USGS
science for a changing world

Prepared in cooperation with the Metropolitan St. Louis Sewer District

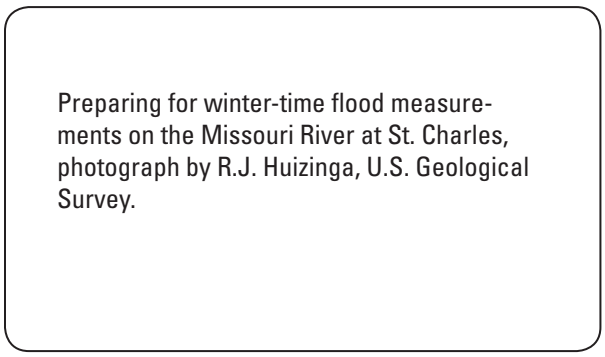
Occurrence and Sources of *Escherichia coli* in Metropolitan St. Louis Streams, October 2004 through September 2007

Scientific Investigations Report 2010–5150

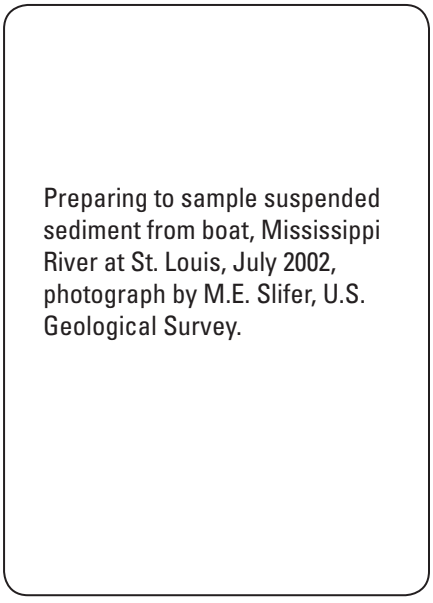
U.S. Department of the Interior
U.S. Geological Survey

Cover photograph index

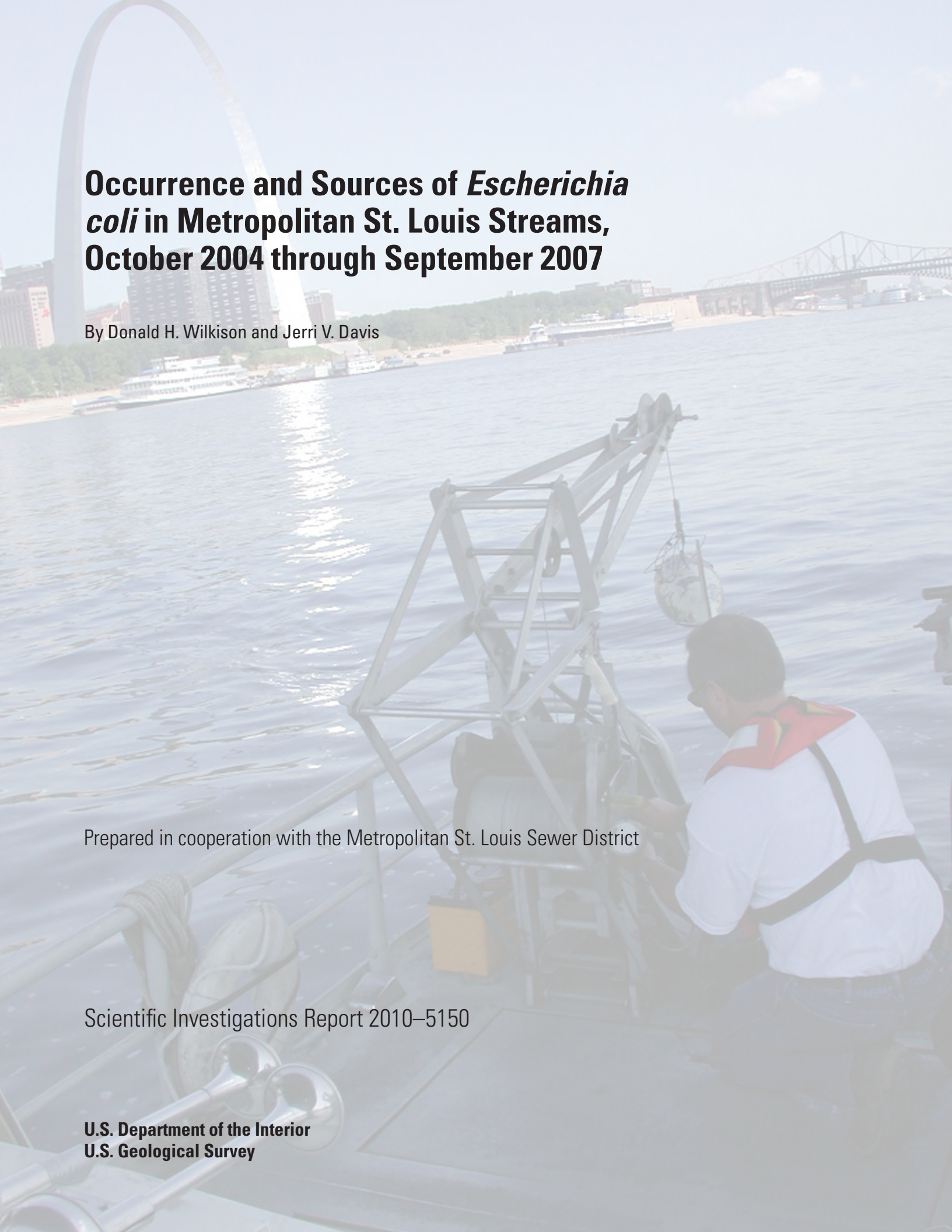
Mississippi River at St. Louis, July 2002, photograph by M.E. Slifer, U.S. Geological Survey.



Preparing for winter-time flood measurements on the Missouri River at St. Charles, photograph by R.J. Huizinga, U.S. Geological Survey.



Preparing to sample suspended sediment from boat, Mississippi River at St. Louis, July 2002, photograph by M.E. Slifer, U.S. Geological Survey.



Occurrence and Sources of *Escherichia coli* in Metropolitan St. Louis Streams, October 2004 through September 2007

By Donald H. Wilkison and Jerri V. Davis

Prepared in cooperation with the Metropolitan St. Louis Sewer District

Scientific Investigations Report 2010–5150

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

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

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

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

Suggested citation:
Wilkison, D.H., Davis, J.V., 2010, Occurrence and sources of *Escherichia coli* in metropolitan St. Louis streams, October 2004 through September 2007: U.S. Geological Survey Scientific Investigations Report 2010–5150, 57 p.

Contents

Figures

Tables

Conversion Factors, Abbreviations, and Datums

SI to Inch/Pound

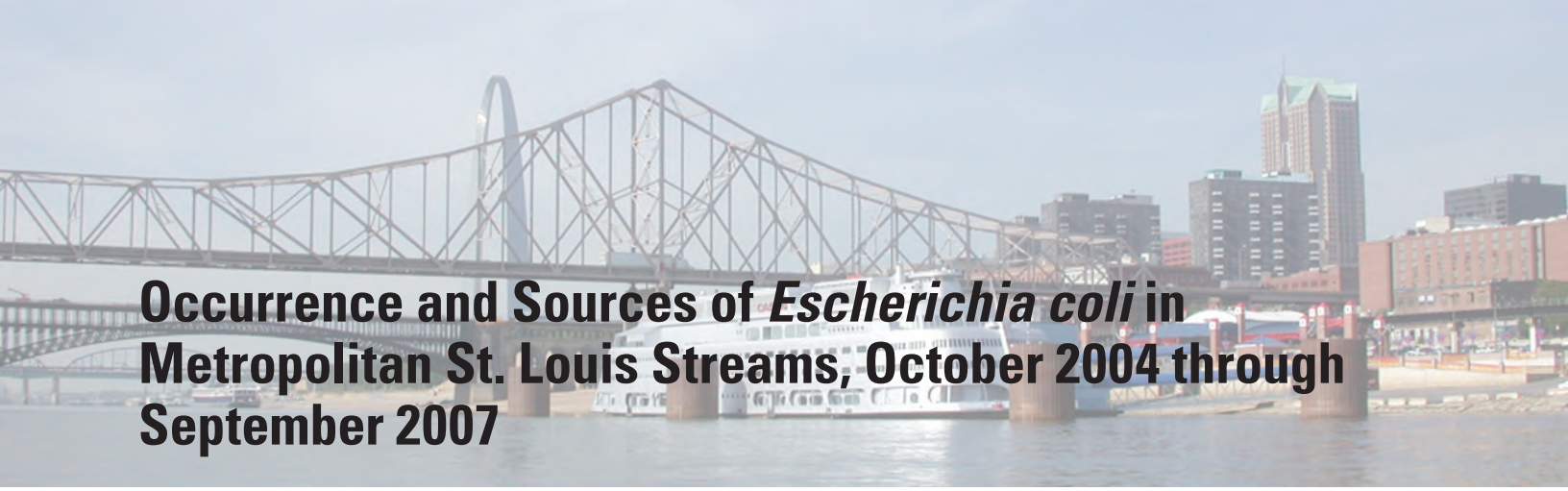
Multiply	By	To obtain
	Length	
meter (m)	3.281	foot (ft)
kilometer (km)	0.6214	mile (mi)
	Area	
square kilometer (km^2)	0.3861	square mile (mi^2)
	Volume	
liter (L)	0.2642	gallon (gal)

Inch/Pound to SI

Multiply	By	To obtain
	Length	
inch (in.)	2.54	centimeter (cm)
	Area	
square foot (ft^2)	0.09290	square meter (m^2)
	Volume	
gallon (gal)	3.785	liter (L)
gallon (gal)	0.003785	cubic meter (m^3)
cubic foot (ft^3)	0.02832	cubic meter (m^3)
	Flow rate	
foot per second (ft/s)	0.3048	meter per second (m/s)
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)

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

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



Occurrence and Sources of *Escherichia coli* in Metropolitan St. Louis Streams, October 2004 through September 2007

By Donald H. Wilkison and Jerri V. Davis

Abstract

The occurrence and sources of *Escherichia coli* (*E. coli*), one of several fecal indicator bacteria, in metropolitan St. Louis streams known to receive nonpoint source runoff, occasional discharges from combined and sanitary sewers, and treated wastewater effluent were investigated from October 2004 through September 2007. Three Missouri River sites, five Mississippi River sites, and six small basin tributary stream sites were sampled during base flow and storm events for the presence of *E. coli* and their sources. *E. coli* host-source determinations were conducted using local library based genotypic methods. Human fecal contamination in stream samples was additionally confirmed by the presence of *Bacteroides thetaiotaomicron*, an anaerobic, enteric bacterium with a high occurrence in, and specificity to, humans.

Missouri River *E. coli* densities and loads during base flow were approximately 10 times greater than those in the Mississippi River above its confluence with the Missouri River. Although substantial amounts of *E. coli* originated from within the study area during base flow and storm events, considerable amounts of *E. coli* in the Missouri River, as well as in the middle Mississippi River sections downstream from its confluence with the Missouri River, originated in Missouri River reaches upstream from the study area. In lower Mississippi River reaches, bacteria contributions from the numerous combined and sanitary sewer overflows within the study area, as well as contributions from nonpoint source runoff, greatly increased instream *E. coli* densities.

Although other urban factors cannot be discounted, average *E. coli* densities in streams were strongly correlated with the number of upstream combined and sanitary sewer overflow points, and the percentage of upstream impervious cover. Small basin sites with the greatest number of combined and sanitary sewer overflows (Maline Creek and the River des Peres) had larger *E. coli* densities, larger loads, and a greater percentage of *E. coli* attributable to humans than other small basin sites; however, even though small basin *E. coli* densities typically were much larger than in large river receiving streams, small basins contributed, on average, only a small part (a maximum of 16 percent) of the total *E. coli* load to larger rivers.

On average, approximately one-third of *E. coli* in metropolitan St. Louis streams was identified as originating from humans. Another one-third of the *E. coli* was determined to have originated from unidentified sources; dogs and geese contributed lesser amounts, 10 and 20 percent, of the total instream bacteria. Sources of *E. coli* were largely independent of hydrologic conditions—an indication that sources remained relatively consistent with time.

Introduction

The Metropolitan St. Louis Sewer District (MSD) is developing a baseline of stream discharge and water-quality data at stream sites within its jurisdictional area (fig. 1; table 1). Streams within the MSD boundaries receive inputs from a variety of sources including, and most predominantly, nonpoint source runoff, combined sewer overflows (CSOs), sanitary sewer overflows (SSOs), and discharges from wastewater treatment plants (WWTPs). One concern is the presence of large densities of fecal indicator bacteria, including *Escherichia coli* (*E. coli*), in streams within the MSD area. To better understand factors that affect stream water quality in the MSD area, the U.S. Geological Survey (USGS), in cooperation with the MSD, initiated a study designed to characterize the occurrence, distribution, and sources of *E. coli* in metropolitan St. Louis streams.

Background

MSD serves approximately 1.4 million people in St. Louis City and St. Louis County. All of St. Louis City and part of eastern St. Louis County are served by a combined sewer system (CSS). The remainder of St. Louis County is served by separate storm and sanitary sewer systems. Approximately 750 municipalities in the United States have a CSS (U.S. Environmental Protection Agency, 2004). Unlike a separate

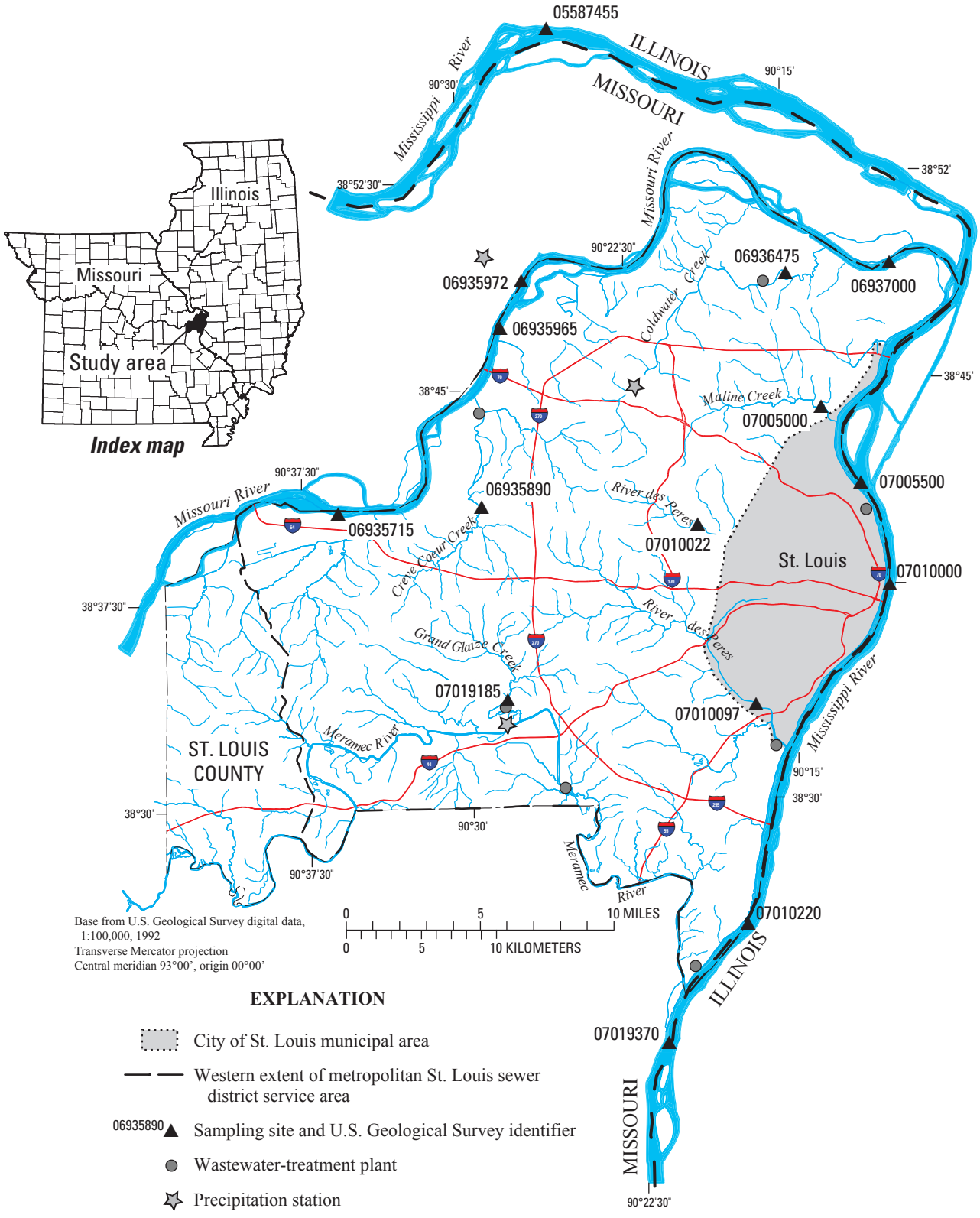


Figure 1. Location of study area and sampling sites.

Table 1. Sites sampled as part of this study.

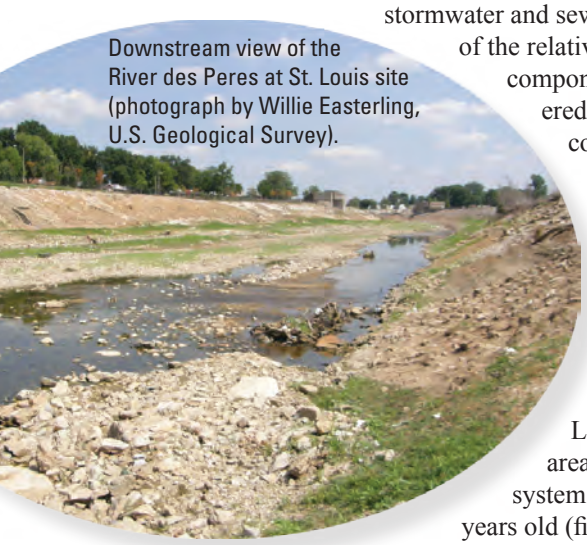
[mm, mile marker; °, degrees;', minutes;", seconds]

Site name (**Bold** part indicates abbreviated name used in text)	Station identifier (fig. 1)	Site type	Latitude	Longitude	Stream reach	General description
			Missouri River sites			
Missouri River near Chesterfield at mm 48	06935715	Large river	38°39'46"	90°43'40"	Upper Missouri	Upstream Missouri River site
Missouri River below St. Charles at mm 24.5	06935972	Large river	38°49'39"	90°26'27"	Mid-Missouri	Midstream Missouri River site below confluence with Creve Coeur Creek
Missouri River at Columbia Bottom Conservation Area at mm 4	06937000	Large river	38°49'18"	90°10'17"	Lower-Missouri	Downstream Missouri River site downstream from the confluence with Coldwater Creek just upstream from the confluence with Mississippi River
			Mississippi River sites			
Mississippi River below Grafton, Illinois	05587455	Large river	38°57'04"	90°22'16"	Upper Mississippi	Upstream Mississippi River site above MSD boundary and confluence with Missouri River
Mississippi River above St. Louis at mm 184.5	07005500	Large river	38°42'03"	90°12'29"	Mid-Mississippi	Mid-Mississippi River site downstream from Missouri River and 3 of the 6 small basin sites
Mississippi River at St. Louis	07010000	Large river	38°37'44.4"	90°10'47.2"	Mid-Mississippi	Mid-Mississippi River site downstream from Missouri River and 3 of the 6 small basin sites
Mississippi River at Oakville at mm 164.5	07010220	Large river	38°25'33"	90°17'39"	Lower Mississippi	Lower Mississippi River stie downstream from other sites in the study area
Mississippi River at Kimmswick, Missouri	07019370	Large river	38°21'28"	90°21'24"	Lower Mississippi	Lower Mississippi River stie downstream from other sites in the study area plus Meramec River
			Small basin sites			
Creve Coeur Creek near Creve Coeur, Missouri	06935890	Small basin	38°40'57.9"	90°29'20.0"	Creve Coeur Creek	Tributary to Missouri River discharging upstream from Missouri River site 06935972
Coldwater Creek near Black Jack, Missouri	06936475	Small basin	38°49'04.8"	90°15'04.5"	Coldwater Creek	Tributary to Missouri River discharging upstream from Missouri River site 06937000
Maline Creek at Bellefontaine Neighbors, Missouri	07005000	Small basin	38°44'12.4"	90°13'34.3"	Maline Creek	Tributary to Mississippi River discharging upstream from Mississippi River site 07005500
River des Peres near University City, Missouri	07010022	Small basin	38°33'33.9"	90°16'59.5"	Upper River des Peres	Tributary to Mississippi River discharging midway between Mid-Mississippi (07005500 and 07010000) and Lower Mississippi sites (07010220 and 07019370)
River des Peres at St. Louis, Missouri	07010097	Small basin	38°33'33.9"	90°16'59.5"	Lower River des Peres	Tributary to Mississippi River discharging midway between Mid-Mississippi (07005500 and 07010000) and Lower Mississippi sites (07010220 and 07019370)
Grand Glaize Creek near Valley Park, Missouri	07019185	Small basin	38°34'06.9"	90°28'16.2"	Grand Glaize Creek	Tributary to Meramec River which then discharges between Lower Mississippi sites (07010220 and 07019370)

sanitary system, CSSs are designed to carry wastewater and storm runoff, and to function differently during dry and wet weather conditions.

In dry weather, a CSS is designed to operate exactly like a separate system and convey sewage from homes, businesses, and industry to a WWTP for treatment. After undergoing treatment, the water is discharged to a receiving stream in accordance with applicable water-quality standards.

During wet weather, the CSS carries sewage and stormwater to the treatment plant where the combination is treated and discharged. If the stormwater and sewage volume exceed pipe or treatment-plant capacities, the excess is diverted into receiving streams. All of this excess flow, a mixture of stormwater and sewage—regardless of the relative ratio of the two components—is considered to be part of a combined sewer overflow (CSO). CSO discharge points primarily are located along the western and eastern edges of the City of St. Louis, primarily in areas where the sewer system is more than 100 years old (fig. 2). Approximately two-thirds of the nearly 200 CSOs in the study area discharge either directly into the River des Peres or one of its tributaries (fig. 2; table 2). Thirty percent of the CSOs discharge directly to the Mississippi River (fig. 2); however, because smaller streams in the study area ultimately drain to the Mississippi River, any CSO discharge eventually makes its way to the Mississippi River. No CSOs in the study area discharge to the Missouri River.



Downstream view of the River des Peres at St. Louis site (photograph by Willie Easterling, U.S. Geological Survey).

Unlike CSSs, separate sanitary sewer systems do not have the capacity to carry stormwater; however, during runoff events, infiltration and inflow into the pipes can cause the collection system to be overloaded. Then, in order to relieve system pressure, excess flow is sometimes diverted to receiving streams—events termed SSOs. In addition to the CSOs, there are approximately 200 constructed SSO points that occasionally discharge in the study area (fig. 2; table 2).

SSOs generally are located along the eastern one-third of St. Louis County (fig. 2). As with CSOs, most SSOs discharge to the River des Peres or its tributaries (fig. 2; table 2). Maline and Coldwater Creek, which are small basin tributaries of the Missouri River (fig. 2), receive approximately one-quarter of the SSO discharges in the study area. Because of the nature of the stream drainage network in the study area, any CSO and SSO discharge ultimately drains to the Mississippi River (fig. 2).

MSD operates seven wastewater treatment plants within the study area (fig. 2). Treated effluent from two of these plants is discharged to the Missouri River, three plants discharge to the Mississippi River, and the remaining two to the Meramec River. Approximately 75 percent of the treated effluent in any given year is discharged to the Mississippi River. An increase in the level of bacteriological treatment is planned for all plants by 2013; however, currently (2010), disinfection is not part of the treatment process (Metropolitan St. Louis Sewer District, 2009a).

Other potential sources of wastewater in the study area include discharges from septic systems, as well as CSOs, SSOs, and treated effluent from WWTPs located outside the MSD jurisdictional area. There are 9 permitted CSOs that discharge into the Mississippi River from the Illinois side of the river. These are located between sites 07005500 and 07010220 (fig. 2). The volume of effluent discharged from WWTPs in the study area not operated by MSD is approximately 15 percent of that from MSD-operated facilities (U.S. Environmental Protection Agency, 2010). The bulk of this effluent is discharged to the Mississippi River.

Long-term control plans, designed to implement strategies that would reduce the volume and frequency of these CSOs and SSOs and to ensure compliance with Federal clean water statutes and applicable water-quality standards (U.S. Environmental Protection Agency, 1994; Missouri Department of Natural Resources, 2009) have been developed (Metropolitan St. Louis Sewer District, 2009b). Data on the system status and expected benefits from system alterations were part of these plans. Such data can be especially important in urban areas where additional factors—beyond CSOs and SSOs—such as nonpoint source runoff may substantially degrade water quality. Water quality degraded by fecal contamination is of particular concern because such contamination can be indicative of the presence of pathogens and lead to increased risk of gastrointestinal illnesses in humans (Wade and others, 2003; Haack and others, 2008; Duris and others, 2009).

Purpose and Scope

This report characterizes the occurrence and sources of the fecal indicator bacteria *E. coli* in metropolitan St. Louis stream reaches that receive urban nonpoint runoff, combined and sanitary sewer overflows, and treated wastewater effluent. Surface water-quality samples were collected from October 2004 through September 2007 during base flow and storm events for indicator bacteria, including *E. coli* and sources of *E. coli*, at the sites listed in table 1. Three sites on the Missouri River, 5 on the Mississippi River, and 6 on small streams affected by CSOs, SSOs, treated effluent, or urban nonpoint source runoff were sampled. In addition, dog and goose feces, collected from landscapes closely associated with study sites, together with untreated human wastewater samples collected from WWTPs operated by MSD (fig. 2), were used to develop a genetically based *E. coli* source library for the study area.

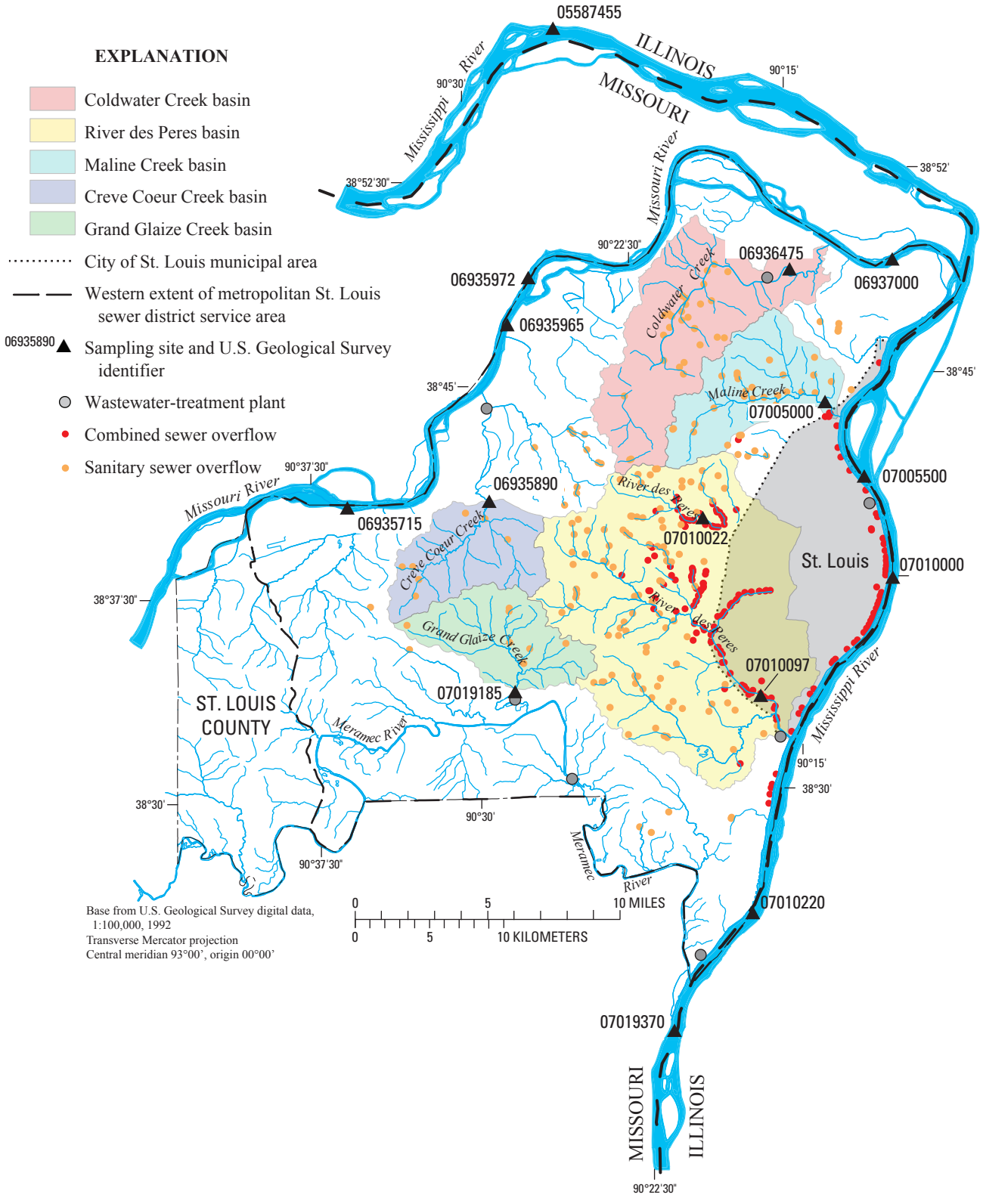


Figure 2. Location of combined sewer overflows, sanitary sewer overflows, and wastewater treatment plants maintained by the Metropolitan St. Louis Sewer District in relation to study area sampling sites.

Table 2. Number of combined and sanitary sewer overflow points upstream from sample sites and estimated travel time between sites or to receiving stream.

[CSOs, Combined Sewer Overflows; SSOs, Sanitary Sewer Overflows; mm, mile marker; f/s, feet per second; --, not applicable]

Site name (**Bold** part indicates abbreviated name used in text)	Station identifier (fig. 1)	Mile marker	Distance from adjacent upstream station or to receiving stream, in miles	Aggregate distance, in miles	Mean storm event velocity, in ft/s	Mean base-flow velocity, in ft/s	Mean velocity, in ft/s	Storm event travel time, in hours	Base-flow travel time, in hours	Mean travel time, in hours	Number of upstream CSOs	Number of upstream SSOs	Receiving stream
Missouri River sites													
Missouri River near Chesterfield at mm 48	06935715	48	--	0	4.0	3.1	--	--	--	--	0	0	--
Missouri River below St. Charles at mm 24.5	06935972	24.5	23.5	23.5	4.0	3.1	3.4	9	11	10	0	20	--
Missouri River at Columbia Bottom Conservation Area at mm 4	06937000	4	20.5	44	4.0	3.1	3.4	8	10	9	0	50	--
Confluence with Mississippi River	--	0	48	48	--	--	3.4	18	23	21	0	50	--
Average travel time between sites	--	--	--	--	--	--	--	--	--	9	--	--	--
Mississippi River sites													
Mississippi River below Grafton, Illinois	05587455	218	--	0	--	--	--	--	--	--	0	0	--
Mouth of Missouri River	--	195	23.0	23.0	5.0	3.2	4.0	7	11	8	0	0	--
Mississippi River above St. Louis at mm 184.5	07005500	184.5	10.5	33.5	5.0	3.2	4.0	3	5	4	9	87	--
Mississippi River at St. Louis	07010000	180	4.5	38.0	5.0	3.2	4.0	1	2	2	35	87	--
Mississippi River at Oakville at mm 164.5	07010220	164.5	15.5	53.5	5.0	3.2	4.0	5	7	6	198	192	--
Mississippi River at Kimmswick, Missouri	07019370	158.6	5.9	59.4	5.0	3.2	4.0	2	3	2	198	203	--
From **Mississippi River below Grafton, Illinois** to **Mississippi River at Kimmswick**, Missouri	"05587455 to 07019370"	--	59.4	59.4	5.0	3.2	4.0	18	27	22	--	--	--

Table 2. Number of combined and sanitary sewer overflow points upstream from sample sites and estimated travel time between sites or to receiving stream.—Continued

[CSOs, Combined Sewer Overflows; SSOs, Sanitary Sewer Overflows; mm, mile marker; f/s, feet per second; --, not applicable]

Site name (**Bold** part indicates abbreviated name used in text)	Station identifier (fig. 1)	Mile marker	Distance from adjacent upstream station or to receiving stream, in miles	Aggregate distance, in miles	Mean storm event velocity, in ft/s	Mean base-flow velocity, in ft/s	Mean velocity, in ft/s	Storm event travel time, in hours	Base-flow travel time, in hours	Mean travel time, in hours	Number of upstream CSOs	Number of upstream SSOs	Receiving stream
Mississippi River sites—Continued													
From **Missouri River near Chesterfield** to **Mississippi River at Kimmswick**, Missouri	"06935715 to 07019370"	--	107	107	4.6	3.2	3.8	35	50	42	--	--	--
Average travel time between sites	--	--	--	--	--	--	--	--	--	5	--	--	--
Small basin sites													
Creve Coeur Creek near Creve Coeur, Missouri	06935890	--	5.7	--	3.6	0.53	2.1	2	16	4	0	7	Missouri River
Coldwater Creek near Black Jack, Missouri	06936475	--	3.8	--	1.7	.56	1.1	3	10	5	0	30	Missouri River
Maline Creek at Bellefontaine Neighbors, Missouri	07005000	--	1.1	--	2.2	.56	1.4	1	3	1	0	26	Mississippi River
River des Peres near University City, Missouri	07010022	--	12.0	--	5.9	2.5	4.2	3	7	4	17	15	River des Peres at St. Louis
River des Peres near University City, Missouri	07010022	--	14.5	--	5.2	2.3	3.7	4	9	6	17	15	Mississippi River
River des Peres at St. Louis, Missouri	07010097	--	2.5	--	2.0	.54	1.3	2	7	3	133	103	Mississippi River
Grand Glaize Creek near Valley Park, Missouri	07019185	--	3.3	--	1.4	.61	1.0	3	8	5	0	7	Meramec River
Grand Glaize Creek near Valley Park, Missouri	07019185	--	23.8	--	1.4	.61	1.0	24	58	34	0	7	Mississippi River
Average travel time between sites	--	--	--	--	--	--	--	--	--	8	--	--	Missouri or Mississippi River

Estimates of annual *E. coli* loads, determined from trend and load estimation models developed from discrete data collected over a wide range of hydrologic conditions from October 1998 through September 2007 also are presented. These data may be used to better understand the relative contribution of point and nonpoint sources to stream contaminants, to understand the role that hydrology has in determining concentration and load patterns and how those patterns change with time, and to provide a baseline for evaluating the effectiveness of long-term CSO control and watershed management plans to meet water-quality standards and protect designated stream uses.

Study Area Description

The study area comprises 14 surface-water sites located in the MSD, a customer-owned utility providing sanitary sewage and stormwater service within the 535 square miles of St. Louis City and most of St. Louis County (fig.1; table 1). Sample sites included 3 sites on the Missouri River, 5 on the Mississippi River, and 6 sites on smaller tributary streams affected by CSOs, SSOs, treated effluent, and/or urban nonpoint runoff (figs. 1 and 2). Continuous (hourly) streamflow data also were collected for the Missouri River at St. Charles (site 06935965; figs.1 and 2). During an average precipitation year, such as 2000, as many as 65 overflow events occur in the study area discharging 13.3 billion gallons of overflow to receiving streams (Metropolitan St. Louis Sewer District, 2009b). More than 95 percent of the CSO volume is discharged to the River des Peres or the Mississippi River (Metropolitan St. Louis Sewer District, 2009b).

Land use in the study area is more than 60 percent urban (Lanclos and others, 2005). Many stream reaches have been substantially modified with resultant changes, such as rapid stormwater and contaminant transport from impervious areas to streams through drainage pipe networks, to hydrology and channel morphology (fig. 3). This typically results in peak lag time reductions and increased water-quality degradation (Walsh and others, 2005). Additionally, extensive engineered modifications designed to facilitate river navigation and flood mitigation have occurred in reaches of the Missouri and Mississippi River throughout the study area (Pinter and others, 2009). One major effect of these modifications has been to alter the sediment transport dynamics of these rivers from being limited by sediment supply rather than transport processes (Meade and Moody, 2010). Nevertheless, suspended sediment concentrations, especially on the Missouri and Mississippi Rivers typically are high; concentrations averaged 494 mg/L for the Missouri River at St. Charles (site 06935965; fig. 1) and 532 mg/L for the Mississippi River at St. Louis (site 07010000) during the course of this study (U.S. Geological Survey, 2006a; 2007; 2008).

Figure 3. View upstream from River des Peres near University City (site 07010022).

Travel times in the study area, estimated from peak arrival times between adjacent stations or stream velocity measurements made during discharge measurements, indicate that during storm events, CSO and SSO discharges quickly move (travel times ranged from 1 to 4 hours) from small basin sites into the larger receiving streams (table 2). Average travel times from one large river site to the next downstream site ranged from 9 hours at Missouri River sites to 5 hours for Mississippi River sites (table 2). Instream velocities at study sites typically were greater than was needed to maintain sediments in suspension; this was especially true at large river sites where average stream velocities were more than 10 times greater than was needed to keep sediment, even coarse sand particles, in suspension (Weiming and Wang, 2006).

Average annual precipitation in the study area, based upon precipitation stations (fig. 1) that have at least 90 years of record, is 38.2 inches (National Climatic Data Center, 2010). Annual precipitation for the 2005 to 2007 water years (from October 1 to September 30 of each year) was 96 percent of the long-term average. The wettest year was 2005 (117 percent of normal), followed by the driest (72 percent of normal) year, and then a return to near normal conditions (97 percent) in 2007 (National Climatic Data Center, 2010).

Previous Studies

Water-quality and streamflow data have been collected in the study area since 1996 as part of a cooperative agreement between the MSD and the USGS. Data at some sites have been collected at long-term stations as part of the USGS National Stream Quality Accounting Network (Hooper and others, 2001). These data, including results from more than 1,800 water-quality samples, have been published in USGS annual reports and made available online (*http://waterdata.usgs.gov/mo/nwis/sw; http://nwis/waterdata.usgs.gov/mo/nwis/qw*).

Previous work (Wilkison and others, 2002; 2006; 2009) demonstrated that the combination of many factors, including inputs from nonpoint source runoff, CSOs, and WWTP discharges, frequently provides a diversity of *E. coli* sources

to urban streams. Other work, albeit in more rural settings, has demonstrated that elevated fecal indicator bacteria densities in receiving streams frequently originate from multiple sources (Schumacher, 2003; Davis and Barr, 2006; Ahmed and others, 2008). These factors, coupled with the rapid evolution of microbial source-tracking methods, have lead other researchers (Cimenti and others, 2007; Santo Domingo and others, 2007; Haack and others, 2008) to insist that comprehensive source assessments of fecal pollution should include multiple approaches.

Once released to the environment, enteric indicator bacteria such as *E. coli* are subjected to a variety of biotic and abiotic pressures that affect survivability. Biotic pressures include grazing and competition for resources by other biota as well as bacteria regrowth. Abiotic pressures include bacterial inactivation by sunlight, temperature, pH, salinity, or chemicals (Hipsey and others, 2008). Of these, solar inactivation is deemed the most important process affecting the environmental mortality of *E. coli* (Whitman and others, 2004; Deller and others, 2006). In general, *E. coli* survival in the environment follows an exponential decay rate (Schultz-Fademrecht and others, 2008); however, a number of studies have demonstrated that little, if any, change in *E. coli* densities occurs within the first 24 hours of release into the environment, and in the case where sunlight is limited—such as turbid, sediment-laden waters—steady-state conditions can persist for several days, if not weeks (Anderson and others, 2005; Chandran and Hatha, 2005; Pote and others, 2009; Sevais and others, 2009).

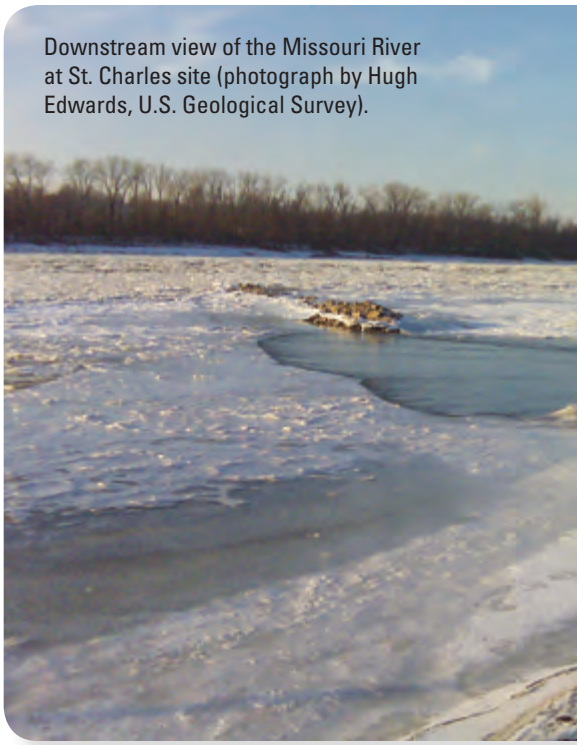
Methods

Approximately 500 water-quality samples were collected from 14 surface-water sites from October 2004 through September 2007 in metropolitan St. Louis. Samples were collected for a variety of hydrologic conditions and analyzed for indicator bacteria (*E. coli* and fecal coliform). The sources of *E. coli* were determined in 328 samples using genotypic methods that included repetitive extragenic palindromic polymerase chain reaction (rep-PCR) and determination of *Bacteroides thetaiotaomicron* (*B. thetaiotaomicron*). Annual load estimates were summed from daily estimates developed from load regression models. A geographic information system (ArcGIS, v. 9.3, ESRI Inc.) was used to determine relations between water-quality data and selected land-use factors to evaluate the relative role of nonpoint source runoff compared to selected point sources (overflows from combined and sanitary sewers) at study sites.

Sampling and Laboratory Protocols

Surface-water samples were collected during base flow and storm events from 14 sites in metropolitan St. Louis between September 2004 and October 2007. Sample collection was distributed over the entire year, but most samples were collected between April 1 through October 31 of any given year to coincide with the State-defined, recreational season (Missouri Department of Natural Resources, 2009). For the purposes of this study, base flow is defined as streamflow unaffected by runoff at small basin sites (table 1). Given the size of the Missouri and Mississippi River Basins, flows in these rivers are, to some extent, always affected by runoff; however, during this study, base-flow conditions indicated that large river sites had not been affected by localized runoff in the previous 72 hours. Likewise, since the intent was to measure local, rather than regional, effects, storm-event sample collection was determined by precipitation events that occurred within the study area; therefore, the hydrologic response at small basin sites was greater when compared to that of the large river sites during storm events.

Streamflow was determined by discharge measurements made at the time of sample collection or from established stage-discharge relations (ratings) using USGS procedures outlined by Rantz and others (1982a, 1982b) and Simpson (2001). Ratings were periodically updated throughout the course of the study as additional measurements and analysis of the stage-discharge relations warranted. Daily mean streamflow and water-quality values were published annually (U.S. Geological Survey, 2006a, 2007, 2008) and are available in the USGS National Water Information System (NWIS) (U.S. Geological Survey, 2009).



Downstream view of the Missouri River at St. Charles site (photograph by Hugh Edwards, U.S. Geological Survey).

All water-quality samples were collected and processed using protocols designed to prevent sample contamination. Collection and processing equipment were comprised of inert materials—glass, fluorocarbon polymer, or stainless steel capable of sterilization (Lane and others, 2003; Wilde, 2004; Wilde and others, 2004; Wilde, 2005). Samples were depth- and width-integrated across streams unless depth or width limitations necessitated the collection of grab samples from the centroid of flow (U.S. Geological Survey, 2006b). On small streams, bacteria samples were collected from the centroid of flow; on large rivers, bacteria samples were

composited from three equally distributed cross-section points. Storm-event samples were collected during, or immediately following, precipitation events that were expected to be of sufficient duration and intensity to trigger CSO and SSO events from April 1 through October 31 of each year. Small basin sites were sampled only after a minimum 1 foot rise in water levels occurred at the gage. Large river sites were sampled following local precipitation events of 0.75 inch or greater within a 24-hour period. Because the drainage area at large river sites was approximately one thousand times greater than that of the study area, flows at large river sites during sampling events were only partly determined by local runoff. Characterization of the magnitude and duration of overflow events was not part of this study, but at least some overflow events were assumed to have occurred during every storm event. Field personnel collected samples before storm peaks passed, or the event was not sampled. Because the collection of storm-event samples was dependent upon local precipitation events, the hydrographic response at small basin sites was more pronounced relative to the response observed at large river sites for these events.

Stream samples were analyzed for physical properties, fecal-indicator bacteria (*E. coli* and fecal coliform) and sources, nutrients, major ions, and trace metals. This report describes the *E. coli* results; physical properties, fecal coliform, nutrients, major ions, and trace metal data are reported elsewhere (U.S. Geological Survey, 2006a, 2007, 2008, 2009).

E. coli samples were analyzed using culture-based membrane filtration techniques (Dufour and others, 1981; U.S. Environmental Protection Agency, 2002; U.S. Environmental Protection Agency, 2006; Myers and others, 2007) and enumerated using multiple dilutions (a minimum of three) to better ensure an optimal range in density; any densities outside of tolerance limits were estimated using standardized criteria for nonideal counts (Myers and others, 2007). Before March 2007 *E. coli* samples were cultured using membrane-thermotolerant *E. coli* (mTEC) agar (U.S. Environmental Protection Agency, 2006), whereas samples collected after that date were cultured using modified membrane-thermotolerant *E. coli* (modified-mTEC) agar (U.S. Environmental Protection Agency, 2002). Both methods utilize the same nutrient growth media, the difference being modified mTEC agar allows for faster and easier enumeration of the target organisms because it does not require the transfer of the membrane to another substrate to stain the colonies (U.S. Environmental Protection Agency, 2000).


September 2008 flood at Grand Glaize Creek near Valley Park site (photograph by Paul Rydlund, U.S. Geological Survey).

Selected base-flow and storm-event samples were analyzed at the University of Missouri, Columbia (UMC), College of Veterinary Medicine, Microbial Source Tracking (MST) laboratory for presumptive host sources using microbial source-tracking methods (Carson and others, 2003; Carson and others, 2005; Davis and Barr, 2006; Wilkison and others, 2005; Yampara-Iquise and others, 2008). The presumptive host sources (dogs, geese, and humans) were chosen because they were known to exist in the study area in sufficient numbers to potentially supply bacteria to streams and because previous studies (Wilkison and others, 2009) had demonstrated these sources were detected frequently in urban streams. Microbial source-tracking methods included rep-PCR for *E. coli* host-source determination and analysis of the human symbiotic bacterium, *B. thetaiotaomicron*. Microbial source-tracking samples were collected in sterile, DNA-free containers, chilled at 4 ºC until delivery to the UMC-MST laboratory, and processed within 24 hours of collection.

The rep-PCR method used multivariate statistical methods to compare the pattern similarity of unknown environmental *E. coli* isolates to the isolate patterns of known sources. For this study, the known host-source library was developed from *E. coli* isolate patterns obtained from sewage (673 isolates), dog (404 isolates), and geese (456 isolates) feces collected within the study area. Library samples were collected at sites that reasonably could have been expected to have contributed fecal contamination to study sites. Library development extended over the study period, October 2004 through September 2007, to minimize geographic and temporal variations that can occur with isolates.

Slightly more than 60 percent (199 of 317 total samples) of rep-PCR samples additionally were analyzed for genetic markers associated with the enteric bacterium, *B. thetaiotaomicron*, a predominant species in human feces (Holdeman and others, 1976). The presence of *B. thetaiotaomicron* was confirmed by PCR amplification using incremental (1 to 10 nanograms) quantities of 16S ribosomal DNA (Teng and others, 2004; Carson and others, 2005; Yampara-Iquise and others, 2008). The presence of *B. thetaiotaomicron* provides important confirmatory information about the presence of human fecal pollution. Because it is considered a human symbiont, *B. thetaiotaomicron* requires different conditions than *E. coli* for survival in the human gut, and is not expected to persist for extended periods once released in the environment (Walters and Field, 2006); thus, the presence of *B. thetaiotaomicron* is considered a reliable marker for recent environmental human fecal contamination.

Multiple lines of evidence were used to evaluate study results, especially as they related to host-source determinations (Stoeckel, 2005). Sampling was designed to evaluate bacteria densities and sources in tributary streams as well as to compare tributary densities and sources to those measured

in the larger river receiving stems during distinct hydrologic conditions. Additionally, data were evaluated in the context of transport pathways; for example, the amount of impervious cover in the basin; potential bacteria contributions, especially those such as CSO, SSO, and WWTP inputs that might be indicative of human sources; and comparison of annual loadings between sites.

The genetic similarity of *E. coli* isolated from water samples was compared to *E. coli* isolated from three hosts—dogs, humans, and geese—all of which were known to be present in the basin based on previous data, field observations, and knowledge of potential contaminant sources. Genetic fingerprint patterns (rep-PCR), isolated from pure *E. coli* cultured from water samples and amplified using BOX A1R primers, were matched against a local host-source library to determine sources (Carson and others, 2003). Genetic fingerprint patterns, consisting of between 18 and 30 bands, from environmental samples were compared to those isolated from known host sources using pattern recognition computer software (Bionumerics software; Applied Maths, Kortrijk, Belgium). Host-source classification was assigned only when matches were 80 percent or greater based on pairwise maximum similarity coefficients calculated by the curve-based Pearson correlation method for discriminant analysis (Carson and others, 2003). Environmental isolates with similarities of less than 80 percent to host sources were classified as unidentified. *E. coli* classified as unidentified may have originated from animals not targeted as part of this study or from one of the three targeted hosts but whose genetic signature was not represented in the host-source library. Classification accuracy was measured by jackknife analysis which qualifies the relative uncertainty of correct classification by measuring the distance in similarity between unknowns and library samples (Ritter and others, 2003). Interpretations related to host-source determinations were made on the central tendency of grouped data to minimize the effect that analytical uncertainties in bacteriological measurements may have had on the results.

Quality Assurance

Approximately 10 percent of all field samples collected consisted of quality-control samples designed to ensure the integrity of the water-quality data analyzed in this report. Field replicate samples were collected to determine the effect that variability in sample collection and processing procedures may have on the precision of environmental concentrations. Field equipment blank samples were used to detect sample contamination during field collection, sample processing and cleaning, or from lack of sterility (in the case of bacteria samples) of sampling and processing equipment.

Precision estimates of fecal indicator bacteria values, determined from the differences between paired environmental samples and field replicates, are presented in figure 4 and table 3. The mean absolute error between 52 replicate sample pair analyses was 17.1 percent. Median absolute error values were lower—14.3 percent for *E. coli* and 10.0 percent for fecal coliform—an indication that the central tendency of sample replicates was slightly less than the mean. Absolute error values below 20 percent generally are regarded as well within the range of the sensitivity of these tests (Griffith and others, 2006; Francy and Darner, 2000; Noble and others, 2003; Wilkison and others, 2009). These data indicate that the combination of sampling and analytical variability contribute relatively small amounts of uncertainty to analytical results.

More than 100 bacteria blanks of various varieties were processed to ensure that sample collection and processing procedures were sterile. At least once during each sampling trip, a container blank was processed to determine if sample collection equipment was properly sterilized. For this blank, buffer water was poured into a sterilized sample collection bottle, and then a 100-mL aliquot was analyzed for bacteria in the same fashion as the environmental samples. Bacteria were not detected in any of these samples. Additionally, filter blanks were prepared at the beginning of each bacteria processing session. For the filter blank, 100 mLs of buffer solution were filtered and cultured to ensure that the filter and buffer were sterile; none of these samples had bacteria detections. After bacteria processing, a procedure blank was prepared to evaluate analyst rinsing techniques and cross-contamination potential between dilutions at any given site. For this blank, the filter holder was rinsed by the analyst (as was done between sample dilutions), and then, 50 mLs of buffer solution were filtered and cultured. Less than 2 percent of samples had bacteria detections and when these did occur, the bacteria densities were many times less than those enumerated in samples. Filter holders were always changed, or sterilized, between sites to ensure that samples were processed using equipment that was free from contaminants at other sites. Together these data indicate that collection and processing techniques maintained

Table 3. Quality-assurance replicate data for fecal indicator bacteria analyzed as part of this study.

[standard error in colonies per 100 milliliters]

Constituent	Mean absolute error, in percent	Median absolute error, in percent	Standard deviation absolute error, percent	Coefficent of detemination	Standard error	Number of pairs
Escherichia coli	19.4	14.3	22.8	0.99	4	27
Fecal coliform	14.8	10.0	12.8	.99	3	25
Average	17.1	12.1	17.8	.99	3	52

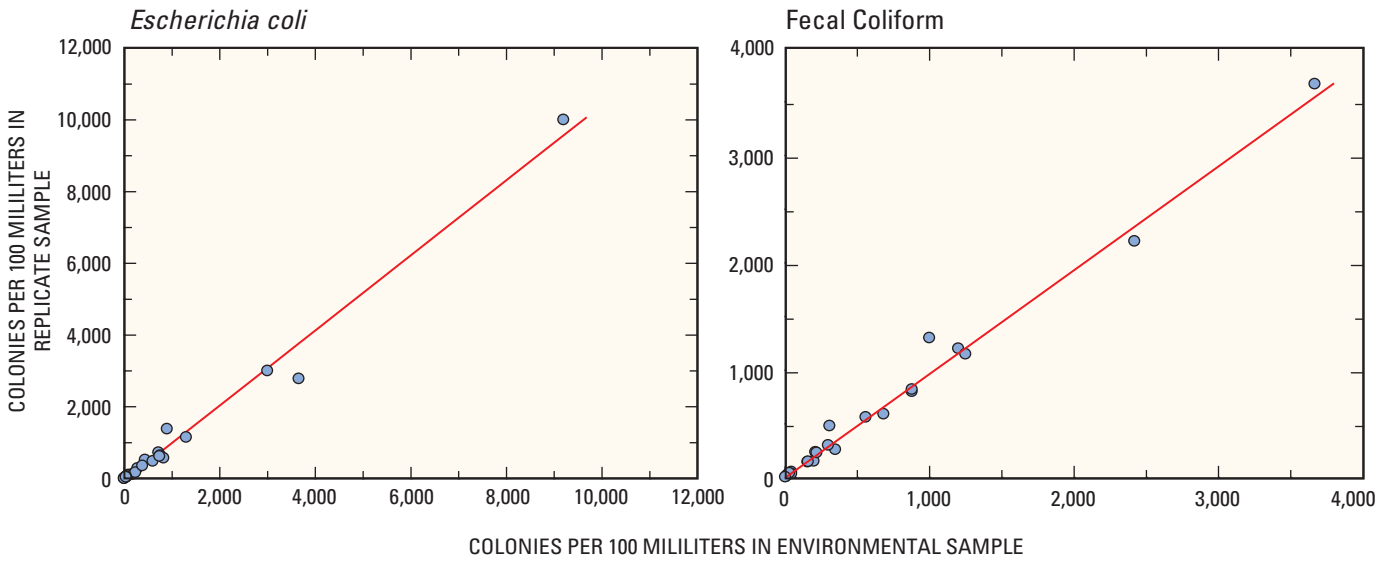


Figure 4. Quantile-quantile plots of *Escherichia coli* and fecal coliform replicate samples collected at sites in the metropolitan St. Louis area.

equipment sterility and that laboratory sample cross-contamination was not an issue in this study.

The precision and accuracy of the microbial source-tracking methods employed in this study have been described previously (Carson and others, 2003; 2005; Griffith and others, 2003; Stoeckel and others, 2004; Yampara-Iquise and others, 2008). To summarize, a five-step, selective growth process (Carson and others, 2001) was utilized to ensure that rep-PCR analyses were performed only on pure *E. coli* isolates. Further, to assess the ability of rep-PCR to determine unknown *E. coli* sources, samples were held from the source library and then presented as unknowns using two distinct approaches—resubstitution and holdout (Carson and others, 2003). Samples had to demonstrate fidelity with the library (greater than 80 percent similarity) before assignment to a host source. Although this approach helps to minimize the potential for false-positives (assignment to a host class when none exists), it also increases the potential for false-negatives (failure to assign to a host source when present). In other words, establishment of this threshold tends to guard more against over-estimation, rather than under-estimation of sources. For the resubstitution method, individual isolates were removed from the library database and then presented later as test subjects; comparisons were determined from Pearson correlation maximum similarity coefficients. This procedure determined the ability of the study library to determine host sources as well as the repeatability of the library predictions with time (Ritter and others, 2003). Resubstituion yielded correct rates of classification of 97 percent for human, 98 percent for dog, and 83 percent for goose (Carson and others, 2003). In the holdout method—considered a more rigorous method test—the validation dataset isolates were not part of the reference library, but were instead presented as unknowns, a technique designed to assess the representativeness of the library for making predictions (Harwood and others, 2000). The rate of correct classification for rep-PCR method as determined by the holdout method, based on the random removal of 25 percent of samples, was determined to be human, 100 percent; dog, 100 percent; and goose, 90 percent (Carson and others, 2003). Additionally, in a separate, controlled blind test using a much smaller library, the rep-PCR method was able to accurately identify human and sewage sources in 83 percent of test samples (Myoda, 2003).

As an additional test of the rep-PCR method, quality-assurance data were collected specific to this study. For example, the library was validated at intervals of about a year, through the use of challenge isolates to test the proficiency of the library to correctly identify sources (Stoeckel and others, 2007). For this technique, essentially a variant of the holdout method, challenge isolates were collected from host sources within the study area and then presented fresh to the library as unknowns. The rate of correct classification of challenge isolates was determined to be 82 percent for human, 75 percent for dog, and 52 percent for geese. The migratory nature of geese may account for variations in genetic signatures and the lower rates of classification. These data indicate that the rep-PCR method and host-source library were sufficiently representative to accurately characterize human and dog *E. coli*, and to a lesser extent, *E. coli* from geese.

Some studies have demonstrated that genetic fingerprint patterns can vary geographically and change with time (Gordon, 2001; Gordon and others, 2002; Hartel and others, 2002, 2003). To minimize the effect such changes might have had on the development of the host-source library, library sample collection varied spatially and temporally in this study and eventually included more than 1,500 isolates—distributed across the three host-source classes—for comparison with environmental samples.

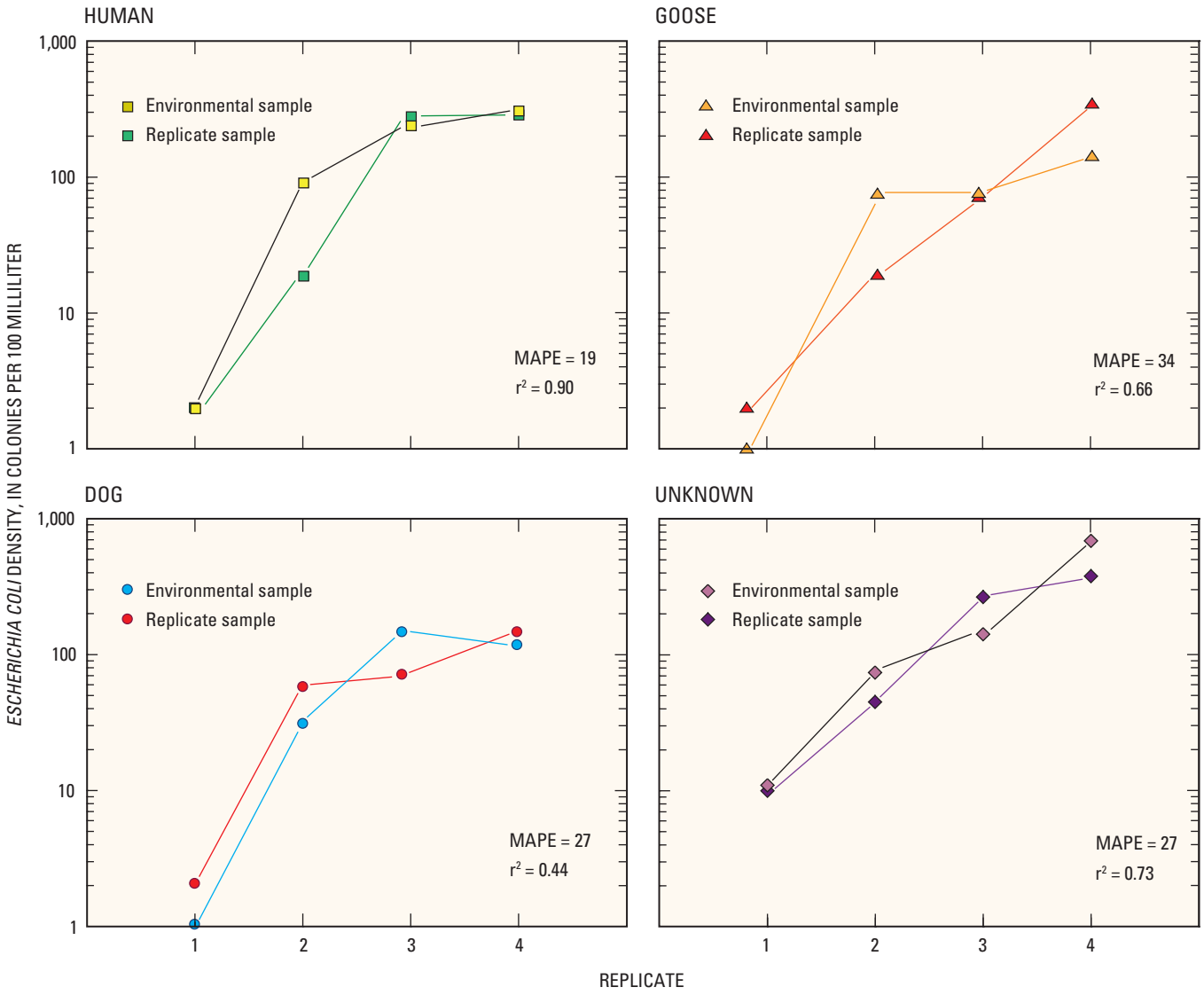


Figure 5. Host-source *Escherichia coli* densities determined in environmental and replicate rep-PCR samples [rep-PCR, repetitive extragenic pallindromic polymerase chain reaction; MAPE, mean absolute percent error; r^2, coefficient of determination].

Replicate rep-PCR samples were collected sequentially in the field and then each sample (environmental and replicate) was processed independently for *E. coli* density as well as the source of *E. coli* by rep-PCR analysis; therefore, replicate rep-PCR samples provide data on how variations in *E. coli* sample collection and enumeration techniques (illustrated in fig. 4 and table 3) coupled with variation in the microbial source-tracking identification procedures may have affected study results. In general, there was good agreement between values determined in environmental samples and those determined in replicates (fig. 5). Samples typed as humans had the smallest mean absolute percent error (19 percent), and those sourced as goose had the greatest (34 percent). The average percent error for all rep-PCR replicates was 27 percent, greater than that of the fecal bacteria measurement errors (table 3) that would be expected because the rep-PCR analysis includes these errors as well. Individual rep-PCR sample results need to be interpreted with caution given the potential range of errors associated with such determinations; therefore, the analysis of host-source determinations in this study focused on the central tendency, or average value, of these data to provide the most meaningful results.

Human fecal contamination was additionally identified using a genetic marker of *B. thetaiotaomicron*, enteric bacterium known to have a frequent occurrence in, and specificity to, humans (Carson and others, 2005). A sensitivity analysis on 1 nanogram of genetic material was used to evaluate the ability of the *B. thetaiotaomicron* marker to verify human fecal contamination. The marker was strongly recovered in 96 percent of human samples, showed faint recovery in 16 percent of dog samples, and was not recovered in any goose samples. Positive detections in dog samples indicated there may be the

potential for some sharing of enteric bacteria between humans and their canine pets but not with geese (Carson and others, 2005).

Data Analysis

Water-quality data were analyzed for various factors that may have been expected to affect *E. coli* densities: loads, patterns, and trends observed in stream samples and at sites during the study. These factors included constituent concentrations and sources, how these factors may have varied spatially and temporally in the basin, and how they may have been related to land cover in the study area. Where applicable, *E. coli* densities have been compared to current (2010) State of Missouri water-quality standards (Missouri Department of Natural Resources, 2009) to demonstrate relevance to established thresholds; however, compliance or noncompliance with numeric criteria was beyond the scope of this study.

Instantaneous *E. coli* loads at stream sites were determined by multiplying the bacteria density in discrete samples (measured in colonies per 100 milliliters) times the streamflow (measured in cubic feet per second) at the time of sample collection and then by an appropriate conversion factor (283.2) to provide data in terms of colonies per second. Host-source *E. coli* allocations were determined by multiplying the instantaneous loads by the percentage of bacteria assigned to any given host. Data were binned by individual site, by river system (large river sites and small basin sites), and by hydrologic event (base flow or storm event) for analysis.

Estimates of *E. coli* annual loads were determined using minimum variance unbiased estimation techniques, a form of multiple linear regression analysis, and the S-LOADEST computer program (Runkel and others, 2004) in Spotfire S-Plus (version 8.1, TIBCO Software, Inc., Palo Alto, California) to develop load estimation models. For model development, the dependent variable was constituent concentration, and the independent variables were streamflow, decimal time, and season. If appropriate, ladders of power transformation of streamflow (Helsel and Hirsch, 1992) and breakpoints in streamflow were used. These procedures were designed to account for nonnormal distributions, seasonal or annual cycles, censored data, biases associated with logarithmic transformation, and serial correlation of the residuals (Cohn, 1988; Cohn and others, 1989).

Model selection was done according to the following criteria. From evaluation of the Akaike information criteria (Akaike, 1981), the best-fit model was selected using combinations of streamflow, natural logarithm of streamflow, square of streamflow, square of the natural logarithm of streamflow, decimal time, square of decimal time, sine and cosine of time, and square of the sine and cosine of time. Residual plots were evaluated for homoscedasticity (constant variance) and normality. Models that failed these critical assumptions were rejected, and additional combinations of the above variables were examined for linearity based upon the rank of the Akaike information criteria. Failing that test, an additional step involved examination of models that incorporated breakpoints in streamflow in combination with the aforementioned time terms.

Each observation in the data set was used to develop a best-fit model, which was then used to estimate daily loads. Daily loads were then summed to provide annual estimates. Yield estimates were determined by dividing the constituent load determined at the site by the site's drainage area. Flow-weighted concentrations were calculated from the estimated loads by dividing the daily mean load by the daily mean streamflow. Flow-adjusted trend, expressed as the average percent change with the time modeled, was determined from the coefficient of the LOADEST model decimal time term using a significance level of 0.05 (Sprague and others, 2006). At the most downstream Mississippi River site (07019370), fecal coliform data were used as a surrogate for the estimation of *E. coli* loads because of the lack of an *E. coli* fitted model and the larger number of samples with fecal coliform data relative to *E. coli* data. Fecal coliform and *E. coli* densities typically are strongly correlated (coefficient of correlations greater than 0.94; Rasmussen and Ziegler, 2003; Wilkison and others, 2006; Garcia-Armisen and others, 2007). On average, 69 percent of the fecal coliform bacteria enumerated at study sites were attributed to *E. coli*. The relation between fecal coliform and *E. coli* densities at metropolitan St. Louis sites is shown in figure 6 (coefficient of correlation, 0.87).

For the purposes of this study, comparisons of *E. coli* densities, loads, and sources between sites assumed that bacteria mortality, inactivation, or regrowth were negligible or remained constant during the time frame needed for downstream transport through the study area. Assessing these conditions was beyond the scope of this study. Although these rates can vary with time (Anderson and others, 2005), given the increased levels of turbidity and suspended sediment at sites, mortality and inactivation of instream *E. coli* would have been minimized as water moved from one site to the next (Whitman and others, 2004; Schultz-Fademrecht and others, 2008; Garcia-Armisen and Servais, 2009; Servais and others, 2009).

The survival profile and clonal composition of *E. coli* species measured in the external environment were assumed to reflect that in the host environments. Some studies have indicated that this might not always be the case (McLellan and others, 2003; Field and Samadpour, 2007); however, these studies typically focused on the behavior of bacteria entering lakes, beaches, or septic systems (Gordon, and others, 2002; McLellan, 2004)—thus, the dynamics affecting survivability would be expected to differ from rivers with increased suspended sediment concentrations and limited light penetration. Variations in the environmental signatures of *E. coli* species were minimized when targeted geographic sampling, such as occurred in this study, were utilized (Kuntz and others, 2003). Additionally, the stability of *E. coli* isolates in natural waters for a wide range of ambient temperatures has been demonstrated for up to 150 days (Seurinck and others,

2003). Analysis of the variation and stability of *E. coli* host species signatures was not part of this study, so it is impossible to determine what effect such changes, if any, may have had on the results. It is likely that some changes did occur during the course of the study; however, the use of multiple approaches to assess fecal sources, such as the combination of PCR techniques and analysis of a human-specific *Bacteroides* marker, has been shown to increase the power of source tracking (Noble and others, 2006). Additionally, given how quickly stream *E. coli* densities can change in response to runoff events, some uncertainty is inherent in any attempt to classify host sources; therefore, percentages assigned to individual host classes were based on the central tendency of the data rather than individual samples.

Occurrence and Sources of *Escherichia coli* in Metropolitan St. Louis Streams

The occurrence and sources of *E. coli*, one of several fecal indicator bacteria, were determined at sites based on several characteristics including hydrologic conditions within the study area (base flow or storm event), site type (large river or small basin), and selected land-cover characteristics such as the percent of upstream impervious cover or potential number of wastewater discharges. In general, *E. coli* densities and loads measured in discrete samples collected from October 2004 through September 2007 were many times greater during storm events than at base flow. This was because *E. coli* densities and flow—a major component of loads—increased as a result of runoff. Median *E. coli* storm-event densities were substantially greater than base-flow densities for all sites. The most substantial increases occurred at small basin sites where median *E. coli* densities increased from 460 colonies per 100 mL (col/100 mL) during base flow to 5,400 col/100 mL during storm events. Median *E. coli* densities at small basin sites during base flow were even greater than the median densities measured in storm-event samples collected at Mississippi River sites (131 col/100 mL) and Missouri River sites (380 col/100 mL) (fig. 7). Even so, *E. coli* loads at small basin sites were small when compared to loads at large river sites. *E. coli* contributions from the Missouri River to the Mississippi River were much greater than contributions from upstream Mississippi River reaches to lower Mississippi River reaches. Increased *E. coli* densities at stream sites were related to increased amounts of impervious cover and the number of upstream CSOs and SSOs.

Escherichia coli Densities in Base Flow and Storm Events

Median *E. coli* densities at Missouri River sites increased slightly through the study area during base flow from a low of 51 col/100 mL at the most upstream site (06935715, Missouri River near Chesterfield) to a peak of 220 col/100 mL at the most downstream site (06937000, Missouri River at Columbia Bottom; fig. 8). During storm events, median *E. coli* densities at the most upstream site (06935715) and middle Missouri River site (06935972, Missouri River below St. Charles) were similar (480 and 580 col/100 mL) and then decreased to about 40 percent of that level (250 col/100 mL) at the most downstream site (06937000, fig. 8).

Median *E. coli* densities at sites on the Mississippi River generally increased in a downstream order through the study area (fig. 8). The lowest median densities were observed at site 05587455, the Mississippi River below Grafton, Illinois, for base flow (13 col/100 mL) and storm events (32 col/100 mL). At the next most downstream Mississippi River site (07005500, Mississippi River above St. Louis)—below the confluence with the Missouri River—median *E. coli* densities were approximately three times greater than densities at the upstream Mississippi River site (05587455; fig. 8). Below the Missouri River confluence, Mississippi River suspended sediment concentrations more than triple and an increasing

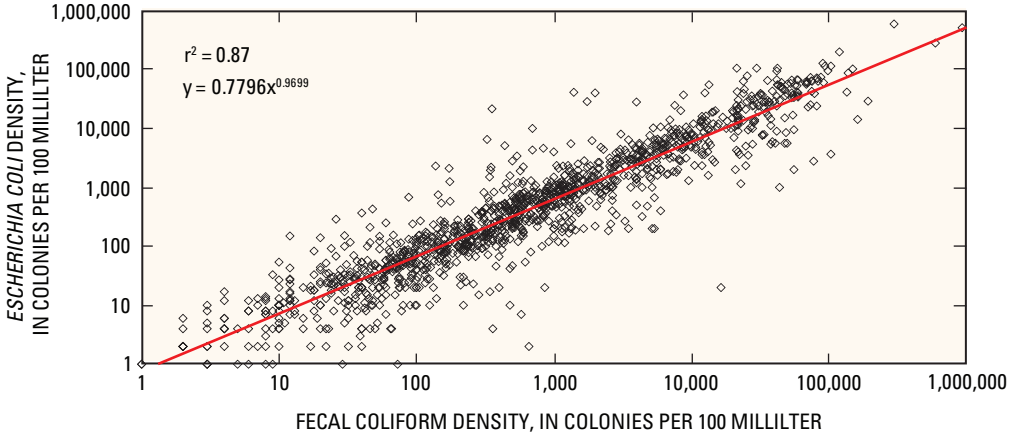


Figure 6. Relation between fecal coliform density and *Escherichia coli* density at metropolitan St. Louis sites.

number of CSOs discharge directly, or indirectly (from tributaries), to the Mississippi River (fig. 2). Additionally, more than three-fourths of SSOs and WWTPs discharge in areas below the Missouri-Mississippi River confluence. Median *E. coli* densities peaked at site 07010220 (Mississippi River at Oakville) and then declined slightly at the most downstream site (07019370, Mississippi River at Kimmswick; fig. 8) during both base flow and storm events. Inputs from CSOs, SSOs, and the River des Peres that contained increased levels of *E. coli* likely played a role in the increases observed at site 07010220. Inflow from the Meramec River that acted to dilute instream *E. coli* densities on the Mississippi River may have accounted for downstream declines at site 07019370.

For small basin sites the largest median *E. coli* densities were observed during storm events at the two River des Peres sites (16,500 col/100 mL at site 07010022, River des Peres near University City and 29,000 col/100 mL at site 07010097, River des Peres at St. Louis; fig. 9). These values were approximately 3 to 6 times greater than median values measured at the other small basin sites: Creve Coeur Creek near Creve Coeur, Missouri (06935890), Coldwater Creek near Black Jack, Missouri (06936475), Maline Creek at Bellefontaine Neighbors, Missouri (07005000), and Grand Glaize Creek near Valley Park, Missouri (07019185), during storm events (fig. 9). This is likely due, in part, because almost one-half of the CSO discharge volume in the study area was expected to have discharged to the River des Peres; additionally, more than one-half of SSOs in the study area discharge into this basin (Metropolitan St. Louis Sewer District, 2009, written comm.).

The upper River des Peres site (07010022) had the largest median *E. coli* densities during base flow (1,780 col/100 mL) followed by samples from Maline Creek (site 07005000; 590 col/100 mL) and the lower River des Peres (site 07010097; 480 col/100 mL). Median *E. coli* densities were approximately 300 col/100 mL at the Creve Coeur, Coldwater, and Grand Glaize Creek sites (fig. 9).

Missouri stream water-quality criteria for *E. coli* are determined by the stream classification and designated use (Missouri Department of Natural Resources, 2009). Streams are classified into two broad categories, whole body contact recreation and secondary contact recreation. Whole body contact recreation refers to activities that result in direct contact with and complete submergence below the water—for example, swimming, water skiing, or diving. Whole body contact recreation is further divided into Class A and Class B categories. Class A stream reaches are public, open-access swimming areas, whereas Class B waters are any other waters of the State designated for whole body contact not contained within Class A. Secondary contact recreation refers to activities that may result in incidental contact with the water in question—for example, boating, fishing, or wading (Missouri Department of Natural Resources, 2009). For sites in the study area, the *E. coli* criterion ranges from 126 col/100 mL for Class A recreational use, to 206 col/100 mL for Class B recreational use, to 1,134 col/100 col mL for secondary contact recreation (table 4).

Numeric water-quality criteria apply to the geometric mean of samples collected during the recreational period which is defined as April 1 through October 31 of each year. Ninety percent of the discrete samples collected during this study were collected within this time frame; however, the study intent was not to determine compliance with water-quality standards.

Regardless, comparison of instream bacteria densities at stream sites to established thresholds can provide useful information. When discrete sample *E. coli* densities at sites were compared to the appropriate criterion for a given stream site (table 5), there was little, if any, difference between samples

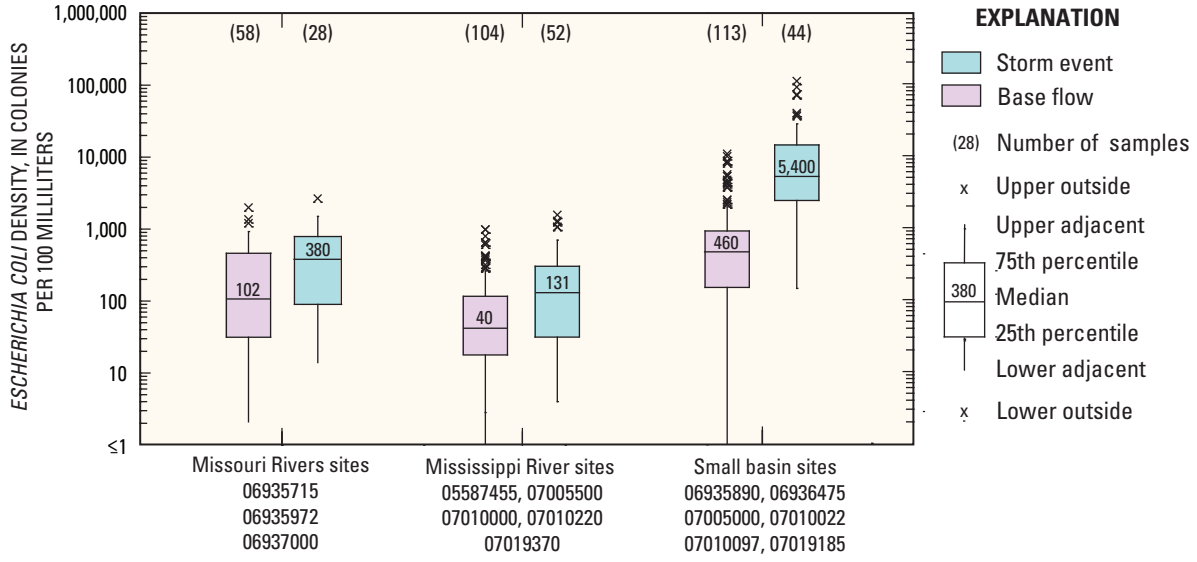


Figure 7. *Escherichia coli* densities in stream samples collected at sites in metropolitan St. Louis between October 2004 and September 2007.

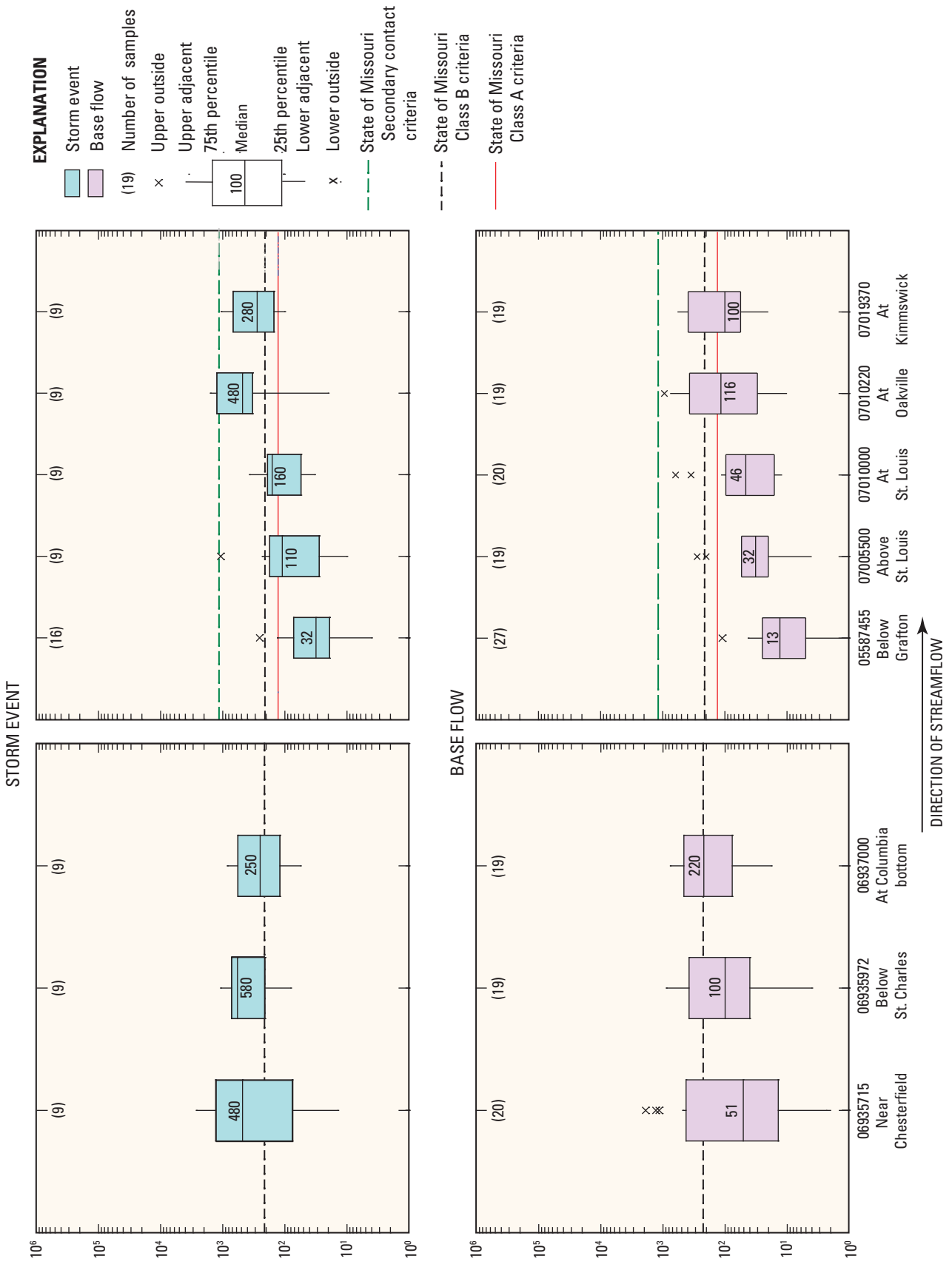


Figure 8. *Escherichia coli* densities in discrete samples collected between October 2004 and September 2007 at large river sites in the metropolitan St. Louis area.

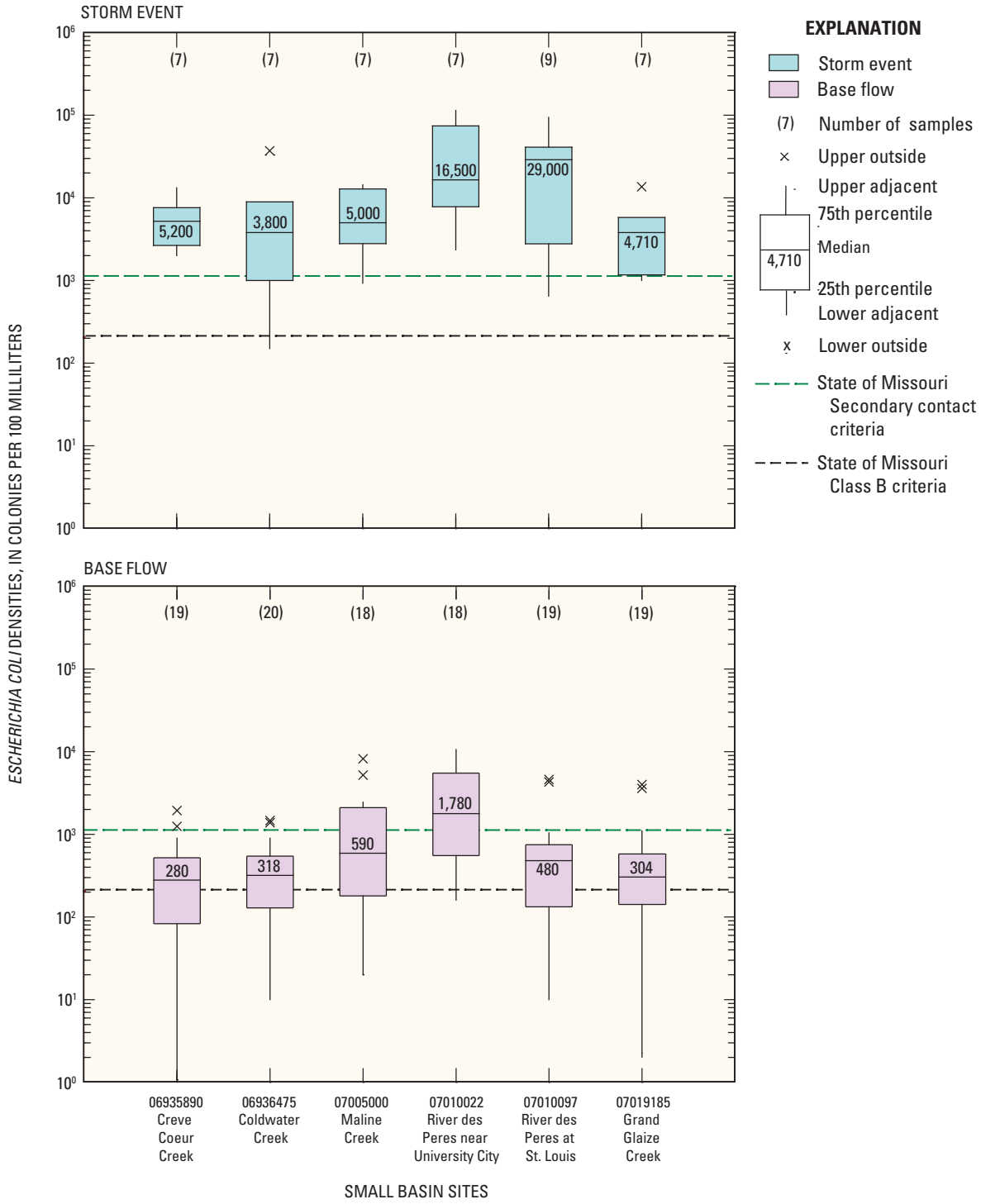


Figure 9. *Escherichia coli* densities in discrete samples collected between October 2004 and September 2007 at small basin sites in the metropolitan St. Louis area.

collected throughout the year compared to those collected during the recreational season; therefore, discussion with respect to the percentage of discrete samples that were below the applicable standard refer to all samples collected over the course of the study.

Sixty percent of Missouri River base-flow samples were below the *E. coli* Class B recreational criterion of 206 col/100 mL (table 5). Because Missouri River storm-event samples had substantially greater amounts of *E. coli* (figs. 7 and 8), only 36 percent of storm-event samples had *E. coli* densities below the criterion (table 5).

Table 4. State of Missouri *Escherichia coli* bacteria criteria applicable to selected metropolitan St. Louis area stream reaches in relation to study area sites.

[col/100 ml, colonies per 100 milliliters of water; --, not applicable]

Stream reach	Applies to site number(s); (fig.1)	Description	Designated use	Criterion
Missouri River	06935715, 06935972, and 06937000	Geometric mean during the recreational season from April 1 to October 31 in waters designated for recreation or at any time in losing streams	Whole body contact -- Class B (Missouri Department of Natural Resources, 2009)	206 col/100 mL[a]
Mississippi River, upstream from the confluence with Missouri River	05587455	Geometric mean during the recreational season from April 1 to October 31 in waters designated for recreation or at any time in losing streams	Whole body contact -- Class A (Missouri Department of Natural Resources, 2009)	126 col/100 mL
Mississippi River, from the Missouri River to 6.3 miles downstream	--	Geometric mean during the recreational season from April 1 to October 31 in waters designated for recreation or at any time in losing streams	Whole body contact -- Class B (Missouri Department of Natural Resources, 2009)	206 col/100 mL[a]
Mississippi River, 6.3 miles downstream from the Missouri River to the Meramec River	07005500, 07010000, and 07010220	Geometric mean during the recreational season from April 1 to October 31 in waters designated for recreation or at any time in losing streams	Secondary contact recreation (Missouri Department of Natural Resources, 2009)	1,134 col/100 mL
Mississippi River, downstream from the Meramec River	07019370	Geometric mean during the recreational season from April 1 to October 31 in waters designated for recreation or at any time in losing streams	Whole body contact -- Class B (Missouri Department of Natural Resources, 2009)	206 col/100 mL[a]
Small basin sites: Creve Coeur Creek, Coldwater Creek, Maline Creek[b,c], and Grand Glaize Creek	06935890, 06936475, 07005000, and 07019185	Geometric mean during the recreational season from April 1 to October 31 in waters designated for recreation or at any time in losing streams	Whole body contact -- Class B (Missouri Department of Natural Resources, 2009)	206 col/100 mL[a]
Small basin site: River des Peres at St. Louis	07010097	Geometric mean during the recreational season from April 1 to October 31 in waters designated for recreation or at any time in losing streams	Secondary contact recreation (Missouri Department of Natural Resources, 2009)	1,134 col/100 mL
Small basin site: River des Peres	07010022	--	--	--

[a]First adopted by emergency rule on December 15, 2008. Previous standard was 528 colonies per 100 milliliters.

[b]Reach from streamgage to 0.5 mile below streamgage designated for whole body contact-Class B.

[c]A 0.6-mile stream reach upstream from the Mississippi River designated for secondary contact recreation.

E. coli criteria for stream reaches of the Mississippi River vary through the study area (table 4). The stream reach above the confluence with the Missouri River, which includes site 05587455, is subject to Class A recreational criterion, whereas a 6.3-mile reach below the confluence is subject to Class B recreational criterion. From this point, downstream to the Meramec River, a secondary contact criterion applies (sites 07005500, 07010000, and 07010220). Below the Meramec River—applicable to site 07019370—the criterion reverts to the Class B recreational standard (table 4).

E. coli densities at Mississippi River sites were below the applicable criterion in approximately 90 percent of base-flow samples (table 5). *E. coli* densities in samples from four sites (05587455, 07005500, 07010000, and 07010220) were below the applicable criterion in 100 percent of the samples, and those in samples from site 07019370 were below the standard 63 percent of the time. On average, 75 percent of storm-event samples collected from Mississippi River sites were below the applicable standard; values ranged from 44 percent to 100 percent (table 5).

Table 5. Percent of discrete *Escherichia coli* bacteria samples collected between October 2004 and September 2007 at stream sites in the metropolitan St. Louis area that met the applicable State of Missouri criterion.

[col/100 ml, colonies per 100 milliliters of water; --, not applicable]

Site	Station identifier (fig. 1)	Base flow all samples (recreational season samples)	Storm event all samples (recreational season samples)	Applicable criterion. Geometric mean of recreational season samples, April 1 to October 31 of each year
Large river sites				
Missouri River Sites				
Missouri River near Chesterfield	06935715	65 (65)	44 (44)	206 col/100 mL
Missouri River below St. Charles	06935972	68 (68)	22 (22)	206 col/100 mL
Missouri River at Columbia Bottoms	06937000	47 (47)	40 (40)	206 col/100 mL
Average (Missouri River sites)	--	60 (60)	36 (36)	206 col/100 mL
Mississippi River sites				
Mississippi River below Grafton	05587455	100 (100)	88 (90)	126 col/100 mL
Mississippi River above St. Louis	07005500	100 (100)	100 (100)	1,134 col/100 mL
Mississippi River at St. Louis	07010000	100 (100)	100 (100)	1,134 col/100 mL
Mississippi River at Oakville	07010220	100 (100)	67 (67)	1,134 col/100 mL
Average	--	100 (100)	89 (89)	1,134 col/100 mL
Mississippi River at Kimmswick	07019370	63 (63)	44 (44)	206 col/100 mL
Average (Mississippi River)	--	91(91)	75 (76)	126-1,134 col/100 mL
Small basin sites				
Creve Coeur Creek	06935890	46 (46)	0 (0)	206 col/100 mL
Coldwater Creek	06936475	40 (40)	14 (14)	206 col/100 mL
Maline Creek	07005000	28 (28)	0 (0)	206 col/100 mL[a]
Grand Glaize Creek	07019185	0 (0)	0 (0)	206 col/100 mL
Average	--	28 (28)	4 (4)	206 col/100 mL
River des Peres at St. Louis	07010097	90 (88)	11 (0)	1,134 col/100 mL
Average Small basin sites	--	41 (40)	5 (5)	206 col/100 mL
River des Peres near University City	07010022	39 (44)	0 (0)	--[b]

[a]Criterion from streamgage to 0.5 mile below streamgage.

[b]No standard currrently (2010) applies. Results shown in comparison to secondary contact limit of 1,134 col/100 mL.

Most small basin sites in the study area are subject to the whole body contact-Class B criterion (table 5). Exceptions are the upper River des Peres site (07010022) where no standard currently (2010) applies, and the lower River des Peres site (07010097), which is subject to the least stringent secondary contact criterion of 1,134 col/100 mL.

On average, during base flow, only 28 percent of samples from sites on Creve Coeur, Coldwater, Maline, and Grand Glaize Creeks were below the Class B criterion (table 5). Conversely, only 4 percent of storm-event samples—which have substantially higher *E. coli* densities (fig. 9) than do base-flow samples—were below this criterion (table 5). Grand Glaize Creek samples never were below the criterion for any hydrologic condition.

Ninety percent of base-flow samples from the lower River des Peres site (07010097) were below the secondary contact criterion (table 5); however, storm-event samples from this site were below the applicable criterion only 11 percent of the time.

Instantaneous *Escherichia coli* Loads

Instantaneous load, the concentration (or density in the case of bacteria) of a constituent times the streamflow, is the amount of a given constituent in the stream at the time of sample collection. Instantaneous loads provide data on the relative amounts of constituents in a particular stream reach or from tributaries.

In general, the largest instantaneous *E. coli* loads were observed at large river sites in the study area (figs. 10 and 11) because flows, a primary component of load, were greatest at these sites. Storm loads were substantially greater than those during base flow, a difference most pronounced at small basin sites (fig. 11). This was because only a small part of the Missouri and Mississippi River Basins lies within the study area, whereas the small basins lie within the study area; therefore, precipitation that fell within the study area affected small basin sites in disproportionally larger amounts than the large river sites. Additionally, this study targeted precipitation events that occurred within the study area as opposed to rarer, more widespread geographic events that covered larger parts of the Missouri or Mississippi River Basins.

For Missouri River sites, instantaneous *E. coli* base-flow loads increased downstream through the study area in response to increased *E. coli* densities, increased streamflow, or both. This phenomenon also was observed at Mississippi River sites (fig. 10). Median base-flow loads from the upper Mississippi River site (05587455) were only 10 percent of the loads measured at the most downstream Missouri River site (06937000; table 6). Median *E. coli* base-flow loads at the lower Mississippi River sites (07010220 and 07019370) were 250 to 400 percent greater than loads measured at middle Mississippi River sites (07005500 and 07010000; fig. 10). Base-flow loads at small basin sites were less than 1 percent of the loads measured in the downstream receiving reach of the Missouri or Mississippi Rivers (table 6). These data indicate that during base flow substantial amounts of *E. coli* originated from within the study area; however, considerable amounts of *E. coli* in the Missouri River, as well as that in sections of the Mississippi River downstream from its confluence with the Missouri River, originated in reaches of the Missouri River upstream from the study area. Lesser amounts of base-flow *E. coli* in the Mississippi River originated in the upstream Mississippi River reaches of the study area, and only minor amounts originated in the small basins.

Although there are differences between sites, in general, the upper Mississippi River and small basin site *E. coli* storm loads were considerably less than those at Missouri River sites (fig. 10 and 11). Median *E. coli* storm loads at the upper Mississippi River site (05587455) were 14 percent of those measured in the most downstream reach of the Missouri River (site 06937000; table 6). Loads at two Missouri River tributary streams, Creve Coeur Creek and Coldwater Creek (sites 06935890 and 06936475), had median *E. coli* storm loads that were no more than 4 percent of those measured in receiving sections of the Missouri River (table 6).

Median *E. coli* storm loads at small basin sites, when compared to those at downstream receiving reaches of the Mississippi River, ranged from a low of 1 percent (Grand Glaize Creek, site 07019185) to a peak of 16 percent (Maline Creek, site 07005000). For River des Peres sites (07010022 and 07010097), median *E. coli* storm loads were 4 and 10 percent of those measured at lower Mississippi River sites (table 6). These comparisons assumed that *E. coli* moved downstream into the next stream reach without degradation or loss.

Although streams in the study area have been modified substantially to efficiently convey water downstream, once released to the environment, some instream loss of bacteria would have been inevitable; however, the sum of the median small basin *E. coli* bacteria loads (at Creve Coeur, Coldwater, Maline, and Grand Glaize Creeks; and the lower River des Peres) during storm events was only 18 percent of the loads measured at the most downstream lower Mississippi River reach (average of loads at sites 07010220 and 07019370) and, during base flow, it is less than 1 percent (table 6). These data indicate that although small basin sites contributed increasing amounts of *E. coli* to large river stream reaches during high-flow conditions, substantial amounts of *E. coli* originated from sections of the Missouri River upstream from the study area, point source discharges (including CSOs, SSOs, and WWTPs in the study area) to the large rivers, or from nonpoint sources within the study area.

The largest *E. coli* loads were observed at the most downstream Mississippi River sites primarily because flows at these sites were greater than at other sites. Large river sites had much lower *E. coli* densities than small basin sites during base flow and storm events. Bacteria densities typically were much greater during runoff periods, and *E. coli* densities frequently increased by several orders of magnitude over base-flow periods.

Base-flow *Escherichia coli* Sources

Samples from three sites on the Missouri River, five sites on the Mississippi River, and six sites on small tributary streams, collected between October 2004 and September 2007, were analyzed for the source of *E. coli* bacteria using rep-PCR (table 7). Samples were collected during base flow and storm events, and the results compared to a locally collected host-source library of human, dog, and goose samples to identify their respective percentages of *E. coli* in any given sample. On average, two-thirds (67 percent) of the more than 4,000 *E. coli* isolates analyzed in this study were presumptively identified with a specific host source; the level of identification was slightly greater in base-flow samples (68 percent) compared to that in storm-event samples (64 percent; table 7). Such differences, although minor in this study, likely were an indication of increased genetic diversity and more varied sources in runoff compared to base flow (Brownell and others, 2007). Of the *E. coli* isolates identified, 1,566 were assigned to human, 466 to dogs, 893 to geese, and 1,490 to unknown sources. Unknown sources would include *E. coli* from urban wildlife, feral cats, and birds—excepting geese—but also may have included some percentage of human, dog, or geese samples that did not meet the 80 percent similarity criteria deemed necessary to be considered a match.

During base flow, the mean percentage of *E. coli* sourced as human generally increased through the study area. For

Table 6. Tributary inputs of *Escherichia coli* loads to receiving streams for samples collected between October 2004 and September 2007.

[--, not applicable; <, less than]

Receiving stream reach	Sites included (fig. 1)	Receiving stream median intantaneous load, in millions of colonies per second		Tributary or upstream reach	Sites included (fig. 1)	Receiving stream median intantaneous load, in millions of colonies per second		Tributary load, as percent of receiving stream load	
		Hydrologic condition				Hydrologic condition		Hydrologic condition	
		Base flow	Storm event			Base flow	Storm event	Base flow	Storm event
Missouri River tributary									
Upper Missouri	06935715	1,180	14,700	--	--	--	--	--	--
Mid-Missouri	06935972	1,370	8,560	Creve Coeur Creek	06935890	0.24	118	<1	1
Lower Missouri	06937000	3,050	7,490	Coldwater Creek	06936475	.47	326	<1	4
				Upper Mississippi[a]	05587455	293	1,040	10	14
Mississippi River tributary									
Mid-Mississippi	07005500, 07010000	1,790	5,850	Maline Creek	07005000	.43	960	<1	16
Lower Mississippi	07010220, 07019370	5,770	18,700	Upper River des Peres	07010022	.51	654	<1	4
				Lower River des Peres	07010097	.22	1,900	<1	10
				Grand Glaize Creek	07019185	.20	157	<1	1
				Average of small basin[b] sites	06935890, 06936475, 07005000, 07010097, 07019185	.26	692	<1	7
				Average of small basin[b] sites	06935890, 06936475, 07005000, 07010097, 07019185	1.6	3,460	<1	18

[a]Comparison is to lower Missouri site (06937000).

[b]Upper River des Peres site (07010022) not included.

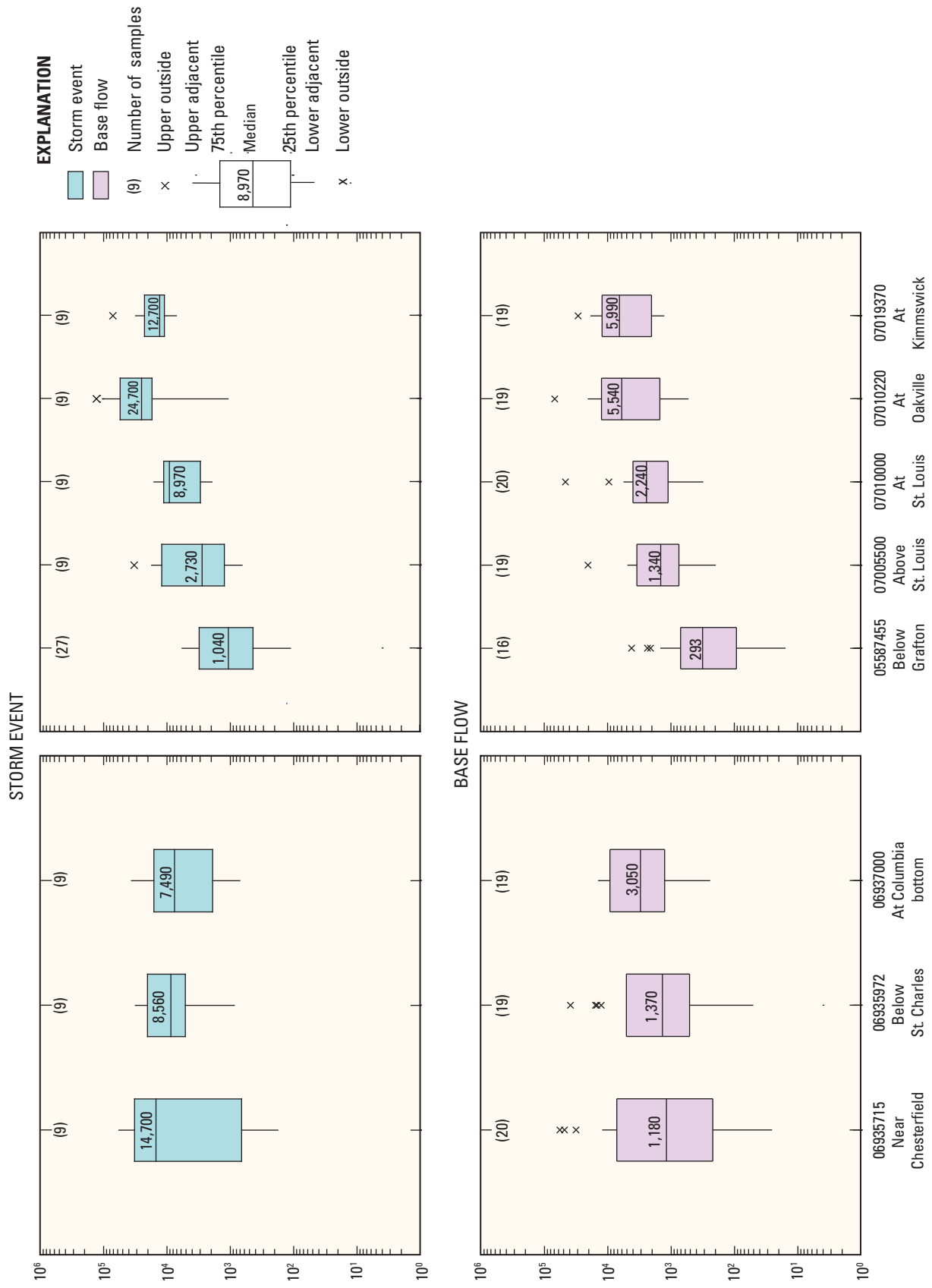


Figure 10. Instantaneous *Escherichia coli* loads from discrete samples collected between October 2004 and September 2007 at large river sites in the metropolitan St. Louis area.

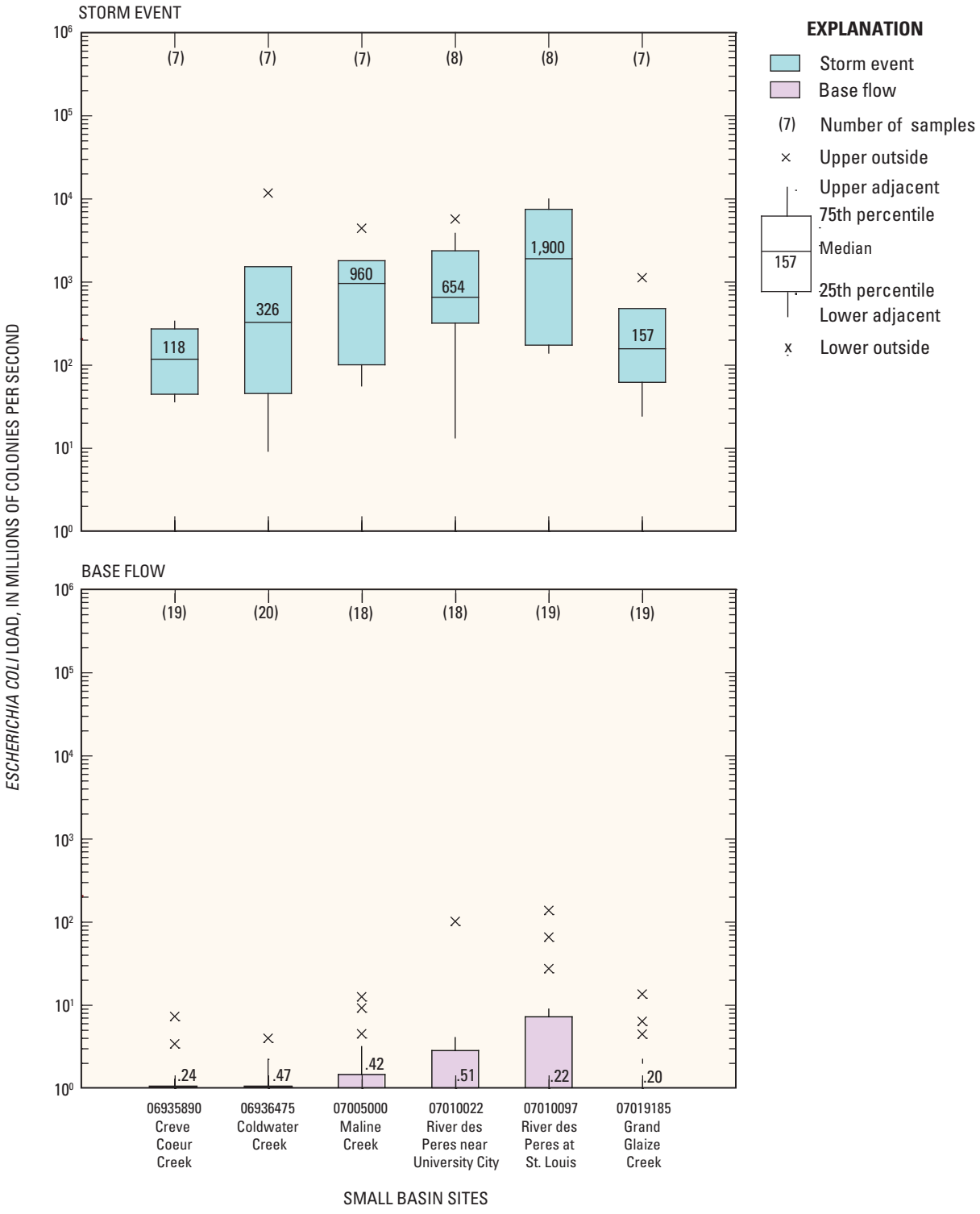


Figure 11. Instantaneous *Escherichia coli* loads from discrete samples collected between October 2004 and September 2007 at small basin sites in the metropolitan St. Louis area.

Missouri River sites, the percent of human *E. coli* increased from a mean of 28 percent at the upstream site (06935715) to 41 percent at the downstream site (06937000; table 8, at the back of this report; fig. 12). A similar increase was observed at Mississippi River sites, although the upstream Mississippi River site (05587455) had a much lower mean percent of human bacteria (14 percent) than did other large river sites. Mississippi River sites below the Missouri River confluence had a mean percent of human *E. coli* from 40 to 44 percent (fig. 12), a value almost three times the percentage above the

confluence. Small basin sites that drained to the Missouri River had smaller mean percent of human *E. coli* (25 percent at site 06935890 and 28 percent at site 06936475) than did small basin sites that drained to the Mississippi River (values ranged from 30 to 37 percent; fig. 12). The largest human *E. coli* mean (37 percent) at small basin sites during base flow was observed at Maline Creek (site 07005000) and the upper River des Peres site (07010022; fig. 12).

In general, dog *E. coli* averaged 10 percent or less of the total *E. coli* in base-flow samples (fig. 12). The middle Missouri River site (06935972) had the largest mean percent of dog *E. coli* (16 percent) of Missouri River sites. The upstream Mississippi River site (05587455) had the lowest mean percent of dog *E. coli* (2 percent) of any site. Dog *E. coli* at Mississippi River sites increased below the Missouri River confluence to a peak of 14 percent (site 07010000) and then declined in downstream reaches (fig. 12). Most small basin sites averaged close to 10 percent of *E. coli* identified as dog, the exception being the Coldwater Creek site (06936475), which averaged 17 percent.

Approximately 20 percent of the *E. coli* was attributable to geese in Missouri River base-flow samples (fig. 12) with the most upstream site (06935715) having the largest mean percentage (23). The upstream Mississippi River site (05587455) and the next downstream site (07005500) had the greatest percent of *E. coli* from geese (20 and 23 percent), and the mean percent then generally declined in downstream Mississippi River reaches (fig. 12). The mean percent of geese *E. coli* in small basin samples ranged from 13 percent (upper River des Peres, site 07010022) to 27 percent at Coldwater Creek (site 06936475).

For Missouri River base-flow samples, the mean percent of unidentified *E. coli* was approximately 30 percent, with the upstream site (06935715) having the largest percent of unidentified *E. coli* (fig. 12). For Mississippi River sites, the most upstream site had the largest percent of unidentified *E. coli* (57 percent). Below the confluence with the Missouri River, this percent declined dramatically to 27 percent and then increased downstream through the study area, but in general, the mean percent of unidentified *E. coli* at Mississippi River sites below the Missouri River confluence was near 31 percent (fig. 12). For small basin sites, the mean percent of unidentified *E. coli* ranged from 28 percent to 39 percent (fig. 12).

Storm-Event *Escherichia coli* Sources

During storm events, the mean percent of *E. coli* attributable to humans at Missouri River sites was greatest (35 percent) at the middle site (06935972) and was approximately 30 percent at other Missouri River sites (fig. 13; table 8). For sites on the Mississippi River, the percent of bacteria attributable to humans indicated substantial increases below the confluence with the Missouri River increasing from a mean of 27 percent at the most upstream site (05587455) to 48 percent at site 07010220 (fig. 13). Small basin sites that drained to the Missouri River averaged substantially less human *E. coli* (20 to 25 percent) than did sites that drained to the Mississippi River (34 to 63 percent; fig. 13).

The mean percent of *E. coli* attributable to dogs at Missouri River sites was the greatest (10 percent) at the middle site (06935972) and lowest (6 percent) at the upstream site (06935715; fig. 13). For Mississippi River sites, the lowest mean percent (2 percent) of *E. coli* attributable to dogs occurred at the upstream site (05587455). This percentage increased at Mississippi River sites in the middle reaches (maximum of 13 percent at site 07010000) and then declined in downstream reaches (fig. 13). At small basin sites, the mean percentage of *E. coli* attributable to dogs was approximately 10 percent (values ranged from 5 to 15 percent) with the highest mean percent at the upper River des Peres site (07010022; fig. 13).

The mean percentage of *E. coli* attributable to geese increased in reaches of the Missouri River from 17 percent (site 06935715) to 28 percent (site 06937000; fig. 13). For sites on the Mississippi River, the mean percentage of *E. coli* from geese was greatest at the most upstream and most downstream sites and declined in the middle reaches (fig. 13). Compared to other sites in the study area, small basin storm-event samples generally had a lower mean percentage of *E. coli* from geese with values ranging from 8 to 20 percent (fig. 13).

For Missouri and Mississippi River sites, the largest percentage of *E. coli* from unidentified sources occurred at the upstream sites (06935715 and 05587455; fig. 13) and then declined in downstream reaches. At small basin sites, the mean percentage of unidentified *E. coli* ranged from 22 percent (site 07010097) to 59 percent (site 06936475). Larger percentages of unidentified bacteria are likely an indication of increased nonpoint source contributions in upstream reaches that contained bacteria from a myriad of sources, in addition to those contributions from human, dog, and goose sources.

Current (2010) water-quality standards have been written to address how stream *E. coli* density compares to applicable numeric criteria (table 4), regardless of the source, or sources, of these bacteria; however, an understanding of how individual sources contributed densities in excess of State criteria could be beneficial to design appropriate reduction and management strategies. Additionally, the presence of human *E. coli* in streams may indicate an increased potential for the presence of other pathogenic bacteria (Wilkes and others, 2009). The percentage of water samples at stream sites that met the applicable State *E. coli* criterion during the recreational season when the total instream bacteria was adjusted for host source is listed in table 9.

Host-source *E. coli* densities were determined from the percentage of the total *E. coli* density in the stream attributable to any given host. Because individual hosts were just part of the total instream bacteria, individual host-source *E. coli* densities were always less than the total density measured in samples. Because one primary concern was to evaluate the contributions of *E. coli* from wastewater sources relative

Table 7. Summary of microbial source-tracking samples analyzed at metropolitan St. Louis sites between October 2004 and September 2007.

[mm, mile marker; rep-PCR, repetitive extragenic pallindromic polymerase chain reaction; B. Tim, *Bacterioides thetatiotaomicron*]

Station name	Station identifier (fig. 1)	Baseflow					
		Number of rep-PCR samples	Number of rep-PCR isolates identified	Mean number of rep-PCR isolates per sample	Mean percent identified to host source	Median percent identied to host source	Number of B. tim samples
Missouri River sites							
Missouri River near Chesterfield at mm 48	06935715	16	180	11	70	72	10
Missouri River below St. Charles at mm 24.5	06935972	16	238	15	71	79	11
Missouri River at Columbia Bottom Conservation Area at mm 4	06937000	16	236	15	73	78	12
All Missouri River sites		48	654	14	71	75	33
Mississippi River sites							
Mississippi River below Grafton, Illinois	05587455	16	74	5	44	38	7
Mississippi River above St. Louis at mm 184.5	07005500	17	171	10	73	76	9
Mississippi River at St. Louis	07010000	18	219	12	70	74	10
Mississippi River at Oakville at mm 164.5	07010220	17	212	12	68	78	13
Mississippi River at Kimmswick, Missouri	07019370	17	206	12	66	78	11
All Mississippi River sites		85	882	10	67	75	50
Small basin sites							
Creve Coeur Creek near Creve Coeur, Missouri	06935890	15	199	13	65	73	9
Coldwater Creek near Black Jack, Missouri	06936475	16	240	15	72	80	6
Maline Creek at Bellefontaine Neighbors, Missouri	07005000	15	216	14	68	80	7
River des Peres near University City, Missouri	07010022	14	225	16	62	64	12
River des Peres at St. Louis, Missouri	07010097	15	212	14	72	75	10
Grand Glaize Creek near Valley Park, Missouri	07019185	16	238	15	61	53	10
All small basin sites		91	1,330	15	67	71	54
Totals		224	2,866	13	68	75	137

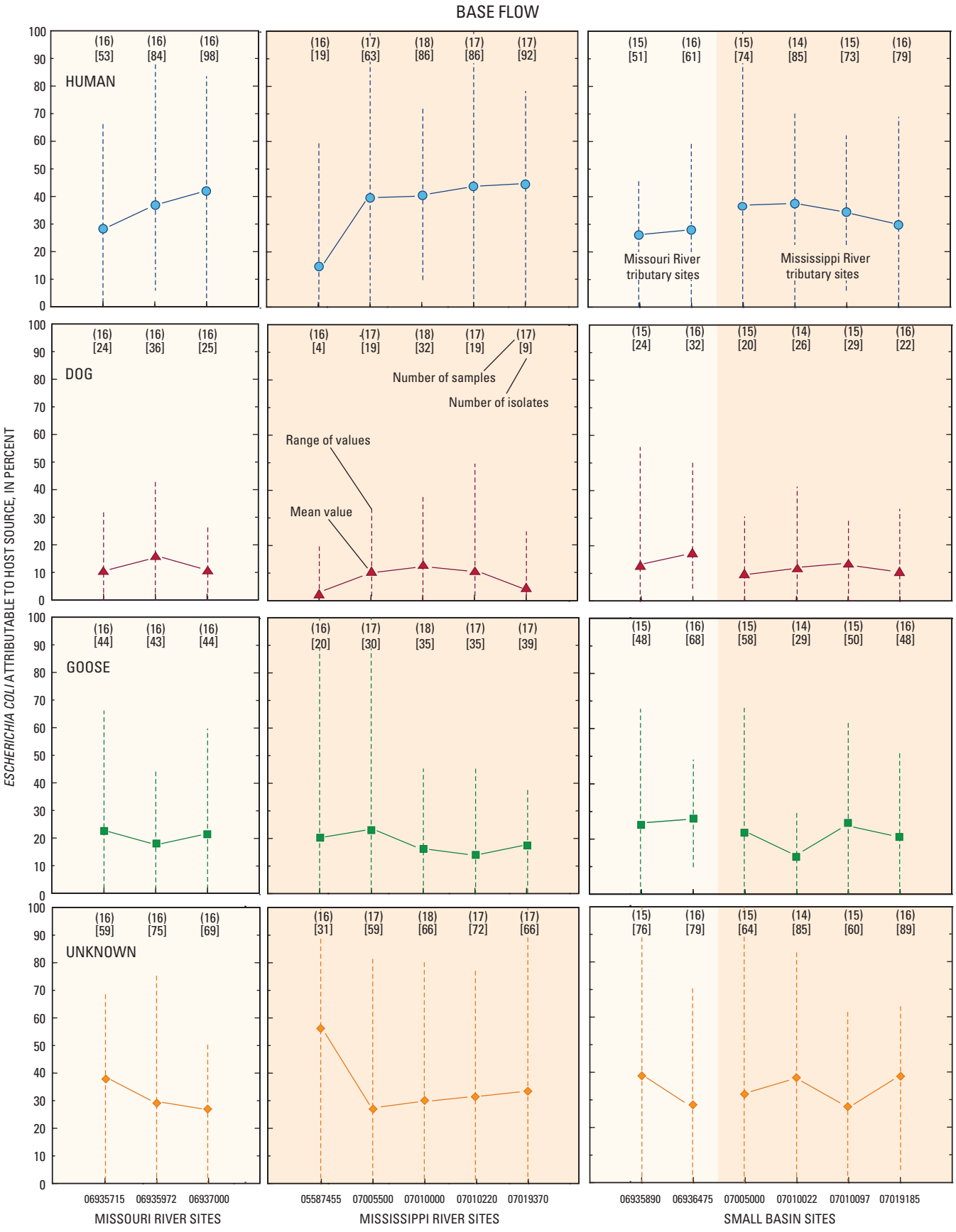


Figure 12. Mean percent of *Escherichia coli* bacteria attributable to host sources at sites in the metropolitan St. Louis area from base-flow samples collected between October 2004 and September 2007.

to those from nonpoint sources, host-source densities were divided into two broad categories—*E. coli* originating from human and *E. coli* originating from nonhuman and unidentified sources. Although there may be some overlap between categories, human *E. coli* was considered to primarily have originated from point sources, whereas the remaining *E. coli* was considered to have originated from nonpoint sources.

When only human *E. coli* bacteria were considered, most (greater than 90 percent) of Mississippi River base-flow and storm-event samples were below the applicable criterion (table 9). Sites on the Missouri River met the applicable criteria, on average, 79 percent of the time during base flow and 60 percent of the time during storm events (table 9). Conversely, human *E. coli* contributions to the Missouri River were sufficient to raise instream bacteria levels above the applicable standard in 21 percent of base-flow samples and 40 percent of storm-event samples. Small basin sites typically had large *E. coli* densities and greater amounts of human *E. coli* in base-flow and storm-event samples when compared to larger river samples. At the small basin site (07010097) where the applicable criterion is 1,134/col mL, when only human *E. coli* are considered, all of the base-flow samples, but none of the storm-event samples were below the standard (table 9). At the four small basin sites where the criterion is lower, 206 col/100 mL, an average of 77 percent of base-flow samples were below the criterion, but only 21 percent of storm-event samples.

When only nonhuman and unidentified *E. coli* are considered, again, most Mississippi River base-flow (an average of 96 percent) and storm-event (86 percent) samples were below the applicable criterion (table 9). Because of greater densities in general, Missouri River sites met the applicable criteria, on average, 65 percent of the time during base flow, and 33 percent of the time during storm events when considering only nonhuman and unidentified *E. coli* (table 9). Nonhuman and unidentified *E. coli* contributions, again, most of which were considered to have originated from nonpoint sources, to small basins were sufficient to raise instream densities above the appropriate criteria, on average, in about one-half (51 percent) of base-flow samples and all storm-event samples. These data indicate that reduction or elimination of nonpoint *E. coli* source contributions to study area streams would likely have an equivalent, if not greater, effect on reducing stream *E. coli* levels below applicable State criteria than would the elimination of human sources of *E. coli*.

Escherichia coli Host-Source Loads

Host-source *E. coli* loads were determined at stream sites by multiplying the total *E. coli* load by the relative percent of bacteria identified by individual host source. Such load calculations provide data on the relative contribution of host sources from tributaries to receiving streams. In general, host-source load patterns were similar to the overall *E. coli* load patterns previously described. Host-source loads measured in small river basins typically were small in contrast to the resident, large river, receiving stream *E. coli* populations during base-flow conditions. During storm events, *E. coli* loads in small river basins increased substantially when compared to base-flow loads. When compared to large river loads, small basin host-source *E. coli* storm loads were substantially larger than base flow, but generally small when compared to receiving stream reach loads (table 10).

During base flow, mean host-source *E. coli* loads at the most downstream Missouri River site (06937000) declined slightly or remained relatively stable when compared to upstream Missouri River sites (fig. 14). By contrast, on the Mississippi River, mean Mississippi River host-source *E. coli* loads generally increased through the study area with a notable increase at sites downstream from the Missouri River confluence (fig. 14). Mean host-source *E. coli* loads at small basin sites typically were lower at Missouri River tributary sites than at Mississippi River tributary sites (fig. 14).

The mean human and dog *E. coli* loads in base-flow samples from the most upstream Mississippi River site (05587455) were 5 percent, or less, of those measured at the most downstream Missouri River site (06937000; table 10). Mean human and dog *E. coli* loads from the upstream Mississippi River site also were less than 10 percent of the mean loads at middle Mississippi River sites (table 10; fig. 14). Although the relative percentages were slightly greater (8 to 13 percent), the mean goose *E. coli* loads from the upstream Mississippi River site indicated a similar pattern (fig. 14). For samples of unidentified origins, mean base-flow loads measured at the most upstream Mississippi River site were approximately 20 percent of the mean loads at the most downstream Missouri River site and 40 percent of those measured at middle Mississippi sites (fig. 14; table 10). Mean host-source *E. coli* base-flow loads at all small basin sites were less than 1 percent of the loads measured at large river sites. Although small basin sites contributed *E. coli* to receiving waters, these data indicate that during base flow little of the bacteria in the Missouri and Mississippi Rivers originated from small basin sites in the study area. Additionally, these data indicate that during base-flow conditions, substantial *E. coli* contributions to the middle and lower Mississippi River originated from within the study area, either from point sources (notably CSOs, SSOs, and WWTPs), nonpoint sources, or a combination of these sources. Substantial contributions to the middle and lower Mississippi River also originated from Missouri River reaches; furthermore, a large percentage of the Missouri River *E. coli* likely originated in areas upstream from the study area.

The pattern of *E. coli* bacteria host-source contribution during storm events (fig. 15) was similar to that during base flow (fig. 14). One exception was that small basin *E. coli* loads increased more substantially, when compared to large river loads, during storm events and as a result, the relative size of small basin *E. coli* storm loads to receiving streams was greater than during base flow.

Mean host-source *E. coli* loads at Missouri River sites during storm events, remained relatively stable (fig. 15)

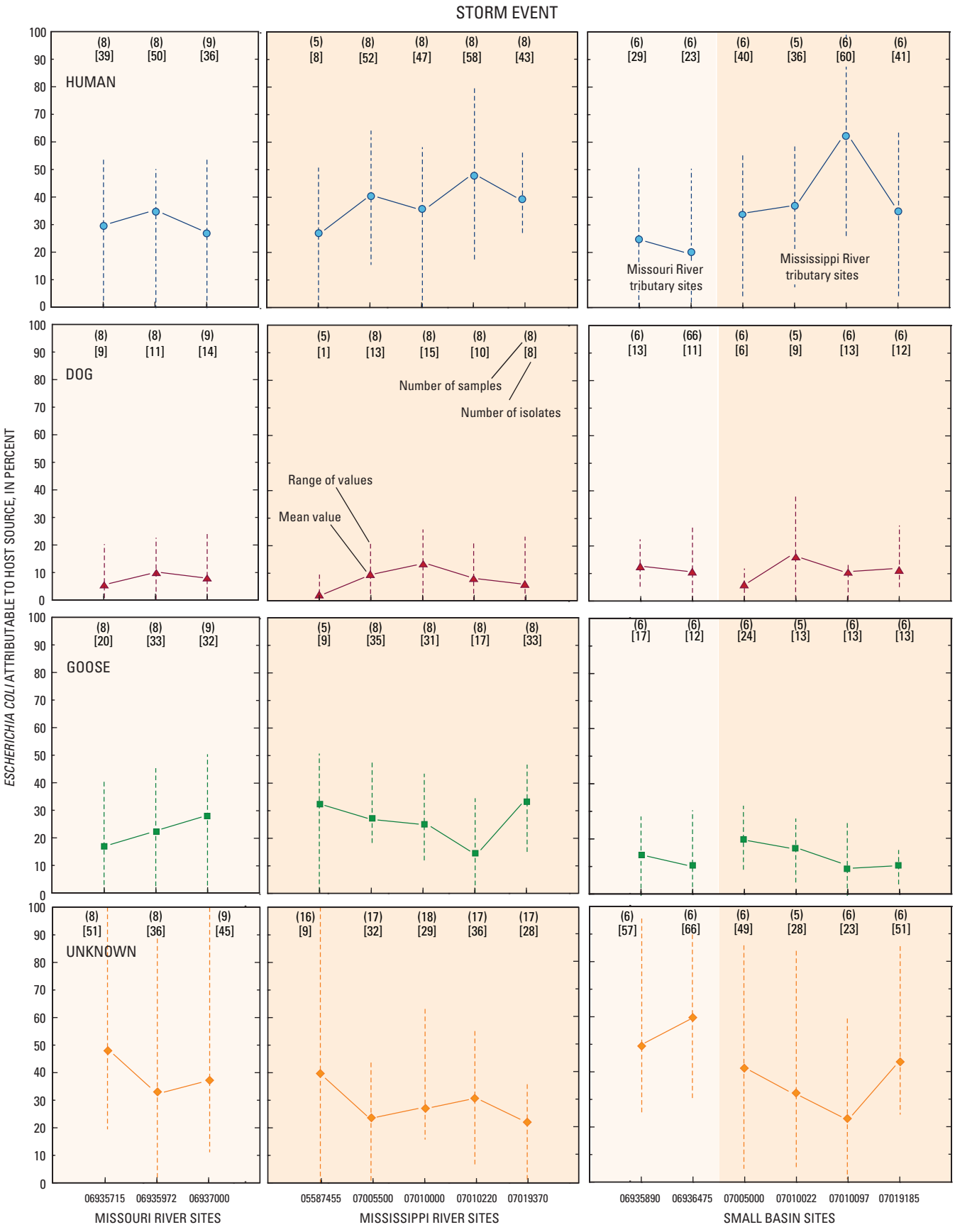


Figure 13. Mean percent of *Escherichia coli* bacteria attributable to host sources at sites in the metropolitan St. Louis area from storm-event samples collected between October 2004 and September 2007.

Table 9. Percent of water samples collected between October 2004 and September 2007 at metropolitan St. Louis area stream sites that met the applicable State of Missouri criterion when adjusted by host-source density estimates.

[all values in percent identifed; col/100 ml, colonies per 100 milliliters of water; --, not applicable]

Site name	Station identifier (fig. 1)	Human		Nonhuman and unidentified		Applicable criterion[a]
		Base flow	Storm event	Base flow	Storm event	
Large river sites						
Missouri River sites						
Missouri River near Chesterfield	06935715	88	63	63	50	206 col/100 mL
Missouri River below St. Charles	06935972	81	50	69	50	206 col/100 mL
Missouri River at Columbia Bottoms	06937000	69	67	63	0	206 col/100 mL
Average	--	79	60	65	33	206 col/100 mL
Mississippi River sites						
Mississippi River below Grafton	05587455	100	100	100	80	126 col/100 mL
Mississippi River above St. Louis	07005500	100	100	100	100	1,134 col/100 mL
Mississippi River at St. Louis	07010000	100	100	100	100	1,134 col/100 mL
Mississippi River at Oakville	07010220	100	100	100	100	1,134 col/100 mL
Mississippi River at Kimmswick	07019370	94	62	82	50	206 col/100 mL
Average	--	99	92	96	86	126–1,134 col/100 mL
Small basin sites						
Coldwater Creek	06935890	87	17	47	0	206 col/100 mL
Creve Coeur Creek	06936475	88	50	50	0	206 col/100 mL
Maline Creek	07005000	60[b]	0[b]	0[b]	0[b]	206 col/100 mL[b]
Grand Glaize Creek	07019185	75	17	56	0	206 col/100 mL
Average	--	77	21	38	0	206 col/100 mL
River des Peres at St. Louis	07010097	100	0	93	0	1,134 col/100 mL
Average, all small basins	--	82	17	49	0	206–1,134 col/100 mL
River des Peres near University City	07010022	64[c]	0[c]	64[c]	0[c]	--[c]

[a]Geometric mean of recreational season samples, April 1 to October 31 of each year.

[b]Criterion from streamgage to 0.5 mile below streamgage.

[c]No standard currrently (2010) applies. Results shown in comparison to secondary contact limit of 1,134 col/100 mL.

because there was little change in either the *E. coli* density, streamflow, or the percentage of the various host sources between Missouri River sites. When compared to either the most downstream Missouri River site (06937000) or the mid-Mississippi River sites (07005500 and 07010000), Mississippi River *E. coli* storm loads at the most upstream site (05587455) for all sources were substantially greater than during base flow (figs. 14 and 15; table 10). Even so, upstream Mississippi River human *E. coli* loads were never more than 19 percent of those measured at the most downstream Missouri River reach. These data indicate that even during storm events, *E. coli* bacteria contributions from the Missouri River to the Mississippi River were considerably larger than those from upstream Mississippi River reaches. This would be expected, in part, because the Missouri River had suspended sediment concentrations that typically were more than three times greater than those on the upper Mississippi (411 mg/L compared to 115 mg/L).

Because discharge and bacteria densities at small basin sites increased greatly in response to storm events, mean *E. coli* loads for all sources were many times greater than those measured during base flow. Mean *E. coli* host-source loads measured at site 06935890, Creve Coeur Creek, were 4 percent or less of those measured at the downstream receiving section of the Missouri River (site 06935972; table 10). Mean host-source *E. coli* loads at site 06936475, Coldwater Creek, ranged from 9 to 48 percent of those measured at the downstream receiving section of the Missouri River (site 06937000;

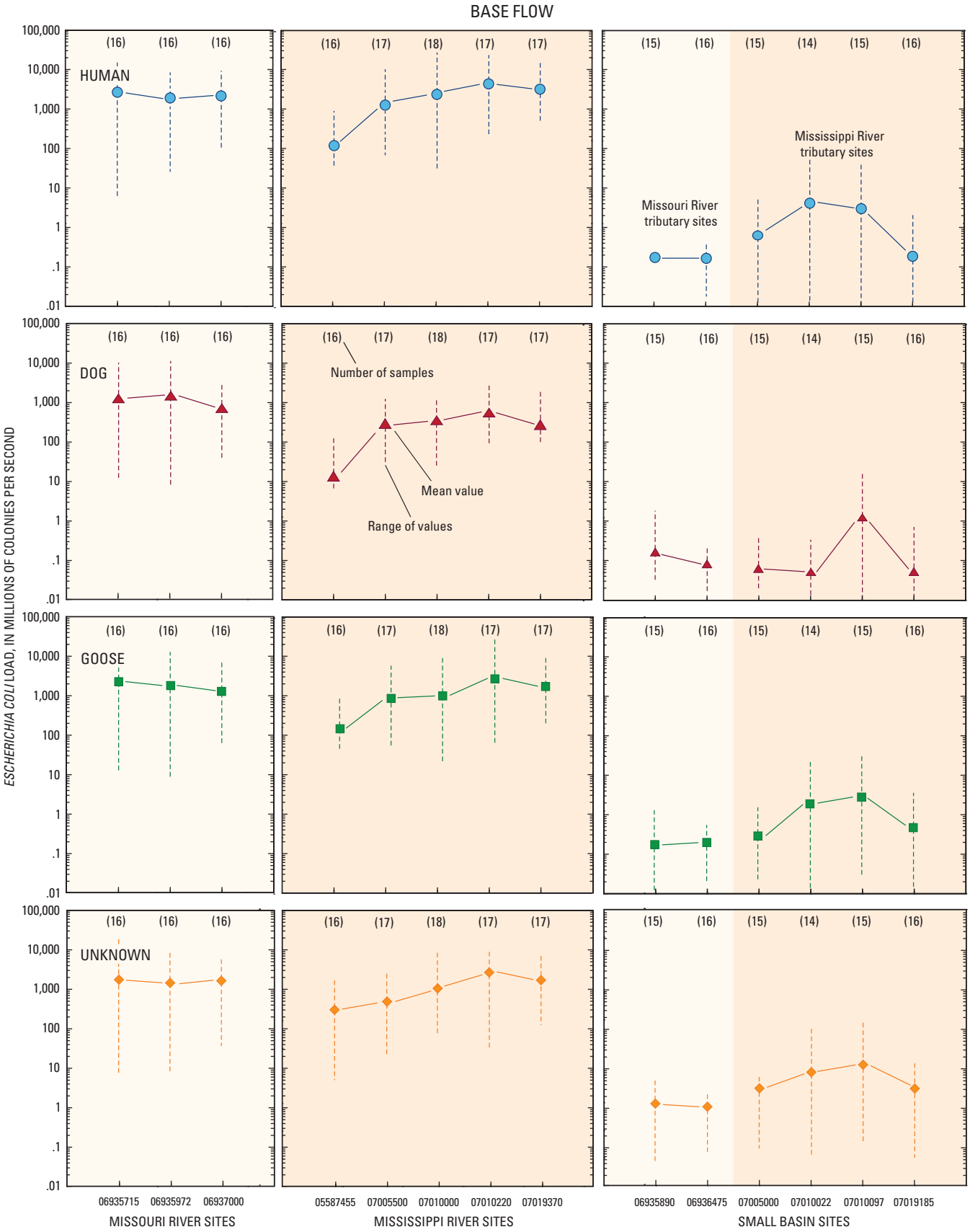


Figure 14. Mean *Escherichia coli load* attributable to host sources at sites in the metropolitan St. Louis area from base-flow samples collected between October 2004 and September 2007.

table 10). Small basin sites on Maline Creek (07005000) and the lower River des Peres (site 07010097), which drain to the Mississippi River, had on average, *E. coli* host-source loads that were approximately 20 percent of lower Mississippi River loads (table 10). Mean *E. coli* loads at the Grand Glaize Creek site (07019185) were 2 percent, or less, of the mean loads in the lower Mississippi River (table 10).

These data indicate that during storm events, as during base flow, large contributions of *E. coli* to the mid-Mississippi River originated from the Missouri River—much of it upstream from the study area. Additionally, inputs from point sources (CSOs, SSOs, and WWTPs) as well as nonpoint sources in the study area contributed substantial amounts of *E. coli* to the mid- and lower Mississippi River. Although *E. coli* contributions from the Mississippi River upstream from the Missouri River confluence increased during storm events, upstream Mississippi River contributions were small when compared to Missouri River contributions. Small basins sites in the study area contributed varying amounts of bacteria to the larger rivers, but these amounts were less than the resident *E. coli* population of the Missouri and Mississippi Rivers. Creve Coeur Creek and Grand Glaize Creek appear to contribute less than 5 percent of the storm-event *E. coli* load for any host source to receiving waters. The largest human *E. coli* source contributions from small basin sites originated from Coldwater Creek, Maline Creek, and the River des Peres; however, these contributions were less than 20 percent of those in receiving streams.

Source typing of *E. coli* bacteria was conducted at 14 sites in the metropolitan St. Louis area between October 2004 and September 2007 using rep-PCR. These data indicated that stream *E. coli* bacteria originated from a diverse population of organisms in, and outside of, the study area. Sources of *E. coli* bacteria varied geographically and by hydrologic condition. The upstream reach of the Mississippi River had smaller total *E. coli* densities and smaller mean percentage contributions of human and dog *E. coli* than did other sites in the basin. *E. coli* densities in downstream reaches of the Mississippi River generally increased below the confluence with the Missouri River, as did the percent of human and dog bacteria, primarily in response to contributions from the Missouri River. During base flow, a substantial amount of the *E. coli* bacteria in middle and lower reaches of the Mississippi River originated from the Missouri River. Although lesser amounts were contributed during storm events, Missouri River *E. coli* contributions also constituted a substantial amount of the bacteria in middle reaches of the Mississippi River; however, point sources—such as CSOs, SSOs, and WWTPs, and nonpoint sources that originated within the study area—also contributed large amounts of *E. coli* to the middle and lower reaches of the Mississippi River.

Small basin sites typically had the greatest *E. coli* densities of streams in the study area. This was especially true during storm events; however, small river basin loads were a small percentage (less than 1 percent) of the *E. coli* load in the larger rivers during base flow, an indication that small basin contributions were small. During storm events, small basin sites contributed much larger amounts of bacteria to large rivers. Coldwater Creek, Maline Creek, and the lower River des Peres contributed the largest amount of human *E. coli* to large rivers during storm events, although in all cases these amounts were less than 20 percent of the total receiving stream load.

On average, slightly more than one-third (35 percent) of all *E. coli* at stream sites was typed as being of human origin using rep-PCR (fig. 16). Smaller percentages of *E. coli* originated from dogs (10 percent) and geese (20 percent). The remaining one-third of *E. coli*, was attributable to unidentified sources (fig. 16). Small basin sites on Coldwater Creek, Maline Creek, and the River des Peres, which collectively are downstream of the majority of CSOs and SSOs in the study area (table 2) had, on average, 36 percent of the *E. coli* sourced as human (table 8), a value consistent with, but generally less than, the percentage of human *E. coli* detected in other urban areas of the State where streams receive CSO discharges (Wilkison and others, 2009).

When host-source samples were grouped together, there was no statistical difference (Wilcoxon rank sum; p-values, 0.23 to 0.61) in the percent of *E. coli* identified in base flow compared to that in storm-event samples for any of the host-source groups (fig. 16). These data are an indication that the general origins of *E. coli* sources in the study area were largely independent of hydrologic conditions and remained relatively consistent with time (fig. 16).

Because *E. coli* densities generally were below the applicable water-quality criterion at Mississippi River sites, human-sourced *E. coli* densities, approximately one-third of the total, almost always were below the criteria—the only exception being the most downstream Mississippi River site. However, because *E. coli* densities at some Missouri River and small basin sites frequently were well above the applicable water criterion, the percentage attributable to human sources was, at times, above the standard—much more so during storms than base flow. When stream *E. coli* loads are taken into account, small basin contributions to large rivers generally were small because flows in the large, receiving streams were greater. This especially was true during base flow when small basin *E. coli* loads were less than 1 percent of those measured at the large river sites. During storm events, *E. coli* loads at small basin sites were, on average, 7 percent of large river, receiving stream loads. These data indicate that although small basin *E. coli* densities were large, small basin *E. coli* contributions (loads) to the larger rivers in the study area were small in comparison to the resident large river *E. coli* populations. This was because, in part, streamflow in the Missouri and Mississippi Rivers was much greater than small basin flows, and also because the contributing drainage area contained within the study area of large rivers was only a small part of the overall drainage area. Thus, precipitation events in the study area, which resulted in large increases in streamflow at small basin sites, had a much smaller effect on the flows in the larger rivers.

Bacteroides thetaiotaomicron

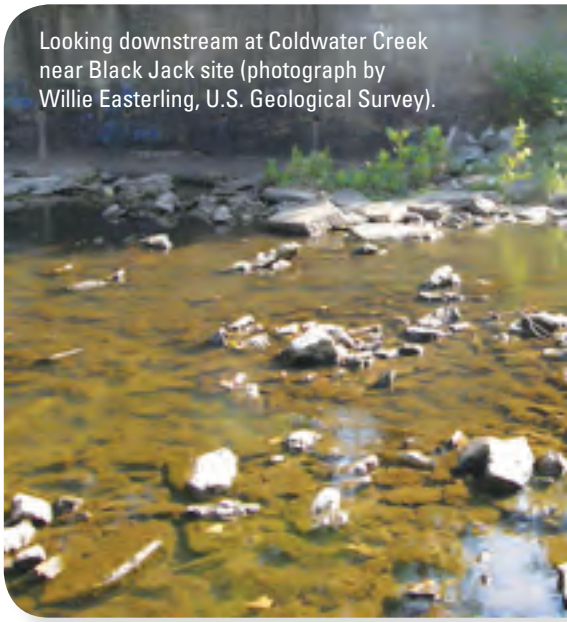
Approximately two-thirds (65 percent) of the samples analyzed for *E. coli* host sources using rep-PCR also were analyzed for the presence of an additional genetic marker, *Bacteroides thetaiotaomicron*, to confirm the presence of human fecal contamination. *B. thetaiotaomicron* has been shown to be a good indicator of human fecal contamination because it predominates in human feces and occurs infrequently in non-human feces (Carson and others, 2005). *B. thetaiotaomicron* was detected in 92 percent of metropolitan St. Louis stream samples where rep-PCR identified the presence of human *E. coli*. Only one percent of samples had no detectable *B. thetaiotaomicron* in the presence of human *E. coli*. Seven percent of samples (14 of 202) had detectable levels of *B. thetaiotaomicron* but not human *E. coli*; however, such samples typically had small *E. coli* densities (less than 70 col/100mL) and larger (greater than 70) percents of unknown isolates. It also is possible that for these few samples, human *E. coli* had degenerated to the point that it could no longer be identified as originating from a human source or could not be sufficiently cultured for the rep-PCR analysis. *B. thetaiotaomicron* has been shown to occur in dogs, although in much smaller amounts than in humans, so it is possible that the *B. thetaiotaomicron* in some of these 14 samples came from dogs; however, less than one-half of these samples had detectable *E. coli* sourced to dogs, which would tend to indicate that sharing, if it did occur, was minimal. It is important to note that these two tests analyzed for different types of bacteria. *E. coli* are aerobic bacteria, whereas *B. thetaiotaomicron* are anaerobic; thus, survival rates in the environment would be expected to differ between these organisms. The presence of *B. thetaiotaomicron* in more than 90 percent of the samples that also had detectable human *E. coli* underscores the commonality of human fecal contamination of surface waters in the study area.

Annual load estimates

Annual load estimates integrated base-flow and storm-event samples for a broader, and in this case, yearly time interval. Estimated annual *E. coli* loads at selected sites were used to provide additional confirmation of the discrete and source-tracking *E. coli* data and provided another measure of relative source contributions in the study area. Regression models and model output at sites where models met the previously defined minimum fit criteria are reported in tables 11, 12, and 13. Estimated annual *E. coli* loads for two Missouri River sites (06935972 and 06937000), two Mississippi River sites (05587455 and 07019370), and all six small basin sites from October 1996 through September 2007 are shown in figure 17. Also shown in figure 17 are how streamflow and precipitation within the study area compared to the long-term (at least 90 years of record) average. Annual load estimates and the 95 percent confidence intervals for those estimates are provided in table 13. Annual load estimates are provided for the period of record available for any given station; however, site comparisons were done only in relation to data from October 2004 through September 2007 (water years 2005 through 2007).

The largest annual *E. coli* loads were observed on the Missouri River (sites 06935972 and 06937000) and downstream Mississippi River site (07019370; fig. 17 and table 13). Estimated annual *E. coli* loads from these sites generally were at least an order of magnitude greater than those from the most upstream Mississippi River site (05587455), and were two to three orders of magnitude greater than the estimated loads at most small basin sites (fig. 17; table 13). One small basin site, the lower River des Peres (07010097), had estimated annual loads of the approximate same size as those from the upper Mississippi River site (05587455).

Comparison of the estimated annual *E. coli* loads at sites with those in downstream receiving streams during water years 2005 through 2007 provides an additional measure, one that integrates base-flow and storm-event contributions of tributary contributions to receiving streams (table 14). The mean annual *E. coli* load at the upper Mississippi River site (05587455) was small when compared to mean loads at sites on the Missouri River (06935972 and 06937000) or the lower Mississippi River (07019370; table 14). The mean annual load for the upper Mississippi River site (05587455) was only 12 percent of that at the lower Mississippi River site (07019370), whereas the lower Missouri River site (06937000) was nearly equivalent to that of the lower Mississippi River. These data indicate that annual *E. coli* contributions from the Mississippi River reach above the Missouri River confluence contributed, on average, a much smaller percent of the *E. coli* to lower Mississippi River reaches than did the Missouri River. The base-flow and storm-event average contributions to receiving streams are shown in table 14 along with the previous instantaneous load determination (table 6) to allow comparisons between the two approaches. In the case of the upper Mississippi River, the values were identical.


Looking downstream at Coldwater Creek near Black Jack site (photograph by Willie Easterling, U.S. Geological Survey).

With the exception of the lower River des Peres (site 07010097), the mean annual *E. coli* load at small basin sites was less than 1 percent of the mean annual load of large river

Table 10. Mean tributary inputs of *Escherichia coli* host-source loads to receiving streams for samples collected between October 2004 and September 2007.

[--, not applicable; <, less than]

Receiving stream reach	Site(s) included (fig. 1)	Mean instantaneous *Escherichia coli* load, in millions of colonies per second		Tributary or upstream reach	Site(s) included (fig. 1)	Mean instantaneous *Escherichia coli* load, in millions of colonies per second		Tributary load, as percent of receiving stream load	
		Base flow	Storm event			Base flow	Storm event	Base flow	Storm event
Human									
Missouri River tributary									
Upper Missouri	06935715	2,770	5,380	--	--	--	--	--	--
Mid-Missouri	06935972	1,900	4,460	Creve Coeur Creek	06935890	0.17	54	<1	1
Lower Missouri	06937000	2,200	3,730	Coldwater Creek	06936475	.16	519	<1	14
				Upper Mississippi[a]	05587455	114	720	5	19
Mississippi River tributary									
Mid-Mississippi	07005500, 07010000	1,750	2,560	Maline Creek	07005000	.61	460	<1	18
Lower Mississippi	07010220, 07019370	3,590	14,900	Upper River des Peres	07010022	4.0	425	<1	3
				Lower River des Peres	07010097	3.0	2,230	<1	15
				Grand Glaize Creek	07019185	.18	74	<1	<1
Dog									
Missouri River tributary									
Upper Missouri	06935715	1,130	1,730	--	--	--	--	--	--
Mid-Missouri	06935972	1,300	897	Creve Coeur Creek	06935890	.17	19	<1	2
Lower Missouri	06937000	606	1,190	Coldwater Creek	06936475	.08	515	<1	43
				Upper Mississippi[a]	05587455	13	103	2	9
Mississippi River tributary									
Mid-Mississippi	07005500, 07010000	311	1,160	Maline Creek	07005000	.06	64	<1	6
Lower Mississippi	07010220, 07019370	408	3,490	Upper River des Peres	07010022	.05	484	<1	14
				Lower River des Peres	07010097	1.3	400	<1	12
				Grand Glaize Creek	07019185	.06	43	<1	1

Table 10. Mean tributary inputs of *Escherichia coli* host-source loads to receiving streams for samples collected between October 2004 and September 2007.—Continued

[--, not applicable; <, less than]

Receiving stream reach	Site(s) included (fig. 1)	Mean instantaneous *Escherichia coli* load, in millions of colonies per second		Tributary or upstream reach	Site(s) included (fig. 1)	Mean instantaneous *Escherichia coli* load, in millions of colonies per second		Tributary load, as percent of receiving stream load	
		Base flow	Storm event			Base flow	Storm event	Base flow	Storm event
Goose									
Missouri River tributary									
Upper Missouri	06935715	2,050	3,100	--	--	--	--	--	--
Mid-Missouri	06935972	1,620	3,320	Creve Coeur Creek	06935890	0.16	27	<1	3
Lower Missouri	06937000	1,220	3,970	Coldwater Creek	06936475	.17	312	<1	9
				Upper Mississippi[a]	05587455	127	663	10	17
Mississippi River tributary									
Mid-Mississippi	07005500, 07010000	823	1,850	Maline Creek	07005000	.26	311	<1	17
Lower Mississippi	07010220, 07019370	1,920	7,590	Upper River des Peres	07010022	1.7	349	<1	5
				Lower River des Peres	07010097	2.5	314	<1	4
				Grand Glaize Creek	07019185	.44	45	<1	1
Unidentified sources									
Missouri River tributary									
Upper Missouri	06935715	1,130	1,730	--	--	--	--	--	--
Mid-Missouri	06935972	1,300	897	Creve Coeur Creek	06935890	.29	78	<1	4
Lower Missouri	06937000	606	1,190	Coldwater Creek	06936475	.26	1,030	<1	48
				Upper Mississippi[a]	05587455	300	658	18	31
Mississippi River tributary									
Mid-Mississippi	07005500, 07010000	311	1,160	Maline Creek	07005000	.73	627	<1	32
Lower Mississippi	07010220, 07019370	408	3,490	Upper River des Peres	07010022	2.0	256	<1	3
				Lower River des Peres	07010097	3.1	1,440	<1	19
				Grand Glaize Creek	07019185	.71	159	<1	2

[a]Comparison is to lower Missouri River site (06937000).

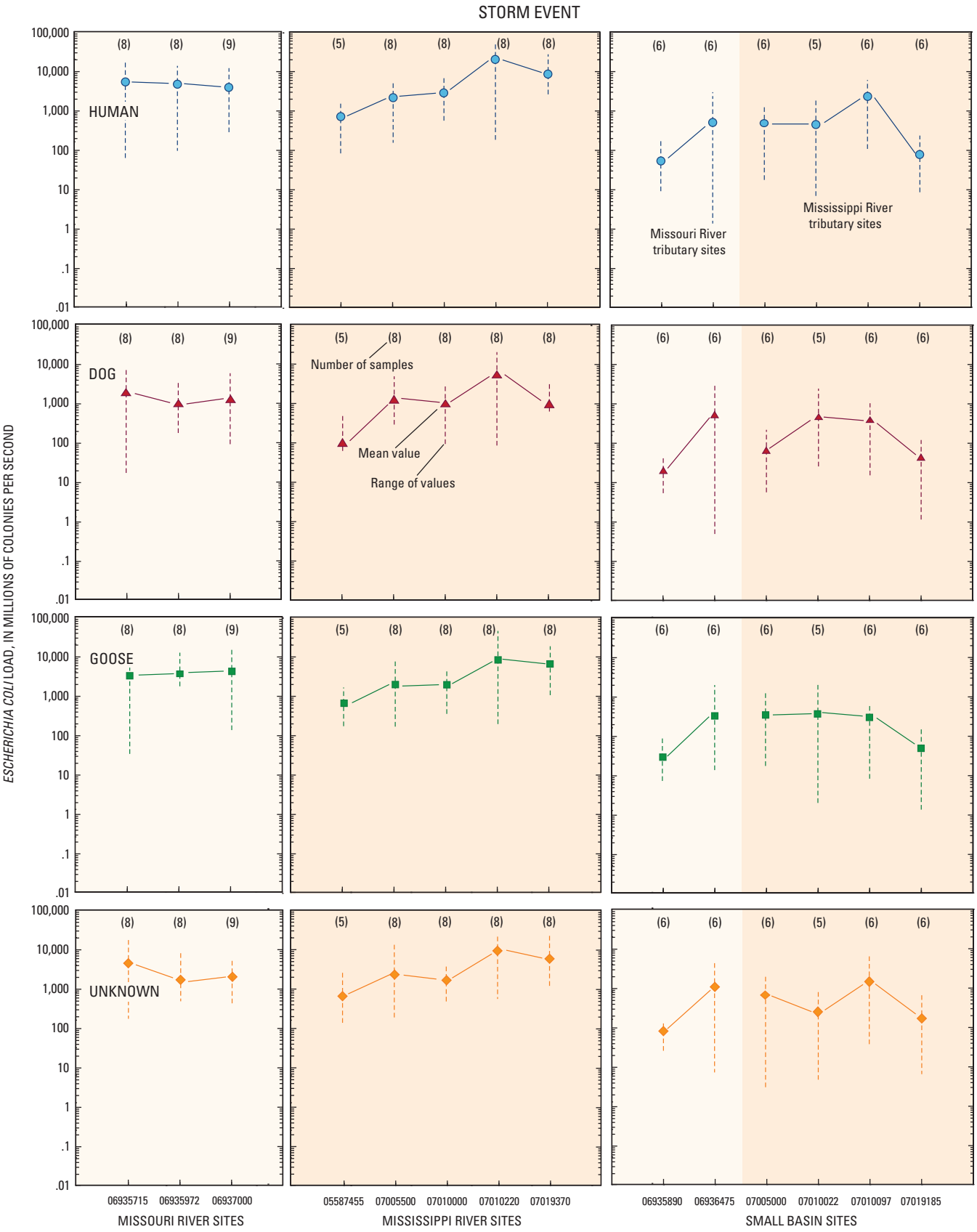


Figure 15. Mean *Escherichia coli* load attributable to host sources at sites in the metropolitan St. Louis area from storm-event samples collected between October 2004 and September 2007.

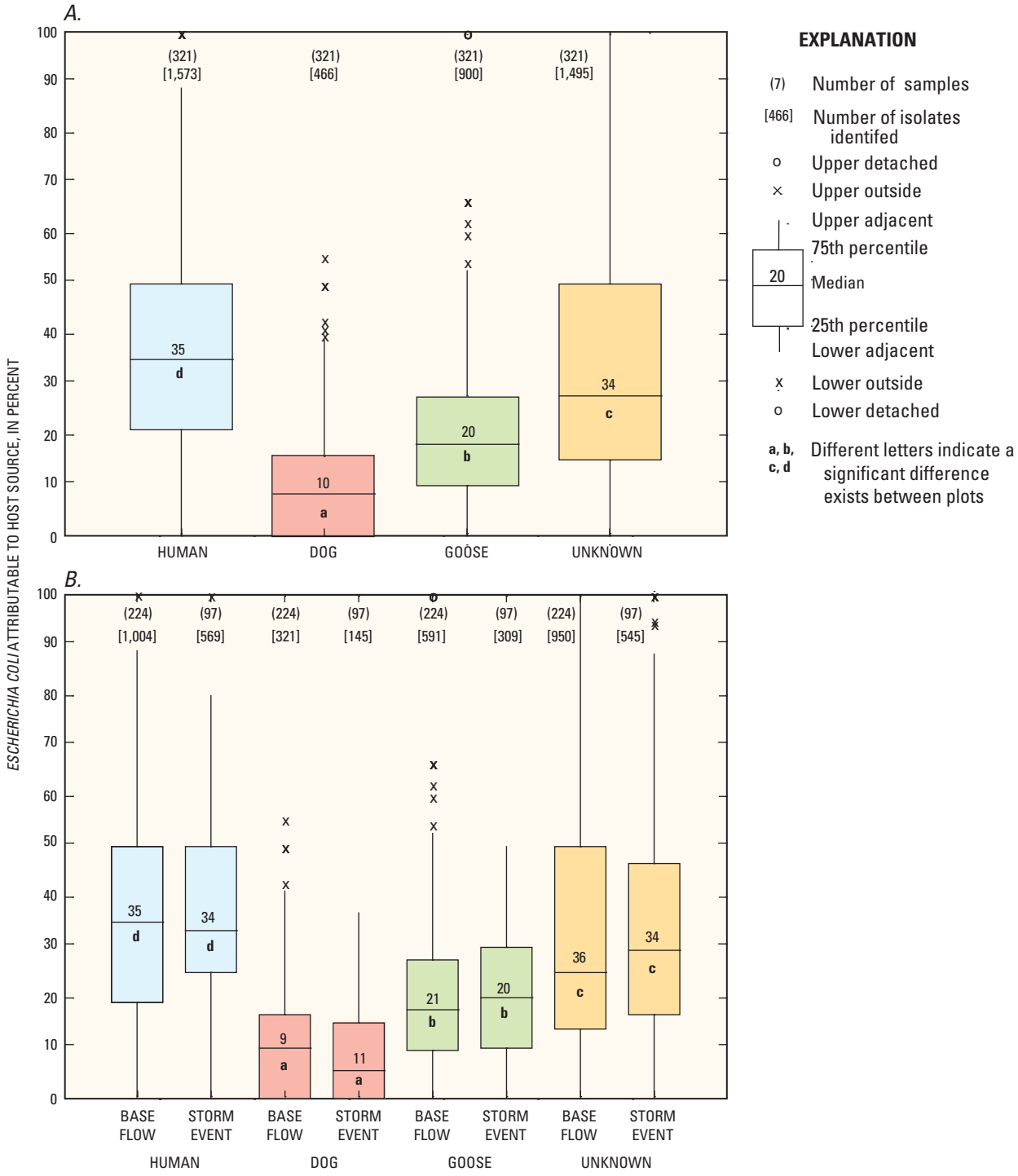


Figure 16. Percent of identified by host-source category in samples collected in the metropolitan St. Louis area between October 2004 and September 2007.

sites (table 14). Mean *E. coli* load at the lower River des Peres site was 9 percent of the mean load in the lower Mississippi River. These data indicate that, when viewed annually, *E. coli* loads at small basin sites in the study area typically were small when compared to loads in receiving sections of large rivers. The largest annual contributions from small basin sites to the larger river receiving streams originated from lower River des Peres. These data do not preclude the fact that some storm events may provide large amounts of *E. coli* to receiving streams, but rather that small basin streams, over the course of any given year, typically contribute no more than 10 percent of the *E. coli* to larger river systems. The bulk of the *E. coli* load to the middle Mississippi River, immediately downstream from the confluence with the Missouri River, appears

to originate from the Missouri River with smaller amounts (approximately 10 percent annually) originating from the upper Mississippi River and the lower River des Peres.

Annual loads at small basin sites closely followed the precipitation pattern within the study area (fig. 17). This would be expected because discharge was a large component of loads. Precipitation in the study area from 1997 to 2007 was 4 percent greater than the long term (90 year) average, and streamflow for the Mississippi River at St. Louis was 1 percent greater than average. For the most part, Mississippi River streamflow mirrored the precipitation pattern, but there were exceptions. For example, 2001 annual precipitation was 16 percent below average, and loads at small basin sites declined accordingly (fig. 17). This was followed by 4 years of slightly above (14 percent) average precipitation and a corresponding increase in loads. Loads then declined in 2006 in response to below average precipitation before increasing in 2007 when precipitation returned to normal levels. For a few years, notably 1999 and 2001, flows in the Mississippi River at St. Louis were greater than the long-term average, although local precipitation decreased. This happens because given the basin's size, areas may experience wetter than normal conditions, whereas others remain dry. These data are another indication that flows, and consequently constituent loads in large rivers within the study area, are only partly controlled by local events.

Yields, which normalize annual loads by contributing drainage area, indicated that *E. coli* contributions per square kilometer in small basins were 2 to 3 orders of magnitude greater than at large river sites (table 14). This was because, in part, the contributing drainage area at large river sites was so much larger than for the small basins, but also because *E. coli* densities in small basins in the study area were much greater than in the large rivers. Additionally, at the basin-scale level, bacteria die-off would be expected to be more of a factor in the Missouri and Mississippi Rivers than for the smaller basins. The largest mean annual yields were at the two River des Peres sites (table 14).

Because estimated annual *E. coli* loads at basin sites were the summation of daily loads, dividing the daily *E. coli* load by the daily mean discharge provided an estimated daily mean *E. coli* density. Estimated daily mean *E. coli* density values covered the range of hydrologic conditions at sites and provided additional measures for comparing the relative difference between streams and sites (fig. 18).

Estimated daily mean *E. coli* densities were significantly lower at the upstream Mississippi River site (05587455; fig. 18) than at other stream reaches in the study area (Wilcoxon rank sum; p-values less than 0.001). Daily mean *E. coli* densities were slightly, but significantly, higher for Missouri River sites when compared to the downstream Mississippi River site (07019370; fig. 18). Small basin sites had estimated daily mean *E. coli* densities that were significantly higher than other stream reaches (fig. 18). Small basin sites located in areas with the greatest number of CSOs and SSOs in the study area—Maline Creek and the River des Peres—had the largest estimated daily mean *E. coli* densities (fig. 18).

As previously noted, the geometric mean of samples collected during the recreational season is used to determine compliance to water-quality criteria; however, estimated daily mean *E. coli* densities, which incorporate all interannual hydrologic fluctuations and cover a larger time span than do discrete samples, provide another measure to compare instream *E. coli* densities against these criteria (table 14). As a means of comparing the two approaches, the weighted average values for discrete base-flow and storm-event samples (table 5) also are provided in table 15.

In general the two approaches were similar (table 15), but more so at sites where bacteria densities fluctuated little in response to hydrologic events such as occurs on the Missouri River and the upper Mississippi River. Based on estimated daily mean *E. coli* values, sites on the Missouri River were below the applicable *E. coli* standard, on average, slightly more than one-half (52 percent) of the time—a value identical to the Missouri River weighted average (52 percent) of the discrete base-flow and storm-event values (table 15). Estimated daily mean *E. coli* values at the upper Mississippi River site (05587455) were below the applicable standard, on average, 94 percent of the time, a value nearly identical to the average (95 percent) of the discrete base-flow and storm-event samples (table 15). For the lower Mississippi River site (07019370), there was less agreement between the two approaches, 38 percent compared to 57 percent. Some of these differences may be an artifact of the model estimation approach at this site. At small basin sites: Creve Coeur, Coldwater Creek, Maline, and Grand Glaize Creeks, where whole body contact-Class B *E. coli* criterion currently (2010) applies, estimated daily mean *E. coli* densities were below the criterion, on average, only 4 percent of the time, which is lower than the average (29 percent) of the discrete base-flow and storm-event values (table 15).

Where secondary contact *E. coli* criterion currently (2010) are in place—the lower River des Peres—estimated daily mean *E. coli* densities were below the criterion, on average, 48 percent of the time, which is lower than the average (65 percent) of the discrete base-flow and storm-event values. Although not intended to illustrate compliance with water-quality standards, these data indicate that, in some instances, broadening the scope of the measurement period to include daily values—compared to the assessments that use less frequent, discrete values—may change assumptions about how frequently criteria are met or exceeded.

Hydrologic Effects on *Escherichia coli* densities in streams

Precipitation affects instream bacteria densities in a number of ways, primarily by mobilizing sediments to which bacteria particles frequently are associated. Because bacteria particles are associated with suspended stream sediment,

Table 11. Regression models for estimating annual loads of *Escherchia coli* in water at metropolitan St. Louis sites.

[RMSE, root mean square error; r^2, coefficient of determination; Ln, natural logarithm; Ecoli, *Escherichia coli*; FLOW, centered value of flow; Time, centered value of time; Sin, Sine; Cos; cosine; FECcoli, fecal coliform; π, pi]"

Station identifier (fig.1)	Regression model	RMSE	r^2
	Missouri River sites		
06935972	Ln(Ecoli) = 2.02Ln(FLOW) - 0.434Time + 0.884Sin(Time2π) + 0.275Cos(2πTime) + 19.7	1.3	53.7
06937000	Ln(Ecoli) = 3.05Ln(FLOW) - 2.163Ln(FLOW)² - 0.336Time - 0.892Time² - 0.135Sin(2πTime) + 1.77Cos(2πTime) + 22.0	1.3	62.5
	Mississippi River sites		
05587455	Ln(Ecoli) = 2.50Ln(FLOW) + 0.946Ln(FLOW)² - 0.114Time - 0.327Sin(Time2π) + 0.392Cos(Time2π) + 17.8	.94	54.9
07019370	Ln(FECcoli) = 1.57Ln(FLOW) + 0.899Ln(FLOW)² - 0.157Time - 0.015Time² - 1.22Sin(Time2π) - 0.915Cos(Time2π) + 25.6	1.6	83.7
	Small basin sites		
06935890	Ln(Ecoli) = 2.05Ln(FLOW) - 0.065Ln(FLOW)² - 0.077Time + 0.055Time² - 1.114in(Time) - 0.672Cos(2πTime) + 13.5	1.37	87.0
06936475	Ln(Ecoli) = 1.74Ln(FLOW) - 0.017Ln(FLOW)² - 0.091Time + 0.046Time² - 0.628Sin(2πTime) - 0.984Cos(2πTime) + 14.0	1.36	90.3
07005000	Ln(Ecoli) = 1.59Ln(FLOW) + 0.115Ln(FLOW)² - 0.112Time - 0.024Time² - 0.388in(Time) - 0.754Cos(2πTime) + 13.6	1.34	89.2
07010022	Ln(Ecoli) = 1.53Ln(FLOW) - 0.026Ln(FLOW)² - 0.192Time - 0.056Time² - 0.410Sin(2πTime) - 0.709Cos(2πTime) + 13.0	1.50	91.3
07010097	Ln(Ecoli) = 1.95Ln(FLOW) - 0.070Time - 0.004Sin(2πTime) + 0.073Cos(2πTime) + 13.6	1.75	88.8
07019185	Ln(Ecoli) = 1.77Ln(FLOW) + 0.029Ln(FLOW)² - 0.098Time - 0.062Time² - 0.601Sin(2πTime) - 1.40Cos(2πTime) + 11.8	1.37	89.8

increased runoff typically results in increased levels of instream bacteria. Runoff events also can trigger CSO, SSO, and WWTP by-pass events, each of which can result in large increases in bacteria loads in streams. Basins with large amounts of impervious surface area potentially have increased runoff, increased stream velocities, and increased channel erosion and therefore, increased levels of streamflow, suspended sediment, and *E. coli* (Paul and Meyer, 2001). There was a strong association (coefficient of correlation, 0.83; $p<0.001$) between the percent of impervious cover and *E. coli* densities in the study area (fig. 19). Water-quality degradation and increased concentrations of constituents, including fecal indicator bacteria, in streams with large amounts of impervious cover, have been demonstrated in numerous studies (Mallin and others, 2000; Wilkison and others, 2006; Poulton and others, 2007; Schueler and others, 2009); however, it is important to note that impervious area alone does not fully represent the complexity of urban land cover and that other factors, such as the pattern, intensity, and connectivity of these areas may be as important as the total area (Alberti and others, 2007).

For sites on the Missouri and Mississippi Rivers, where most of the basin lies outside the metropolitan St. Louis, instream bacteria concentrations were only partly determined by localized runoff events. When grouped by hydrologic event, median *E. coli* densities in Missouri and Mississippi River storm-event samples were approximately 4 times greater than in base-flow samples (fig. 7); however, small basin storm-event samples had much larger increases in *E. coli* densities over those measured in base-flow samples. At small basin sites, the median *E. coli* densities in storm-event samples (5,400 col/100 mL) was more than 10 times greater than the density measured in base-flow samples (460 col/100 mL; fig. 7). This is likely because the small basin sites were draining largely urban land use in the metropolitan St. Louis area, whereas most of the area upstream from Missouri and Mississippi River sites lies outside of the St. Louis area, of which only a small part is urban.

In addition to mobilizing nonpoint source runoff, precipitation events, especially where intense or prolonged, trigger CSOS and SSOs. Such overflows contain large bacteria densities and thus increase instream bacteria densities of receiving streams. The combined number of CSOs and SSOs upstream from sample sites in the study area ranged from zero at the upstream Missouri and Mississippi River sites (06935715 and 05587455) to more than 400 at the most downstream Mississippi River site (07019370) (table 2; fig. 2). Although these eventually drain to the lower Mississippi River, most of the CSOs and SSOs in the study area were located in the River des

Table 12. Model (adjusted maximum likelihood estimation method) output for flow-adjusted trends in *Escherichia coli* concentration at metropolitan St. Louis sites.

[CI, confidence interval; n, number of observations; nC, number of censored observations; RMSE, root mean square error; r^2, coefficient of determination; bold numbers indicate significant flow-adjusted trend existed at site]

Site name	Station ID (fig.1)	Reference concentration, in colonies per 100 milliliters	Flow-adjusted trend, in average percent per year				Properties of the calibration data set					Properties of the time term				Properties of the fitted model	
			Water years[a]	Modeled estimate	Upper 95 percent CI	Lower 95 percent CI	Start date	End date	n	nC	Central value of flow	Coefficient	Standard deviation	p-value	Central value of time	RMSE	r^2
Missouri River sites																	
Missouri River below St. Charles	06935972	230	2005–2007	-28.9	30.3	-163.9	10/18/2004	8/13/2007	27	0	73,930	-0.668	0.486	0.19	2006.34	1.27	53.7
Missouri River at Columbia Bottom	06937000	280	2005–2007	-13.9	21.5	-76.6	10/18/2004	8/13/2007	28	0	74,600	-.336	.272	.16	2006.34	1.27	62.5
Mississippi River sites																	
Mississippi River below Grafton, Ill.	05587455	52	1998–2007	- 4.6	4.2	-14.7	10/16/1997	11/1/2007	155	1	109,200	-.053	.047	.25	2005.27	.49	54.9
Mississippi River at Kimmswick	07019370	1,400[b]	1998–2007	-3.1	-13.5	-18.0	8/13/1975	11/1/2007	47	0	146,000	- .157	.011	.06	1991.49	.96	83.7
Small Basin sites																	
Creve Coeur Creek	06935890	610	1998–2007	-6.3	3.3	-19.2	8/27/1997	9/12/2007	67	1	30	-.077	.057	.15	2002.94	1.37	87.0
Coldwater Creek near Black Jack	06936475	600	1997–2007	-6.0	0.9	-19.2	8/1/1996	9/12/2007	73	2	66	-.091	.050	.05	2002.34	1.36	90.3
Maline Creek	07005000	1,420	1996–2007	-6.1	-1.5	-20.8	8/1/1996	9/12/2007	71	0	26	-.112	.048	.71	2002.49	1.34	89.2
River des Peres near University City	07010022	4,150	1998–2007	-8.8	-5.8	-32.6	8/19/1997	9/12/2007	67	0	4.3	-.192	.067	.11	2002.92	1.50	91.3
River des Peres at St. Louis	07010097	740	2004–2007	21.6	54.6	-25.3	10/29/2002	9/12/2007	38	1	30	.146	.200	.47	2005.37	1.75	88.8
Grand Glaize Creek	07019185	570	1998–2007	-7.1	1.2	-21.2	8/27/1997	9/12/2007	67	1	16	-.098	.057	.07	2002.97	1.37	89.8

[a]Water year runs from October 1 to September 30 of each year.

[b]Fecal coliform.

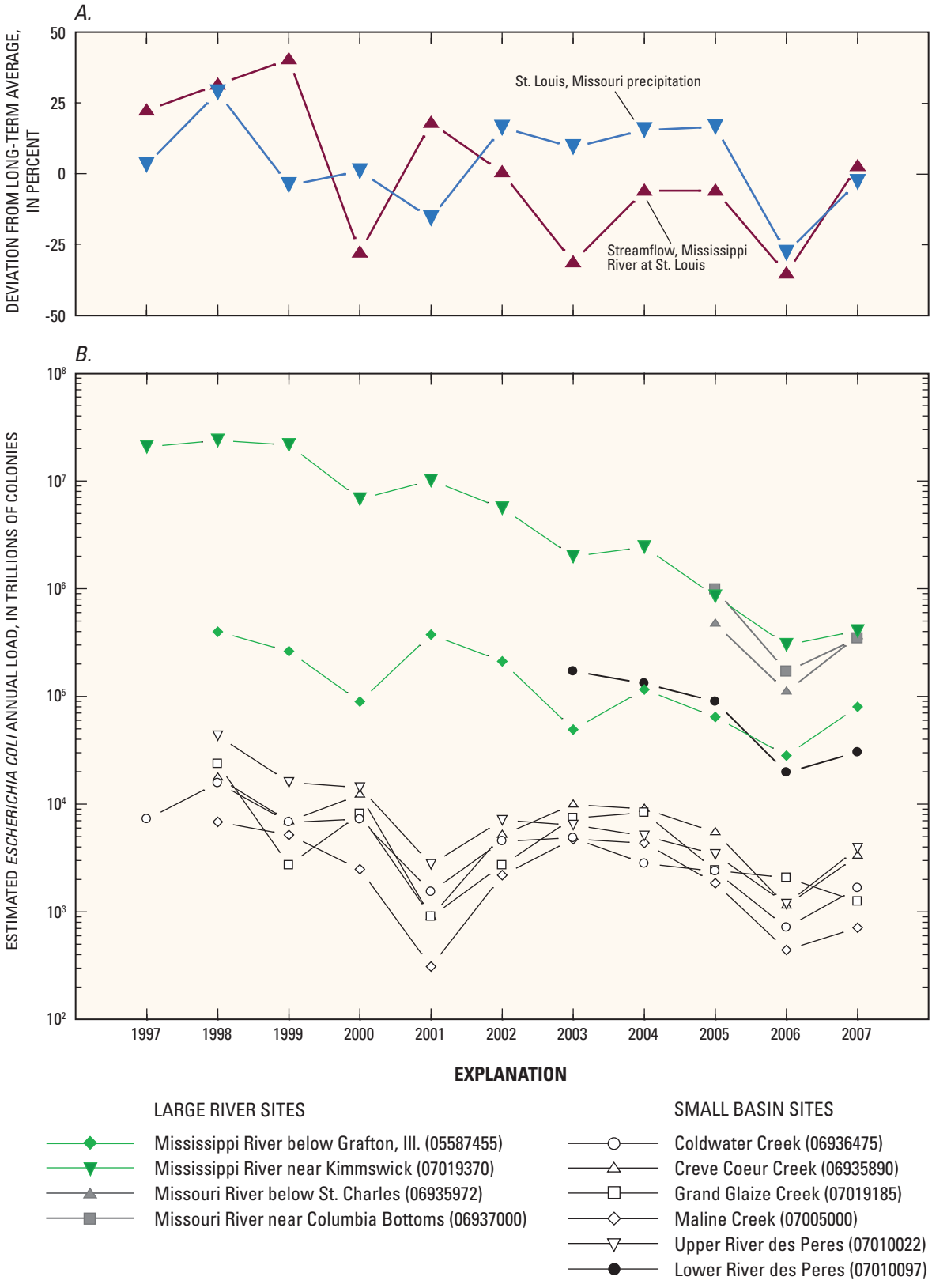


Figure 17. Estimated annual loads of *Escherichia coli* for sites in the metropolitan St. Louis area from October 1996 through September 2007 and streamflow and precipitation comparison to the long-term (90-year) average.

Table 13. Estimated annual loads, in trillions of colonies, of *Escherichia coli* at metropolitan St. Louis sites for water years 1997 through 2007.

[--; not determined; Lower 95%, lower 95 percent confidence interval; Upper 95%, upper 95 percent confidence interval]

Water year	Missouri River below St. Charles (06935972)			Missouri River at Columbia Bottom (06937000)			Mississippi River below Grafton, Illinois (05587455)			Mississippi River at Kimmswick, Mo (07019370)		
	Load	Lower 95%	Upper 95%	Load	Lower 95%	Upper 95%	Load	Lower 95%	Upper 95%	Load	Lower 95%	Upper 95%
Large river sites												
	Missouri River sites						Mississippi River sites					
1997	--	--	--	--	--	--	--	--	--	20,700,000	26,100	138,000,000
1998	--	--	--	--	--	--	399,000	174,000	788,000	23,800,000	24,200	156,000,000
1999	--	--	--	--	--	--	263,000	137,000	459,000	21,600,000	33,700	145,000,000
2000	--	--	--	--	--	--	89,700	41,200	171,000	3,780,000	84,000	43,000,000
2001	--	--	--	--	--	--	376,000	169,000	727,000	10,100,000	48,700	68,700,000
2002	--	--	--	--	--	--	212,000	93,400	416,000	5,590,000	31,500	37,800,000
2003	--	--	--	--	--	--	49,300	26,900	83,200	1,990,000	294,000	70,020,000
2004	--	--	--	--	--	--	116,000	56,000	214,000	2,440,000	339,000	8,790,000
2005	472,000	16,600	2,570,000	985,000	241,000	2,740,000	64,000	35,000	109,000	852,000	312,000	1,880,000
2006	111,000	30,300	291,000	170,000	79,800	319,000	28,300	14,800	49,000	302,000	172,000	492,000
2007	361,000	65,600	1,160,000	346,000	144,000	704,000	79,900	39,700	144,000	404,000	173,000	810,000
Mean[a]	**315,000**	**37,500**	**1,340,000**	**500,000**	**155,000**	**1,250,000**	**57,500**	**29,900**	**101,000**	**519,000**	**219,000**	**1,060,000**

Water year	Creve Coeur Creek (06935890)			Coldwater Creek (06936475)		
	Load	Lower 95%	Upper 95%	Load	Lower 95%	Upper 95%
Small basin sites						
	Missouri River tributary					
1997	--	--	--	7,270	1,180	24,500
1998	17,600	2,110	67,400	15,700	1,190	70,300
1999	6,910	794	26,800	6,810	868	25,400
2000	12,200	547	62,700	7,220	539	32,300
2001	900	171	2,740	1,530	298	4,780
2002	5,170	675	19,100	4,540	716	15,500
2003	9,920	956	41,000	4,840	356	21,900
2004	9,030	965	35,900	2,810	526	8,860
2005	5,490	737	20,100	2,390	465	7,440
2006	1,140	113	4,680	715	112	2,450
2007	3,320	651	10,300	1,670	308	5,330
Mean[a]	**3,320**	**500**	**11,700**	**1,590**	**295**	**5,080**

Water year	Maline Creek (07005000)			River des Peres near University City (07010022)			River des Peres at St. Louis (07010097)			Grand Glaize Creek (07019185)		
	Load	Lower 95%	Upper 95%	Load	Lower 95%	Upper 95%	Load	Lower 95%	Upper 95%	Load	Lower 95%	Upper 95%
Small basin sites—Continued												
	Mississippi River tributary											
1997	--	--	--	--	--	--	--	--	--			
1998	6,840	1,090	23,300	43,200	5,720	159,000	--	--	--	23,700	1,780	106,000
1999	5,170	684	19,000	15,900	1,770	62,500	--	--	--	2,710	270	11,100
2000	2,480	267	9,830	14,300	951	66,000	--	--	--	8,140	375	41,700
2001	311	75	872	2,700	464	9,200	--	--	--	905	108	3,470
2002	2,190	382	7,180	7,080	1,340	22,300	--	--	--	2,710	219	11,900
2003	4,730	293	22,400	6,400	946	22,500	171,000	3,320	1,030,000	7,420	341	38,000
2004	4,350	419	17,900	5,060	803	17,200	132,000	2,830	746,000	8,350	850	33,900
2005	1,840	193	7,390	3,410	704	10,300	89,000	4,390	450,000	2,420	414	8,000
2006	443	58	1,640	1,180	199	3,920	19,700	775	104,000	2,070	113	10,100
2007	712	142	2,190	3,900	610	13,410	30,300	1,740	147,000	1,250	225	4,030
Mean[a]	**999**	**131**	**3,740**	**2,830**	**505**	**9,230**	**46,400**	**2,300**	**234,000**	**1,910**	**251**	**7,390**

[a]Water years 2005 through 2007 (October 1 to September 30).

Table 14. Mean annual *Escherichia coli* estimated loads and yields at stream sites in metropolitan St. Louis and tributary inputs to receiving streams for water years 2005 through 2007.

[<, less than]

Receiving stream reach	Site included (fig. 1)	Mean annual *Escherichia coli* load, in trillions of colonies (table 12)	Mean annual *Escherichia coli* yield, in billions of colonies per square kilometer	Tributary or upstream reach	Site included	Mean annual *Escherichia coli* load, in trillions of colonies (table 12)	Mean annual *Escherichia coli* yield, in billions of colonies per square kilometer	Tributary load, as percent of receiving stream load	Mean of base-flow and storm-event tributary loads, as percent of receiving stream load (table 6)
Missouri River tributary									
Mid-Missouri	06935972	315,000	229	Creve Coeur Creek	06935890	3,320	58,200	1	<1
Lower Missouri	06937000	500,000	364	Coldwater Creek	06936475	1,590	15,200	<1	2
				Upper Mississippi	05587455	57,500	129	12	12
Mississippi River tributary									
Lower Mississippi	07019370	519,000[a]	285	Maline Creek	07005000	999	15,800	<1	8
				Upper River des Peres	07010022	2,830	122,000	<1	2
				Lower River des Peres	07010097	46,400	217,000	9	5
				Grand Glaize Creek	07019185	1,910	33,900	<1	<1

[a]Estimated annual fecal coliform load in trillions of colonies.

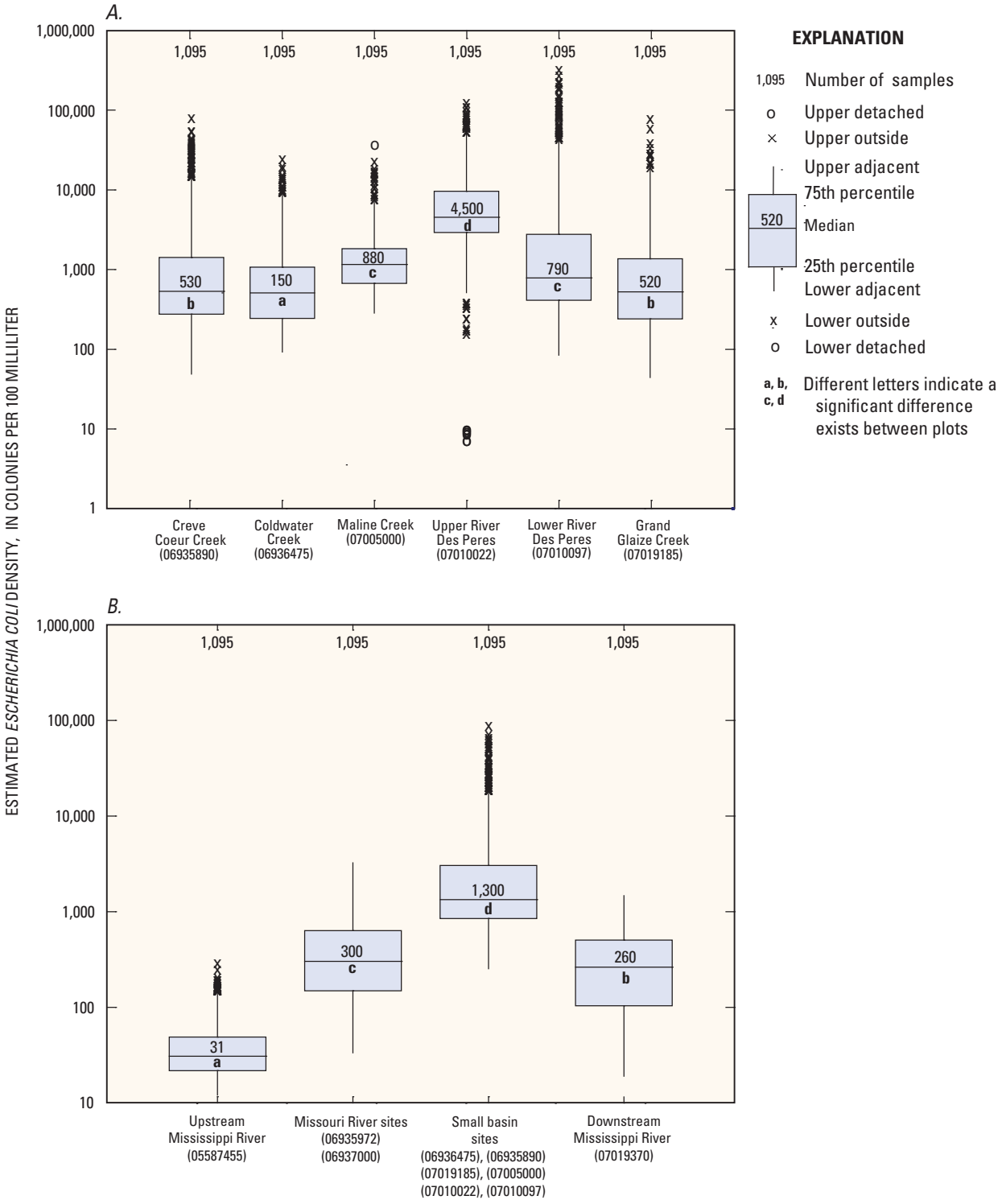


Figure 18. Estimated daily mean *Escherichia coli* densities for streams in metropolitan St. Louis from October 2004 through September 2007.

Table 15. Percent of estimated daily mean *Escherichia coli* densities at stream sites in the metropolitan St. Louis area that met the applicable State of Missouri criterion from October 2004 through September 2007.

[--; no data; col/100 ml, colonies per 100 milliliters of water]

Site	Station identifier	Percent of days or samples		Applicable criterion[a]
		Estimated daily mean values during recreational season (April 1st to October 31st)	Discrete base-flow and storm-event sample, weighted average (table 5)	
Large river sites				
Missouri River sites				
Missouri River near Chesterfield	06935715	--	59	206 col/100 mL
Missouri River below St. Charles	06935972	52	54	206 col/100 mL
Missouri River at Columbia Bottom	06937000	51	45	206 col/100 mL
Average	--	52	52	206 col/100 mL
Mississippi River sites				
Mississippi River below Grafton	05587455	94	95	126 col/100 mL
Mississippi River above St. Louis	07005500	--	100	1,134 col/100 mL
Mississippi River at St. Louis	07010000	--	100	1,134 col/100 mL
Mississippi River at Oakville	07010220	--	89	1,134 col/100 mL
Average	--	--	96	1,134 col/100 mL
Mississippi River at Kimmswick	07019370	38[b]	57	206 col/100 mL
Average	--	66	88	126–1,1134 col/100 mL
Small basin sites				
Creve Coeur Creek	06935890	11	36	206 col/100 mL
Coldwater Creek	06936475	2	33	206 col/100 mL
Maline Creek	07005000	0	20	206 col/100 mL[c]
Grand Glaize Creek	07019185	3	27	206 col/100 mL
Average	--	4	29	206 col/100 mL
River des Peres at St. Louis	07010097	48	65	1,134 col/100 mL
Average, all small basin	--	13	36	206 col/100 mL
River des Peres near University City	07010022	6	28	--[d]

[a]Geometric mean of recreational season samples, April 1 to October 31 of each year.

[b]Estimated from fecal coliform densities.

[c]Reach from streamgage to 0.5 mile below streamgage.

[d]No standard currrently (2010) applies. Results shown in comparison to secondary contact limit of 1,134 col/100 mL.

Peres Basin (fig. 2). To evaluate the effect that overflow events may have had on instream bacteria densities, the combination of upstream CSOs and SSOs were compared to the average (base flow and storm events) *E. coli* densities measured at downstream sites. For the Missouri River, average *E. coli* densities at sites decreased with increasing numbers of CSOs and SSOs (coefficient of correlation, 0.71; p=0.45). At Mississippi River sites there was a weak correlation (coefficient of correlation, 0.47; p=0.16) between an increase in the number of upstream CSOs and SSOs and instream *E. coli* densities; however, at small basin sites there was a strong correlation between the number of upstream CSOs and SSOs (coefficient of correlation, 0.94, p<0.01) and the average instream *E. coli* density. Together these data indicate that any discharges from CSOs and SSOs had a negligible effect on *E. coli* densities in the Missouri River, in part because there were relatively few of these that discharge to the Missouri River. Although *E. coli* associated with CSO and SSO discharges increased instream

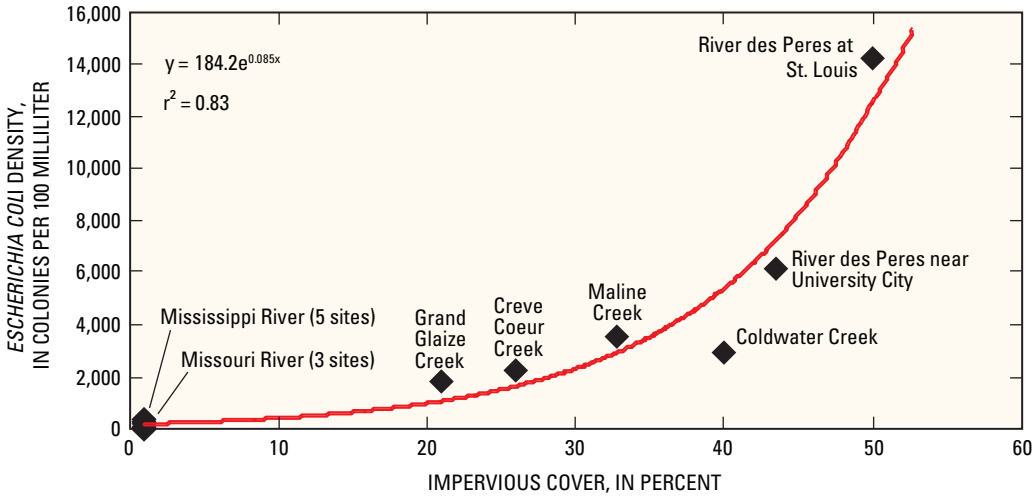


Figure 19. Relation between *Escherichia coli* densities and the percent of upstream impervious cover at sites in the metropolitan St. Louis area.

Mississippi River *E. coli* densities, these contributions were not statistically significant, primarily because other, larger, basin scale factors—such as inputs from the Missouri River and nonpoint source runoff—played a large role. Unlike the large rivers, CSO and SSO discharges likely played a large role in *E. coli* densities observed in the small basins, especially the River des Peres. Therefore, CSO and SSO elimination could reduce small basin *E. coli* densities to a greater extent than that expected in the larger rivers.

Summary and Conclusions

Fecal bacteria contamination, especially *E. coli* believed to have originated from humans, of metropolitan St. Louis streams is a concern. The U.S. Geological Survey in cooperation with the Metropolitan St. Louis Sewer District, which supplies wastewater treatment to a large part of the St. Louis metropolitan area, conducted a study to determine the occurrence, distribution, and sources of *E. coli* in streams. As part of this effort, 14 surface-water sites in metropolitan St. Louis were sampled between October 2004 and September 2007 for *E. coli* and *E. coli* sources. Source sampling was conducted using genotypic, local library-based methods that included *E. coli* host-source identification using rep-PCR and the presence of the anaerobic, enteric human bacteria, *B. thetaiotaomicron*. Samples were collected during base flow and storm events (determined solely by conditions within the study area) from three sites on the Missouri River, five sites on the Mississippi River, and six sites in smaller basins: Creve Coeur, Coldwater, Maline, and Grand Glaize Creeks and the River des Peres, all of which are tributaries to the larger rivers. The relative contribution of human, dog, goose, and unidentified *E. coli* at these sites was determined. Linear regression models, developed from data collected during a range of hydrologic conditions, were used to estimate annual *E. coli* loads at 10 sites. Water-quality data were compared to selected land-cover factors to evaluate the relative role of nonpoint source runoff relative to selected point sources (overflows from combined and sanitary sewers) at study sites.

E. coli densities and loads typically were many times greater in storm events than at base flow, primarily because *E. coli* densities and flow—a major load component—increased as a result of runoff. Instantaneous *E. coli* densities and loads at Missouri River sites were about 10 times greater than those measured at the most upstream Mississippi River site. A substantial part of the *E. coli* in the middle Mississippi River sections downstream from its confluence with the Missouri River originated from the Missouri River upstream from the study area. In lower Mississippi River reaches, bacteria contributions from the numerous combined and sanitary sewer overflows within the study area, as well as contributions from nonpoint source runoff, greatly increased instream *E. coli* densities.

Small basin *E. coli* densities, especially during storm events, were substantially larger than those in the Missouri and Mississippi Rivers, but *E. coli* loads from small basins were only a small fraction of the larger, receiving stream loads. Median small basin *E. coli* base-flow loads were less than 1 percent of those measured in the large rivers. Small basin *E. coli* contributions increased substantially during storms, but were never more than 16 percent of loads measured in receiving sections of the larger rivers. Small basin streams with the greatest number of CSOs and SSOs (Maline Creek and the River des Peres) had larger *E. coli* densities and larger amounts of bacteria attributed to human sources than other small basin sites.

Instream *E. coli* densities were compared to current (2010) State of Missouri criteria to demonstrate relevance to established thresholds rather than numeric compliance

which is determined from the geometric mean of recreational season (April 1 to October 31) samples. Missouri River *E. coli* densities were below the applicable State water-quality *E. coli* criterion, on average, in 60 percent of base-flow and 36 percent of storm-event samples. In contrast, Mississippi River *E. coli* densities were below the applicable State criteria in approximately 90 percent of base-flow samples. Primarily as a result of increased inputs from runoff, a smaller percent (75) of Mississippi River storm-event samples were below the applicable criteria, primarily in the most downstream reach where a whole body contact-Class B criterion (206 col/100mL) applied. For small basin sites where whole body contact-Class B criterion applied, approximately 30 percent of base-flow samples but only 4 percent of storm-event samples were below the standard. At the small basin site where a less stringent secondary contact recreation criterion (1,134 col/100mL) applied, 90 percent of base-flow samples, but only 11 percent of storm-event samples were below the standard.

Although there were differences among sites, on average, the relative contribution of *E. coli* from various sources in the study area did not significantly change between base flow and storm events, an indication that the sources remained relatively consistent and independent of hydrologic conditions. Approximately one-third of the *E. coli* in the streams was identified as human origin. Another one-third was determined to be from unidentified sources, and lesser amounts were identified as originating from geese (20 percent) and dogs (10 percent), indicating that much of the *E. coli* in the study area likely originated from nonpoint source runoff. Additionally, average instream *E. coli* densities were correlated strongly with the percent of upstream impervious cover and at small basin sites, the combined number of upstream CSOs and SSOs. CSOs and SSOs had a negligible effect on *E. coli* densities in the Missouri River, in part because there are relatively few that discharge to the Missouri River, and did not have a statistically significant effect on Mississippi River *E. coli* densities because other, larger, basin-scale factors—such as inputs from the Missouri River and nonpoint source runoff—played a large role.

References Cited

Ahmed, W., Hargreaves, M., Goonetilleke, A., and Katouli, M., 2008, Population similarity analysis of indicator bacteria for source prediction of faecal pollution in a coastal lake: Marine Pollution Bulletin, v. 56, no. 8, p. 1,469–1,475.

Akaike, H., 1981, Likelihood of a model and information criteria: Journal of Econometrics, v. 16, p. 3–14.

Alberti, M., Booth, D., Hill, K., Coburn, B., Avolio, C., Coe, S., and Spirandelli, D., 2007, The impact of urban patterns on aquatic ecosystems: An empirical analysis in Puget lowland sub-basins: Landscape and Urban Planning, v. 80, no. 4, p. 345–361.

Anderson, K.L., Whitlock, J.E., and Harwood, V.J., 2005, Persistence and differential survival of fecal indicator bacteria in subtropical waters and sediments: Applied and Environmental Microbiology, v. 71, no. 6, p. 3,041–3,048.

Brownell, M.J., Harwood, V.J., Kurz, R.C., McQuaig, S.M., Lukasik, J., and Scott, T.M., 2007, Confirmation of putative stormwater impact of water quality at a Florida beach by microbial source tracking methods and structure of indicator organism populations: Water Research, v. 41, no.16, p.3, 747–3,757.

Carson, A.C., Christiansen, J.M., Yampara-Isquise, H., Benson, V.W., Bauffaut, C., Davis, J.V., Broz, R.R., Kurtz, W.B., Rogers, W.M., and Fales, W.H., 2005, Specificity of a *Bacteroides thetaiotaomicron* marker for human feces: Applied and Environmental Microbiology, v. 71, no. 8, p. 4,945–4,949.

Carson, A.C., Shear, B.L., Ellersieck, M.R., and Asfaw, A., 2001, Identification of fecal *Escherichia coli* from humans and animals by ribotyping: Applied and Environmental Microbiology, v.67, no.4, p. 1,503–1,507.

Carson, A.C., Shear, B.L., Ellershieck, M.R., and Schnell, J.D., 2003, Comparison of ribotyping and repetitive extragenic palindromic-PCR for identification of fecal *Escherichia coli* from humans and animals: Applied and Environmental Microbiology, v. 69, no. 3, p. 1,836–1,839.

Chandran, A., and Hatha, A.A.M., 2005, Relative survival of *Escherichia coli* and Salmonella typhimurium in a tropical estuary: Water Research, v. 39, p. 1,397–1,403.

Cimenti, M., Hubberstey, A., Bewtra, and Biswas, N., 2007, Alternative methods in tracking sources of microbial contamination in waters: Water SA, v. 33, no.2, p. 183–194.

Cohn, T.A., 1988, Adjusted maximum likelihood-estimation of the moments of lognormal populations from Type I censored samples: U.S. Geological Survey Open-File Report 88–350, 34 p.

Cohn, T.A., DeLong, L.L., Gilroy, E.J., Hirsch, R.M., and Wells, D.K., 1989, Estimating contaminant loads: Water Resources Research, v. 25, no. 5, p. 937–942.

Davis, J.V., and Barr, M.N., 2006, Assessment of possible sources of microbiological contamination in water column and streambed sediments of the Jacks Fork, Ozark National Scenic Riverways, Missouri—Phase III: U.S. Geological Survey Scientific Investigations Report 2006–5161, 32 p.

Deller, S., Mascher, F., Platzer, S., Reinthaler, F.F., and Marh, E., 2006, Effect of solar radiation on survival of indicator bacteria in bathing waters: Central European Journal of Public Health, v.14, no.3, p.133–137.

Dufour, A.P., Strickland, E.R., and Cabelli, V.J., 1981, Membrane method for enumerating *Escherichia coli*: Applied and Environmental Microbiology, v. 41, no. 5. p. 1,152–1,158.

Duris, J.W., Haack, S.K., and Fogarty, L.R., 2009, Gene and antigen markers of shiga-toxin producing *E. coli* from Michigan and Indiana river water: occurrence and relation to recreational water quality criteria: Journal of Environmental Quality, v. 38, no.5, p. 1,878–1,885.

Field, K.G., and Samadpour, M., 2007, Fecal source tracking, the indicator paradigm, and managing water quality: Water Research, v. 41, p. 3,517–3,538.

Francy, D.S., and Darner, R.A., 2000, Comparison of methods for determining *Escherichia coli* concentrations in recreational waters: Water Research, v. 34, no. 10, p. 2,770–2,778.

Garcia-Armisen, T. and Servais, P., 2009, Partitioning and fate of particle-associated *E. coli* in river waters: Water Environment Research, v. 81, no.1, p. 21–28.

Garcia-Armisen, T., Prats, J., and Servais, P., 2007, Comparison of culturable fecal coliforms and *Escherichia coli* enumeration in freshwaters: Canadian Journal of Microbiology, v. 53, no. 6, p. 798–801.

Gordon, D.M., 2001, Geographical structure and host specificity in bacteria and the implications for tracing the source of coliform contamination: Microbiology, v. 147, no.5., p. 1,079–1,085.

Gordon, D.M., Bauer, S., and Johnson, J.R., 2002, The genetic structure of *Escherichia coli* populations in primary and secondary habitats: Microbiology, v. 148, p. 1,513–1,522.

Griffith, J.F., Aumand, L.A., Lee, I.M., McGhee, C.D., Othman, L.L, Ritter, K.J., Walker, K.O., and Weisberg, S.B., 2006, Comparison and verification of bacterial water quality indicator measurement methods using ambient coastal water samples: Environmental Monitoring and Assessment, v. 116, p. 335–344.

Griffith, J.F., Weisberg, S.B., and McGhee, C.D., 2003, Evaluation of microbial source tracking methods using mixed fecal sources in aqueous test samples: Journal of Water and Health, v. 1, no. 4, p. 141–151.

Haack, S.K., Duris, J.W., Fogarty, L.R., Kolpin, D.W., Focazio, M.J., Furlong, E.T., and Meyers, M.T., 2008, Comparing wastewater chemicals, indicator bacteria concentrations, and bacterial pathogen genes as fecal pollution indicators: Journal of Environmental Quality, v. 38, no.1, p. 248–258.

Hartel, P.G., Summer, J.D., Hill, J.L., Collins, J.V., Entry, J.A., and Segers, W.I., 2002, Geographic variability of *Escherichia coli* ribotypes from animals in Idaho and Georgia: Journal of Environmental Quality, v.31, no. 4, p. 1,273–1,278.

Hartel, P.G., Summer, J.D., and Segars, W.I., 2003, Deer diet affects ribotype diversity of *Escherichia coli* for bacterial source tracking: Water Research, v. 37, no.13, p. 3,263–3,268.

Harwood, V.J., Whitlock, J., and Withington, V., 2000, Identification of antibiotic resistance patterns of indicator bacteria by discriminant analysis: use in predicting the source of fecal contamination in subtropical waters: Applied and Environmental Microbiology, v.66, no.9, p. 3,698–3,704.

Hauck, H.S., and Harris, T.R., 2005, Water resources data – Missouri, water year 2004: U.S. Geological Survey Water-Data Report MO-04-1, cd rom, 798 p.

Helsel, D.R., and Hirsch, R.M., 1992, Statistical methods in water resources: Studies in environmental science 49: New York, Elsevier Science Publishing Co., 522 p.

Hipsey, M.R., Antenucci, J.P., and Brookes, J.D., 2008, A generic process-based model of microbial pollution in aquatic systems: Water Resources Research, v. 44, W07408, doi:10.1029/2007WR006395, 26 p.

Holdeman, L.V., Good, I.J., and Moore, W.E., 1976, Human fecal flora: variation in bacterial composition within individuals and a possible effect of emotional stress: Applied and Environmental Microbiology, v. 31, no.3, p. 359–375.

Hooper, R.P., Aulenbach, B.T., and Kelly, V.J., 2001, The National Stream Quality Accounting Network: a flux-based approach to monitoring the water quality of large rivers: Hydrological Processes, v. 15, no. 7, p. 1,089–1,106.

Kuntz, R.L., Hartel, P.G., Godfrey, D.G., McDonald, J.L., Gates, K.W., and Segars, W.I., 2003, Targeted sampling protocol as prelude to bacterial source tracking with Enterococcus faecalis: Journal of Environmental Quality, v. 32, no.6, p. 2,311–2,318.

Lanclos, M.M., Blodgett, C., Diamond, D., and Foster, W., 2005, Urban remote sensing for land use change and impacts: Missouri Resource Assessment Partnership Map Series MS-2005-001, Columbia, Missouri, 1 sheet.

Lane, S.L., Flanagan, Sarah, and Wilde, F.D., 2003, Selection of equipment for water-sampling (ver. 2.0): U.S. Geological Survey Techniques of Water-Resources Investigations, book 9, chap. A2, March, accessed December 2004 at *http://pubs.water.usgs.gov/twri9A/*.

Mallin, M.A., Williams, K.E., Esham, E.C., and Lowe, R.P., 2000, Effect of human development on bacteriological water quality in coastal watersheds: Ecological Applications, v. 10, no. 4, p. 1,047–1,056.

McLellan, S.L., 2004, Genetic Diversity of *Escherichia coli* isolated from urban rivers and beach water: Applied and Environmental Microbiology, v. 70, no. 4, p. 4,658–4,665.

McLellan, S.L., Daniels, A.D., and Salmore, A.K., 2003, Genetic Characterization of *Escherichia coli* populations from host sources of fecal pollution by using DNA fingerprinting: Applied and Environmental Microbiology, v. 69, no. 5, p. 2,587–2,594.

Meade, R.H., and Moody, J.A., 2010, Causes for the decline of suspended-sediment discharge in the Mississippi River system, 1940-2007: Hydrological Processes, v. 24, no. 1, p. 25–49.

Metropolitan St. Louis Sewer District, 2009a, Comprehensive Annual Financial Report: St. Louis, Missouri, 62 p., accessed May 2010 at *http://www.stlmsd.com/aboutmsd/fiscal/annualreport/2009%20MSD%20CAFR.pdf.*

Metropolitan St. Louis Sewer District, 2009b, Combined Sewer Overflow Long-term Control Plan Update Report: St. Louis, Missouri accessed December 2009 at *http://www.stlmsd.com/MSD/Outreach/Overflows/LTCPUpd.pdf.*

Missouri Department of Natural Resources, 2009, Rules of Department of Natural Resources, Division 20 – Clean Water Commission, Chapter 7 – Water Quality, Title 10 CSR 20.7.031, accessed January 2010 at *http://www.sos.mo.gov/adrules/csr/current/10csr/10c20-7.pdf.*

Myoda, S.P., 2003, Comparision of gentypic-based microbial source tracking methods requiring a host origin database: Journal of Water and Health, v. 1, p. 167–180.

Myers, D.N., Stoeckel, D.M., Bushon, R.N., Francy, D.S., and Brady, A.M.G., 2007, Fecal-indicator bacteria (ver. 2.0): U.S. Geological Survey Techniques of Water-Resources Investigations, book 9, chap. A7, section 7.1 (version 2.0), accessed April 2007 at *http://pubs.water.usgs.gov/twri9A7/.*

National Climatic Data Center, 2010, accessed February 2010 at *http://www.ncdc.noaa.gov/oa/ncdc.html.*

Noble, R.T., Weisberg, S.B., Leecaster, M.K., McGee, C.D., Ritter, K., Walker, K.O., and Vainak, P.M., 2003, Comparison of beach bacterial water quality indicator measurement methods: Environmental Monitoring and Assessment, v. 81, p. 301–312.

Noble, R.T., Griffith, J.F., Blackwood, A.D., Fuhrman, J.A., Gregory, J.B., Hernandez, X., Liang, X., Bera, A.A., and Schiff, K., 2006, Multitiered approach using quantitative PCR to track sources of fecal pollution affecting Santa Monica Bay, California: Applied and Environmental Microbiology, v. 72, no. 2, p. 1,604–1,612.

Paul, M.J., and Meyer, J.L., 2001, Streams in the urban landscape: Annual Review of Ecology and Systematics, v. 32, p. 333–365.

Pinter, N., Jemberie, A.A., Remo, J.W.F., Heine, R.A., and Ickes, B.S., 2009, Cumulative impacts of river engineering, Mississippi and lower Missouri Rivers: River Research and Applications, 7 p., accessed January 2010 at *http://www3.interscience.wiley.com/cgi-bin/fulltext/122459134/PDFSTART.*

Pote, J., Haller, L., Kottelat, R., Sastre, V., Arpagaus, P., and Wildi, W., 2009, Persistence and growth of faecal culturable bacterial indicators in water column and sediments of Vidy Bay, Lake Geneva, Switzerland: Journal of Environmental Sciences, v. 21, p. 62–69.

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

Rantz, S.E., and others, 1982a, Measurement and computation of streamflow –Volume 1. Measurement of stage and discharge: U.S. Geological Survey Water-Supply Paper 2175, p. 1–284.

Rantz, S.E., and others, 1982b, Measurement and computation of streamflow –Volume 2. Computation of discharge: U.S. Geological Survey Water-Supply Paper 2175, p. 285–631.

Runkel, R.L., Crawford, C.G., and Cohn, T.A., 2004, Load Estimator (LOADEST): A FORTRAN Program for estimating constituent loads in streams and rivers: U.S. Geological Survey Techniques and Methods, book 4, chap. A5, 69 p.

Rasmussen, P.P. and Ziegler, A.C., 2003, Comparison and continuous estimates of fecal coliform and *Escherichia coli* bacteria in selected Kansas streams, May 1999 through April 2002: U.S. Geological Survey Water-Resources Investigations Report 03–4056, 80 p.

Ritter, K.J., Carruthers, E., Carson, A.C., Ellender, R.D., Harwood, V.J., Kingsley, K.S, Nakatsu, C.H., Sadwosky, M.J, Shear, B.L, West, B.R., Whitlock, J.E., Wiggins, B.A., and Wilbur, J.D., 2003, Assessment of statistical methods used in library-based approaches to microbial source tracking: Journal of Water Health, v. 1, no. 4, p.209–223.

Santo Domingo, J.W., Bambic, D.G., Edge, T.A., and Wuertz, S., 2007, Quo vadis source tracking? Towards a strategic framework for environmental monitoring of fecal pollution: Water Research, v. 41, no. 16, p. 3,539–3,552.

Seurinck, S., Verstraete, W., and Siciliano, S.D., 2003, Use of 16s-23s rRNA intergenic spacer region PCR and repetitive extragenic palindromic PCR analyses of *Escherichia coli* isolates to identify nonpoint fecal sources: Applied and Environmental Microbiology, v. 69, no. 8, p. 4,942–4,950.

Schueler, T.R., Fraley-MacNeal, L., and Cappiella, K., 2009, Is impervious cover still important? Review of recent research: Journal of Hydrologic Engineering, v. 14, no. 4, p. 309–315.

Schultz-Fademrecht, C., Wichern, M., and Horn, H., 2008, The impact of sunlight on inactivation of indicator microorganisms both in river water and benthic biofilms: Water Research, v. 42, no. 19, p. 4,771–4,779.

Schumacher, J.G., 2003, Survival, transport, and sources of fecal bacteria in streams and survival in land-applied poultry litter in the Upper Shoal Creek Basin, southwestern Missouri, 2001-2003: U.S. Geological Survey Water-Resources Investigations Report 03–4243, 46 p.

Servais, P., Prats, J., Passerat, J., Garcia-Armisen, T., 2009, Abundance of cultural versus viable *Escherichia coli* in freshwater: Canadian Journal of Microbiology, v. 55, p. 905–909.

Simpson, M., 2001, Discharge measurements using a broadband acoustic Doppler current profiler: U.S. Geological Survey Open-File Report 01–01, 123 p.

Stoeckel, D.M., 2005, Selection and application of microbial source tracking tools for water-quality investigations: U.S. Geological Survey Techniques and Methods, book 2, chap., A3, 43 p.

Stoeckel, D.M., and Harwood, V. J., 2007, Performance, design, and analysis in microbial source tracking studies: Applied and Environmental Microbiology, v. 73, p. 2,405–2,454

Stoeckel, D.M., Mathes, M.V., Hyer, K.E., Hagedorn, C., Kator, H., Lukasik, H., O'Brien, T.L., Fenger, T.W., Samadpour, M., Strickler, K.M., and Wiggins, B.A., 2004, Comparison of seven protocols to identify fecal contamination sources using *Eshcherichia coli*: Environmental Science and Technology, v. 38, no. 22, p. 6,109–6,117.

Sprague, L.A., Clark, M.L., Rus, D.L., Zelt, R.B., Flynn, J.L., and Davis, J.V., 2006, Nutrient and suspended-sediment trends in the Missouri River Basin, 1993-2003: U.S. Geological Survey Scientific Investigations Report 2006–5231, 80 p.

Teng, L.-J., Hsueh, P.-R., Huang, Y.-H., and Tsai, J.-C., 2004, Identification of *Bacteroides thetaiotaomicron* on the basis of an unexpected specific amplicon of universal 16S ribosomal DNA PCR: Journal of Clinical Microbiology, v. 42, no. 4, p.1,727–1,730.

U.S. Environmental Protection Agency, 1994, Combined Sewer Overflow (CSO) control policy, final policy: U.S. Federal Register, v. 59, no.75, p. 18,688–18,698.

U.S. Environmental Protection Agency, 2000, Improved enumeration methods for recreational water quality indicators: Enterococci and *Escherichia coli*: Washington, D.C., Office of Science and Technology, EPA 821/R-97/-004, variously paged, accessed December 2009 at *http://www.epa.gov/nerlcwww/RecManv.pdf.*

U.S. Environmental Protection Agency, 2002, Method 1103.1: *Escherichia coli* (*E. coli*) in water by membrane filtration using modified membrane-thermotolerant *Escherichia coli* agar (modified mTEC): Washington, D.C., Office of Water, EPA 821-R-02-023, 27 p., accessed December 2009 at *http://www.epa.gov/nerlcwww/1603sp02.pdf.*

U.S. Environmental Protection Agency, 2004, Report to Congress: impacts and control of CSOs and SSOs: Washington, D.C., Office of Water, EPA 833-R-04-001, variously paged, accessed August 2009 at *http://www.epa.gov/npdes/pubs/csossoRTC2004_executive_summary.pdf.*

U.S. Environmental Protection Agency, 2006, Method 1103.1: *Escherichia coli* (*E. coli*) in water by membrane filtration using membrane-thermotolerant *Escherichia coli* agar (mTEC): Washington, D.C., Office of Water, EPA 821-R-06-010, 27 p., accessed December 2009 at *http://www.epa.gov/waterscience/methods/method/biological/1103_1.pdf.*

U.S. Environmental Protection Agency, 2010, Enforcement and Compliance History Online, accessed February 2010 at www.epa-echo.gov/echo/.

U.S. Geological Survey, 2006a, Water-resources data for the United States— Water Year 2005, accessed January 2008 at *http://wdr.water.usgs.gov/wy2005/search.jsp.*

U.S. Geological Survey, 2006b, Collection of water samples (ver. 2.0): U.S. Geological Survey Techniques of Water-Resources Investigations, book 9, chap. A4, September, accessed January 2007 at *http://pubs.water.usgs.gov/twri9A4/*

U.S. Geological Survey, 2007, Water-resources data for the United States— Water Year 2006, accessed January 2008 at *http://wdr.water.usgs.gov/wy2006/search.jsp.*

U.S. Geological Survey, 2008, Water-resources data for the United States —Water Year 2007, at accessed May 2008 *http://wdr.water.usgs.gov/wy2007/search.jsp.*

U.S. Geological Survey, 2009, USGS Water Data for Missouri, at *http://waterdata.usgs.gov/mo/nwis/*.

Wade, T.J., Pia, N., Eisenberg, J.N.S., and Colford, J.M. Jr., 2003, Do U.S. Environmental Protection Agency water quality guidelines for recreational waters prevent gastrointestinal illness? A systematic review and meta-analysis: Environmental Health Perspectives, v. 111, no. 8, p. 1,102–1,109.

Walsh, C.J., Roy, A.H., Feminella, J.W., Cottingham, P.D., Groffman, P.M., and Morgan. R.P.II., 2005, The urban stream syndrome: current knowledge and the search for a cure: Journal of American Benthological Society, v. 24, no. 3, p. 706–723.

Walters, S.P., and Field, K.G., 2006, Persistence and growth of fecal Bacteroidales assessed by bromdeoxyuridine immunocapture: Applied and Environmental Microbiology, v.72, no.7, p. 4,532–4,539.

Weiming, W., and Wang, S.S.Y., 2006, Formulas for sediment porosity and settling velocity: Journal of Hydraulic Engineering, v. 132, no. 8, p. 858–862.

Whitman, R.L., Nevers, M.B., Korinek, G.C., and Byappanahalli, M.N., 2004, Solar and temporal effects of *Escherichia coli* concentration at a Lake Michigan swimming beach: Applied and Environmental Microbiology, v. 70, no.7, p. 4,276–4,285.

Wilde, F.D., ed., 2004, Cleaning of equipment for water sampling (ver. 2.0): U.S. Geological Survey Techniques of Water-Resources Investigations, book 9, chap. A3, April, accessed September 2005 at *http://pubs.water.usgs.gov/twri9A3/*.

Wilde, F.D., 2005, Preparations for water sampling: U.S. Geological Survey Techniques of Water-Resources Investigations, book 9, chap. A1, January, accessed September 2006 at *http://pubs.water.usgs.gov/twri9A1/*.

Wilde, F.D., Radtke, D.B., Gibs, J., and Iwatsubo, R.T., eds., 2004, Processing of water samples (version 2.1): U.S. Geological Survey Techniques of Water-Resources Investigations, book 9, chap. A5, April, accessed April 2004 at *http://pubs.water.usgs.gov/twri9A5/*.

Wilkes, G., Edge, T., Gannon, V., Jokinen, C., Lyautey, E., Medeiros, D., Neumann, N., Ruecker, N., Topp, E., and Lapen, D.R., 2009, Seasonal relationships among indicator bacteria, pathogenic bacteria, Cryptosporidium oocysts, Giardia cysts, and hydrological indices for surface waters within an agricultural landscape: Water Research, v. 43, no. 8, p. 2,209–2,223.

Wilkison, D.H., Armstrong, D.J., and Blevins, D.W., 2002, Effects of wastewater and combined sewer overflows on water quality in the Blue River Basin, Kansas City, Missouri and Kansas, July 1998–October 2004: U.S. Geological Survey Water-Resources Investigations Report 02–4107, p. 162.

Wilkison, D.H., Armstrong, D. J., Brown, R.E., Poulton, B.C., Cahill, J.D., and Zaugg, S.D., 2005, Water-Quality and biologic data for the Blue River Basin, Kansas City Metropolitan Area, Missouri and Kansas, October 2000 to October 2004: U.S. Geological Survey Data Series 127, p. 158.

Wilkison, D.H., Armstrong, D.J, Hampton, S.A, 2009, Character and trends of water quality in the Blue River Basin, Kansas City Metropolitan Area, Missouri and Kansas, 1998 through 2007: U.S. Geological Survey Scientific Investigations Report 2009-5169, p. 211.

Wilkison, D.H., Armstrong, D.J., and Norman, R.D., Poulton, B.C., Furlong, E.T., and Zaugg, S.D, 2006, Water quality in the Blue River Basin, Kansas City Metropolitan Area, Missouri and Kansas, July 1998 to October 2004: U.S. Geological Survey Scientific Investigations Report 2006-5147, p. 170.

Yampara-Iquise, H., Zheng, G., Jones, J.E., and Carson, A.C., 2008, Use of *Bacteroides thetaiotaomicron*-specific α-1-6, mannanase quantitative PCR to detect human faecal pollution in water: Journal of Applied Microbiology, v. 105, no. 5, p. 1,686–1,693.

Table 8

Table 8. Summary statistics for *Escherchia coli* host-source determinations by repetitive extragenic pallindromic polymerase chain reaction (rep-PCR).

[Values in percent of *Escherichia coli* determined in samples; N, number]

	Human		Dog		Goose		Unknown	
	Base flow	Storm event	Base flow	Storm event	Base flow	Storm event	Base flow	Storm event
Missouri River sites								
Missouri River near Chesterfield (06935715)								
Minimum value	0	0	0	0	0	0	0	20
1st quartile	14	24	0	0	0	4	24	21
Mean	28	30	11	6	23	17	39	47
Median	28	28	10	0	19	15	32	41
3rd quartile	39	41	17	9	34	28	44	65
Maximum value	67	53	33	20	67	40	100	100
N, samples	16	8	16	8	16	8	16	8
N, isolates identified	53	39	24	9	44	20	59	51
Missouri River below St. Charles (06935972)								
Minimum value	6	0	0	0	0	0	0	0
1st quartile	24	20	6	4	10	0	14	10
Mean	37	35	16	10	18	22	29	33
Median	36	47	16	8	17	28	21	11
3rd quartile	46	50	24	18	25	37	43	62
Maximum value	89	50	43	22	45	45	75	88
N, samples	16	8	16	8	16	8	16	8
N, isolates identified	84	50	36	11	43	33	75	36
Missouri River at Columbia Bottoms (06937000)								
Minimum value	0	0	0	0	0	0	0	11
1st quartile	31	17	4	0	11	20	17	20
Mean	41	27	11	8	21	28	27	37
Median	41	32	11	7	19	33	22	28
3rd quartile	50	37	17	11	25	37	39	47
Maximum value	83	53	26	25	60	50	50	100
N, samples	16	9	16	9	16	9	16	9
N, isolates identified	98	36	25	14	44	32	69	45
All Missouri River sites								
Minimum value	0	0	0	0	0	0	0	0
1st quartile	21	22	4	0	10	5	17	15
Mean	35	30	13	8	20	23	32	39
Median	34	32	11	5	17	25	25	28
3rd quartile	46	45	20	17	32	35	41	56
Maximum value	89	53	43	25	67	50	100	100
N, samples	48	25	48	25	48	25	48	25
N, isolates identified	235	125	85	34	131	85	203	132

Table 8. Summary statistics for *Escherchia coli* host-source determinations by repetitive extragenic pallindromic polymerase chain reaction (rep-PCR). —Continued

[Values in percent of *Escherichia coli* determined in samples; N, number]

	Human		Dog		Goose		Unknown	
	Base flow	Storm event	Base flow	Storm event	Base flow	Storm event	Base flow	Storm event
Mississippi River sites								
Mississippi River below Grafton (05587455)								
Minimum value	0	0	0	0	0	0	0	0
1st quartile	0	20	0	0	0	18	4	13
Mean	14	27	2	2	20	32	57	40
Median	0	27	0	0	0	40	65	40
3rd quartile	34	38	0	0	27	50	100	45
Maximum value	60	50	20	9	100	50	100	100
N, samples	16	5	16	5	16	5	16	5
N, isolates identified	19	8	4	1	20	9	31	9
Mississippi River above St. Louis (07005500)								
Minimum value	0	16	0	0	0	18	0	0
1st quartile	33	28	0	0	6	21	13	17
Mean	40	40	11	10	23	27	27	24
Median	40	42	7	8	19	26	24	24
3rd quartile	50	50	18	19	27	27	38	31
Maximum value	100	64	33	21	100	47	81	43
N, samples	17	8	17	8	17	8	17	8
N, isolates identified	63	52	19	13	30	35	59	32
Mississippi River at St. Louis (07010000)								
Minimum value	10	0	0	0	0	12	0	16
1st quartile	29	31	0	5	6	15	8	20
Mean	40	36	14	13	16	25	30	26
Median	41	39	12	15	15	21	26	21
3rd quartile	53	47	26	19	25	36	42	24
Maximum value	71	57	39	25	44	42	80	63
N, samples	18	8	18	8	18	8	18	8
N, isolates identified	86	47	32	15	35	31	66	29
Mississippi River at Oakville (07010220)								
Minimum value	0	18	0	0	0	0	0	7
1st quartile	25	38	0	4	5	7	15	16
Mean	43	48	11	8	14	14	32	30
Median	44	48	6	6	13	14	22	32
3rd quartile	64	58	18	11	18	19	50	39
Maximum value	100	80	50	21	45	33	77	55
N, samples	17	8	17	8	17	8	17	8
N, isolates identified	86	58	19	10	35	17	72	36
Mississippi River at Kimmswick (07019370)								
Minimum value	0	28	0	0	0	15	0	0
1st quartile	36	32	0	0	10	24	16	11
Mean	44	39	5	6	18	33	34	22
Median	45	40	5	3	17	33	22	28
3rd quartile	59	45	6	10	27	43	43	31
Maximum value	78	56	25	22	38	45	100	35
N, samples	17	8	17	8	17	8	17	8
N, isolates identified	92	43	9	8	39	33	66	28
All Mississippi River sites								
Minimum value	0	0	0	0	0	0	0	0
1st quartile	13	29	0	0	0	16	8	16
Mean	37	39	9	8	18	25	36	27
Median	38	40	5	5	14	22	25	26
3rd quartile	53	47	13	17	25	36	63	35
Maximum value	100	80	50	25	100	50	100	100
N, samples	85	37	85	37	85	37	85	37
N, isolates identified	346	208	83	47	159	125	294	134

Table 8. Summary statistics for *Escherchia coli* host-source determinations by repetitive extragenic pallindromic polymerase chain reaction (rep-PCR). —Continued

[Values in percent of *Escherichia coli* determined in samples; N, number]

	Human		Dog		Goose		Unknown	
	Base flow	Storm event	Base flow	Storm event	Base flow	Storm event	Base flow	Storm event
Small basin sites								
Creve Coeur Creek(06935890)								
Minimum value	0	0	0	5	0	0	0	25
1st quartile	14	21	3	7	13	8	22	36
Mean	25	25	12	11	25	15	39	49
Median	22	24	10	10	20	15	30	43
3rd quartile	38	29	11	14	34	23	53	51
Maximum value	45	50	56	21	67	28	100	95
N, samples	15	6	15	6	15	6	15	6
N, isolates identified	51	29	24	13	48	17	76	57
Coldwater Creek (06936475)								
Minimum value	5	0	5	0	10	0	0	29
1st quartile	19	4	9	6	19	3	10	36
Mean	28	20	17	10	27	11	28	59
Median	26	21	15	8	24	10	21	59
3rd quartile	40	28	20	11	36	14	50	79
Maximum value	60	50	50	25	47	29	70	94
N, samples	16	6	16	6	16	6	16	6
N, isolates identified	61	23	32	11	68	12	79	66
Maline Creek (07005000)								
Minimum value	0	5	0	0	0	10	0	5
1st quartile	26	23	0	1	10	15	12	20
Mean	37	34	9	5	22	20	32	41
Median	30	35	6	5	14	20	20	38
3rd quartile	42	49	15	9	32	25	50	59
Maximum value	100	55	30	11	67	32	100	85
N, samples	15	6	15	6	15	6	15	6
N, isolates identified	74	40	20	6	58	24	64	49
River des Peres near Unversity City (07010022)								
Minimum value	0	8	0	0	0	6	0	6
1st quartile	22	27	0	3	6	10	19	12
Mean	37	37	11	15	13	17	38	32
Median	37	40	9	13	11	18	36	25
3rd quartile	52	50	14	21	22	23	57	40
Maximum value	70	59	41	37	29	26	83	83
N, samples	14	6	14	6	14	6	14	6
N, isolates identified	85	36	26	9	29	13	85	28
River des Peres at St. Louis (07010097)								
Minimum value	6	26	0	0	0	0	0	0
1st quartile	24	53	3	0	20	5	14	12
Mean	35	63	13	6	25	8	28	22
Median	31	65	13	10	25	5	25	20
3rd quartile	50	71	20	11	29	6	39	21
Maximum value	62	100	29	12	63	26	61	58
N, samples	15	5	15	5	15	5	15	5
N, isolates identified	73	60	29	13	50	13	60	23

Table 8. Summary statistics for *Escherchia coli* host-source determinations by repetitive extragenic pallindromic polymerase chain reaction (rep-PCR). —Continued

[Values in percent of *Escherichia coli* determined in samples; N, number]

	Human		Dog		Goose		Unknown	
	Base flow	Storm event	Base flow	Storm event	Base flow	Storm event	Base flow	Storm event
Small basin sites—Continued								
Grand Glaize Creek (07019185)								
Minimum value	0	5	0	5	0	5	5	25
1st quartile	14	22	5	5	15	6	25	28
Mean	30	35	10	10	21	11	39	43
Median	32	32	11	8	19	13	47	34
3rd quartile	43	54	13	10	25	16	53	50
Maximum value	68	63	33	26	50	16	63	85
N, samples	16	6	16	6	16	6	16	6
N, isolates identified	79	41	22	12	48	13	89	51
All small basin sites								
Minimum value	0	0	0	0	0	0	0	0
1st quartile	17	20	5	5	11	6	15	24
Mean	32	34	12	10	22	14	34	43
Median	30	29	11	10	20	15	29	36
3rd quartile	44	51	16	12	29	21	50	60
Maximum value	100	100	56	37	67	32	100	95
N, samples	91	35	91	35	91	35	91	35
N, isolates identified	423	229	153	64	301	92	453	274

Publishing support provided by:
Rolla Publishing Service Center
For more information concerning this publication, contact:
Director, U.S. Geological Survey
Missouri Water Science Center
1400 Independence Road
Rolla, MO 65401
(573) 308–3667
Or visit the Missouri Water Science Center website at:
http://mo.water.usgs.gov

ISBN 978-1-4113-2927-0