

# Locating Point and Non-point Sources of *Escherichia coli* in the Mechumps Creek Watershed, Hanover County, Virginia



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## Executive Summary

The project-based curriculum of Randolph-Macon College's Environmental Studies Program enabled a partnership with the Virginia Department of Environmental Quality (VADEQ) designed to locate sources of fecal coliform bacteria (using the indicator species *Escherichia coli* or *E. coli*) in the College's local watershed. In 1998 and 2002, the VADEQ listed 5.69 stream miles along Mechumps Creek, Hanover County, Virginia as impaired because of violations of fecal coliform bacteria (VADEQ 2004). This current project involved repeated water quality sampling once a month for 10 months at 12 sample sites within the watershed. In addition to fecal coliform, other water quality parameters such as pH and conductivity were measured.

Water quality samples obtained during variable weather conditions revealed that:

1. *E. coli* violations corresponded with stormflows and higher streamflows produced by rainfall and snowmelt. Violations of the water quality standard occurred primarily at high discharges.
2. Water quality samples obtained during higher flows during the late winter months (January and February) do not exceed the standard without rain or snow. Thus, high streamflows maintained primarily by baseflow during late winter-early spring recharge periods do not appear to be a mechanism for *E. coli* delivery to the stream without rain or snowmelt.
3. Violations occurred rarely during low flow and when no rainfall occurred.

The locations of *E. coli* violations do not correspond with those found by the VADEQ in previous efforts. In particular, an unknown source in the Town of Ashland contributes *E. coli* to the main stem of Mechumps Creek near its headwaters. In addition, an unknown source located in an agricultural area adjacent to an unnamed tributary contributes *E. coli* to Mechumps. This tributary empties into Mechumps Creek near its confluence with the Pamunky River. However, no violations were found at the site used by the VADEQ to list Mechumps as impaired near the Rt. 301 bridge (Station 8-

MCP002.42). These findings raise questions concerning *E. coli* sources, pathways, and residence times. Other single violations occurred within the watershed including a site near Lee's Mobile on Rt. 54, adjacent to a trailer park along Arbor Oak Drive in the Town of Ashland, and in a rural area in the central region of the watershed near Taylor's Pond.

Future studies should address the following remaining questions:

1. Why do discrepancies exist between the VADEQ and RMC findings with respect to the location of *E. coli* in the watershed?
2. What are the specific sources of *E. coli*? Is a sanitary sewer inspection needed? Do failing septic systems exist in the watershed? Can we facilitate the VADEQ's program to exclude livestock from streams? Can we determine *E. coli* contributions by wildlife? (See Section 8.3.5 in VADEQ, 2004)
3. What is the residence time of *E. coli* in natural waters?
4. Can we improve TMDL development by establishing in-stream gages along Mechumps Creek?

*E. coli* reduction necessitates finding sources of violations – this study demonstrates the complexity of this task in watersheds that occupy both rural and growing urban regions. However, state – academic collaboration provides a venue for probing more deeply into impaired streams that may have multiple sources of contaminants and complicated pathways.

## Introduction

In 2004, Virginia's Department of Environmental Quality (VADEQ) developed the Bacterial Total Maximum Daily Load (TMDL) for the Mechumps Creek Watershed in response to fecal bacteria water quality violations reported in 1998 and 2002 (VADEQ, 1998, 2002, 2004) and as mandated by Section 303(d) of the Clean Water Act and U.S. Environmental Protection Agency's (EPA's) Water Quality Planning and Management Regulations (40 CFR Part 130). The results of Biological Source Tracking (BST) analyses showed that 78% of the fecal bacteria (*Escherichia coli*) came from anthropogenic sources including pets, humans and livestock (VADEQ, 2004).

Beginning in September 2005, the VADEQ and Randolph-Macon College's (RMC) Environmental Studies (EVST) Program partnered to identify the unknown point and/or non-point sources of *E. coli* that contributed to the 5.69 mile long impaired segment of Mechumps Creek. The reach listed by the VADEQ as impaired extends from the confluence of Slayden Creek and Mechumps Creek downstream to the confluence of Mechumps Creek and the Pamunkey River (VADEQ, 1998; 2002; 2004). The VADEQ chose the Mechumps-Slayden confluence as the upstream limit of impairment because of the difficulty involved in pinpointing upstream sources beyond this area. Slayden Creek flows through rural and forested areas while the upstream branch of Mechumps Creek flows through the relatively urbanized Town of Ashland, Virginia. Potentially failing septic systems, a Hanover County pet kennel, and a Mobile gasoline station presented the initial suspects for suppliers of *E. coli* loads to the impaired segment.

The 2004 Bacteria TMDL Report for Mechumps Creek (reference) states that:

One of the major obstacles to improving stream water quality is that the potential sources of bacteria are numerous and the dominant sources and/or pathways are generally unknown. This can make it difficult to direct effective cleanup efforts.

This report summarizes the results of the project undertaken by Randolph-Macon College's Environmental Studies Program to determine the impacts of various land uses

(i.e., urbanization) on stream health in general and to locate the point and non-point sources and pathways of *E. coli* bacteria within the Mechumps Creek watershed in particular. This project augments previous work conducted by RMC's EVST Program within Mechumps Creek watershed to assess stream health (Gowan et al., 2005).

### **Study Area / Sampling Scheme**

Mechumps Creek is situated in Hanover County, Virginia within the larger York River Basin (Figure 1). Mechumps Creek flows as a 16.1 km tributary to the Pamunkey River which, in turn, flows into the York River and ultimately into the Chesapeake Bay. The watershed has a total area of 56.5 km<sup>2</sup> and 46.9 km of stream length (VADEQ, 2004). The VADEQ's TMDL report (VADEQ 2004) and Gowan et al. (2005) describe the natural setting and land uses within the Mechumps Creek watershed.

Mechumps Creek has three primary named tributaries (i.e., Slayden Creek, Campbell Creek, and Cady Creek) and several unnamed tributaries. Mechumps Creek has its headwaters in the Town of Ashland where three unnamed branches deliver water to the uppermost main stem approximately 0.2 km south of Rt. 54 and east of Rt. 1. Because of their potential for providing a source of fecal coliform, as well as for convenience, we label these (previously unnamed) branches the North Fork, Middle Fork, and South Fork from north to south (Figure 2). The North Fork extends from its confluence at Mechumps Creek near the southeast corner of the intersection of Rt. 1 and Rt. 54 upstream to the campus of Randolph-Macon College. In between, the flow is directed through culverts beneath Rt. 54 after receiving drainage from RMC and a shopping park anchored by the Ukrops grocery chain. The Middle Fork originates beneath the Henry Clay Shopping Center and flows above and below ground until it emerges permanently on the east side of Rt. 1. Approximately 0.1-0.2 km downstream of Rt. 1, the North Fork and Middle Fork merge upstream of Sample Site 2. The South Fork also begins just west of Rt. 1, flows beneath a trailer park east of Rt. 1, then under Rt. 1 past the Sedgefield Trailer Park and a small shopping center (Advance Auto Parts, Tavius Hair Salon, and Pla-Mor Pool Spas), and behind the shopping center anchored by Food

Lion before entering Mechumps Creek approximately 25 m downstream of the BMP spillway discharge pipe for this shopping center and downstream of the confluence of the North and Middle Forks. It should be noted that all upstream tributaries appear connected to Hanover County's storm water drainage system.

## **Methods**

The sampling scheme consisted of sampling once per month for 10 months at 12 stations located within the watershed using standard DEQ procedures (Figure 3). At eight locations, we resampled VADEQ sample sites. VADEQ and RMC officials collaborated on the selection of four additional sites prior to this study in order to increase the sample spacing density and consequently, the possibility of identifying loading sources and pathways. Table 1 provides a brief description of the sample locations and corresponds with the locations shown in Figure 3.

Water samples were collected in sterile containers and transported on ice to the laboratory. Bacteria colonies were allowed to incubate at 37.5° C for 24-36 hours in a hardened mixture of 2 ml of water sample and Coliscan media. We used a YSI 100 instrument to obtain pH values and a YSI 30 meter for water temperature and conductivity values.

The EVST Program's project-based curriculum enabled students from two classes and a senior research student to participate in this effort. In December, 2005, students of Introduction to Environmental Problem Solving obtained water samples from the 12 locations once per month from September through December and presented their preliminary findings to Virginia DEQ officials in December 2005. During RMC's January term, the Introduction to Geology and the Environment class sampled the 12 sites and conducted the lab analyses. From February to May, an EVST major conducted this project as a one semester senior research study. Schedule conflicts prevented us from collecting samples during June. In July 2006, Dr. Fenster and Dr. Gowan conducted the sampling, laboratory procedures, and analyses. Dr. Fenster provided oversight to each

effort to ensure sampling, laboratory, and analytical consistency. To date, RMC students and faculty have analyzed a total of 10 months of *E. coli* data. In addition, pH and other water quality data such as conductivity were sampled in five separate months over the course of the study period. Efforts were made to sample during a range of precipitation and streamflow conditions. In particular, we sampled during rainfalls to capture runoff as indicated by rising limb on the stream hydrograph and during dry periods. In addition, we sampled during both low and high streamflow conditions (minimum = 3.7 cfs; maximum = 45.0 cfs; average = 19.0 cfs).

*E. coli* loads were plotted on VADEQ-derived TMDL plots<sup>1</sup>. Water quality data were supplemented with rainfall data obtained from a weather station located on the roof of RMC's Copley Science Center. All stream data come from the United States Geological Survey (USGS) Totopotomoy Gage Number 01673550.

## Results

Samples obtained during precipitation events and rising limbs on the stream hydrograph include 25 October 2005, 17 April 2006, and 8 May 2006. The 6 December 2005 samples followed a snowmelt in which runoff effects exceeded those of precipitation.

The TMDL plot with constituent loads in cfu/yr versus flow duration shows that 12 water quality standard violations occurred out 132 fecal coliform samples collected throughout the watershed (9%; Figure 4). At least one location exceeded the water quality standard on five of the ten sampling dates (Figure 4). Three of the five sample dates with *E. coli* violations corresponded with the greatest rainfalls and streamflows experienced during the study period (25 October 2005=25% EP<sup>2</sup>; 17 April 2006=44% EP; 8 May 2006=12% EP) and one date with several site violations corresponded with a

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<sup>1</sup> The DEQ developed TMDL curves using an off-site water gage located on Totopotomoy Creek. In order to increase TMDL accuracy, the EVST Program at RMC is developing rating curves at three locations within the Mechumps Creek watershed.

<sup>2</sup> EP = Exceedence Probability. The percentage of the time that a particular streamflow is exceeded in the stream.

substantial snowmelt event (6 December 2005=20% EP) (Figures 5 and 6). One date had one site violation during a relatively low flow (11 July 2006=73.5% EP). Conversely, three sample dates with little to no precipitation and low flows had no violations of the *E. coli* standards (27 September 2005=91% EP, 15 November 2005=60% EP, and 22 March 2006=55%). No violations of the *E. coli* standard also occurred during higher flows in the winter months (16 January 2006=20% EP, 22 February 2006=40% EP). These results indicate that:

1. *E. coli* violations corresponded with rainfall, snowmelt, and higher flow events when runoff contributed overland flow to the stream. Exceedences of the water quality standard occur primarily at high stream flows.
2. High flows that occurred during the late winter months (January and February) do not result in violations without rain or snow. Thus, high base flows during late winter-early spring recharge periods did not appear to be a mechanism for *E. coli* delivery to the stream unless rain or snowmelt occurred.
3. Violations occurred rarely during low flows and when no rainfall occurred (e.g., Site 9 on 11 July 2006).

An examination of violations by site shows that 6 of the 12 sites violated the TMDL standard at least once during the study period and six sites had no violations (Table 2; Figure 7). Site 2 on Mechumps Creek in Ashland contained the most number of violations (4), followed by Site 9 (3), Site 4 (2), and Sites 1, 11, and 12 with (1). Of these violations, three occurred on 6 December 2005 during the snowmelt, three on 17 April 2006 after 0.29 inches of rain 24 hours prior to sampling, and three on 6 May 2006 following 1.48 inches of rainfall. Site 9 contained the only violation that did not coincide with a runoff-producing event.

## Summary

Ten months of sampling at 12 locations within the Mechumps Creek watershed enabled us to identify two primary reaches where fecal coliform bacteria exceeded the TMDL. However, no violations occurred in the reach previously identified as impaired by the VADEQ. Sample Sites 2, 4, 6, and 8 are located along the mainstem Mechumps Creek from west (upstream) to east (downstream). Site 2 samples in the Town of Ashland exceeded the TMDL standard more than any other site at 40% of the time (4 of 10). Because Site 1 on the South Fork violated the standard only one time (10% of the time), we can assume that either the Middle Fork or North Fork of Mechumps' headwater tributaries contribute *E. coli* to Site 2. We have briefly surveyed these branches by foot without success at identifying potential sources. Future studies should investigate these reaches more thoroughly.

On two of the same dates that Site 2 exceeded the *E. coli* TMDL limit, the downstream Site 4 also violated the TMDL standard (i.e., the snowmelt on 6 Dec 2005 and the 1.5 inch rainfall on 6 May 2006). While these results suggest that the *E. coli* found at Site 2 on these dates may have traveled downstream to Site 4, this was not the case on the other two dates that the limits were exceeded at Site 2 – despite the rainfall that occurred on those dates (25 October 2005 = 1.23 inches rain and 17 April 2006 = 0.29 inches rain). This phenomenon is difficult to explain plausibly. It should be noted, however, that Sites 6 and 8, downstream of Site 4, contained no bacteria above the TMDL. Site 6 is the upstream limit of current impairment. Thus, the source of *E. coli* to the reach officially designated as impaired was not active during our study period. This temporal variability in *E. coli* loads complicates further the effort to identify sources.

The only tributary that exceeded the TMDL limit more than once was the unnamed one that drains into Mechumps Creek near its confluence with the Pamunky River. This

tributary drains through primarily agricultural land with a smaller percentage of forested land. A reconnaissance of the area indicated that potential sources of *E. coli* include livestock and waterfowl, especially a farm pond that sometimes holds a large number of geese. More work is needed to identify drainage connections between ponds and first and second order streams in this part of the watershed and to determine potential *E. coli* sources.

The other sites violated the water quality standard one time in ten samples. Lees Mobile adjacent to Site 12 has a Virginia Pollution Discharge Elimination System (VPDES) permit (permit number VAG404066) as a point source facility to discharge 126 cfu/100 ml and an *E. coli* wasteload allocation of  $1.74 \times 10^9$  cfu/yr (VADEQ, 2004). The load at this site on 6 May 2006 was 500 cfu/100 ml (Table 2).

Site 1 on the South Fork tributary to Mechumps Creek and located between a relatively large trailer park, Rt. 1, and an auto parts retail store violated the standard one time. Site 11 on another unnamed tributary and adjacent to Taylor's Pond also exceeded the water quality standard one time. While the pond and creek itself appeared eutrophic during non-winter months, we found no evidence for *E. coli* sources. It should be noted that this tributary drains into the mainstem directly upstream from Site 8 near the Rt. 301 bridge. The VADEQ used Site 8 (VADEQ Station 8-MCP002.42) as the assessment station from which to list Mechumps Creek as impaired on Virginia's 1998 and 2002 303(d) Total Maximum Daily Load Priority List and Report as a result of fecal coliform violations. Our study found no violations at Site 8 despite the one violation at Site 11 and the upstream violations at Sites 1, 2, 4, 12, and 11 (in a general west to east downstream direction). This finding again raises the question of residence time of *E. coli* in natural waters.

The Hanover County Soil and Water Conservation District (SWCD) collected coliscan samples at Sites 1-9 between 8 January and 11 November 2003. Their data indicate that violations only occurred at Sites 1 and 2.

## Future Studies

Our efforts during the past year have enabled us to narrow down the possible sources of fecal coliform bacterial in the Mechumps Creek watershed. However, many important unanswered questions remain:

1. Why do discrepancies exist between the VADEQ and RMC findings with respect to the impaired reach?
2. What are the specific sources of *E. coli*? Is a sanitary sewer inspection needed? Do failing septic systems exist in the watershed? Can we facilitate the VADEQ's program to exclude livestock exclusion from streams? Can we determine *E. coli* contributions by wildlife (see Section 8.3.5 Addressing Wildlife Contributions in VADEQ, 2004 Report)?
3. What effect does residence time have on *E. coli* bacteria in natural waters?
4. Can we improve TMDL development by establishing in-stream gages along Mechumps Creek?

## References

Gowan, C. and students and faculty at Randolph-Macon College in collaboration with government, citizen, and business stakeholders, 2005. A Watershed Management Plan for Mechumps Creek, Hanover County, Virginia, Technical Report: RMC-EVST-2005-1.

VADEQ (Virginia Department of Environmental Quality), 1998 303(d) Total Maximum Daily Load Priority List and Report.

VADEQ (Virginia Department of Environmental Quality), 2002 303(d) Report on Impaired Waters.

VADEQ (Virginia Department of Environmental Quality), 2004. Bacteria TMDL for Mechumps Creek; Hanover County, Virginia.

Table 1. Locations of 12 sample site within the Mechumps Creek watershed in Hanover County, Virginia.

Site Number	Location
1	Mechumps Creek upstream of Arbor Oak Drive in Ashland.
2	Mechumps Creek downstream of Cottage Drive in Ashland.
3	Slayden Creek upstream of Providence Church Rd (Rt. 662)
4	Mechumps Creek downstream of Mt. Hermon Rd.
5	Campbell Creek downstream of Mt. Hermon Rd.
6	Mechumps Creek upstream of Goddin Hill Rd (just upstream of confluence with Slayden)
7	Slayden Creek upstream of Rt. 54
8	Mechumps Creek upstream of Rt. 301.
9	Un-named tributary on Norman's Bridge Rd
10	Cady Creek on Cady's Mill Rd.
11	Un-named tributary on Taylor's Pond Rd.
12	Un-named tributary at Rt. 54, Lee's Mobil

Table 2. Violations of the E. coli standard (235 cfu/100 ml) by site and date. Site numbers listed in a general downstream direction. Asterisks indicate mainstem Mechumps Creek sample sites. **Reference figure below contains site number in circles and number of violations in squares.**

Site Number	Number of Violations Out of a Total 10 (>235 cfu/100 ml)	E. coli count (cfu/100 ml)	Date
1	1	400	6 Dec 05
2*	4	250 1150 1450 1750	25 Oct 05 6 Dec 05 17 Apr 06 6 May 06
3	0		
4*	2	500 600	6 Dec 05 6 May 06
5	0		
6*	0		
7	0		
8*	0		
9	3	1900 1000 450	6 Dec 05 17 Apr 06 11 Jul 06
10	0		
11	1	350	17 Apr 06
12	1	500	6 May 06

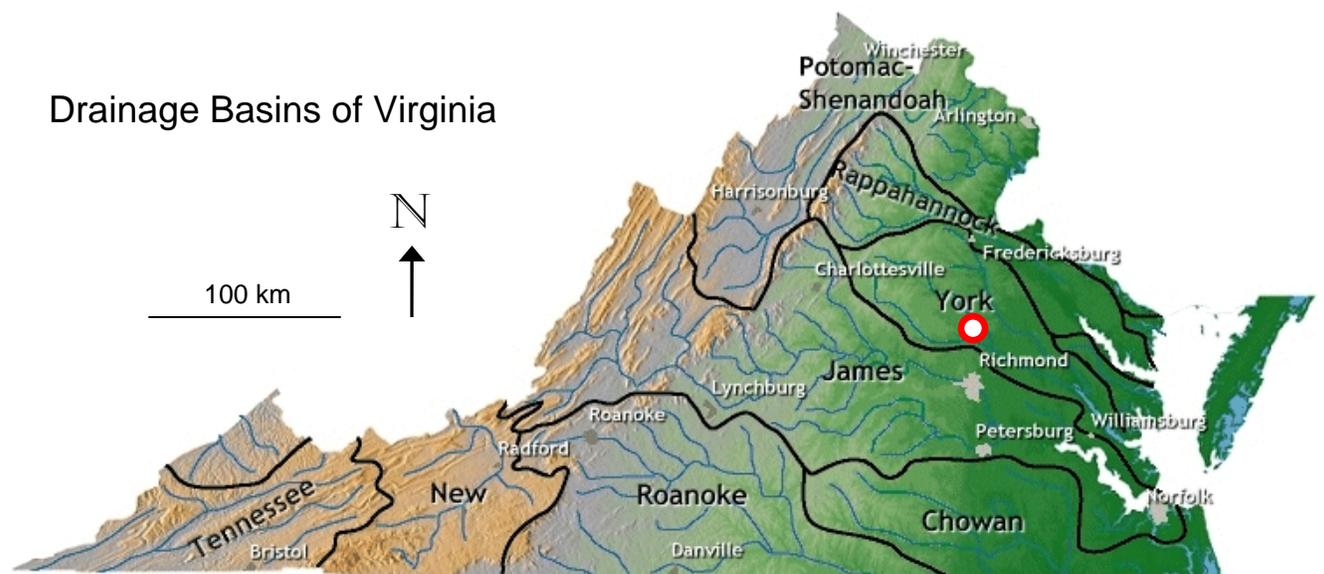


Figure 1. Study area shown by red and white circle within the York River drainage basin, Virginia (after Edwards, 1999).

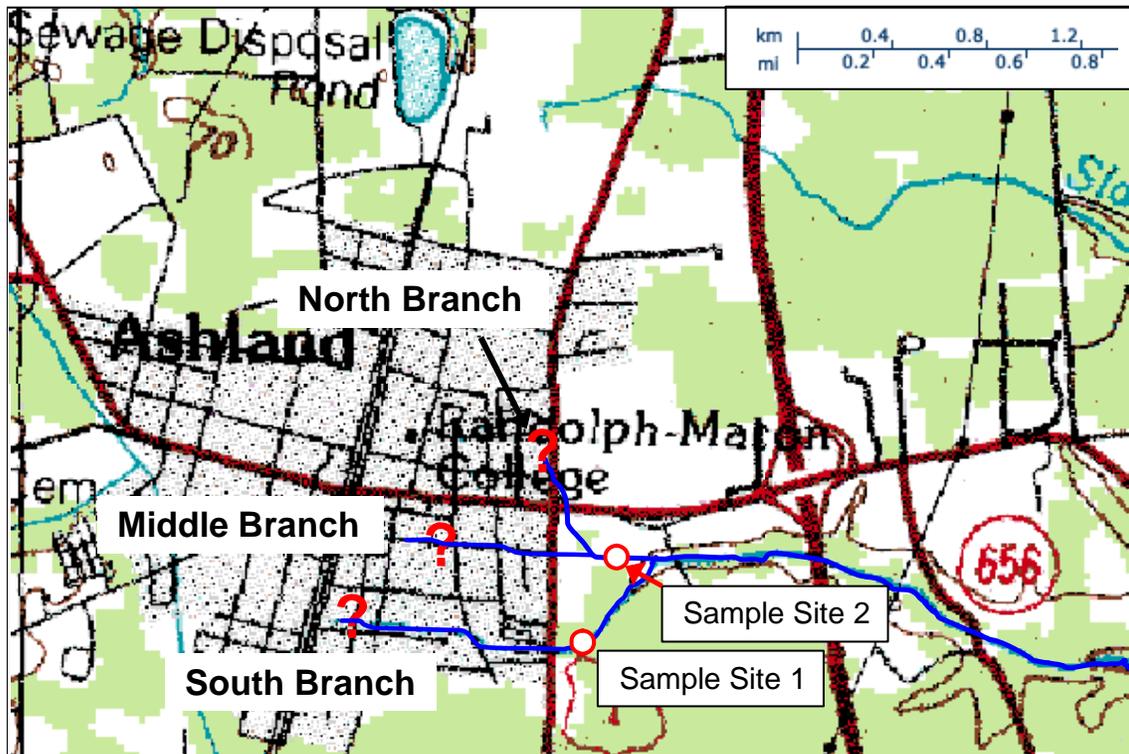


Figure 2. Headwaters of Mechumps Creek showing the location of the North, Middle, and South Branches.

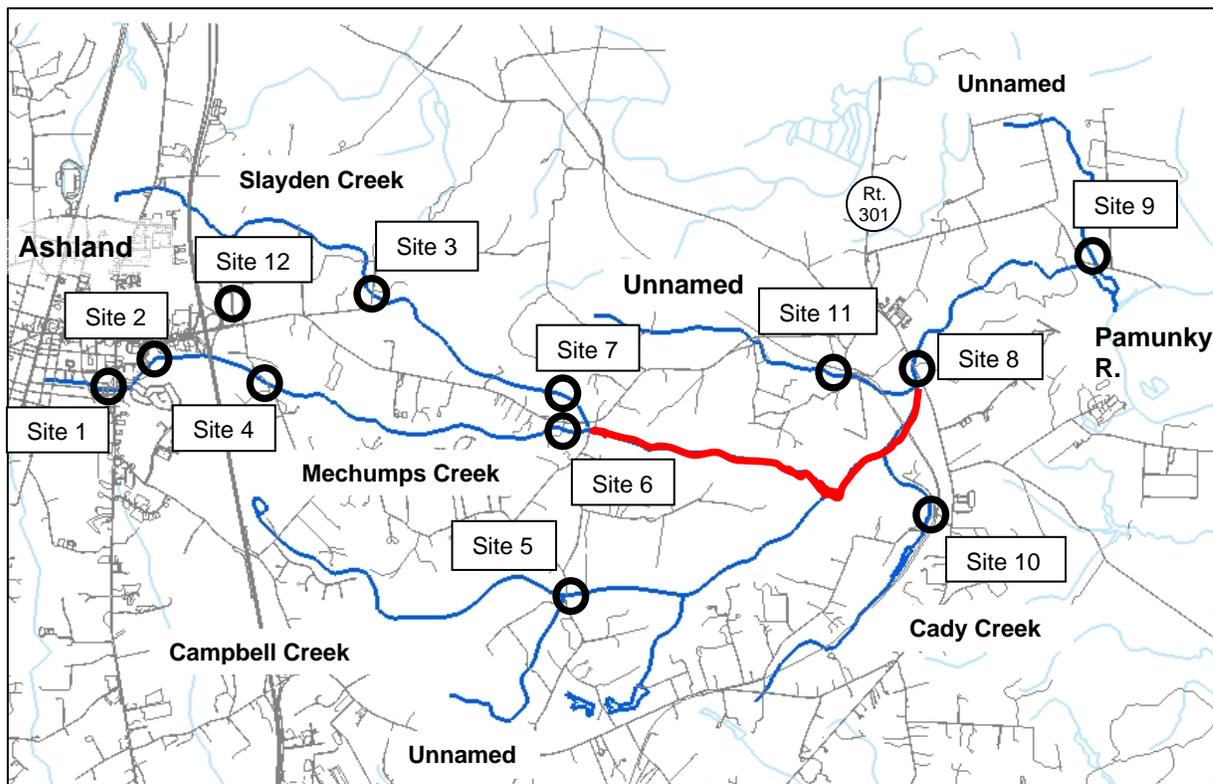


Figure 3. Map of Mechumps Creek watershed with sample site locations. Impaired reach indicated by red line.

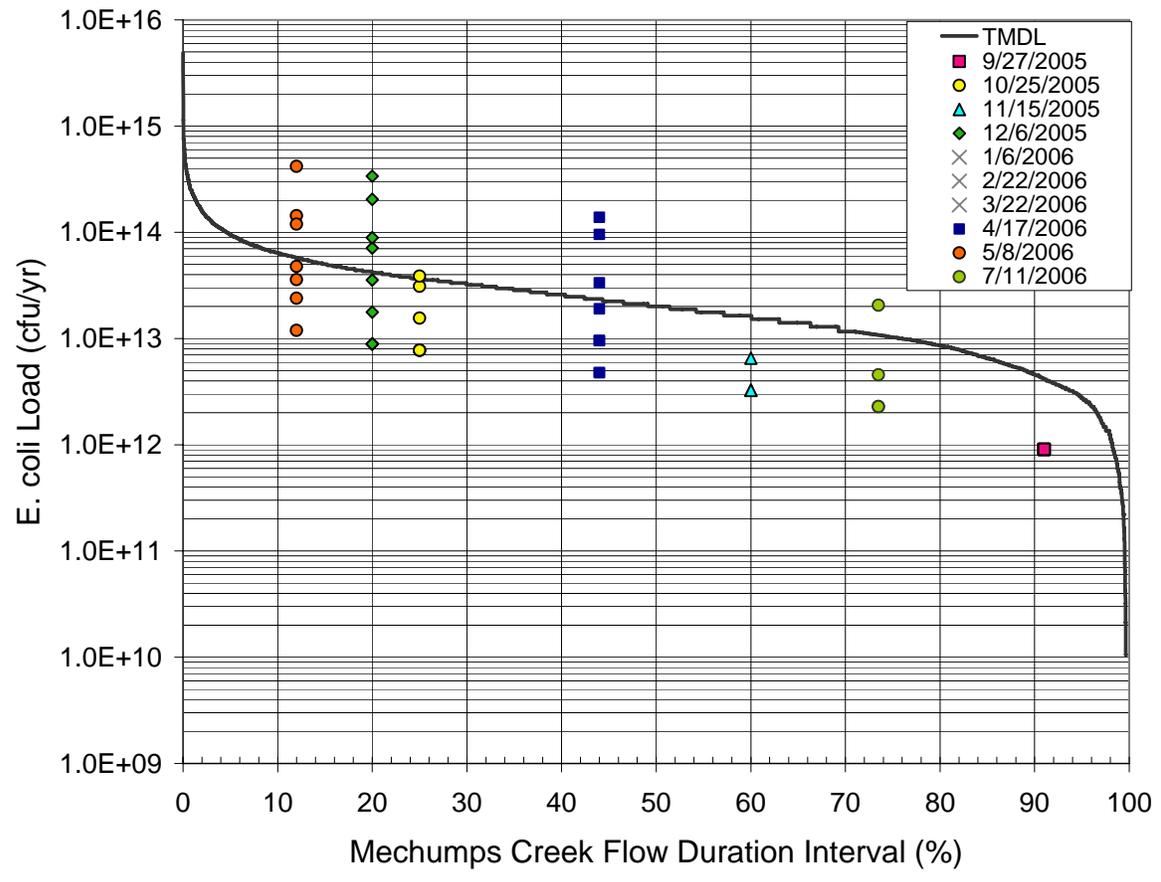


Figure 4. TMDL plot of E. coli loads for 10 months at 12 stations within the Mechumps Creek watershed.

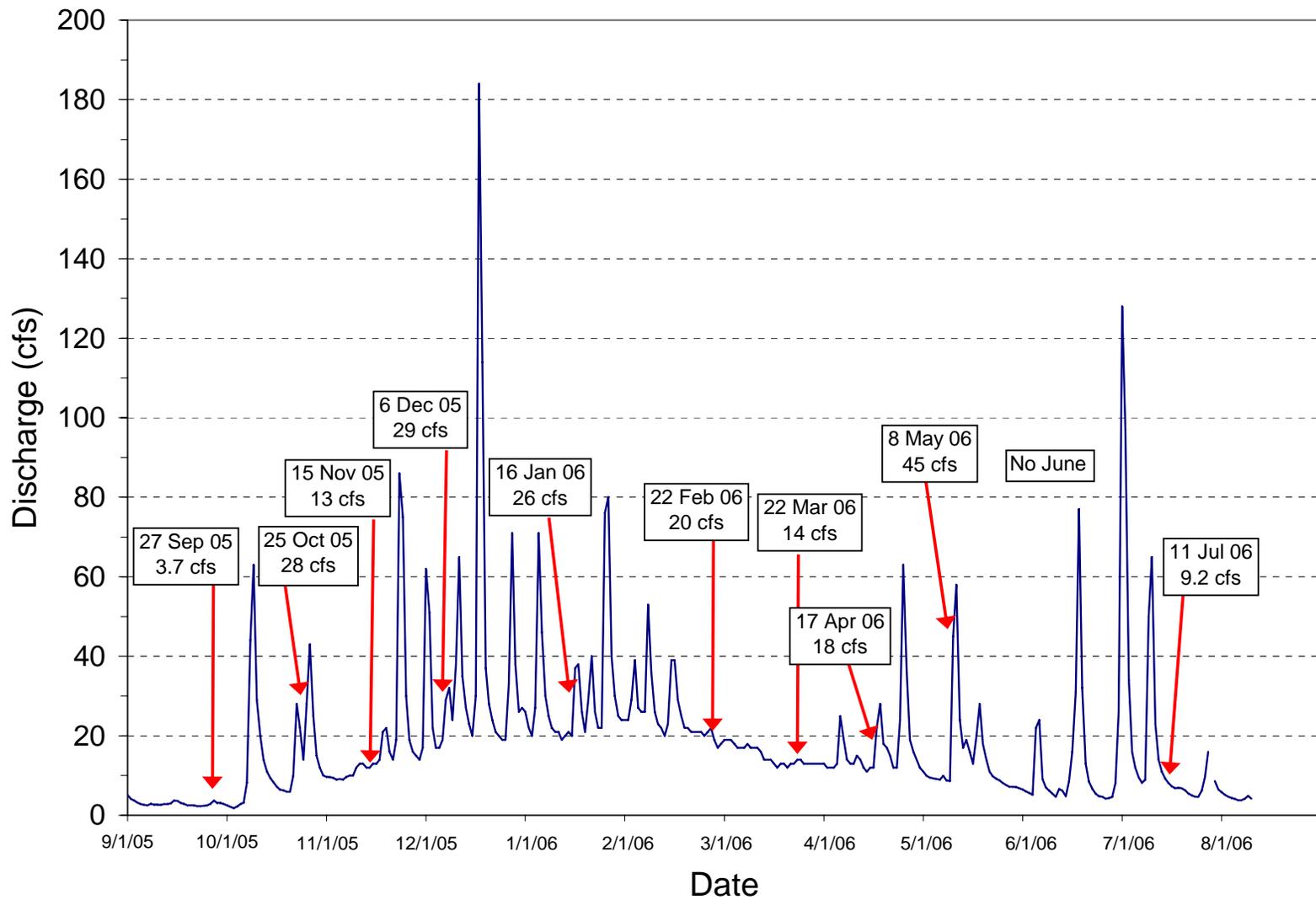


Figure 5. Stream hydrograph for Totopotomoy USGS Gage Number 01673550 during sample period. Sample dates indicated by red arrow with discharge on sample day shown in box

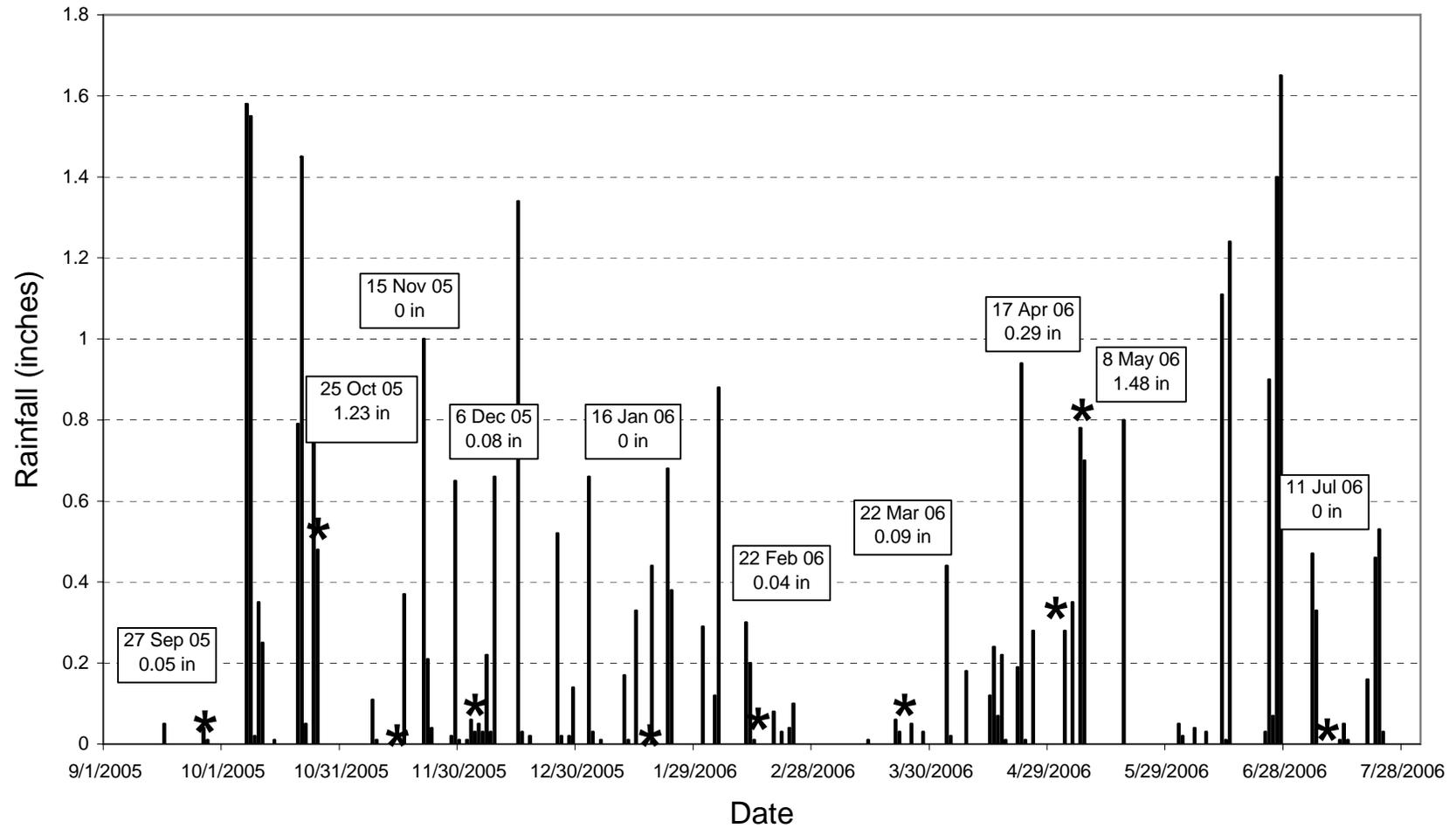


Figure 6. Rainfall occurring during the study period. Rainfall received at the Copley Science Center weather station 24 hours prior to sampling dates (indicated by asterisks) shown in boxes.

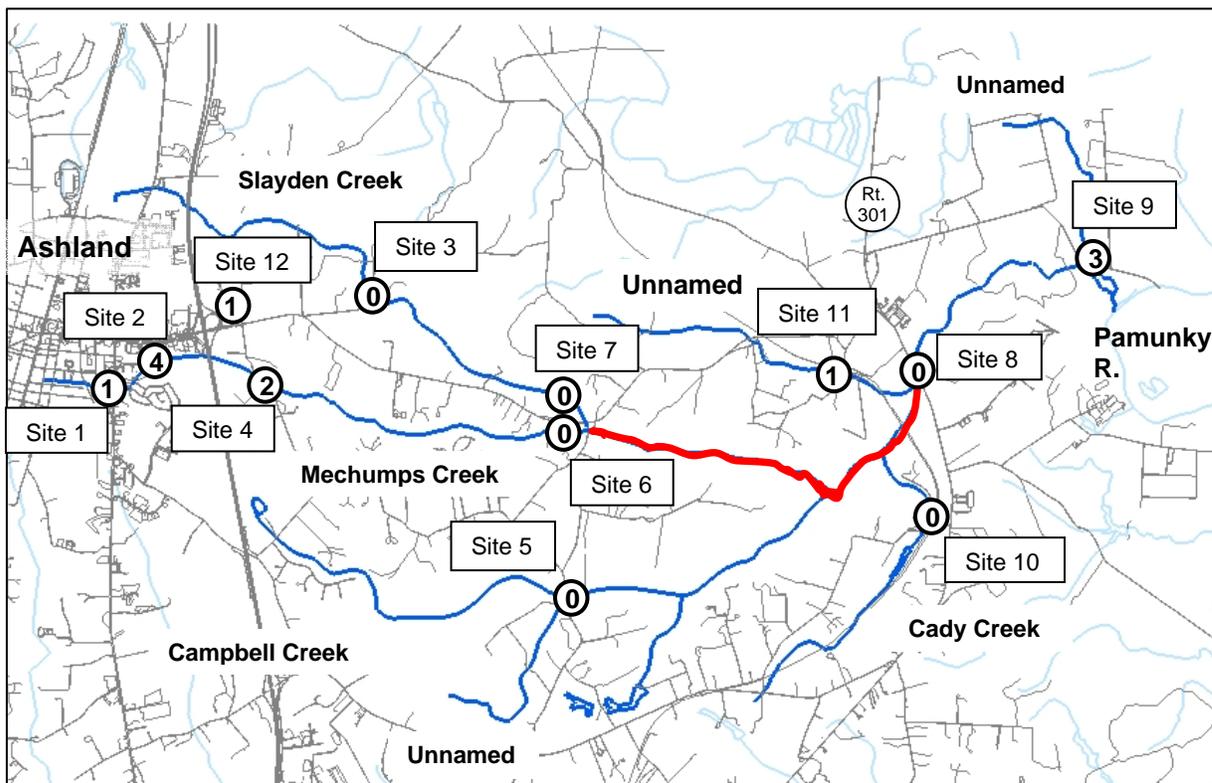


Figure 7. Sample sites within the Mechumps Creek watershed with number of *E. coli* violations (circles).