

**REQUEST FOR EXCEPTION TO
RAPID CITY DESIGN STANDARD / CRITERIA / REGULATIONS**

PROJECT Moon Meadows

DATE: 3/2/2017 SUBMITTED BY: Mike Stetson, KTM Design Solutions, Inc.

PIN #: 60876 / 11238 mikes@ktmdsi.com, (605) 791-5866

LEGAL DESCRIPTION: SW1/4 of the NW1/4 less Lot H1, Lot H2, and less ROW, located
Section 35, T1N, R7E, BHM, Rapid City, Pennington County, South Dakota; SE1/4 of the NE1/4 East of
Highway 16, located Section 34, T1N, R7E, BHM, Rapid City, Pennington County, South Dakota

EXCEPTION REQUESTED: SECTION _____ STD / CRITERIA / REG Criteria

DESCRIPTION OF REQUEST: Waive the requirements to install curb and gutter, street light conduit,
water, and sewer along Sammis Trail. It is proposed to constructed a 26 foot wide paved surface with grass ditches
and sidewalks in a 70 foot wide right-of-way.

JUSTIFICATION:

(Please use back of sheet if additional room is needed) See Attached Justification Letter

SUPPORTING DOCUMENTATION:

☒ Yes ☐ No

PROPERTY OWNER'S SIGNATURE**:

DATE: 2-2-17

**Or Agent, if previously designated by the Owner in writing.

FOR STAFF ONLY

STAFF COMMENTS: See attached letter dated 3/14/2017

STAFF RECOMMENDATION: Deny. See attached letter dated
3/14/2017.

REVIEWED BY:

DATE: 3/14/2017

AUTHORIZATION:

☐ APPROVED

☒ DENIED

COMMUNITY PLANNING DIRECTOR

☐ APPROVED

DATE

☒ DENIED

PUBLIC WORKS DIRECTOR*

DATE

FILE #: 17EX064

ASSOCIATED FILE#: 16PL096

Revised 08/3/12

*Public Works Director's signature is not required for Lot
Length to Width Exceptions, Ordinance No. 5434.

RECEIVED

MAR 6 2017

**ENGINEERING
SERVICES**

Copy to Utility Maintenance: _____ Copy to Water: _____ Copy to Waste Water: _____ Copy to Streets: _____ Copy to Traffic: _____ Copy to Construction: _____



CITY OF RAPID CITY

RAPID CITY, SOUTH DAKOTA 57701

Public Works Department Engineering Services Division

300 Sixth Street

Telephone: (605) 394-4154 FAX: (605) 355-3083

Web: www.rcgov.org

March 16, 2017

KTM Design Solutions
Mike Stetson
528 Kansas City Street, Suite 4
Rapid City, SD 57701

Re: Exception File No. 17EX064

Dear Mike Stetson:

Enclosed please find a copy of the original exception request that was filed with the assigned file number and the decision details.

In the event that an exception request is denied, the Director of Public Works or the Director of Community Planning will advise the applicant of such denial in writing. Any applicant that disputes the denial of an exception may appeal such denial. In order to appeal the denial the applicant shall file a written request of appeal to the Director within ten (10) working days of the denial. The appeal will be placed on the next Public Works Committee agenda, which will then go to The City Council for final consideration.

If you have any questions or need additional information, please contact our office at 605-394-4154.

Sincerely,

Susan Donat

Susan Donat
Administrative Secretary

Enclosure



EQUAL OPPORTUNITY EMPLOYER



CITY OF RAPID CITY

RAPID CITY, SOUTH DAKOTA 57701

Public Works Department Engineering Services Division

300 Sixth Street

Telephone: (605) 394-4154 FAX: (605) 355-3083

Web: www.rcgov.org

March 14, 2017

KTM Design Solutions

Attn: Mike Stetson, mikes@ktmdsi.com

(605) 791-5866

Re: Request to waive the requirements to install curb, gutter, street light conduit, water and sewer in Sammis Trail
Associated with Moon Meadows
City File # 17EX064, Related Files 16PL096

Dear KTM Design Solutions,

The request to waive the requirements to install curb, gutter, street light conduit, water and sewer in Sammis Trail and only construct a 26 foot wide paved surface with grass ditches and sidewalk in 70' of right-of-way is denied.

Subdivision improvements including pavement, curb, gutter, sidewalk, street light conduit, water main and sewer main are triggered during the platting process for all adjacent roadways. The proposed Moon Meadows plat has frontage to Sammis Trail for approximately 1300' and provides access to four existing parcels. Staff sees Sammis Trail as a permanent street connection to these parcels. Today Sammis Trail exists in 66' of right-of-way with 20' wide gravel surfacing and no other improvements.

Similar to the exception request submitted in 2016 (City File 16EX076) to not improve Sammis Trail, Staff does not support any exceptions to the required improvements within Sammis Trail that don't meet the City's minimum standards for a commercial street. Nor does Staff support the use of a rural pavement section, particularly adjacent to a commercial area. Staff does not believe a rural pavement section is appropriate for this area as it develops and have many concerns regarding the proposed rural pavement section including drainage, design of the road, width of the right-of-way, and drainage ditch sizing and slope. Sammis Trail shall be constructed to minimum commercial street standards.

For sewer, the Rapid City Infrastructure Design Criteria Manual Section 3.5.5 states "Sewer mains shall be extended across the full frontage of each parcel to be served, except... when the City determines that no possibility exists that the main will need to be extended to serve adjacent property." If an exception to sewer in Sammis Trail is being sought, an analysis of the sewer service basin based on the existing sewer main invert at the Moon Meadows Drive and access easement intersection should be provided to the City for consideration, including how properties south of Sammis Trail will be provided with sewer. Sewer should be extended as far as possible



EQUAL HOUSING
OPPORTUNITY

EQUAL OPPORTUNITY EMPLOYER

for adjacent properties. Even though sewer service for the proposed Moon Meadows development comes from the sewer main in Moon Meadows Drive, the developer is still responsible to extend sewer across the full frontage of their property so that it is available to service neighboring properties. In this case, a dry sewer main would be installed in Sammis Trail, until a connecting sewer main is constructed within the extension of Healing Way from Moon Meadows Drive. These improvements should be installed at the time of plat, as required by Ordinance, so they are available for neighboring properties.

For water, the Rapid City Infrastructure Design Criteria Manual Section 3.5.4 states "Water mains shall be extended across the full frontage of each parcel to be served." Water main looping is an essential component to provide redundancy within a water distribution system. A water main loop from Sammis Trail to the existing water main in Hwy 16 would provide redundancy for the area to allow water to be feed from two directions and will be necessary at some point. Even though water service for the proposed Moon Meadows development comes from the water main in Moon Meadows Drive, the developer is still responsible to extend water main across the full frontage of their property so that it is available to service neighboring properties. In this case, a dry water main would be installed in Sammis Trail, until a connecting water main is constructed within the extension of Healing Way from Moon Meadows Drive. These improvements should be installed at the time of plat, as required by Ordinance, so they are available for neighboring properties.

The denial of this exception request may be appealed to the City Council by requesting it be placed on the next Public Works Committee agenda. The City Council has final approval of exception requests. In order to appeal the denial the applicant shall file a written request of appeal to the Public Works Director within 10 working days of the denial. Please contact the Public Works Engineering Department if you desire to appeal.

Sincerely,
City of Rapid City

A handwritten signature in black ink, appearing to read "Nicole Lecy", written over the printed name.

Nicole Lecy, Project Engineer

March 6, 2017

Ms. Nicole Lecy
Development Review – City of Rapid City
300 Sixth Street
Rapid City, SD 57701

**RE: Request for Exception to Rapid City Design Criteria
Moon Meadows – Sammis Trail
KTM Project No. 12-0653.3**

Dear Ms. Lecy:

The purpose of this letter is to provide justification to supplement the attached request for Exception to Rapid City Design Criteria Manual for the above referenced project.

The exception request is to waive the requirement to install curb and gutter, street light conduit, water and sewer within the Sammis Trail right-of-way (ROW) per the Rapid City Infrastructure Design Criteria Manual (IDCM). It is proposed to provide a 26 foot wide crowned, paved surface with grass ditches and sidewalks in the Sammis Trail ROW. Sidewalks are proposed 1 foot from the edge of the ROW. The existing ROW is proposed to be widened from 66 feet to 70 feet. An exhibit showing the typical section of the street and ROW is attached. Sammis Trail has an existing 26 foot wide graveled surface that provides access to residential properties. Sammis Trail no longer extends to Mount Rushmore Road, which eliminated the outlet at the west end. Therefore the traffic on the road is minimal and only serves as a driveway to two residential properties south of Sammis Trail. The following is a list of justifications to support the request:

1. Install Curb and Gutter

The proposed street section is a rural type with a crowned street and grass ditches within the ROW. Maintaining the existing street section and not installing curb and gutter has several benefits and advantages.

a. Low Impact Development

The Rapid City Stormwater Quality Manual 2009 Edition discusses the impact a typical curb and gutter street section has on runoff volumes and Section 2.1.1 states that “depending on the magnitude of changes to the land surface, the total runoff volume can increase dramatically. These changes not only increase the total volume of runoff, but also accelerate the rate at which runoff flows across the land. This effect is further exacerbated by drainage systems such as gutters, storm sewers and lined channels that are designed to quickly carry runoff to creeks and lakes.”

This section of Sammis Trail is an excellent location for grass ditches within the ROW based on several factors. The longitudinal slope is flat (0.5 percent to 3 percent) and there is a small upstream drainage area that flows into the ditches. The Meadows Apartments project is proposed to flow north into the Moon Meadows Drive storm sewer. The remaining area north of Sammis Trail is also proposed to flow north into the Moon Meadows Drive storm sewer. The existing grass ditches could provide water quality benefits by functioning as grass swale water quality elements that slowly convey runoff. Section 2.3.7 of the Rapid City Stormwater Quality Manual 2009 Edition states “[grass swales] can be made a part of the plans to minimize a directly connected impervious area by using them as an alternative to a curb-and-gutter system if approved by the Growth Management Director.” Eliminating curb and gutter and maintaining ditches within the ROW has numerous water quality benefits, including improved groundwater recharge, reduced downstream runoff or flooding by attenuating stormwater peak flow rates, and increased evaporation. The improved groundwater recharge reduces the amount of pollutants such as oil, bacteria, sediments, metals, hydrocarbons and nutrients from impervious surfaces that reach local waters. Attenuating stormwater flow rates is accomplished by not providing directly connected impervious area flow peaks, which increases time of concentration.

b. Stormwater Quality Benefit

U.S. Geological Survey Scientific Investigations Report 2015-5069 “Water-Quality Characteristics of Stormwater Runoff in Rapid City, South Dakota, 2008-14” analyzed the urban stormwater runoff in three drainage basins within Rapid City, including Arrowhead and Meade-Hawthorne. This report was prepared in cooperation with the City of Rapid City. Concentrations of total suspended solids (TSS) and bacteria in stormwater runoff were evaluated. On page 2, the main conveyance channels in the Arrowhead drainage basin are described as “roughly 90 percent open vegetated channel, where plants can slow the stormwater runoff and use it by way of evapotranspiration.” Page 3 states “the conveyance structures in the Meade-Hawthorne drainage basin differ greatly from those

in the Arrowhead drainage basin, with roughly 80 percent consisting of concrete channels and culverts, allowing for little to no infiltration.”

The results, on page 16, are described as “comparing concentrations between the Arrowhead and Meade-Hawthorne drainage drains, median EMCs [event-mean concentrations] for TSS were more than two times greater at the Meade-Hawthorne outlet at site MH [Meade-Hawthorne outfall] (520 mg/L) than the Arrowhead outlet at site MBG [Meadowbrook Golf Course] (200 mg/L; table 5 and fig. 8). Median EMCs for fecal coliform bacteria also were greater at site MH (30,000 cfu/100 mL) than at site MBG (17,000 cfu/100 mL). Median EMCs for E. coli were about three times greater at site MH (21,000 mpn/100 mL) than at site MBG 7,200 mpn/100 mL.” The report examples the lower concentrations due to “the presence of more vegetated channels in the Arrowhead drainage basin (in contrast to the concrete structures predominantly found in the Meade-Hawthorne drainage basin) allows for passive treatment of stormwater.” The lower concentrations of TSS and bacteria are attributed to the greater use of vegetated channels and lower impervious area in the Arrowhead drainage basin. The use of vegetated ditches along Sammis Trail would have similar stormwater quality benefits as those shown in this report.

c. Future Maintenance Costs

Ditches within the ROW will have lower maintenance and replacement costs compared to traditional storm sewer system with pipes and inlets. Routine sediment removal in the ditches is the only required maintenance. A traditional storm sewer system increases downstream peak flow rates by providing an impervious surface or pipe a direct connection to a receiving stream. The increased flow rates cause erosion in the receiving streams and increase maintenance costs in these receiving streams.

d. Phased Construction

Sammis Trail will be constructed in multiple phases as adjacent properties are developed, under the IDCM requirement that adjacent ROW or easements to properties to be improved to City standards. Construction of the street in phases would create a disjointed street section where ditches within the ROW would flow into a standard City street section with curb and gutter. The ditches would need to be raised to flow into the curb and gutter where the transition between the typical sections occurs, which could cause erosion issues. Without a transition between the typical sections, the ditches would flow into a sump area that would likely require an outlet pipe.

2. **Install Water Main**

A water main along Sammis Trail would not currently serve any property and should only be constructed when needed for development. A water main would not connect to the existing

Rapid City water main network. Therefore the pipe, valves, and fittings for the water main would be dry and deterioration would begin, such as soil corrosion to valves and fittings, while the water main isn't providing service. This effectively shortens the usable service life of the water main.

The existing water main located within Moon Meadows Drive ROW has stub outs to provide service to the proposed lots north of Sammis Trail, including the proposed Meadows Apartments that will have an internal water main loop. A water main along Sammis Trail would only provide service for development south of Sammis Trail. The timing or layout for development south of Sammis Trail is unknown and to properly size the water main is difficult without knowing the demand for the property to the south. The area south of Sammis Trail may be developed in a way that eliminates the need for a water main along Sammis Trail. As per the Rapid City Utility Master Plan, a future reservoir is proposed southeast of Sammis Trail. A water main along Sammis Trail should only be constructed when the reservoir is constructed or property to the south is developed.

3. Install Sanitary Sewer

A sanitary sewer along Sammis Trail would not currently serve any property and should only be constructed when needed for development. A sanitary sewer would not connect to the existing Rapid City sanitary sewer network. Therefore the pipe and manholes for the sanitary sewer would be dry and deterioration would begin while the sanitary sewer isn't providing service. This effectively shortens the usable service life of the sanitary sewer.

The existing sanitary sewer located within Moon Meadows Drive ROW has stub outs to provide service to the proposed lots north of Sammis Trail, including the proposed Meadows Apartments. A sanitary sewer along Sammis Trail would only provide service for development south of Sammis Trail. The timing or layout for development south of Sammis Trail is unknown and to provide adequate sewer depth is difficult without knowing the future grading of property to the south. The area south of Sammis Trail may be developed in a way that eliminates the need for a sanitary sewer along Sammis Trail. A sanitary sewer along Sammis Trail should only be constructed when property to the south is developed.

4. Install Street Light Conduit

The adjacent lots north of Sammis Trail will have street lights once developed. Street lights along Sammis Trail would rarely be utilized due to the minimal traffic and only add to light pollution.

Thank you for your consideration in this matter. If you have questions or need additional information, please do not hesitate to contact me at (605) 791-5866 or mikes@ktmdsi.com.

Sincerely,



Mike Stetson
Project Engineer
KTM Design Solutions, Inc.

Prepared in cooperation with the City of Rapid City

Water-Quality Characteristics of Stormwater Runoff in Rapid City, South Dakota, 2008–14



Scientific Investigations Report 2015–5069

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



Water-Quality Characteristics of Stormwater Runoff in Rapid City, South Dakota, 2008–14

By Galen K. Hoogestraat

Prepared in cooperation with the City of Rapid City

Scientific Investigations Report 2015–5069

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

Water-Quality Characteristics of Stormwater Runoff in Rapid City, South Dakota, 2008–14

By Galen K. Hoogestraat

Abstract

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, actively used for recreation, and a seasonal municipal water supply for the City of Rapid City. This report presents the current (2008–14) water-quality characteristics of urban stormwater runoff in selected drainage networks within the City of Rapid City, and provides an evaluation of the pollutant reductions of wetland channels implemented as a best-management practice. Stormwater runoff data were collected at nine sites in three drainage basins within Rapid City: the Arrowhead (2 monitoring sites), Meade-Hawthorne (1 monitoring site), and Downtown (6 monitoring sites) drainage basins. Stormwater runoff was evaluated for concentrations of total suspended solids (TSS) and bacteria at sites in the Arrowhead and Meade-Hawthorne drainage basins, and for concentrations of TSS, chloride, bacteria, nutrients, and metals at sites in the Downtown drainage basin.

For the Arrowhead and Meade-Hawthorne sites, event-mean concentrations typically exceeded the TSS and bacteria beneficial-use criteria for Rapid Creek by 1–2 orders of magnitude. Comparing the two drainage basins, median TSS event-mean concentrations were more than two times greater at the Meade-Hawthorne outlet (520 milligrams per liter) than the Arrowhead outlet (200 milligrams per liter). Median fecal coliform bacteria event-mean concentrations also were greater at the Meade-Hawthorne outlet site (30,000 colony forming units per 100 milliliters) than the Arrowhead outlet site (17,000 colony forming units per 100 milliliters). A comparison to relevant standards indicates that stormwater runoff from the Downtown drainage basin exceeded criteria for bacteria and TSS, but concentrations generally were below standards for nutrients and metals. Stormwater-quality conditions from the Downtown drainage basin outfalls were similar to or better than stormwater-quality conditions observed in the Arrowhead and Meade-Hawthorne drainage basins. Three wetland channels located at the outlet of the Downtown drainage basin were evaluated for their pollutant reduction capability. Mean reductions in TSS and lead concentrations were greater than 40 percent for all three wetland channels. Total nitrogen,

phosphorus, copper, and zinc concentrations also were reduced by at least 20 percent at all three wetlands. Fecal coliform bacteria concentrations typically were reduced by about 21 and 36 percent at the 1st and 2nd Street wetlands, respectively, but the reduction at the 3rd Street wetland channel was nearly zero percent. Total wetland storage volume affected pollutant reductions because TSS, phosphorus, and ammonia reductions were greatest in the wetland with the greatest volume. Chloride concentrations typically increased from inflow to outflow at the 2nd and 3rd Street wetland channels.

Introduction

Storm runoff from urbanized lands is known to harm surface-water resources by increasing stream velocities, destroying natural habitat, and increasing pollutant loads in the receiving waters (for example, U.S. Environmental Protection Agency, 2003; Rasmussen and Schmidt, 2009). This uncontrolled discharge from affected lands can cause physical, biological, and chemical changes in the receiving waters, which impairs designated uses (U.S. Environmental Protection Agency, 2010). As runoff flows over the land or impervious surfaces (paved streets, parking lots, and building rooftops), the runoff accumulates debris, chemicals, sediment, or other pollutants that could adversely affect water quality if the runoff is discharged untreated. 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, actively used for recreation, and a seasonal municipal water supply for the City of Rapid City. The City of Rapid City is mandated by the U.S. Environmental Protection Agency to reduce the quantity of pollutants transported in urban runoff to the maximum extent possible. The associated regulations are described by Phase II of the National Pollutant Discharge Elimination System as applied to municipal separate storm sewer systems in small municipalities (populations of more than 50,000 and a density of at least 1,000 people per square mile). Water produced by municipal separate storm sewer systems must satisfy the water-quality requirements of the Clean Water Act (U.S. Environmental Protection Agency, 2010).

2 Water-Quality Characteristics of Stormwater Runoff in Rapid City, South Dakota, 2008–14

In accordance with the Clean Water Act, the South Dakota Department of Environment and Natural Resources lists beneficial uses of major streams and rivers in the State. Rapid Creek within the city of 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). The satisfaction of these beneficial uses are determined using numeric water-quality criteria, such as total suspended solids (TSS), fecal coliform and *Escherichia coli* (*E. coli*) bacteria, nutrients, and chloride. As of 2014, water quality in Rapid Creek for reaches upstream from Rapid City meets water-quality standards for designated beneficial uses; however, Rapid Creek from Canyon Lake to the Cheyenne River has poor water quality due to excessive fecal coliform and (or) *E. coli* bacteria levels (South Dakota Department of Environment and Natural Resources, 2014). A total maximum daily load (TMDL) for bacteria for the reaches within and downstream from Rapid City was approved by the South Dakota Department of Environment and Natural Resources 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, 2015). Approval of a TMDL for a waterbody commonly is followed by an implementation project with goals to reduce pollution sources within the drainage basin.

Control of sediment generated by construction sites and from urban land use within Rapid City is necessary for Rapid Creek to maintain a water-quality condition that satisfies its beneficial uses. The City of Rapid City encourages use of various best-management practices (BMPs), such as detention ponds, vegetated channels, and disconnected impervious area, for reducing the environmental effects of stormwater pollution. As part of its program, Rapid City has published the “Rapid City Stormwater Quality Manual” (City of Rapid City, 2009) on construction and post-construction control of stormwater discharges through BMPs. Within the “Rapid City Stormwater Quality Manual,” various BMP devices are suggested and described in detail; however, little information exists on field-verified performance measures of these BMPs in Rapid City. Several BMP devices recently (after 2005) have been installed during site developments that include designs targeted at improving water quality. Such devices include extended sand-filter detention basins and constructed wetlands. To characterize the composition of stormwater runoff and to better understand the effects of BMPs on the quality of stormwater runoff, the U.S. Geological Survey (USGS) completed a study in cooperation with the City of Rapid City. The objectives of this study were to characterize the current (2008–14) composition of urban stormwater runoff in selected drainage networks within the City of Rapid City, and evaluate the pollutant reductions of wetland channels implemented as a BMP.

Purpose and Scope

The purpose of this report is to describe the water-quality characteristics of stormwater runoff from three drainage basins within the City of Rapid City during 2008–14 and compare those characteristics to relevant water-quality standards. Stormwater runoff data were collected in three drainage basins within Rapid City: the Arrowhead, Meade-Hawthorne, and Downtown drainage basins. Stormwater runoff was evaluated for concentrations of TSS and bacteria at sites in all three drainage basins, and for concentrations of TSS, chloride, bacteria, nutrients, and metals at sites in the Downtown drainage basin. Datasets from sites in the Downtown drainage basin were used to provide a comparison of inflow and outflow concentrations at stormwater treatment wetlands to assess the pollutant reduction capabilities of this BMP.

Description of the Study Area

Stormwater data were collected in three drainage basins within Rapid City: the Arrowhead (2 monitoring sites), Meade-Hawthorne (1 monitoring site), and Downtown drainage basins (6 monitoring sites; fig. 1, table 1). Rapid City is located on the eastern foothills of the Black Hills, which are susceptible to short-duration, intense, convective thunderstorm events 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. The mean annual flow for water years 1964–2014 for Rapid Creek at Rapid City (USGS streamgage 06414000) is 70.8 cubic feet per second (ft³/s) (U.S. Geological Survey, 2015).

Arrowhead Drainage Basin

The Arrowhead drainage basin (figs. 1–2) is located on the southwestern edge of Rapid City and drains approximately 5.8 square miles (mi²) upon entering Rapid Creek. All drainage area values listed in this report were determined using geographical information system software, unless otherwise noted. The mean percentage of impervious area over the Arrowhead basin is 9.6 percent, as calculated using the National Land Cover Database (Fry and others, 2011). The predominant land use/land cover is agricultural/forest (57 percent) followed by low-density residential (27 percent) and park (6.4 percent) with less than 5 percent of medium-density residential, mobile home residential, public, general commercial, and floodway. The main conveyance channel is roughly 90 percent open vegetated channel, where plants can slow the stormwater runoff and use it by way of evapotranspiration.

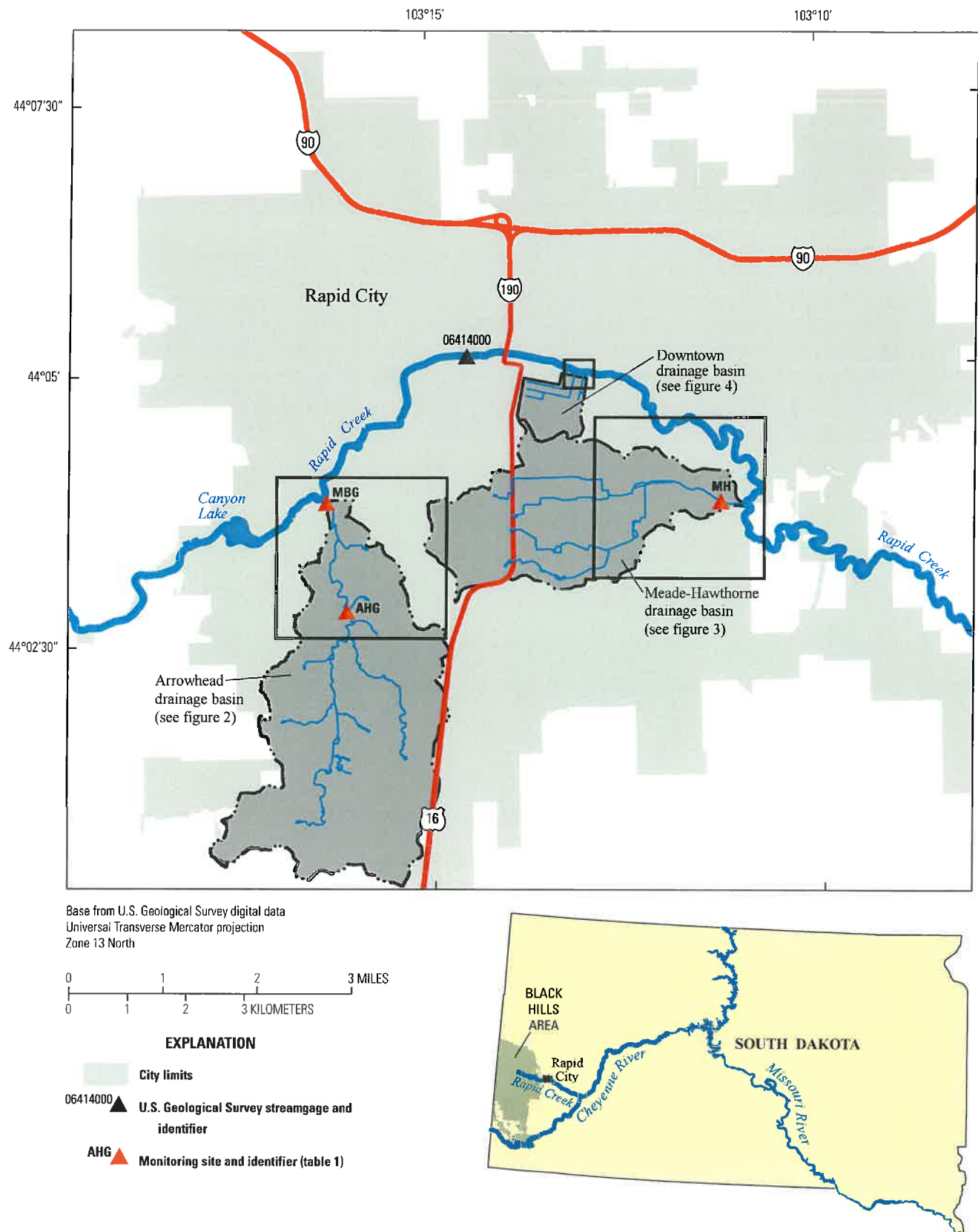


Figure 1. Location of U.S. Geological Survey streamgages, stormwater monitoring sites, and drainage areas, Rapid City, South Dakota.

4 Water-Quality Characteristics of Stormwater Runoff in Rapid City, South Dakota, 2008–14

Two monitoring sites were located within the Arrowhead drainage basin: at Arrowhead Country Club (hereafter referred to as the “AHG site”) and the basin outlet at Meadowbrook Golf Course (hereafter referred to as the “MBG site”; table 1, fig. 2). The AHG site is located downstream from the most developed areas of the Arrowhead drainage basin. The area between the AHG and MBG sites is predominately golf course land, which typically attenuates stormwater flow during runoff events.

Meade-Hawthorne Drainage Basin

The Meade-Hawthorne drainage basin is located in south-central Rapid City and drains approximately 3.3 mi² upon entering Rapid Creek (figs. 1 and 3). The mean percentage of impervious area for the Meade-Hawthorne basin is 38 percent (Fry and others, 2011). The predominant land use/land cover is low-density residential (31 percent) followed by medium-density residential (25 percent), agricultural (15 percent), general commercial (9 percent), park and forest (9 percent), and small portions of neighborhood and office commercial, heavy and light industrial, and public. The conveyance structures in the Meade-Hawthorne drainage basin differ greatly from those in the Arrowhead drainage basin, with roughly 80 percent consisting of concrete channels and culverts, allowing for little to no infiltration. The Meade-Hawthorne monitoring site (hereafter referred to as the “MH site”; table 1) is located at Creek Drive near the basin outlet, about 0.20 mile (mi) upstream from the confluence with Rapid Creek (fig. 3).

Downtown Drainage Basin

The Downtown drainage basin consists of several small drainage networks originating from the highly urbanized areas

of downtown Rapid City (figs. 1 and 4). The areas monitored in this study were the 1st, 2nd, and 3rd Street outfalls and their wetland channel BMPs. Collectively, the three outfalls have a contributing drainage area of about 0.42 mi² (table 2), with land use composed of 56 percent commercial, 16 percent high-density residential, 13 percent medium-density residential, and 15 percent parks or forest. Impervious area accounts for 50 percent of the 1st Street drainage area, 66 percent for the 2nd Street, and 93 percent of the 3rd Street drainage area (Fry and others, 2011). Before construction of the wetland channels in 2011, all stormwater from these basins discharged directly to Rapid Creek. Since construction of the wetland channels, stormwater enters the approximately 300-foot (ft) long by 30-ft wide channels by way of a flow divider structure (fig. 5), which routes flows into the wetland channel by way of an 18-inch diversion culvert (approximate free-flow capacity of 7.4 ft³/s). Larger stormwater flows discharge directly to Rapid Creek with an overflow weir at an elevation higher than the culvert top (fig. 5). Retention time through the wetlands is about 8–10 minutes during the maximum inflow (table 2). At each wetland outflow, a concrete outlet weir maintains a shallow water level (about 1.5-ft deep at weir) and allows for measurement of outflow to Rapid Creek (fig. 6). Monitoring sites were located at the inflow and outflow for each wetland channel. The 2nd Street wetland has substantially less retention volume (76 cubic feet [ft³]) than the other two wetlands (1,100 ft³ for the 1st and 3rd Street wetlands; table 2). Retention volume is defined as water stored below the outlet weir elevation; detention volume is defined as water stored above the outlet weir elevation. During 2013–14, the retention pool for the 1st and 2nd Street wetlands would dry completely in the absence of precipitation events, whereas the 3rd Street wetland maintained a permanent pool fed by a nearly continuous trickle (less than 1 ft³/s) flow from the stormwater outfall through the diversion culvert.

Table 1. List of monitoring sites in the Arrowhead, Meade-Hawthorne, and Downtown drainage basins, Rapid City, South Dakota.

[ID, identifier; USGS, U.S. Geological Survey]

Drainage basin	Short ID	USGS site ID	Site name
Arrowhead	AHG	440247103160400	Arrowhead drainage at Arrowhead Country Club.
	MBG	440349103162000	Arrowhead drainage at Meadowbrook Golf Course.
Meade-Hawthorne	MH	440344103111300	Meade drainage at Creek Drive.
Downtown	1-IN	440457103130000	1st Street outfall wetland inlet at Rapid City, S. Dak.
	1-OUT	440457103125600	1st Street outfall wetland outlet at Rapid City, S. Dak.
	2-IN	440458103130700	2nd Street outfall wetland inlet at Rapid City, S. Dak.
	2-OUT	440457103130200	2nd Street outfall wetland outlet at Rapid City, S. Dak.
	3-IN	440500103131300	3rd Street outfall wetland inlet at Rapid City, S. Dak.
	3-OUT	440458103130800	3rd Street outfall wetland outlet at Rapid City, S. Dak.



Figure 2. Monitoring sites in the Arrowhead drainage basin.

6 Water-Quality Characteristics of Stormwater Runoff in Rapid City, South Dakota, 2008–14



Figure 3. Monitoring site in the Meade-Hawthorne drainage basin.

8 Water-Quality Characteristics of Stormwater Runoff in Rapid City, South Dakota, 2008–14

Table 2. Select design information for three wetland channels located at the 1st, 2nd, and 3rd Street outfalls of the Downtown drainage basin.

[mi², square miles; ft³/s, cubic feet per second; ft³, cubic feet; ft, feet; min, minutes]

Characteristic	Units	1st Street outlet	2nd Street outlet	3rd Street outlet
Drainage area	mi ²	0.12	0.27	0.027
Percent impervious surfaces	percent	50	66	93
Maximum outlet pipe discharge	ft ³ /s	52	348	87
Diversion pipe maximum discharge	ft ³ /s	7.4	7.4	7.4
Detention volume	ft ³	2,800	3,200	3,400
Retention volume	ft ³	1,100	76	1,100
Wetland channel surface area	acres	0.13	0.25	0.18
Wetland channel length	ft	270	360	330
Minimum retention time ¹	min	9	8	10

¹Minimum retention time for maximum diversion culvert discharge of 7.4 ft³/s.

Previous Studies

In the past 35 years, multiple studies have examined the quantity and quality of the runoff from storm events in the Rapid City area. Pirner and Harms (1978) performed a study to determine the potential of urban runoff as a source of pollution in Rapid Creek. The Nationwide Urban Runoff Program chose Rapid City as one of its locations for study during the early 1980s and tested for numerous water-quality constituents (U.S. Environmental Protection Agency, 1983). In a report to the South Dakota Department of Environment and Natural Resources and the City of Rapid City, Kenner and Craft (1997) described a study on different parts of the Rapid Creek drainage to assess the effects on the quality of the overall creek system. Krantz (2002) implemented a 2-year water-quality sampling program on Rapid Creek to investigate potential effects of stormwater runoff on the brown trout population. Results of the study by Krantz (2002) indicated that TSS and turbidity increase in Rapid Creek through the City of Rapid City to levels greater than those that could potentially pose a threat to trout health. Baker (2010) presented an early subset of the water-quality data for the Arrowhead drainage basin. Fisher (2011) evaluated the effectiveness of several BMP structures for the management of stormwater quantity and quality on the Rapid Creek drainage basin. Schiferl (2011) evaluated the potential contribution of bottom sediments as a source of fecal coliform bacteria in stormwater runoff in both the Arrowhead and Meade-Hawthorne drainage basins in Rapid City. Prann (2013) evaluated the effect of impervious surfaces on water quality using calibrated hydrologic models. All of these studies indicate that the TSS and fecal coliform concentrations in the stormwater runoff in the Arrowhead and Meade-Hawthorne drainage basins have the potential to adversely affect the quality of the waters in the Rapid Creek drainage basin.

Methods

The following sections describe the methods used for collection of stage and discharge information, collection and processing of water-quality samples, and development of event-mean concentrations. Datasets collected at the Arrowhead and Meade-Hawthorne monitoring sites differed slightly from those collected at the Downtown monitoring sites. For the Arrowhead sites, five to seven independent storm runoff events were sampled each year during 2008–11 and one storm event was sampled during 2012. For the Meade-Hawthorne sites, five to seven independent storm runoff events were sampled each year during 2010–11 and one storm event was sampled during 2012. Continuous stage and discharge information (15-minute intervals) was collected at the sites in the Arrowhead and Meade-Hawthorne drainage basins, allowing for calculation of event-mean concentrations. Precipitation estimates for each storm event at the Arrowhead sites was obtained from the AHG site (table 1), which was equipped with a tipping-bucket rain gage to measure storm precipitation totals in 0.01-inch increments. Precipitation estimates for the Meade-Hawthorne storm events were obtained from National Weather Service Station 396948 (fig. 3; National Oceanic and Atmospheric Administration, 2015). During 2013–14, water-quality data were collected at the 1st, 2nd, and 3rd Street outfalls of the Downtown drainage basin for approximately six storm runoff events each year. Precipitation totals for the Downtown drainage basin events were all similar (mean event total was 0.27 inches at National Weather Service Station 396948), but are not presented in this report.

Stage, Discharge, and Precipitation Measurements

Equipment used to measure stage at monitoring sites included submerged pressure transducers, stage bubbler systems, and automated sampling devices using methods described in Sauer and Turnipseed, 2010). At the Arrowhead and Meade-Hawthorne sites, automated samplers with a submerged probe flow module were used for water-stage measurement and sample collection (fig. 7). Stage plates were mounted to posts driven into the streambank or concrete wingwalls of flow structures to be used for verification or correction of stage data. A stage-discharge rating curve was developed at each site using a series of open-channel discharge measurements (Turnipseed and Sauer, 2010) during the sampling period that was used to determine discharge during sample collection periods (appendix 1).

At the Downtown drainage basin sites, wetland inflow stage was monitored using a bubbler system. Wetland outflow stage was recorded using a non-vented submersible pressure transducer enclosed in a polyvinyl chloride stilling well corrected with a separate barometric pressure logger located in the gage housing at the inflow site. Continuous stage information (5-minute intervals) was collected at each of the three wetland inflow and outflow sites of the Downtown drainage basin; however, no inflow or outflow discharge information at the Downtown drainage basin is presented in this report. It was determined that all three inflow sites commonly experienced backwater conditions (when the culvert outflow was submerged at the entry to the wetland channels) during runoff events; therefore, accurate discharge information at the wetland inflow sites was not available.

Precipitation data were collected at the AHG site using a tipping bucket to measure precipitation to the nearest 0.1 inch (U.S. Geological Survey, 2010) and data loggers to record the data at 10-minute intervals. Additional precipitation data were obtained from the National Weather Service Station 396948 (National Oceanic and Atmospheric Administration, 2015).

Collection, Processing, and Analysis of Water Samples

At the Arrowhead and Meade-Hawthorne sites, the automated samplers were programmed to collect samples when the stage increases above a certain baseline level, indicating the beginning of a runoff event. Sample intake lines consisted of 3/8-inch diameter Tygon® tubing with a stainless steel strainer connected at the intake point. The strainer was staked to the center of the channel in a downstream orientation about 6 to 12 inches above the stream bottom. Each automated sampler can fill twenty-four 1-liter high-density polyethylene (HDPE) bottles at user-defined intervals. After the bottles were filled by the automated sampler, they were transported to the USGS office laboratory in Rapid City for processing. Raw water from the 1-liter bottles was split into smaller aliquots and

transported to the analyzing laboratory within 24 hours. For most storm events, at least four discrete samples were sent for laboratory analyses, covering all sections of the hydrograph (rising, peak, and falling). For more complicated hydrographs, such as multiple peaks, additional samples were submitted. A similar sampling approach was used at the Downtown drainage basin; however, most storm events were sampled manually by staff collecting grab samples directly into 1-liter HDPE bottles. Grab samples were obtained at wetland inflow sites by immersing the bottles in the center of flow at the upstream end of the diversion culvert (fig. 5). All bottles were rinsed with sample water immediately prior to collection of the sample for analyses. Grab samples at the wetland outflow sites followed a similar procedure, with samples collected on the upstream side of the weir center at a depth of about 6–12 inches from the water surface (fig. 6).

Water-quality constituents analyzed were TSS, chloride, nitrogen species (nitrate plus nitrite, ammonia, organic), phosphorus, *E. coli*, fecal coliform bacteria, cadmium, copper, lead, and zinc (table 3). These water-quality constituents were selected based on three factors: (1) the presence of a water-quality standard for the receiving waterbody (Rapid Creek); (2) whether or not the constituent was listed in table 2.1 of the “Rapid City Stormwater Quality Manual” (City of Rapid City, 2009), which presents literature-based removal efficiencies of selected pollutants for various BMPs; or (3) if the constituent was a pollutant that has been identified as frequently occurring in large concentrations by previous urban runoff literature (such as U.S. Environmental Protection Agency, 1983; Lopes and others, 1994). All water-quality constituents listed in table 3 were unfiltered analyses, with the exceptions of ammonia and nitrate plus nitrite.

Samples of TSS, chloride, and bacteria were analyzed at Energy Laboratories (Rapid City, S.Dak.). The TSS concentration was measured by taking a known volume of sample and passing it through a glass fiber filter disc and then drying the sample. The residue from the filter was weighed, which determined the concentration in mass per volume given in milligrams per liter (American Public Health Association, 2015). Chloride was measured using ion chromatography according to U.S. Environmental Protection Agency method 300.0 (Pfaff, 1993). Fecal coliform bacteria were analyzed by use of the m-FC agar medium membrane filtration method (section 9222D in American Public Health Association, 2015), quantified in colony forming units per 100 milliliters (cfu/100 mL). *E. coli* was determined by use of the enzyme substrate test (American Public Health Association, 2015), which uses a special medium that reacts to the *E. coli* and changes color, and concentration is given in most probable number per 100 milliliters (mpn/100 mL). Colony forming units and most probable number units have been used interchangeably (Wisconsin Department of Natural Resources, 2009) but are determined using different methods. Samples were analyzed for selected nutrients (nitrate, nitrite, ammonia, and orthophosphate) and metals (cadmium, copper, lead, and zinc) at the USGS National Water-Quality Laboratory (Lakewood,

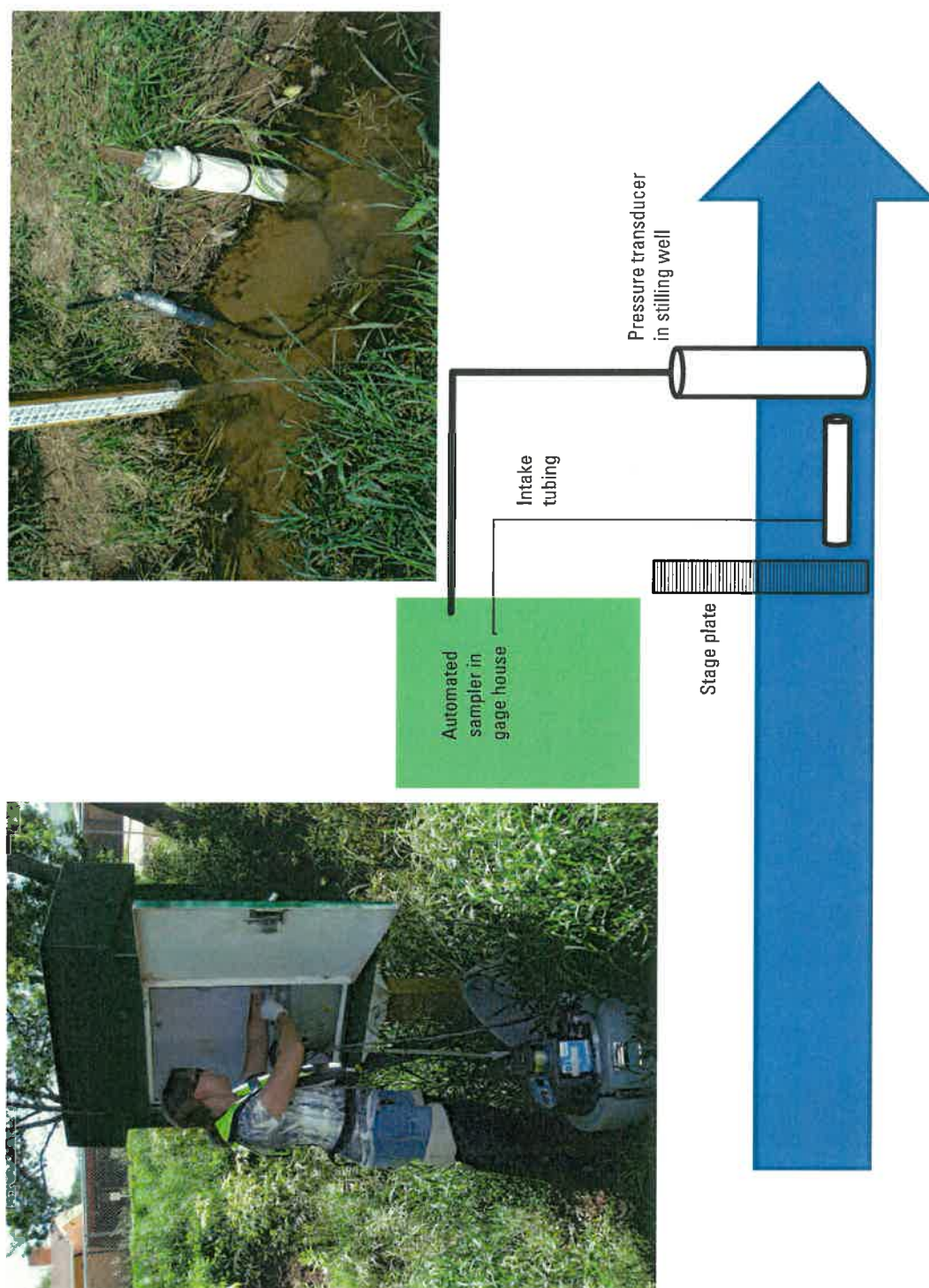


Figure 7. Automated sampler at Arrowhead and Meade-Hawthorne drainage basin monitoring sites.

Table 3. Water-quality constituents measured in stormwater samples, and relevant standards or limits for Rapid Creek at Rapid City, South Dakota.

[USGS, U.S. Geological Survey; AH, Arrowhead; MH, Meade-Hawthorne; --, not measured or available; X, measured; $\mu\text{S}/\text{cm}$ at 25 °C, microsiemens per centimeter at 25 degrees Celsius; mg/L , milligrams per liter; mg/L as N, milligrams per liter as nitrogen; $\text{mpn}/100$ mL; most probable number per 100 milliliters; $\text{cfu}/100$ mL, colony forming units per 100 milliliters; $\mu\text{g}/\text{L}$, micrograms per liter]

Constituent	USGS parameter code	Units	AH and MH drainage basins (2008–12)	Downtown drainage basin (2013–14)	Standard or limit ¹	Reference
pH	00400	standard units	--	X	6.5–9.0	(²)
Specific conductance	00095	$\mu\text{S}/\text{cm}$ at 25 °C	--	X	--	--
Total suspended solids	00530	mg/L	X	X	30 / 53	(²)
Chloride	99220	mg/L	--	X	100 / 175	(²)
Ammonia plus organic nitrogen	00625	mg/L as N	--	X	--	--
Ammonia	00608	mg/L as N	--	X	2.8 / 6.8	(²)
Nitrate plus nitrite	00631	mg/L as N	--	X	-- / 10	(²)
Organic nitrogen	00605	mg/L as N	--	X	--	--
Phosphorus	00665	mg/L	--	X	--	--
Total nitrogen ³	00600	mg/L as N	--	X	--	--
<i>Escherichia coli</i>	31689	$\text{mpn}/100$ mL	X	--	126 / 235	(²)
Fecal coliform bacteria	61215	$\text{cfu}/100$ mL	X	X	200 / 400	(²)
Cadmium	01027	$\mu\text{g}/\text{L}$	--	X	-- / 5	(⁴)
Copper	01042	$\mu\text{g}/\text{L}$	--	X	-- / 1,000	(⁴)
Lead	01051	$\mu\text{g}/\text{L}$	--	X	-- / 15	(⁴)
Zinc	01092	$\mu\text{g}/\text{L}$	--	X	-- / 5,000	(⁴)

¹First value is the 30-day mean concentration / second value is the daily maximum concentration; pH values represent a range of acceptable values.

²Beneficial-use criteria from South Dakota Department of Environment and Natural Resources (2014).

³Total nitrogen is calculated as sum of ammonia plus organic nitrogen and nitrate plus nitrite.

⁴Drinking water standard from U.S. Environmental Protection Agency (2014).

Colorado) using standard methods (Fishman, 1993; Hoffman and others, 1996). Field measurements for pH and specific conductance were analyzed by USGS staff at the Rapid City office laboratory, using aliquots of raw water collected in the same bottles used for other constituent analyses (U.S. Geological Survey, variously dated).

Event-Mean Concentrations

Event-mean concentrations (EMCs) were calculated where discharge and water-quality data were sufficient to represent a storm hydrograph (typically defined as having at least three samples—one from the rising limb, one near the peak, and one during the falling limb). The EMCs were calculated only for sites in the Arrowhead and Meade-Hawthorne drainage basins. The EMC is a flow-weighted concentration, calculated as the pollutant load (in mass units) divided by the

total flow volume (U.S. Environmental Protection Agency, 1983) as shown in equation 1:

$$EMC = \sum VC / \sum V = \sum [(Q_i + Q_{i-1})/2](t_i - t_{i-1})[(C_i + C_{i-1})/2] / \sum [(Q_i + Q_{i-1})/2](t_i - t_{i-1}) \quad (1)$$

where

- V is the flow volume, in cubic feet;
- C_i is the pollutant (for example, TSS) concentration, in milligrams per liter, at time t_i , in seconds; and
- Q_i is the flow, in cubic feet per second, at time t_i , in seconds.

Estimates of EMC can be converted to event load (in milligrams) or basin yield (load divided by drainage area, in milligrams per square mile).

Quality Assurance and Quality Control

A quality-assurance/quality-control approach was used to identify possible cases of random or systemic errors in the field sampling, shipping, and laboratory analyses. Quality-assurance measures include using standard procedures for discharge measurement and water-quality sample collection according to the USGS National Field Manual (U.S. Geological Survey, variously dated). Water-level readings were inspected during each field visit for agreement between staff gages and data stored on monitoring equipment. Tubing and bottles used in automated sampling equipment were routinely cleaned as described in the USGS National Field Manual (U.S. Geological Survey, variously dated) or replaced following sampling events. For water-quality samples, field-equipment blank and sequential replicate samples were used to determine the potential for sample contamination.

Field-equipment blank samples were collected at sites by passing analyte-free water through the collection and processing equipment used for the environmental samples and by using procedures identical to those used to collect and process the environmental samples. Constituent concentrations less than the minimum reporting level (MRL) in field-equipment blank samples indicate that the overall process of sample collection, processing, and laboratory analysis was free of substantial contamination. The MRL is the lowest measured concentration of a constituent that may be reliably reported from the use of a given analytical method (Timme, 1995). Sporadic, infrequent detections at concentrations near the MRL probably represent contamination from sample collection, processing, or shipping that is not likely to cause bias in the study results. Consistent detections in the field-equipment blank samples at concentrations within the range of concentrations in the environmental samples indicate that environmental concentrations need to be qualified or omitted from study results. Field-equipment blank samples were collected with 11 samples for analyses of fecal coliform bacteria, 8 samples for analyses of TSS, and 7 samples for analyses nutrients and metals. Fecal coliform was detected in 1 of 11 blank samples at a concentration of 200 cfu/100 mL; all TSS concentrations in blank samples were less than the MRL. Ammonia was detected at small concentrations (less than $[<] 0.021$ milligrams per liter [mg/L]) in 3 of 7 blank samples, nitrate plus nitrite was detected in 1 of 7 blank samples at a concentration of 0.212 mg/L, and copper was detected in 1 of 7 blank samples at a concentration of 3.5 micrograms per liter ($\mu\text{g/L}$). These detections were characterized as infrequent, and concentrations were near the MRLs; no further action for censoring of the environmental concentration data was taken.

Precision of analytical results for field replicate 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. Eight field replicate samples were analyzed for fecal coliform bacteria, six replicate samples were analyzed for TSS, four replicate samples were analyzed for *E. coli*, and one replicate sample was analyzed for chloride, nutrients, and metals. Relative percent difference was calculated as the difference in concentration divided by mean concentration multiplied by 100 for the environmental/replicate pair. The median relative percent differences for all environmental/replicate pairs for both fecal coliform and *E. coli* bacteria were about 30 percent, indicating fairly large variability with field and laboratory processes. The median relative percent difference for TSS was 7 percent. The relative percent differences for the environmental/replicate pair for chloride, nutrients, and metals were all less than 5 percent, indicating satisfactory data quality control on these constituents.

Water-Quality Characteristics of Stormwater

Complete water-quality results and associated discharge estimates (where available) are presented in appendix 1. The EMCs and statistical summaries are presented for the Arrowhead and Meade-Hawthorne drainage basins in the following sections to provide a characterization of the stormwater quality transported from these basins. Statistical summaries of concentration data for the 1st, 2nd, and 3rd Street outfall wetlands in the Downtown drainage basin are presented to provide a comparison to Arrowhead and Meade-Hawthorne conditions. In addition, a summary of concentration reductions between inflow and outflow monitoring sites at the wetlands are presented to describe constituent removal (or addition) relevant to this type of BMP. The EMCs from the Downtown drainage basin are not presented because accurate discharge estimates were not obtained from the outfalls (inflow to the wetlands was affected by variable backwater conditions).

Arrowhead and Meade-Hawthorne Drainage Basins

At the three monitoring sites in the Arrowhead and Meade-Hawthorne drainage basins, a total of 357 water-quality samples were collected during 2008–12. At the AHG site, 190 samples were collected during 20 different storm events, 76 samples were collected at the MBG site during 9 different storm events, and 91 samples were collected at the MH site during 12 different storm events. Water-quality results for TSS, fecal coliform bacteria, and *E. coli* indicate substantial sediment and bacteria transport from these basins (table 4). All EMCs exceeded the TSS and bacteria beneficial-use criteria for Rapid Creek (table 3), typically by 1–2 orders of magnitude.

Table 4. Event-mean concentrations of total suspended solids, fecal coliform bacteria, and *Escherichia coli* for the Arrowhead and Meade-Hawthorne drainage basins, 2008–12.

[TSS, total suspended solids; mg/L, milligrams per liter; cfu/100 mL, colony forming units per 100 milliliters; mpn/100 mL, most probable number per 100 milliliters, --, not available]

Date	Short identifier (table 1)	Event precipitation (inches) ¹	TSS (mg/L)	Fecal coliform bacteria (cfu/100 mL)	<i>Escherichia coli</i> (mpn/100 mL)
07/23/2008	AHG	0.86	1,600	(²)	--
10/05/2008	AHG	0.07	74	(²)	--
04/16/2009	AHG	0.34	160	(²)	--
05/07/2009	AHG	0.13	260	1,000	--
06/05/2009	AHG	0.15	320	1,800	--
06/09/2009	AHG	0.15	140	6,100	--
06/18/2009	AHG	0.27	1,900	10,000	--
06/26/2009	AHG	0.54	1,200	37,000	--
07/13/2009	AHG	0.43	200	11,000	--
05/10/2010	AHG	2.33	120	1,100	540
06/22/2010	AHG	0.44	150	47,000	30,000
07/12/2010	AHG	0.28	84	2,200	3,200
07/19/2010	AHG	0.84	270	34,000	18,000
08/03/2010	AHG	1.39	950	21,000	9,900
07/25/2011	AHG	0.42	280	300,000	53,000
07/27/2011	AHG	0.80	1,200	23,000	31,000
08/07/2011	AHG	0.83	610	12,000	8,400
09/01/2011	AHG	0.27	170	26,000	14,000
10/06/2011	AHG	0.30	110	59,000	37,000
05/19/2012	AHG	0.43	220	2,900	--
06/26/2009	MBG	0.54	600	28,000	--
07/13/2009	MBG	0.43	260	150,000	--
08/04/2009	MBG	0.40	160	40,000	7,500
05/10/2010	MBG	2.33	200	1,800	430
08/03/2010	MBG	1.39	840	50,000	12,000
09/09/2010	MBG	0.79	130	8,000	690
07/27/2011	MBG	0.80	600	17,000	23,000
08/07/2011	MBG	0.83	140	8,700	6,900
05/19/2012	MBG	0.43	32	1,000	--
06/10/2010	MH	0.09	130	37,000	21,000
06/22/2010	MH	0.33	880	86,000	26,000
07/11/2010	MH	0.25	76	27,000	20,000
07/19/2010	MH	0.58	1,500	39,000	22,000
08/03/2010	MH	1.04	1,100	49,000	22,000
09/09/2010	MH	0.71	1,400	40,000	22,000
06/09/2011	MH	0.56	320	12,000	14,000
07/01/2011	MH	0.32	410	29,000	21,000
07/25/2011	MH	0.17	300	27,000	21,000
09/01/2011	MH	0.29	700	31,000	21,000
10/06/2011	MH	0.48	490	24,000	28,000
05/19/2012	MH	0.60	540	3,500	--

¹For AHG and MBG sites, precipitation is from AHG site. For MH site, precipitation is from National Weather Service station 396948.

²Bacteria dilutions at laboratory were too low to provide quantitative concentrations.

Comparing concentrations between the Arrowhead and Meade-Hawthorne drainage basins, median EMCs for TSS were more than two times greater at the Meade-Hawthorne outlet at site MH (520 mg/L) than the Arrowhead outlet at site MBG (200 mg/L; table 5 and fig. 8). Median EMCs for fecal coliform bacteria also were greater at site MH (30,000 cfu/100 mL) than at site MBG (17,000 cfu/100 mL). Median EMCs for *E. coli* were about three times greater at site MH (21,000 mpn/100 mL) than at site MBG (7,200 mpn/100 mL). The EMCs for fecal coliform bacteria and *E. coli* were far less variable in the Meade-Hawthorne drainage basin (site MH) compared to the Arrowhead drainage basin (sites AHG and MBG), as shown by the smaller inter-quartile ranges (boxes) in figure 8. The bacteria EMC data are not normally distributed (Kolmogorov-Smirnov test, significance level less than 0.05; Haan, 1977); thus, the median statistic represents a better measure of central tendency than does the mean value. The greater EMCs for TSS and bacteria in the Meade-Hawthorne drainage basin may be explained by differences in land use and conveyance channels. The Meade-Hawthorne drainage basin is much more urbanized than the Arrowhead drainage basin (38 and 9.6 percent impervious, respectively). The presence of more vegetated channels in the Arrowhead drainage basin (in contrast to the concrete structures predominantly found in the Meade-Hawthorne drainage basin) allows for passive treatment of stormwater.

Comparing the two sites within the Arrowhead drainage basin, median EMCs for TSS were similar between the AHG and MBG sites (240 and 200 mg/L, respectively; table 5). The median EMCs for fecal coliform bacteria were lower at the upstream AHG site than at the downstream MBG site (12,000 and 17,000 cfu/100 mL, respectively); however, median EMCs for *E. coli* were much lower at site MBG (7,200 mpn/100 mL) than at site AHG (16,000 mpn/100 mL). The drainage area immediately upstream from the AHG site is predominantly low- to medium-density residential land use that contributes stormwater runoff from impervious surfaces. The intervening drainage area between the AHG and MBG sites contains about 25 percent low- to medium-density residential land use. Although the predominant park and forest land use in this reach helps attenuate the stormwater flows, no instream BMPs have been designed to reduce pollutant concentrations, as evidenced by the similarity between EMC distributions for TSS and fecal coliform bacteria at the two sites.

To gain a better understanding of the co-occurrence of stormwater pollutants, correlations between monitored pollutant concentrations were examined. Several other case studies have documented the relation of sediment (turbidity) concentration to bacterial density in perennial streams (Lawrence, 2012; Rasmussen and Ziegler, 2003). In these studies, turbidity values were shown to be a statistically significant predictor of bacteria concentrations. For considerations involving stormwater BMPs, it is often assumed that reductions in sediment also will result in reductions of bacteria and other pollutants. At the Arrowhead and Meade-Hawthorne sites, the relation between TSS and fecal coliform bacteria

concentrations generally was poor (fig. 9A), as indicated by the low coefficients of determination (R^2) for the multivariate regression models (Helsel and Hirsch, 2002) that ranged from 0.047 for site MH to 0.42 for site MBG. The strength of correlation increases as R^2 approaches a value of 1. The TSS concentration would be a poor surrogate for bacteria concentration based on the data collected at these sites. These data indicate that control or treatment of sediment in stormwater may not result in a corresponding reduction of bacteria. The relation between *E. coli* and fecal coliform bacteria indicated a much stronger correlation (R^2 values ranging from 0.45 to 0.87, fig. 9B), indicating that a monitoring program for either bacteria type could help characterize bacteriological loads of the other type of bacteria. The amount of precipitation during each storm event does not seem to be an important factor for the TSS EMCs (R^2 values ranging from 0.021 to 0.42, fig. 9C), indicating that a variety of rainfall-event volumes (storm totals) were capable of delivering large storm-event TSS concentrations.

Downtown Drainage Basin

Water-quality information for the 118 samples collected from the Downtown drainage basin is presented in appendix 1, and statistical summaries are presented in table 6 and figure 10. The number of samples collected at each site varied from 8 to 29. More samples were collected from wetland inflow sites than wetland outflow sites. During some events, personnel or equipment limitations did not allow for all sites to be sampled, and priority was placed on the inflow locations to more accurately characterize the water quality originating from the Downtown drainage basin.

A comparison of concentration data in samples collected from sites in the Downtown drainage basin to relevant standards indicated that stormwater from the Downtown drainage basin exceeded criteria for fecal coliform bacteria and TSS, but concentrations generally were below standards for nutrients and metals. Median concentrations of fecal coliform bacteria at all wetland inflows and outflows (table 6) were an order of magnitude greater than the daily maximum beneficial-use criterion for Rapid Creek (400 cfu/100 mL; table 3). Median TSS concentrations were greater than the daily maximum beneficial-use criterion (53 mg/L) at the wetland inflow sites, but median concentrations were greatly reduced at the outflow sites. The median TSS concentrations at the 1st, 2nd, and 3rd Street wetland outflow sites were 180, 83, and 44 mg/L, respectively, with the latter value less than the daily maximum beneficial-use criterion (tables 3 and 6). Chloride concentrations typically were greater at wetland outflow sites than inflow sites, but median concentrations were all below the daily maximum beneficial-use criteria of 175 mg/L. Ammonia and nitrate plus nitrite concentrations were all about an order of magnitude below relevant standards. Compared to drinking-water standards (table 3; U.S. Environmental Protection Agency, 2014), most metal concentrations were well below

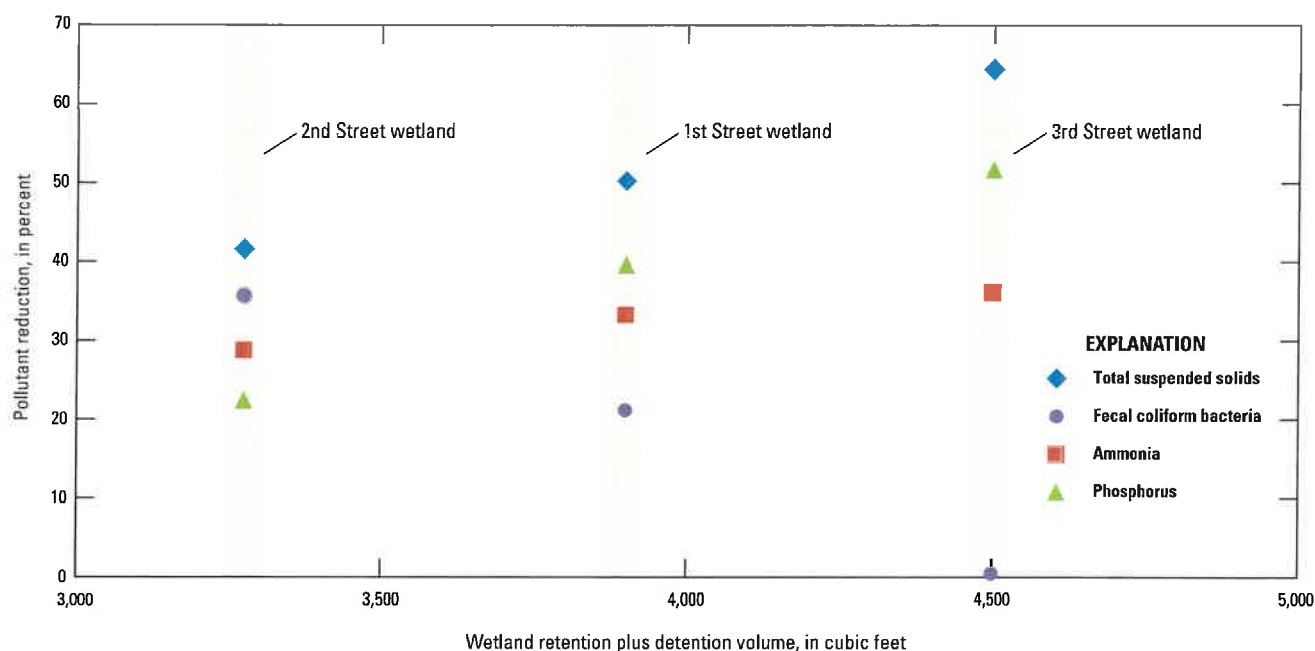


Figure 12. Relation between wetland total volume and pollutant reductions for total suspended solids, ammonia, phosphorus, and fecal coliform bacteria for the wetland channels in the Downtown drainage basin, 2013–14.

Summary

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, actively used for recreation, and a seasonal municipal water supply for the City of Rapid City. Control of sediment generated by construction sites and from urban land use within Rapid City is necessary for Rapid Creek to maintain a water-quality condition that satisfies its beneficial uses. To characterize the composition of stormwater runoff and to better understand the effects of best-management practices on the quality of stormwater runoff, the U.S. Geological Survey (USGS) completed a study in cooperation with the City of Rapid City. The objectives of this study were to characterize the current (2008–14) composition of urban stormwater runoff in selected drainage networks within the City of Rapid City, and evaluate the pollutant reductions of wetland channels implemented as a best-management practice.

Stormwater data were collected in three drainage basins within Rapid City: the Arrowhead, Meade-Hawthorne, and Downtown drainage basins. Land-use characteristics differ among the three basins. The mean percentage of impervious area for the Meade-Hawthorne drainage basin is 38 percent, compared to 9.6 percent in the Arrowhead drainage basin. The predominantly open vegetated channels in the Arrowhead drainage basin contrast to the concrete channels and conduits in the Meade-Hawthorne drainage basin. The Downtown

drainage basin consists of several small drainage networks originating from the highly urbanized areas of downtown Rapid City, with impervious areas greater than 90 percent. The areas monitored in the Downtown drainage basin as part of this study include the 1st, 2nd, and 3rd Street outfalls and their wetland channel best-management practices. Water-quality concentration information includes total suspended solids (TSS) and bacteria concentrations at the Arrowhead and Meade-Hawthorne drainage basins, and in addition, chloride, nutrients, and metals at the Downtown drainage basin.

At the two monitoring sites in the Arrowhead drainage basin (an upstream site and a downstream site at the basin outlet into Rapid Creek) and the one monitoring site in the Meade-Hawthorne drainage basin (at the basin outlet to Rapid Creek), a total of 357 water-quality samples were collected during 2008–12 and analyzed for TSS, fecal coliform, and *Escherichia coli*. All event-mean concentrations (EMCs) exceeded the TSS and bacteria beneficial-use criteria for Rapid Creek, typically by 1–2 orders of magnitude. Comparing TSS concentrations between the Arrowhead and Meade-Hawthorne drainage basins, median EMCs were more than two times greater at the Meade-Hawthorne outlet (520 milligrams per liter) than at the Arrowhead outlet (200 milligrams per liter). Median EMCs for fecal coliform bacteria also were greater at the Meade-Hawthorne outlet (30,000 colony forming units per 100 milliliters) than at the Arrowhead outlet (17,000 colony forming units per 100 milliliters). Median EMCs for TSS were similar between the upstream and downstream sites in the

Arrowhead drainage basin because no instream BMPs have been designed to reduce pollutant concentrations between these sites. At the Arrowhead and Meade-Hawthorne sites, the correlation of EMCs for TSS and bacteria was poor.

During 2013–14, 118 water-quality samples were collected at the 1st, 2nd, and 3rd Street outfalls of the Downtown drainage basin from six sites. A comparison of concentrations in stormwater runoff samples to relevant standards indicated that stormwater runoff from the Downtown drainage basin exceeded criteria for fecal coliform bacteria and TSS, but concentrations generally were below standards for nutrients and metals. Stormwater quality conditions from the Downtown drainage basin outfalls were similar to or better than those observed in the Arrowhead and Meade-Hawthorne drainage basins. Three wetland channels located at the outlet of the Downtown drainage basin were evaluated for their pollutant reduction capability. Certain water-quality constituents were uniformly reduced between the wetland inflow and outflow during most events, whereas other constituents were unchanged or even increased in concentration from inflow to outflow. The constituents associated with suspended sediments showed the most efficacy for removal in the wetland channels. Mean reductions in TSS and lead concentrations were greater than 40 percent for all three wetland channels. Total nitrogen, phosphorus, copper, and zinc concentrations also were reduced by at least 20 percent at all three wetlands. Fecal coliform bacteria concentrations typically were reduced by about 21 and 36 percent at the 1st and 2nd Street wetlands, respectively, but indicated a mean of zero percent reduction at the 3rd Street wetland channel. Total storage volume (retention plus detention) affects pollutant reductions because TSS, phosphorus, and ammonia reductions were greatest in the wetland with the greatest volume. Chloride concentrations typically increased from inflow to outflow at the 2nd and 3rd Street wetland channels.

References Cited

- American Public Health Association, 2015, Standard methods for the examination of water and wastewater (online edition): Washington, D.C., American Public Health Association, American Water Works Association, and Water Environment Federation, accessed March 18, 2015, at <http://www.standardmethods.org/store/>.
- Baker, K.K., 2010, Monitoring stormwater quality in the Arrowhead drainage basin, Rapid City, South Dakota, 2008–2009: Rapid City, South Dakota School of Mines and Technology M.S. Thesis, 109 p.
- City of Rapid City, 2009, City of Rapid City stormwater quality manual: accessed May 1, 2013, at <http://www.rcgov.org/Public-Works/stormwater-homepage.html>.
- Driscoll, D.G., Bunkers, M.J., Carter, J.M., Stamm, J.F., and Williamson, J.E., 2010, Thunderstorms and flooding of August 17, 2007, with a context provided by a history of other large storm and flood events in the Black Hills area of South Dakota: U.S. Geological Survey Scientific Investigations Report 2010–5187, 139 p. [Also available at <http://pubs.usgs.gov/sir/2010/5187/>.]
- Fisher, E., 2011, Monitoring and performance of best management practices for stormwater runoff in Rapid City, SD: Rapid City, South Dakota School of Mines and Technology M.S. Thesis, 52 p.
- Fishman, M.J., ed., 1993, Methods of analysis by the U.S. Geological Survey National Water Quality Laboratory—Determination of inorganic and organic constituents in water and fluvial sediments: U.S. Geological Survey Open-File Report 93–125, 217 p.
- Fry, J., Xian, G., Jin, S., Dewitz, J., Homer, C., Yang, L., Barnes, C., Herold, N., and Wickham, J., 2011, Completion of the 2006 national land cover database for the conterminous United States: Photogrammetric Engineering and Remote Sensing, v. 77, no. 8, p. 858–864.
- Haan, C.T., 1977, Statistical methods in hydrology: Ames, Iowa, Iowa State University Press, p. 176–178.
- Helsel, D.R. and Hirsch, R.M., 2002, Statistical methods in water resources: U.S. Geological Survey Techniques of Water-Resources Investigations, book 4, chapter A3, 522 p.
- Hoffman, G.L., Fishman, M.J., and Garbarino, J.R., 1996, Methods of analysis by the U.S. Geological Survey National Water Quality Laboratory—In-bottle acid digestion of whole-water samples: U.S. Geological Survey Open-File Report 96–225, 28 p.
- Kenner, S., and Craft, L., 1997, Prioritization of storm water impact on water quality for development of a best management practice demonstration project: Rapid City, South Dakota, School of Mines and Technology, 171 p.
- Krantz, E.L., 2002, Urban runoff water-quality impacts to brown trout (*Salmo trutta*) in Rapid Creek, Rapid City, South Dakota: Rapid City, South Dakota School of Mines and Technology M.S. Thesis, 115 p.
- Lawrence, S.J., 2012, *Escherichia coli* bacteria density in relation to turbidity, streamflow characteristics, and season in the Chattahoochee River near Atlanta, Georgia, October 2000 through September 2008—Description, statistical analysis, and predictive modeling: U.S. Geological Survey Scientific Investigations Report 2012–5037, 81 p. [Also available at <http://pubs.usgs.gov/sir/2012/5037/>.]

LID

Low Impact
Development
a design manual
for urban areas

UACDC

Low Impact Development: a design manual for urban areas



How to Use This Manual

Environmental planning typically enjoys success in natural settings, but the real challenge for developing sustainable cities is ensuring ecosystem integrity within urban contexts. Naturally-determined ecosystems have been irrevocably altered by human activity. Indeed, the greatest ongoing problem in planning involves designing within human-dominated ecosystems. After all, 80% of the US population now lives in urban areas. *Low Impact Development: A Design Manual for Urban Areas* introduces general audiences to designing landscapes for urban stormwater runoff – a primary source of watershed pollution. This manual can be reviewed episodically, much like a lifestyle publication, or read in its entirety for a comprehensive understanding. The goal is to motivate awareness and implementation of LID in a wide cross-section of stakeholders, from property owners to municipal governments that regulate infrastructure development. Though not exhaustive in its coverage of LID techniques (i.e., you will not be able to engineer a LID project from this manual), this manual does provide a holistic framework in which a novice homeowner and an experienced developer can each find an equally transformative role to enact.



If you live in the blue, this manual is for you!



FAY JONES SCHOOL OF ARCHITECTURE
UNIVERSITY OF ARKANSAS PRESS
A COLLABORATION
FAYETTEVILLE 2010



©2010 UACDC, Fayetteville, Arkansas <http://uacdc.uark.edu>

optimal level of service
detention/filtration/infiltration

location in LID network
downstream of flow control facilities,
upstream of catchment components,
overflow basins, or outlets

scale
small watershed runoff area, like low
density projects or small impervious
surfaces

management regime
semiannual inspection for erosion, and
removal of sediment and debris

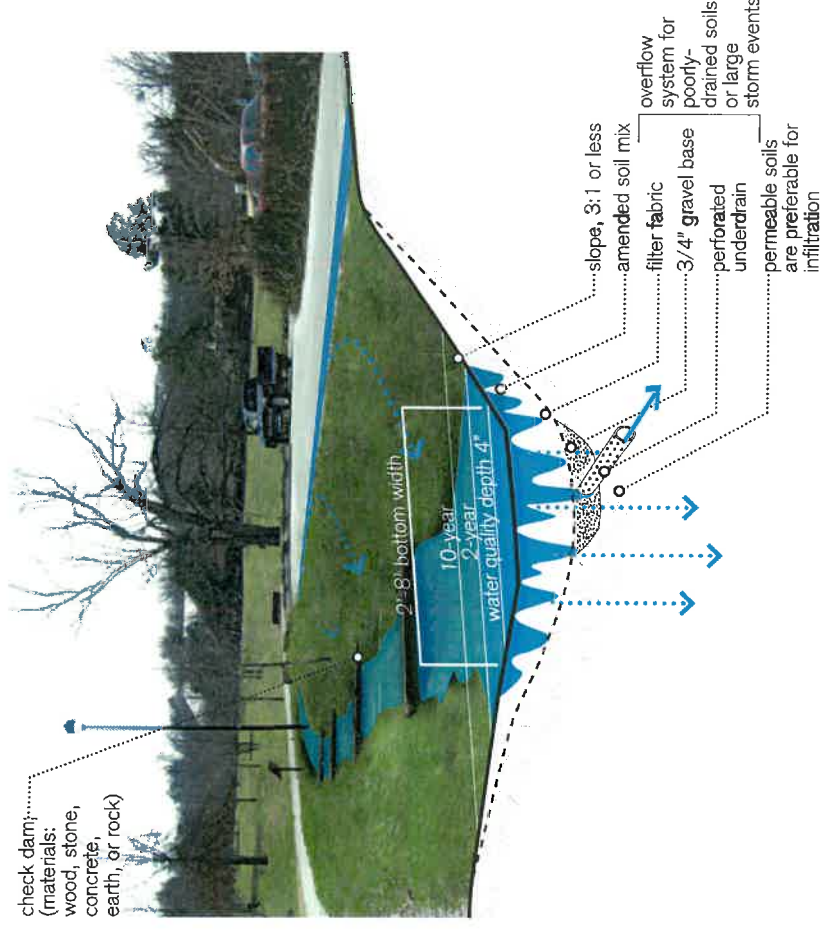


Dry Swale

A dry swale, or grassed swale, is an open grassed conveyance channel that filters, attenuates, and detains stormwater runoff as it moves downstream.

In place of hard-engineered concrete channels, dry swales offer services beyond peak flow reduction that include runoff detention and sedimentation. Dry swales, when combined with check dams and underdrains, detain stormwater and increase infiltration. Often located in drainage easements, they are a cost effective way to convey water between buildings, land uses, and along roadsides. Water quality is optimized when the channel profile is two to eight foot maximum in bottom width, holding a four inch water volume depth. During the establishment newly seeded banks should be stabilized with erosion control devices.

Dry swales can improve site aesthetics and provide wildlife habitat, depending on the type of grasses planted. Periodic inspections of dry swales are needed in order to manage grass growth, and remove large debris and/or trash. Annual inspections should assess the slope of the dry swale, as well as the infiltration rate.



References:
Low Impact Development Design Strategies—An Integrated Design Approach
Low Impact Development Manual for Michigan
United States Department of Housing and Urban Development
Stormwater Management Handbook
Minnesota Urban Small Sites BMP Manual



A Design Guide for Implementers and Reviewers

Low Impact Development Manual for Michigan



BMP Fact Sheet

Vegetated Swale

A vegetated swale (or bioswale) is a shallow stormwater channel that is densely planted with a variety of grasses, shrubs, and/or trees designed to slow, filter, and infiltrate stormwater runoff. Check dams can be used to improve performance and maximize infiltration, especially in steeper areas.



Vegetated swale at the Pokagon Edawat Housing Development in Dowagiac, MI.
Source: Pokagon Band of Potawatomi Indians

Applications		Stormwater Quantity Functions	
Residential	Yes	Volume	Low/Med
Commercial	Yes	Groundwater Recharge	Low/Med
Ultra Urban	Limited	Peak Rate	Low/Med
Industrial	Yes	Stormwater Quality Functions	
Retrofit	Limited	TSS	Med/High
Highway/Road	Yes	TP	Low/High
Recreational	Yes	TN	Medium
		Temperature	Medium

Additional Considerations	
Cost	Low/Med
Maintenance	Low/Med
Winter Performance	Medium

Variations

- Vegetated swale with infiltration trench
- Linear wetland swale
- Grass swale

Key Design Features

- Handles the 10-year storm event with some freeboard
- Two-year storm flows do not cause erosion
- Maximum size is five acres
- Bottom width of two to eight feet
- Side slopes from 3:1 (H:V) to 5:1
- Longitudinal slope from one to six percent
- Check dams can provide additional storage and infiltration.

Site Factors

- Water table to bedrock depth – two-foot minimum.*
- Soils – A, B preferred; C & D may require an underdrain (see infiltration BMP)
- Slope –one to six percent. (< one percent can be used w/ infiltration)
- Potential hotspots – No
- Maximum drainage area – five acres

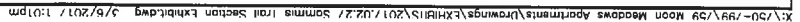
Benefits

- Can replace curb and gutter for site drainage and provide significant cost savings
- Water quality
- Peak and volume control with infiltration

Limitations

- Limited application in areas where space is a concern
- Unless designed for infiltration, there is limited peak and volume control

* four feet recommended, if possible.



**PRELIMINARY
FOR REVIEW ONLY**

CIVIL ENGINEERING | LAND PLANNING | CONSTRUCTION ADMINISTRATION
www.ktmdesignsolutions.com