# Recovery of Streams in the Mill Creek Watershed of Davidson County from the May 2010 Flood using *Escherichia coli* as Indicator Bacteria

Mary Garmon
December 2010

A Research Paper Submitted to the Faculty of
The University of Tennessee at Martin
Fulfilling Requirements for the
Master of Science in Agriculture and Natural Resources Systems Management
Concentration: Natural Resources Systems Management

# Author's Limited-use Agreement

In presenting this completed paper in partial fulfillment of the requirements for an academic degree, I represent that it is an original Work and therefore assert the rights of an Author under Title 17 of the *United States Code* (copyright). I understand the University maintains one or more copies of the Work in its institutional archive as the permanent record of the Work's acceptance toward the degree, with the understanding that the University will maintain archival copies of the Work in such forms as best ensures its permanent preservation and continued public accessibility.

Notwithstanding the retention of copyright and all other rights to this Work, I recognize the University of Tennessee as the effective publisher of this paper and grant irrevocably to the University the following limited use of the Work in perpetuity:

a) representing the University, UTM University Archives may duplicate and distribute copies of the Work on the following terms, without recovering royalty payments or other considerations for the Author:

- i) the archival copy will be publicly accessible upon deposit and acceptance of the degree, and an electronic version of the Work will be posted for public accessibility and distribution on an institutional repository as an archival document, which may be downloaded by users without charge;
- ii) the UTM University Archives may duplicate copies of the Work as requested for the holdings of other academic libraries, so long as reproduction costs amount only to a sum required to recover actual duplication costs and shipping; however, the limited uses granted here do not transfer to other institutions holding copies of the work;

b) in the event that the Author or their heirs cannot be located after a documented good-faith effort is made by a user,

- i) the Author's lead graduate-committee professor shall have authority to grant permission for extensive quotation from the Work during the term of copyright, but not for publication of the Work;
- ii) in the professor's absence, University Archives shall have authority to grant permission for extensive quotation in its function as archival custodian for University theses and papers, but not for publication or performance of the work;
- iii) the University shall have authority to grant publication or performance permission to the Work as it stands in the deposit copy, provided the use is determined to be primarily scholarly or for demonstration, and non-commercial;

c) any duplication or use of the Work for financial gain of a user, except as stated here, is prohibited and duplication may be refused.

Author: ______________________

Date: 11/19/2010

## Information

Name: Mary Garmon

Date of Degree: December 2010

Institution: The University of Tennessee at Martin

Major Field: Natural Resources Management

Major Professor: Dr. Barb Darroch

Title of Study: Recovery of Streams in the Mill Creek Watershed of Davidson County from the May 2010 Flood using *Escherichia coli* as Indicator Bacteria

Pages Contained in Study: 38

Candidate for Master of Science Degree in Agriculture and Natural Resources Systems Management

## Acknowledgements

I would like to acknowledge my coworkers at Metro Water Services: Michelle Barbero, Megan Sitzlar, and Dr. Steve Winesett. Their assistance and expertise was an integral part of this project. Sample collection and analyses were a shared responsibility and I am very grateful for their professional standard of work. I also enjoy there sense of humor, thank you!

I would also like to thank Dr. Barb Darroch for her assistance in the statistical portion of the project. She has been encouraging when I needed her to be. I think that future students in the MSANR program are lucky to have such a considerate professor. She made me feel like a part of the program even though I was not on campus.

## Abstract

Between May 1st and 2nd, 2010, Nashville, TN received an unprecedented 13.53 inches of precipitation. During the subsequent flood, pollutants inundated receiving waters and public health and safety became a major concern. Bacteria levels increased due to runoff pollutants and exceeded water quality standards.

This study focuses on the Lower Mill Creek Watershed, which is located in the Greater Nashville Area. *Escherichia coli* levels were studied before and after the catastrophic storm to determine if and when bacteria levels returned to pre-flood conditions. There were 11 sample sites selected in nine streams within Lower Mill Creek Watershed. F-tests and t-tests were used to compare variance and means of *E. coli* samples taken before and after the flood. A paired t-test determined the significance of overall means before and after the flood. Dissolved oxygen, conductivity, temperature, and pH were also measured for each water sample.

On average, *E. coli* concentrations increased ($P=0.0005$) from 215 MPN before the flood to 560 MPN after the flood. Six of the 12 sample sites had significantly ($P\leq 0.05$) higher *E. coli* concentrations after the flood. Sanitary sewer overflows were prevalent on many of the streams that exhibited high *E. coli* values. The *E. coli* values remained elevated in many streams until the end of June 2010. Trends in the chemical properties of the streams reflected normal changes in temperature and season during the study period, which complicated the statistical analyses. Forecasting the level of impact of a large-scale flood on a stream is a difficult task. However, the results showed that flooding can have long-term effects, including biological hazards, on receiving waters. *E. coli* levels in many of the streams were significantly higher after the flood for extended

periods of time.  It is advisable to avoid human contact with receiving waters after a storm or flood event to reduce the potential for transmission of harmful bacteria.

## Table of Contents

## List of Tables

## List of Figures

## Introduction

On May 1st 2010, 6.32 inches of rain fell on Nashville TN, with an additional 7.25 inches of precipitation the following day (NOAA, 2010). Twenty-nine people lost their lives in the ensuing flood and thousands lost their homes and livelihood. The governor declared 95 counties in Tennessee a National State of Disaster. The record-breaking two-day total of 13.53 inches of rain left businesses and homes in shambles. The Cumberland River crested at 51.85 feet, 12 feet above flood stage. According to the USGS gauge station at Woodland Street in Nashville, it remained at flood stage for 5 days. Water quality during the flood was of great concern from a public health standpoint. Sewer overflows were caused by the rain event and many sewer pump stations were out of service. The degradation of water quality in local streams and water bodies was extensive. Water quality professionals questioned how long it would take for water quality parameters to return to baseline levels after an event of this magnitude.

# Literature Review

## Water Quality in Streams

Recreational use of public waters is a popular pastime for many Americans. The 2000-2001 U.S. National Survey on Recreation and the Environment reported that 89 million people swim in recreational public waters annually (Wade et al., 2006). Results from a study on water quality indicate a direct correlation between elevated levels of fecal indicator species and illness (Wade et al., 2006). According to the Center for Disease Control, there were 29 reported outbreaks of infection from contaminated waters in 2001, which is more than had ever been reported before (Wade et al., 2006).

Pathogens have become a primary impairment on many of the 303d streams within the United States (Peterson et al., 2005). The 303d list is named after section 303d of the Clean Water Act which requires "states to maintain a list of streams that do not meet water quality standards" (Peterson et al., 2005). Both point source and non-point source pollution are responsible for pathogenic contamination (Peterson et al., 2005). Point source pollution refers to sources that can be traced back to a pipe. Non-point source pollution includes stormwater runoff, septic system inputs, and wildlife and pet waste. Non-point sources can be difficult to track in urban areas especially, because there are so many factors involved (Peterson et al., 2005).

With public health and safety in mind, it is necessary to regulate contaminants entering public waters and eliminate any illicit discharges. Looking for fecal indicating bacteria and, more importantly, identifying the source, is a crucial component to this process. *Escherichia coli (E. coli)* are the primary indicator organism used for feces detection (TDEC, 2009b). However, other studies suggest using different fecal-present bacteria, such as *Bacteriodes*, for fecal presence and source tracking (Layton et al., 2006).

*E. coli* are a diverse group of coliform bacteria that are often used as an indicator species of contaminated waters. According to the State of Oregon Department of Environment and Conservation, *E. coli* is a reliable indicator because it is present in feces of humans and animals (Redman, 2003). Also, *E. coli* bacteria occur at higher volumes than pathogens, do not grow rapidly in aquatic ecosystems, do not require complex methods for sampling and detection, will be present if there are pathogens present, and have some resistance to disinfection (Redman, 2003).

## Pathogen Monitoring

There are many classifications for water use in the state of Tennessee. All streams in Tennessee are classified for "recreational use". This means that the public can safely swim in, wade in, and eat fish from Tennessee streams (TDEC, 2009a). To ensure the safety of the public, streams are monitored for quality. *E. coli* are used as an indicator bacterium for fecal contamination in water (TDEC, 2008a). Chapter 1200-4-3 of the Rules of Tennessee Department of Water Pollution Control states

> "the concentration of the *E. coli* group shall not exceed 126 colony forming units per 100 ml, as a geometric mean based on a minimum of 5 samples collected from a sampling site over a period of not more than 30 consecutive days with individual samples being collected at intervals of not less than 12 hours" (TDEC, 2008a).

The geomean or geometric mean is the average of a group of numbers that indicates the central tendency. The National Pollution Discharge Elimination System (NPDES) office for Davidson County is required, per their permit, to monitor discharges to the storm sewer. Thus, a monitoring program was initiated in the Mill Creek watershed in March 2010, just prior to the catastrophic flood.

Many factors must be considered when studying the levels of bacteria in a stream, such as sampling techniques and laboratory methods. Meays et al. (2006) studied diurnal variability of *E. coli* concentration by taking 96 grab samples over a 24 hour period from three different creeks on three different days. The samples were tested for *E. coli* and tracked to the source of contamination with a method known as ribotyping. The sources of *E.* coli in this study included avian, bear, bovine, canine, deer/elk, horse, raccoon, rodent, and unknown. Meays et al. (2006) found that many factors, including sample location, must be taken into consideration when sampling for *E. coli.* Bacteria levels increased as they moved from the headwaters to the lower elevations of streams. Land use upstream from sample site is also very important when choosing sample locations (Meays et al., 2006). For example, highly populated areas are more like to have higher levels of bacteria. Timing is the third important consideration when planning a sampling event because creek flow and amount of rainfall prior to sampling can affect bacteria concentration in water. The levels of bacteria during a rain event increase due to runoff from non-point sources (Meays et al., 2006).

Urban streams have a great propensity to receive high loads of fecal material from sewer overflows and stormwater runoff (Heberger et al., 2008). Rainwater influx and infiltration can trigger sewer overflows. Heberger et al. (2008) studied the Mystic River Watershed in the summers of 2002 and 2003 to estimate the length of time after a rainfall that there should be a health advisory in recreational waters. The amount of precipitation and time after the last rainfall was used to predict the levels of fecal coliform bacteria, using *Enterococcus* indicator bacteria. Multi-variable regression models were developed and were able to correctly predict levels of *Enterococci*, 85% of the time (Heberger et al., 2008). Having such models would be helpful when data are not available after a rain event.

## Additional Water Quality Parameters

In addition to bacteria, streams are often monitored for dissolved oxygen (DO), conductivity, temperature and pH. Dissolved oxygen measures the oxygen that is available to aquatic organisms for respiration (Eaton et al., 1995). For this reason, it is a direct measure of the quality of the streams. Urban stormwater runoff can cause increased fluctuations in DO, thereby stressing the ecosystem (Eaton et al., 1995). Conductivity measures the ability of water to carry an electric current (Eaton et al., 1995). Streams in Nashville typically have a conductance between 450 and 650 μS/cm. Any abnormal measurement of conductance indicates the stream is possibly receiving polluted or illicit discharges. Monitoring conductivity regularly helps recognize any abnormalities in stream chemical composition. Temperature is an important water quality parameter because it has significant ecological effects (Eaton et al., 1995). pH measures the acidity of a substance (Eaton et al., 1995). It is important to measure pH because it also affects biological processes in aquatic ecosystems.

## The Watershed Approach to Water Quality in Tennessee

Tennessee Department of Environment and Conservation (TDEC), Division of Water Pollution Control adopted a watershed approach to water quality in 2008. This approach focuses on the watershed as a whole in order to control both point source pollutants and non-point source pollutants (TDEC, 2008b). The watershed approach stems from the idea that watersheds do not conform to traditional borders that are defined by city boundaries or state/county lines. This approach requires the participation of the community and stakeholders of the watershed in order to address water-quality problems. An 8-digit Hydrologic Unit Code (HUC-8) is used for organizing the watersheds. This can be further broken into smaller watersheds defined by 10 digits (HUC-10) or 12 digits (HUC-12).

The Cheatham Lake Watershed, with the HUC identification number 05130202 is approximately 647 square miles and encompasses portions of six different counties in middle Tennessee (Figure 1; TDEC, 2008b). The Cheatham Lake Watershed is divided into 3 HUC-10 watersheds, each of which is further divided into even smaller HUC-12 watersheds. The watershed that was the focus of this study is a HUC-12 sub-watershed, Lower Mill Creek number 051302020202.

Water quality studies on effects of discharges in a watershed are appropriate for watersheds at the HUC-12 size because this size of land area allows for proper consideration of non-point and point source pollutants. For this reason, restoration plans are written at the sub-watershed level.

There have been many benefits to the watershed approach. It helps focus on water quality as a whole instead of goals of individual stakeholders (TDEC, 2008b). This process has also allowed for data sharing and interagency communication. The greater number of observations made in the watershed allow for better recognition of pollution sources. In addition, collection of water samples from watershed streams over time allows for comparison of water quality before and after flood events.

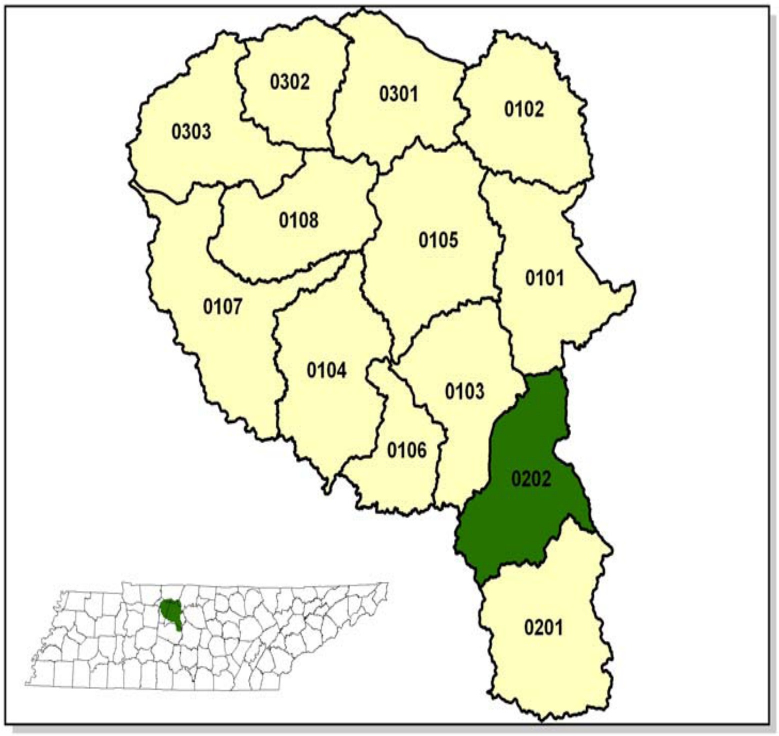

**Figure 1. The Cheatham Lake Watershed is highlighted in green on the reference map. The Lower Mill Creek Watershed is highlighted in green within the larger map of the Cheatham Lake Watershed (TDEC, 2008b).**

## Lower Mill Creek Watershed

Mill Creek Watershed is especially important to the Middle Tennessee region because it is the only watershed containing the endangered Nashville crayfish, *Orconectes shoupi* (Cumberland River Compact, 2010). This watershed sprawls from the Williamson/Davidson county line to the Cumberland River. The Lower Mill Creek Watershed, which encompasses only Davidson County streams, was studied in this research project.

The confluence of Mill Creek and the Cumberland is located directly upstream of the Omohundro water treatment plant. This water treatment plant provides the majority of the drinking water to the citizens of Nashville. Water quality became a great concern when the plant was threatened by flood waters the week following May 1st, 2010. The other treatment plant for Nashville, which is upstream of the confluence with Mill Creek, was compromised during the flood, putting a strain on the water distribution system for the month of May and part of June 2010.

While compromising the drinking water system was an imminent risk to public health and safety, there was also uncertainty of water quality in streams and other bodies of water after the May 2010 flood. From May 1st through 4th, there were 96 reported sanitary sewer overflows (SSO), including both public and private sewers, in the Metropolitan Nashville Area (Metro Water Services, 2010a). Thirty-four pump stations were out of service, which means that the waste from those stations was being discharged to local streams or storm sewers (Metro Water Services, 2010b). Figure 2 shows the sanitary sewer overflows and the flooded pump stations that were caused by the May 2010 flood. Eleven overflows were located within the Lower Mill Creek Watershed (Figure 3). Modeling levels of bacteria after a flood like this one is useful for individuals that must work in flooded waters where sanitary sewer discharges have recently occurred or when data are just not available.

Another important component of the Lower Mill Creek Watershed is land use. The most prevalent land uses include open space, developments, forests, and pasture (Figure 4, Table 1). Open space represents 35% of the land area in the watershed and developed areas (including low, medium and high intensity) represent 43% of the land

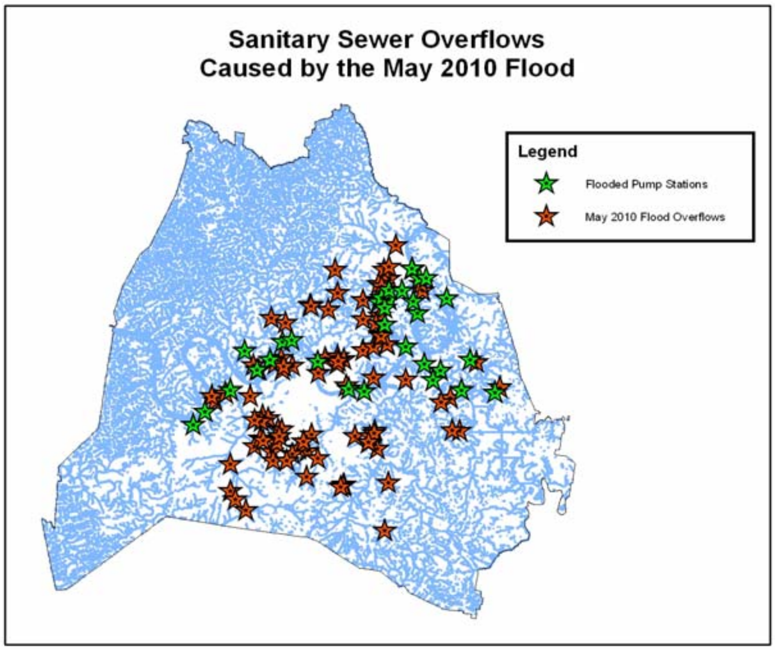

**Figure 2. Sanitary sewer overflows that occurred between May 1st and 4th in Nashville (Metro Water Services, 2010a and 2010b).**

.

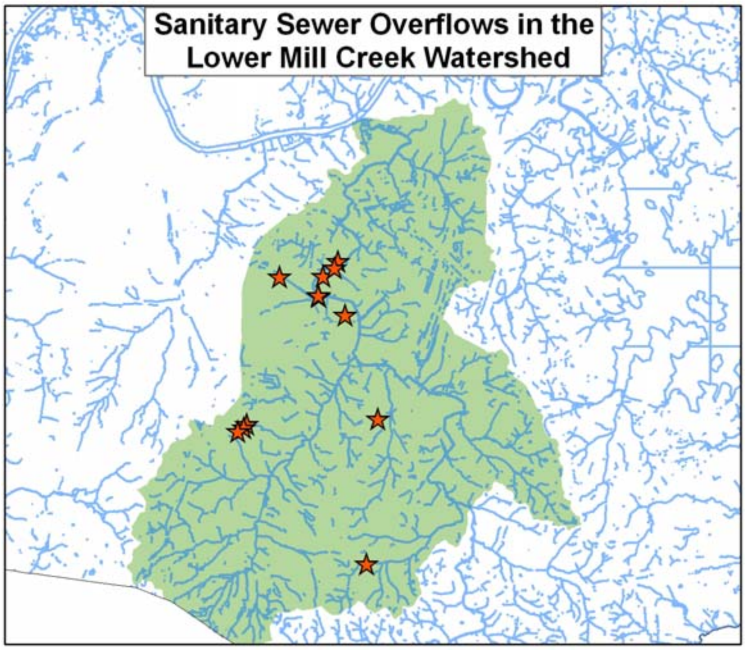

**Figure 3. Overflows that occurred in the Lower Mill Creek Watershed (Metro Water Services, 2010a).**

area (Table 1). The mixed use of the watershed is indicative of an urban landscape. Water integrity is impacted by mixed sources due to these varied land-use activities (Wang et al., 2009). Because of the varied land use within the Lower Mill Creek Watershed, there are many different inputs during a heavy rain event that can affect water quality. For this reason, this watershed is an excellent model of what presumably occurred throughout the county during this substantial flood event. Additionally, sufficient pre-flood data from the Lower Mill Creek watershed was available for statistical analysis.

Floods of the magnitude of the one experienced in Nashville this May are not easily forecast, therefore, water quality data as related to flood events can be difficult to obtain. Because of the existing sampling protocol, pre- and post-flood water sample analyses were performed with proper quality assurance/quality control (QA/QC). The ability to forecast bacteria levels in streams helps with making decisions to protect people. In an event like the May 2010 Flood, there are many reasons it can be difficult to obtain water quality data, such as logistics, equipment failure, lack of personnel, and general chaos.

## Objectives

The objective of this research was to examine the impact of the May 2010 flood on water quality of urban streams, specifically the Lower Mill Creek Watershed. Bacteria, specifically *E. coli*, were the parameter of interest; however, dissolved oxygen, conductivity, temperature and pH were also studied.

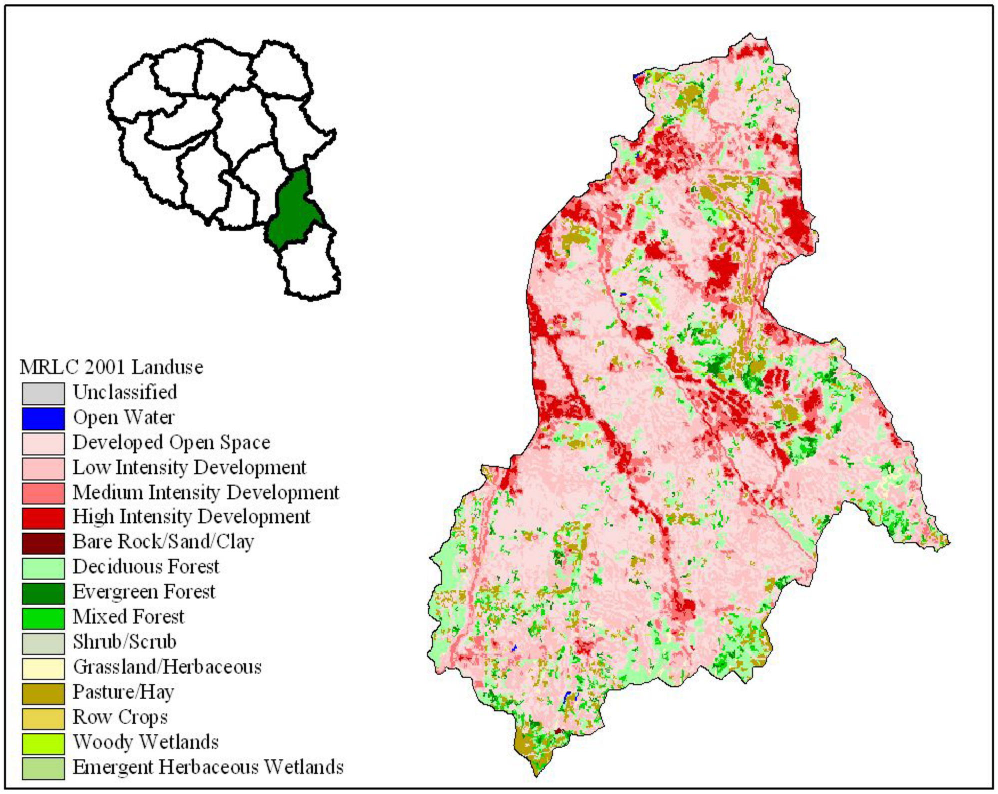

**Figure 4. Land use in the Lower Mill Creek Watershed (TDEC, 2008b).**

**Table. 1. Landuse distribution in the Lower Mill Creek Watershed (TDEC, 2008b).**

| **Landuse** | **Percent** | **Landuse** | **Percent** |
|---|---|---|---|
| Developed Open Space | 35.22% | Evergreen Forest | 1.23% |
| Low Intensity Development | 26.88% | Shrub/Scrub | 1.00% |
| Medium intensity Development | 10.42% | Grassland/Herbacious | 0.53% |
| Deciduous Forest | 9.93% | Woody Wetlands | 0.27% |
| High Intensity Development | 5.97% | Row Crops | 0.13% |
| Pasture/Hay | 5.54% | Open Water | 0.05% |
| Mixed Forest | 2.79% | Bare Rock/ Sand/ Clay | 0.03% |

# Materials & Methods

## Collection of Samples

Samples were collected in compliance with the Tennessee Department of Environment and Conservation (TDEC) procedures and guidelines (TDEC, 2009b), which ensured that all data collected were in compliance with TDEC and United States Environmental Protection Agency (EPA) guidelines. In addition to collecting bacteria samples, all sites were monitored for dissolved oxygen (DO), pH, temperature ($^{o}$C) and conductivity (µS/L).

Post-flood sampling began on May 10, 2010 and ended on September 29, 2010. All samples were collected in dry weather conditions, which are defined as less than one-tenth of an inch of rain within the previous 36 hours of the sample event. Twelve sampling sites were selected on nine creeks based on the following criteria: comparability to TDEC's sites, ease of entry, proximity to the confluence with an adjoining creek, and safety. Samples were collected only in Davidson County due to regulations that prevented travel outside the county line. The sites were rotated in two groups and sampled five times within a 30-day period. This facilitated the calculation of the geometric mean that can be used for comparison among creeks. Based on these criteria, nine creeks were selected: Cathy Jo, Finley, Mill, Pavilion Branch, Sevenmile, Shasta, Sims, Sorghum, and Whittemore. These creeks are all located within the Mill Creek watershed (Figure 5). Because they are larger streams, Mill Creek and Sevenmile creek were split into segments. There were three sample sites in Mill Creek and two sample sites in Sevenmile Creek.

Samples were either taken from bridges or directly from streams depending on accessibility to the channel (in compliance with TDEC's Water Pollution Control Quality SOP; TDEC, 2009b). In-stream samples were taken from the fastest flowing section of the creek (thalweg), facing upstream, without disturbing sediment. Bridge samples were taken on the upstream side of the bridge to eliminate any effects from the bridge. Samples were kept below 4˚C during transport and quality control blanks and standards were analyzed with samples to ensure that there was no contamination during transport or sample collection.

Flow is an important consideration when comparing bacteria levels in streams because the fluctuations in flow can affect the abundance of bacteria. Figure 5 shows the two U.S. Geological Survey flow gauges located in the Lower Mill Creek Watershed, both of which are located in Mill Creek. Gauge number 03431030 remained online during the sample period, while gauge number 03431000 was not operating. Flow data from the operating gauge was included in this study to determine if flow impacted bacteria levels in the watershed.

## Analysis of Samples

Bacteria samples were analyzed for the presence of *E. coli* using the IDEXX laboratories Colilert method (IDEXX Laboratories, Inc, 2010). Colilert is an approved method according to the Standard Methods for Examination of Water and Wastewater (IDEXX Laboratories, Inc, 2010). This method is used by the Tennessee State Laboratory and allows for in-house analysis, which was preferable due to time and

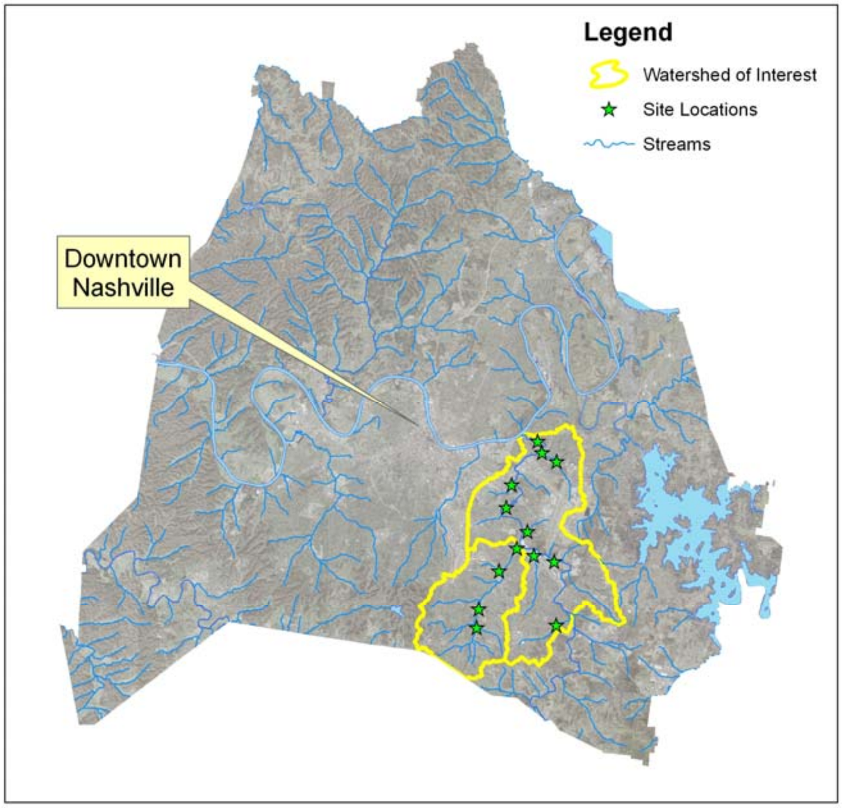

**Figure 5. Map of Davidson County, TN, indicating Lower Mill Creek Watershed and sampling locations.**

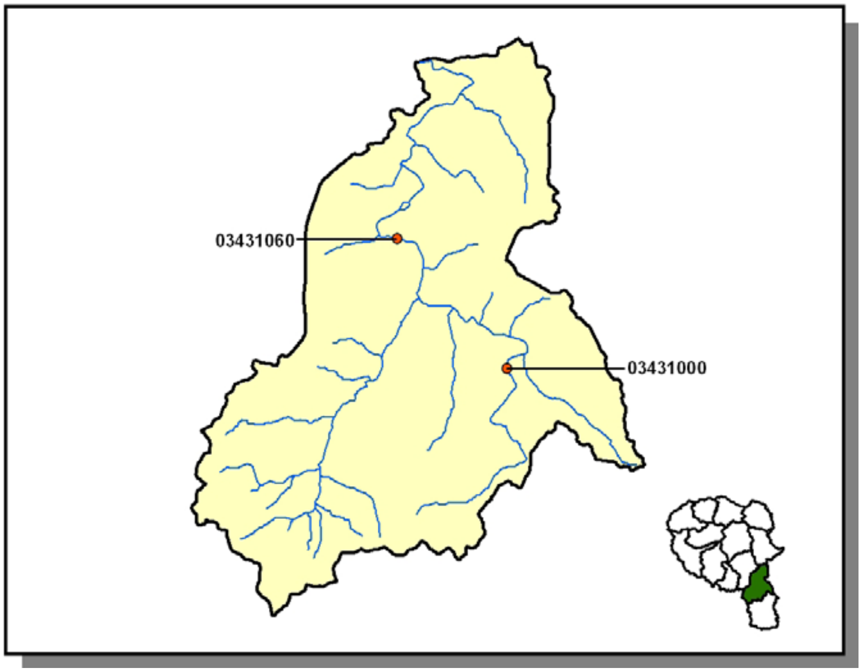

**Figure 6. Location of USGS flow gauges in the Lower Mill Creek Watershed (TDEC, 2008b).**

budget constraints (TDEC, 2009a). The Colilert method uses enzymes as an indicator of *E. coli* and the results are reported as “the most probable number” (MPN) of bacteria present in a 100 ml sample. Samples were incubated for 24 hrs at 35˚ C and analyzed using a florescent light 365 nm) to count illuminated cells. Fluorescent cells indicated the presence of *E. coli* and the ratio of fluorescent to non-fluorescent cells was used to generate the MPN. Most probable number directly correlates to colony forming units (CFU) of the Standard Plate count method.

Quality control measures ensured the integrity of collected data. Trip blanks, field blanks, and duplicate samples were analyzed to indicate that sampling, transport and analysis techniques and procedures were conducted properly. IDEXX standards for *E. coli, Pseudomonas aeruginosa, Klebsiella pneumoniae* were analyzed as an additional quality control measure.

pH was measured with a Hach Sension meter. The meter was calibrated and recorded each day before sampling. DO, conductivity, and temperature were all measured with an YSI 85 meter (YSI, Incorporated). The meter was calibrated for temperature and conductivity at the beginning of each week and DO was calibrated and recorded each day before sampling. All parameters were measured upstream from each sample site directly after the sample was taken. Parameters were measured in the bucket if a bridge sample was required.

### Statistical Analysis

Data for each location and each measured variable were divided into before and after the flood. F-tests were used to compare pre-flood variance with post-flood variance.

Then, the appropriate t-test was used to compare pre-flood means with post-flood means for each location. Mean values for *E. coli* from each stream were then combined and a paired t-test was used to compare overall *E. coli* levels before and after the flood.

Historical bacteria data exist for 2007 to 2009 for six of the 12 sites selected for this study. This baseline data was used to look at seasonal trends in bacteria levels that may be caused by change in temperature or stream flow. Flow values from the sampling dates were taken from the USGS gauging station (located where Mill Creek goes under Thompson Lane) and were plotted with temperature data to examine seasonal trends throughout the study period. Data from 2008 and 2009 of four of the sample locations was used to compare historical data to 2010 data.

# Results and Discussion

## *E. coli*

The overall variability of *E. coli* concentration in water samples increased after the flood. The composition of runoff to each stream varied and therefore each stream was impacted differently. Seven of 12 sites showed significantly ($P \leq 0.05$) higher variability after the flood; four of those were highly significant ($P \leq 0.01$; Figure 7). The paired t-test for mean variances before and after the flood (combined from all sites) was highly significant ($P = 0.0089$) as well.

The paired t-test of sample means from all locations showed that there was a highly significant difference ($P = 0.0005$) in samples before and after the flood. The overall mean before the flood was 215 MPN, whereas the overall mean after the flood was 560 MPN. Six of the twelve sampling locations had significantly ($P \leq 0.05$) higher *E. coli* concentrations after the flood; three of these were highly significant ($P \leq 0.01$; Figure 8). The results were not uniform across streams that were sampled due to the complexity of stream ecology, bacteria growth, and pollution sources.

*E. coli* values over time are illustrated in Figures 9-12 for each stream. There was a clear distinction between the streams that were highly affected and those that were minimally affected by flooding. For example, Shasta, Sorghum, and Whittemore had elevated *E. coli* levels after the flood (Figure 10). Cathy Jo, Sevenmile 1, and Sevenmile 2 were not as affected by *E. coli* inputs during or after the flood (Figure 9). It is important to note that each creek was inundated for different amounts of time and each

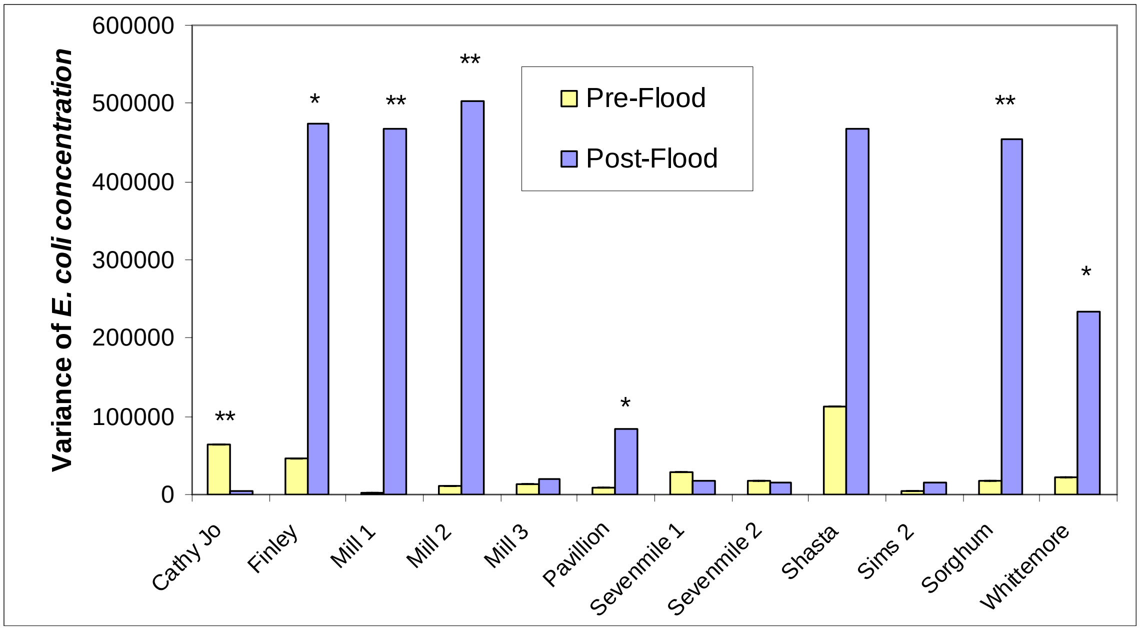

**Figure 7. Variance of the *E. coli* values before the flood and after the flood. * significant difference (P≤ 0.05) between pre- and post-flood means; ** highly significant difference (P≤ 0.01) between pre- and post-flood means.**

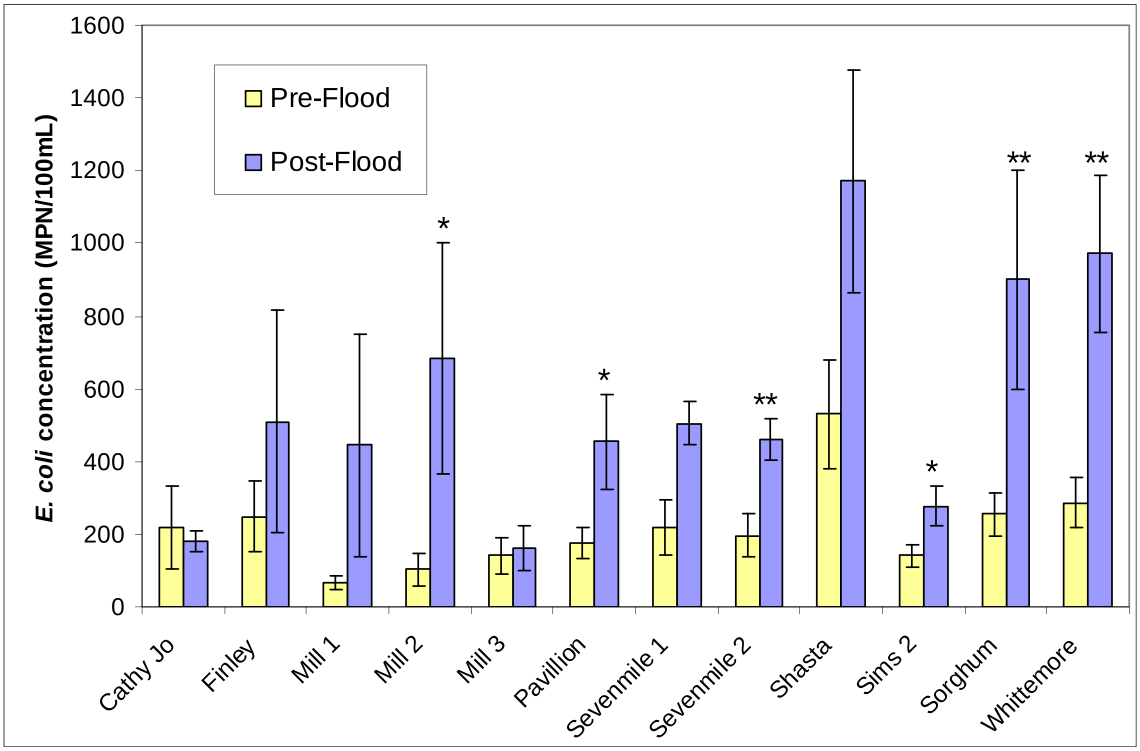

**Figure 8. Mean concentrations of *E. coli* before and after the May 1st, 2010 flood at each of the sample locations. MPN – most probably number. * significant difference (P≤ 0.05) between pre- and post-flood means; ** highly significant difference (P≤ 0.01) between pre- and post-flood means. Error bars represent the standard error of the mean.**

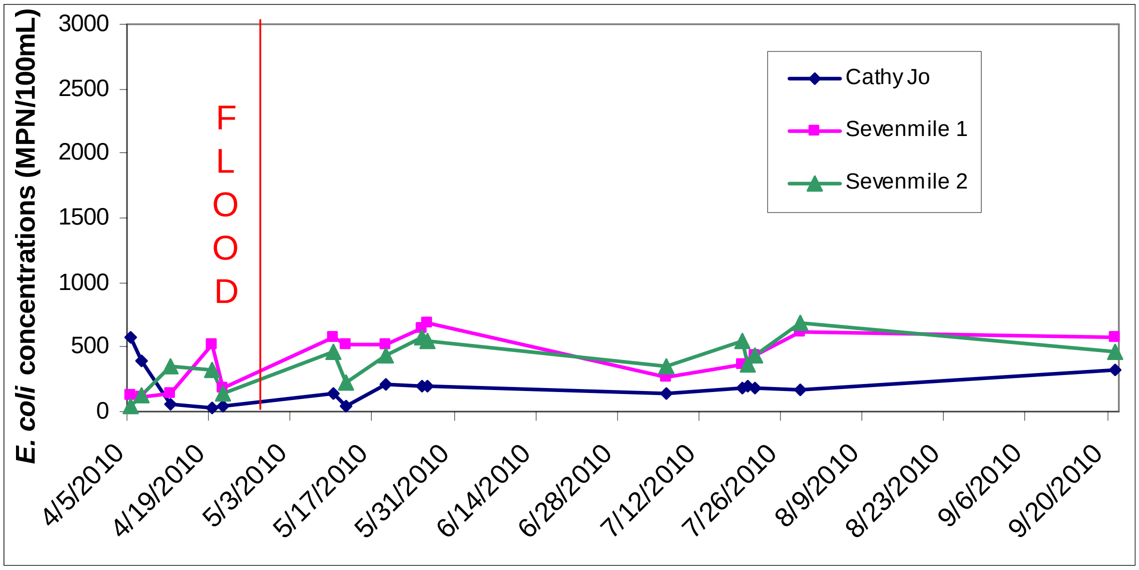

**Figure 9.** ***E. coli*** **values over time for Cathy Jo Branch, Sevenmile 1 and 2. The vertical red line indicates when the flood occurred during the sampling period.**

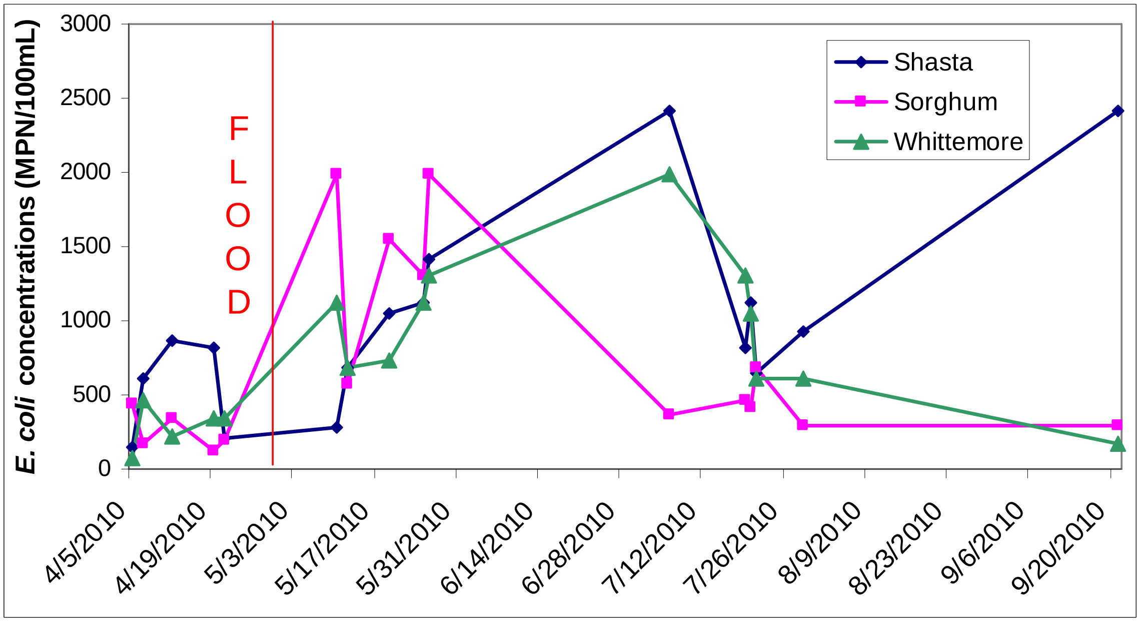

**Figure 10.** ***E. coli*** **values over time for Shasta, Sorghum and Whittimore Branch. The vertical red line indicates when the flood occurred during the sampling period.**

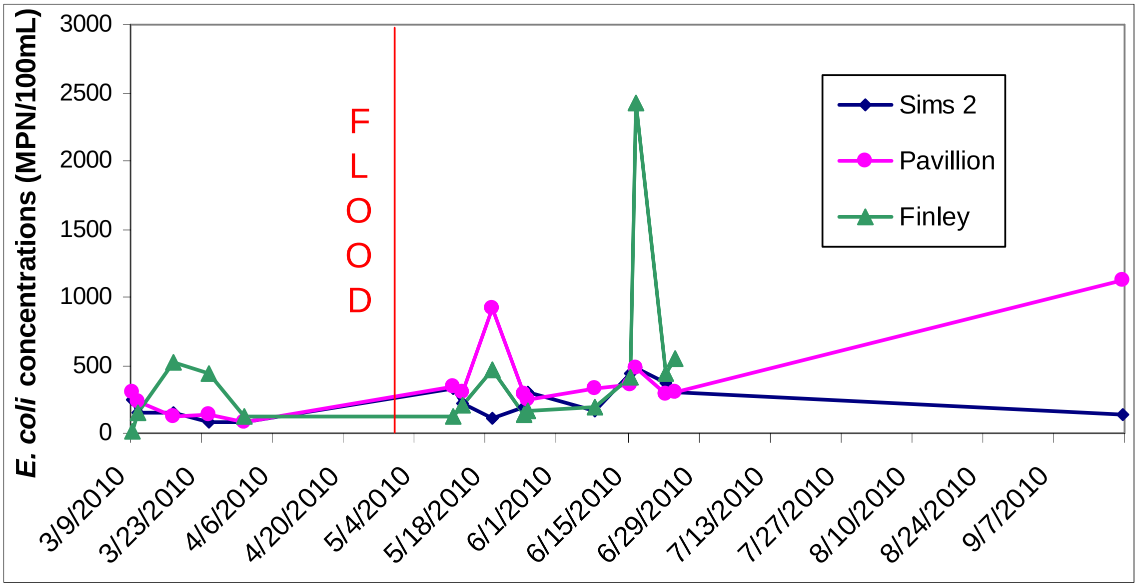

**Figure 11.** ***E. coli*** **values over time for Sims 2, Pavillion Branch and Finley. The vertical red line indicates when the flood occurred during the sampling period.**

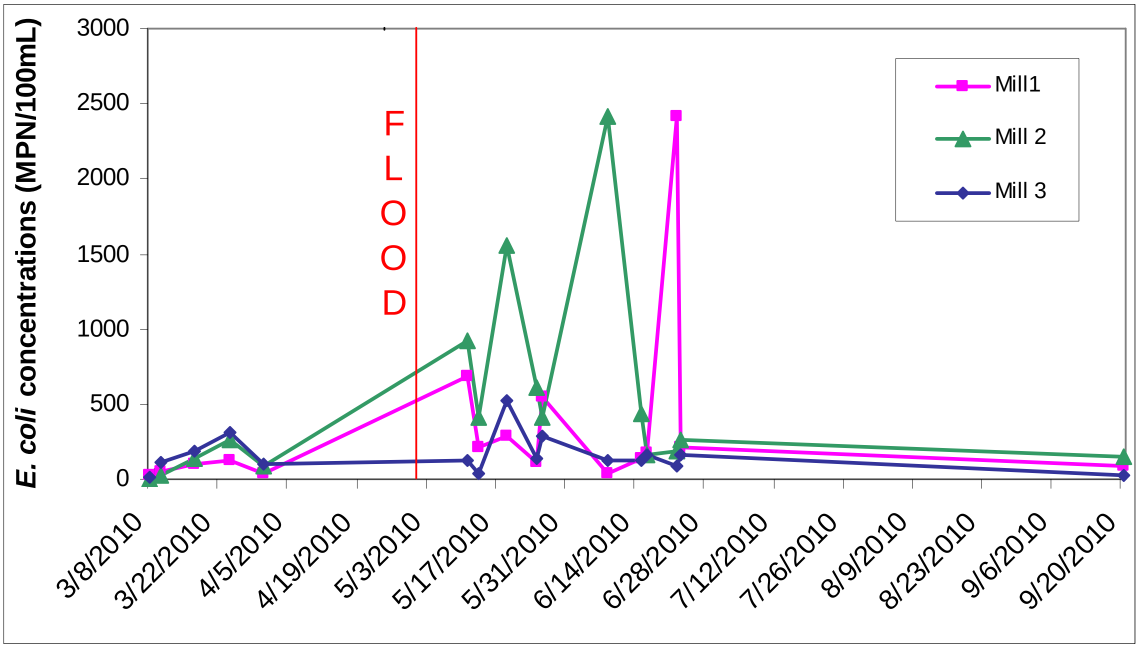

**Figure 12.** ***E. coli*** **values over time for Mill Creek 1, 2 and 3. The vertical red line indicates when the flood occurred during the sampling period.**

was exposed to different pollution sources. Water quality at all three Mill Creek sites met or almost met water quality standards by the end of June (Figure 12). Sorghum Branch and Whittemore Branch both returned to below water quality standards after July (Figure 10). *E. coli* levels in Shasta Branch have fluctuated since the storm, which may indicate that there are other influences on bacteria in its watershed (Figure 10). Whereas it is difficult to predict levels of *E. coli* after a flood, flood water can transport bacteria that are harmful to human health (Marsalek and Rochfort, 2004). In the days following the flood, sanitary sewers overflowed in or near Mill 2, Sorghum Branch and Whittemore Branch (Figure 13). There were significant ($P \leq 0.05$) increases in *E. coli* values at each of these locations (Figure 8). Sewer overflows likely contributed to the increased bacteria levels after the flood.

Water flow was measured at a gauging station just upstream from Mill 2. The amount of flow decreased and the temperature increased over the time period of the study: March 8th to September 21st (Figure 14). The summer heat caused a drop in flow and increase in temperature of the water, as would be expected.

Similar flow patterns were observed in 2008 and 2009 (Figure 15). However, *E. coli* values for the previous two years did not follow the same pattern observed in 2010. In fact, there were no spikes in *E. coli* for any of the sites in 2009. The elevated *E. coli* values in 2008 could be explained by sewer overflows; however, this was difficult to determine based on the data available. The 2008 levels of *E.* coli were much lower than those observed at some sites in 2010. Sources of pollutants are difficult to forecast, but are likely to be prevalent in streams in the days following a major flood. As noted by

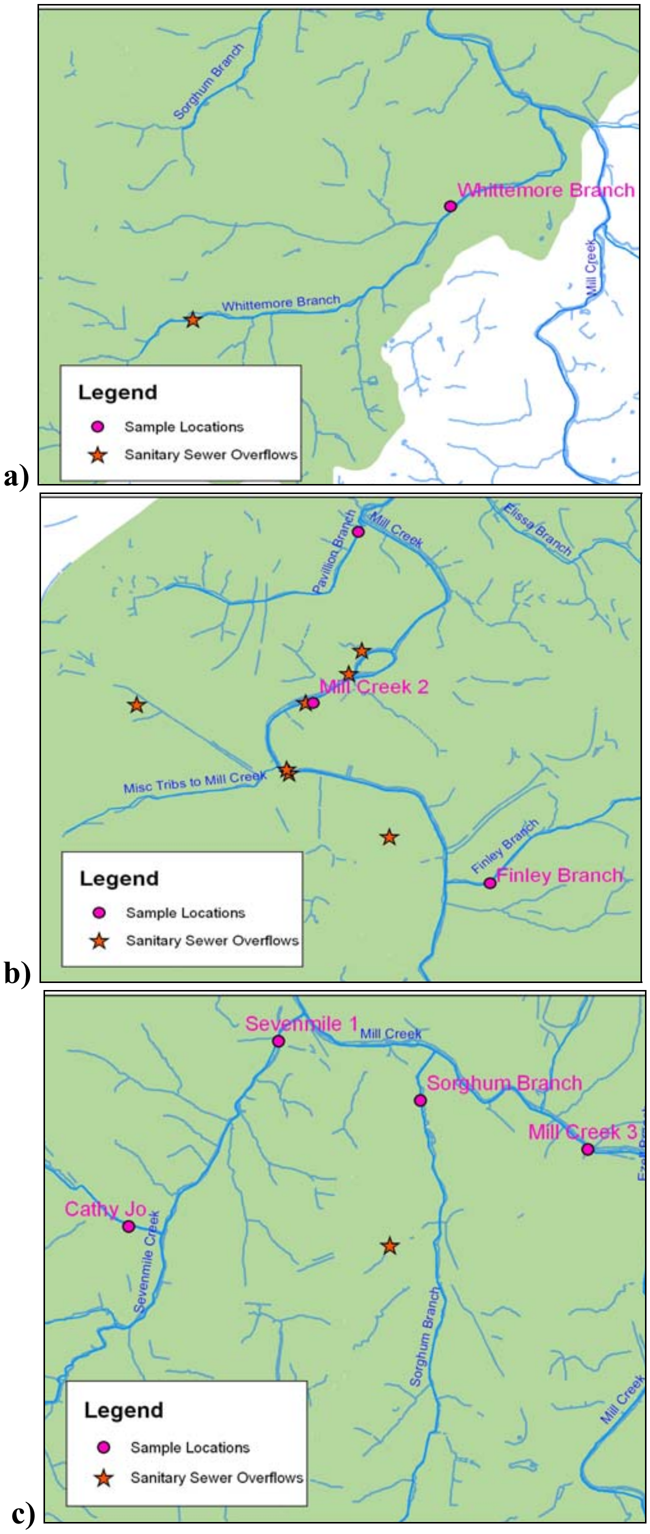

**Figure 13. Sample locations and locations of sanitary sewer overflows during the May 2010 flood in: a) Whittemore Branch, b) Mill Creek and, and c) Sorghum Branch.**

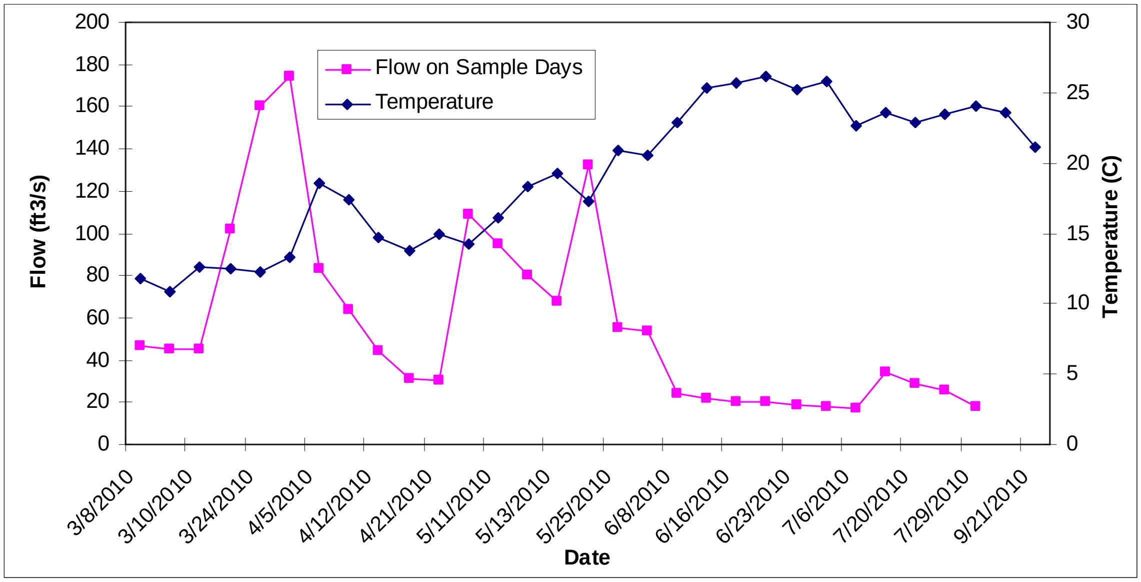

**Figure 14. Stream flow and water temperature from March to September, 2010, at USGS gauging station located on Mill Creek at the Thompson Lane overpass.**

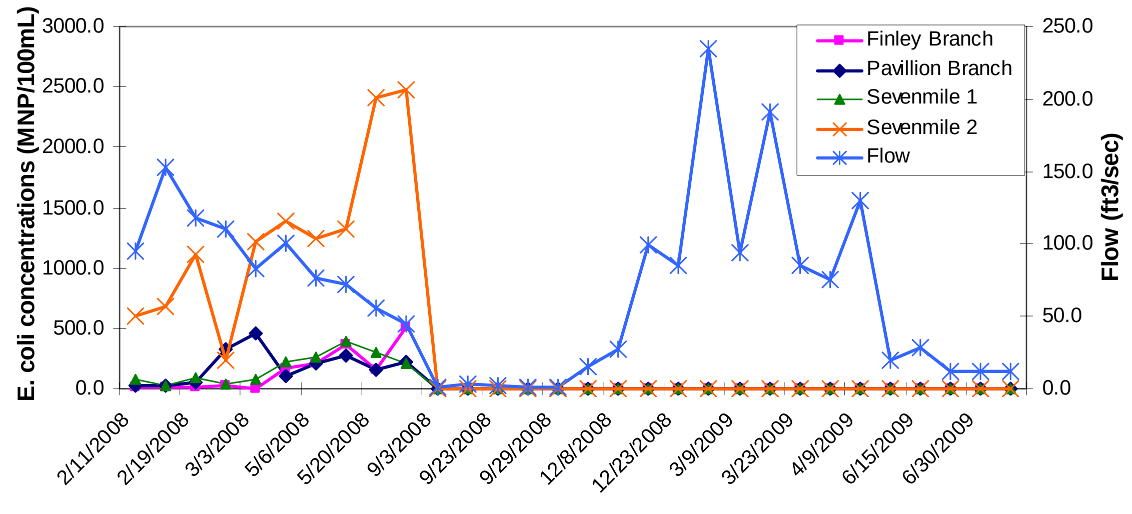

**Figure 15.** ***E. coli*** **and flow data from 2008 and 2009 at sample locations for Finley, Pavillion Branch, Sevenmile 1, and Sevenmile 2.**

Heberger et al. (2008), rainwater increases bacteria loads in streams, often as a result of sewer overflows.

## Dissolved Oxygen

The dissolved oxygen (DO) levels in 11 of the 12 sampled streams were significantly ($P \leq 0.05$) lower after the flood than before the flood (Figure 16). However, dissolved oxygen is such a complex water quality parameter that it is difficult to determine if the flood caused these decreased levels. Alp and Melching (2009) studied the effect of storms on in-stream water quality and stated that DO concentration is complex because it is influenced by many conditions and processes including temperature, flow dilution, treatment plant loads, chemical biological oxygen demand (CBOD5), the nitrogen cycle, sediment oxygen demand, and algal growth and death. Each of these factors is subject to a different duration during a storm.

The paired t-test showed that the variance before and after sample the flood means was not significantly different ($P = 1.0$). Variance of DO was significantly less ($P \leq 0.05$) after the flood for only two of the creeks studied (Figure 17). The overall mean was significantly ($P= 0.000009$) less after the flood than before the flood. Whereas, DO could have been affected by the flood, other factors that influence DO make it difficult to determine if the flood was the driving force behind lower DO concentrations. Dissolved oxygen tends to decrease in the summer months. Historical data from 2008 and 2009 showed the same seasonal trends that were observed in the 2010 sample period (Figures 18 and 19).

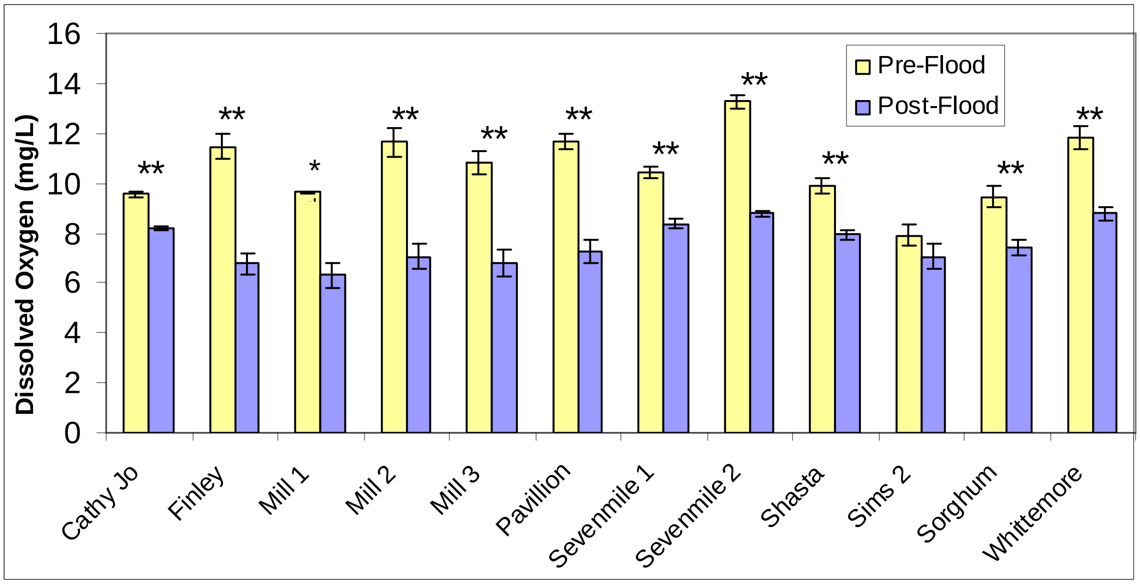

**Figure 16. Mean dissolved oxygen concentrations before and after the May 1st, 2010 flood at each of the sampling locations. * significant difference ($P \leq 0.05$) between pre= and post-flood means; ** highly significant difference ($P \leq 0.01$) between pre- and post-flood means. Error bars represent the standard error of the mean.**

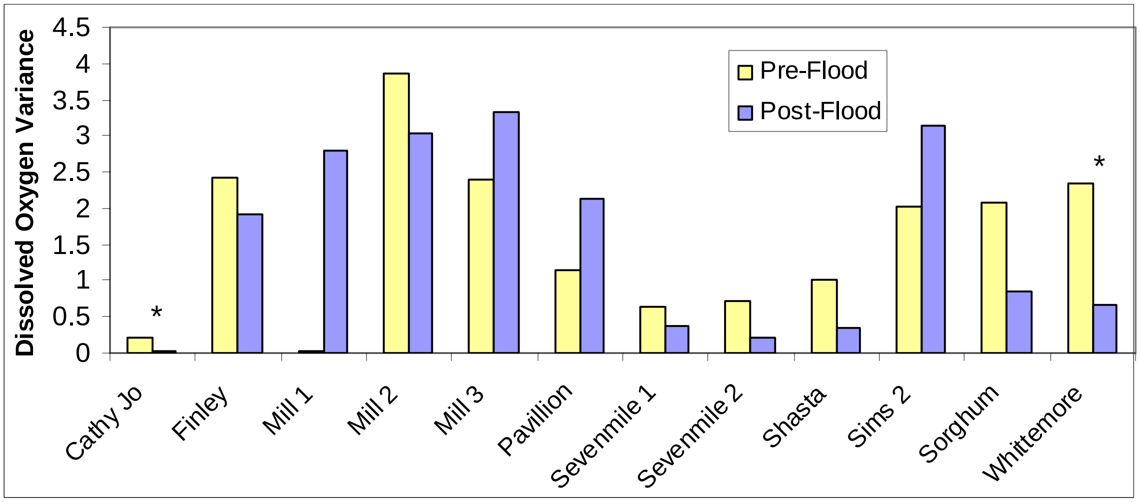

**Figure 17. Variance of dissolved oxygen samples before and after the May 1st, 2010 flood at each of the sampling locations. * significant difference ($P \leq 0.05$) between pre= and post-flood means; ** highly significant difference ($P \leq 0.01$) between pre- and post-flood means.**

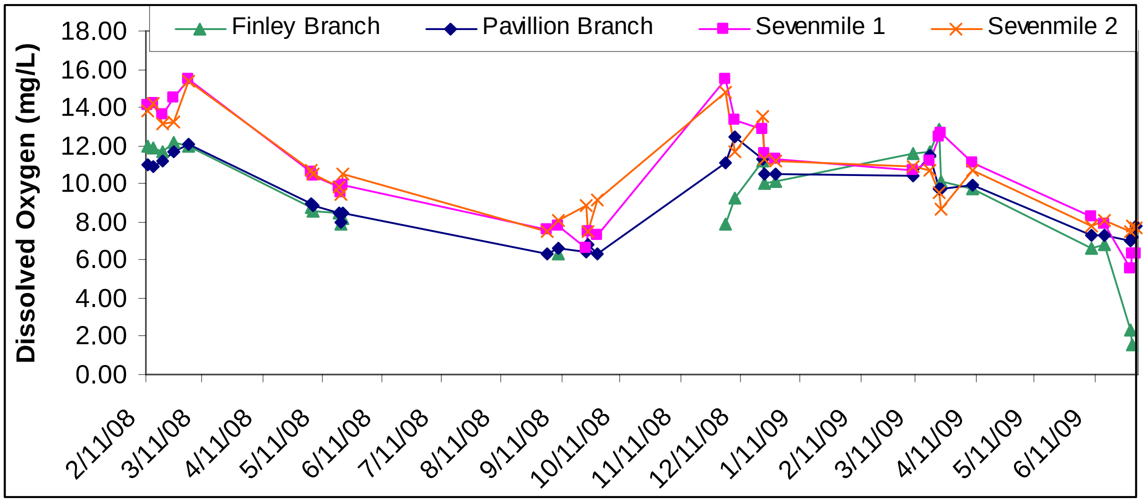

**Figure18. Dissolved oxygen concentrations over time at four of the twelve samples sites in 2008 and 2009.**

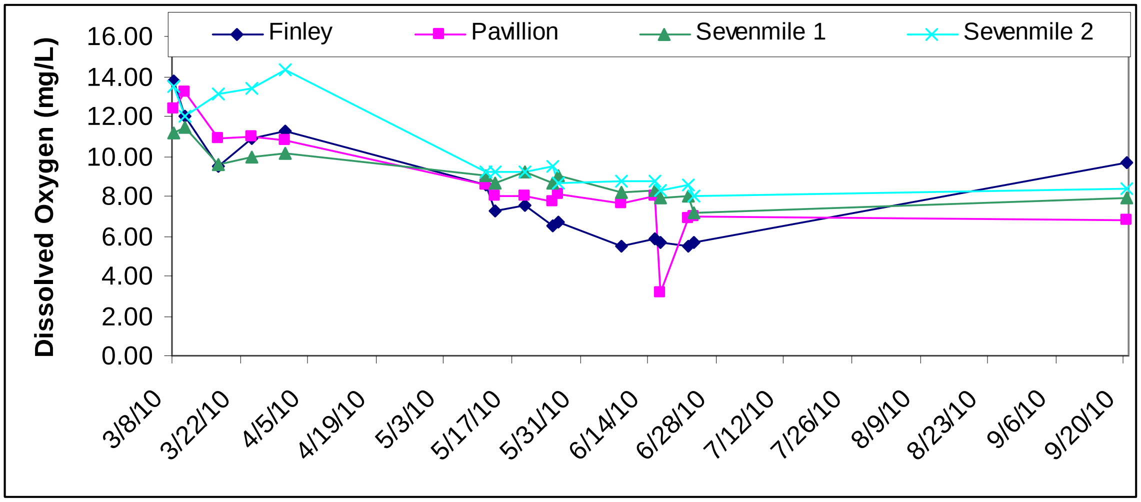

**Figure19. Dissolved oxygen concentrations over time for the 2010 sample period.**

## Conductivity

Conductivity measures the electrical conductance of water or its ability to conduct an electric current (Heathcote, 2009). Ions in solution conduct electricity, so the conductivity of water will increase as ionic strength increases (Heathcote, 2009). For example, salt water has a higher conductivity than fresh water because there are more ions in solution due to the higher concentration of sodium or salts. In the present study, there were no significant differences in overall variance ($P = 0.999$) or mean conductivity ($P = 0.098$) before and after the flood. Conductivity levels were significantly ($P \leq 0.05$) higher after the flood for only one site: Mill 3 (Figure 20). The variance was significantly ($P \leq 0.05$) higher after the flood for two of the sites: Mill 3 and Sorghum Branch (Figure 21). Historical data (Figure 22) compared to the 2010 sample data (Figure 23) shows that there was little fluctuations in conductivity over time. Although conductivity is useful as an indicator of water hardness, it is not a good water quality indicator for biological hazards in streams after a flood.

## pH

The paired t-test on combined data showed that there was a highly significant ($P = 0.0001$) difference in the before (mean pH= 8.19) and after (mean pH= 7.92) sample means. There were significant ($P \leq 0.05$) decreases in the mean pH levels at seven out of 12 sample sites and highly significant ($P \leq 0.01$) decreases at five of those seven sites (Figure 24). There was no significant difference ($P = 0.18$) between the overall variance between before and after the flood. However, the variance of individual sites before and after the flood was significantly different at five of the twelve sites (Figure 25). The

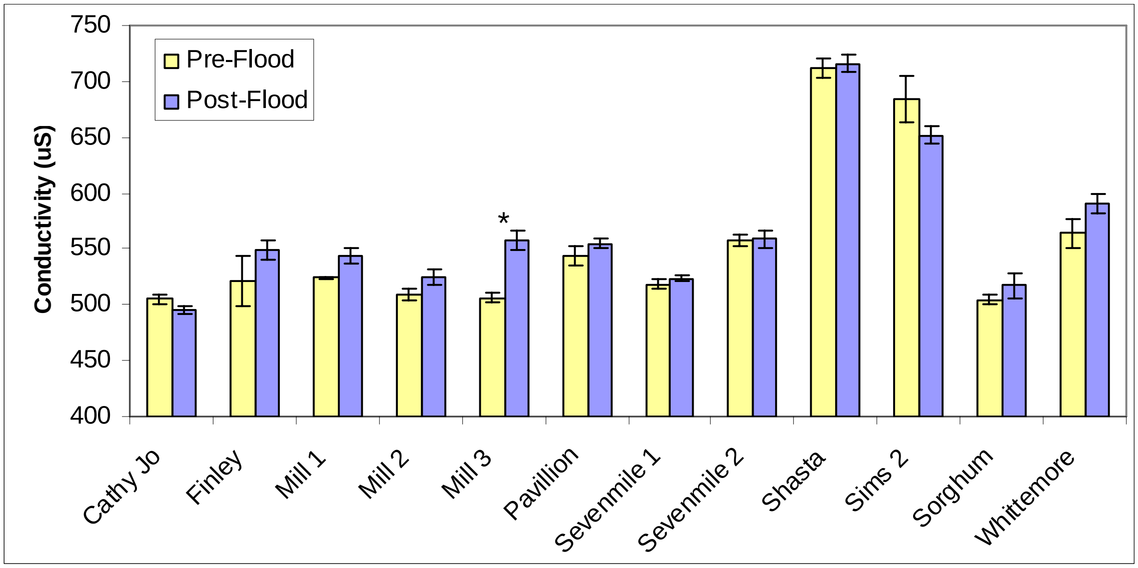

**Figure 20. Mean conductivity levels before and after the May 1$^{st}$, 2010 flood at each of the sampling location. * significant difference ($P \leq 0.05$) between pre- and post-flood means; ** highly significant difference ($P \leq 0.01$) between pre- and post-flood means. Error bars represent the standard error of the mean.**

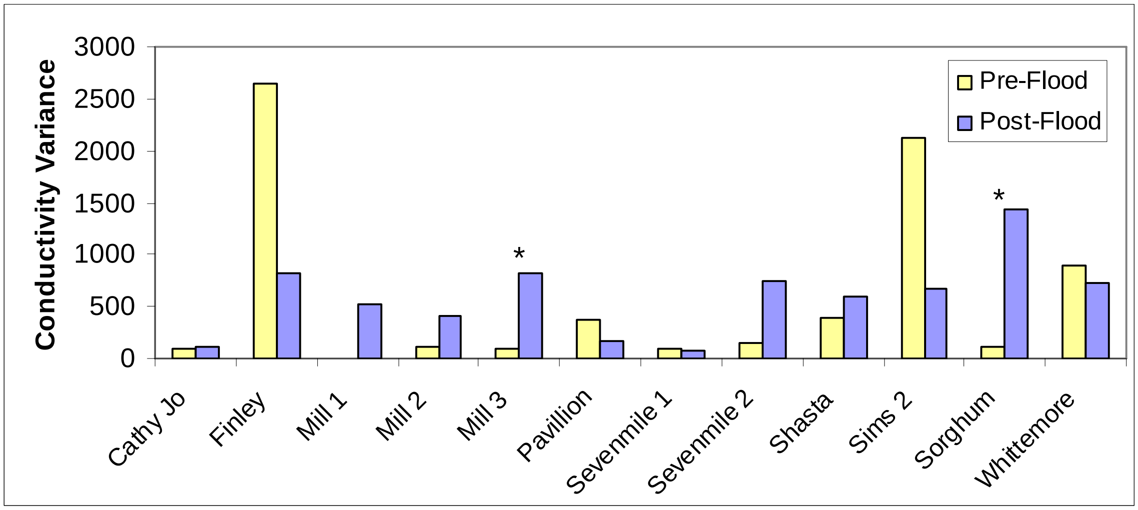

**Figure 21. Variance of conductivity levels before and after the May 1$^{st}$, 2010 flood. * significant difference ($P \leq 0.05$) between pre- and post-flood means; ** highly significant difference ($P \leq 0.01$) between pre- and post-flood means.**

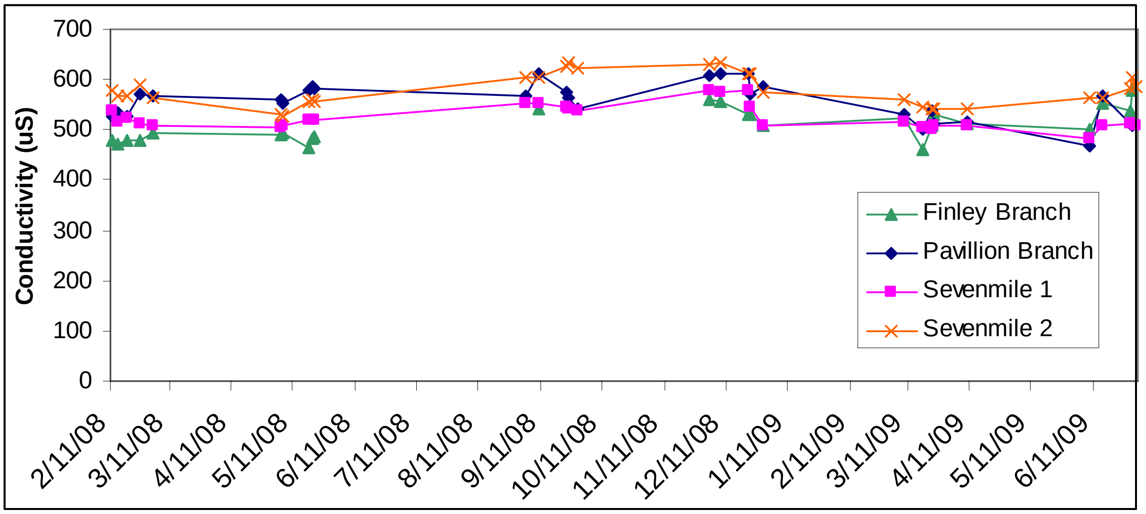

**Figure 22. Conductivity levels over time at four of the twelve sites in 2008 and 2009.**

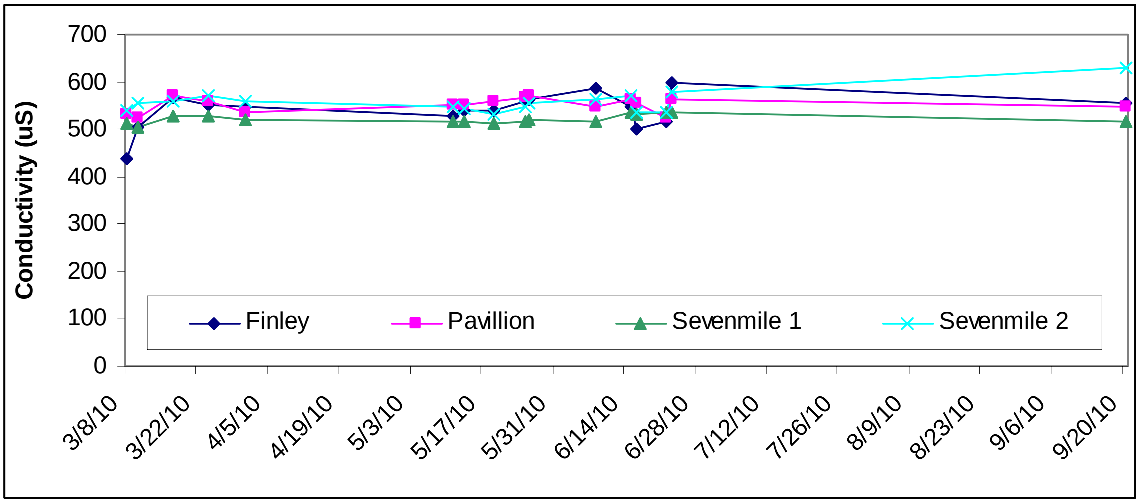

**Figure 23. Conductivity levels over time during the 2010 sample period.**

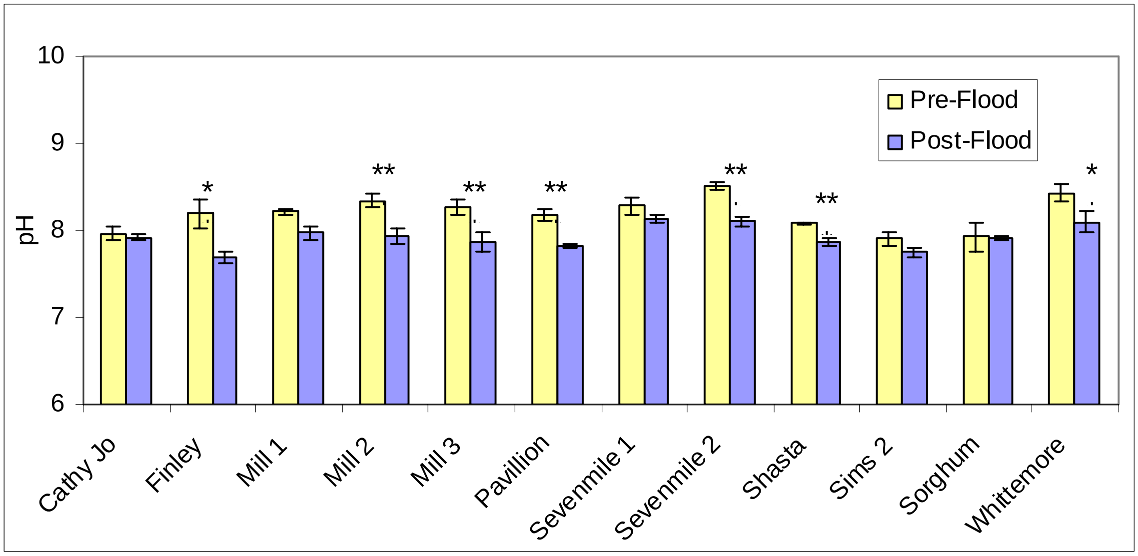

**Figure 24. pH levels before and after the May 1st, 2010 flood at each of the sample locations. * significant difference (P≤ 0.05) between pre- and post-flood means; ** highly significant difference (P≤ 0.01) between pre- and post-flood means. Error bars represent the standard error of the mean.**

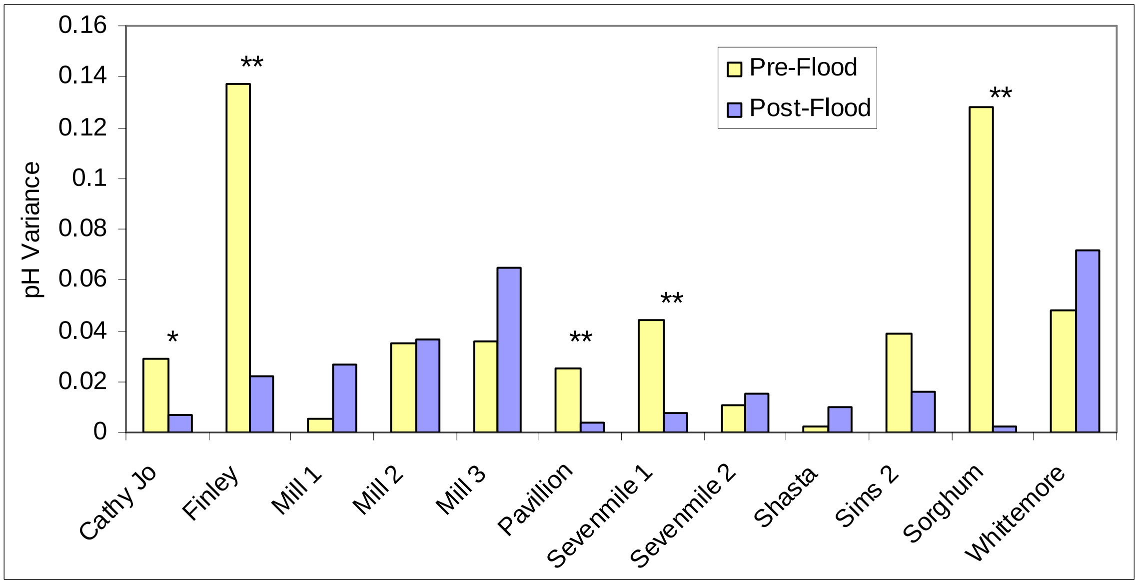

**Figure 25. Variance of pH samples before and after the May 1st, 2010 flood. * significant difference (P≤ 0.05) between pre- and post-flood means; ** highly significant difference (P≤ 0.01) between pre- and post-flood means.**

decrease in pH was probably associated with the presence of algae before the flood and the depletion of algae caused by the flood. According to the North Carolina Division of Water Quality (2010), when algal blooms are present, water pH can increase due to the removal of carbon dioxide ($CO_2$) during photosynthesis, leading to increased levels of hydroxide ($OH^-$). Scoured stream bottoms after the flood caused algae populations to die off, causing a reduction in pH. Because algae were not prevalent in all of the streams, there was no consistency between sample locations. Historical data (Figure 26) showed a slight decrease in pH levels during the summer months. Comparison of 2008 and 2009 data (Figure 26) with the 2010 sample period (Figure 27) shows that pH levels in 2010 were not abnormal due to the flood.

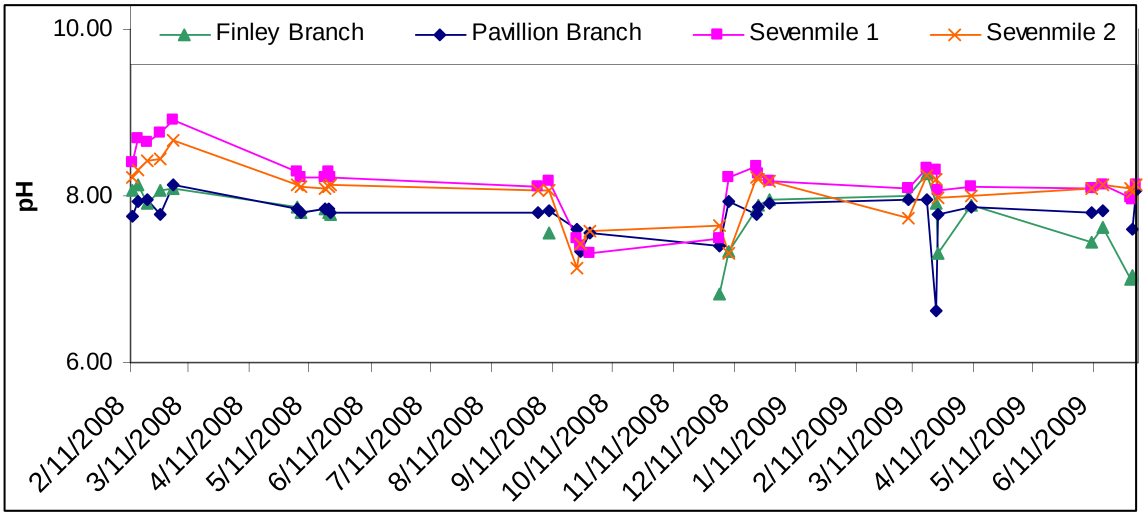

**Figure 26. pH data over time at four of the twelve sites in 2008 and 2009.**

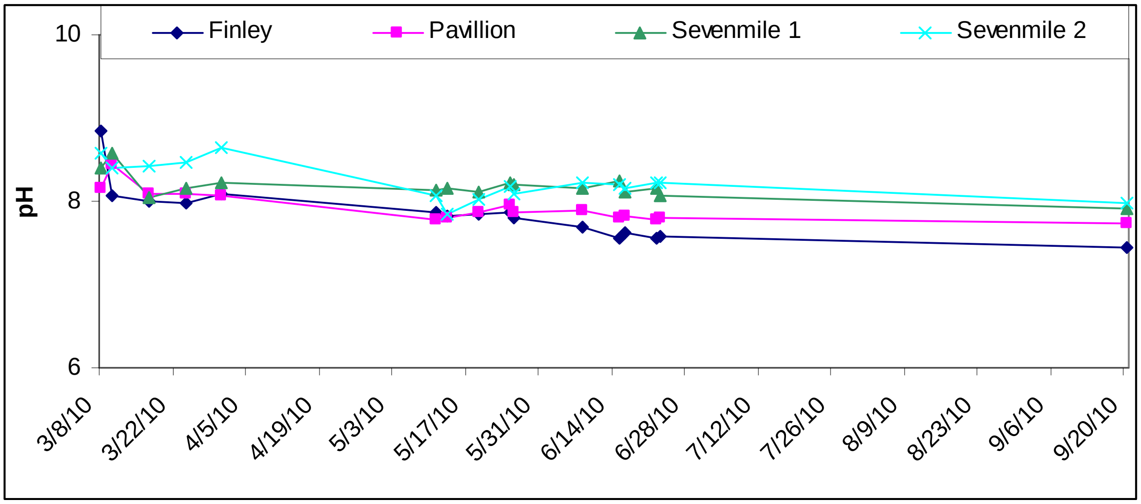

**Figure 27. pH values over time during the 2010 sample period.**

## Conclusion

Public health and safety is a concern when people come in contact with streams or other bodies of water that were recently flooded. This study determined that the receiving flood waters are likely to have elevated *E. coli* for extended periods of time (for three months or more) due to various inputs of pollution. One prevalent source is sanitary sewers that fail during a storm event. In this study, sample locations in proximity to sanitary sewer overflows had elevated *E. coli* levels. The complexity of stormwater runoff makes it difficult to predict the effects of floods on receiving waters. Land use is a characteristic that should be taken into consideration. Because urban streams often have mixed land uses, it is difficult to track pollution sources. Dissolved oxygen, conductivity and pH are sensitive to seasonal change and therefore are not good indicators of hazardous water. It is advisable to avoid human contact with receiving waters after a storm or flood event to reduce the potential for transmission of harmful bacteria.

# References

Alp, Emre and Charles S. Melching. 2009. Evaluation of the duration of storm effects on in-stream water quality. Journal of Water Resources Planning and Management. 135, (2):107-116.

Cumberland River Compact. 2010. Mill Creek Watershed Association. Discovering an Urban Watershed. http://www.millcreeknashville.org/home.cfm (accessed July 28, 2010).

Eaton, Andrew D., Lenore S. Clesceri, and Arnold E. Greenberg. 1995. *Standard methods for the examination of water and wastewater.* 19th ed. Washington, DC: American Public Health Association.

Heathcote, Isobel W. 2009. *Integrated watershed management.* 2nd ed. New Jersey: John Wiley and Sons, Inc.

Heberger, Matthew G., John L Durant, Kimberly A. Oriel, Paul H. Kirshen, and Lee Minardi. 2008. Combining real-time bacteria models and uncertainty analysis for establishing health advisories for recreational waters. Journal of Water Resources Planning and Management 134, (1): 73-82.

IDEXX Laboratories, Inc. 2010. How to Use Colilert. http://www.idexx.com/view/xhtml/en_us/water/colilert.jsf?selectedTab=Overview (accessed July 28, 2010).

Layton, Alice, Larry McKay, Dan Williams, Victoria Garrett, Randall Gentry, and Gary Sayler. 2006. Development of *Bacteroides* 16S rRNA gene taqman-based real-time PCR assays for estimation of total, human, and bovine fecal pollution in water. Applied and Environmental Microbiology 72, (6):4214-4224.

Marsealek, Jiri, and Quintin Rochfort. 2004. Urban wet-weather flows: sources of fecal contaminatin impacting on recreational waters and threatening drinking-water sources. Journal of Toxicology and Environmental Health 67: 1765-1777.

Meays, Cindy L., Klaas Broersma, Rick Nordin, Asit Mazumder, and Mansour Samadpour. 2006. Diurnal variability in concentrations and sources of *Escherichia coli* in three streams. Canadian Journal of Microbiology 52, (11):130-1135.

Metro Water Services. 2010a. Overflow Notification Spreadsheet May 1-4, 2010.

Metro Water Services. 2010b. Flooded Pumping Station List.

National Oceanic and Atmospheric Administration (NOAA) National Climatic Data Center. 2010. State of Climate Global Hazards: May 2010. Retrieved from http://www.ncdc.noaa.gov/sotc/?report=hazards&year=2010&month=5&submitted=Get+Report

North Carolina Division of Water Quality. 2010. Algal blooms. North Carolina Division of Natural Resources. http://portal.ncdenr.org/web/wq/ess/eco/blooms (accessed October 14, 2010).

Peterson, Tina M, Rifai S. Hanadi, Monica P. Suarez, A. Ron Stein. 2005. Bacteria loads from point and nonpoint sources in an urban watershed. Journal of Environmental Engineering 131, no. (10): 1414-1425.

Redman, Charles L. 2003. Memorandum: *E. coli* methods and holding time. State of Oregon Department of Environmental Quality.

Tennessee Department of Environment and Conservation. 2008a. Tennessee Water Quality Control Board, General Water Quality Criteria, Chapter 1200-4-3.

Tennessee Department of Environment and Conservation. 2008b. Cheatham Lake Watershed (05130202) of the Cumberland River Basin Watershed Water Quality Management Plan.

Tennessee Department of Environment and Conservation. 2009a. Division of Water Pollution Control. 2007-8 Probabilistic Monitoring of Wadeable Streams in Tennessee.

Tennessee Department of Environment and Conservation. 2009b. Division of Water Pollution Control. Quality System Standard Operating Procedure for Chemical and Bacteriological Sampling of Surface Water. Revision 3.

United States Geological Survey (USGS). 2010. National Water Information System. Retrieved from http://waterdata.usgs.gov/ (accessed October 14, 2010).

Wade, Timothy J., Rebecca L. Calderon, Elizabeth Sams, Michael Beach, Kristen P. Brenner, Ann H. Williams, and Alfred P. Dufour. 2006. Rapidly measured indicators of recreational water quality are predictive of swimming-associated gastrointestinal illness. Environmental Health Perspectives 114, (1):24-28.

Wang, Xiaoyan, OU Yang, DOU Peiqian, and Fang Xiaoduo. 2009. Relationship between the variation of water quality in rivers and the characteristics of watershed at Miyun, Beijing, China. Chinese Journal of Geochemistry. No.28: 112-118.

# Appendix

**Table A.1.Variance and mean *E. coli* concentrations before and after the May 1st, 2010 flood.**

| | Variance | | F-test | Mean (MPN) | | t-test |
|---|---|---|---|---|---|---|
| Site | Pre - Flood | Post-Flood | P value | Pre - Flood | Post-Flood | P value |
| Cathy Jo | 63619 | 4465 | 0.0004 | 217 | 180 | 0.7616 |
| Finley | 47014 | 473644 | 0.0200 | 248 | 510 | 0.2931 |
| Mill 1 | 1857 | 468466 | 3.74E-05 | 66 | 445 | 0.0971 |
| Mill 2* | 10513 | 503067 | 0.0010 | 103 | 683 | 0.0225 |
| Mill 3 | 12648 | 18942 | 0.3711 | 140 | 163 | 0.7560 |
| Pavillion* | 8762 | 83767 | 0.0217 | 177 | 454 | 0.0132 |
| Sevenmile 1 | 28585 | 18091 | 0.2536 | 218 | 505 | 0.0025 |
| Sevenmile 2** | 17364 | 16020 | 0.4149 | 196 | 462 | 0.0018 |
| Shasta | 111950 | 467871 | 0.0903 | 532 | 1172 | 0.0698 |
| Sims 2* | 4825 | 14995 | 0.1429 | 141 | 276 | 0.0398 |
| Sorghum** | 17033 | 455487 | 0.0031 | 255 | 901 | 0.0100 |
| Whittemore** | 22212 | 233199 | 0.0183 | 287 | 971 | 0.0009 |

**Table A.2. Variance and mean dissolved oxygen concentrations before and after the May 1st, 2010 flood.**

| | Variance | | F-test | Mean (mg/L) | | t-test |
|---|---|---|---|---|---|---|
| Site | Pre - Flood | Post-Flood | P value | Pre - Flood | Post-Flood | P value |
| Cathy Jo | 0.22 | 0.04 | 0.0122 | 9.55 | 8.21 | 0.0017 |
| Finley | 2.43 | 1.92 | 0.3442 | 11.48 | 6.77 | 2.85E-05 |
| Mill 1 | 0.02 | 2.80 | 0.0624 | 9.66 | 6.32 | 0.0200 |
| Mill 2* | 3.86 | 3.04 | 0.3447 | 11.63 | 7.07 | 0.0007 |
| Mill 3 | 2.40 | 3.32 | 0.4044 | 10.79 | 6.78 | 0.0008 |
| Pavillion* | 1.14 | 2.14 | 0.2847 | 11.67 | 7.26 | 3.24E-05 |
| Sevenmile 1 | 0.64 | 0.38 | 0.2235 | 10.44 | 8.36 | 0.0001 |
| Sevenmile 2** | 0.71 | 0.21 | 0.0548 | 13.27 | 8.78 | 1.23E-09 |
| Shasta | 1.02 | 0.34 | 0.0727 | 9.92 | 7.94 | 0.0002 |
| Sims 2* | 2.03 | 3.15 | 0.3578 | 7.90 | 7.07 | 0.3762 |
| Sorghum** | 2.07 | 0.86 | 0.1196 | 9.44 | 7.43 | 0.0043 |
| Whittemore** | 2.34 | 0.67 | 0.0498 | 11.86 | 8.78 | 0.0082 |

**Table A.3. Variance and mean conductivity levels before and after the May 1st, 2010 flood.**

| | Variance | | F-test | Mean | | t-test |
|---|---|---|---|---|---|---|
| Site | Pre - Flood | Post-Flood | P value | P value | Post-Flood | P value |
| Cathy Jo | 86.2 | 117.9 | 0.4089 | 505.3 | 495.0 | 0.0881 |
| Finley | 2648.3 | 812.5 | 0.0590 | 521.3 | 548.4 | 0.1913 |
| Mill 1 | 4.5 | 519.3 | 0.0723 | 524.5 | 543.3 | 0.2834 |
| Mill 2* | 113.3 | 412.2 | 0.1124 | 509.4 | 524.8 | 0.1372 |
| Mill 3 | 101.9 | 815.7 | 0.0299 | 506.5 | 557.4 | 0.0001 |
| Pavillion* | 367.3 | 172.3 | 0.1512 | 543.6 | 554.6 | 0.1968 |
| Sevenmile 1 | 90.3 | 81.0 | 0.4023 | 518.4 | 523.3 | 0.3401 |
| Sevenmile 2** | 149.7 | 742.5 | 0.0683 | 557.2 | 558.5 | 0.9185 |
| Shasta | 392.8 | 588.5 | 0.3710 | 712.4 | 716.1 | 0.7712 |
| Sims 2* | 2127.7 | 668.1 | 0.0625 | 684.2 | 651.5 | 0.0866 |
| Sorghum** | 115.3 | 1433.5 | 0.0134 | 504.6 | 517.2 | 0.3279 |
| Whittemore** | 896.7 | 729.0 | 0.3583 | 563.8 | 590.7 | 0.0949 |

**Table A.4. Variance and mean temperatures before and after the May 1st, 2010 flood.**

| | Variance | | F-test | Mean (˚C) | | t-test |
|---|---|---|---|---|---|---|
| Site | Pre - Flood | Post-Flood | P value | Pre - Flood | Post-Flood | P value |
| Cathy Jo | 1.4 | 3.4 | 0.2064 | 15.9 | 19.4 | 0.0017 |
| Finley | 2.2 | 7.8 | 0.1145 | 11.7 | 20.3 | 1.69E-05 |
| Mill 1 | 3.9 | 21.3 | 0.3228 | 11.7 | 25.2 | 0.0023 |
| Mill 2* | 1.0 | 11.9 | 0.0147 | 11.7 | 24.3 | 8.61E-07 |
| Mill 3 | 0.9 | 22.2 | 0.0034 | 11.3 | 24.2 | 1.55E-06 |
| Pavillion* | 1.3 | 4.5 | 0.1241 | 12.2 | 19.9 | 2.57E-06 |
| Sevenmile 1 | 7.1 | 12.8 | 0.3002 | 15.5 | 21.1 | 0.0082 |
| Sevenmile 2** | 5.1 | 15.4 | 0.1497 | 15.8 | 21.1 | 0.0157 |
| Shasta | 5.4 | 11.1 | 0.2579 | 16.1 | 19.5 | 0.0596 |
| Sims 2* | 4.2 | 8.2 | 0.2746 | 13.5 | 21.7 | 4.96E-05 |
| Sorghum** | 5.6 | 13.2 | 0.2089 | 15.2 | 21.2 | 0.0052 |
| Whittemore** | 6.1 | 16.7 | 0.1718 | 16.7 | 20.6 | 0.0674 |

**Table A.6 Variance and mean pH concentrations before and after the May 1st, 2010 flood.**

| | Variance | | F-test | Mean | | t-test |
|---|---|---|---|---|---|---|
| Site | Pre – Flood | Post-Flood | P value | Pre - Flood | Post-Flood | P value |
| Cathy Jo | 0.03 | 0.01 | 0.0251 | 7.96 | 7.92 | 0.6620 |
| Finley | 0.14 | 0.02 | 0.0089 | 8.19 | 7.70 | 0.0336 |
| Mill 1 | 0.00 | 0.03 | 0.3259 | 8.22 | 7.97 | 0.0619 |
| Mill 2* | 0.03 | 0.04 | 0.5264 | 8.34 | 7.93 | 0.0014 |
| Mill 3 | 0.04 | 0.07 | 0.2990 | 8.27 | 7.87 | 0.0078 |
| Pavillion* | 0.02 | 0.00 | 0.0065 | 8.17 | 7.82 | 0.0049 |
| Sevenmile 1 | 0.04 | 0.01 | 0.0100 | 8.28 | 8.13 | 0.1908 |
| Sevenmile 2** | 0.01 | 0.02 | 0.3878 | 8.51 | 8.11 | 2.03E-05 |
| Shasta | 0.00 | 0.01 | 0.0807 | 8.08 | 7.86 | 0.0005 |
| Sims 2* | 0.04 | 0.02 | 0.1215 | 7.90 | 7.75 | 0.0787 |
| Sorghum** | 0.13 | 0.00 | 0.0000 | 7.93 | 7.91 | 0.5237 |
| Whittemore** | 0.05 | 0.07 | 0.3713 | 8.43 | 8.10 | 0.0319 |