National Water-Quality Assessment Program

Trends in Suspended-Sediment Loads and Concentrations in the Mississippi River Basin, 1950–2009

Scientific Investigations Report 2011–5200

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

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Conversion Factors

SI to Inch/Pound

Multiply	By	To obtain
	Length	
millimeter (mm)	0.03937	inch (in.)
kilometer (km)	0.62137	mile (mi)
	Area	
square kilometer (km^2)	0.38610	square mile (mi^2)
hectare-meter (ha-m)	8.1071	acre-feet (ac-ft)
	Volume	
liter (L)	0.26417	gallon (gal)
	Flow rate	
cubic meter per second (m^3/s)	35.3147	cubic feet per second (ft^3/s)
	Mass	
metric ton (t)	1.10231	ton, short (2,000 lb)

Acronyms

FA SSC	flow-adjusted suspended-sediment concentration (the positive and negative residuals of a linear regression model constructed from streamflow and suspended-sediment concentration data pairs, expressed in milligrams per liter)
FA SSDC	flow-adjusted suspended-sand concentration (the positive and negative residuals of a linear regression model constructed from streamflow and suspended-sand concentration data pairs, expressed in milligrams per liter)
FW SCC	flow-weighted suspended-sediment concentration (computed as the daily suspended-sediment load divided by the corresponding daily mean streamflow)
FW SSDC	flow-weighted suspended-sand concentration (computed as the daily suspended-sand load divided by the corresponding daily mean streamflow)
SSC	suspended-sediment concentration
SSDC	suspended-sand concentration
SSDL	suspended-sand loads
SSL	suspended-sediment loads

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Abstract

Trends in loads and concentrations of suspended sediment and suspended sand generally were downward for stations within the Mississippi River Basin during the 60-, 34-, and 12-year periods analyzed. Sediment transport in the lower Mississippi River has historically been, and continues to be, most closely correlative to sediment contributions from the Missouri River, which generally carried the largest annual suspended-sediment load of the major Mississippi River subbasins. The closure of Fort Randall Dam in the upper Missouri River in 1952 was the single largest event in the recorded historical decline of suspended-sediment loads in the Mississippi River Basin. Impoundments on tributaries and sediment reductions as a result of implementation of agricultural conservation practices throughout the basin likely account for much of the remaining Mississippi River sediment transport decline. Scour of the main-stem channel downstream from the upper Missouri River impoundments is likely the largest source of suspended sand in the lower Missouri River. The Ohio River was second to the Missouri River in terms of sediment contributions, followed by the upper Mississippi and Arkansas Rivers. Declines in sediment loads and concentrations continued through the most recent analysis period (1998–2009) at available Mississippi River Basin stations. Analyses of flow-adjusted concentrations of suspended sediment indicate the recent downward temporal changes generally can be explained by corresponding decreases in streamflows.

Introduction

Suspended-sediment concentrations (SSCs) were first recorded in the Mississippi River Basin in 1804 along the Missouri River by William Clark during the Lewis and Clark Expedition (Moulton, 1986; Blevins, 2006), and in 1838 near the mouth of the Mississippi River by Andrew Talcott (U.S. Army Corp of Engineers, 1930; Keown and others, 1981). Monitoring of sediment transport within the Mississippi River Basin has continued through the present day (2011), which has led to an increasingly better understanding of its role and importance in the geomorphic and ecological integrity of the river channels and riparian resources throughout the basin.

Present-day suspended-sediment loads (SSLs) of the Mississippi River delivered to the Gulf of Mexico are about one-half of the pre-1950s loads (Tuttle and Comb, 1981; Keown and others, 1986; Meade and Parker, 1985; Meade, 1995). This reduced Mississippi River sediment transport has been attributed to impoundments, implementation of soil conservation practices, and bank-stabilization efforts that have reduced contributions from the Missouri River Basin (Keown and others, 1981; Tuttle and Combe, 1981; Kesel, 1988; Meade and Moody, 2010), but other possible causes of the reductions include numerous engineering structures and channel modifications in the Mississippi River (Keown and others, 1981; Keown and others, 1986; Smith and Winkley, 1996; Biedenharn and others, 2000).

Substantial State and Federal funds have been spent to address multiple concerns resulting from the reduced SSLs in the Missouri and Mississippi River Basins, yet funds also are spent to reduce soil erosion and limit contributions of sediment to the Missouri and Mississippi Rivers. Reductions in SSLs in the Missouri River have lead to bed degradation in long reaches of the lower part of the river, which, in turn, has had large economic effects owing from the necessary alterations of river structures, increased pumping costs for water requirements, and modifications to aggregate mining operations (United States Army Corp of Engineers, 2009a) along with adverse effects on aquatic and riparian habitat (U.S. Fish and Wildlife, 2003). Reduced sediment transport from the Mississippi River Basin is cited as a factor in the loss of coastal wetlands in Louisiana (Kesel, 1988, 1989; van Heerden and DeRouen, 1997). Sediment transport is an important factor in assessing opportunities and constraints of several large-scale ecosystem restoration programs within the Mississippi River Basin including the Louisiana Coastal Area Restoration Program (U.S. Army Corps of Engineers, Louisiana Coastal Area Restoration Program, accessed August 2010, *http://www.lca.gov/.*), Missouri River Recovery Program (U.S. Army Corps of Engineers, Missouri River Recovery Program, accessed November 2010, *http://www.moriverrecovery.org/mrrp/f?p=136:1:1186003470123021*), and Upper Mississippi River Environmental Management Program (U.S. Army Corps of Engineers, Upper Mississippi River Environmental

Management Program, accessed November 2010, *http://www.mvp.usace.army.mil/environment/default.asp?pageid=74*). At the same time, sediment transport is closely associated with nutrient transport and the reduction of nutrient transport in the Mississippi River Basin to mitigate hypoxia (dissolved oxygen reductions) in the northern Gulf of Mexico is an objective of current State and Federal programs, including the Mississippi River Basin Healthy Watersheds Initiative (National Resources Conservation Service, Mississippi River Basin Healthy Watersheds Initiative, accessed November 12, 2010, *http://www.nrcs.usda.gov/wps/portal/nrcs/detailfull/national/programs/farmbill/initiatives/?&cid=nrcsdev11_024120*). Quantifying sediment and nutrient transport is a means of assessing the effectiveness of erosion control and conservation practices at multiple scales. Therefore, information on the spatial and temporal variability in the quantity of sediment transport at locations throughout the Mississippi River Basin is necessary to assess the feasibility of management alternatives of multiple local, State, and Federal interests.

Concerns related to sediment transport in the Mississippi River Basin and the need for an assessment of that transport prompted a study, as described in this report, of the changes in SSLs and SSCs at selected stations throughout the Mississippi River Basin and analyses of the relative contributions of sediment from the major subbasins. The Mississippi River Basin (fig. 1) is the largest river basin in the United States (U.S.) [3.21 million square kilometers (km^2)] draining 41 percent of the conterminous United States. The Mississippi River transports more sediment than any other river in North America (Meade and others, 1990). The river extends 3,700 km from its headwaters in northern Minnesota to the mouth at the Gulf of Mexico. The upper Mississippi River main stem (upstream from the junction of the Mississippi River with the Ohio River near Cairo, Illinois) has been substantially altered by the construction of 29 navigation locks and dams between Minneapolis, Minnesota and Saint Louis, Missouri, most of which were completed during the 1930s (O'Brien and others, 1992; Knox, 2007). A primary tributary to the upper Mississippi River, the Illinois River/Illinois Waterway, has eight locks and dams that were constructed by 1933 between Chicago and the junction of the Illinois River with the Mississippi River at Grafton, Illinois (West Consultants Inc., 2000).

The lower Mississippi River was modified by bank stabilization, levees, meander cutoffs, and channel constrictions between 1930 and 1955 (Smith and Winkley, 1996). About 58 percent of the total Mississippi River Basin is regulated by hundreds of reservoirs (Tuttle and Combe, 1981). In 1963, the U.S. Army Corps of Engineers (USACE) completed a flow-control structure on the lower Mississippi River that controls flows between the Mississippi River and the Atchafalaya River through the Old River Outflow Channel (Mossa, 1996). The diversion maintains the flow in the Atchafalaya River at about 30 percent of the combined Mississippi and Red River flows. Total sediment transport from the Mississippi River Basin is, therefore, measured as the combined SSLs of the Mississippi and Atchafalaya Rivers.

Major tributaries to the lower Mississippi River include the Missouri (44.6 percent of contributing area), upper Mississippi (16.5 percent), Arkansas (15.4 percent), and Ohio (15.2 percent) Rivers (Knox, 2007). The lower Mississippi River receives a disproportionately large influx of sediment from the Missouri River and a disproportionately large contribution of its flow from the Ohio River (Meade, 1995; Knox, 2007).

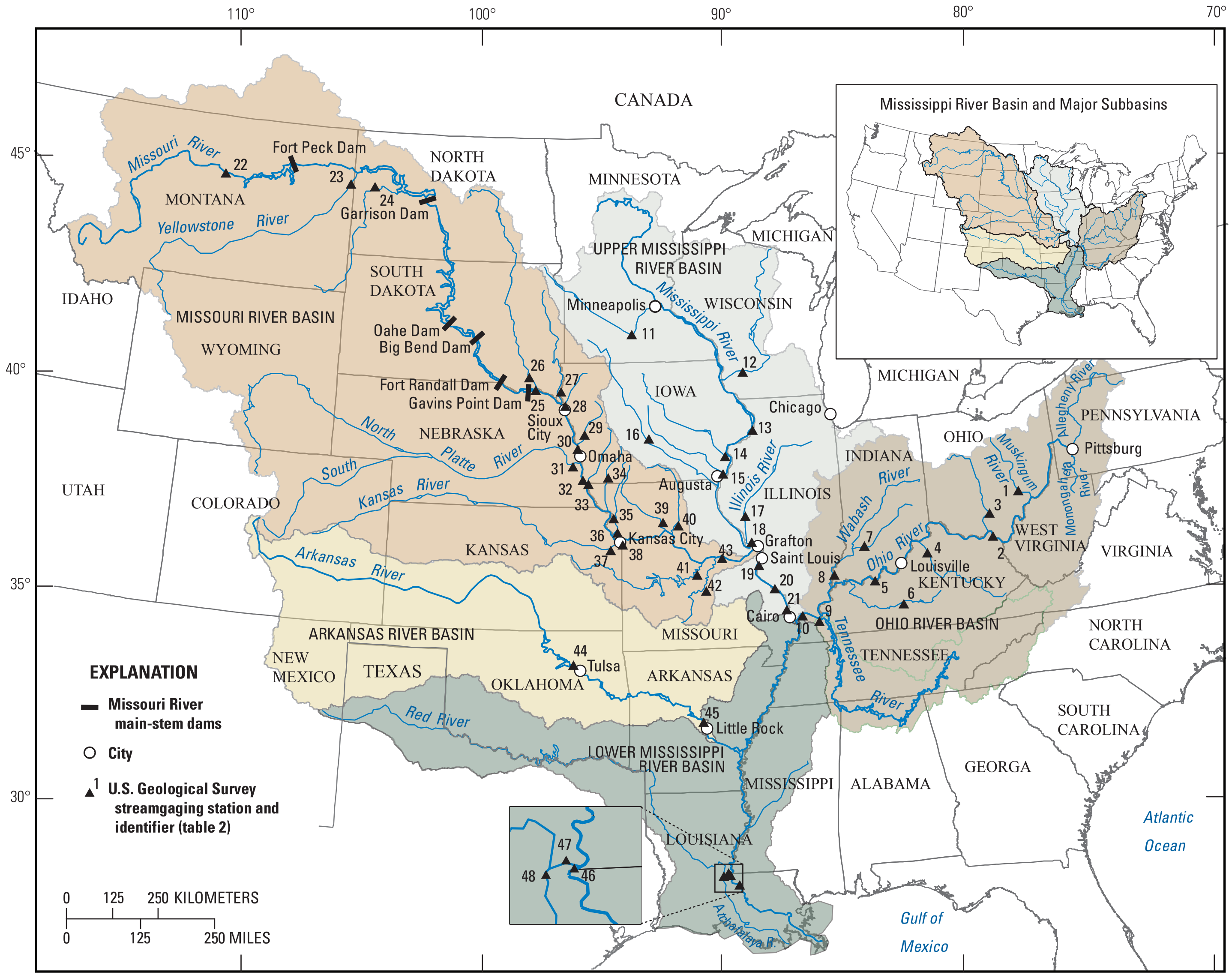
The Missouri River Basin is the largest tributary to the Mississippi River Basin and the second largest river basin in the United States draining about one-sixth of the conterminous United States (1.37 million km^2). The Missouri River is 3,770 km long from its headwaters in western Montana to its mouth at Saint Louis, Missouri, which also makes it the longest river in the United States. Bank stabilization and channel modifications to the Missouri River, associated with the Bank Stabilization and Navigation Project (BSNP), began in earnest in the 1930s and continued through the 1980s (U.S. Army Corp of Engineers, 2009a). Six major impoundments that regulate the flow from 53 percent of the basin area upstream from Saint Louis, Missouri also were constructed in the upper Missouri River (upstream from Yankton, South Dakota) between the beginning of construction in 1933 and the filling of the last impoundment in 1966 (table 1). These engineered modifications, along with land-use changes including changes in agricultural practices, and other engineered structures in the lower Mississippi River (meander cutoffs, river-training structures, bank revetments) have resulted in a reported 70 percent decline in sediment transported by the Missouri River to the Mississippi River (Meade and Moody, 2010) since the early 1950s.

The principal tributaries to the Missouri River include the Yellowstone, Platte (Nebraska), and Kansas Rivers. The Yellowstone River, the largest tributary to the Missouri in terms

Table 1. Main-stem reservoirs of the upper Missouri River Basin.

[Table modified from National Research Council, 2011]

Reservoir	Dam	Year started	Year closed	Year completed	Storage (hectare meter)
Fort Peck	Fort Peck	1933	1937	1940	1,210,000
Sakakawea	Garrison	1946	1953	1954	2,840,000
Oahe	Oahe	1948	1958	1962	2,900,000
Sharpe	Big Bend	1959	1963	1966	234,000
Francis Case	Fort Randall	1946	1952	1953	678,000
Lewis and Clark	Gavins Point	1952	1955	1957	60,700



Base Map from USGS Digital Data, 1:2,000,000, 1990
Albers Equal-Area Conic projection

Figure 1. Mississippi River Basin, major subbasins, and U.S. Geological Survey streamgaging and sediment stations included in study.

of discharge (Missouri Basin Inter-Agency Committee, 1969), with a drainage area of 182,000 km^2, flows through Wyoming and Montana before it joins the Missouri River in western North Dakota. The lack of reservoirs on the Yellowstone River main stem makes it one of the longest free-flowing rivers in the United States. Hundreds of small impoundments, however, have been built on major tributaries (Zelt and others, 1999) of the Yellowstone River that were constructed for water supply, recreation, energy production, and flood control purposes. The Platte River originates in Colorado and Wyoming and flows eastward through Nebraska draining 230,000 km^2 (Galat and others, 2005). Beginning in the early 1900s, many impoundments were built on the North and South Platte Rivers for public supply and irrigation. The Kansas River Basin is about 159,000 km^2 and drains parts of Colorado, Nebraska, and Kansas. Eighteen Federal reservoirs have been constructed in the Kansas River Basin beginning in 1946, with 7 of the 18 completed by 1953. Present-day impoundments on the major tributaries of the Kansas River and regulate about 85 percent of the flow from the basin (Perry, 1994).

The Arkansas River, the third largest tributary to the Mississippi River, drains an area of 505,000 km^2. Reservoir and flood control projects on the Arkansas began in the late 1930s and modifications continued with the construction of 18 navigation locks and dams in the McClellan-Kerr Arkansas River Navigation System between 1967 and 2004 (17 of 18 were complete by 1970; The Encyclopedia of Arkansas History and Culture, McClellan-Kerr Arkansas River Navigation System (MKARNS) accessed June 2010, *http://encyclopediaofarkansas.net/encyclopedia/entry-detail.aspx?entryID=2309*). More than 40 large reservoirs were constructed between 1936 and the late 1960s within the Arkansas River Basin in Colorado, Kansas, Oklahoma, and Arkansas. Most of the major reservoirs on the lower Arkansas River in Oklahoma that reinforce the McClellan–Kerr Navigation System were completed by 1964.

The Ohio River is formed at the junction of the Allegheny and Monongahela Rivers at Pittsburgh, Pennsylvania, and is 1,580 km long to its mouth at the Mississippi River near Cairo, Illinois. The Ohio River Basin is the smallest of the four major lower Mississippi River contributing subbasins in terms of area, 490,000 km^2, but the largest in terms of contributing flow volume (Knox, 2007). A concrete lock and dam system for navigation has been in place on the Ohio River since the 1950s (Meade, 2004), and currently (2010) there are 21 locks and dams. Eighty-three reservoirs, about 95 major local flood-protection projects, and numerous small flood-control projects have been built on tributaries in the basin. Construction of the reservoirs and flood-control projects began in the late 1930s and most were completed by the 1950s (U.S. Army Corp of Engineers, 2009b).

The Tennessee River is the largest tributary of the Ohio River with a basin area of 106,000 km^2 (White and others, 2005). The river is regulated by numerous impoundments including nine main-stem dams operated by the Tennessee Valley Authority that were completed between 1913 and 1967, although most were completed by the mid-1940s.

The Wabash River is the second largest tributary to the Ohio River (85,340 km^2), and whereas the upper 103 km has been regulated by a Corps of Engineers reservoir since 1968, the lower 661 km is the longest stretch of free-flowing river east of the Mississippi River (Karns and others, 2006). Despite the free-flowing status of the lower Wabash River main stem, Pyron and Neumann (2008) note that the hydrology of the river has been substantially altered by the construction of reservoirs and by land-cover changes within the basin during the past century.

Assessments of changes in water-quality constituents over time are a primary goal of the U.S. Geological Survey's (USGS) National Water-Quality Assessment (NAWQA) program (Gilliom and others, 2001). Previous studies have documented analyses of suspended-sediment trends in the Missouri (Sprague and others, 2006), upper Mississippi and Ohio (Lorenz and others, 2009), Tennessee (Hoos and others, 2000) and lower Mississippi and Atchafalaya Rivers (Rebich and Demcheck, 2007) for various periods between 1974 and 2004. Horowitz (2010) also examined trends in SSLs and flow-weighted (FW) SSCs at selected USGS streamgaging stations in the Mississippi River Basin for the 1981–2007 period.

The primary objective of the study described here, and the purpose of this report is to augment existing information by computing the relative sediment contributions from Mississippi River subbasins and determine temporal trends in streamflow, suspended sediment loads and concentrations at multiple Mississippi River main-stem and tributary stations, and for multiple time scales. The sediment contributions and trends in sediment contributions from subbasins could then be used to determine which tributaries, subbasins, or regions affect recent suspended-sediment trends near the mouth of the Mississippi River and in large receiving rivers such as the Missouri.

Study Methods

Station Selection

Station selection began with an assessment of published SSLs or SSCs and daily streamflow data at USGS streamgaging stations within the major subbasins of the Mississippi River Basin. The USGS National Water Information System (NWIS) database (*http://waterdata.usgs.gov/nwis*) was searched for main-stem and primary tributary stream stations with a drainage area of at least 2,500 km^2 and for which daily sediment loads or discrete sediment concentrations and concurrent daily streamflow record of at least 10 years were available. Further selection criteria for those stations with sediment loads that were not already determined included selecting stations with SSC and suspended-sand concentration (SSDC) samples distributed throughout the water year (Oct. 1 to

Sept. 30) and over the range of observed streamflows. At a minimum, the most downstream station with adequate suspended-sediment record from each major subbasin of the Mississippi River Basin (fig. 1) was selected for trend analyses.

Impoundments on the upper main stem of the Missouri River have had a substantial effect on sediment transport in the lower Missouri and Mississippi River downstream from Saint Louis, Missouri. To conduct step-trend analyses to assess changes in sediment transport in main-stem and tributary stations between pre- and post-impoundment periods, available stations with continuous or non-continuous sediment record spanning both periods were selected for analysis. As in previous studies (Keown and others, 1986; Jacobson and others, 2009) the pre-impoundment period in this study was defined as pre-1953—before the closure of the downstream Fort Randall Dam. The post-impoundment period was defined as post-1967—after the last completed reservoir, Lake Sharpe (impounded by Big Bend Dam), was filled.

Final station selection and trend analysis periods were determined by maximizing the number of stations within multiple, selected analysis periods based on record availability. Stations were selected from the Missouri, upper Mississippi, Ohio, Arkansas, lower Mississippi, and Atchafalaya River Basins as shown in figure 1 and table 2 for trend analysis periods encompassing the last 60 years (1950–2009), the last 34 years (1976–2009), and the last 12 years (1998–2009) of available record. The multiple time periods used in trend analysis also provide a long-term context within which to view the more recent changes in streamflows and in the concentrations and loads of suspended sediment.

Determination of Annual Suspended-Sediment Loads

Annual SSLs and SSDLs described in this report refer to the suspended portion of transported sediment, and, therefore, do not include bedload. Bedload in large, low gradient rivers has been estimated to range from less than 5 percent (Holmes, 1996; Nittrouer and others, 2008) to 8 percent (Gaeuman and Jacobson, 2007) of the total sediment load.

The data for annual SSLs and suspended-sand loads (SSDLs) used in the analyses were obtained from preexisting USGS and USACE published or unpublished daily or annual loads, or were calculated specifically for this study using concentration and daily streamflow data. Sources of sediment load, sediment concentration, and streamflow data used in this study are provided by Heimann and others (2010) and Heimann and others (2011). Annual SSL and SSDL values were computed for this study using the LOADEST program and technique (Runkel and others, 2004). The S-LOADEST version of the program, written for the commercial statistical package TIBCO Spotfire S+ (TIBCO Software Inc., version 8.1), was used to compute load estimates as described by Heimann and others (2010). LOADEST incorporates explanatory variables of streamflow (a linear or quadratic relation), time (a linear or quadratic relation), and season into one of nine predefined regression models.

The analysis of trends in annual loads (and corresponding annual flow-weighted concentrations) can be problematic when the loads are estimated from a single model. In such situations, the estimated loads are not independent from one another and are likely to be less variable over time than the actual loads. As a result, the probability of a Type I error (false positive) in the subsequent test for trend is inflated (the probability of detecting a trend is inflated). In this study, a moving-window approach was used in the estimation of the annual LOADEST sediment loads to address these two issues. The load model for a given year was developed using 3, 5, or 7 years (determined by data availability) of suspended-sediment or suspended-sand concentration data centered about the computation year. For example, assuming a 3-year window, the model for the load estimate for 1975 used calibration data from 1974–1976; the model for the 1976 estimate used calibration data from 1975–1977; the model for the 1977 estimate used calibration data from 1976–1978; the model for the 1978 estimate used calibration data from 1977–1979, and so forth. Only those load estimates derived from unique calibration data sets were used in the trend analyses. In this example, estimates from every third year (1975, 1978, and so forth) were included. The calibration data set used in the computation of each of the annual loads included in statistical analyses was unique; no calibration data point was used in more than one window. As a result, the loads used in the trend analysis all were independent from one another. The use of unique models for each window also allowed the model coefficients to change over time, thereby incorporating variability in the relation between load and streamflow and season over time. As a result, the loads used in the trend analysis also were more variable over time than if they had been derived from a single model with fixed coefficients. The moving-window approach likely only partially addressed the variability issue; because the loads are modeled estimates, some of the variability present in actual loads may still be missing. Because data used in the computation of annual loads by the tabular day-by-day method (U.S. Army Corp of Engineers, 1976; Porterfield, 1977) and turbidity surrogate methods (Rasmussen and others, 2009) were from the year of computation, all annual loads computed using these methods were included in the statistical analyses.

To determine if trends in sediment loads could be affected by combining results from multiple sediment-load computation methods, annual loads within overlapping periods of published and calculated loads were compared. Computed (LOADEST) and published (day-by-day method) SSLs from seven stations with a total of 223 years of overlapping record were compared by station. When the same SSC data used in computing the published loads were used in the LOADEST computations, there were no statistically significant differences in the annual SSLs. The lack of significant difference was based on the Wilcoxon signed rank test (Helsel and Hirsch, 2002) using a significance level of 0.05. The probability

Table 2. U.S. Geological Survey (USGS) streamgaging stations in the Mississippi River Basin used in study.

[km², square kilometer]

Map reference number (fig. 1)	USGS station name	Period of available record	Drainage area (km²)	Trend analyses[a]
		Ohio River Basin		
1	Muskingum River at McConnelsville, Ohio	1979–91	19,223	--
2	Ohio River at Greenup Dam near Greenup, Kentucky	1974–85, 1997–2007	160,579	D, F
3	Scioto River at Higby, Ohio	1954–74, 1979–93	13,289	--
4	Kentucky River at Lock 2 at Lockport, Kentucky	1974–94	16,000	--
5	Ohio River at Cannelton Dam at Cannelton, Indiana	1976–86,1996–2009	251,229	D
6	Green River at Munfordville, Kentucky	1952–94, 2004–08	4,333	D
7	White River at Hazleton, Indiana	1974–84,1991–2009	29,280	D
8	Wabash River at New Harmony, Indiana	1975–86, 1997–2008	75,716	D
9	Tennessee River at Highway 60 near Paducah, Kentucky	1974–86, 1997–2009	104,454	D
10	Ohio River at Dam 53 Near Grand Chain, Illinois	1973–2009	526,027	D
		Upper Mississippi River Basin		
11	Minnesota River at Mankato, Minnesota	1968–2009	38,591	D, F
12	Wisconsin River at Muscoda, Wisconsin	1976–93	26,936	--
13	Mississippi River at Clinton, Iowa	1943–87, 1991–2009	221,703	D
14	Iowa River at Wapello, Iowa	1978–2009	32,375	D, F
15	Skunk River at Augusta, Iowa	1976–2009	11,168	D, F
16	Des Moines River near Saylorville, Iowa	1978–2004	15,128	--
17	Illinois River at Valley City, Illinois	1975–2009	69,264	D, F
18	Mississippi River below Grafton, Illinois	1975–2009	443,665	D, F
19	Mississippi River at Saint Louis, Missouri	1949–2009	1,805,222	A, B, D, F
20	Mississippi River at Chester, Illinois	1983–2009	1,835,266	F
21	Mississippi River at Thebes, Illinois	1983–2009	1,847,180	F
		Missouri River Basin		
22	Missouri River near Landusky, Montana	1949–51, 1959–62, 1964–65, 1969, 1971–2006	106,156	A, B, D, F
23	Yellowstone River near Sidney, Montana	1948–2009	178,924	A, B, D
24	Little Missouri River near Watford, North Dakota	1948–76	21,522	A
25	Missouri River at Yankton, South Dakota	1940–59, 1961–68, 2001–08	723,902	A
26	James River near Scotland, South Dakota	1975–95	53,491	--
27	Big Sioux River at Akron, Iowa	1941–51, 1971–94	21,818	A
28	Missouri River at Sioux City, Iowa	1955–2000, 2004–09	814,810	D, F
29	Boyer River at Logan, Iowa	1940–51, 1969–74, 2004–09	2,256	A
30	Missouri River at Omaha, Nebraska	1940–2009	836,048	A, B, D, F
31	Platte River at Louisville, Nebraska	1940–51, 1953–71, 1973–2009	221,107	A, B, D
32	Missouri River at Nebraska City, Nebraska	1958–2009	1,061,895	D, F
33	Nishnabotna River above Hamburg, Iowa	1940–51, 1982–93, 2004–09	7,268	A

Table 2. U.S. Geological Survey (USGS) streamgaging stations in the Mississippi River Basin used in study.—Continued

[km^2, square kilometer]

Map reference number (fig. 1)	USGS station name	Period of available record	Drainage area (km^2)	Trend analyses[a]
	Missouri River Basin—Continued			
34	Nodaway River at Clarinda, Iowa	1970–74, 1976–92	1,974	--
35	Missouri River at Saint Joseph, Missouri	1949–2009	1,104,630	A, B, C, D, E, F
36	Platte River at Sharps Station, Missouri	1980–92	6,164	--
37	Kansas River at DeSoto, Kansas	1949–74, 1976–91, 2000–05	154,767	A
38	Missouri River at Kansas City, Missouri	1949–81, 1988–2009	1,253,813	A, B, C, D, E
39	Grand River near Sumner, Missouri	1974–93	17,819	--
40	Chariton River near Prairie Hill, Missouri	1978–86	4,843	--
41	Osage River below Saint Thomas, Missouri	1975–94	37,772	--
42	Gasconade River at Jerome, Missouri	1978–92	7,356	--
43	Missouri River at Hermann, Missouri	1949–2009	1,353,269	A, B, C, D, E, F
	Arkansas River Basin			
44	Arkansas River at Tulsa, Oklahoma	1950–95	193,252	B
45	Arkansas River at David D. Terry Lock and Dam below Little Rock, Arkansas	1941–2009	410,329	B, D
	Lower Mississippi River Basin			
46	Mississippi River at Tarbert Landing, Mississippi	1950–2009	2,913,478	A, B, D, F
47	Old River Outflow Channel near Knox Landing, Louisiana	1966–2009	Indeterminate	D, F
48	Atchafalaya River at Simmesport, Louisiana	1952–2009	226,805[b]	B, D, F

[a] Analysis Categories:

A – Step trends in suspended sediment and suspended sand, pre-1953 and post-1967 periods
B – Trends in suspended sediment, 1950–2009
C – Trends in suspended sand, 1950–2004
D – Trends in suspended sediment, 1976–2009
E – Trends in suspended sand, 1975–2004
F – Trends in suspended sediment 1998–2009

[b] Drainage area does not include that area apportioned to the river based on the fraction of streamflow diverted from the Mississippi River main stem.

values of the comparison tests (0.07–1.0) exceeded the significance level of 0.05 indicating that the chances the differences between the distributions were not true were greater than the specified significance level. Therefore, the LOADEST moving window approach allowed for the use of independent, annual SSL estimates in determining trends in loads and produced annual loads that were statistically comparable to previously published values.

Trend Analyses

Temporal changes in streamflow and suspended-sediment loads and concentrations were assessed using statistical analyses of step trends (test to determine if median differences between data values for two time periods are significantly different than zero), statistical analyses of monotonic trends (test to determine if the average rate of change of the data for a specified time period is significantly different than zero), and qualitative presentations of temporal relations. Such analyses provide an indication of the magnitude and direction of changes in sediment transport characteristics and streamflows at specific stations that, when taken collectively, can explain net changes in transport on a basin scale.

Step Trends

Step-trend analyses were conducted on the annual SSL, flow-weighted (FW) SSC (the ratio of the annual sediment load and annual streamflow, expressed in milligrams per liter), and streamflow data to identify and evaluate the effects of the construction of main-stem Missouri River impoundments and other land-use and channel modifications in the Missouri River Basin, on suspended-sediment transport characteristics at selected stations in the Missouri and lower Mississippi Rivers. A step-trend approach was selected because the impoundment completion dates were well defined (table 1) and spanned a relatively short time period. Similar step-trend analyses were not made with data for the remaining major subbasins of the Mississippi River Basin because the sediment-altering event was not well defined, available pre-event sediment data were limited, or the sediment-altering event predated the available sediment record entirely. The step trends in SSLs, FW SSCs, and streamflows were determined for the periods corresponding to pre- and post-Missouri River main-stem impoundment construction. The statistical comparison of the sediment and streamflow data for the pre- and post-impoundment periods was conducted using a Wilcoxon Rank Sum test at a significance level of 0.05. Whereas the Missouri River impoundments would directly affect only the Missouri and downstream Mississippi River main-stem stations, Missouri River tributary stations with available record also were included in the step-trend analyses to assess the occurrence and magnitude of secondary factors (for example, tributary impoundments or implementation of conservation practices) on sediment transport during the analysis periods.

Monotonic Trends and Qualitative Temporal Variations in Suspended-Sediment Loads, Concentrations, and Streamflow

Monotonic trends (increases or decreases without reversals) in SSL, FW SSC, and streamflow data were determined for selected stations and for three trend periods—1950–2009, 1976–2009, and 1998–2009— using the Mann-Kendall test (Mann, 1945; Kendall, 1975) at a significance level of 0.05 and Sen slope estimates (Sen, 1968) within the TIBCO Spotfire S+ (TIBCO Software Inc., version 8.1) statistical package. The computed Kendall rank correlation coefficients (Kendall's tau) range from 1 to -1 with a value of 1 indicating the ranking of the two variables are the same, a value of -1 indicating the rankings are the reverse of each other, and a value of 0 indicating the absence of association. Only stations with a minimum of seven annual load, concentration, and streamflow values spanning the trend period were used in the analyses.

Monotonic trends in SSDL, FW SSDC (the ratio of the annual sand load and annual streamflow, expressed in milligrams per liter), and SSDL percentage of SSL data were computed for three stations with available continuous sand-fraction record including the Missouri River at Saint Joseph, at Kansas City, and at Hermann, Missouri. Trends were computed for two periods—1950–2004 and 1976–2004—using the Mann-Kendall test and Sen slope estimates.

Qualitative temporal variations in annual SSL and SSDL and flow-adjusted (FA) SSC (the positive and negative residuals of SSC values, expressed in milligrams per liter, resulting from a linear regression model of observed streamflow and SSC pairs) and FA SSDC (the positive and negative residuals of SSDC, expressed in milligrams per liter, resulting from a linear regression model of observed streamflow and SSDC pairs) data also were assessed using locally estimated scatterplot smoothing (LOESS) curves (Cleveland and Devlin, 1988). Qualitative temporal relations in FA concentrations were determined to evaluate the changes in SSC (for the 1950–2009, 1976–2009, and 1998–2009 periods) and SSDCs (for the 1950–2004 and 1976–2004 periods) resulting from effects other than changes in flow. These effects were determined by calculating the residuals of streamflow–sediment concentration regression models developed using the observed streamflow and concentration data for the entire trend-analysis period at a station. A LOESS curve then was fit to the positive and negative residuals of the models to qualitatively assess changes in the FA concentrations with time.

Suspended-Sediment Trends In The Mississippi River Basin

The relative sediment contributions from and within each major Mississippi River subbasin including the Missouri, Ohio, upper Mississippi and lower Mississippi River Basins were computed. The temporal trends and qualitative temporal relations in sediment characteristics and streamflow were then assessed at multiple selected stations and for multiple time periods.

Relative Sediment Contributions from Mississippi River Subbasins

During the period 1976 through 2009, of the four primary contributing subbasins to the lower Mississippi River, the Missouri River provided the greatest median suspended-sediment load (56.9 Mt/yr (million metric tons per year)) followed by the Ohio (32.5 Mt/yr), upper Mississippi (22.5 Mt/yr), and Arkansas Rivers (2.4 Mt/yr). The Missouri River provided the largest annual SSLs during 26 of the 34 years analyzed and the Ohio River transported the largest annual SSLs during the remaining 8 years (fig. 2). The large sediment contributions of the Missouri River to the lower Mississippi River have been well documented (Keown and others, 1981; Meade and Parker, 1985; Meade and others, 1990; Meade and Moody, 2010) and overall, sediment transport in the lower Mississippi River is most closely correlative with the contributions of suspended sediment from the Missouri River Basin.

Annual SSLs were computed for gaged tributary streams within the Missouri, Ohio, and upper Mississippi Basins to further determine major sediment-contributing sources within the subbasins. SSLs were computed for 12 primary Missouri River tributary stations for the period 1975–91. The Grand River near Sumner, Missouri had the largest median annual

SSL (10.8 Mt) and the next largest sediment contributors were the Platte River at Louisville, Nebraska (9.6 Mt), and Yellowstone River at Sidney, Montana ((9.0 Mt) (table 3). The median load from these tributary rivers represented 14-16 percent of the 1975–91 median load of the Missouri River at Hermann, Missouri. Such comparisons are not meant to imply that all sediment transported from the tributary stations will pass the outlet station in a continuous manner because the sediment may be temporarily deposited or "trapped", in this case, in intervening navigation dams, and sediment likely is transported episodically between the stations.

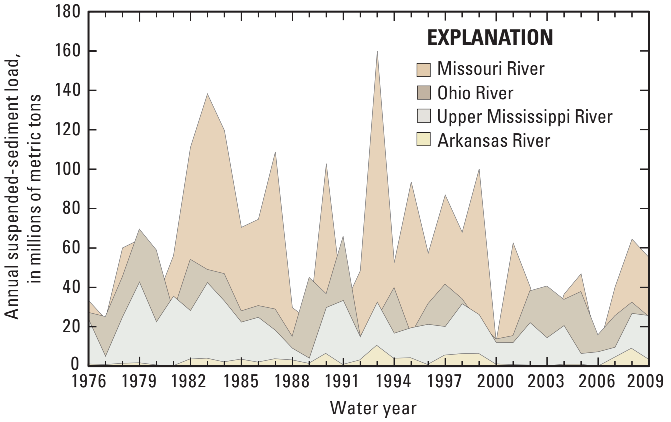


Figure 2. Annual suspended-sediment loads of the Missouri, Ohio, upper Mississippi, and Arkansas Rivers, 1976–2009.

Data from six gaged Ohio River tributary stations were analyzed for sediment load contributions during the record period of 1979–86. The Wabash River, with a median annual load of 11.5 Mt, provided the largest sediment contribution to the Ohio River (table 3). The Wabash River accounted for about 23 percent of the sediment load of the Ohio River at Grand Chain, Illinois, whereas the next largest contributors (Tennessee and Muskingum Rivers) each accounted for about 2 percent of the total Ohio River sediment load.

Analyses of records of sediment contributions from five, gaged, upper Mississippi River tributary stations for the 1978–93 period indicated that the Illinois River at Valley City, Illinois was the largest sediment contributor (table 3). The median annual sediment load of 5.9 Mt was about 22 percent of the upper Mississippi River Basin suspended-sediment load during the period. The Iowa River at Wapello, Iowa (2.9 Mt), and Skunk River at Augusta, Iowa (2.6 Mt), each accounted for more than 8 percent of the median annual SSL at the upper Mississippi River outlet station at Grafton, Illinois.

All four major subbasins contributing sediment to the lower Mississippi River have main-stem and tributary structures that retard sediment transport and increase the relative contributions of sediment from tributaries downstream from primary channel control structures. Of the 22 gaged major tributary basins included in the sediment contribution analyses, 15 were impounded by major structures on their main stems (table 3).

The largest contributor of suspended sand to the lower Missouri River between 1981 and 1991 was estimated to be the main-stem reach from the Gavins Point Dam, South Dakota, to Sioux City, Iowa, followed by contributions from the Platte River in Nebraska (table 4). Much of the transported suspended sand in the Gavins Point to Sioux City reach likely is from scour of the main channel as the SSDL increased from near zero in Gavins Point Dam outflows (Paul Boyd, U.S. Army Corp of Engineers, personal commun., 2011) at Yankton, South Dakota, to 6.36 Mt/yr at Sioux City, Iowa (table 4), about 122 km downstream, with little or no input from the small interim tributaries. SSDL estimates for the Platte River near Louisville, Nebraska, station were about 4.6 Mt/yr. The 6.36 Mt/yr estimated SSDL from channel scour, along with the 4.6 Mt/yr estimate contribution from the Platte River, alone account for about 50 percent of the 19.7 Mt/yr median SSDL at Hermann, Missouri. If additional potential diversions that substantially reduce flows take place in the Platte River (Sidle and Faanes, 1997) there likely will be a substantial reduction in SSDLs from this primary tributary. About 3.0 Mt/yr (on average) of sand were contributed to the Missouri River from tributaries between Kansas City and Hermann, Missouri, with the Grand River near Sumner, Missouri, and Chariton River near Prairie Hill, Missouri, stations having estimated median SSDLs in excess of 1.2 Mt/yr.

The longitudinal gradient in Missouri River sand transport is evident in the results as the 1981–91 median sand load as a percentage of total load decreased from 62 percent at the Missouri River at Sioux City, Iowa, station to 25 percent at the Missouri River at Hermann, Missouri (table 4). Reported sand fractions of total loads during 1981–91 at the Mississippi River at Tarbert Landing, Mississippi, were 15 percent (U.S. Army Corp of Engineers, New Orleans District, unpub. data, 1950–2006).

Step Trends

Results of step-trend analyses to examine changes in annual SSLs, SSDLs, FW SSCs, FW SSDCs, and streamflows between the pre-and post-Missouri River main-stem impoundment periods indicated decreases in SSLs and SSCs at most stations. Significant (Wilcoxon Rank Sum test, p <0.001–0.042) decreases in SSLs were determined at all stations except one Missouri River main-stem station upstream from the impoundments and one Missouri River tributary station (table 5). Differences in pre- and post-impoundment SSLs could not be explained simply by corresponding differences in flows as changes in flows between the two periods generally were not statistically different (table 5).

The greatest difference in median SSLs between the two periods (-99.8 percent) was recorded at the Missouri River at Yankton, South Dakota, about 8 km downstream from Gavins Point Dam. The difference of about 126 Mt between

Table 3. Summary of contributions of suspended-sediment loads from gaged tributaries to major subbasins of the lower Mississippi River Basin.

[SSL, suspended-sediment load; SSC, suspended-sediment concentration; mg/L, milligrams per liter; km^2, square kilometer; m^3/s, cubic meters per second]

USGS station name	Map reference number (fig. 1)	Median-annual SSL (metric tons)	Percent of basin outlet gaging station sediment load[a]	Median annual flow-weighted SSC (mg/L)	Median-annual yield (metric tons/km^2)	Median-annual streamflow (m^3/s)
			Ohio River Basin 1979–86			
Muskingum River at McConnelsville, Ohio	1	986,000	2.2	124	51.3	263
Scioto River at Higby, Ohio[b]	3	935,000	1.9	216	70.4	140
Kentucky River at Lock 2 at Lockport, Kentucky[b]	4	741,000	1.6	112	46.3	203
Green River at Munfordville, Kentucky[b]	6	486,000	1.1	188	112	81.5
Wabash River at New Harmony, Indiana[b]	8	11,500,000	22.6	372	152	967
Tennessee River at Highway 60 near Paducah, Kentucky[b]	9	1,140,000	2.1	19.0	10.9	1,850
			Upper Mississippi River Basin 1978–93			
Minnesota River at Mankato, Minnesota	11	1,120,000	4.6	314	29.0	126
Wisconsin River at Muscoda, Wisconsin[b]	12	294,000	1.4	43.3	10.9	271
Iowa River at Wapello, Iowa[b]	14	2,890,000	8.2	285	89.3	296
Skunk River at Augusta, Iowa[b]	15	2,580,000	8.8	909	231	99.0
Illinois River at Valley City, Illinois[b]	17	5,910,000	22.2	317	85.3	765
			Missouri River Basin 1975–91			
Yellowstone River near Sidney, Montana	23	9,020,000	16.0	901	50.4	347
James River near Scotland, South Dakota[b]	26	36,800	.1	151	.69	7.72
Big Sioux River at Akron, Iowa	27	334,000	.6	390	15.3	22.5
Platte River at Louisville, Nebraska[b]	31	9,600,000	13.8	1,270	43.4	166
Nishnabotna River above Hamburg, Iowa[b]	33	4,540,000	6.4	3,490	625	46.5
Nodaway River at Clarinda, Iowa	34	2,220,000	3.2	5,160	1,130	9.85
Platte River at Sharps Station, Missouri[b,d]	36	1,480,000	2.2	1,710	239	34.8
Kansas River at DeSoto, Kansas[b]	37	5,970,000	11.7	1,160	38.6	180
Grand River near Sumner, Missouri	39	10,800,000	16.0	2,820	604	123
Chariton River near Prairie Hill, Missouri[b,e]	40	2,690,000	4.0	1,820	555	67.9
Osage River below Saint Thomas, Missouri[b]	41	583,000	1.0	66.8	15.4	328
Gasconade River at Jerome, Missouri[c]	42	165,000	.2	65.9	22.5	81.6

[a] Outlet gage for the Ohio River is the Ohio River at Grand Chain, Illinois; upper Mississippi River is the Mississippi River at Grafton, Illinois; and the Missouri River is the Missouri River at Hermann, Missouri.

[b] Main-stem upstream from gaging station is controlled by at least one permanent impoundment.

[c] 1982–91 median.

[d] 1980–91 median.

[e] 1989–91 median.

Table 4. Median annual suspended-sand loads at selected Missouri River Basin streamgaging stations, 1981–91.

[--, not applicable]

USGS station name	Map reference number (fig. 1)	Median annual suspended-sand load 1981–91	Median annual interim load[a] 1981–91 (metric ton)	Median annual percent suspended-sand	Probable source of interim suspended-sand load contributions
Yellowstone River near Sidney, Montana	23	1,620,000	--	16.0	--
Gavins Point Dam, South Dakota	--	--	--	--	--
	--	--	6,360,000	--	Main-stem channel, James, Big Sioux Rivers
Missouri River at Sioux City, Iowa	28	6,360,000	--	62.0	
		--	2,260,000	--	Little Sioux, Boyer Rivers
Missouri River at Omaha, Nebraska	30	8,630,000	--	55.3	--
Platte River at Louisville, Nebraska	31	4,590,000	--	--	--
			--	--	--
Missouri River at Nebraska City, Nebraska	32	11,100,000	--	48.1	--
	--	--	1,500,000	--	Nishnabotna, Nodaway Rivers
Missouri River at Saint Joseph, Missouri	35	11,000,000	--	34.5	--
Platte River at Sharps Station, Missouri	36	160,000	--	5.7	--
	--	--	870,000[b]	--	Kansas River
Missouri River at Kansas City, Missouri	38	8,390,000[b]	--	32.2[b]	--
Grand River near Sumner, Missouri	39	1,230,000	--	15.5	--
Chariton River near Prairie Hill, Missouri	40	1,260,000[c]	--	40.2[c]	--
Osage River below Saint Thomas, Missouri	41	154,000	--	41.3	--
Gasconade River at Jerome, Missouri	42	36,400	--	26.0	--
	--	--	2,970,000[b]	--	--
Missouri River at Hermann, Missouri	43	19,700,000	--	25.1	--

[a] Median difference between main-stem stations (shown in bold).

[b] 1981, 1988–91 median.

[c] 1981–86 median.

the pre-1953 and post-1967 periods at this station provides a median annual estimate of sediment trapped by the upstream reservoirs. This represents about 56 percent of the 224 Mt post-impoundment median annual "deficit" at Hermann, Missouri. The remaining 98 Mt, or 44 percent, of the Hermann load reduction can be attributed to other factors including reductions in sediment from tributaries. Although the stations on the Missouri River near Landusky, Montana, and the Yellowstone River near Sydney, Montana, are upstream from the impoundments, the post-impoundment values of SSL and SSC at the stations showed reductions from pre-impoundment values of about 50 percent. The most likely cause for the reduction in sediment transport in these tributaries/reaches is trapping of sediment by impoundments as there is little (<8 percent) cropland agriculture in these basins (Zelt and others, 1999; U.S. Department of Agriculture, 2009). Similarly, the SSL values for the Kansas River at Desoto, Kansas, showed an 89 percent reduction in SSLs between the two periods as

11 major reservoirs were completed in this basin between 1953 and 1967 (U.S. Army Corp of Engineers, 2009a). Records from only five tributaries to the lower Missouri River were sufficient to be included in the step-trend analysis, but the median reduction in SSLs from these tributaries alone was about 69 Mt/yr or 70 percent of the remaining 98 Mt/yr load reduction at Hermann, Missouri. About 47 percent of the post-1967 SSL reduction of the lower Mississippi River (Mississippi River at Tarbert Landing, Mississippi, and the Atchafalaya River at Simmesport, Louisiana) could be accounted for by post-impoundment reductions from the Missouri River at Hermann, Missouri.

Post-impoundment Mississippi River SSDLs were significantly lower than pre-impoundment values at the Mississippi River at Tarbert Landing, Mississippi (table 5), although the decline in sand loads (-55 percent) and FW SSDCs (-55 percent) were not as great as the decline in SSLs (-73 percent) and FW SSCs (-65 percent). Declines in post-impoundment sand loads and concentration also were less than corresponding declines in total loads and concentrations at the Missouri River at Saint Joseph, Kansas City, and Hermann.

Corresponding differences in pre- and post-impoundment distributions of FW SSCs were significant at most stations, whereas differences in the distributions of streamflow were not significant at most stations (table 5). Decreases in median values of FW SSCs ranged from 29 to more than 99 percent, with the largest decline again at the Missouri River at the Yankton, South Dakota station. Changes in annual streamflows during these periods were significant at only 4 of the 15 stations listed in table 5.

Monotonic Trends and Qualitative Temporal Relations

Monotonic trends and qualitative temporal relations were determined for suspended-sediment and streamflow data for the last 60 years of available record (1950–2009), 34 years (1976–2009) and 12 years (1998–2009). Similarly, monotonic trends and qualitative temporal relations for suspended-sand concentrations and loads were determined for the last 55 years of available record (1950–2004) and 29 years (1976–2004).

Suspended Sediment 1950–2009

By 1950, some channel modifications or navigation structures already were in place, or in progress, in all major subbasins of the Mississippi River Basin, but most of the main-stem Missouri River impoundments and Arkansas River Basin navigation structures and reservoirs had yet to be constructed. Also, land-conservation practices were in place because of the passage of the Soil Conservation Act of 1935 (Steiner, 1987). The 1950s and 1960s were a channel-modification period in the Missouri, Arkansas, and lower Mississippi Rivers.

The results of the trend analyses of data for the period 1950 through 2009 indicate that downward trends in SSLs and FW SSCs were widespread throughout the Missouri and lower Mississippi River Basin main-stem stations. There were significant (Mann-Kendall test; p <0.001–0.032) downward trends in SSLs and FW SSCs at most stations (fig. 3*A*, 3*B,* table 6). Downward trends in SSLs were significant at all stations within the Missouri and lower Mississippi River subbasins but not at the representative stations within the upper Mississippi, Ohio, or Arkansas River subbasins. Cumulative reductions in sediment transport in the Missouri and lower Mississippi Rivers resulted in an overall reduction of about -1.3 percent/yr at the Mississippi River at Tarbert Landing, Mississippi, and -1.8 percent/yr at the Atchafalaya River at Simmesport, Louisiana, over the 60-year period. Downward trends in FW SSCs were significant at all but one upper Missouri River station (fig. 3*B*, table 6). Median slopes in streamflow temporal changes generally were upward, with significant trends in streamflow detected at about one-half of the stations (fig. 3*C*, table 6).

Decreasing SSLs, despite concurrent increases in streamflow indicate, at most stations, that sediment declines can be explained by a decline in source material. Abrupt declines in suspended sediment in the Missouri River as a result of impoundments on the upper Missouri River have been well documented (Keown and others, 1981; Meade and others*,* 1990; Meade 1995; Jacobson and others*,* 2009; National Resource Council, 2011) as has the resulting effects of these reduced contributions at downstream Mississippi River stations (Keown and others, 1986; Kesel, 1988; Mossa, 1996). Kesel (1988) notes estimated declines in SSLs in the lower Mississippi River between 1850 and 1952 of about 25 percent; therefore, pre-dam SSLs likely represent declines from earlier transport conditions but are still greater than presettlement conditions (Knox, 1977). Even the earliest pre-impoundment record used in the trend analyses made here was collected following the closing of the Fort Peck Dam in 1937 and following early channel modifications on the Missouri, Ohio, upper Mississippi and lower Mississippi Rivers. Temporal variations in annual SSLs indicated that the Missouri River impoundments accounted for the most abrupt declines during the 1950–2009 period, and the effects of reduced contributions from the Arkansas River in the mid-1960s also are evident in SSLs at the Mississippi River at Tarbert Landing, Mississippi. The steady declines in SSLs at lower Mississippi River stations that followed the 1953 declines from the Missouri River and mid-1960s declines from the Arkansas River are not as easily explained. Other factors that have been cited as contributing to the reduction of SSLs in the Mississippi River Basin, in addition to the closing of Missouri main-stem impoundments, include the decreases in sediment contributions from the Missouri River tributaries (Meade and Moody, 2010), depletion of stored sediments in the system (Knox, 1977, 1987; Trimble, 1983; Beach, 1994; Meade and Moody, 2010), and implementation of conservation measures throughout the Mississippi River Basin (Knox, 1977; Meade and

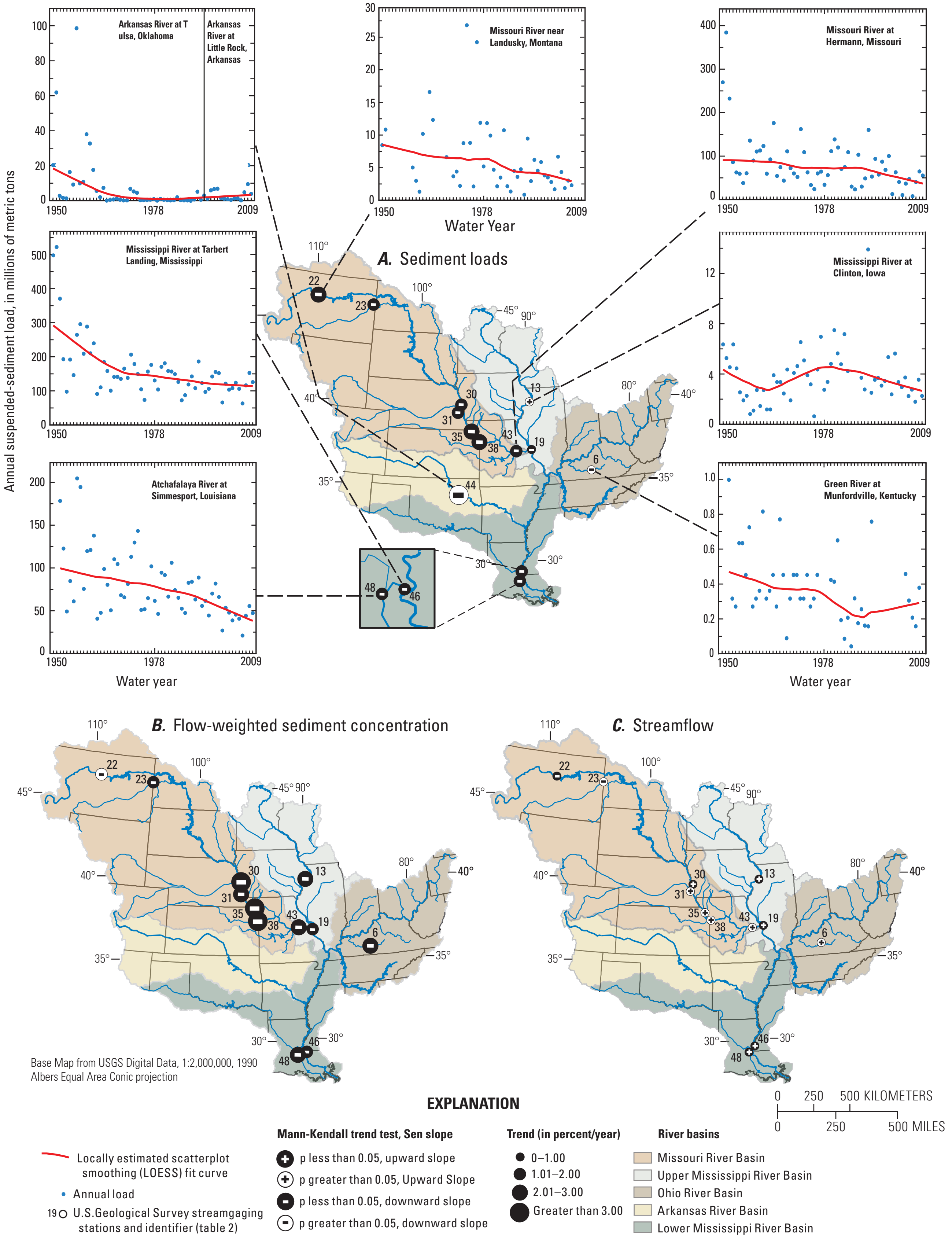


Figure 3. Summary of trends in annual suspended-sediment loads, flow-weighted concentrations, and streamflows at selected U.S. Geological Survey streamgaging stations in the Mississippi River Basin, 1950–2009.

Table 5. Summary of step-trend analyses of suspended-sediment characteristics and streamflows for pre- (pre-1953) and post-Missouri River main-stem impoundment (post-1967) periods at selected Missouri River and lower Mississippi River Basin stations.

[SSL, suspended–sediment load; *SSDL*, suspended-sand load; FW SSC, flow-weighted suspended-sediment concentration; FW *SSDC*, flow-weighted suspended-sand concentration mg/L, milligrams per liter; p-value, statistical probability level; m^3/s, cubic meters per second; <, less than; --, not computed]

USGS station name	Map reference number (fig. 1)	Number of values used in analysis		Median annual SSL, *SSDL* (metric tons)			Change in SSL, *SSDL* (percent)
		pre-1953	post-1967	pre-1953	post-1967	p-value	
Mississippi River at Saint Louis, Missouri	19	4	42	**278,000,000**[a]	**91,100,000**	**<0.001**	-67.2
Missouri River near Landusky, Montana	22	3	37	8,440,000	4,400,000	1.00	-47.8
Yellowstone River near Sidney, Montana	23	5	16	**21,600,000**	**13,000,000**	**.015**	-39.8
Little Missouri River near Watford, North Dakota	24	4	9	6,714,000	6,829,000	.825	1.71
Missouri River at Yankton, South Dakota	25	13	4	**126,000,000**	**233,000**	**<.001**	-99.8
Big Sioux River at Akron, Iowa	27	11	5	**1,060,000**	**461,000**	**.038**	-56.5
Boyer River at Logan, Iowa	29	12	8	**9,010,000**	**989,000**	**<.001**	-89.0
Missouri River at Omaha, Nebraska	30	13	24	**143,000,000**	**17,300,000**	**<.001**	-87.9
Platte River at Louisville, Nebraska	31	12	16	**14,600,000**	**7,230,000**	**.042**	-50.5
Nishnabotna River above Hamburg, Iowa	33	12	4	**10,200,000**	**2,960,000**	**.008**	-71.0
Missouri River at Saint Joseph, Missouri	35	4	26	**215,000,000**	**33,900,000**	**<.001**	-84.2
		3	31	*52,200,000*	*11,000,000*	--	*-78.9*
Kansas River at DeSoto, Kansas	37	4	18	**51,200,000**	**5,550,000**	**.001**	-89.2
Missouri River at Kansas City, Missouri	38	4	21	**261,000,000**	**48,400,000**	**<.001**	-81.5
		4	27	*45,700,000*	*12,900,000*	--	*-71.8*
Missouri River at Hermann, Missouri	43	4	26	**284,000,000**	**60,200,000**	**<.001**	-78.8
		3	42	*62,800,000*	*19,000,000*	--	*-69.7*
Mississippi River at Tarbert Landing, Mississippi	46	3	42	**497,000,000**	**133,000,000**	**<.001**	-73.2
		3	39	*67,000,000*	*29,900,000*	*.004*	*-55.4*
Atchafalaya River at Simmesport, Louisiana	48	1	42	**178,000,000**	**64,900,000**	**--**	-61.1
		1	39	*44,400,000*	*15,200,000*	--	*-65.8*

USGS station name	Map reference number (fig. 1)	Median FW SSC, *SSDC* (mg/L)			Change in FW SSC, *SSDC* (percent)	Annual median streamflow (m^3/s)			Change in flow (percent)
		pre-1953	post-1967	p-value		pre-1953	post-1967	p-value	
Mississippi River at Saint Louis, Missouri	19	**1,650**	**492**	**<0.001**	-70.2	6,120	5,920	0.807	-3.27
Missouri River near Landusky, Montana	22	984	694	1.00	-29.5	294	261	.750	-4.51
Yellowstone River near Sidney, Montana	23	**1,880**	**994**	**<.001**	-47.1	370	363	.780	-1.89
Little Missouri River near Watford, North Dakota	24	8,000	11,100	.199	38.8	24.1	12.8	.699	-46.9
Missouri River at Yankton, South Dakota	25	**4,170**	**13.8**	**<.001**	-99.7	**937**	**557**	**.045**	-40.6
Big Sioux River at Akron, Iowa	27	**968**	**390**	**.006**	-59.7	33.2	41.9	.827	26.3
Boyer River at Logan, Iowa	29	**29,900**	**2,020**	**<.001**	-93.2	8.42	11.0	.427	30.6
Missouri River at Omaha, Nebraska	30	**4,520**	**521**	**<.001**	-88.5	1,030	1,010	.938	-1.94
Platte River at Louisville, Nebraska	31	**2,950**	**1,330**	**<.001**	-54.9	**150**	**197**	**.037**	31.6
Nishnabotna River above Hamburg, Iowa	33	**11,500**	**1,990**	**.001**	-82.7	31.1	47.2	.521	51.6
Missouri River at, St. Joseph, Missouri	35	**4,960**	**791**	**<.001**	-84.1	1,560	1,290	.108	-17.3
		999	*246*	--	-75.4	--	--	--	--
Kansas River at DeSoto, Kansas	37	**5,500**	**1,050**	**<.001**	-80.9	**297**	**169**	**.042**	-43.1
Missouri River at Kansas City, Missouri	38	**4,840**	**873**	**<.001**	-82.0	**1,910**	**1,490**	**.047**	-22.0
		732	*246*	--	-66.4	--	--	--	--
Missouri River at Hermann, Missouri	43	**3,190**	**791**	**<.001**	-75.2	2,800	2,400	.170	-14.3
		566	*213*	--	-62.4	--	--	--	--
Mississippi River at Tarbert Landing, Mississippi	46	**832**	**289**	**<.001**	-65.3	17,400	14,700	.122	-15.5
		137	**61.6**	**.003**	-55.0	--	--	--	--
Atchafalaya River at Simmesport, Louisiana	48	**907**	**334**	**--**	-63.2	6,250	6,530	--	4.48
		226	*72.6*	--	-67.9	--	--	--	--

[a] Values in bold are statistically significant ($p<0.05$).

[b] Record from 1949–68 from Missouri River near Power Plant Ferry, Montana and from 1969–71 from Missouri River at Robinson Bridge near Landusky, Montana.

Table 6. Summary of analyses of monotonic trends in annual suspended-sediment loads, flow-weighted concentrations, and streamflows between 1950 and 2009 at selected Mississippi River Basin streamgaging stations.

[p-value, statistical probability level; mg/L, milligrams per liter; <, less than; yr, year; m^3/s, cubic meter per second]

USGS station name	Map reference number (fig. 1)	Number of values used in analysis	Suspended-sediment loads				Trend[b] (in percent/yr)
			Mann-Kendall tau	p-value	Sen slope (metric tons/yr)	Median (metric tons)	
Green River at Munfordville, Kentucky	6	33	-0.227	0.062	-3,520	363,000	-0.97
Mississippi River at Clinton, Iowa	13	40	.076	.499	12,100	3,360,000	.36
Mississippi River at Saint Louis, Missouri	19	60	**-.190**[a]	**.032**	**-791,000**	**91,500,000**	-.86
Missouri River near Landusky, Montana	22	45	**-.271**	**.009**	**-103,000**	**4,530,000**	-2.27
Yellowstone River near Sidney, Montana	23	34	**-.305**	**.012**	**-236,000**	**15,200,000**	-1.55
Missouri River at Omaha, Nebraska	30	42	**-.524**	**<.001**	**-422,000**	**23,300,000**	-1.81
Platte River at Louisville, Nebraska	31	33	**-.311**	**.012**	**-169,000**	**8,910,000**	-1.90
Missouri River at Saint Joseph, Missouri	35	39	**-.457**	**<.001**	**-829,000**	**37,300,000**	-2.22
Missouri River at Kansas City, Missouri	38	44	**-.439**	**<.001**	**-1,380,000**	**56,500,000**	-2.44
Missouri River at Hermann, Missouri	43	44	**-.332**	**.002**	**-1,170,000**	**63,600,000**	-1.84
Arkansas River at Tulsa, Oklahoma[c]	44	20	-.232	.163	-46,300	1,390,000	-3.33
Mississippi River at Tarbert Landing, Mississippi	46	60	**-.401**	**<.001**	**-1,890,000**	**142,000,000**	-1.33
Atchafalaya River at Simmesport, Louisiana	48	58	**-.412**	**<.001**	**-1,170,000**	**66,200,000**	-1.77

USGS station name	Map reference number	Number of values used in analysis	Flow-weighted suspended-sediment concentrations				Trend[b] (in percent/yr)
			Mann-Kendall tau	p-value	Sen slope ((mg/L)/yr)	Median (mg/L)	
Green River at Munfordville, Kentucky	6	33	**-0.591**	**<0.001**	**-3.74**	**167**	-2.24
Mississippi River at Clinton, Iowa	13	40	**-.699**	**<.001**	**-8.76**	**362**	-2.42
Mississippi River at Saint Louis, Missouri	19	60	**-.513**	**<.001**	**-8.50**	**538**	-1.58
Missouri River near Landusky, Montana	22	45	-.164	.115	-6.41	572	-1.12
Yellowstone River near Sidney, Montana	23	34	**-.401**	**<.001**	**-22.5**	**1,360**	-1.65
Missouri River at Omaha, Nebraska	30	42	**-.738**	**<.001**	**-23.2**	**765**	-3.03
Platte River at Louisville, Nebraska	31	33	**-.468**	**<.001**	**-43.6**	**1,812**	-2.41
Missouri River at Saint Joseph, Missouri	35	39	**-.605**	**<.001**	**-33.4**	**1,050**	-3.18
Missouri River at Kansas City, Missouri	38	44	**-.644**	**<.001**	**-41.7**	**1,220**	-3.42
Missouri River at Hermann, Missouri	43	44	**-.643**	**<.001**	**-27.4**	**993**	-2.76
Arkansas River at Tulsa, Oklahoma	44	20	**-.558**	**<.001**	**-13.7**	**97.6**	-14.00
Mississippi River at Tarbert Landing, Mississippi	46	60	**-.666**	**<.001**	**-5.74**	**313**	-1.84
Atchafalaya River at Simmesport, Louisiana	48	58	**-.699**	**<.001**	**-8.76**	**362**	-2.42

USGS station name	Map reference number	Number of values used in analysis	Streamflow				Trend[b] (in percent/yr)
			Mann-Kendall tau	p-value	Sen slope ((m^3/s)/yr)	Median (m^3/s)	
Green River at Munfordville, Kentucky	6	33	0.138	0.260	0.375	78.2	0.48
Mississippi River at Clinton, Iowa	13	40	**.280**	**.011**	**9.26**	**1440**	.64
Mississippi River at Saint Louis, Missouri	19	60	**.197**	**.027**	**30.0**	**5,410**	.55
Missouri River near Landusky, Montana	22	45	**-.337**	**.001**	**-2.51**	**267**	-.94
Yellowstone River near Sidney, Montana	23	34	-.034	.790	-.425	360	-.12
Missouri River at Omaha, Nebraska	30	42	**.228**	**.035**	**4.36**	**866**	.50
Platte River at Louisville, Nebraska	31	33	.141	.263	.716	168	.43
Missouri River at Saint Joseph, Missouri	35	39	.197	.061	5.12	1,130	.45
Missouri River at Kansas City, Missouri	38	44	.169	.134	6.55	1,410	.46
Missouri River at Hermann, Missouri	43	44	.200	.057	14.4	2,220	.65
Arkansas River at Tulsa, Oklahoma	44	20	--	--	--	--	--
Mississippi River at Tarbert Landing, Mississippi	46	60	**.199**	**.025**	**62.2**	**14,000**	.44
Atchafalaya River at Simmesport, Louisiana	48	58	**.233**	**.010**	**30.3**	**6,060**	.50

[a] Values in bold are statistically significant (p<0.05).

[b] Trend in percent/yr is calculated as the ratio of the Sen slope and median constituent values.

[c] Sediment load and record information from Arkansas River at Tulsa, Oklahoma from 1951 through 1993 and from Arkansas River at Little Rock, Arkansas from 1994 through 2006.

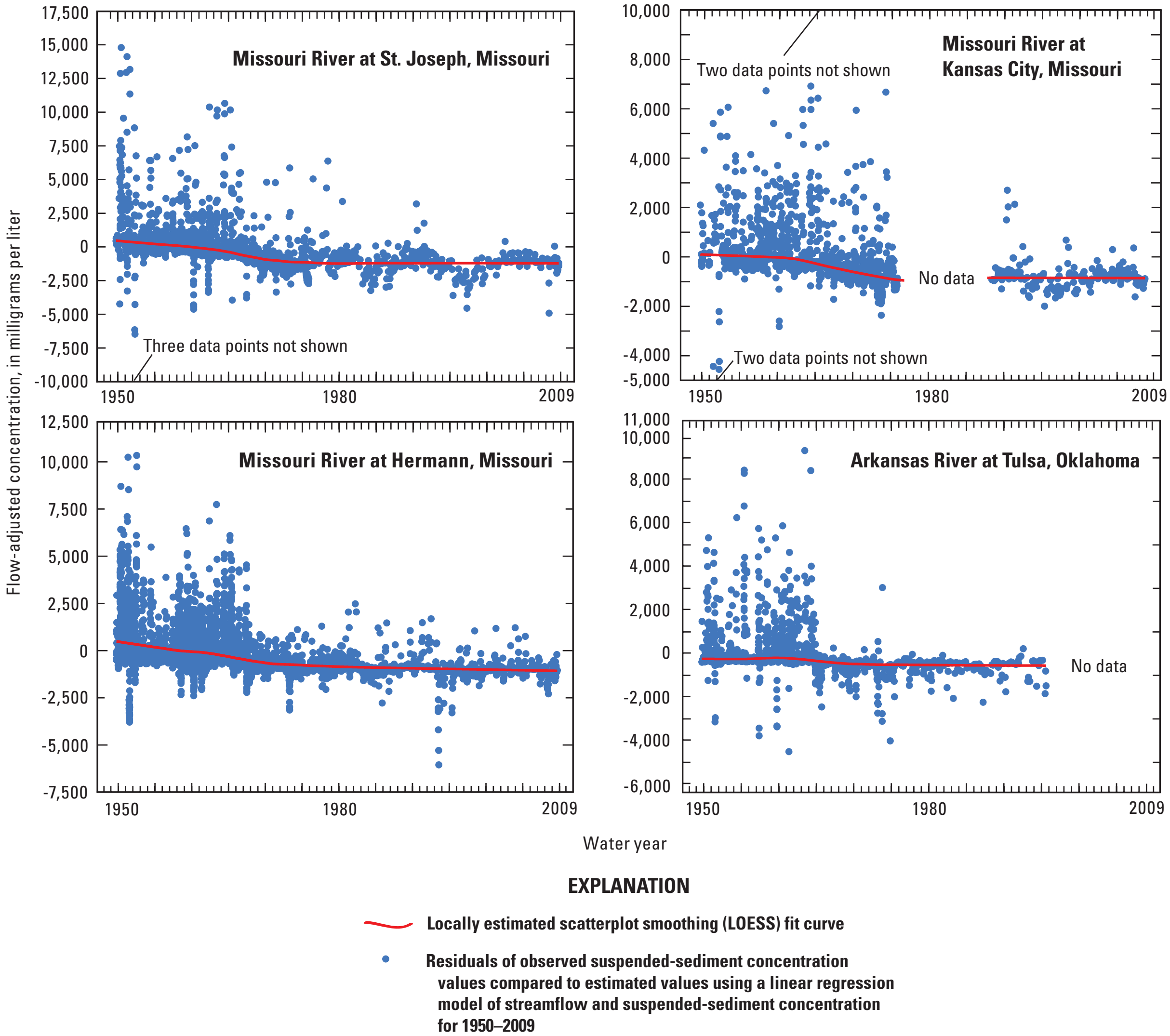


Figure 4. Summary of temporal variations in flow-adjusted concentrations for selected U.S. Geological Survey streamgaging stations in the Mississippi River Basin, 1950–2009.

Moody, 2010). Most gaged tributaries within major Mississippi River subbasins have main-stem impoundments (table 3) that could account for much of the sediment transport deficit not accounted for directly by the Missouri River main-stem impoundments.

The Arkansas River is the primary tributary sediment contributor to the lower Mississippi River Basin and there were significant decreases in SSLs in this basin during the 1950–2009 period. SSLs at the Arkansas River at Tulsa, Oklahoma, station decreased abruptly in the mid-1960s and this likely was the result of the construction of impoundments and navigation structures associated with the McClellan-Kerr navigation system. Keown and others (1986) noted substantial declines in SSLs at a downstream station, the Arkansas River at Little Rock, Arkansas, at which the 1941–62 average SSL was about 93 Mt/yr and the 1970–78 average was about 11.4 Mt/yr. This represents about an 88 percent reduction in SSLs from the Arkansas River Basin and exceeds the 79 percent reduction in SSLs in the Missouri River Basin (Missouri River at Hermann, Missouri, station; table 5) that followed channel modifications.

Decreases in SSLs in the lower Mississippi River corresponding to the declines in the Missouri and Arkansas Rivers were immediate and substantial. Pre-1953 (pre-Missouri River impoundment) SSLs in the lower Mississippi River (Mississippi River at Tarbert Landing, Mississippi, and Atchafalaya River at Simmesport, Louisiana) averaged 641 Mt/yr. This average declined to 296 Mt/yr during the 1953–64 period and to 198 Mt/yr following declines in contributions from the Arkansas River Basin in the mid-1960s (fig. 3)—a total SSL reduction of about 69 percent.

FA SSCs for Missouri River and Arkansas River stations decreased during the 1950–2009 analysis period (fig. 4). Plots of FA SSCs show downward changes in the fitted LOESS curves for each Missouri River station indicating deviations from the overall streamflow-SSC relation. At each station there were changes in the transport relation in about 1962 and 1972 with no substantial changes thereafter. The large negative FA SSCs in 1951, 1952, 1973, 1993, and 1995 correspond with large floods in those years, but these events had no apparent long-term effects on FA SSCs. FA SSCs for the available 1950–95 period at the Arkansas River at Tulsa, Oklahoma, also show apparent sediment transport relation changes around 1963 and 1974 with stable relations thereafter (fig. 4). Whereas abrupt changes in annual SSLs were evident following the closing of Fort Randall Dam in 1952, the changes in FA SSCs at Saint Joseph, Kansas City, and Hermann, Missouri, were lagged and subtle. The decrease in FA SSCs at these stations indicate less suspended material was being transported for a given flow condition and likely corresponds to adjustments in the system from a transport-limited to a supply-limited system, as suggested by Horowitz (2010), and by Meade and Moody (2010). The magnitude of variability of FA SSCs declined during the mid-1960s, likely a result of regulated flows and limitations in sediment supply. The decrease in FA SSCs at the Arkansas River at Tulsa, Oklahoma, also is a likely indication of adjustments in this sediment conveyance system from a transport-limited towards supply-limited conditions.

Suspended Sand 1950–2004

Trends in SSDLs, SSDCs, and SSDL percentage of SSLs were determined for three Missouri River and two lower Mississippi River stations for 1950–2004. Significant downward trends in SSDLs were determined for the Missouri River at Saint Joseph and Kansas City, Missouri and for the Mississippi River at Tarbert Landing, Mississippi, and Atchafalaya River at Simmesport, Louisiana, stations (table 7). The downward change in SSDLs at Hermann, Missouri, however, was not significant (p = 0.055). Decreases in FW SSDCs were

Table 7. Summary of analyses of monotonic trends in annual suspended-sand loads, flow-weighted suspended-sand concentrations, and sand load as a percentage of total suspended-sediment load between 1950 and 2004 at selected Missouri River and lower Mississippi River Basin stations.

[p-value, statistical probability level; yr, year; mg/L, milligrams per liter; m^3/s, cubic meter per second; <, less than;]

USGS station name	Map reference number (fig. 1)	Number of values used in analysis	Suspended-sand load				Trend (in percent/yr)
			Mann-Kendall tau	p-value	Sen slope (metric tons/yr)	Median (metric tons)	
Missouri River at Saint Joseph, Missouri	35	20	**-0.537**[a]	**0.001**	**-323,000**	**15,200,000**	-2.13
Missouri River at Kansas City, Missouri	38	19	**-.491**	**.004**	**-298,000**	**14,200,000**	-2.10
Missouri River at Hermann, Missouri	43	22	-.299	.055	-270,000	19,400,000	-1.39
Mississippi River at Tarbert Landing, Mississippi	46	55	**-.282**	**.002**	**-550,000**	**31,900,000**	-1.72
Atchafalaya River at Simmesport, Louisiana	48	53[b]	**-.232**	**.014**	**-246,000**	**16,600,000**	-1.48

USGS station name	Map reference number (fig. 1)	Number of values used in analysis	Flow-weighted suspended-sediment concentrations				Trend (in percent/yr)
			Mann-Kendall tau	p-value	Sen slope ((mg/L)/yr)	Median (mg/L)	
Missouri River at Saint Joseph, Missouri	35	20	**-0.747**	**<0.001**	**-10.8**	**340**	-3.18
Missouri River at Kansas City, Missouri	38	19	**-.790**	**<.001**	**-8.69**	**346**	-2.51
Missouri River at Hermann, Missouri	43	22	**-.533**	**<.001**	**-4.26**	**221**	-1.93
Mississippi River at Tarbert Landing, Mississippi	46	55	**-.410**	**<.001**	**-1.61**	**73.7**	-2.18
Atchafalaya River at Simmesport, Louisiana	48	53	**-.441**	**<.001**	**-2.24**	**90.7**	-2.47

USGS station name	Map reference number (fig. 1)	Number of values used in analysis	Suspended-sand load percentage of suspended-sediment load				Trend (in percent/yr)
			Mann-Kendall tau	p-value	Sen slope ((m^3/s)/yr)	Median (m^3/s)	
Missouri River at Saint Joseph, Missouri	35	20	-0.179	0.284	-0.393	33.3	-1.18
Missouri River at Kansas City, Missouri	38	19	-.076	.675	-.125	27.1	-.46
Missouri River at Hermann, Missouri	43	22	-.013	.955	-.008	27.6	-.03
Mississippi River at Tarbert Landing, Mississippi	46	55	.017	.861	0	20.0	0
Atchafalaya River at Simmesport, Louisiana	48	53	-.003	.982	0	23.0	0

[a] Values in bold are statistically significant ($p < 0.05$).

[b] Available sediment record is from 1952–2004.

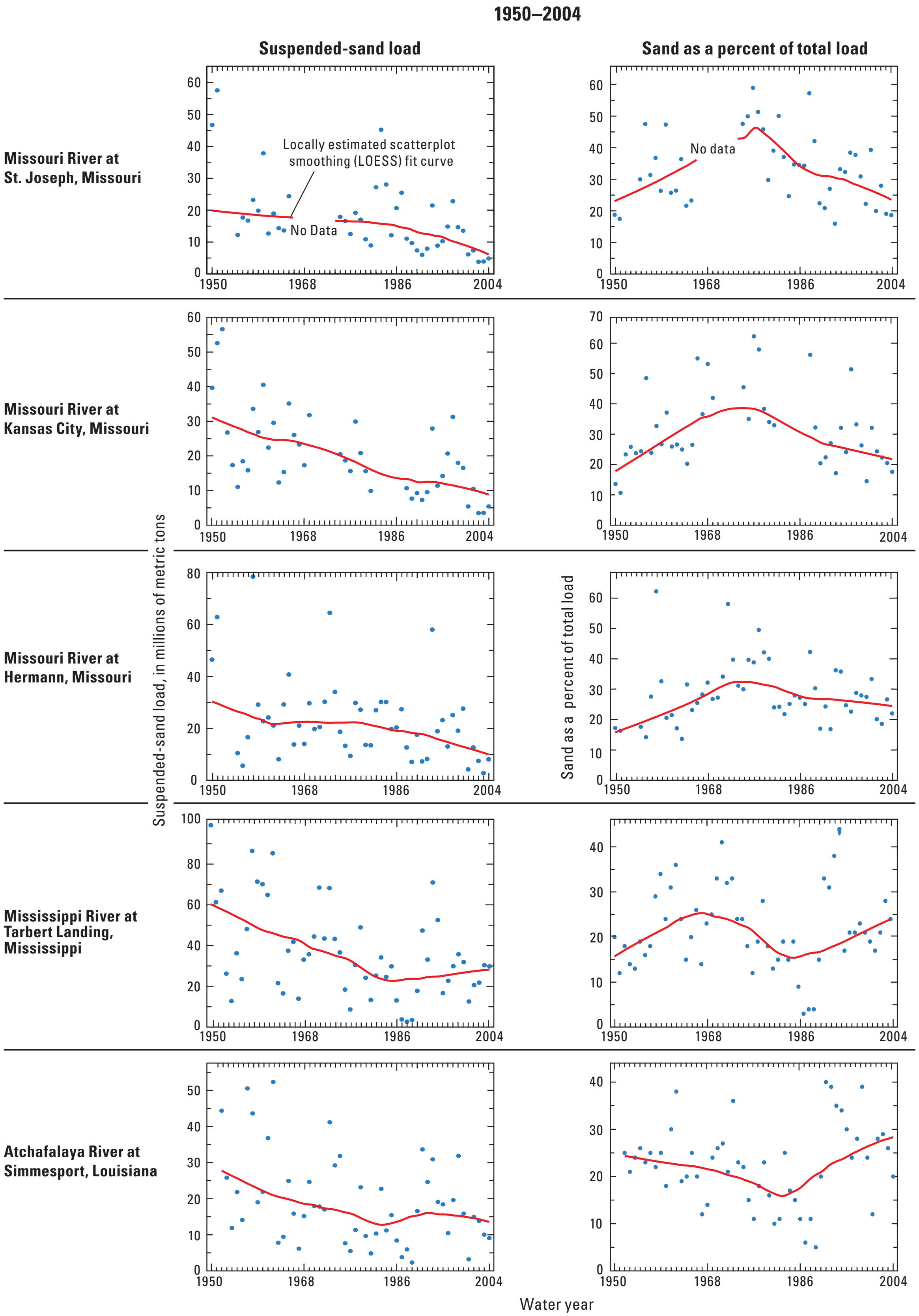


Figure 5. Summary of temporal variations in annual suspended-sand loads and annual sand as a percentage of total suspended-sediment loads, 1950–2004.

significant at all five stations, but there were no significant monotonic trends in the sand percentage of total sediment loads at any of the five stations for the 1950–2004 period (table 7). Qualitative temporal relations in SSDLs and SSDCs indicate the declines in SSDLs were abrupt following the 1952 dam closure, but SSDL declines (fig. 5) were more gradual than declines in SSLs (fig. 3). The corresponding temporal changes in SSDL percentage of SSLs showed increases in the portion of total loads comprised of sand between 1950 and about 1978 at all three Missouri River stations, followed by a decline in the portion of total loads comprised of sand from 1978 through 2004 (fig. 5). Similar temporal changes were not evident at the Tarbert Landing, Mississippi, or Simmesport, Louisiana, stations.

In addition to being the largest contributor of total suspended sediment to the Mississippi River, the Missouri River also is likely the largest contributor of suspended sand to the Mississippi River. The stations at Saint Joseph and Kansas City, Missouri, receive the majority of sand from the upstream main-stem channel of the Missouri and from the Platte River in Nebraska. The lack of a discernable trend in SSDLs at Hermann, Missouri, could be a consequence of the longitudinal distance from this primary source and the moderating effects in sediment transport over a great distance. Another possible moderating effect could be the substantial contributions of sand from major, and relatively unaltered, tributaries between Kansas City and Hermann (Grand and Chariton Rivers, Missouri).

An increase in SSDL percentage of SSLs from 1950 through about 1980 at the three Missouri River stations coincided with a period of declining SSLs and SSDLs (fig. 3, fig. 5) and indicated the silt and clay fractions of total load declined more than the sand fraction during this period. Further evidence of the larger declines in silt and clay fraction is indicated in the larger declines in SSLs and SSCs than SSDLs and SSDCs at several Missouri and Mississippi River stations (table 5), in the post-impoundment period. A larger decline in silt and clay fractions of sediment transport in the system could possibly reflect the effects of conservation practices in the basin that would target topsoil containing more silt and clay than sand. The reversal of this trend from 1980–2004 could be explained by the increased downward change in sand transport at these stations that began about 1980 (fig. 5), but the direct cause is unclear. The source of the change in the trend originates upstream from the Saint Joseph station and does not seem to be the result of a change in the streamflow-SSDC transport relation. The larger relative decline in SSDLs may simply be the result of a low-flow period in the sand-supply reach, downstream from Gavins Point Dam, as the Sioux City station showed significant downward trends in streamflow during the 1976–2009 period (table 8).

FA SSDCs at the Missouri River at Saint Joseph, Kansas City, and Hermann, Missouri for the 1950–2004 period showed subtle but apparent slope changes in LOESS fitted curves around 1956–58 and again around 1963–70 depending on the station (fig. 6). These slope changes, therefore, preceded the changes in FA SSCs for the 1950–2009 period at these stations by about 5 years. Unlike FA SSCs, however, which showed downward slope breaks between 1950 and 1975, there was at least one period of increases in FA SSDCs between 1950 and 1970 at each of the three stations. The specific causes of the transport relation transitions are difficult to determine with available information and likely include lagged channel adaptations to the main-stem impoundments.

Suspended Sediment 1976–2009

By 1976, most of the channel modifications in the major Mississippi River subbasins had been completed, although work continued on the Missouri River through the 1980s, the McClellan–Kerr navigation system on the Arkansas River through the early 2000s, and the Red River through the early 2000s. There were downward changes in SSLs at 19 of 27 Mississippi River Basin stations and statistically significant downward monotonic trends at 9 of 27 stations during the 1976 through 2009 analysis period, including stations in all major subbasins except the Arkansas River Basin (fig. 7, table 8). Eight stations, at least one within each major subbasin, showed upward changes in SSLs although none were significant (p= 0.102– 0.940). Downward changes in FW SSCs were significant at 13 stations including stations in each of the major subbasins except the Arkansas River Basin (fig. 7, table 8). Two stations, the Missouri River near Landusky, Montana and Sioux City, Iowa, showed significant downward trends in streamflow during the 34-year analysis period (fig. 7, table 8).

During 1976–2009, most stations had stready declines in sediment loads including stations within the upper Mississippi, Missouri, Ohio, and lower Mississippi River subbasins (fig. 7). Exceptions included the Wabash River at New Harmony, Indiana, which showed variable SSLs ending with an increase, and the Iowa River at Wapello, Iowa, which also ended the period with increasing SSLs.

Although not expressed in the fitted 1950–2009 FA SSC LOESS curves for the stations on the Missouri River at Saint Joseph and Kansas City, Missouri (fig. 4), subtle downward changes appear in the fitted 1976–2009 FA SSC curves for these stations, indicating a change in the streamflow-SSC relation coinciding with the 1993 and 1995 floods (fig. 8). There was a subsequent increase in the FA SSCs beginning in about 1997 and continuing through 2003, indicating a system recovery from the 1993 and 1995 floods. There were large negative FA SSCs at the Missouri River at Hermann, Missouri, in 1993 and 1995, but these declines were not expressed in the fitted LOESS curve.

Suspended Sand 1976–2004

Trends in SSDL, FW SSDCs, and SSDL percentage of SSLs during the 1976–2004 post-impoundment period were analyzed at seven stations including four Missouri River Basin and three lower Mississippi River stations for the 1976–2004

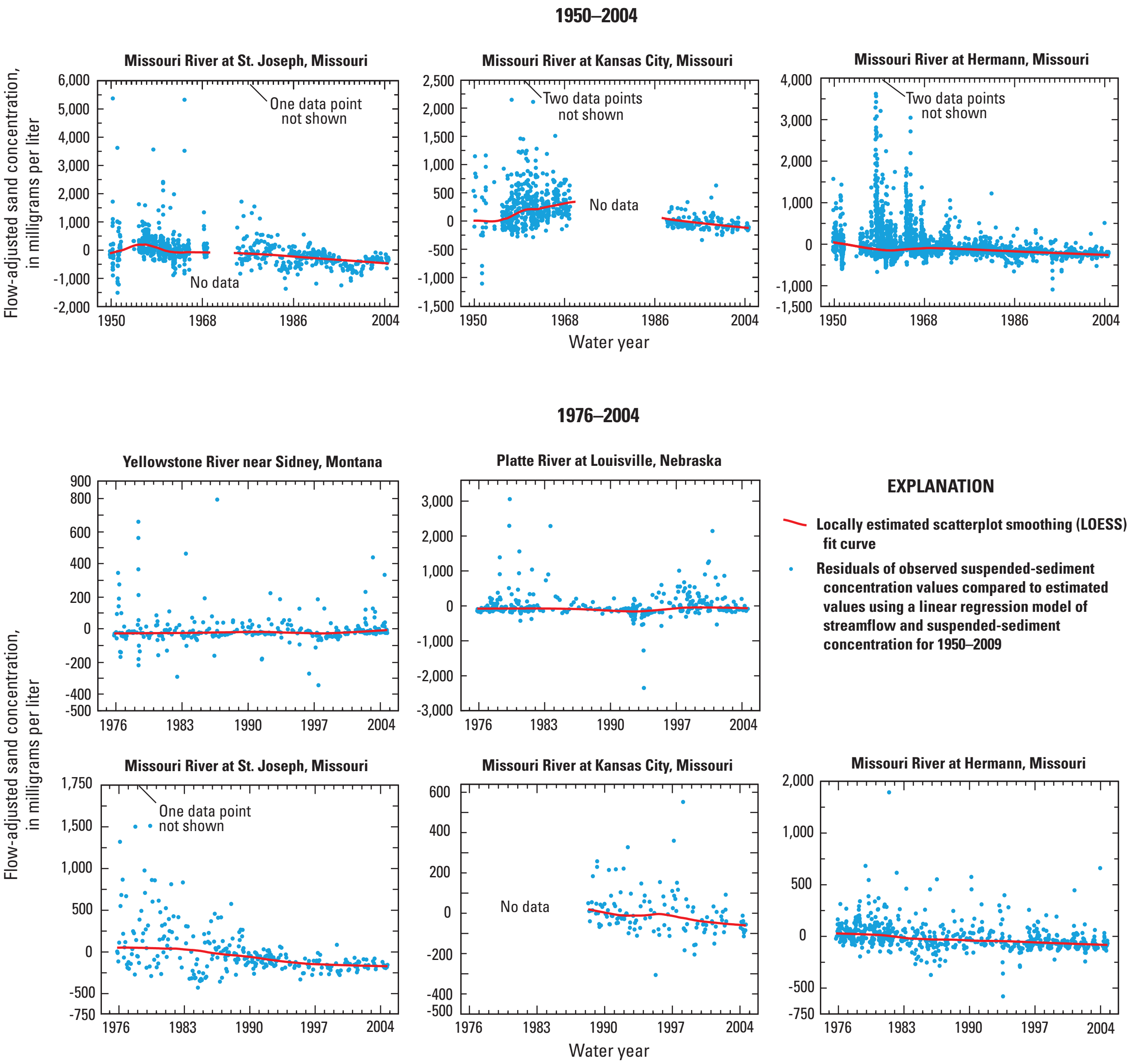
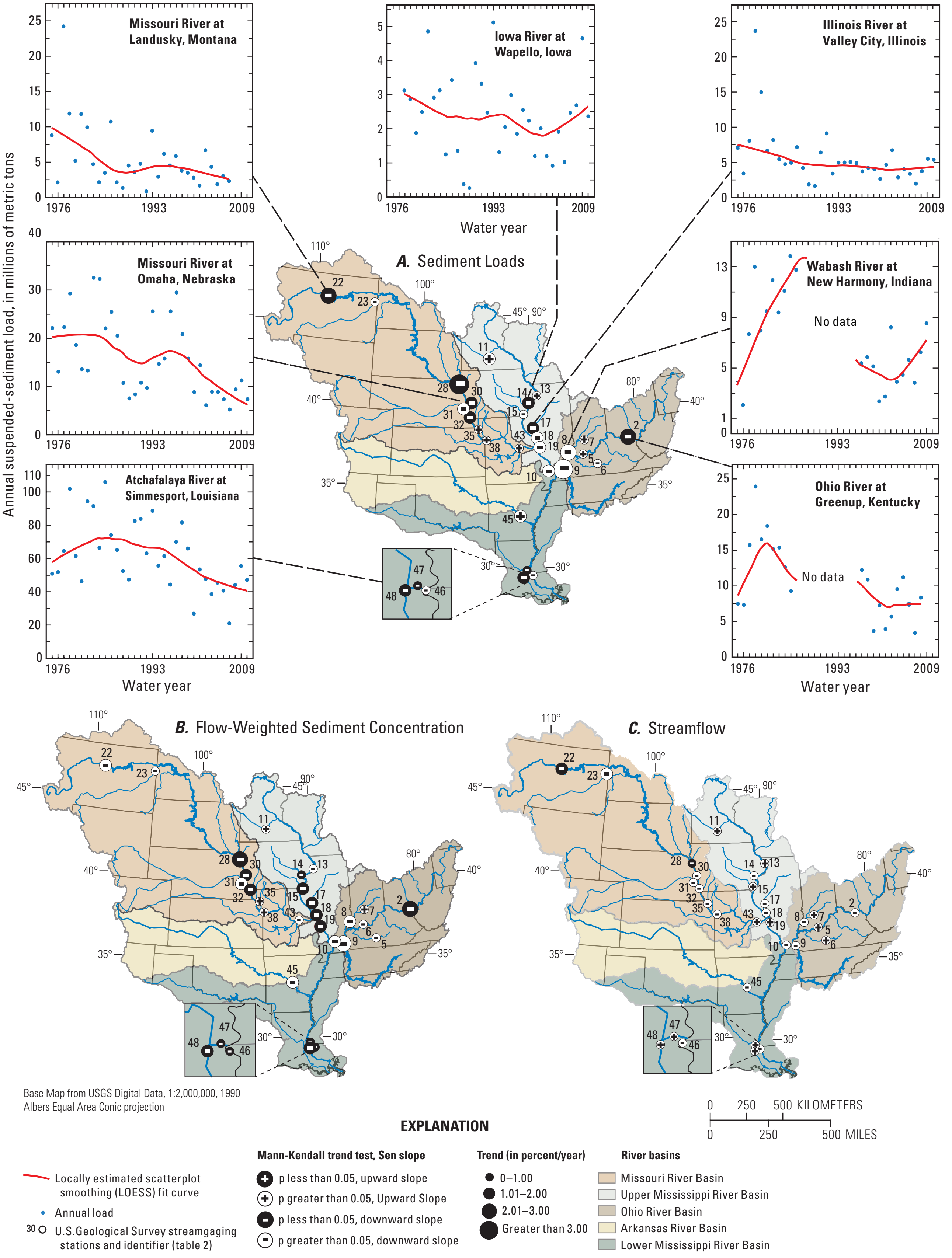


Figure 6. Summary of temporal variations in flow-adjusted sand concentrations, 1950–2004 and 1976–2004.

post-impoundment period (table 9). Of the five stations with downward changes in SSDLs during this time period, two (Missouri River at Saint Joseph and Kansas City, Missouri) had significant downward trends. The remaining two stations (Mississippi River at Tarbert Landing, Mississippi, and Atchafalaya River at Simmesport, Louisiana) had upward, but not statistically significant, changes in SSDLs and SSDCs (table 9). Downward monotonic trends in FW SSDCs and the SSDL percentage of SSLs were significant at all three Missouri River main-stem stations (table 9) but not at any other stations.

Sand from the Missouri River main-stem reach between Gavins Point Dam and Sioux City, Iowa, likely was the primary contributor to SSDLs in the Missouri River during the 1981–1991 analysis period (table 4). The downward trends in SSDLs, FW SSDCs, and SSDL percentage of SSLs at the Missouri River at Sioux City, Iowa, for the 1976–2004 period are likely the result of downward trends in flows rather than a depletion of readily available upstream sand sources. The U.S. Army Corps of Engineers (2004) reported a 3.3-meter (m) decline in stage for a reference flow at the Gavins Point Dam outflow and at the Sioux City station between 1955 and the early 1980s. During the dry period of 1985–1991, sand loads at Sioux City were reduced and the river stage increased by 0.3 m. A succession of high-flow years in the 1990s, however, resulted in a further 1-m decline in stage at a reference flow at this station through 2003, indicating a continued availability of source material.



Base Map from USGS Digital Data, 1:2,000,000, 1990
Albers Equal Area Conic projection

Figure 7. Summary of trends in annual suspended-sediment loads, flow-weighted concentrations, and streamflows at selected U.S. Geological Survey streamgaging stations in the Mississippi River Basin, 1976–2009.

Table 8. Summary of analyses of monotonic trends in annual suspended-sediment loads, flow-weighted concentrations, and streamflows between 1976 and 2009 at selected Mississippi River Basin streamgaging stations.

[p-value, statistical probability level; yr, year; mg/L, milligrams per liter; <, less than; m^3/s, cubic meter per second]

Short name (table 2)	Map reference number (fig. 1)	Number of values used in analysis	Suspended-sediment loads				Trend (in percent/yr)
			Mann-Kendall tau	p-value	Sen slope (metric tons/yr)	Median (metric tons)	
Ohio River at Greenup Dam near Greenup, Kentucky	2	21	**-0.429**[a]	**0.007**	**-291,000**	9,560,000	-3.04
Ohio River at Cannelton Dam at Cannelton, Indiana	5	8	.143	.764	54,500	28,600,000	.19
Green River at Munfordville, Kentucky	6	9	0	1.00	-110	318,000	-.03
White River at Hazleton, Indiana	7	9	.111	.755	14,400	2,030,000	.71
Wabash River at New Harmony, Indiana	8	8	-.143	.711	-229,000	6,060,000	-3.78
Tennessee River at Highway 60 near Paducah, Kentucky	9	8	-.357	.266	-20,900	461,000	-4.53
Ohio River at Dam 53 Near Grand Chain, Illinois	10	11	-.236	.350	-645,000	40,300,000	-1.60
Minnesota River at Mankato, Minnesota	11	32	.206	.102	22,300	1,210,000	1.84
Mississippi River at Clinton, Iowa	13	36	.033	.913	1,920	3,450,000	.06
Iowa River at Wapello, Iowa	14	29	**-.276**	**.037**	**-47,300**	2,240,000	-2.11
Skunk River at Augusta, Iowa	15	34	-.123	.313	-28,500	2,300,000	-1.24
Illinois River at Valley City, Illinois	17	12	**-.320**	**.012**	**-107,000**	4,890,000	-2.19
Mississippi River below Grafton, Illinois	18	24	-.261	.078	-451,000	21,200,000	-2.13
Mississippi River at Saint Louis, Missouri	19	34	-.234	.054	-1,640,000	91,100,000	-1.80
Missouri River near Landusky, Montana	22	31	**-.290**	**.023**	**-162,000**	4,320,000	-3.75
Yellowstone River near Sidney, Montana	23	11	-.200	.436	-74,300	5,330,000	-1.39
Missouri River at Sioux City, Iowa	28	13	**-.495**	**.003**	**-363,000**	6,740,000	-5.39
Missouri River at Omaha, Nebraska	30	19	**-.368**	**.030**	**-430,000**	14,700,000	-2.93
Platte River at Louisville, Nebraska	31	11	-.236	.350	-160,000	6,200,000	-2.58
Missouri River at Nebraska City, Nebraska	32	23	**-.328**	**.030**	**-573,000**	23,100,000	-2.48
Missouri River at Saint Joseph, Missouri	35	18	.020	.940	17,500	31,800,000	.06
Kansas River at DeSoto, Kansas	37	20	.103	.669	167,000	41,600,000	.40
Missouri River at Hermann, Missouri	43	18	.046	.820	115,000	55,800,000	.21
Arkansas River at David D. Terry Lock and Dam below Little Rock, Arkansas	45	11	-.200	.436	60,300	2,040,000	2.96
Mississippi River at Tarbert Landing, Mississippi	46	34	-.166	.173	-811,000	124,000,000	-.65
Old River Outflow Channel near Knox Landing, Louisiana	47	34	**-.244**	**.044**	**-427,000**	31,800,000	-1.34
Atchafalaya River at Simmesport, Louisiana	48	34	**-.355**	**.003**	**-1,020,000**	58,600,000	-1.74

Short name	Map reference number (fig. 1)	Number of values used in analysis	Flow-weighted suspended-sediment concentrations				Trend (in percent/yr)
			Mann-Kendall tau	p-value	Sen slope ((mg/L)/yr)	Median (mg/L)	
Ohio River at Greenup Dam near Greenup, Kentucky	2	21	**-0.514**	**0.001**	**-4.06**	125	-3.25
Ohio River at Cannelton Dam at Cannelton, Indiana	5	8	-.048	1.00	-.528	206	-.26
Green River at Munfordville, Kentucky	6	9	-.167	.602	-1.34	116	-1.16
White River at Hazleton, Indiana	7	9	.056	.917	.247	175	.14
Wabash River at New Harmony, Indiana	8	8	-.429	.174	-3.42	183	-1.87
Mississippi River at Clinton, Iowa	13	36	-.165	.443	-.756	65.3	-1.16
Iowa River at Wapello, Iowa	14	29	**-.261**	**.049**	**-3.12**	231	-1.35
Skunk River at Augusta, Iowa	15	34	**-.362**	**.003**	**-18.0**	785	-2.29
Illinois River at Valley City, Illinois	17	12	**-.320**	**.012**	**-3.29**	200	-1.65
Mississippi River below Grafton, Illinois	18	24	**-.297**	**.045**	**-4.68**	177	-2.65
Mississippi River at Saint Louis, Missouri	19	34	**-.447**	**<.001**	**-9.84**	475	-2.07
Missouri River near Landusky, Montana	22	31	-.187	.144	-8.77	534	-1.64
Yellowstone River near Sidney, Montana	23	11	-0.127	0.640	-8.37	691	-1.21

Table 8. Summary of analyses of monotonic trends in annual suspended-sediment loads, flow-weighted concentrations, and streamflows between 1976 and 2009 at selected Mississippi River Basin streamgaging stations.—Continued

[p-value, statistical probability level; yr, year; mg/L, milligrams per liter; <, less than; m^3/s, cubic meter per second]

Short name	Map reference number (fig. 1)	Number of values used in analysis	Flow-weighted suspended-sediment concentrations				Trend (in percent/yr)
			Mann-Kendall tau	p-value	Sen slope ((mg/L)/yr)	Median (mg/L)	
Missouri River at Sioux City, Iowa	28	13	**-.547**	**<.001**	**-8.32**	254	-3.27
Missouri River at Omaha, Nebraska	30	19	**-.392**	**.021**	**-8.50**	493	-1.72
Platte River at Louisville, Nebraska	31	11	-.273	.276	-21.7	831	-2.61
Missouri River at Nebraska City, Nebraska	32	23	**-.336**	**.027**	**-8.93**	632	-1.41
Missouri River at Saint Joseph, Missouri	35	18	.007	1.00	.587	743	.08
Kansas River at DeSoto, Kansas	37	20	.026	.951	1.19	830	.14
Missouri River at Hermann, Missouri	43	18	-.033	.880	-1.24	657	-.19
Arkansas River at David D. Terry Lock and Dam below Little Rock, Arkansas	45	11	-.309	.213	-1.45	59.6	-2.43
Mississippi River at Tarbert Landing, Mississippi	46	34	**-.259**	**.033**	**-1.85**	268	-.69
Old River Outflow Channel near Knox Landing, Louisiana	47	34	**-.444**	**<.001**	**-2.91**	238	-1.22
Atchafalaya River at Simmesport, Louisiana	48	34	**-.497**	**<.001**	**-5.55**	318	-1.75

Short name	Map reference number (fig. 1)	Number of values used in analysis	Streamflow				Trend (in percent/yr)
			Mann-Kendall tau	p-value	Sen slope ((m^3/s)/yr)	Median (m^3/s)	
Ohio River at Greenup Dam near Greenup, Kentucky	2	21	-0.038	0.838	-3.03	2370	-0.13
Ohio River at Cannelton Dam at Cannelton, Indiana	5	8	.238	.548	6.61	3,970	.17
Green River at Munfordville, Kentucky	6	9	0	1.00	.022	82.1	.03
White River at Hazleton, Indiana	7	9	.278	.348	4.02	408	.99
Wabash River at New Harmony, Indiana	8	8	-.071	.902	-.467	1,020	-.05
Tennessee River at Highway 60 near Paducah, Kentucky	9	8	-.429	.174	-23.2	1,640	-1.42
Ohio River at Dam 53 Near Grand Chain, Illinois	10	11	-.091	.732	-32.0	8,480	-.38
Minnesota River at Mankato, Minnesota	11	32	.130	.286	1.68	142	1.18
Mississippi River at Clinton, Iowa	13	36	.187	.381	16.8	1,720	.98
Iowa River at Wapello, Iowa	14	29	-.143	.285	-2.27	260	-.87
Skunk River at Augusta, Iowa	15	34	.037	.767	.271	85.9	.32
Illinois River at Valley City, Illinois	17	12	-.058	.659	-2.17	740	-.29
Mississippi River below Grafton, Illinois	18	24	-.065	.673	-9.28	3,550	-.26
Mississippi River at Saint Louis, Missouri	19	34	.034	.790	7.55	6,240	.12
Missouri River near Landusky, Montana	22	31	**-.372**	**.004**	**-4.74**	232	-2.04
Yellowstone River near Sidney, Montana	23	11	-.346	.161	-5.45	265	-2.06
Missouri River at Sioux City, Iowa	28	13	**-.379**	**.021**	**-11.0**	784	-1.40
Missouri River at Omaha, Nebraska	30	19	-.275	.108	-10.8	1,020	-1.05
Platte River at Louisville, Nebraska	31	11	-.018	1.00	-1.06	166	-.64
Missouri River at Nebraska City, Nebraska	32	23	-.296	.051	-13.0	1,080	-1.21
Missouri River at Saint Joseph, Missouri	35	18	-.163	.363	-6.76	1,250	-.54
Kansas River at DeSoto, Kansas	37	20	-.026	.951	-2.05	1,460	-.14
Missouri River at Hermann, Missouri	43	18	.111	.545	9.79	2,330	.42
Arkansas River at David D. Terry Lock and Dam below Little Rock, Arkansas	45	11	-.200	.436	-15.2	1,130	-1.35
Mississippi River at Tarbert Landing, Mississippi	46	34	-.037	.767	-24.3	14,700	-.17
Old River Outflow Channel near Knox Landing, Louisiana	47	34	.119	.328	16.6	4,170	.40
Atchafalaya River at Simmesport, Louisiana	48	34	.023	.859	5.71	6,410	.09

[a] Values in bold are statistically significant ($p < 0.05$).

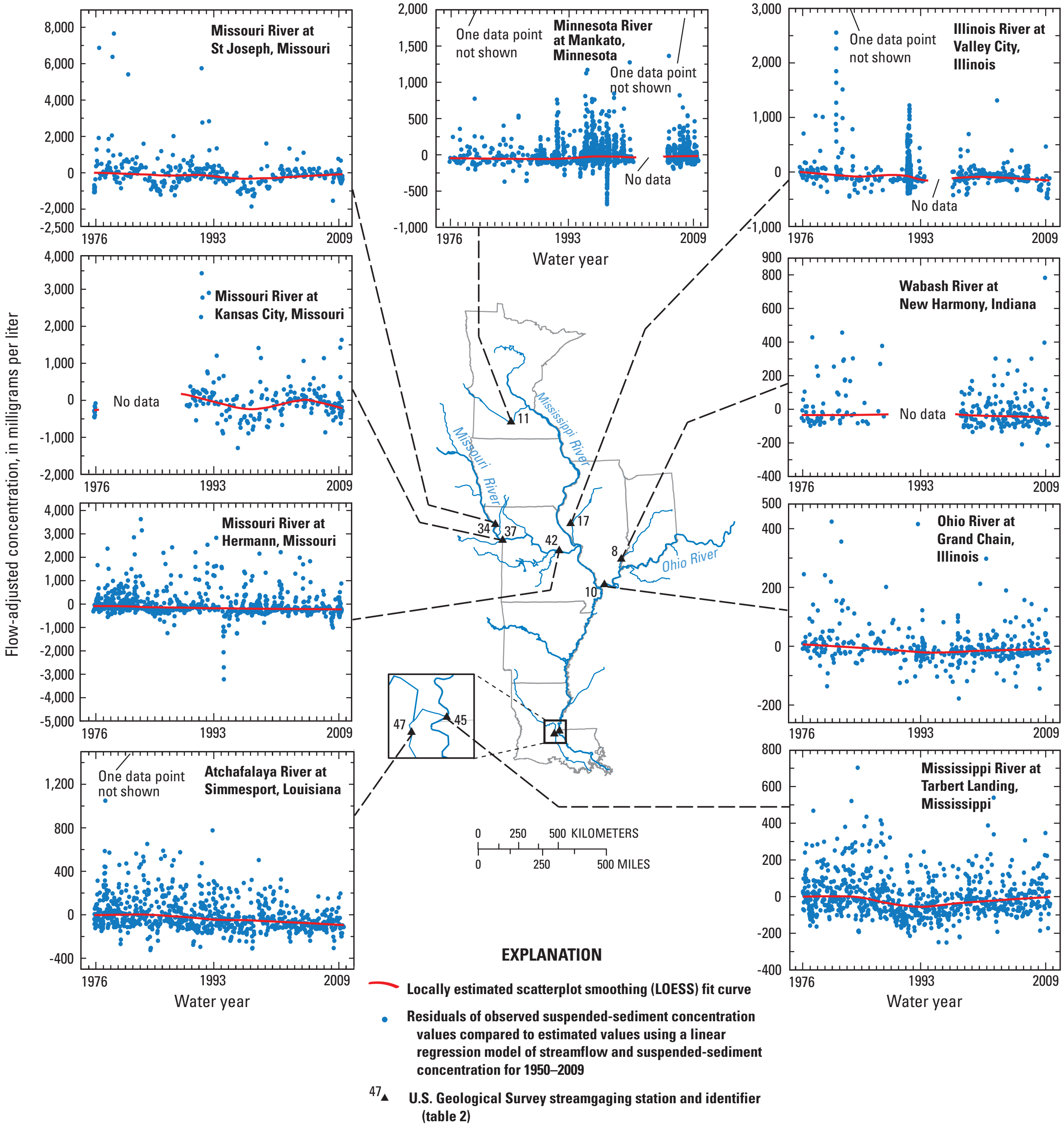


Figure 8. Summary of temporal variations in flow-adjusted sediment concentrations for selected U.S. Geological Survey streamgaging stations in the Mississippi River Basin, 1976–2009.

There were downward changes in FA SSDCs at four of five Missouri River Basin stations during 1976–2004 (fig. 6), whereas FA SSDCs at the remaining station were relatively unchanged. The FA SSDCs at the Missouri River at Saint Joseph, Kansas City, and Hermann, Missouri (fig. 6), showed small but steady declines during 1976–2004. There was, however, a period of primarily negative FA SSDCs, that is, lower measured concentrations for a particular flow than would be expected from an overall streamflow-SSC relation, at the Missouri River at Kansas City and Hermann, Missouri, between 1993 and 1996 (fig. 6). The declines in FA SSDCs were short term and were not expressed in the fitted LOESS curve. The subtle decline in FA SSDCs at the Platte River at Louisville, Nebraska, station may be the result of high flows in 1987, 1993, and 1995, but the apparent effects in the SSDC-streamflow relation were temporary. There was a subtle “dip” in FA SSDCs between 1988 and 1997 at the Platte River at Louisville, Nebraska, station but no apparent changes in the FA SSDCs at the Yellowstone River at Sidney, Montana.

Table 9. Summary of analyses of monotonic trends in annual suspended-sand loads, flow-weighted suspended-sand concentrations, and suspended-sand load as a percentage of total suspended-sediment loads between 1976 and 2004 at selected Missouri River and lower Mississippi River Basin stations.

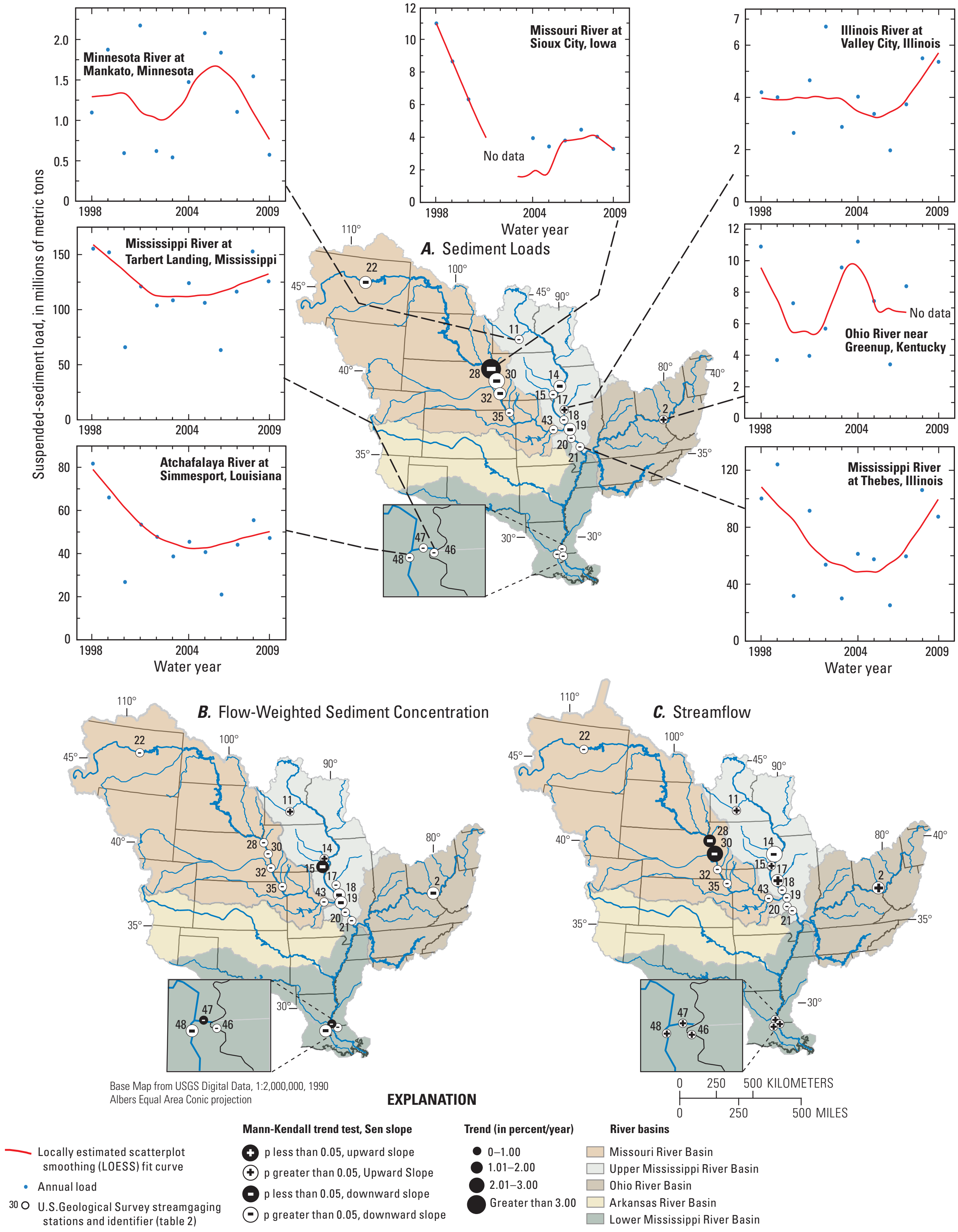
[p-value, statistical probability level; <, less than; yr, year; mg/L, milligrams per liter; m^3/s, cubic meter per second]

USGS station name)	Map reference number (fig. 1)	Number of values used in analysis	Suspended-sand load				Trend (in percent/yr)
			Mann-Kendall tau	p-value	Sen slope (metric tons)	Median (metric tons)	
Yellowstone River near Sidney, Montana	23	10	-0.289	0.283	-85,800	1,750,000	-4.90
Missouri River at Saint Joseph, Missouri	35	15	**-.448**[a]	**.023**	-333,000	**11,300,000**	-2.95
Missouri River at Kansas City, Missouri	38	13	**-.5**	**.02**	-379,000	**14,200,000**	-2.67
Missouri River at Hermann, Missouri	43	15	-.181	.373	-105,000	12,800,000	-.82
Mississippi River at Tarbert Landing, Mississippi	46	30	.03	.83	101,000	24,900,000	.41
Old River Outflow Channel near Knox Landing, Louisiana	47	30	-.136	.301	-83,300	5,140,000	-1.62
Atchafalaya River at Simmesport, Louisiana	48	30	.03	.83	50,700	12,600,000	.40

USGS station name	Map reference number (fig. 1)	Number of values used in analysis	Flow-weighted suspended-sand concentration				Trend (in percent/yr)
			Mann-Kendall tau	p-value	Sen slope (mg/L)	Median (mg/L)	
Yellowstone River near Sidney, Montana	23	10	-0.244	0.371	-5.1	192	-2.66
Missouri River at Saint Joseph, Missouri	35	15	**-.638**	**.001**	-7.4	**291**	-2.54
Missouri River at Kansas City, Missouri	38	13	**-.795**	**<.001**	-8.09	**251**	-3.22
Missouri River at Hermann, Missouri	43	15	**-.505**	**.01**	-3.74	**207**	-1.81
Mississippi River at Tarbert Landing, Mississippi	46	30	.025	.858	.151	53.3	.28
Old River Outflow Channel near Knox Landing, Louisiana	47	30	-.145	.269	-.466	37.6	-1.24
Atchafalaya River at Simmesport, Louisiana	48	30	.053	.695	.288	62.3	0.46

USGS station name	Map reference number (fig. 1)	Number of values used in analysis	Suspended-sand load percentage of uspended-sand load				Trend (in percent/yr)
			Mann-Kendall tau	p-value	Sen slope (m^3/s)	Median (m^3/s)	
Yellowstone River near Sidney, Montana	23	10	0.244	0.371	0.524	17.6	2.98
Missouri River at Saint Joseph, Missouri	35	15	**-.695**	**<.001**	-1.09	36.9	-2.95
Missouri River at Kansas City, Missouri	38	13	**-.821**	**<.001**	-.832	32.9	-2.53
Missouri River at Hermann, Missouri	43	15	**-.448**	**.023**	-.744	28.0	-2.66
Mississippi River at Tarbert Landing, Mississippi	46	30	.214	.099	.214	19.0	1.13
Old River Outflow Channel near Knox Landing, Louisiana	47	30	.03	.83	0	15.0	0
Atchafalaya River at Simmesport, Louisiana	48	30	.253	.051	.435	21.0	2.07

[a] Values in bold are statistically significant ($p < 0.05$).



Base Map from USGS Digital Data, 1:2,000,000, 1990
Albers Equal Area Conic projection

Figure 9. Summary of trends in annual suspended-sediment loads, flow-weighted concentrations, and streamflows at selected U.S. Geological Survey streamgaging stations in the Mississippi River Basin, 1998–2009.

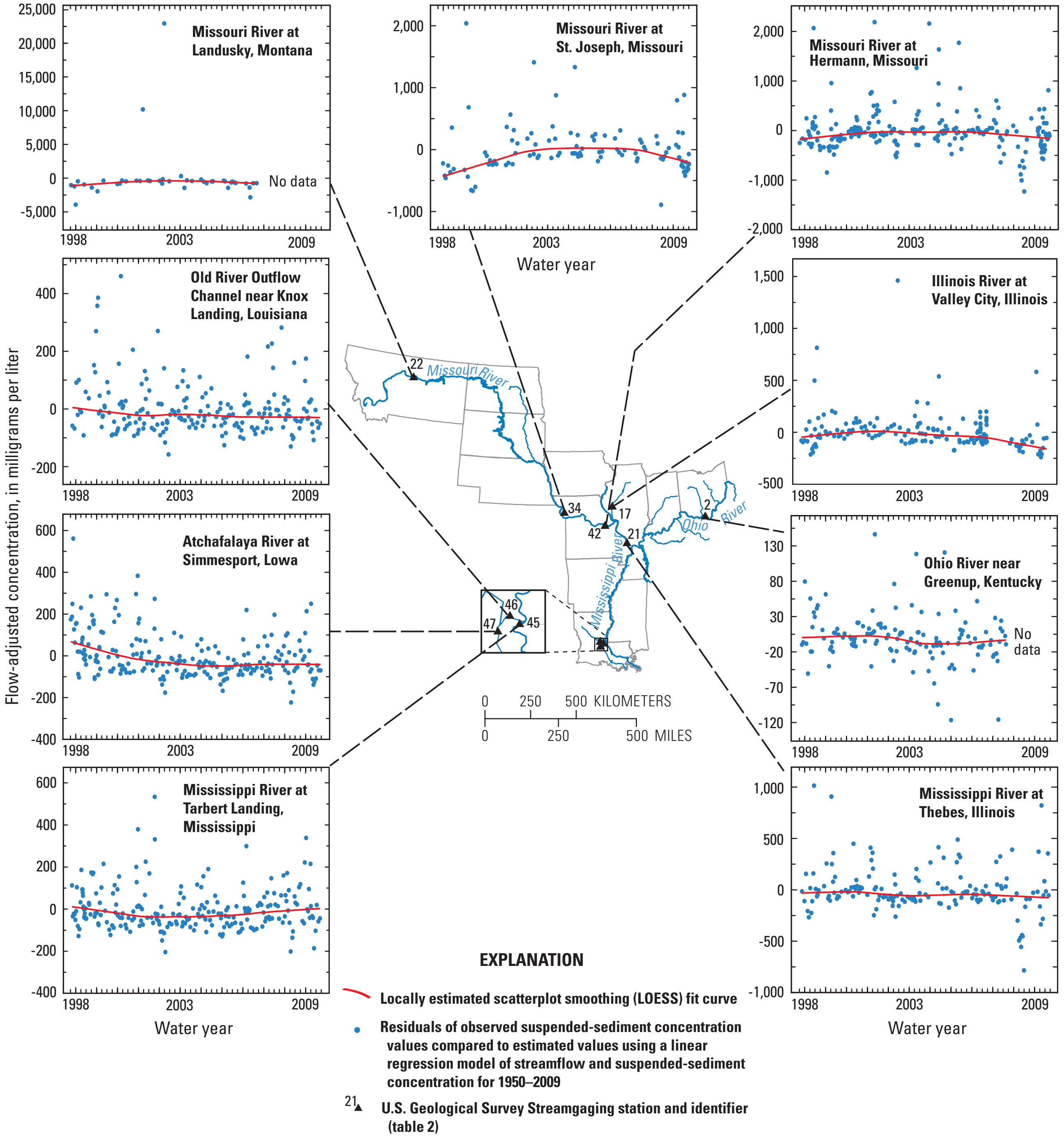


Figure 10. Summary of temporal variations in flow-adjusted sediment concentrations for selected U.S. Geological Survey streamgaging stations in the Mississippi River Basin, 1998–2009.

Suspended Sediment 1998–2009

Analyses of monotonic trends in SSLs, FW SSCs, and streamflows over a recent (1998–2009) post-channel modification period in the subbasins indicate that slopes of these constituents were generally downward but few temporal changes were significant (fig. 9, table 10). A significant downward trend in SSLs was indicated for the Missouri River at Sioux City, Iowa, but temporal changes in SSLs were not significant at any of the remaining 17 stations. The downward trends in FW SSCs were significant during the 12-year period only at the Skunk River at Augusta, Iowa, in the upper Mississippi River Basin and the Old River Outflow station in Louisiana. Significant downward trends in streamflow were determined for two Missouri River stations including the Missouri River at Sioux City, Iowa, and at Omaha, Nebraska.

Table 10. Summary of analyses of monotonic trends in annual suspended-sediment loads, flow-weighted suspended-sediment concentrations, and streamflows between 1998 and 2009 at selected Mississippi River Basin streamgaging stations.

[p-value, statistical probability level; yr, year; mg/L, milligrams per liter; m^3/s, cubic meter per second]

USGS station name	Map reference number (fig. 1)	Number of values used in analysis	Suspended-sediment load				Trend (in percent/yr)
			Mann-Kendall tau	p-value	Sen slope (metric tons/yr)	Median (metric tons)	
Ohio River at Greenup Dam near Greenup, Kentucky	2	10	0.067	0.858	51,800	7,370,000	0.70
Minnesota River at Mankato, Minnesota	11	11	-.127	.64	-37,000	1,470,000	-2.52
Iowa River at Wapello, Iowa	14	9	-.333	.252	-80,600	1,910,000	-4.22
Skunk River at Augusta, Iowa	15	12	-.091	.732	-35,100	1,930,000	-1.82
Illinois River at Valley City, Illinois	17	12	.061	.837	82,000	4,020,000	2.04
Mississippi River below Grafton, Illinois	18	12	-.182	.451	-644,000	17,800,000	-3.62
Mississippi River at Saint Louis, Missouri	19	12	-.182	.451	-2,770,000	60,600,000	-4.57
Mississippi River at Chester, Illinois	20	12	-.121	.631	-1,020,000	70,200,000	-1.45
Mississippi River at Thebes, Illinois	21	12	-.091	.732	-847,000	60,400,000	-1.40
Missouri River near Landusky, Montana	22	9	-.222	.466	-179,000	3,030,000	-5.91
Missouri River at Sioux City, Iowa	28	9	**-.611**[a]	**.029**	**-520,000**	**4,028,000**	-12.91
Missouri River at Omaha, Nebraska	30	8	-.429	.174	-1,160,000	10,100,000	-11.49
Missouri River at Nebraska City, Nebraska	32	12	-.152	.537	-590,000	14,200,000	-4.15
Missouri River at Saint Joseph, Missouri	35	7	-.143	.764	-745,000	33,900,000	-2.20
Missouri River at Hermann, Missouri	43	7	-.143	.764	-921,000	55,400,000	-1.66
Mississippi River at Tarbert Landing, Mississippi	46	12	-.03	.945	-349,000	119,000,000	-.29
Old River Outflow Channel near Knox Landing, Louisiana	47	12	-.091	.732	-381,000	29,200,000	-1.30
Atchafalaya River at Simmesport, Louisiana	48	12	-.242	.304	-1,720,000	46,400,000	-3.71

USGS station name	Map reference number (fig. 1)	Number of values used in analysis	Flow-weighted suspended-sediment concentration				Trend (in percent/yr)
			Mann-Kendall tau	p-value	Sen slope ((mg/L)/yr)	Median (mg/L)	
Ohio River at Greenup Dam near Greenup, Kentucky	2	10	-0.20	0.474	-3.76	91.8	-4.10
Minnesota River at Mankato, Minnesota	11	11	.018	1.00	.247	272	.09
Iowa River at Wapello, Iowa	14	9	.056	.917	1.81	223	.81
Skunk River at Augusta, Iowa	15	12	**-.727**	**.001**	**-46.4**	716	-6.48
Illinois River at Valley City, Illinois	17	12	-.303	.193	-4.67	183	-2.55
Mississippi River below Grafton, Illinois	18	12	-.364	.115	-7.31	162	-4.51
Mississippi River at Saint Louis, Missouri	19	12	-.182	.451	-14.8	352	-4.21
Mississippi River at Chester, Illinois	20	12	-.242	.304	-10.7	399	-2.68
Mississippi River at Thebes, Illinois	21	12	-.121	.631	-5.44	339	-1.60
Missouri River near Landusky, Montana	22	9	-.111	.734	-8.10	480	-1.69
Missouri River at Sioux City, Iowa	28	9	-.389	.175	-7.50	219	-3.43
Missouri River at Omaha, Nebraska	30	8	-.214	.536	-3.84	388	-.99
Missouri River at Nebraska City, Nebraska	32	12	-.03	.945	-5.53	520	-1.06
Missouri River at Saint Joseph, Missouri	35	7	-.238	.548	-7.13	773	-.92
Missouri River at Hermann, Missouri	43	7	-.048	1.00	-2.10	634	-.33
Mississippi River at Tarbert Landing, Mississippi	46	12	-.152	.537	-3.20	265	-1.21
Old River Outflow Channel near Knox Landing, Louisiana	47	12	**-.515**	**.024**	**-4.10**	**222**	-1.85
Atchafalaya River at Simmesport, Louisiana	48	12	-.303	.193	-9.75	228	-4.27

Table 10. Summary of analyses of monotonic trends in annual suspended-sediment loads, flow-weighted suspended-sediment concentrations, and streamflows between 1998 and 2009 at selected Mississippi River Basin streamgaging stations.—Continued

[p-value, statistical probability level; yr, year; mg/L, milligrams per liter; m^3/s, cubic meter per second]

USGS station name	Map reference number (fig. 1)	Number of values used in analysis	Streamflow				Trend (in percent/yr)
			Mann-Kendall tau	p-value	Sen slope ((m^3/s)/yr)	Median (m^3/s)	
Ohio River at Greenup Dam near Greenup, Kentucky	2	10	0.378	0.152	118	2,310	5.11
Minnesota River at Mankato, Minnesota	11	11	0	1.00	.393	133	.30
Iowa River at Wapello, Iowa	14	9	-.389	.175	-22.1	204	-10.82
Skunk River at Augusta, Iowa	15	12	.152	.537	3.06	87	3.52
Illinois River at Valley City, Illinois	17	12	.212	.373	27.8	677	4.10
Mississippi River below Grafton, Illinois	18	12	-.03	.945	-18.1	3,410	-.53
Mississippi River at Saint Louis, Missouri	19	12	-.061	.837	-37.2	5,480	-.68
Mississippi River at Chester, Illinois	20	12	-.03	.945	-23.5	5,700	-.41
Mississippi River at Thebes, Illinois	21	12	-.061	.837	-16.6	6,040	-.28
Missouri River near Landusky, Montana	22	9	-.222	.466	-4.84	170	-2.84
Missouri River at Sioux City, Iowa	28	9	**-.722**	**.009**	**-49.2**	659	-7.47
Missouri River at Omaha, Nebraska	30	8	**-.786**	**.009**	**-76.6**	812	-9.43
Missouri River at Nebraska City, Nebraska	32	12	-.364	.115	-37.4	955	-3.91
Missouri River at Saint Joseph, Missouri	35	7	-.143	.764	-18.1	1,130	-1.6
Missouri River at Hermann, Missouri	43	7	-.048	1.00	-6.80	2,410	-.28
Mississippi River at Tarbert Landing, Mississippi	46	12	0	1.00	.871	15,000	.01
Old River Outflow Channel near Knox Landing, Louisiana	47	12	.091	.732	25.0	4,450	.56
Atchafalaya River at Simmesport, Louisiana	48	12	0	1.00	1.89	6,430	.03

[a] Values in bold are statistically significant ($p<0.05$).

The downward temporal changes in streamflow could account for the SSL declines as temporal relations in FA SSCs at most stations did not show substantial corresponding changes in the sediment transport relations (fig. 10). Exceptions included a decline in the sediment concentration for a given flow at the Atchafalaya River at Simmesport, Louisiana, indicating an adjustment to limitations in sediment supply, and an increase in the sediment concentration for a given flow at the Missouri River at Saint Joseph, Missouri, station during an apparent sediment supply recovery period following the 1993 and 1995 floods.

Summary

Of the four primary contributing subbasins to the lower Mississippi River, the Missouri River provided the greatest median suspended-sediment load followed by the Ohio River, upper Mississippi, and Arkansas Rivers during the 1976–2009 analysis period. The Missouri River provided the largest annual suspended-sediment loads during 26 of the 34 years analyzed, and the Ohio River transported the largest annual loads during the remaining 8 years. Overall, sediment transport in the lower Mississippi River is most closely correlative with the contributions of suspended sediment from the Missouri River Basin.

Annual suspended-sediment loads were computed for gaged tributary streams within the Missouri, Ohio, and upper Mississippi Basins to further determine major sediment-contributing sources within the subbasins. The Grand River near Sumner, Missouri and the Platte River at Louisville, Nebraska had the largest median annual loads within the Missouri River Basin. The Wabash River provided the largest sediment contribution to the Ohio River, whereas the Illinois River was the largest sediment contributor to the upper Mississippi River.

The largest contributor of suspended sand to the lower Missouri River between 1981 and 1991 was estimated to be sand from the main-stem reach between Gavins Point Dam, South Dakota, and Sioux City, Iowa, followed by contributions from the Platte River in Nebraska. If additional potential diversions that substantially reduce flows take place in the Platte River there likely will be a substantial reduction in sand loads from this primary tributary.

Results of step-trend analyses to examine changes in annual loads, concentrations, and streamflows between the pre- (pre-1953) and post- (post-1967) Missouri River main-stem impoundment periods indicated statistically significant declines in loads and concentrations at most stations. The greatest difference in median sediment loads between the two periods (-99.8 percent) was recorded at the Missouri River at Yankton, South Dakota, about 8 kilometers downstream from the most downstream main-stem impoundment. The difference of about 126 million metric tons between the pre-1953 and post-1967 periods at this station provides a median annual estimate of sediment trapped by the upstream reservoirs. This represents about 56 percent of the median annual load decline of 224 million metric tons at Hermann, Missouri in the post-impoundment period. The remaining 98 million metric tons, or 44 percent, of the Hermann load reduction can be attributed to other factors including reductions in sediment from tributaries. About 47 percent of the post-1967 sediment load reduction of the lower Mississippi River (Mississippi River at Tarbert Landing, Mississippi, and the Atchafalaya River at Simmesport, Louisiana) could be accounted for by post-impoundment reductions from the Missouri River at Hermann, Missouri.

The sediment transport regimes of all five major subbasins within the Mississippi River Basin have been affected by channel modifications, navigation structures, and main-stem or tributary impoundments. Changes in suspended-sediment and suspended-sand loads and concentrations generally were downward for the 60-, 34-, and 12-year periods analyzed in this study. The downward trend in sediment loads began before the construction of main-stem impoundments on the Missouri River, but the abrupt and extensive decline in sediment transport following the closure of Fort Randall Dam in 1952 was the single largest event accelerating the decline in sediment from the Mississippi River Basin. The downward trend in sediment transport at Missouri River and downstream Mississippi River stations has continued since the completion of the Missouri River main-stem impoundments.

The results of 1950–2009 trend analyses indicate that declines in suspended-sediment loads and flow-weighted concentrations were widespread throughout the Missouri and lower Mississippi River Basin stations. A decrease in flow-adjusted suspended-sediment concentrations at Missouri and Arkansas River stations in the 1960s and 1970s indicated that less suspended material was being transported for a given flow condition and likely correspond to adjustments in the sediment conveyance system in these rivers from a transport-limited system to a supply-limited system following the construction of impoundments.

There were larger declines in suspended-sediment loads and concentrations than sand loads and concentrations in the post-impoundment period at several stations in the Missouri River Basin and the most downstream station on the Mississippi River. A larger decline in silt and clay fractions of sediment transport in the system could possibly reflect the effects of conservation practices in the basin that would target topsoil containing more silt and clay than sand.

All significant trends in suspended-sediment loads and flow-weighted concentrations during the 1976–2009 period were downward and included stations within each major subbasin in the Mississippi River Basin except the Arkansas River Basin. The temporal changes in flow-adjusted suspended-sediment concentrations during the 1976–2009 period indicated there were substantial effects of the 1993 and 1995 floods on sediment transport at the Missouri River at Saint Joseph and Kansas City, Missouri, stations. The downward changes in flow-adjusted concentrations recovered at both stations by about 2003.

The majority of Mississippi River Basin stations also showed downward but nonsignificant temporal changes in suspended-sediment loads, concentrations, and streamflows during the post-channel modification analysis period of 1998–2009. The downward temporal changes in streamflows during the analysis period likely account for most of the declines in loads and concentrations.

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