	1	51	0.84	0.34	5.99	<0.01
CL1a	Log(SSL) = 1.13log(Qtotal) + 0.48log(P5) - 0.33	2		.90	.27	4.01	<.01
CL1	Log(SSL) = 1.80log(Qtotal) - 1.65	1	88	.93	.39	13.3	<.01
CL1	Log(SSL) =1.67log(Qtotal) + .47log(P15) - 1.41	2		.95	.34	10.4	<.01
CL1	Log(SSL) =1.68log(Qtotal) + .46log(P15) - .15(Sed60) - 1.01	3		.95	.32	9.44	<.01
CL2	Log(SSL) = 1.64log(Qtotal) - 1.69	1	92	.90	.39	14.03	<.01
CL2	Log(SSL) =1.50log(Qtotal) + 0.49log(P15) - 1.39	2		.92	.34	11.04	<.01
CL2	Log(SSL) =1.60log(Qtotal) + 0.47log(P15) - .015log(Q15) - 1.31	3		.93	.33	10.28	<.01
CO1	Log(SSL) = 1.25log(Qtotal) - 1.29	1	91	.79	.47	20.58	<.01
CO1	Log(SSL) =1.09log(Qtotal) + 0.56log(P60) - 0.78	2		.86	.39	14.36	<.01
CO1	Log(SSL) =1.18log(Qtotal) + 0.49log(P60) - 0.20log(Q15)- 0.56	3		.56	.38	14.01	.04
LM1	Log(SSL) = 1.59log(Qtotal) - 1.76	1	98	.75	.42	17.55	<.01
LM1	Log(SSL) =1.15log(Qtotal) + 0.80log(P15) - 0.81	2		.86	.31	9.52	<.01
LM1	Log(SSL) = 1.14log(Qtotal) + 0.81log(P15) -0.81log(Q60) + 0.84	3		.88	.28	8.12	<.01
LM2	Log(SSL) = 1.73log(Qtotal) - 1.98	1	91	.86	.43	16.92	<.01
LM2	Log(SSL) = 1.52(Qtotal) + 0.69log(P5) - 1.61	2		.92	.33	9.89	<.01
LM2	Log(SSL) = 1.56(Qtotal) + 0.64log(P5) - 0.20log(Q15) - 1.24	3		.92	.31	9.29	<.01
MI3	Log(SSL) = 1.19log(Qtotal) - 0.71	1	87	.85	.3	7.75	<.01
MI3	Log(SSL) = 1.07(Qtotal) + 0.34log(P5) - 0.56	2		.88	.26	6.07	<.01
MI3	Log(SSL) = 1.13(Qtotal) + 0.30log(P5) - 0.42log(Q15) + 0.40	3		.90	.24	5.25	<.01
MI4	Log(SSL) = 1.57log(Qtotal) - 1.74	1	99	.83	.41	16.89	<.01
MI4	Log(SSL) = 1.40(Qtotal) + 0.54log(P15) - 1.28	2		.87	.36	13.03	<.01
MI4	Log(SSL) = 1.36(Qtotal) + 0.61log(P15) - 0.67(Q90) + 1.32	3		.89	.33	10.87	<.01
MI5	Log(SSL) = 1.78log(Qtotal) - 2.27	1	77	.91	.31	7.57	<.01
MI5	Log(SSL) = 1.65(Qtotal) + 0.41log(P15) - 1.93	2		.93	.27	5.96	<.01
MI5	Log(SSL) = 1.61(Qtotal) + 0.48log(P15) - 0.47log(Q60) - .14	3		.94	.25	5.19	<.01
MI7	Log(SSL) = 1.76log(Qtotal) - 2.52	1	89	.89	.36	11.7	<.01
MI7	Log(SSL) = 1.61(Qtotal) + 0.41log(P15) - 2.07	2		.92	.32	9.76	<.01
MI7	Log(SSL) = 1.61(Qtotal) + 0.41log(P15) - 0.34(Q60) - 0.73	3		.92	.31	9.21	<.01
SM1	Log(SSL) = 1.57log(Qtotal) - 0.64	1	74	.86	.43	14.46	<.01
SM1	Log(SSL) = 1.48(Qtotal) + 0.49log(P5) - 0.57	2		.91	.35	9.93	<.01
SM1	Log(SSL) = 1.46(Qtotal) + 0.51log(P5) - 0.52log(Q90) + 0.69	3		.92	.33	8.81	<.01

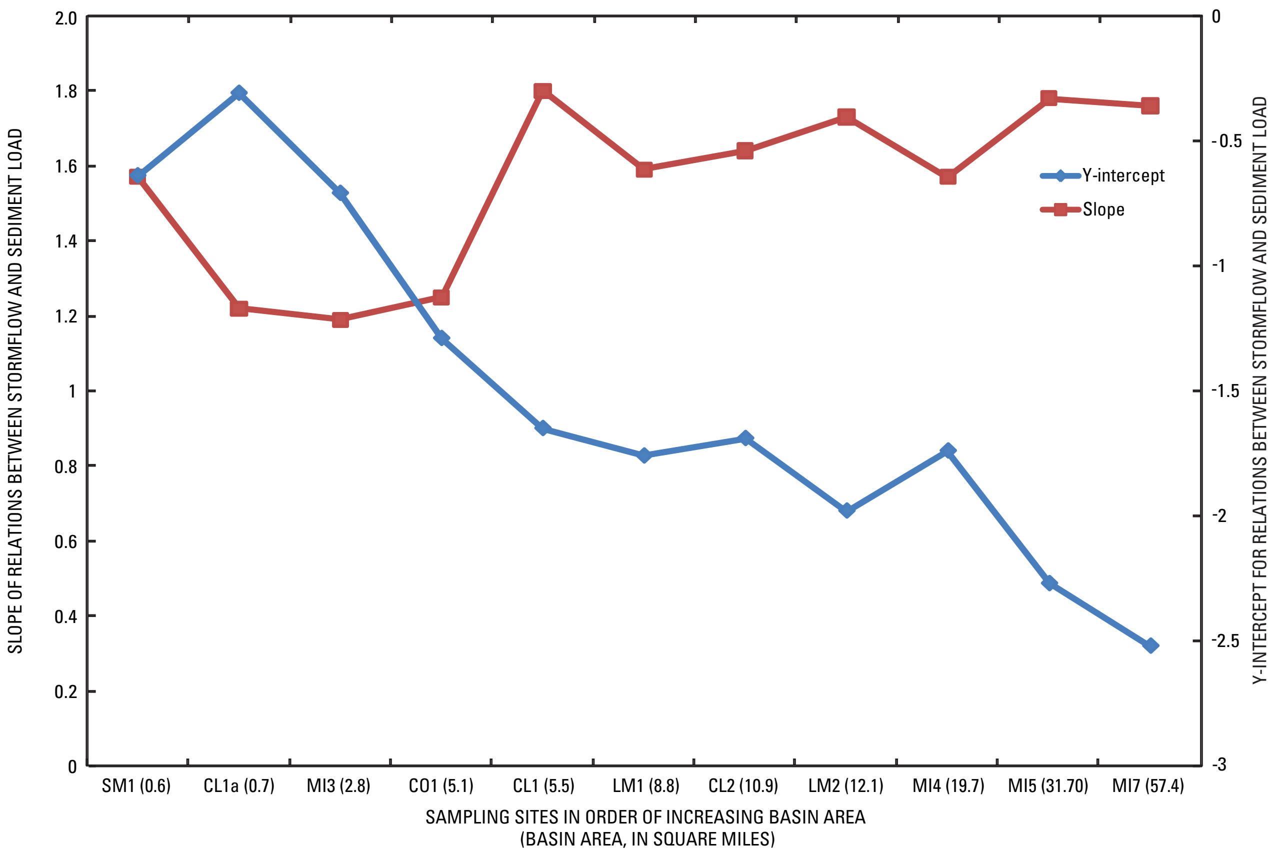


Figure 24. Slope and y-intercept of log-log relations between streamflow and sediment loading for storms at Mill Creek sampling sites, Johnson County, northeast Kansas, February 2006 through November 2008.

for a comparable storm, sediment loading at site IN6 during 2008 is subject to substantial uncertainty.

Throughout the study period, Indian Creek transported more stormflow and sediment relative to the other large urbanizing and rural basins, only slightly less than yields observed from subbasins in the Mill Creek Basin which were immediately downstream from concentrated urban construction (table 11). Stormflow yields from 2006 to 2008 (calculated by summing stormflows for each year and dividing by drainage area) from the Indian Creek Basin were more than 1.5 times those from the urbanizing Mill Creek and primarily rural Blue River Basins, and sediment yields from 2006 through 2008 were more than 2.3 times those from the Mill Creek or Blue River Basin. Comparison of all five basins from 2006 to 2007 (monitors were removed from the Cedar and Kill Creek Basins during 2008), indicated that the smallest stormflow and sediment yields were observed in the rural Kill Creek Basin, and predominantly rural Cedar Creek Basin (table 11). Blue River, despite having predominantly rural land use and little urban development (1.3 percent impervious surface increase since 2003; fig. 7), had similar sediment yields to Mill Creek in 2006 and 2007, and substantially larger sediment yields in 2008. One potential explanation is that the Blue River Basin has no large (greater than 30-acre) impoundments, and thus has a larger area contributing sediments relative to the Cedar, Kill, and Mill Creek Basins.

Comparison of annual stormflow and sediment transport can help illustrate differences within and among basins during wet and dry periods. In 2006, the five largest basins had annual rainfall totals ranging from 29.2 in. (site KI6b) to 31.8 in. (site MI7) compared to 39.7 in. of rainfall (site KI6b) to 45.5 in. of rainfall (site MI7) in 2007 (Overland Park Stormwatch, 2009). Although rainfall was only about 1.25 times greater in 2007 than in 2006, stormflows at rural sites (BL5, CE6, and KI6b) in 2007 were 3.6 to 5.0 times those of 2006, whereas stormflows at urban and urbanizing sites in 2007 were only 1.5 times (IN6) and 2.5 times (MI7) those in 2006. This is because impervious surfaces in more urban basins route rainfall to streams during both wet and dry periods, whereas soils and vegetation in rural basins absorb a larger percentage of rainfall during dry periods. Thus stormflow and sediment yields from more urban basins are substantially larger than those from primarily rural basins during dry years (such as 2006; table 11). However, during wet years (such as 2007 and 2008), saturated soils or rainfall in excess of soil infiltration capacity result in more pronounced increases in stormflow and sediment loading in rural basins compared to more urban basins (table 11). Increased flows in the rural Cedar and Kill Creek Basins in 2007 relative to 2006 resulted in larger

Table 11. Annual stormflow, stormflow yield, suspended-sediment load and yield, and stormflow-weighted suspended-sediment concentrations at sampling sites in Johnson County, northeast Kansas, February 2006 through November 2008.

[mi², square mile; mg/L, milligrams per liter; --, no data]

Sampling site (fig. 1)	Basin area (mi²)	Total stormflow (acre-feet)			Stormflow yield (acre-feet/mi²)			Suspended-sediment load (tons)			Suspended-sediment yield (tons/mi²)			Stormflow-weighted suspended-sediment concentration (mg/L)		
		2006	2007	2008	2006	2007	2008	2006	2007	2008	2006	2007	2008	2006	2007	2008
Sampling sites in the Mill Creek Basin																
CL1a	0.7	--	340	470	--	490	670	--	570	440	--	810	630	--	1,220	690
CL1b	2.8	--	2,600	--	--	900	--	--	5,300	--	--	1,900	--	--	1,500	--
CL1	5.5	1,100	4,000	4,500	200	700	800	1,100	10,100	7,500	200	1,800	1,400	740	1,800	1,200
CL2	10.9	3,000	7,800	9,900	270	700	910	2,000	14,800	11,900	180	1,400	1,100	490	1,400	890
CO1	5.1	1,400	3,900	6,000	280	760	1,170	280	1,200	1,800	60	230	350	150	220	220
LM1	8.8	3,500	7,100	8,200	400	810	930	1,400	4,900	4,200	160	550	470	290	500	370
LM2	12.1	3,300	8,000	8,200	270	660	680	1,600	7,000	7,600	130	570	620	350	640	680
MI3	2.8	1,600	2,600	3,000	560	940	1,060	620	1,100	930	220	380	330	290	290	230
MI4	19.7	7,300	15,700	17,400	370	800	880	5,800	14,300	12,800	300	730	650	590	670	540
MI5	31.7	8,900	18,100	21,200	280	570	670	6,100	16,900	23,100	190	530	730	500	690	800
MI7	57.4	14,200	34,100	40,400	250	610	730	10,400	36,200	39,500	180	630	690	540	750	700
SM1	.6	--	540	860	--	1,000	1,500	--	990	1,300	--	1,700	2,200	--	1,200	1,100
SM1a	1.3	--	--	1,400	--	--	1,090	--	--	1,300	--	--	1,000	--	--	660
SM2	.2	--	40	--	--	200	--	--	20	--	--	100	--	--	370	--
Sites at outlets of other large basins																
BL5	65.7	11,700	42,300	50,400	180	640	770	15,400	38,200	64,100	230	580	980	970	660	930
CE6	58.5	8,800	32,900	--	150	560	--	5,000	30,500	--	90	520	--	420	680	--
IN6	63.1	35,900	54,700	64,000	570	900	1,000	34,300	84,100	150,900	540	1,300	2,400	700	1,100	1,700
KI6b	48.6	4,700	23,500	--	100	480	--	2,100	17,600	--	44	360	--	330	550	--

increases in stormflow (3.7 and 5.0 times, respectively) and sediment loading (6.1 to 8.4 times, respectively) than increases in stormflow and sediment load observed at site IN6 from 2006 to 2007 (1.5 times the stormflow, 2.4 times the sediment load). For unknown reasons, site BL5 was the only site that had a larger relative increase in stormflow (3.6 times) than in sediment loading (2.5 times) from 2006 to 2007.

Streamflow and sediment transport were defined for individual storms to further characterize when and how sediments are transported through the larger basins. From 2006 to 2007, 95 individual storms were observed to increase streamflow relative to base-flow conditions at Indian Creek, compared to 55 at Mill Creek, 51 at Cedar Creek, 38 at Kill Creek, and 24 at Blue River. Fifty-one storms were observed in 2008 at Indian Creek, 39 at Mill Creek, and 27 at Blue River (number of storms shown in figure 25 for 2006 through 2008 are slightly less because of occasional turbidity sensor malfunction during storms). Impervious surfaces in urbanized basins increased runoff relative to rainfall, resulting in the observation of more storms.

Among four of the five largest sampling sites, SWSCs during storms with more than 5,000 acre-ft of flow were smaller than during storms consisting of 1,000 to 5,000 acre-ft of flow, indicating that sediment supplies are becoming limited during the largest storms. During smaller-sized storms, SWSCs are among the smallest at the Indian Creek sampling site, likely because runoff from small storms (0 to 500 acre-ft) was transported from impervious surfaces, and thus did not erode surface soils and had little capacity to erode stream channels. However, nearly twice the number of large storms (greater than 1,000 acre-ft) were observed at the Indian Creek sampling site relative to other sites, and SWSCs for these storms were larger than those observed at other sites. Thus despite having larger and more frequent stormflows, sediment supplies are abundant enough within the Indian Creek Basin and stream channel to result in larger SWSCs than observed at other basins in the county. The number of large storms was relatively similar among Blue River and Mill Creek, but SWSCs were larger at Blue River for all storms greater than 500 acre-ft. As previously described, this is likely partially related to differences in the occurrence of large impoundments between the two basins. Fewer storms were observed at the Cedar and Kill Creek sites because data were not collected in 2008, and because rainfall resulted in less runoff at these sites. Increased construction activity (1.8 percent increase in impervious surface from 2003 to 2008; fig. 7) in the Cedar Creek Basin is potentially the cause of increased sediment loads relative to the Kill Creek Basin (table 11; fig. 25).

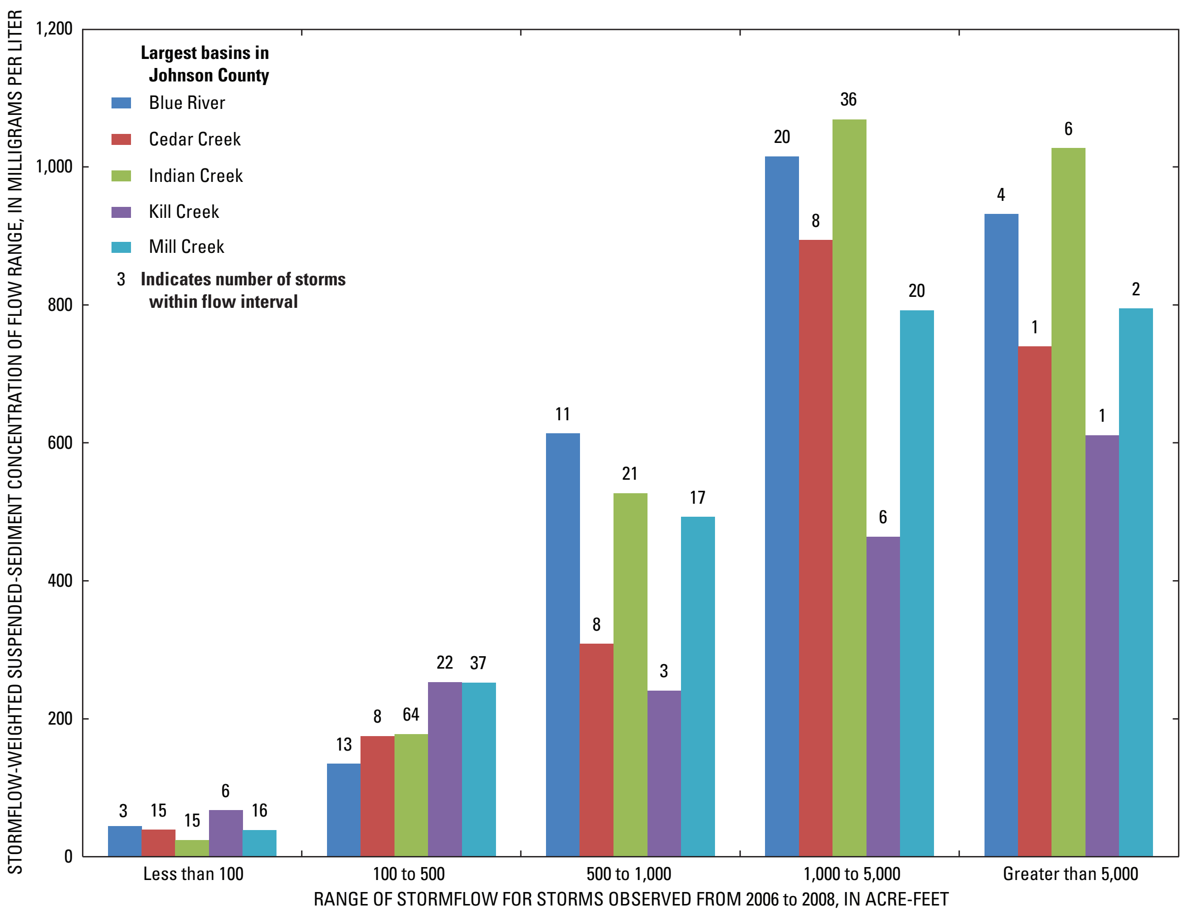


Figure 25. Stormflow-weighted suspended-sediment concentrations during different storm sizes at the five largest sites in Johnson County, northeast Kansas, February 2006 through November 2008.

Since 2003, the amount of urban construction has been similar between Indian and Mill Creek (3.7 percent increases in impervious surface area), but sediment yields at site IN6 are more than double that of site MI7. Increased stormflow and sediment yields in the Indian Creek Basin relative to other large basins in Johnson County can primarily be attributed to (1) fewer small, and no large surface-water impoundments within Indian Creek, and (2) differences in how the timing or urban development affects sediment transport in larger basins. Although only 10 percent of the Mill Creek Basin is controlled by larger (more than 30-acre) impoundments, there also are substantially more small impoundments which act to trap sediment and reduce downstream sediment transport relative to the Indian Creek Basin.

Consistently larger sediment loading in Indian Creek from 2004 to 2008 relative to other basins in Johnson County (Rasmussen and others, 2008) indicates that the basin and stream channel are still adjusting in response to historical urbanization in the basin. Increased sediment transport in the Indian Creek Basin relative to smaller sediment loads from similar urban subbasins within the Mill Creek Basin is likely a result of the scale at which sediment transport is being assessed. Along with natural variability in soils, topography, and geology, contributing basin area is an important factor controlling how human disturbances affect downstream sediment transport. Sediment deposition on the floodplains and streambeds of larger, less-sloping stream channels has been shown to delay (or mask) relations between surface erosion and downstream sediment transport (Trimble, 1977, 1997, 1999; Simon and Rinaldi, 2000; Gellis and others, 2008). Historically deposited sediments can decrease streambank stability and be resuspended by subsequent stormflows, thus delaying increases in sediment transport relative to the initial change in surface erosion. Also, more frequent, larger stormflows in urban basins increase erosive forces on streambanks, which may have decreased stability as a result of previous sediment deposition or changes to riparian land use (Trimble, 1997). Additionally, as eroded sediments reach streams in urbanized basins, they are more efficiently transported by larger total and peak streamflows and shorter stormflow recessions. The resulting pattern more efficiently transports sediments during extreme flows, while leaving less opportunity for sediment deposition during stormflow recession periods. Reconnaissance of the Indian Creek Basin after the 25-year storm on July 30, 2008, indicated little to no deposition of sediment of floodplains (fig. 26*A*) and several mass failures of sections of channel bank (fig. 26*B*). Soils from channel-bank failures typically were still aggregated, likely to be transported by subsequent storms. Therefore, increased sediment transport from the Indian Creek Basin is likely caused by frequent stormflows that erode streambed and streambank sediments.

Summary and Conclusions

The U.S. Geological Survey, in cooperation with the Johnson County Stormwater Management Program, investigated the effects of urbanization, construction activity, management practices, and impoundments on sediment transport in Johnson County, Kansas, from February 2006 through November 2008. Streamgages and continuous turbidity sensors were operated at 15 sampling sites in the urbanizing Mill Creek Basin, and at 4 sampling sites downstream from the other largest basins in Johnson County. Six of the sites within the Mill Creek Basin were used to assess sediment transport from two subbasins (Clear Creek headwaters and upstream from Shawnee Mission Lake) with substantial area under construction both before and during the study period.

Among the sites monitored continuously in the Mill Creek Basin from 2006 to 2008, sediment yields were largest from the urbanizing Clear Creek Basin; approximately 2 to 3 times those from older, more stable urban or rural basins. Subbasins partially regulated by impoundments and those with stable urban land use had the smallest sediment concentrations and loads in the Mill Creek Basin. Cumulative sediment yields from 2006 to 2008 increased coincidental with increases in impervious surface from 2005 to 2006, but were unrelated to increases in impervious surface from 2006 to 2008. This is potentially because there was more construction (and thus soil disturbance) from 2005 to 2006, and relatively little stormflow during 2006 to transport sediment through the stream network. Although increased sediment transport was generally related to increased construction activity in small basins within Mill Creek, several site-specific factors, such as management practice, impoundments, construction-site slope, site proximity to streams, sediment deposition and resuspension, and stream-channel erosion complicate relations between landscape activities and sediment yield.

Mean-daily turbidity values at sampling sites downstream from small basins with increased construction activity were compared to U.S. Environmental Protection Agency turbidity criteria designed to reduce discharge of pollutants from construction sites. The U.S. Environmental Protection Agency numeric turbidity criteria specifies that effluent from construction sites greater than 20 acres not exceed a mean-daily turbidity value of 280 nephelometric turbidity units beginning in 2011; this criteria will apply to sites greater than 10 acres beginning in 2014. Although the numeric criteria would not have been applicable to data from sampling sites in Johnson County because they were not directly downstream from construction sites and because individual states still have to determine details regarding enforcement of this criteria, a comparison was made to characterize the potential of construction site effluent in Johnson County to exceed U.S. Environmental Protection Agency Criteria, even under extensive erosion and sediment controls. Numeric criteria were exceeded at sampling sites downstream from basins with increased construction activity for multiple days during the study period, potentially

Figure 26. *A*, High-water mark on golf course and *B*, area of channel-bank failure after the 25-year storm on July 30, 2008, at Indian Creek, Johnson County, northeast Kansas.

indicating the need for additional erosion and sediment controls and (or) treatment to bring discharges from construction sites into compliance with future numeric turbidity criteria.

Sites downstream from increased recent and active construction sites in the headwaters of the Clear Creek Basin had among the largest annual sediment yields in the Mill Creek Basin (630 to 1,900 tons per square mile). Although the most upstream site in the Clear Creek Basin (0.7 square mile) had the largest percentage of area undergoing construction, and multiple failures of sediment controls were observed, sediment yields at this site were consistently smaller than those observed at downstream sampling sites. This may have been because construction sites in the headwaters of the basin were distant from streams, and thus sediments eroded form these sites were more likely to deposit on land surfaces and within smaller stream channels. Comparison of sediment yields among headwater and downstream sites in the Clear Creek Basin indicated that factors such as site and stream slope, the current phase of construction, management practices, and site location relative to streams affect the amount and length of time it takes eroded sediment to be transported downstream.

Annual sediment yields attributed to a large, 68-acre construction site upstream from Shawnee Mission Lake (9,300 tons per square mile in 2007; 12,200 tons per square mile in 2008) were 5 to 55 times those from other sampling sites in the Mill Creek Basin. However given increased precipitation, steep slopes, and erodible soils, annual sediment yields were relatively small compared to the range in values historically observed from construction sites without erosion and sediment controls in the United States (2,300 tons per square mile to 140,000 tons per square mile). Sediment loads were monitored from the sampling site 1,400 feet downstream from the construction site through a 1.8-acre-foot sediment forebay and a 7-acre-foot constructed wetland into Shawnee Mission Lake. The sediment forebay is estimated to have reduced downstream sediment loading by approximately 33 percent; the wetland did not have a measureable effect on downstream sediment transport. Comparison of relations between turbidity and sediment concentration upstream and downstream from the sediment forebay indicate that the sediment forebay likely caused deposition of larger, silt-sized particles, whereas smaller-sized sediments were transported through the wetland and into the lake. Comparison of mean sediment concentrations during storms at sites up and downstream from the constructed wetland indicated that hydraulic retention by the wetland did not substantially reduce sediment loading to Shawnee Mission Lake.

More detailed analysis of continuous streamflow and continuous turbidity-computed sediment concentrations was conducted to better understand how various factors affect the magnitude and timing of sediment transport in the Mill Creek Basin. Sediment concentrations at sites downstream from increased construction activity were larger than during both stormflow and base-flow conditions, likely decreasing light penetration through streamwater and increasing fine sediment deposition to streambeds. Urban and rural basins with reservoirs had decreased sediment loading relative to similar basins without reservoirs. Analysis of sediment loading across streamflow conditions indicated that the largest 1 percent of streamflows transported 73 to 91 percent of total sediment loads among sampling sites, and that the largest 10 percent of streamflows transported 93 to 100 percent of stream-sediment loads. Reservoirs in the Mill Creek Basin trapped sediments, decreasing downstream sediment loads, and reducing sediment concentrations primarily during peak-flow conditions. Multiple regression analysis of the factors affecting sediment transport indicated that increasing stormflow volume and rainfall intensity resulted in significant increases in sediment loading at all sites, whereas recent, large storms decreased sediment supplies available for transport by subsequent storms.

Among the five largest sampling sites in Johnson County (Blue River and Cedar, Indian, Kill, and Mill Creeks) the mature, highly urbanized basin (Indian Creek) had sediment yields more than double those observed from other large basins in the county, only slightly less than yields observed from small subbasins in the Mill Creek Basin which were immediately downstream from increased construction activity. The smallest stormflow and sediment yields were observed in the predominantly rural Cedar and Kill Creek Basins. Larger sediment yields observed in the predominantly rural Blue River Basin were similar to those in the urbanizing Mill Creek Basin, in part because of a lack of large surface-water impoundments. Consistently large sediment yields observed at Indian Creek since sampling began in 2004 indicate that increased sediment transport is likely caused by a large-scale basin and stream-channel response to urbanization (rather than specific construction activities). Although a lack of large and small impoundments partially explains larger sediment yields from the Indian Creek Basin, increased sediment transport is likely caused by frequent stormflows that erode streambed and streambank sediments.

References Cited

Bragg, H.M., Sobieszczyk, S., Uhrich, M.A., and Piatt, D.R., 2007, Suspended-sediment loads and yields in the North Santiam River basin, Oregon, water years 1999–2004: U.S. Geological Survey Scientific Investigations Report 2007–5187, 26 p.

Brown, L.C., and Foster, G.R., 1987, Storm erosivity using idealized intensity distributions: Transactions of the American Society of Agricultural Engineers, v. 30, p. 379–386.

Christensen, V.G., Jian, X., and Ziegler, A.C., 2000, Regression analysis and real-time water-quality monitoring to estimate constituent concentrations, loads, and yields in the Little Arkansas River, south-central Kansas, 1995–1999: U.S. Geological Survey Water-Resources Investigations Report 00–4126, 36 p.

Downing, J., 2006, Twenty-five years with OBS sensors—The good, the bad, and the ugly: Continental Shelf Research, v. 26, p. 2,299–2,318.

Duan, N., 1983, Smearing estimate—a nonparametric retransformation method: Journal of the American Statistical Association, v. 78, p. 605–610.

Evans, B.C., 2003, Soil survey of Johnson County, Kansas: U.S. Department of Agriculture, Natural Resources Conservation Service, p. 367.

Freeman, P.L., and Schorr, M.S., 2004, Influence of basin urbanization on fine sediment and macroinvertebrate assemblage characteristics in Tennessee Ridge and valley streams: Journal of Freshwater Ecology, v. 19, no. 3, p. 353–362.

Gellis, A.C., and others, 2008, Sources, transport, and storage of sediment in the Chesapeake Bay Watershed: U.S. Geological Survey Scientific Investigations Report 2008–5186, 95 p.

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.

Guy, H.P., 1970, Sediment problems in urban areas: U.S. Geological Survey Circular 601–E, 13 p.

Helsel, D.R., 1984, Contributions of suspended sediment from highway construction and other land uses to the Olentangy River, Columbus, Ohio: U.S. Geological Survey Water-Resources Investigations Report 84–4336, 35 p.

Helsel, D.R., and Hirsch, R.M., 2002, Statistical methods in water resources—Hydrologic analysis and interpretation: U.S. Geological Survey Techniques of Water-Resources Investigations, book 4, chap. A3, 510 p., accessed March 2008, at *http://pubs.usgs.gov/twri/twri4a3/*.

Hirsch, R.M., and Gilroy, E.J., 1984, Methods of fitting a straight line to data—Examples in water resources: Water Resources Bulletin, v. 20, no. 5, p. 705–711.

Kennedy, E.J., 1983, Computation of continuous records of streamflow: U.S. Geological Survey Techniques of Water-Resources Investigations, book 3, chap. A13, 53 p.

Kennedy, E.J., 1984, Discharge ratings at gaging sites: U.S. Geological Survey Techniques of Water-Resources Investigations, book 3, chap A10, 59 p.

Lee, C.J., Mau, D.P., and Rasmussen, T.J., 2005, Effects of nonpoint and selected point contaminant sources on stream-water quality and relation to land use in Johnson County, northeastern Kansas, October 2002 through June 2004: U.S. Geological Survey Scientific Investigations Report 2005–5144, 104 p.

Lee, C.J., Juracek, K.E., and Fuller, C.C., 2007, Bottom-sediment accumulation and quality in Shawnee Mission Lake, Johnson County, Kansas, 2006: U.S. Geological Survey Scientific Investigations Report 2007–5274, 10 p.

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, 2007–08: U.S. Geological Survey Scientific Investigations Report 2008–5123, 25 p.

Lee, C.J., Rasmussen, P.P., Ziegler, A.C., and Fuller, C.C., 2009, Transport and sources of suspended sediment in the Mill Creek Basin, Johnson County, northeast Kansas, 2006–07: U.S. Geological Survey Scientific Investigations Report 2009–5001, 52 p.

Leopold, L.B., Huppman, R., and Miller, A., 2005, Geomorphic effects of urbanization in forty-one years of observation: Proceedings of the American Philosophical Society, v. 149, no. 3, p. 349–371.

Morris, G.L., and Fan, Jiahua, 1997, Reservoir sedimentation handbook: New York, McGraw-Hill, [variously paged].

National Oceanic and Atmospheric Administration, 2009, Climatological data summary for Olathe, Kansas: National Climatic Data Center database, accessed March 3, 2009, at *http://www.ncdc.noaa.gov/oa/climate/sitelocator.html*.

Nolan, M.K., Gray, J.R., and Glysson, D.G., 2005, Introduction to suspended-sediment sampling: U.S. Geological Survey Scientific Investigations Report 2005–5077, CD–ROM.

O'Connor, H.G., 1971, Johnson County geohydrology: Kansas Geological Survey, accessed July 2008, at *http://www.kgs.ku.edu/General/Geology/Johnson/index.html*.

Osterkamp, W.R., Heilman, P., and Lane, L.J., 1998, Economic considerations of Continental Sediment-Monitoring Program: International Journal of Sediment Research, v. 13, no. 4, p. 12–24.

Overland Park Stormwatch, 2009, Overland Park, Kansas, flood warning system: City of Overland Park, accessed January 6, 2009, at *http://www.stormwatch.com/index.asp*.

Owens, D.W., Jopke, P., Hall, D.W., Balousek, J., and Roa, A., 2000, Soil erosion from two small construction sites, Dane County, Wisconsin: U.S. Geological Survey Fact Sheet 109–00, 4 p.

Pavelich, M.P., 2002, Turbidity studies at the national water quality laboratory, *in* Proceedings of the Turbidity and Other Surrogates Workshop, April 30–May 2, 2002, Reno, Nev., 3 p.

Perry, C.A., Wolock, D.M., and Artman, J.A., 2004, Estimates of flow duration, mean flow, and peak-discharge frequency values for Kansas stream locations: U.S. Geological Survey Scientific Investigations Report 2004–5033, 219 p.

Poff, L.N., Bledsoe, B.P., and Cuhaciyan, C.O., 2006, Hydrologic variation with land use across the contiguous United States—Geomorphic and ecological consequences for stream systems: Geomorphology, v. 79, p. 264–285.

Poulton, B.C., Rasmussen, T.J., and Lee, C.J., 2007, Assessment of biological conditions at selected stream sites in Johnson County, Kansas, and Cass and Jackson Counties, Missouri, 2003 and 2004: U.S. Geological Survey Scientific Investigations Report 2007–5108, 68 p.

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.

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, 103 p.

Rasmussen, P.P., Gray, J.R., Glysson, G.D., and Ziegler, A.C., 2009a, 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, 18 p.

Rasmussen, T.J., Poulton, B.C., and Graham, J.L., 2009b, Quality of streams in Johnson County, Kansas, and relations to environmental variables, 2003–07: U.S. Geological Survey Scientific Investigations Report 2009–5235, 84 p.

Renwick, W.H., Smith, S.V., Bartley, J.D., and Buddemeier, R.W., 2005, The role of impoundments in the sediment budget of the conterminous United States: Geomorphology, v. 71, p. 99–111.

Sadar, M.J., 1998, Turbidity Science: Hach Company Technical Information Series Booklet No. 11, accessed May 18, 2010, at *http://www.hach.com/fmmimghach?/CODE:L7061549|1*.

Schoewe, W.H., 1949, The geography of Kansas: Transactions of the Kansas Academy of Science, v. 52, no. 3, p. 261–333.

Simon, A., and Rinaldi, M., 2000, Channel instability in the loess area of the Midwestern United States: Journal of the American Water Resources Association, v. 36, no. 1, p. 133–150.

Thiessen, A.H., and Alter, J.C., 1911, Climatological data for July 1911—District No. 10, Great Basin: Monthly Weather Review, July 1911, p. 1,082–1,089.

Trimble, S.W., 1977, The fallacy of stream equilibrium in contemporary denudation studies: American Journal of Science, v. 277, p. 876–887.

Trimble, S.W., 1997, Contribution of stream channel erosion to sediment yield from an urbanizing watershed: Science, v. 278, p. 1,442–1,444.

Trimble, S.W., 1999, Decreased rates of alluvial sediment storage in the Coon Creek basin, Wisconsin: Science, v. 285, p. 1,244–1,246.

U.S. Census Bureau, 2008, State and county quickfacts: U.S. Census Bureau database, accessed November 2009, at *http://quickfacts.census.gov/qfd/states/20/20091.html*.

U.S. Department of Commerce, 1961, Rainfall frequency atlas of the United States for durations from 30 minutes to 24 hours and return periods from 1 to 100 years: Weather Bureau Technical Paper No. 40, 65 p.

U.S. Environmental Protection Agency, 2005, Stormwater phase II final rule, Construction site runoff minimum control measure: Fact Sheet 2.6, EPA 833–F–00–008, 4 p.

U.S. Environmental Protection Agency, 2006, Wadeable streams assessment: EPA 841–B–06–002, p. 1–98.

U.S. Environmental Protection Agency, 2009, Effluent limitations guidelines and standards for the construction and development point source category—Final rule, Federal Register, 40 CFR Part 450, 64 p.

Vice, R.B., Guy, H.P., and Ferguson, G.P., 1969, Sediment movement in an area of suburban highway construction, Scott Run basin, Fairfax County, Virginia, 1961–1964: U.S. Geological Survey Water-Supply Paper 1591–E, 46 p.

Wagner, R.J., Boulger, R.W., Jr., Oblinger, C.J., and Smith, B.A., 2006, Guidelines and standard procedures for continuous water-quality monitors—Site operation, record computation, and data reporting: U.S. Geological Survey Techniques and Methods 1–D3, 51 p. plus 8 attachments, accessed November 2006, at *http://pubs.water.usgs.gov/tm1d3*.

Wahl, T.L., and Wahl, K.L., 2006, BFI—A computer program for determining an index to base flow: Bureau of Reclamation, accessed August 26, 2008, at *http://www.usbr.gov/pmts/hydraulics_lab/twahl/bfi/*.

Walling, D.E., and Gregory, K.J., 1970, The measurement of the effects of building construction on drainage basin dymanics: Journal of Hydrology, v. 11, no. 2, p. 129–144.

Walters, D.M., Leigh, D.S., and Bearden, A.B., 2003, Urbanization, sedimentation, and the homogenization of fish assemblages in the Etowah River Basin, USA: Hydrobiologia, v. 494, p. 5–10.

Wolman, M.G., 1967, A cycle of sedimentation and erosion in urban river channels: Geografiska Annaler, v. 49a, no. 2–4, p. 385–395.

Wolman, M.G., and Schick, A.P., 1967, Effects of construction on fluvial sediment, urban and suburban areas of Maryland: Water Resources Research, v. 3, no. 2, p. 451–464.

Wood, P.J., and Armitage, P.D., 1997, Biological effects of fine sediment in the lotic environment: Environmental Management, v. 21, no. 2, p. 203–217.

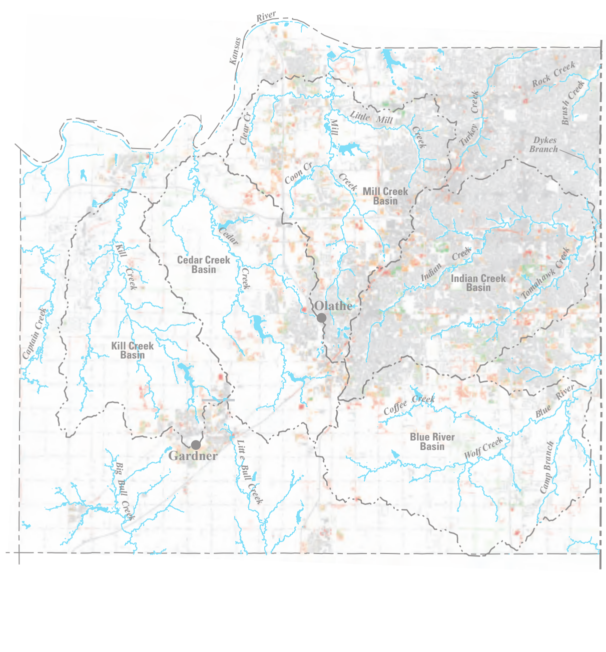
YSI Incorporated, 2010, YSI 6136 turbidity sensor documentation: YSI Incorporated, accessed February 26, 2010, at *www.ysi.com/media/pdfs/spec-sheets/E56-6136-Turbidity-Sensor.pdf.*

Yorke, T.H., and Herb, W.J., 1978, Effects of urbanization on streamflow and sediment transport in the Rock Creek and Anacostia River basins, Montgomery County, Maryland, 1962–74: U.S. Geological Survey Water-Supply Paper 1003, 76 p.

Publishing support provided by:
Rolla Publishing Service Center

For more information concerning this publication, contact:
Director, USGS Kansas Water Science Center
4821 Quail Crest Place
Lawrence, KS 66049
(785) 842–9909

Or visit the Kansas Water Science Center Web site at:
http://ks.water.usgs.gov



Back cover. Map showing location of basin boundaries in Johnson County, northeast Kansas, 2008.

Lee and Ziegler—**Effects on Suspended-Sediment Transport in Johnson County, Northeast Kansas, February 2006 through November 2008**—SIR 2010–5128