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Stormwater Quality of Infrastructure Elements in Rapid City, South Dakota, 2016–18

Scientific Investigations Report 2020–5004

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

Cover: Upper photograph, Stormwater channel best-management practice near Jackson Boulevard in Rapid City, South Dakota. (Photograph by Galen Hoogestraat, U.S. Geological Survey). Lower photographs, Trinity Eco Prayer Park area near downtown Rapid City, South Dakota. (Photographs by Ken Steinken).

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Conversion Factors

U.S. customary units to International System of Units

Multiply	By	To obtain
	Length	
inch (in.)	2.54	centimeter (cm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Area	
square mile (mi^2)	2.590	square kilometer (km^2)
	Flow rate	
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)

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

°C = (°F – 32) / 1.8.

Datum

Horizontal coordinate information is referenced to the North American Datum of 1983.

Supplemental Information

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

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

Water year (WY) is the 12-month period, October 1 through September 30, and is designated by the calendar year in which it ends. Thus, the water year ending September 30, 2016, is called the “2016” water year.

Abbreviations

BMP	best management practice
CHN	open channel
CRB	street curb and gutter
DSP	downspout
E. coli	*Escherichia coli*
FIB	fecal indicator bacteria
PKL	parking lot
RPD	relative percent difference
TMDL	total maximum daily load
TSS	total suspended solids
USGS	U.S. Geological Survey
USS	underground storm sewer

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By Galen K. Hoogestraat

Abstract

As runoff flows over the land or impervious surfaces (paved streets, parking lots, and building roofs), it accumulates debris, chemicals, sediment, and other contaminants that can adversely affect water quality if the runoff discharge remains untreated. Pathogens, commonly measured using fecal indicator bacteria such as *Escherichia coli*, enterococci, or fecal coliform, are the most-frequent cause of water-quality impairment in rivers and streams in the United States. Rapid Creek originates in the western Black Hills area and flows east through Rapid City, South Dakota, to its mouth at the Cheyenne River. The water quality of Rapid Creek is important because the reach that flows through Rapid City is a valuable spawning area for a self-sustaining trout fishery, is actively used for recreation, and is a seasonal municipal water supply for the City of Rapid City. These uses (fishery, recreation, and water supply) are considered beneficial uses by the South Dakota Department of Environment and Natural Resources. Numerical criteria have been established for total suspended solids and *Escherichia coli* concentrations, among other water-quality constituents, for these beneficial uses. The objectives of this study were to improve the method by which fecal indicator bacteria and total suspended solids are quantified in the urban drainages within Rapid City and to provide information that helps identify origins of fecal indicator bacteria and total suspended solids. This information can be used in hydrologic models to estimate fecal indicator bacteria and total suspended solid loading from certain infrastructure elements in urban environments.

Stormwater samples analyzed for *Escherichia coli*, total suspended solids, specific conductance, and pH were collected in three drainage basin flowpaths within Rapid City: Jackson, Wildwood, and the Eco Prayer Park. Data-collection activities for this study focused on upgradient urban flowpath elements during rainfall events. This approach builds upon previous stormwater assessments that characterized the water quality in urban basin outlets near the downstream end of the stormwater flowpaths. Within each flowpath group, 4–6 sites were selected to represent the various infrastructure elements of the runoff process. These elements included roof downspouts, parking lots, street curbs and gutters, open channels, underground storm sewers, and stormwater ponds or best-management practice facilities.

In general, the concentrations of *Escherichia coli* and total suspended solids increased in the downstream direction for all flowpath sites. The wash-off process after the first flush is evident for total suspended solids and specific conductance; however, *Escherichia coli* concentrations did not necessarily follow the same pattern. *Escherichia coli* concentrations in the latter part of the runoff period were similar to or greater than the initial concentrations of the first set of samples. Stormwater-quality data were summarized by infrastructure type (roof downspout, parking lot, street curb, and channel/storm sewer) to provide information about approximate water-quality concentrations originating at the upper end of urban flowpaths. *Escherichia coli* and total suspended solid concentrations were lowest in samples collected from locations most isolated from human influence (roof downspouts); the median concentrations at these sites were 4 most probable number per 100 milliliters and 15 milligrams per liter, respectively. The delivery potential of fecal indicator bacteria and sediment from parking lots and street curbs was similar; median concentrations of *Escherichia coli* and total suspended solids were around 150–220 most probable number per 100 milliliters and 56–86 milligrams per liter, respectively. The downstream receiving channels and storm sewers where stormwater was aggregated typically contained the highest *Escherichia coli* concentrations (median was 1,800 most probable number per 100 milliliters), but the total suspended solid concentrations were similar to upstream elements in the flowpath (median was 69 milligrams per liter). The data collected from this study demonstrate that stormwater is contaminated with fecal indicator bacteria upon initial contact with impervious surfaces and highlight the importance of controlling the volume of stormwater discharges into receiving waterbodies via storage structures and pervious elements. Diluting stormwater with high concentrations of *Escherichia coli* with the receiving water's (Rapid Creek) lower concentration of *Escherichia coli* is likely the primary mechanism for meeting the beneficial-use criterion threshold of 235 most probable number per 100 milliliters. Although total suspended solid concentrations in the upper parts of the basin (parking lots and street curbs) also begin at concentrations (56 to 86 milligrams per liter) above the beneficial-use criterion for Rapid Creek (53 milligrams per liter), current stormwater-control practices (storage ponds, swales, and wetlands) may be able to reduce suspended-sediment concentrations to meet this threshold.

Introduction

Stormwater runoff from urbanized lands can cause physical, biological, and chemical changes in the receiving waters, which can impair designated uses (U.S. Environmental Protection Agency, 2010). As runoff flows over the land or impervious surfaces (paved streets, parking lots, and building roofs), it accumulates debris, chemicals, sediment, or other contaminants that could adversely affect water quality if the runoff remains untreated. Pathogens are the most-frequent cause of water-quality impairment in rivers and streams in the United States; more than 180,000 river miles are listed as impaired by pathogens on State 303(d) lists (U.S. Environmental Protection Agency, 2019; American Society of Civil Engineers, 2014). Pathogen impairments usually are identified based on elevated counts of fecal indicator bacteria (FIB), such as *Escherichia coli* (*E. coli*), enterococci, or fecal coliform. Sediment is the second-most-frequent cause of water-quality impairment in rivers and streams in the United States; more than 130,000 river miles are listed as impaired by sediment on State 303(d) lists (U.S. Environmental Protection Agency, 2019).

Rapid Creek is a valuable natural resource, and protecting its water quality is important because the reach that flows through Rapid City, South Dakota, is a critical spawning area for a self-sustaining trout fishery, is actively used for recreation, and is a seasonal municipal water supply for the City of Rapid City. Per the Clean Water Act, the South Dakota Department of Environment and Natural Resources (DENR) lists beneficial uses of major streams and rivers in the State. For example, Rapid Creek through Rapid City has beneficial uses of domestic water supply, coldwater permanent fish life propagation, immersion recreation, and limited-contact recreation (South Dakota Department of Environment and Natural Resources, 2010). For total suspended solids (TSS), the most restrictive of the water-quality requirements is related to the beneficial use of cold-water permanent fish life propagation. The water-quality standard/requirement for TSS is a geometric-mean concentration not to exceed 30 milligrams per liter (mg/L) during a 30-day period, and a single sample should not exceed 53 mg/L. Immersion recreation carries a designation based on FIB concentrations: *E. coli* concentrations should not exceed 126 most probable number per 100 milliliters (mpn/100 mL) during a 30-day period or 235 mpn/100 mL for a single sample (South Dakota Department of Environment and Natural Resources, 2010).

During 2014, water quality in Rapid Creek for reaches upstream from Rapid City met designated beneficial-use water-quality standards; however, Rapid Creek from Canyon Lake to the Cheyenne River was impaired because of excessive fecal coliform, *E. coli*, or both bacteria levels (South Dakota Department of Environment and Natural Resources, 2014). A recent compilation of water-quality data for Rapid City drainages documented event-mean concentrations for *E. coli* of 7,200 to 21,000 mpn/100 mL in developed basins (Hoogestraat, 2015), demonstrating the presence of high FIB concentrations entering Rapid Creek during runoff. A total maximum daily load (TMDL) criterion for FIB for reaches within and downstream from Rapid City was approved by the South Dakota DENR in 2010. A TMDL is a calculation of the maximum amount of a pollutant that a waterbody can receive and still meet water-quality standards (South Dakota Department of Environment and Natural Resources, 2019). Approval of a TMDL for a waterbody commonly is followed by an implementation project with goals to reduce pollution sources within the drainage basin. Major purposes of the TMDL assessment are to identify potential causes or sources of the water-quality impairment and to suggest best-management practices (BMPs) for reducing those impairments (South Dakota Department of Environment and Natural Resources, 2019). Methods of identifying FIB impairments in surface water are usually limited to a general assessment of sources (typically grouped as livestock, wildlife, or human). For the Rapid Creek bacteria TMDL, FIB load estimates were derived from the Bacteria Indicator Tool (U.S. Environmental Protection Agency, 2000), which models loads primarily based on land-use classifications. This derivation is common for bacteria TMDLs because FIB sample data about specific sources typically are not available. The lack of data to connect FIB concentrations in receiving waterbodies to its actual sources represents an area of needed research in the TMDL process. Implementation projects may target a source within the watershed that does not contribute to the FIB load, and those sources that do contribute FIB load are overlooked. An improvement on this process would include collecting FIB data from various flowpaths, which would allow for isolating and targeting specific contributing areas where FIB is known to originate. The U.S. Geological Survey (USGS), in cooperation with the City of Rapid City, began a stormwater-quality study in 2016 to improve the method by which FIB and TSS are quantified in the urban drainages within Rapid City and to provide information that helps identify origins of FIB and TSS.

Purpose and Scope

The purposes of this report are to describe the methods and data collected from urban flowpath sites in Rapid City during 2016–18 and to provide statistical summaries of the water-quality data for the various infrastructure site types that were sampled for the stormwater-quality study. This information could be used in hydrologic models to estimate FIB and TSS loading from certain infrastructure elements in urban environments. This study only involved data collection within the city of Rapid City; however, the results are transferable to urban drainages in cities with similar infrastructure and climate.

Description of the Study Area

Stormwater datasets were collected in 3 urban flowpaths within Rapid City: Jackson (6 sampling sites), Wildwood (6 sampling sites), and Eco Prayer Park (4 sampling sites; fig. 1). Rapid City has a population of about 75,000 (U.S. Census Bureau, 2019) and is in the eastern foothills of the Black Hills. Within the city limits, the areas developed with the most impervious infrastructure are along the Highway 16/I–190 corridor and to the east (fig. 1). The west side of Rapid City generally has less intense development, more open space, and natural grass-lined drainage channels. The Rapid City region is susceptible to short-duration, intense, convective thunderstorms during the spring and summer months (Driscoll and others, 2010). The mean annual (1981–2010) precipitation for Rapid City is 19.8 inches, of which 12.0 inches fall during April–July (National Oceanic and Atmospheric Administration, 2014).

Rapid Creek originates in the western Black Hills area and flows east through Rapid City to its mouth at the Cheyenne River (fig. 1). The mean annual streamflow for Rapid Creek above Canyon Lake (USGS streamgage 06412500; fig. 1; table 1) was 56 cubic feet per second (ft^3/s) during water years 1981–2017 with a drainage area of 374 square miles (mi^2). All streamflow data are from the USGS National Water Information System (U.S. Geological Survey, 2019). The mean annual streamflow for Rapid Creek at Rapid City (USGS streamgage 06414000) was 77 ft^3/s with a drainage area of 413 mi^2. The mean annual streamflow for Rapid Creek below the sewage treatment plant near Rapid City (USGS streamgage 06418900, not shown on fig. 1, located 2 miles east) was 90 ft^3/s with a drainage area of 456 mi^2.

Mean annual streamflow increases 21 ft^3/s in the 39 mi^2 between the streamgage on the upstream west boundary (streamgage 06412500) and in the middle (streamgage 06414000) of Rapid City. This increase includes mean annual springflow of about 14 ft^3/s from two springs on the west side of Rapid City (streamgages 06412810 and 06413650; fig. 1; table 1). The remaining 7 ft^3/s increase in mean annual streamflow can be attributed to the predominantly developed, urban 39-mi^2 drainage area, or an increase of 0.18 ft^3/s per square mile of drainage area on the west side of Rapid City. Mean annual streamflow increases 13 ft^3/s in the 43 mi^2 between the streamgage in the middle (streamgage 06414000) and on the downstream east boundary (streamgage 06418900) of Rapid City, or 0.29 ft^3/s per square mile of drainage area on the east side of Rapid City. The mean annual streamflow of Rapid Creek increases a total of 34 ft^3/s (60 percent) between the upstream and downstream boundaries of Rapid City (which includes the 14 ft^3/s from springflow), or an increase of 20 ft^3/s (37 percent) from the intervening urban drainage area without including springflow.

Previous Studies

In the past 40 years, several studies have examined stormwater runoff in the Rapid City area, mostly focusing on the quantity and quality of runoff as it enters Rapid Creek. Hoogestraat (2015) provides the most recent compilation of stormwater information in the Rapid City area, wherein stormwater quality was assessed in three urban drainages during 2008–14. In that study, event-mean concentrations of TSS and FIB typically exceeded relevant beneficial-use criteria for Rapid Creek by 1–2 orders of magnitude. Three wetland channels at the outlet of an urban drainage basin were assessed for contaminant removal capability. The assessment indicated that these treatment controls were capable of reducing TSS concentrations by 40 percent; however, bacteria removal rates were lower, and in some cases, concentrations increased (Hoogestraat, 2015). Pirner and Harms (1978) studied urban runoff as a potential source of pollution in Rapid Creek. The Nationwide Urban Runoff Program chose Rapid City as one of its study locations during the early 1980s and analyzed numerous water-quality constituents (U.S. Environmental Protection Agency, 1983). Prann (2013) evaluated the effect of impervious surfaces in Rapid City on water quality using calibrated hydrologic models.

These local studies indicated that TSS and bacteria concentrations in stormwater runoff have the potential to adversely affect water quality in the Rapid Creek drainage basin; however, research regarding sources of the bacteria or loading estimates from the headwaters (urban infrastructure) is sparse. A study in southern California (Tiefenthaler and others, 2011) quantified the relative levels and flux patterns of *E. coli*, enterococci, and total coliforms from representative land-use types (such as high-density residential, industrial, or commercial). Bacteria and sediment loads from urban infrastructure have been estimated most frequently using model simulations (Riebschleager and others, 2012; Granato, 2013).

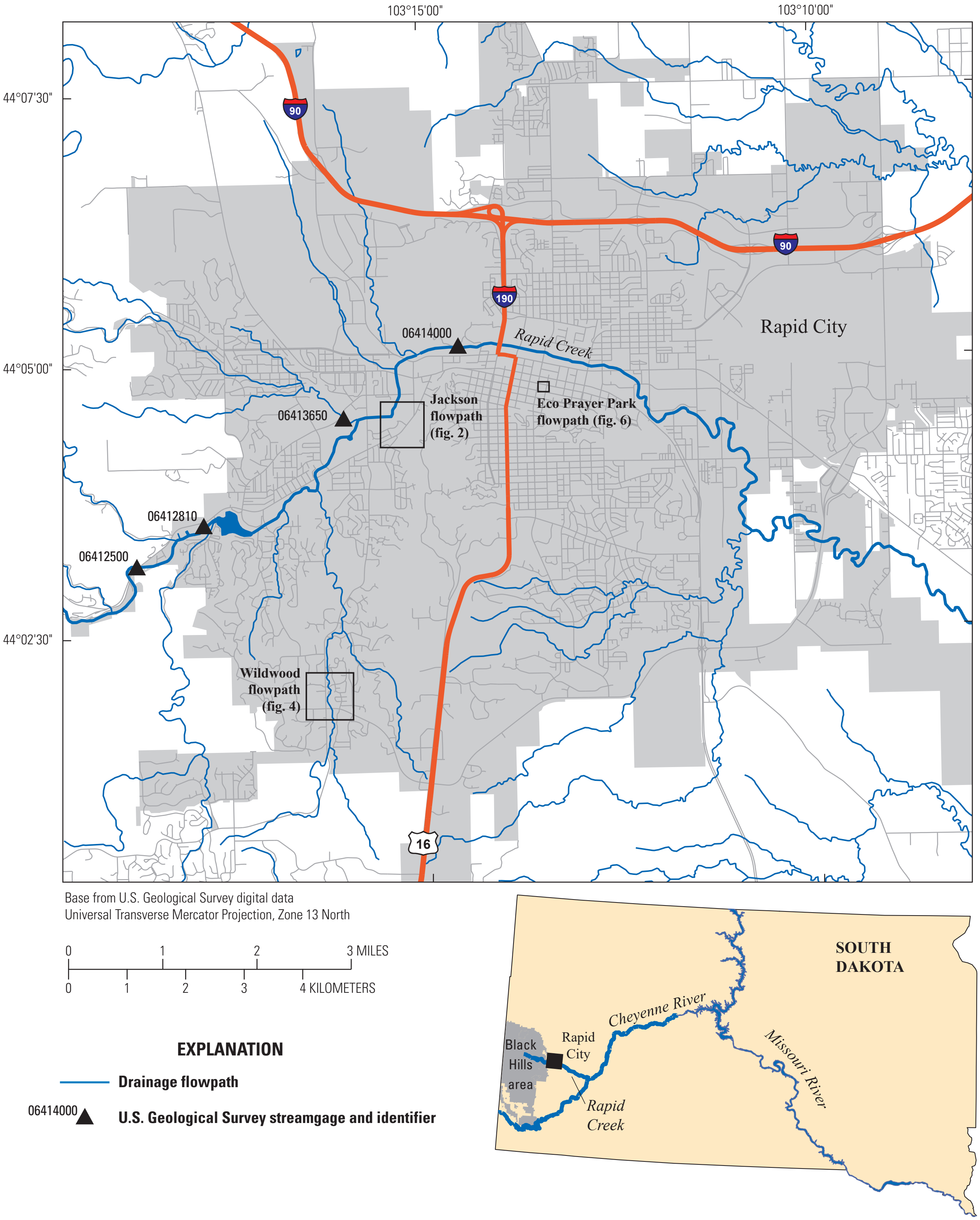

Figure 1. Study area, U.S. Geological Survey streamgages, and stormwater-quality flowpath site groups in Rapid City, South Dakota.

Table 1. U.S. Geological Survey site information for Rapid Creek sites near Rapid City, South Dakota.

[Data are from the National Water Information System database (U.S. Geological Survey, 2019). mi^2, square mile; ft^3/s, cubic foot per second; --, not applicable]

U.S. Geological Survey site number	U.S. Geological Survey site name	Drainage area (mi^2)	Mean annual flow (ft^3/s)	Data period
06412500	Rapid Creek above Canyon Lake near Rapid City, South Dakota	374	56	1981–2017
06412810	Cleghorn Springs at Rapid City, South Dakota	--	12	1993–2017
06413650	Lime Creek at Mouth at Rapid City, South Dakota	9.8	2	1988–2002
06414000	Rapid Creek at Rapid City, South Dakota	413	77	1981–2017
06418900	Rapid Creek below sewage treatment plant near Rapid City, South Dakota	456	90	1981–2017

Methods

Data-collection activities for this study focused on the upgradient urban flowpath elements during rainfall, including roof downspouts, parking lots, street curbs, and drainage channels. The sampling plan started at the source (beginning) of the urban flowpath (roof) and moved downgradient along the urban flowpath. This approach builds upon a previous stormwater assessment (Hoogestraat, 2015) that characterized the water quality in urban basin outlets near the downstream end of the stormwater flowpaths. Three flowpath site groups, which are in separate areas within Rapid City (fig. 1), were sampled for water quality in 2016–18. Within each flowpath group, 4–6 sites were selected to represent the various elements of the runoff process. These elements include roof downspouts (DSP), parking lots (PKL), street curbs and gutters (CRB), open channels (CHN), underground storm sewers (USS), and stormwater ponds or BMP facilities.

Selection and Description of Sampling Sites

The flowpath sampling sites were selected based on several factors: availability of previous water-quality data within the same drainage, previous undocumented observations of flow, sampling logistics (quick response for personnel during runoff events), and presence of multiple infrastructure element types within a short flowpath distance. These selected sites (table 2) were used to examine the potential bacteria and sediment loads of various infrastructure elements. The Jackson flowpath sites were selected based on ease of sampling logistics (quickest access for staff during runoff events) and because they included a mix of multiple infrastructure types in a short flowpath distance. The Wildwood flowpath sites were selected based on sampling logistics and on the availability of multiple infrastructure drainage sources (street curb and parking lots) nearby and because stormwater-quality data were previously collected downstream within the same drainage (Hoogestraat, 2015). The Eco Prayer Park sites were selected because they were in an area where best-management practices (stormwater-treatment area) were in place and where well-defined inflow and outflow points existed.

Each of the three flowpaths represents a unique set of land-use characteristics that affect stormwater quality. The Jackson flowpath (figs. 2–3) originates at a commercial office complex (fig. 3*A*) and includes a curb (fig. 3*B*), an underground storm sewer (fig. 3*C*), and an open concrete-lined channel flow before flowing into an infiltration trench/retention area (fig. 3*D*). The Jackson flowpath sampling sites represented all infrastructure types targeted in this study, including a roof downspout, parking lot, underground storm sewer, open drainage channel, and BMP channel outlet. Samples were generally collected at the downspout, parking lot, and street curb sites before sample collection at the channel and storm sewer sites farther down the flowpath. The channel and storm sewer sites (table 2) in the Jackson flowpath (WTP–USS, WTP–CHN, and WTP–BMP) included stormwater drainage from a highly developed commercial corridor area (northwest corner of fig. 2) not represented by the upstream flowpath sites (USG–DSP, USG–PKL, and USG–CRB).

The Wildwood flowpath contains a mix of low-density residential and commercial uses in the drainage area. The upper end of the Wildwood flowpath (figs. 4–5) contains primarily low-density residential lots with septic systems. When FIB are detected in surface water that originates from these areas, a common hypothesis has been that septic systems are a likely source; however, past monitoring has indicated that higher bacteria concentrations are often measured in Rapid City urban basins that do not have septic systems (Hoogestraat, 2015). The Wildwood flowpath includes commercial parking lot outfalls, curb discharges, and grass-lined channels in the same general area. The Wildwood flowpath sampling sites (table 2; fig. 4) included 1 roof downspout (CLC–DSP; fig. 5*C*), 2 parking lots (CLC–PKL and ATH–PKL; figs. 5*A* and 5*D*), 2 street curbs (WDW–CRB and SDC–CRB; figs. 5*B* and 5*E*), and 1 open grass-lined drainage channel (SDC–CHN; fig. 5*E*).

The Eco Prayer Park flowpath (figs. 6–7) represents the most uniform land use because the basin elements are completely impervious. FIB and sediment from this flowpath can

Table 2. List of stormwater-quality sampling sites for the Jackson, Wildwood, and Eco Prayer Park flowpaths in Rapid City, South Dakota.

Site information is from the National Water Information System database (U.S. Geological Survey, 2019).

Short identifier	U.S. Geological Survey site number	U.S. Geological Survey site name	Site type
Jackson flowpath			
USG–DSP	440416103151700	Downspout at the U.S. Geological Survey office at Rapid City, South Dakota	Roof downspout
USG–PKL	440416103151900	Parking lot runoff at the U.S. Geological Survey at Rapid City, South Dakota	Parking lot
USG–CRB	440417103152202	Curb at Mt. View Road at Rapid City, South Dakota	Street curb
WTP–CHN	440429103151300	Storm drain channel at the water treatment plant at Rapid City, South Dakota	Channel/storm sewer
WTP–USS	440430103151000	Storm sewer outfall at Jackson at Rapid City, South Dakota	Channel/storm sewer
WTP–BMP	440436103151400	Storm sewer best-management practice outlet at Rapid City, South Dakota	Channel/storm sewer
Wildwood flowpath			
CLC–DSP	440155103162100	Roof downspout near Sheridan Lake Road at Rapid City, South Dakota	Roof downspout
CLC–PKL	440154103162100	Church parking lot near Sheridan Lake Road at Rapid City, South Dakota	Parking lot
WDW–CRB	440150103162300	Curb at Wildwood Drive at Rapid City, South Dakota	Street curb
ATH–PKL	440156103161800	Parking lot at Autumn Hills at Rapid City, South Dakota	Parking lot
SDC–CRB	440202103161600	Curb at Summerset Drive at Rapid City, South Dakota	Street curb
SDC–CHN	440201103161500	Arrowhead drainage at Summerset Drive	Channel/storm sewer
Eco Prayer Park flowpath			
EPP–DSP	440444103132800	Downspout at Trinity Lutheran Church at Rapid City, South Dakota	Roof downspout
EPP–PKL	440445103132900	Eco Prayer Park inlet at Rapid City, South Dakota	Parking lot
EPP–CHN	440445103132700	Eco Prayer Park pond inlet at Rapid City, South Dakota	Channel/storm sewer
EPP–BMP	440445103132600	Eco Prayer Park outlet at Rapid City, South Dakota	Channel/storm sewer

be attributed entirely to commercial uses and street traffic. The Eco Prayer Park flowpath sites (table 2) included 1 roof downspout (EPP–DSP; fig. 7*A*), 1 parking lot (EPP–PKL; fig. 7*B*), 1 rock-lined channel (EPP–CHN; fig. 7*C*), and 1 outlet from a small retention pond BMP (EPP–BMP; fig. 7*D*). A stage plate was installed in the retention pond to record changes in the water level during runoff at the EPP–BMP site (fig. 7*D*). During high inflows to the Eco Prayer Park, the flow splits between the rock channel and an overflow path into a grassed lawn area to the north side (fig. 6). This grassed lawn contains underdrains that flow back into the retention pond.

Collection and Analyses of Water Samples

Water-quality samples were collected at each flowpath site during storm events during May–September in 2016–18. A storm event was defined as having at least 0.10 inch of precipitation that was separated by at least 72 hours of preceding dry weather conditions. Collection generally began at the upstream sites and continued downstream in consecutive order. Multiple samples were collected at each flowpath site during runoff events to capture the variability in water-quality concentrations as the runoff hydrograph rises (“first flush” process) and falls after the peak runoff (when material from impervious surfaces have “washed off”). The number of samples collected at each flowpath site during a sampling event varied depending on the duration of precipitation and the resulting runoff. Estimates of depth of flow using a ruler or wading rod were made at each site during sample collection to assess whether the runoff was increasing or decreasing, but depth or flow information are not presented in this report.

Water-quality samples were collected by USGS personnel and analyzed for *E. coli* and TSS by Mid Continent Testing Laboratories (Rapid City, S. Dak.) according to standard procedures (American Public Health Association, 2015). Standard procedures for water-quality sample collection followed the USGS National Field Manual (U.S. Geological Survey, 2006). Bottles used in sampling procedures were routinely cleaned

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Figure 2. Jackson stormwater-quality flowpath sampling sites and drainage flowpath network in Rapid City, South Dakota.

Figure 3. Jackson stormwater-quality flowpath sampling site types in Rapid City, South Dakota. *A*, roof downspout site USG–DSP; *B*, street curb site USG–CRB; *C*, underground storm sewer outfall site WTP–USS; *D*, channel/storm sewer site WTP–BMP.

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Figure 4. Wildwood stormwater-quality flowpath sampling sites and drainage flowpath network, Rapid City, South Dakota.

Figure 5. Wildwood stormwater-quality flowpath sampling site types in Rapid City, South Dakota. *A*, parking lot site CLC–PKL; *B*, street curb site WDW–CRB; *C*, outlet pipe from roof downspout site CLC–DSP; *D*, parking lot site ATH–PKL; *E*, street curb site SDC–CRB in center of photograph and channel/storm sewer site SDC–CHN at culvert on right side of photograph.

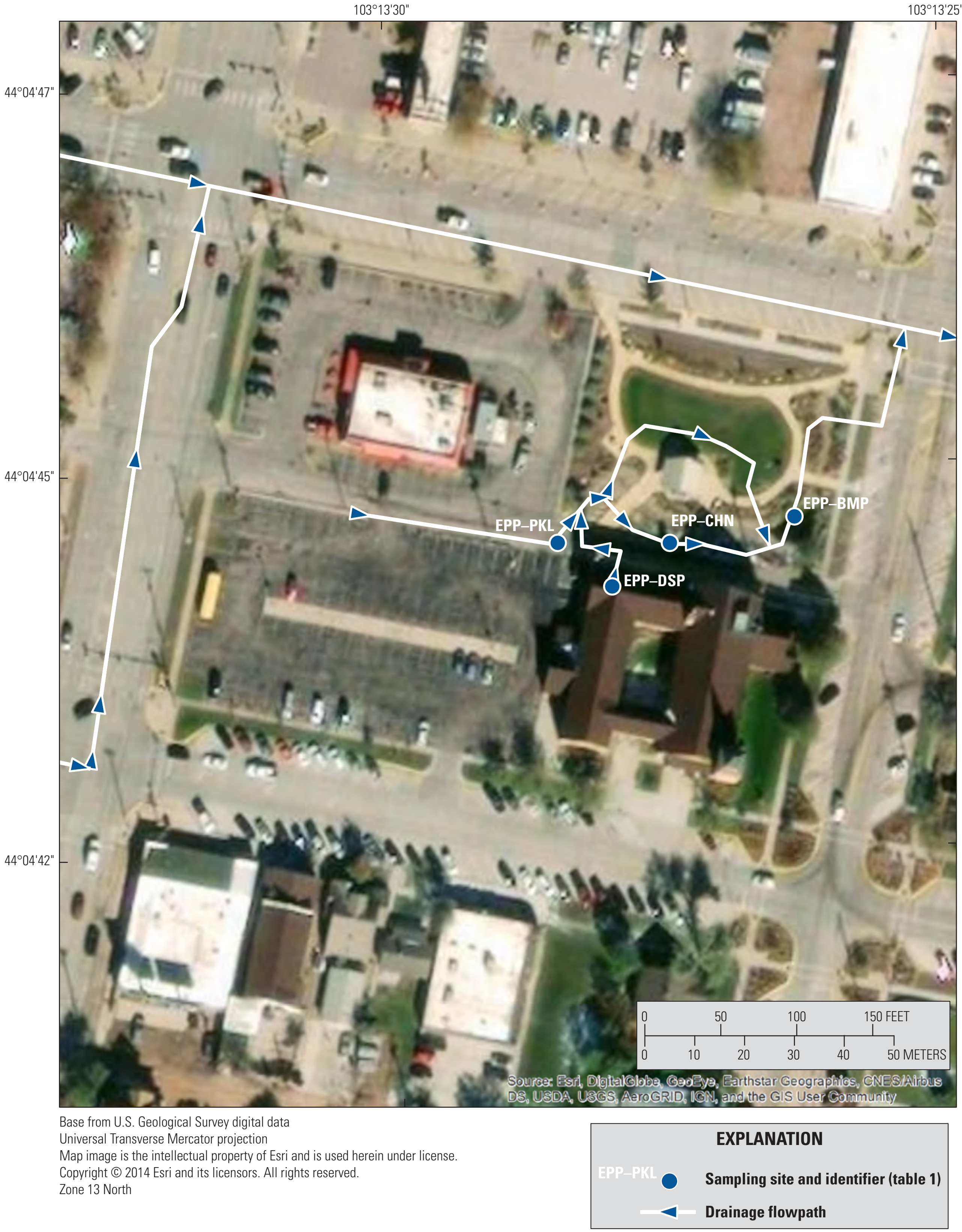

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Figure 6. Eco Prayer Park stormwater-quality flowpath sampling sites and drainage flowpath network in Rapid City, South Dakota.

Figure 7. Eco Prayer Park stormwater-quality flowpath sampling site types in Rapid City, South Dakota. *A*, roof downspout site EPP–DSP; *B*, parking lot site EPP–PKL; *C*, retention pond stage plate site EPP–BMP; *D*, rock channel site EPP–CHN.

as described in the USGS National Field Manual (Wilde, 2004) or replaced after sampling. Samples were collected in sterile 1-liter plastic bottles using grab-sampling techniques (U.S. Geological Survey, 2006). Flow at most sites was confined to relatively narrow channels (such as a downspout or curb) or through a culvert pipe, so width- and depth-integrating sampling techniques were not feasible or warranted. Sample bottles were brought to the USGS Rapid City laboratory where specific conductance and pH values were measured, and water samples were transferred into containers supplied by Mid Continent Testing Laboratories.

Specific conductance is a measure of the ability of water to conduct an electrical current and is a surrogate measure of dissolved solids (Hem, 1985). For stormwater samples, specific conductance usually correlates with total dissolved solids (Granato and Smith, 1999) and is used to help assess the wash-off process. The wash-off process refers to decreases in suspended and dissolved solids concentrations with time during a storm event. Pure liquid rainwater has a very low specific conductance (less than 100 microsiemens per centimeter at 25 degrees Celsius; Hem, 1985), and thus, stormwater samples collected during the receding limb of a runoff hydrograph typically have specific conductance values much less than the rising limb of the hydrograph (also referred to as the “first flush”). Although pH data were also collected with samples, no analyses of the results were completed for this report; however, the results are available with other water-quality constituents in appendix 1 (U.S. Geological Survey, 2019).

Quality Assurance and Quality Control

Quality-assurance and quality-control procedures were used to identify possible random or systemic errors in the field sampling and laboratory analyses. For quality control, equipment blank and sequential replicate samples were collected to determine precision and identify potential sample contamination. During the 3-year study, 147 environmental water-quality samples were collected for laboratory analyses, and 9 quality-control samples were collected. Five equipment blanks were collected to assess the sample equipment cleaning procedures and laboratory methods, and four sequential replicate samples were collected to measure variability associated with sample collection, processing, and analysis (table 3).

Precision of analytical results for water-quality samples may be affected by numerous sources of potential variability in field and laboratory processes, including sample collection, sample processing and handling, and laboratory preparation and analysis. Analyses of field replicate samples, therefore, can indicate the reproducibility of environmental data and provide information on the variability associated with sample collection and analysis. The precision of environmental/replicate sample pairs can be assessed using the absolute difference in concentrations and the relative percent difference (RPD), calculated as the difference in concentration divided by the mean concentration multiplied by 100 for the environmental/replicate pair. For *E. coli* concentrations in environmental/replicate pairs, the RPD ranged from 0 to 17 percent, and the RPD for TSS concentrations in environmental/replicate pairs ranged from 2.2 to 80 percent (table 3). However, the greatest RPD in a TSS replicate sample coincided with a relatively low concentration in the environmental sample (8.4 mg/L) and small absolute difference (4.8 mg/L). For the remaining replicate samples with relatively high RPD (greater than 15 percent), the differences can be attributed mainly to the rapidly changing water-quality conditions that are common with short-term runoff events, because replicate samples were collected in separate bottles immediately after the environmental sample. Data from the WTP–USS site on August 2, 2017, are as an example of how quickly *E. coli* concentrations can change in stormwater samples collected from the same site. In four samples collected at times separated by an interval of 4 to 14 minutes within a 30-minute period, *E. coli* concentrations were 4,100 mpn/100 mL, 120,000 mpn/100 mL, 20,000 mpn/100 mL, and 11,000 mpn/100 mL. Replicate samples of *E. coli* and fecal coliform bacteria from previous stormwater sampling in Rapid City had a median RPD of about 30 percent (Hoogestraat, 2015). All blank samples for *E. coli* and TSS were below laboratory reporting levels, indicating satisfactory cleaning procedures and equipment.

Table 3. Blank and replicate water-quality sample results for samples collected at various stormwater flowpath sites in Rapid City, South Dakota.

[Shading represents the environmental sample. mm/dd/yyyy, month/day/year; hh:mm, hour:minute (military time); mpn/100 mL, most probable number per 100 milliliters; mg/L, milligram per liter; <, less than; --, not available]

Short identifier (table 1)	Date (mm/dd/yyy)	Time (hh:mm)	*Escherichia coli* (mpn/100 mL)	Total suspended solids (mg/L)
Equipment blank samples				
(Not applicable—Filled at laboratory)	06/13/2016	17:14	<1	<4
	06/13/2016	17:15	<1	<4
	08/09/2016	08:00	<1	<4
	05/17/2017	10:20	<1	<4
	07/12/2017	14:50	<1	<4
Environmental/replicate sample pairs				
EPP–DSP	07/01/2016	09:00	<10	--
EPP–DSP	07/01/2016	09:01	<10	--
Relative percent difference			0	--
Absolute difference			0	--
SDC–CHN	05/17/2017	09:20	488	8.4
SDC–CHN	05/17/2017	09:21	517	3.6
Relative percent difference			5.8	80
Absolute difference			29	4.8
EPP–PKL	07/12/2017	14:20	727	159
EPP–PKL	07/12/2017	14:21	866	128
Relative percent difference			17	22
Absolute difference			139	31
WTP–USS	08/06/2018	16:15	14,200	141
WTP–USS	08/06/2018	16:16	16,700	138
Relative percent difference			16	2.2
Absolute difference			2,500	3

Stormwater Quality of Infrastructure Elements

A complete listing of water-quality sample results from this study are presented in appendix 1, and all data are available from the USGS National Water Information System database (U.S. Geological Survey, 2019). The following sections describe the statistical summaries of water-quality data collected from the Jackson, Wildwood, and Eco Prayer Park flowpaths, as well as a listing of statistics categorized by infrastructure site type. The minimum, median, and maximum concentrations of *E. coli*, TSS, and specific conductance for each sampling site are listed in table 4.

Jackson Flowpath

In general, the concentrations of *E. coli* and TSS increased in the downstream direction among the Jackson flowpath sites (table 4). Figure 8 shows an example stormwater-quality data plot for a runoff event on May 24, 2016. The wash-off process after the first flush is evident in the plots for TSS and specific conductance, as noted by the decreasing concentrations with sample time in figures 8*B* and 8*C*. However, *E. coli* concentrations do not necessarily follow the same pattern: concentrations in the latter part of the runoff period sampled were similar to or greater than the initial concentrations of the first set of samples (fig. 8*A*).

Samples collected from the roof downspout site (USG–DSP) during the beginning of storm events had relatively low, but quantifiable, amounts of *E. coli* for 50 percent of the storms; final samples collected during the same storm events usually had *E. coli* concentrations below detection levels (appendix 1). TSS concentrations from the roof downspout

Table 4. Summary statistics for water-quality results at stormwater sampling sites in Rapid City, South Dakota.

[mpn/100 mL, most probable number per 100 milliliters; mg/L, milligram per liter; µS/cm at 25 °C, microsiemen per centimeter at 25 degrees Celsius; min, minimum; med, median; max, maximum; <, less than]

Short identifier (table 1)	Site type	Storm events sampled	Sample count	*Escherichia coli* (mpn/100 mL)			Total suspended solids (mg/L)			Specific conductance (µS/cm at 25 °C)		
				Min	Med	Max	Min	Med	Max	Min	Med	Max
Jackson flowpath												
USG–DSP	Roof downspout	4	10	<1	1	17	<4	18	183	17	28	90
USG–PKL	Parking lot	4	10	11	275	4,800	19	48	118	64	79	161
USG–CRB	Street curb	4	11	<10	98	690	26	83	197	68	93	153
WTP–CHN	Channel/storm sewer	1	3	63	110	110	120	142	152	120	136	148
WTP–USS	Channel/storm sewer	4	12	330	3,050	120,000	18	156	547	125	161	343
WTP–BMP	Channel/storm sewer	1	2	1,700	1,850	2,000	111	143	175	175	179	182
Wildwood flowpath												
CLC–DSP	Roof downspout	4	11	1	1	13	5	10	84	29	43	160
CLC–PKL	Parking lot	4	11	2	230	5,900	<4	47	131	30	74	420
WDW–CRB	Street curb	4	9	4	100	400	40	95	687	69	87	220
ATH–PKL	Parking lot	4	8	17	93	14,000	22	86	446	59	70	200
SDC–CRB	Street curb	3	7	96	290	2,800	4	54	463	47	82	105
SDC–CHN	Channel/storm sewer	3	8	490	2,400	7,200	6	14	150	92	120	1,120
Eco Prayer Park flowpath												
EPP–DSP	Roof downspout	4	10	<10	99	1,100	<4	15	220	18	72	180
EPP–PKL	Parking lot	5	16	14	400	20,000	19	125	546	30	155	420
EPP–CHN	Channel/storm sewer	5	13	78	920	33,000	6	31	644	92	250	550
EPP–BMP	Channel/storm sewer	3	6	600	13,800	150,000	<4	65	108	200	240	340

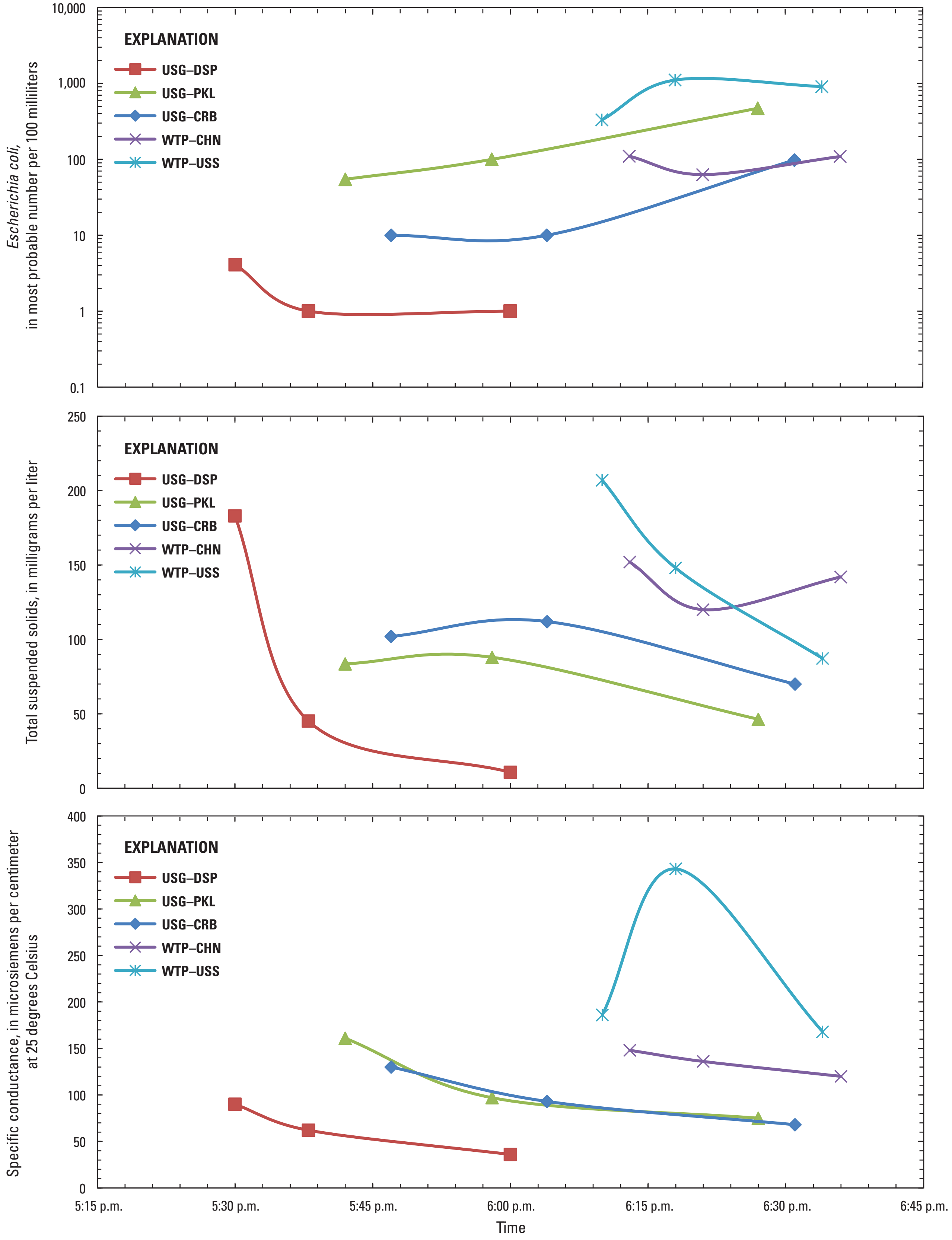

Figure 8. Example stormwater-quality data plot for Jackson flowpath on May 24, 2016.

site (USGS–DSP) ranged from 183 mg/L in samples collected during the first flush to less than (<) 4 mg/L in samples collected during the later wash-off period of a storm event (table 4). *E. coli* concentrations from the parking lot (USG–PKL) and street curb (USG–CRB) sites ranged from <10 to 4,800 mpn/100 mL but did not typically show an apparent decreasing (or increasing) pattern during individual storm events, as would be expected with sediment wash-off processes. TSS concentrations from these two sites ranged from about 200 mg/L in samples collected during the initial flush to about 20 mg/L in samples collected later during the same storm event. The underground storm sewer site (WTP–USS) farther downstream (where stormwater also collects from the larger drainage network) had the highest *E. coli* concentrations, ranging from 330 to 120,000 mpn/100 mL (median was 3,050 mpn/100 mL), and had the greatest TSS concentrations, ranging from about 550 mg/L during the first flush down to about 20 mg/L after the wash off (median was 156 mg/L). Another storm drainage channel (WTP–CHN) joins the flow from WTP–USS, and then flows downstream through a grassed swale BMP (WTP–BMP) before entering Rapid Creek. The flow from the WTP–CHN site was much smaller than the WTP–USS site during all site visits; thus, the WTP–BMP location represented mostly (greater than 90 percent) stormwater from the WTP–USS site. Only two samples were collected from the WTP–BMP site during one relatively large storm event compared to other storms in this study. During this large storm on June 27, 2017, the *E. coli* concentrations ranged from 1,500 to 2,000 mpn/100mL at the upstream WTP–USS site and were at similar concentrations after flowing through the grassed BMP area (*E. coli* concentrations ranged from 1,700 to 2,000 mpn/100 mL at the WTP–BMP site). However, TSS concentrations were reduced from a range of 211 to 547 mg/L at the WTP–USS site to a range of 111 to 175 mg/L at the WTP–BMP site during this same storm. For the remaining (smaller precipitation) storms when the Jackson flowpath sites were sampled, the flow infiltrated into the grassed areas of the BMP and did not reach the outlet of the flowpath.

Wildwood Flowpath

In the Wildwood flowpath, *E. coli* concentrations were lowest in samples collected at the roof downspout site (CLC–DSP) and greatest in samples collected at the main drainage channel (SDC–CHN) farther down the flowpath (table 4). *E. coli* concentrations at the CLC–DSP site were all 13 mpn/100 mL or less, and the *E. coli* concentration at the SDC–CHN site ranged from 490 to 7,200 mpn/100 mL. The parking lot (CLC–PKL and ATH–PKL) and street curb (WDW–CRB and SDC–CRB) sites in the Wildwood flowpath had variable *E. coli* concentrations, ranging from 2 to 14,000 mpn/100 mL with site median values between 93 and 290 mpn/100 mL. Contrary to *E. coli* results, TSS concentrations at the farthest downstream site (SDC–CHN) were lower (median was 14 mg/L) than the parking lot and street curb sites (site medians ranged from 47 to 95 mg/L). Example stormwater-quality data plots for the Wildwood flowpath are shown in figure 9, demonstrating the first flush and wash-off processes where the TSS concentrations decrease as the runoff hydrograph progresses, whereas the *E. coli* concentrations remain fairly stable or increase.

Eco Prayer Park Flowpath

Samples collected from the Eco Prayer Park flowpath had higher *E. coli* concentrations than samples collected from the Jackson and Wildwood flowpath sites. The roof downspout site (EPP–DSP) had a median *E. coli* concentration of 99 mpn/100 mL for 10 samples, ranging from <10 to 1,100 mpn/100 mL. The parking lot site (EPP–PKL) and next downstream rock channel site (EPP–CHN) had median concentrations of 400 and 920 mpn/100 mL, respectively, with a maximum concentration of 33,000 mpn/100 mL at the EPP–CHN site. The *E. coli* concentrations from the outlet of the retention pond (EPP–BMP) were greater than the inlet site (EPP–CHN), with a median concentration of 13,800 mpn/100 mL and a maximum *E. coli* concentration of 150,000 mpn/100 mL. However, TSS concentrations were reduced by the retention pond and infiltration by the rock channel because the median concentration at the outlet site (EPP–BMP) was 65 mg/L compared to the parking lot inflow (EPP–PKL) median concentration of 125 mg/L.

Typical water-quality behavior during a runoff event at the Eco Prayer Park sites is demonstrated in figure 10. The dashed line in figure 10 is the retention pond depth, as measured by readings from the stage plate during sampling, and is an estimate of the runoff hydrograph. Water from the retention pond flows into the overflow pipe and connects to the underground storm sewer system when the depth is above 1.3 feet. The sediment washoff process is evident because TSS concentrations decreased during the storm event; however, *E. coli* concentrations remained fairly constant during the complete runoff period.

Infrastructure Site Type Summary

A primary objective of this study was to improve on the method by which FIB (for example, *E. coli*) and TSS are evaluated in the urban drainages within Rapid City, S. Dak. and to provide information that helps identify origins of FIB and TSS. Stormwater quality has been characterized as it enters Rapid Creek during runoff events (Hoogestraat, 2015) and within Rapid Creek itself (Pirner and Harms, 1978; Krantz, 2002), but the data collected in this study help describe the stormwater quality farther upstream in the urban basins. Data collected during this study was summarized by infrastructure site type to provide information about approximate water-quality concentrations at various points along the upper end of urban flowpaths. Median concentrations of *E. coli*, TSS,

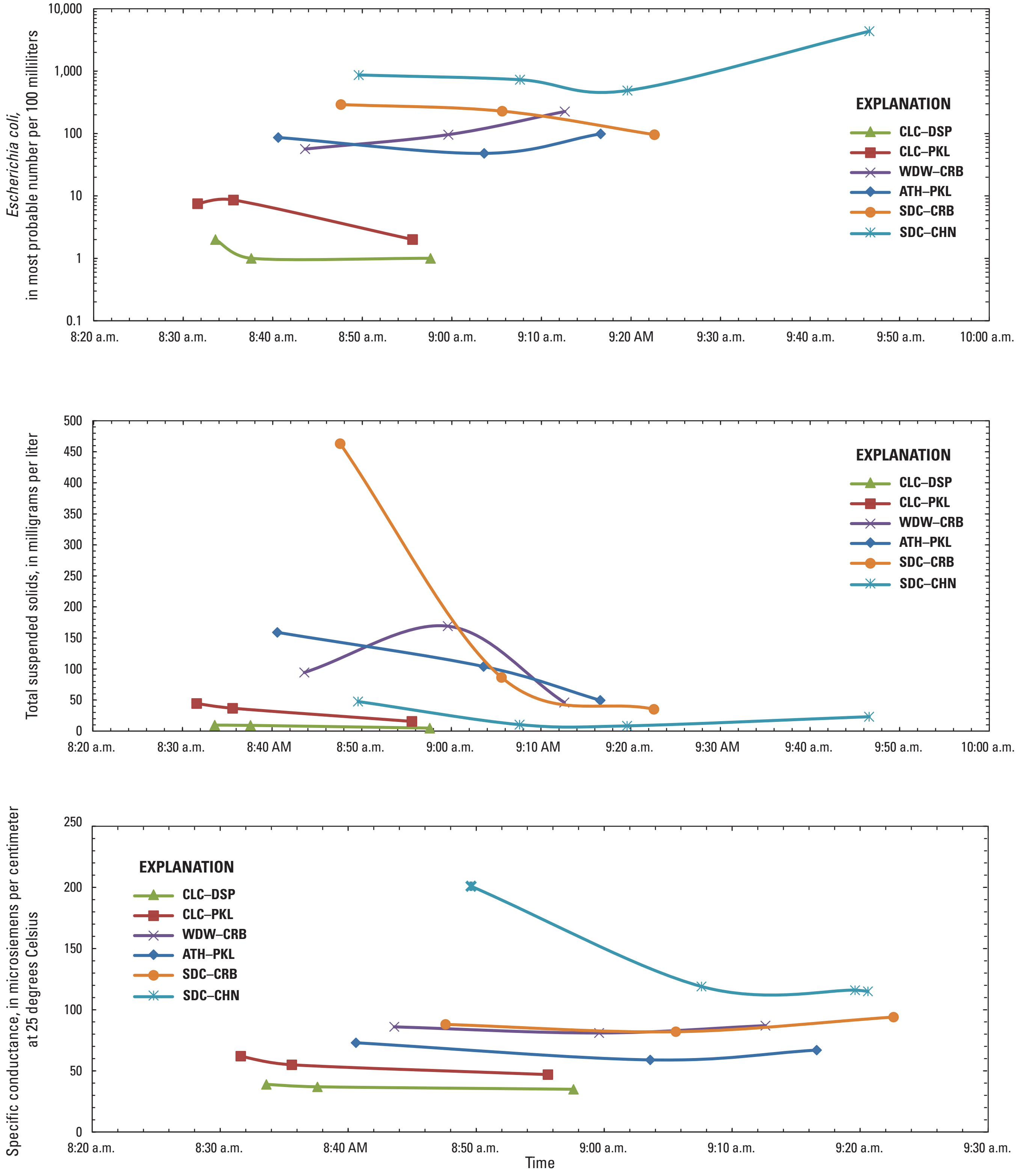

Figure 9. Example stormwater-quality data plot for Wildwood flowpath on May 17, 2017.

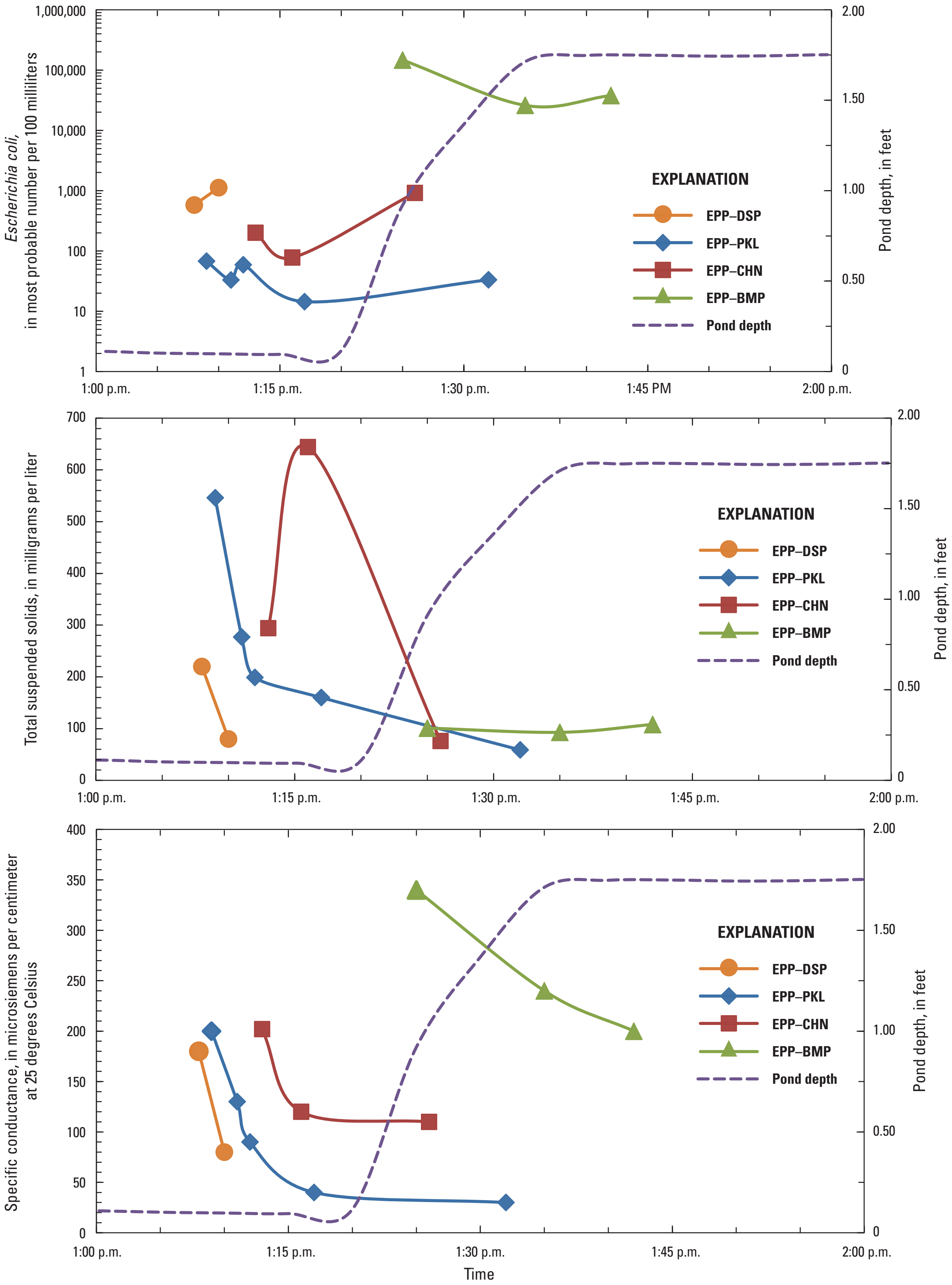

Figure 10. Example stormwater-quality data plot for Eco Prayer Park flowpath on September 12, 2017.

and specific conductance for the four infrastructure site types that were evaluated for this study (roof downspout, parking lot, street curb, and channel/storm sewer) are listed in table 5. This information can be used in hydrologic models to better estimate FIB and TSS loading from urban environments.

E. coli and TSS concentrations were lowest in samples collected from locations most isolated from human influence (roof downspouts). The median concentrations at these sites were 4 mpn/100 mL and 15 mg/L, respectively. The delivery potential of FIB and sediment from parking lots and street curbs was similar; median concentrations of *E. coli* were around 150 to 220 mpn/100 mL and 56 to 86 mg/L for TSS. The receiving channels and storm sewers where stormwater was aggregated typically contained the highest *E. coli* concentrations (median of 1,800 mpn/100 mL), but TSS concentrations were similar to upstream elements (parking lots and street curbs) in the flowpath (median was 69 mg/L). For the Wildwood and Eco Prayer Park flowpaths, the median TSS for the channel and storm sewer site types was lower than the upstream elements but not for the Jackson flowpath sites.

Previous research (Schueler, 2000) has suggested that current stormwater, buffer, and source-control practices are incapable of removing enough bacteria to meet current water contact recreation standards in stormwater discharges, unless the discharging water is well mixed and diluted with cleaner water. *E. coli* concentrations at the outflow sites of most stormwater drainages in Rapid City are about 7,200 to 21,000 mpn/100 mL (Hoogestraat, 2015), and urban drainages account for about 37 percent of the Rapid Creek streamflow at the downstream boundary of Rapid City. It is probable that bacterial concentrations in streams that receive stormwater runoff will always exceed predevelopment conditions, even if stormwater treatment and buffer practices are fully implemented and all wastewater discharges are eliminated (Schueler, 2000). The current beneficial-use criterion for *E. coli* in Rapid Creek is 235 mpn/100 mL, which is only slightly greater than the median concentration that washes off parking lots and street curbs in the upstream end of the urban flowpath (median of 150 to 220 mpn/100 mL). The data collected from this study demonstrate that stormwater is almost immediately contaminated with FIB upon touching impervious surfaces, which highlights the importance of controlling the volume of stormwater discharges into receiving waterbodies via storage structures and pervious elements. An example of this reduction in volume is the observations from the BMP area sampled in the Jackson flowpath during this study, where flow during smaller storms were completely infiltrated into the grassed channels before reaching the outlet into Rapid Creek. Diluting stormwater containing high concentrations of *E. coli* with the receiving water's (Rapid Creek) lower concentration of *E. coli* is likely the primary mechanism for meeting the 235 mpn/100 mL beneficial-use criterion threshold.

TSS concentrations in the upstream end of the urban flowpath (parking lots and street curbs) also begin at concentrations (56 to 86 mg/L) above the beneficial-use criterion for Rapid Creek (53 mg/L); however, previous research has indicated that current stormwater-control practices (storage ponds, swales, wetlands) were able to reduce suspended-sediment concentrations by 40 to 60 percent (Hoogestraat, 2015). The BMP area in the lower end of the Jackson flowpath is another example of how a stormwater-control practice can reduce TSS concentrations. TSS concentrations were reduced from a peak of 547 mg/L at the inflow to the BMP area (WTP–USS site) to concentrations less than 200 mg/L at the outlet site (WTP–BMP) during this same event. Dilution with receiving waters is not the only mechanism for meeting beneficial-use criteria for TSS because concentrations of TSS in the upstream end of Rapid City stormwater flowpaths were generally closer to the criterion when compared to the difference between *E. coli* concentrations and the corresponding criterion. For example, in order for stormwater to meet the TSS beneficial-use criterion of Rapid Creek (53 mg/L), the median concentration of TSS from street curbs during this study (86 mg/L) would need to be reduced by 39 percent, which is within the expected range of most current stormwater-control practices.

Table 5. Median *Escherichia coli* concentration, total suspended solids concentration, and specific conductance of site types sampled in 2016–18, Rapid City, South Dakota.

[mpn/100 mL, most probable number per 100 milliliters; mg/L, milligram per liter; µS/cm at 25 °C, microsiemen per centimeter at 25 degrees Celsius]

Site type	Median concentration		
	Escherichia coli **(mpn/100 mL)**	**Total suspended solids (mg/L)**	**Specific conductance (µS/cm at 25 °C)**
Roof downspout	4	15	43
Parking lot	220	56	93
Street curb	150	86	87
Channel/ storm sewer	1,800	69	176

Summary

As runoff flows over the land or impervious surfaces (paved streets, parking lots, and building roofs), it accumulates debris, chemicals, sediment, and other contaminants that can adversely affect water quality if the runoff discharge remains untreated. Fecal indicator bacteria (FIB), such as *Escherichia coli* (*E. coli*), enterococci, or fecal coliform, are the most-frequent cause of water-quality impairment in rivers and streams in the United States. Rapid Creek originates in the western Black Hills area and flows east through Rapid City to its mouth at the Cheyenne River. The water quality of Rapid Creek is important because the reach that flows through Rapid City, South Dakota, is a valuable spawning area for a self-sustaining trout fishery, is actively used for recreation, and is a seasonal municipal water supply for the City of Rapid City. The fishery and recreational uses are considered “beneficial uses” by the South Dakota Department of Environment and Natural Resources, which carry numerical criteria for total suspended solids (TSS) and *E. coli* concentrations, among other water-quality constituents for additional beneficial uses. Current methods of identifying FIB impairments in surface water are usually limited to a general assessment of sources (typically grouped as livestock, wildlife, or human), and FIB sample data relative to specific sources typically are not available. The objectives of this study were to improve on the method by which FIB and TSS are quantified in the urban drainages within Rapid City and to provide information that helps identify origins of FIB and TSS. This information can be used in hydrologic models to estimate FIB and TSS loading from certain infrastructure elements in urban environments.

Stormwater-quality data were collected in three drainage basin flowpaths within Rapid City: Jackson, Wildwood, and Eco Prayer Park. Data-collection activities for this study focused on the beginning urban flowpath elements during rainfall events, including building roofs, parking lots, street curbs, and drainage channels. This approach builds upon previous stormwater assessments that characterized the water quality in urban basin outlets near the downstream end of the stormwater flowpaths. Within each flowpath group, 4–6 sites were selected to represent the various infrastructure elements of the runoff process. These elements included roof downspouts, parking lots, street curbs and gutters, open channels, underground storm sewers, and stormwater ponds or best-management practice facilities. Water-quality samples were collected at each flowpath site during storm events during May–September in 2016–18. Multiple samples were collected at each flowpath site during runoff events to capture the variability in water-quality concentrations as the runoff hydrograph rises (“first flush” process) and falls after the peak runoff flow (when material from impervious surfaces have “washed off”). A total of 147 water-quality samples were analyzed for *E. coli*, TSS, specific conductance, and pH.

In general, the concentrations of *E. coli* and TSS increased in the downstream direction among the Jackson flowpath sites. The wash-off process after the first flush was evident in the plots for TSS and specific conductance; however, *E. coli* concentrations did not necessarily follow the same pattern. *E. coli* concentrations in the latter part of the runoff period were similar to or greater than the initial concentrations of the first set of samples. In the Wildwood flowpath, *E. coli* concentrations were lowest at the roof downspout site (less than or equal to 13 most probable number per 100 milliliters [mpn/100 mL]) and greatest at the main drainage channel farther down the flowpath (ranged from 490 to 7,200 mpn/100 mL). The parking lot and street curb sites’ *E. coli* concentrations in the Wildwood flowpath ranged from 2 to 14,000 mpn/100 mL; site median values were between 93 and 290 mpn/100 mL. Contrary to *E. coli* results, TSS concentrations at the lowest stormwater channel site were lower (median was 14 milligrams per liter [mg/L]) than the parking lot and street curb sites (site medians ranged from 47 to 95 mg/L). In the Eco Prayer Park flowpath, *E. coli* concentrations were greater than the other two flowpath groups. The Eco Prayer Park parking lot site and next downstream rock channel site had median *E. coli* concentrations of 400 and 920 mpn/100 mL, respectively, with a maximum concentration of 33,000 mpn/100 mL. TSS concentrations were reduced by the retention pond within the Eco Prayer Park because the median concentration at the outlet site was 65 mg/L compared to a parking lot median concentration of 125 mg/L.

Data collected during this study were summarized by infrastructure type (roof downspout, parking lot, street curb, and channel/storm sewer) to provide information about approximate water-quality concentrations at various points along the upper end of urban flowpaths. *E. coli* and TSS concentrations were lowest in samples collected from locations most isolated from human, animal, or both influences (roof downspouts). The median concentrations at these roof downspout sites were 4 mpn/100 mL and 15 mg/L, respectively. The delivery potential of FIB and sediment from parking lots and street curbs was similar, with median concentrations of *E. coli* and TSS around 150 to 220 mpn/100 mL and 56 to 86 mg/L, respectively. The downstream receiving channels and storm sewers where stormwater was aggregated typically contained the highest *E. coli* concentrations (median of 1,800 mpn/100 mL), but the TSS concentrations were similar to upstream elements (parking lots and street curbs) in the flowpath (median was 69 mg/L). The data collected from this study demonstrate that stormwater is almost immediately contaminated with FIB upon contacting impervious surfaces. This highlights the importance of controlling the volume of stormwater discharges into receiving waterbodies via storage structures and pervious elements. Diluting stormwater with high concentrations of *E. coli* with the receiving water’s (Rapid Creek) lower concentration of *E. coli* is likely the primary mechanism for meeting the 235 mpn/100 mL beneficial-use criterion threshold. Although TSS concentrations in the upper ends of the basin (parking lots and street curbs) also begin at concentrations (56 to 86 mg/L) above the beneficial-use criterion for Rapid Creek (53 mg/L), current stormwater-control practices (storage ponds, swales, and wetlands) may be able to reduce suspended-sediment concentrations to meet this threshold.

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Appendix 1 Stormwater-Quality Data

Appendix 1 is a comma-separated values (.csv) file that contains the water-quality sample results for data used in this report and is available for download at https://doi.org/10.3133/sir20205004. These data are also stored in the USGS National Water Information System database (U.S. Geological Survey, 2019) and are packaged herein for convenience.

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