Lambert Creek Bacterial Source Identification Study Final Report

Vadnais Lake Area Water Management Organization

Lambert Creek Bacterial Source Identification Study
Project No. 78186

August 21, 2020

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prepared for

Vadnais Lake Area Water Management Organization
Vadnais Heights, MN

Project No. 78186

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LIST OF ABBREVIATIONS

Abbreviation	**Term/Phrase/Name**
bgs	gelow ground surface
BMP	best management practice
Burns & McDonnell	Burns & McDonnell Engineering, Inc.
cfs	cubic feet per second
COC	Chain of Custody
ft/s	feet per second
GIS	Geographic Information System
I-35E	Interstate 35E
mL	milliliter
MPN	Most Probable Number
MS4	municipal separate storm sewer system
PVC	polyvinyl chloride
qPCR	quantitative polymerase chain reaction
SOP	Standard Operating Procedure
SPRWS	Saint Paul Regional Water Service
TMDL	total maximum daily load
VLAWMO	Vadnais Lake Area Water Management Organization

1.0 INTRODUCTION

Lambert Creek is located in the northeast Twin Cities Metropolitan Area of Minnesota in the Upper Mississippi River Basin. The Lambert Creek Watershed covers an area of approximately 25 square miles and includes portions of the cities of North Oaks, White Bear Lake, Gem Lake, Vadnais Heights, Lino Lakes, and White Bear Township, Minnesota. The watershed falls within the jurisdiction of the Vadnais Lake Area Water Management Organization (VLAWMO) and consists of a mix of urban, open space, parks, and agricultural land uses. A map of the Lambert Creek Watershed is shown on Figure 1-1.

Lambert Creek does not currently meet Minnesota State standards for the indicator bacteria *Escherichia coli* (*E. coli*) and has been placed on the State's 303(d) List of Impaired Water Bodies. As a result, in August 2013, the Minnesota Pollution Control Agency developed a total maximum daily load (TMDL) for *E. coli* in Lambert Creek (Wenck, 2013), which is the total amount of a pollutant that a water body can assimilate without exceeding the established water quality standard for that pollutant.

In response to the TMDL, VLAWMO contracted Burns and McDonnell Engineering, Inc. (Burns & McDonnell) to conduct a bacterial source identification study to identify the sources of *E. coli* in the Lambert Creek Watershed and recommend best management practices (BMPs) that can be implemented to meet the load reduction requirements of the TMDL. This document summarizes the results of monitoring conduced in the Watershed from 2014 through 2017 as part of the Lambert Creek Bacterial Source Identification Study (Source Identification Study).

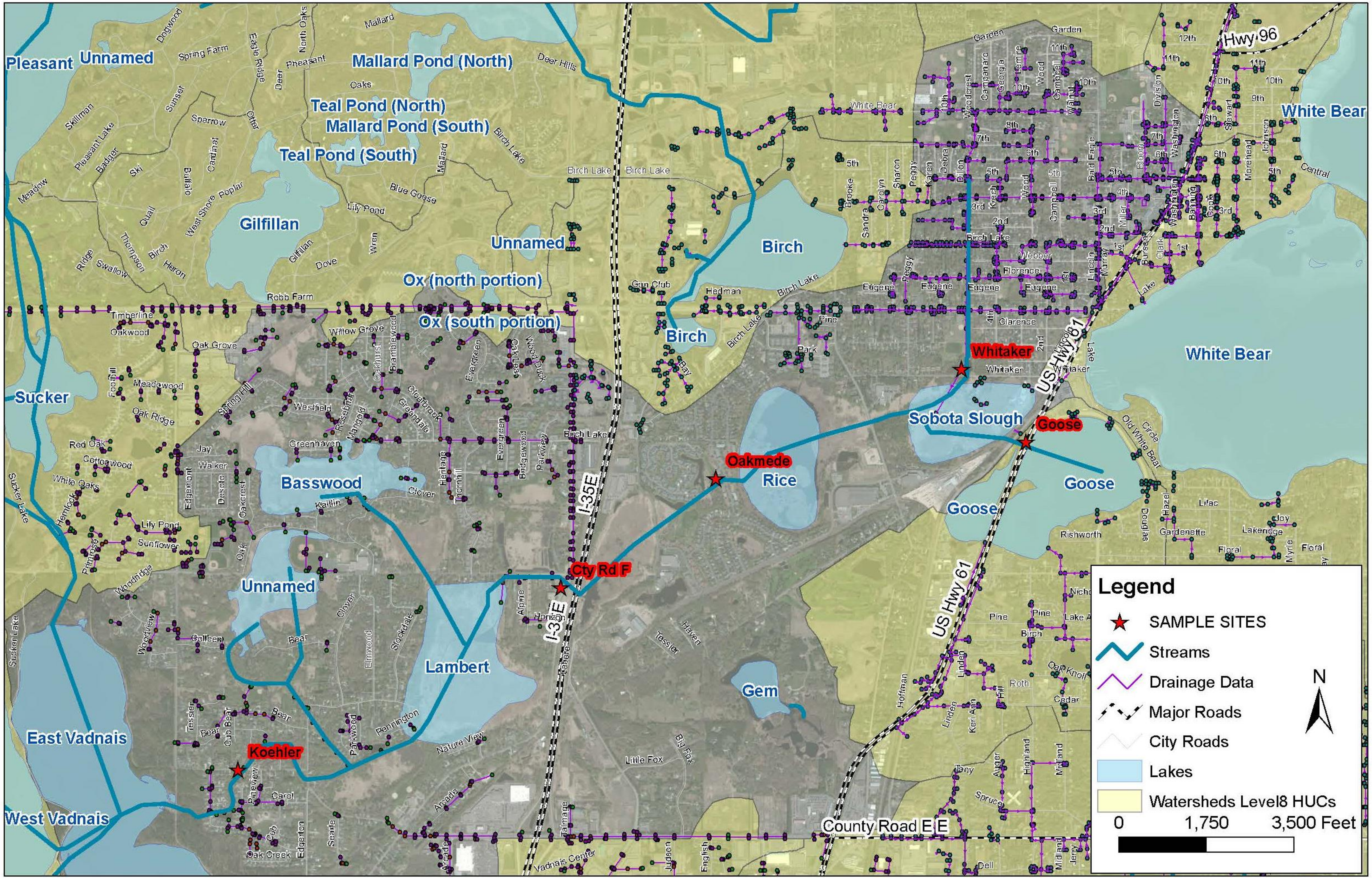
1.1 Project Objectives

The Lambert Creek Watershed encompasses the following five contiguous drainages, each with a Primary Monitoring Site at its base where TMDL compliance monitoring is conducted: Whitaker, Goose, Oakmede, Country Road F, and Koehler (Figure 1-1). A Monitoring Plan for the Source Identification Study was developed in the summer of 2014 to identify the sources of bacteria in two of the five Lambert Creek drainages: Oakmede and County Road F. Although the TMDL requires bacterial load reductions during both dry and wet weather, this first phase of the Source Identification Study, which was conducted in the summer and fall of 2014, focused exclusively on identifying bacterial sources in dry weather in the County Road F and Oakmede drainages (i.e., at least 72 hours following a rain event). The 2015 study focused on bacterial sources in dry weather for the Goose and Whitaker drainages, the 2016 study focused on wet weather in the County Road F and Oakmede drainages, and the final 2017 study focused on wet weather in the Goose and Whitaker drainages. The Koehler drainage was not assessed as part of the Source Identification Study.

1.2 Project Team

This final report for the Source Identification Study was produced by Burns & McDonnell, but the field sampling, assessment, and coordination with the required laboratories was conducted primarily by staff from VLAWMO.

Figure 1-1: Map of the Lambert Creek Watershed and Five Primary Monitoring Sites



2.0 STUDY DESIGN

The study design for the Source Identification Study was based on similar studies conducted in other regions of the county for identifying sources of indicator bacteria in urban watersheds. It is based on three design approaches that have been shown to be effective in identifying sources of bacteria in urban watersheds throughout the country (SCCWRP, 2013). The study design approaches are: (1) Phased, (2) Tiered, and (3) Adaptive. Each of these design approaches is described briefly, below.

2.1 Phased Approach

The Lambert Creek Watershed encompasses approximately 25 square miles (Wenck, 2013), consisting of a diverse mix of urban, open space, and recreational land uses intermixed with numerous creeks, wetlands, and lakes. The TMDL requires that the water quality standards for *E. coli* are met at all monitoring locations within the watershed during both dry and wet conditions. In order to identify the sources of bacteria in this diverse watershed, the study was phased to focus first on dry weather conditions (at least 72 hours following precipitation). Dry weather conditions were assessed in the Oakmede and County Road F drainages in 2014, and in the Goose and Whitaker drainages in 2016. Identifying and remediating sources of bacteria is simpler under dry weather conditions than wet weather conditions, particularly when the watershed has not been thoroughly characterized or monitored. Following the dry weather studies, wet weather conditions were assessed in the Oakmede and County Road F drainages in 2015, and the Goose and Whitaker drainages in 2017.

The phased approach will provide for an efficient use of limited resources and an effective means of initiating the bacterial source identification study for the Lambert Creek Watershed.

2.2 Tiered Approach

The Tiered Approach uses a stepwise process of assessing the watershed and identifying sources of bacteria in a prioritized, progressive process. This tiered approach has been developed from similar monitoring programs (SCCWRP, 2013) and modified with elements specific to the Lambert Creek Watershed.

The study was implemented using the following tiered steps:

1. Characterize the watershed by obtaining infrastructure maps, examining historical monitoring data for spatial and temporal trends, and conducting visual inspections during a site reconnaissance to develop a list of potential fecal contamination sources and transport mechanisms.

2. Based on the watershed characterization, develop a list of Study Questions to be addressed by the assessment and that are specific to the conditions within that drainage.
3. Conduct initial monitoring to produce a more detailed picture of spatial and temporal patterns in the drainage.
4. Where human sources are a potential contributor, test ambient waters for human source-specific genetic markers (even if traditional tools have not identified a leaking sanitary system). Place high priority on either detecting or confirming a human fecal source, as this source may pose the greatest relative human health risk.
5. Where leakage from a sanitary system is a potential source, investigate it using traditional tools such as closed-circuit television inspections or dye testing.
6. Where human sources have been accounted for and the relative human loadings are better understood, and/or a likely animal fecal pollution source (e.g., runoff from a dog park) has been identified, test ambient waters using non-human (animal) source-specific genetic markers.
7. Where source-specific genetic markers have yet to be developed for the suspected source(s), consider testing ambient waters using microbial community analysis (MCA) methods.

The basic steps listed above were modified to meet the specific characteristics of the drainages within the Lambert Creek watershed.

2.3 Adaptive Approach

Source identification studies can be difficult to conduct due to the ubiquitous nature of bacteria in the environment, the multiple sources within a given watershed, and the potential for regrowth of bacteria outside the host animal. For these reasons, source identification studies often do not lend themselves to prescriptive monitoring plans where the details of each monitoring element are determined prior to the initiation of the study. Instead, the most effective source identification studies rely on a basic monitoring framework with elements developed from the tiered approach discussed above. The details of each monitoring element are adaptive, whereby the results of the first element are used to focus the design for subsequent elements in the study. The adaptive approach allows the design of each element of the study to be built upon the results of the previous element, resulting in an increasingly focused approach to identifying the sources of bacteria in the drainage. The end result is a comprehensive and efficient assessment of potential bacterial sources in the drainage, leading to multiple lines of evidence for identifying those sources that have the greatest impact on water quality. These results also allow for focused recommendations on effective and efficient BMPs to remediate the bacterial source.

In this study, elements were developed specifically for the different drainages and basic monitoring schedules were provided to answer the drainage-specific Study Questions. When the results from the initial assessments were collected and analyzed, additional details were provided in the Monitoring Plan for subsequent monitoring, referred to in this report as Special Studies.

2.3.1 Study Questions

The Study was designed to answer specific study questions to better-understand the sources of *E. coli* in the watershed and the pathways that transport bacteria to the receiving waters. The Study questions for the dry and wet weather assessments are presented below.

Based on the information collected during the site reconnaissance and a review of eixitng information at the start of the Study, the following Study were assessed for each of the four drainages:

1. What are the potential sources of *E. coli* in each of the drainages in the Lambert Creek Watershed (e.g., local wildlife, domestic animals, leaking sewer or septic lines, other human sources, natural, etc.)?
2. How does bacteria survival, propagation, or re-growth contribute to *E. coli* levels in the storm drain system (e.g., leaf litter and grass clippings along curb lines or ditches) and discharge to surface waters of the creek?
3. Does the *E. coli* in the Watershed originate from human sources?
4. How can VLAWMO and their partners adapt current management practices to reduce levels of *E. coli* in Lambert Creek?

2.3.2 Monitoring Elements

The monitoring elements listed in Table 2-1 were designed to answer the Study Questions listed above for each of the four drainages. Because the study design for this assessment uses an adaptive approach, whereby the results of the first element are used to focus the design for subsequent elements, the elements were conducted sequentially as listed in Table 2-1.

Table 2-1: Monitoring Elements used to Assess the Four Drainages in the Lambert Creek Watershed to Determine Source of *E. coli*

Element Number	Monitoring Element
1	Visual Observations
2	*E. coli* Monitoring (culture)
3	Flow Monitoring
4	Human Origin Assessment
5	Non-human Origin Assessment
6	Special Studies (as needed)

Each monitoring element is described in Section 4.0 Materials and Methods.

3.0 MATERIALS AND METHODS

The sampling and analysis procedures used over the course of the study are discussed below.

3.1 Visual Observations

Visual observations are a critical component to bacterial source tracking investigations. They provide a direct means of assessing potential anthropogenic and non-anthropogenic bacterial inputs that are often unanticipated or over-looked when a project is designed. In this study, visual observations were made at each site during every field visit and recorded on a Visual Observation Form designed for the Lambert Creek Watershed. The Visual Observation form contains information for each site visited, including weather (including last time since rainfall), watershed and assessment location, site conditions, evidence of human bacterial sources, evidence of non-human bacterial sources, and evidence of flow or other transport mechanism. These visual observations were critical to the dry and wet weather assessments of each of the drainages.

3.2 Pollutograph Analysis

A pollutograph is a means of depicting the changes in concentrations of a pollutant over the course of a storm event. It is created by plotting the stream hydrograph from the beginning to the end of a storm event. Samples are collected over the course of the storm event (ascending limb, peak, and descending limb of the hydrograph) and the pollutant concentrations are plotted at the time they were collected on the hydrograph. In this way, changes in the pollutant concentrations can be seen as the creek rises, peaks, and falls (as depicted in the hydrograph). Pollutographs can be very helpful in identifying pollutant sources by helping to elucidate when the pollutant enters the receiving waters. They can also be helpful in designing BMPs to reduce pollutant concentrations and loads in the receiving waters because they demonstrate the capacity of the BMP needed to reduce a given load (e.g., as required for TMDLs).

3.3 Flow Monitoring

Flow was monitored during wet weather events at sites within each of the drainages. The primary monitoring site for each drainage has an established weir with a staff gage already installed. The field team monitored flow at these sites with a field camera that collects time-lapse imagery of the water level from the staff gage at the weir over the course of the storm event. These data for stream stage were converted to flow using the Manning Equation and known physical parameters of the creek at each of the weirs. Flow data wereplotted against time for the duration of the storm to produce a hydrograph for each site. Ideally, flow data from at least three storm events (0.25-0.50 inches in less than 3 to 4 hours) were recorded in this way. At other locations within each drainage, instantaneous flow was measured periodically throughout the course of the storm with a Marsh McBirney velocity meter. Estimates of flow were determined from the velocity data and the channel dimensions.

3.4 *E. coli* Monitoring

The purpose of the *E. coli* monitoring is to address Study Questions 1 through 4 for each of the drainages. *E. coli* monitoring was conducted at least 72 hours after a storm event during dry weather assessments. During wet weather, initial *E. coli* monitoring consisted of collecting samples over the course of a storm event at several sites to create a pollutograph, as described below. In addition to pollutograph monitoring, spot samples were collected at additional sites during wet weather. The spot samples were collected on an as-needed basis depending on the nature and extent of flow at the site.

Understanding the spatial and temporal patterns of *E. coli* concentrations during storm events from the primary monitoring sites and at locations that discharge to the primary sites allowed us to assess the spatial conditions over the course of a storm event that contribute to elevated *E. coli* levels.

3.5 Human Origin Assessment

The purpose of the Human Origin Assessment element was to address whether *E. coli* in each of the drainages originates from human sources. To answer this question, samples were collected and analyzed for the human markers at different locations in each of the drainages.

For molecular analyses during wet weather, samples were collected and composited to represent the ascending limb of the hydrograph (composite of first 2-3 samples of the storm), peak of the hydrograph (composite of middle 2-3 samples of the storm), and descending limb of the hydrograph (composite of final 2-3 samples of the storm). Two samples were collected at each monitoring location for each sampling event: one for *E. coli* analysis (which was stored on ice until delivery to the lab) and one for the human marker, which was stored on ice after collection, then composited with subsequent samples for each phase of the storm.

3.6 Non-Human Origin Assessment

The purpose of Non-Human Origin Assessment is to address whether the *E. coli* in each of the drainages originates from fecal material from non-human sources. During wet weather, this element was conducted for the first storm event in the same manner as the human marker assessment described above. The composite samples that represent the ascending limb, peak, and descending limb of the hydrograph that were assessed for the Human Marker were also analyzed for the avian and canine makers. The composite samples were delivered to the laboratory for filtration and the filter from that sample was sent to Weston Solutions for analyses of the human, avian, and canine markers. Similar to the human marker, the results of the non-human markers were assessed and additional samples were collected and analyzed at other sites during subsequent monitoring.

3.7 Sample Collection for Culture Analyses

Grab samples of water were collected at each sampling location from the center of the channel or storm drain (as applicable). Samples were collected in sterile, plastic, 100-mL bottles. Sample containers were kept in clear, resealable plastic bags until use. Just prior to sampling, the bag and sample container were opened, with both container and lid held face-down to prevent airborne particulate contamination. The bottle was filled and capped. No sediment or debris was allowed to enter the sample bottle.

Each field sample was labeled and identified with the project title, appropriate identification number, date and time of sample collection, and preservation method. The sample container was then sealed in the plastic bag. All samples were stored on ice in the dark from the time of sample collection until delivery to the analytical laboratory. All samples were delivered to the analytical laboratory in time to meet the required 6-hour holding time limitation.

To verify proper sampling technique, field blanks were collected at a rate of 5 percent of the overall samples per field event. Field blanks were collected using the sampling technique described above except that reagent-grade, nuclease-free water was substituted for the water sample.

3.8 Sample Collection for Molecular Analyses

Field collection procedures for samples that were analyzed for genetic markers (human or non-human) are detailed in the Standard Operating Procedures (SOP) for the Collection, Storage, and Transport of Samples for Molecular Analysis in SCCWRP (2013).

3.9 Laboratory Analyses for Culture Samples

Samples collected for culture analysis were analyzed by the Saint Paul Regional Water Service (SPRWS) in Saint Paul, Minnesota. All samples collected for culture analysis were analyzed by Method SM 9223B (Colilert® Quanti-Tray®)-97. The SPRWS is accredited for this analysis under the Safe Drinking Program.

3.10 Laboratory Analyses for Molecular Samples

The samples collected for molecular analyses were filtered by staff at the Ramsey County Department of Public Works and shipped on dry ice to Weston Solutions in Carlsbad, California. Laboratory analyses for the human and non-human (e.g., avian) genetic markers followed the protocols for qPCR assays described in SCCWRP (2013).

3.11 Sample Handling and Tracking

Each sample collected over the course of the study received a unique alphanumeric code (sample I.D. number) for tracking. This code was standardized for all samples and contained information as to the monitoring site, sample date, and sample interval number or sequential monitoring event number (as appropriate).

To verify proper tracking and handling of the samples, Chain-of-Custody (COC) Forms (provided by VLAWMO and/or participating laboratories) accompanied the samples from the initial pickup to the final extractions and analysis. These forms, or equivalent, were used to track and handle samples. All samples collected were labeled with the following information:

- Project name
- Date
- Time
- Sampling location name and number
- Preservative
- Collector’s initials
- Sample I.D. number
- Analyte(s) to be analyzed

Completed COC forms were placed in a plastic bag and kept inside the container containing the samples. Once delivered to the laboratory, the COC form was signed by the person receiving the samples. The condition of the samples were noted and recorded by the receiver. COC records were included in the final reports prepared by the analytical laboratories.

Upon delivery to the laboratory, the laboratory manager inspected the condition of the samples and reconciled the label information to the COC form. The time of sample collection was noted, and the samples were stored at the appropriate temperature until analysis began, always within the 6-hour holding time limitation.

4.0 DRAINAGE STUDIES

4.1 Oakmede Drainage

The Oakmede Drainage lies near the center of the Lambert Creek Watershed, as shown on Figure 1-1. The drainage is less urbanized than the other drainages in the Watershed with the majority of urban runoff flowing into Rice Lake, which comprises nearly a third of the Oakmede Drainage. Flows exit Rice Lake on the west side, approximately 250 feet upstream of the Oakmede Primary Monitoring Site (Oak-P), which is located just downstream (west) of Oakmede Lane (Figure 4-1). Water flowing out of Rice Lake passes over a weir and through a short reach before passing under Oakmede Lane via a culvert just upstream of Oak-P. It is assumed that nearly 100 percent of the dry weather flow in the Oakmede Drainage passes through Rice Lake before reaching Oak-P.

In addition to the flows from the Oakmede Drainage that pass through Rice Lake upstream of Oak-P, there is a very small drainage of urbanized area that flows directly to Site Oak-P via surface streets along Oakmede Lane to the south of Site Oak-P and Oakmede Lane, with Fisher Lane to the north. This sub-drainage is shown in red on Figure 4-1. There are no storm drains in this small sub-drainage, and any flow that may reach Oak-P was conveyed along Oakmede Lane by gutters that discharge to Lambert Creek via storm drain inlets just upstream of Site Oak-P. Other urbanized areas in the Oakmede Drainage discharge directly to Rice Lake via the municipal separate storm sewer system (MS4) outfalls before passing over the weir upstream of Oakmede Lane and eventually Oak-P.

The reach of Lambert Creek between the Rice Lake Weir (Site Oak-C1) to just downstream of Oak-P was restored in 2013. Prior to restoration, stream bank erosion was apparent on both sides of the reach, there was extensive riparian overgrowth, and large amounts of wood debris, detritus, and sediment had accumulated in the stream (Figure 4-2). Over the course of the restoration project, riparian cover was thinned, debris was removed from the stream channel, and the banks were stabilized.

Figure 4-1: Map of the Oakmede Drainage and Monitoring Sites

Figure 4-2: Lambert Creek at Oakmede Monitoring Site Before (A) and After (B) Restoration

A field reconnaissance of the Oakmede Drainage was conducted on May 16, 2014. Based on the results of the reconnaissance, field maps created from Geographic Information System (GIS) files provided by VLAWMO were updated to include the extent of the drainage with direct inputs to Oak-P, as shown in red on Figure 4-1. Besides the flows passing over the Rice Lake Weir and the potential for dry weather flows from direct surface runoff, other potential sources of *E. coli* observed during the reconnaissance were some wading birds and ducks seen just downstream of Oak-P.

4.1.1 Monitoring Locations

Site selection for the bacterial source identification in the Oakmede Drainage was based on historical data available for the drainage and the results of the site reconnaissance conducted in May 2014. The monitoring sites are shown graphically on Figure 4-1and described in Table 4-1.

Table 4-1: Monitoring Sites for the Oakmede Drainage

Site ID	Site Location	Site Sub-drainage Description
Oak-P	Primary Monitoring Site at base of Oakmede Drainage just downstream (west) of Oakmede Lane	The entire Oakmede Drainage
Oak-A1	On Oakmede Lane north of storm drain inlet that discharges to Lambert Creek upstream of Oak-P	Oakmede Lane and Fisher Lane south of Bibeau Road and north of Lambert Creek
Oak-B1	On Oakmede Lane south of storm drain inlet that discharges to Lambert Creek	Oakmede Lane south of Lambert Creek
Oak-C1	A t Rice Lake Weir	Entire Oakmede Drainage except reach between weir and Oak-P

4.1.2 Wetland Sediment Special Study

The objective of the Wetland Sediment Special Study was to determine the extent to which sediments in the bottom of Rice Lake act as a reservoir for *E. coli* that, when suspended during storm events, contribute to the E. coli concentrations in Lambert Creek.

The following Study Questions were addressed in the Sediment Special Study:

- Do the wetland sediments at the bottom of Rice Lake contain elevated levels of *E. coli*?
- Do the terrestrial soils surrounding Rice Lake contain elevated levels of *E. coli*?
- Do *E. coli* concentrations in Lambert Creek increase when Rice Lake sediments are re-suspended?
- What is the host origin of the E. coli in the sediments of Rice Lake?

To address these questions, two experiments were conducted in the Rice Lake wetland immediately upstream of Site Oak-P. The first experiment characterized *E. coli* levels in Rice Lake sediments and soils in the adjacent watershed. Table 4-2 below summarizes the number and type of samples that were collected for characterization of sediment within the Rice Lake Wetland.

Table 4-2. Summary of the Wetland Sediment Sampling Regimen for the Wetland Sediment Special Study

Site	Wetland Sediment		
	Overlying Water (*E. coli*)	**Sediment *E. coli***	**Sediment Grain Size**
Oak-C1	3	3	1 (comp)
Oak-C2	3	3	1 (comp)
Oak-C3	3	3	1 (comp)
Oak-C4	3	3	1 (comp)
Oak-C5	3	3	1 (comp)
Oak-P	3	3	1 (comp)
Oak-Mid	3	3	1 (comp)
TOTAL:	**21**	**21**	**7**

Sites Oak-C1 through Oak-C5 were collected immediately in front of the points of discharge for the sub-drainages that discharge to Rice Lake during storm events (Figure 4-1). The intent was to sample the sediments that may have accumulated in front of the sub-drainage outfalls to determine if they act as reservoirs for *E. coli* that may be entrained in the water column during storm events. Site Oak-P was sampled from sediments in Lambert Creek at the primary monitoring location just upstream of the Oakmede weir. Site Oak-Mid was sampled in the middle of Rice Lake where current velocities during storm events were likely to be greatest.

Samples were collected from a small boat that was positioned at the site location. Upon arrival at the site, water samples were collected from a depth of approximately one foot above the surface of the bottom sediment. The water sample was collected with a Niskin bottle lowered over the side of the boat and triggered at the appropriate depth. Care was taken not to disturb the bottom sediments prior to sampling. Upon retrieval, the water sample was decanted into a pre-labelled, sterile 100-mL plastic bottle and stored on ice until delivery to the laboratory. Three water samples were collected in this manner at each site. The Niskin bottle was sterilized between uses with biodegradable soap on the boat deck and air dried.

After the water samples were collected, surficial sediment from the site was collected. Sediment was collected with a sediment grab sampler lowered from the surface of the boat. Upon retrieval, the sediment was split into two equivalent sub-samples. One sub-sample was placed in a pre-labelled, food-grade plastic bag for *E. coli* analysis. The other sample was placed into a one-quart pre-labelled plastic bag for grain size analysis. The grain size sample consisted of a composite of three grabs taken at each site. Three sediment samples were collected in this manner at each site. The sampler was sterilized between uses with biodegradable soap on the boat deck and air dried. All water and sediment samples were placed on ice in a cooler immediately after collection and brought to the analytical laboratory within required holding times. Values for *E. coli* in sediment were reported in MPN per dry gram of sediment.

To characterize *E. coli* levels in terrestrial soils surrounding Rice Lake, soil samples were collected from the sites Oak-C2, Oak-C3, and Oak-C5 (Figure 4-1), all of which discharge to Rice Lake during storm events. At each site, three soil samples were collected from downstream of the outfall within the alluvial fan of the discharge, upstream of the surface water in Rice Lake. These samples were labelled with the site name, followed by the suffix A. Three additional soil samples were collected adjacent to these samples, but outside of the alluvial fan of the discharge and away from the influence of storm flows originating from the outfalls. These samples were labelled with the site name, followed by the suffix B. Table 4-3 summarizes the number and type of samples that were collected from the terrestrial soils adjacent to Rice Lake to characterize *E.coli* levels.

Table 4-3. Summary of Terrestrial Soil Sampling Regimen for the Wetland Sediment Special Study

Site	Terrestrial Soil		
	Soil *E. coli*	Soil Grain Size	Soil Molecular
Oak-C2-A[(a)]	3	1 (comp)	1 (comp)
Oak-C2-B[(b)]	3	1 (comp)	1 (comp)
Oak-C3-A	3	1 (comp)	1 (comp)
Oak-C3-B	3	1 (comp)	1 (comp)
Oak-C5-A	3	1 (comp)	1 (comp)
Oak-C5-B	3	1 (comp)	1 (comp)
TOTAL:	**18**	**6**	**6**

(a) Samples with the A suffix are collected from the alluvial fan of the outfall

(b) Samples with the B suffix are collected outside of the alluvial fan of the outfall

Samples were collected from each site using a sterile plastic bottle to scoop soil into pre-labelled, sterile plastic bags. Three separate samples were collected and bagged at each site for *E. coli* analysis. One composite soil sample was collected from each site for grain size analysis, consisting of approximately equal volumes of soil from each of the three locations combined into a single, pre-labelled, one-quart sterile plastic bag. In addition, one composite sample was collected from each site for molecular analyses (human, canine, and avian genetic probes). Approximately 100 grams of composited soil were collected from each of the six sites, and placed in individual, pre-labelled, one quart sterile plastic bags. All soil samples were placed on ice in a cooler immediately after collection and brought to the analytical laboratory within required holding times. The six composite samples for molecular analyses were placed in a cooler, packed with blue ice, and shipped via overnight courier to Weston Solutions in Carlsbad, CA. Values for *E. coli* were reported in MPN per dry gram of soil.

The second experiment of the Sediment Special Study characterized the effect of sediment re-suspension on receiving water *E. coli* concentrations and was conducted at least 24 hours after the first experiment for wetland sediment sampling was completed. Table 4-4 below summarizes the number and type of samples collected from Rice Lake for the sediment re-suspension experiment. Sediments from sites Oak-C1 through Oak-C5 were collected immediately in front of the points of discharge for the sub-drainages that discharge to Rice Lake during storm events (Figure 4-1). Sediments from Site Oak-P were collected from the Lambert Creek sediment just upstream of the Oakmede weir.

At each site, two types of samples were collected: a clear water sample and a suspended sediment sample. The clear water sample was collected by wading to the site (in hip or chest waders) and collecting a sample with a pre-labelled, sterile, 100-mL plastic bottle secured to a sampling pole. The bottle was inverted (placed upside down) at the surface of the water, lowered in the inverted position to approximately six inches to one foot above the surface of the sediment, then turned upright to fill the bottle with water from the appropriate depth. Care was taken not to disturb the sediment prior to sample collection so that the sample was as free of sediment as possible. Three clear water samples were collected at each site in this manner (Table 4-4).

Table 4-4. Summary of the Sediment Re-suspension Experiment Sampling Regimen for the Wetland Sediment Special Study

	Clear Water	Suspended Sediment Water		
Site	***E. coli***	***E. coli***	**TSS**	**Molecular**
Oak-C1	3	3	3	1 (comp)
Oak-C2	3	3	3	1 (comp)
Oak-C3	3	3	3	1 (comp)
Oak-C4	3	3	3	1 (comp)
Oak-C5	3	3	3	1 (comp)
Oak-P	3	3	3	1 (comp)
TOTAL:	**18**	**18**	**18**	**7**

After the clear water samples were collected, suspended sediment samples were collected from the same location. The field staff, wearing waders, suspended the bottom sediment by disturbing the sediment with his feet. When a plume of suspended sediment was been produced in the water column, the field staff collected a sample of the water by passing a one liter, pre-labelled, sterile plastic bottle secured to a sampling pole through the plume to collect the sediment laden water. This sample was used for analyses of both *E. coli* and total suspended solids (TSS). Field staff then collected a second sample from the sediment plume with a 250-mL pre-labelled, sterile plastic bottle in the same manner as described above. This sample was used for molecular analysis (human, canine, and avian molecular probes). This procedure was repeated three times at each site. In between sites, field staff conducting the sampling sterilized all equipment use for the procedure described above (including waders and sampling poles) in the field with biodegradable soap.

After the samples were collected at each site, the samples were distributed to the appropriate bottles as follows. The one-liter bottle was gently mixed to re-suspend the sediment and a 100 mL sub-sample was decanted into a pre-labelled, sterile plastic bottle for *E. coli* analysis. The remaining volume in the one liter bottle was used for TSS analysis. The three 250-mL samples for molecular analyses were composited into a single sample by pouring approximately one third of each of the three samples into a fourth pre-labelled, sterile 250-mL plastic bottle for molecular analyses.

When the sampling was completed at a site, filed staff collected the following samples:

- Three 100 mL clear water samples for *E. coli* analysis
- Three 100 mL suspended sediment water samples for *E. coli* analysis
- Three one liter suspended sediment samples for TSS analysis and
- One 250-mL composite sample for molecular analysis (human, avian, and canine markers)

After the samples were collected and distributed as described above, they were placed in coolers on ice and delivered to the appropriate laboratories for processing and analysis.

4.1.3 Results

<u>2014 Dry Weather Assessment</u>

4.1.3.1 Visual Observations

A total of 22 observations were made in the Oakmede Drainage in 2014. During all observation days, flow in Lambert Creek was observed at the weir below Rice Lake (Site Oak-C1; see Figure 4-1) and at Oak-P. However, no flow was observed along Oakmede Lane during any of the observation periods, and there was no evidence of dry weather flows entering Lambert Creek from the storm drain inlets along Oakmede Lane (Sites Oak-A1 and Oak-B1). Therefore, field staff were not able to collect samples from these monitoring locations.

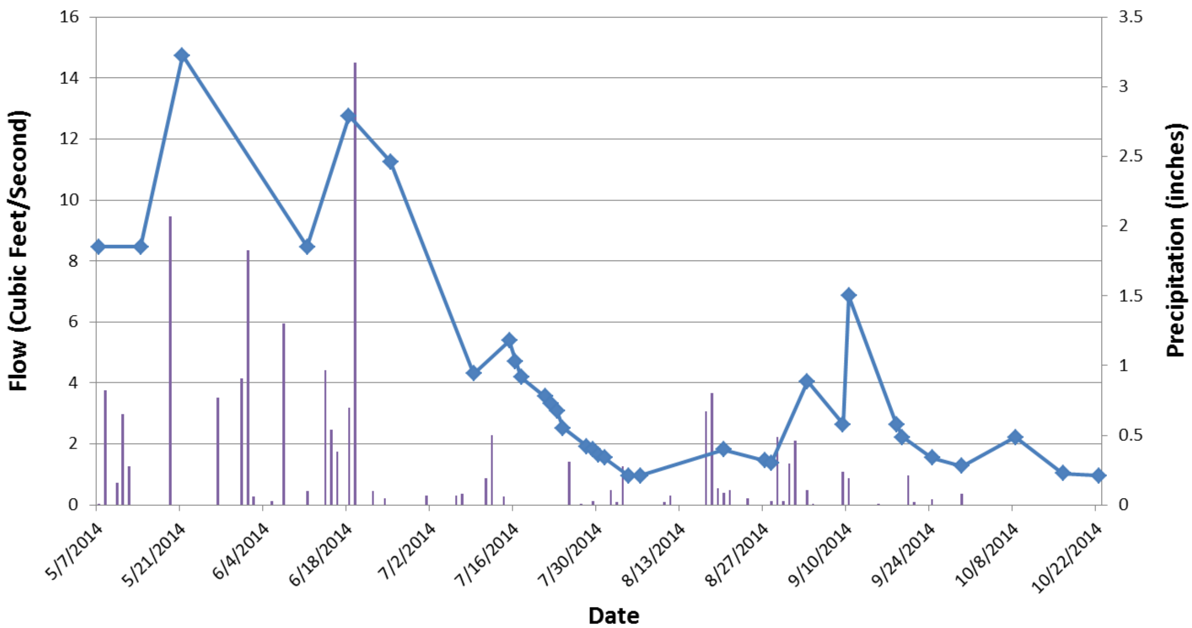
There was no evidence of human waste at any of the Oakmede sites over the Monitoring Period (no signs of homeless encampments, sewage leaks, odors, etc.). Birds were observed at Site Oak-C1 over the course of the study, including Canadian geese, ducks, and blue herons. Bird fecal matter was also observed at Site Oak-C1, on the Rice Lake Weir and just downstream of it.

4.1.3.2 Flow Monitoring

Instantaneous flow was measured by VLAWMO staff at Oak-P 33 times over the Monitoring Period by measuring stream stage at the weir and converting the results to flow. The data are presented on Figure 4-3 along with precipitation data for Vadnais Heights over the same period of time. Flows were typically measured weekly and when a bacterial sample was collected at the site.

Flow was greatest at Oak-P from May through early July (ranging from 8.5 to 14.7 cubic feet per second [cfs]), reflecting the rain events that impacted the region during that time period (Figure 4-3). Stream flows decreased in mid-July and generally remained below 5 cfs through the end of October, except for a spike in flow that occurred in early September.

Figure 4-3: Stream Flow (Blue Line) at Oakmede Primary Monitoring Site and Precipitation Data (Purple Bars) for Vadnais Heights, Minnesota



Source of precipitation data: Accuweather website: www.accuweather.com/en/us/vadnais-heights-mn/55127/august-weather/338928?monyr=8/1/2014 &view=tableE. coli Monitoring

4.1.3.3 *E. coli* Monitoring

Concentrations of *E. coli* from samples collected at the Oak-P and Oak-C1 sites (Figure 4-1) over the Monitoring Period are presented in Table 4-5. A total of 22 dry weather samples were collected from Oak-P during the Monitoring Period for *E. coli* enumeration. Sixteen samples were collected and analyzed from the Oak-C1 Site over the Monitoring Period. *E. coli* concentrations at the Oak-C1 Site were greater than those at the Oak-P site for the first 2 weeks of the Monitoring Period (July 15 through July 30), but that trend was not observed for the remainder of the Monitoring Period. Overall, the geometric mean concentration for samples collected from the Oak-C1 site (51.04 Most Probable Number [MPN] / 100 milliliters [mL]) was greater than that at the Oak-P Site (23.95 MPN /100 mL); however, the geometric means were not significantly different from one another (student's t-test, p = 0.06).

Table 4-5: *E. coli* Concentrations at the Oak-P and Oak-C1 Sites by Date

Date	*E. coli* Concentrations (MPN / 100 mL)	
	Oak-P Site	**Oak-C1 Site**
7/15/2014	28	57
7/16/2014	21	43
7/17/2014	68	93
7/21/2014	16	104
7/22/2014	28	142
7/23/2014	28	114
7/24/2014	16	28
7/28/2014	46	35
7/29/2014	20	276
7/30/2014	18	72
7/31/2014	36	18
8/4/2014	14	13
8/27/2014	25	ns[a]
8/28/2014	28	ns[a]
9/3/2014	76	26
9/9/2014	26	17
9/18/2014	56	49
9/24/2014	53	ns[a]
9/29/2014	56	56
10/8/2014	6	ns[a]
10/16/2014	8	ns[a]
10/22/2014	3	ns[a]
Geometric mean	**23.95**	**51.04**

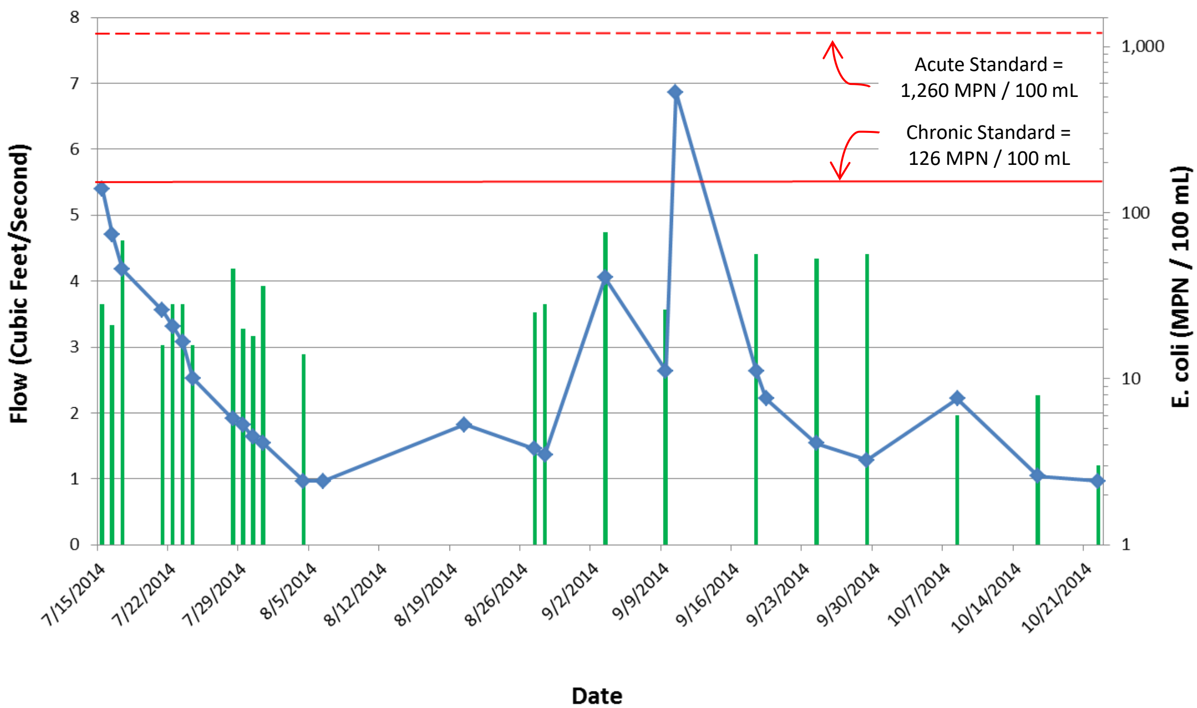
(a) No sample collected

E. coli concentrations at the Oak-P Site are plotted along with flow on Figure 4-4. The chronic and acute State standards for *E. coli* concentrations used in the Lambert Creek *E. coli* TMDL (Wenck, 2013) are also plotted on Figure 4-4 and defined as follows:

- Chronic Standard: The 30-day geometric mean *E. coli* concentration of five or more samples collected in a calendar month are not to exceed 126 MPN / 100 mL
- Acute Standard: 10 percent of samples collected in a calendar month are not to exceed an *E. coli* concentration of 1,260 MPN / 100 mL

The chronic and acute standards are represented on Figure 4-4 as solid and dashed lines, respectively. The data presented in Table 4-5 and on Figure 4-4 indicate that *E. coli* concentrations during dry weather at the Oak-P and Oak-C1 sites were below both the chronic and acute standards in the TMDL.

Figure 4-4: Stream Flow (Blue Line) and *E. coli* Concentrations (Green Bars) at the Oakmede Primary Monitoring Site Showing Acute and Chronic Water Quality Standards



4.1.3.4 Human and Non-human Origin Assessment

A limited number of samples were collected from sites Oak-P and Oak C and analyzed for two genetic markers using qPCR: the Human Marker and the Bird Marker. The results are presented in Table 4-6. Eight samples were collected and analyzed for the Human Marker. All were negative. Six samples were collected and analyzed for the Bird Marker. All were positive.

Table 4-6: Results of Human and Non-human Genetic Marker Assays at Monitoring Sites Oak-P and Oak-C1

Date	Site	Human Marker	Bird Marker
9/3/2014	Oak-P	Negative	Positive
	Oak-C1	Negative	Positive
9/8/2014	Oak-P	Negative	ns[a]
	Oak-C1	Negative	ns[a]
9/9/2014	Oak-P	Negative	Positive
	Oak-C1	Negative	Positive

Date	Site	Human Marker	Bird Marker
9/29/2014	Oak-P	Negative	Positive
	Oak-C1	Negative	ns[a]

(a) No sample collected

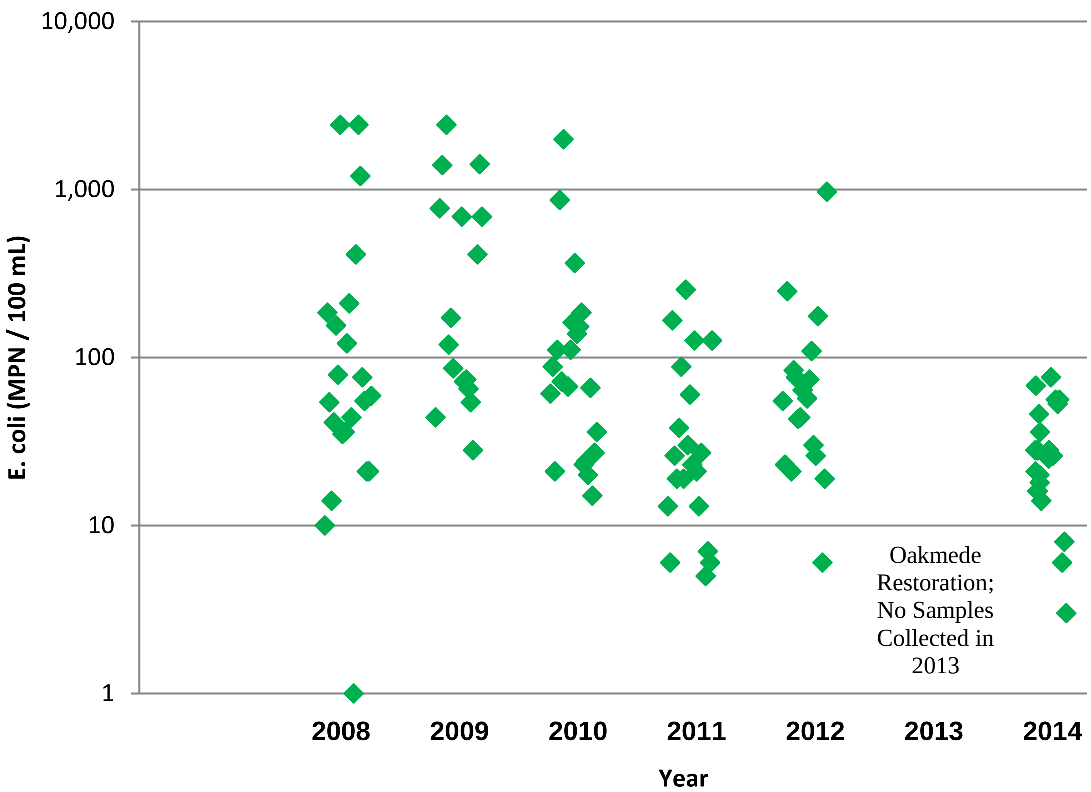
4.1.3.5 Annual *E. coli* Assessment

Study Question 2 for the Oakmede Drainage was: How do concentrations differ at Oak-P before and after restoration? Restoration of the stream reach between the Rice Lake Weir to just downstream of Oak-P was conducted in 2013, as discussed in Section 2.1 and depicted on Figure 4-2. In order to address this Study Question, *E. coli* data from samples collected by VLAWMO staff at Oak-P from 2008 through 2014 were assessed. A summary of the *E. coli* results for samples collected over this period are presented in Table 4-7. Discrete dry weather *E. coli* concentrations are shown graphically by year on Figure 4-5. No samples were collected in 2013 when the site was being restored.

Table 4-7: Summary Statistics of Dry Weather *E. coli* Concentrations at Site Oak-P

Year	Annual Number of Samples (n)	*E. coli* Concentrations (MPN / 100 mL)			Percent of Values > 126 MPN / 100 mL	Percent of Values > 1,260 MPN / 100 mL
		Annual Geometric Mean	Minimum Value	Maximum Value		
2008	22	77	1	2,420	32%	9%
2009	16	219	28	2,420	50%	19%
2010	21	84	15	1,986	33%	5%
2011	20	28	5	253	20%	0%
2012	18	57	6	968	17%	0%
2013	No data collected					
2014	22	24	3	76	0%	0%

Figure 4-5: Dry Weather *E. coli* Concentrations at Site Oak-P



Over the 7-year period, the geometric mean *E. coli* concentration was greatest in 2009 and generally followed a decreasing tend from 2009 through 2014 (Table 4-7). The annual geometric mean concentration in 2012 (57 MPN / 100 mL), prior to restoration, was twice that in 2014 (24 MPN / 100 mL), after restoration had been completed. In addition, the data presented on Figure 4-5 suggest that the number of samples that exceeded the concentration threshold of 126 MPN / 100 mL have decreased from a peak in 2009 (when 50 percent of the samples exceeded the threshold) to zero exceedances in 2014. A total of 17 percent of the samples exceeded the threshold in 2012, the year prior to restoration.

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4.1.3.6 Flow Monitoring

Instantaneous flow was measured at Oak-P by monitoring stream stage at the Oakmede weir during storm events and converting stream stage values to flow using the Manning Equation (as described in Section 3.3, above). Two storm events were monitored, the first on 7/5/2016 and the second on 8/4/2016. Fourteen flow measurements were taken during the storm event on 7/5/2016, the first at 18:00 and the last at 21:00. Flow measurements ranged from 0.68 ft^3/s at the beginning of the storm event to 27.04 ft^3/s during peak flow. Eight flow measurements were taken during the storm event on 8/4/2016, the first at

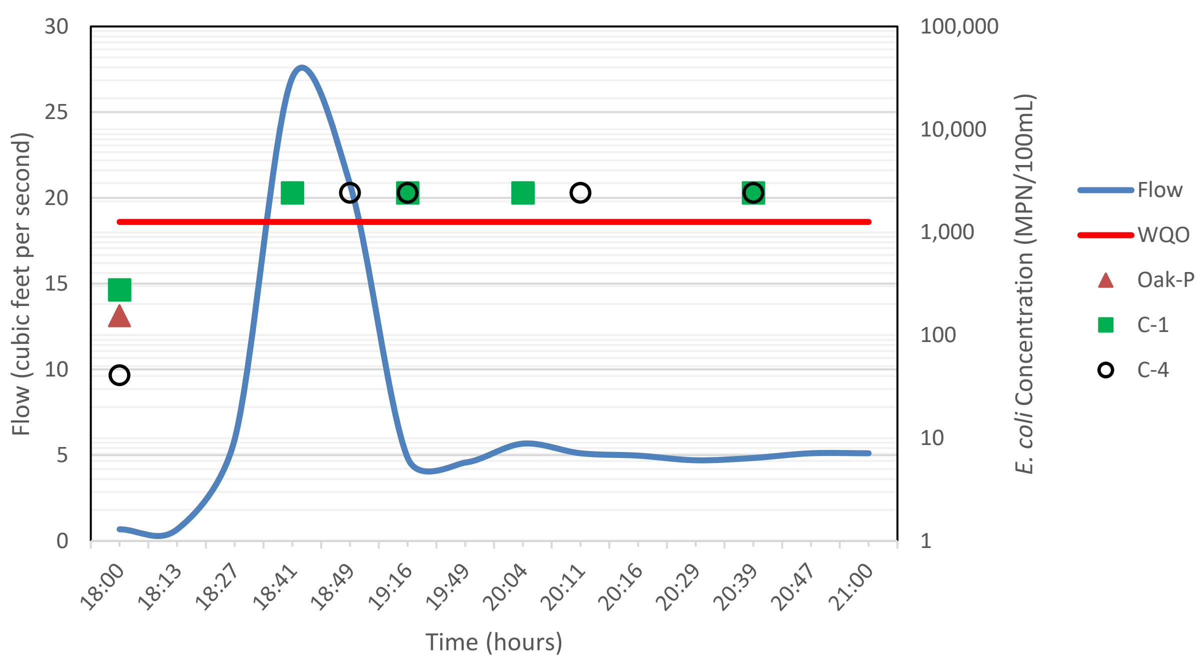
6:45 and the last at 9:45. Flow measurements ranged from 2.53 ft^3/s at the beginning of the storm event to 19.42 ft^3/s during peak flow. Storm event flow measurements can be found on a pollutograph with *E. coli* concentrations discussed below.

4.1.3.7 *E. coli* Monitoring

E. coli samples were collected at Oak-P, Oak-C1, Oak-C2, Oak-C3, Oak-C4, Oak-C5, Oak-A1, and Oak-B1 during the two storm events that were monitored in 2016 (7/5/2016 and 8/4/2016). Pollutograph monitoring was conducted at Oak-P, Oak-C1, and Oak-C4 for both storms, and spot samples were collected at the other sampling locations.

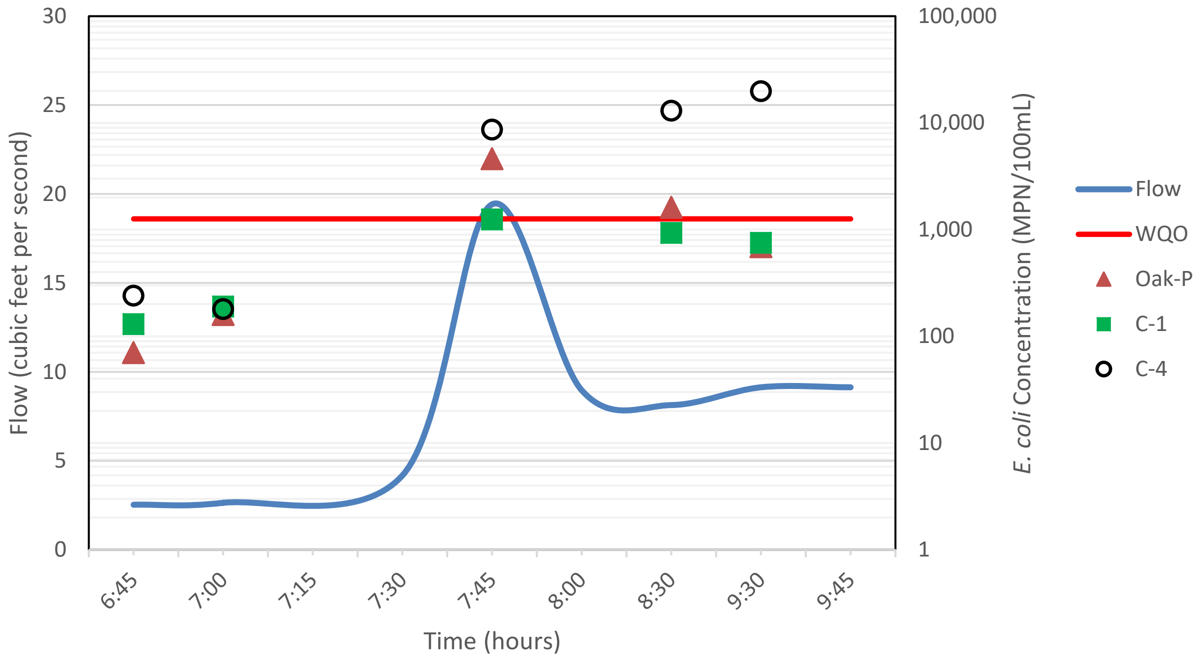
Results from the pollutograph monitoring of the first storm event on 7/5/2016 can be found on Figure 4-6, below.

Figure 4-6: Pollutograph of *E. coli* Concentrations and Flow in the Oakmede Drainage During 7/5/2016 Storm Event



Results from the pollutograph monitoring of the second storm event (8/4/2016) can be found on Figure 4-7, below.

Figure 4-7: Pollutograph of *E. coli* Concentrations and Flow in the Oakmede Drainage During 8/4/2016 Storm Event



4.1.3.8 Human Origin Assessment

Human origin assessment was done to address the question of whether *E. coli* in the Oakmede drainage originates from human sources. Six samples were collected from sites Oak-P1 and Oak-C4 during a storm event on 7/5/2016 and analyzed for the Human Marker. Three of the six samples tested positive for the Human Marker. The results are presented in Table 4-8, below.

Table 4-8: Results of Human Marker Assays at Monitoring Sites Oak-P1 and Oak-C4

Date	Site	Human Marker
7/5/2016	Oak-P1-1	Negative
	Oak-C4-1	Negative
	Oak-P1-2	Positive
	Oak-C4-2	Positive
	Oak-P1-3	Negative
	Oak-C4-3	Positive

4.1.3.9 Non-human Origin Assessment

Non-human origin assessment was done to address the question of whether *E. coli* in the Oakmede drainage originates from non-human sources. Six samples were collected from sites Oak-P1 and Oak-C4 during a storm event on 7/5/2016 and analyzed for the Avian and Canine Marker. All six samples were positive for the Avian Marker. Two of the six samples were positive for the Canine Marker. The results are presented in Table 4-9 below.

Table 4-9: Results of Non-human Marker Assays at Monitoring Sites Oak-P1 and Oak-C4

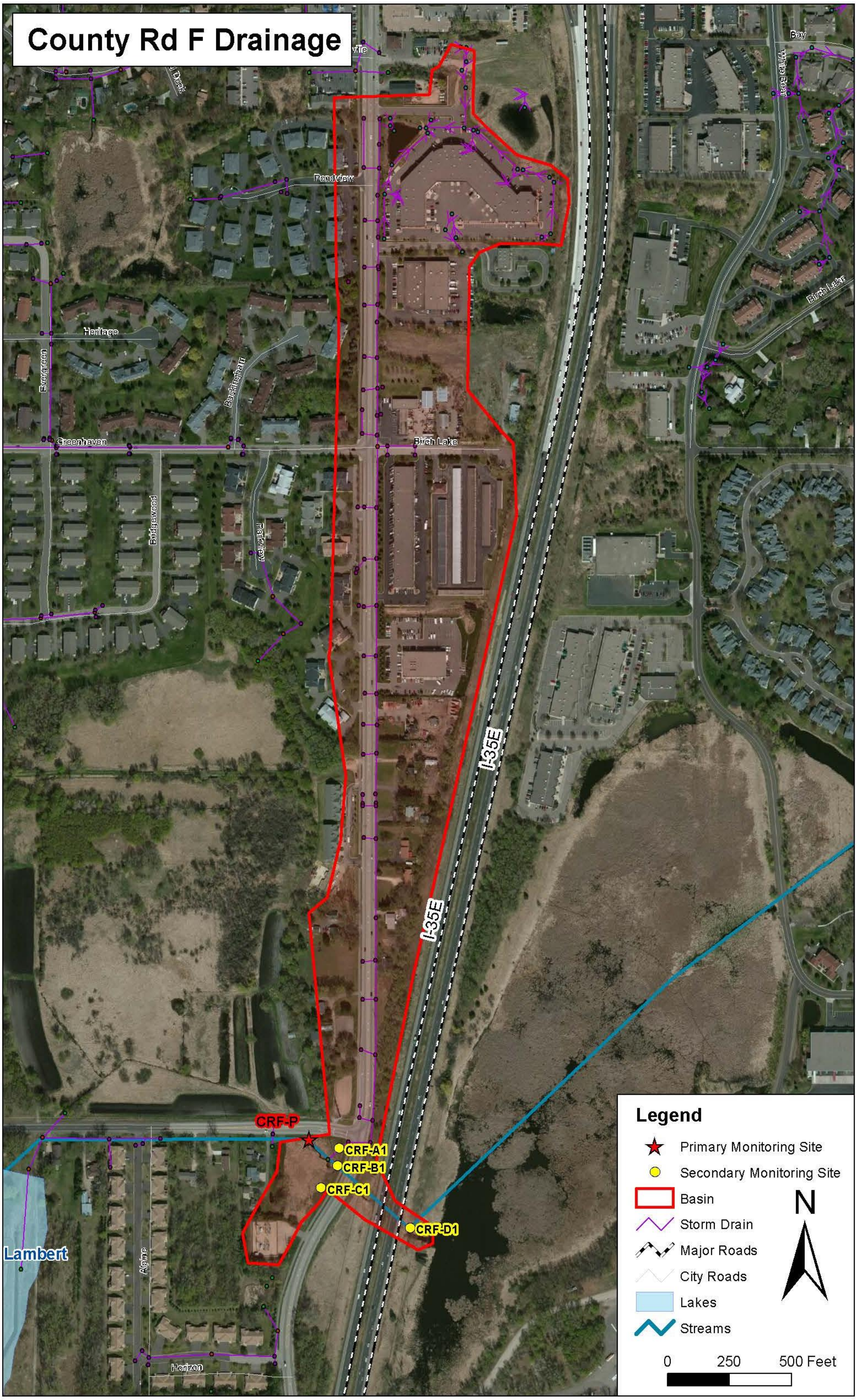
Date	Site	Avian Marker	Canine Marker
7/5/2016	Oak-P1-1	Positive	Positive
	Oak-C4-1	Positive	Negative
	Oak-P1-2	Positive	Negative
	Oak-C4-2	Positive	Negative
	Oak-P1-3	Positive	Negative
	Oak-C4-3	Positive	Positive

4.2 County Road F Drainage

The County Road F Drainage is in the lower portion of the Lambert Creek Watershed, as shown on Figure 1-1. A field reconnaissance of the County Road F Drainage was conducted on May 16, 2014. Based on the results of the reconnaissance and GIS layers provided by VLAWMO, a map of the drainage showing potential future monitoring sites was produced (Figure 4-8). The drainage is relatively small and consists primarily of mixed residential, light commercial, and open space land uses intermixed with a wetland located just to the east of Interstate 35E (I-35E).

The Primary Monitoring Site for the County Road F Drainage (CRF-P) is located near the intersection of County Road F and Centerville Road, east of I-35E (Figure 4-8). There are three main sources of flow that co-mingle just upstream of CRF-P. The largest flows come from the mainstem of Lambert Creek, which conveys flows from a wetland on the east side of I-35E. The outfall of the mainstem is located on the west side of I-35E (Site CRF-B1) where it co-mingles with flows from the second outfall (Site CRF-A1). During the field reconnaissance, the source of water flowing from this outfall was determined to be a storm drain that conveyed flow from a small detention pond at the top of the County Road F Drainage on the east side of Centerville Road (across from Pondview Court). The third potential source of flow to Site CRF-P is a small drainage south of CRF-P that discharges via an outfall adjacent to Centerville Road (Site CRF-C1). This outfall was dry during the field reconnaissance.

Figure 4-8: Map of the County Road F Drainage and Monitoring Sites



4.2.1 Monitoring Locations

Site selection for the bacterial source identification in the County Road F Drainage was based on historical data available for the drainage and the results of the site reconnaissance conducted throughout 2014, 2015, and the spring of 2016. The monitoring sites are shown graphically on Figure 4-8 and described in Table 4-10.

Table 4-10. Monitoring site IDs, locations, and drainage area descriptions for the County Road F Drainage

Site ID	Site Name / Sample Location	Site Drainage Description	Photos
CRF-P	Primary Monitoring Site / Weir at Base of County Road F Drainage at County Road F and Centerville Road	The entire County Road F Drainage	
CRF-A1	Centerville Road / At the storm drain outfall that drains the Centerville Road from Pondview Court to County Road F (outfall to the left in the photograph)	Centerville Road north of County Road F	
CRF-A2	Retention Pond / At the grated storm drain outlet on the southwest corner of the pond	Small business park area at the top of Centerville Road	
CRF-B1	I-35E Outfall / At the storm drain outfall on the mainstem on the west side of I-35E (outfall to the right in the photograph)	Reach under I-35E between the wetland and outfall on west side of I-35E	

Site ID	Site Name / Sample Location	Site Drainage Description	Photos
CRF-C1	South Centerville Road / West of Centerville Road and south of outfalls CRF-A1 and CRF-B1	Small area to south of CRF-P adjacent to Centerville Road	
CRF-D1	Wetland Weir / At wetland weir on east side of I-35E	Entire County Road F Drainage except Centerville Road areas	
CRF-D2	White Bear Parkway / West (downstream) side of White Bear Parkway where mainstem of Lambert Creek crosses under road	Entire drainage upstream of White Bear Parkway, including Whitaker, Goose, and Oakmede drainages	

4.2.2 Results

2014 Dry Weather Assessment

The County Road F Drainage was monitored a total of 33 times between May 7 and October 22, 2014. All observations and sampling was conducted during dry weather, at least 72 hours after the last storm event. The results are presented below.

4.2.2.1 Visual Observations

A total of 23 observations were made in the County Road F Drainage in 2014. Observations were conducted at four locations: CRF-P, CRF-A1, CRF-B1, and CRF-D1 (Figure 4-8). No flow was observed at Site CRF-C1 over the course of the Monitoring Period, and this site was not sampled. During all observation days, flow in Lambert Creek was observed at CRF-P, CRF-B1, and at the wetland weir

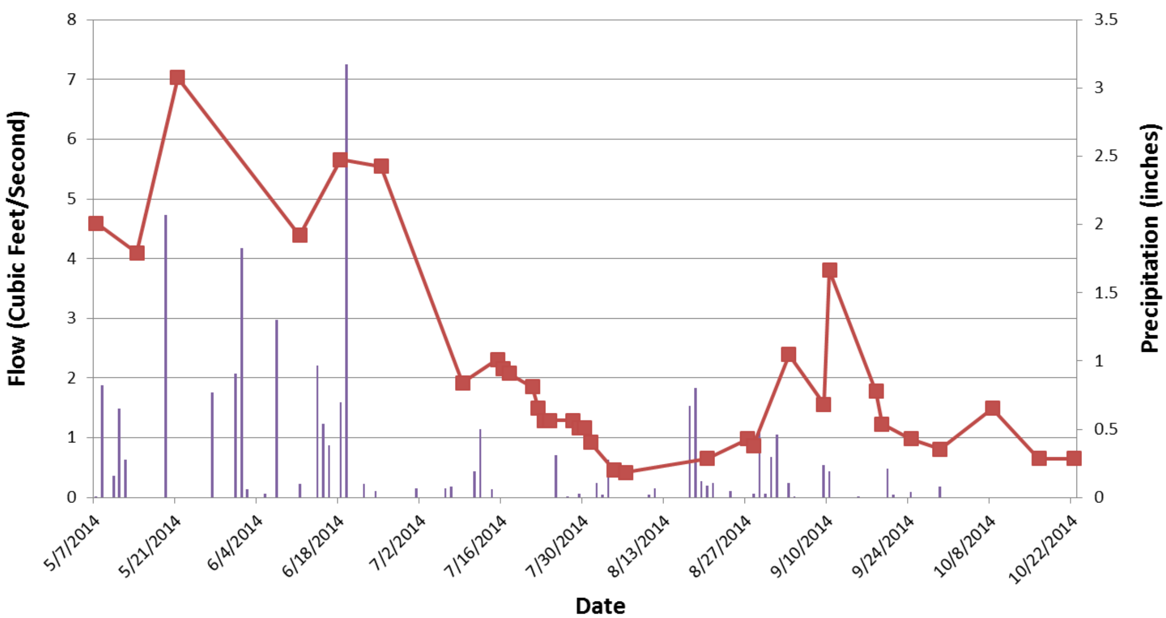
(CRF-D1). At Site CRF-A1, which drains Centerville Road north of County Road F, there was no flow (stagnant, ponded water only) or flow was minimal.

There was no evidence of human waste at any of the County Road F sites over the Monitoring Period (no signs of homeless encampments, sewage leaks, odors, etc.). Birds were observed in the watershed over the course of the study at Site CRF-D (near the wetland weir, (Figure 4-8), including Canadian geese, ducks, and blue herons. Birds were not observed at the other sites over the Monitoring Period; however, bird waste was observed on the flume at Site CRF-P during monitoring conducted on July 28.

4.2.2.2 Flow Monitoring

Instantaneous flow was measured at CRF-P a total of 33 times between May 7 and October 22, 2014, by measuring stream stage at the weir and converting the results to flow. The data are presented on Figure 4-9 along with precipitation data for Vadnais Heights over the same period of time. Flows were typically measured weekly and when a bacterial sample was collected at the site.

Figure 4-9: Stream Flow (Brown Line) at County Road F Primary Monitoring Site and Precipitation Data (Purple Bars) for Vadnais Heights, Minnesota



Source of precipitation data: Accuweather website: www.accuweather.com/en/us/vadnais-heights-mn/55127/august-weather/338928?monyr=8/1/2014 &view=table

Flow at CRF-P (Figure 4-9) was similar to that observed at Oak-P (Figure 4-3). Flow was greatest from May through early July (ranging from 4.1 to 7.0 cfs), reflecting the rain events that impacted the region during that time period. Stream flows decreased in mid-July and generally remained below 2 cfs through the end of October, except for a spike in flow that occurred in mid-September.

4.2.2.3 *E. coli* Monitoring

Concentrations of E. coli from samples collected at the four County Road F sites where flow was observed are presented in Table 4-11.

Table 4-11: *E. coli* Concentrations at the County Road F Monitoring Sites by Date

Date	*E. coli* Concentrations (MPN / 100 ML)			
	CRF-P Site	**CRF-A1 Site**	**CRF-B1 Site**	**CRF-D1 Site**
7/15/2014	54	31	62	57
7/16/2014	214	47	248	35
7/17/2014	40	3	47	48
7/21/2014	55	3	57	36
7/22/2014	68	3	63	57
7/23/2014	39	3	34	32
7/24/2014	26	132	28	22
7/28/2014	18	31	10	21
7/29/2014	44	37	41	30
7/30/2014	28	30	37	25
7/31/2014	28	3	11	15
8/4/2014	13	30	118	23
8/27/2014	52	ns[a]	ns[a]	ns[a]
8/28/2014	55	ns[a]	ns[a]	ns[a]
9/3/2014	148	ns[a]	ns[a]	157
9/8/2014	ns	ns[a]	ns[a]	ns[a]
9/9/2014	71	ns[a]	ns[a]	126
9/18/2014	118	ns[a]	ns[a]	135
9/24/2014	91	ns[a]	ns[a]	ns[a]
9/29/2014	1,120[b]	ns[a]	ns[a]	96
10/8/2014	140	ns[a]	ns[a]	ns[a]
10/16/2014	124	ns[a]	ns[a]	ns[a]
10/22/2014	14	ns[a]	ns[a]	ns[a]
Geometric mean	**52.05**	**13.81**	**43.71**	**43.93**

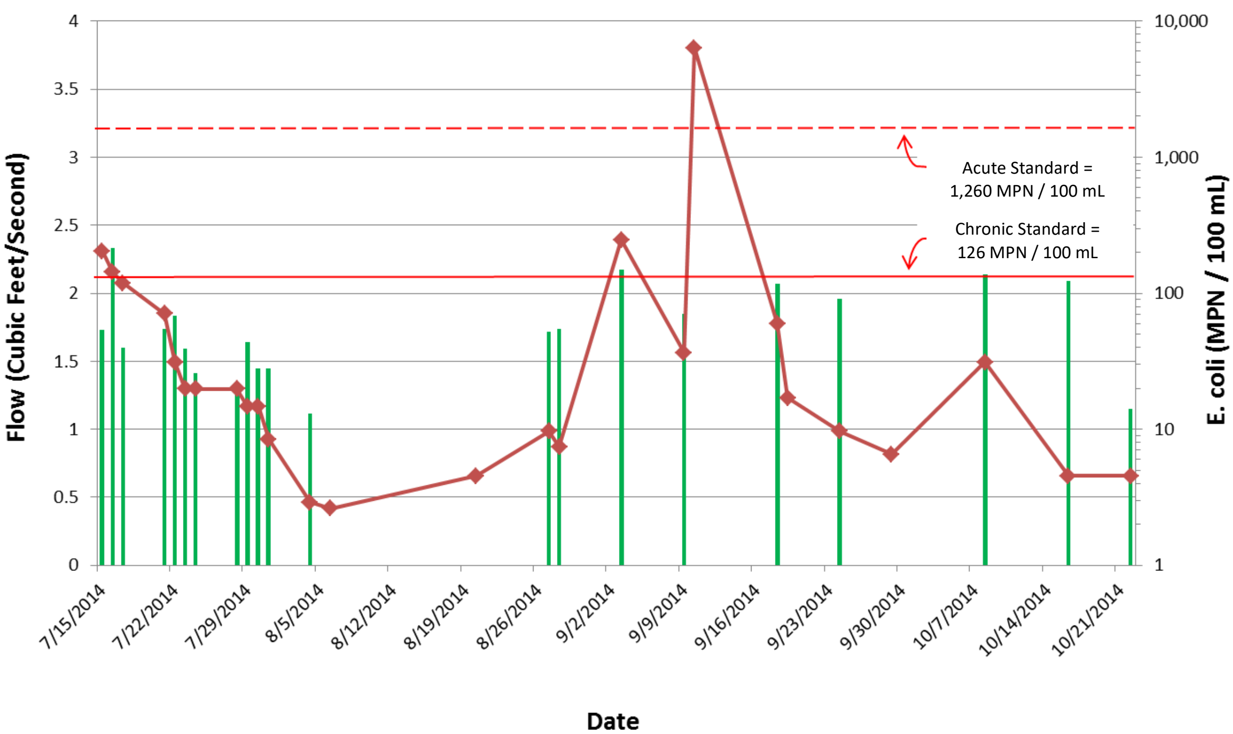
(a) No sample collected
(b) Storm drain flow was heavy due to fire hydrant flushing being conducted by the City. This data point was removed from the geometric mean calculation.

A total of 22 dry weather samples were collected from the County Road F monitoring sites during the Monitoring Period for *E. coli* enumeration. All samples had concentrations less than 250 MPN/100 mL except for one sample that was collected from CRF-P on September 29, 2014, which had an *E. coli* concentration of 1,120 MPN/100 mL. Observations made during this sampling event indicate that flow in the storm drain was very high due to hydrant flushing that was being conducted by the City at the time of sample collection.

The geometric mean concentrations of *E. coli* at Site CRF-P (52.05 MPN/100 mL) was significantly greater than that at Site CRF-A1 (13.81 MPN/100 mL) (Student's t-test, p = 0.018). However, the geometric mean concentration at Site CRF-P was not significantly different from those at site CRF-B1 (Student's t-test, p = 0.491) or CRF-D1 (Student's t-test, p = 0.487). In addition, the geometric mean concentration at Site CRF-D1 at the wetland weir was not significantly different than that at Site CRF-B1 downstream (Student's t-test, p = 0.794).

E. coli concentrations at the CRF-P Site are plotted along with flow on Figure 4-10. The criteria used in the Lambert Creek *E. coli* TMDL (see Section 5.1.3) (Wenck, 2013) are also plotted on Figure 4-10. The data represented in Table 4-11 and on Figure 4-10 indicate that *E. coli* concentrations during dry weather at the CRF-P were below the chronic and acute standards in the TMDL.

Figure 4-10: Stream Flow (Brown Line) and *E. coli* Concentrations (Green Bars) at the County Road F Primary Monitoring Site Showing Acute and Chronic Water Quality Standards



4.2.2.4 Human and Non-human Origin Assessment

A limited number of samples were collected from sites CRF-P and CRF-D1 (Figure 4-8) and analyzed for two genetic markers using qPCR: the Human Marker and the Bird Marker. The results are presented in Table 4-12. Eight samples were collected and analyzed for the Human Marker. All were negative. Five samples were collected and analyzed for the Bird Marker. All were positive.

Table 4-12: Results of Human and Non-human Genetic Marker Assays at Monitoring Sites CRF-P and CRF-D1

Date	Site	Human	Bird
9/3/2014	CRF-P	Negative	Positive
	CRF-D1	Negative	Positive
9/8/2014	CRF-P	Negative	ns[a]
	CRF-D1	Negative	ns[a]
9/9/2014	CRF-P	Negative	Positive
	CRF-D1	Negative	Positive
9/29/2014	CRF-P	Negative	Positive
	CRF-D1	Negative	ns[a]

(a) No sample collected

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4.2.2.5 Flow Monitoring

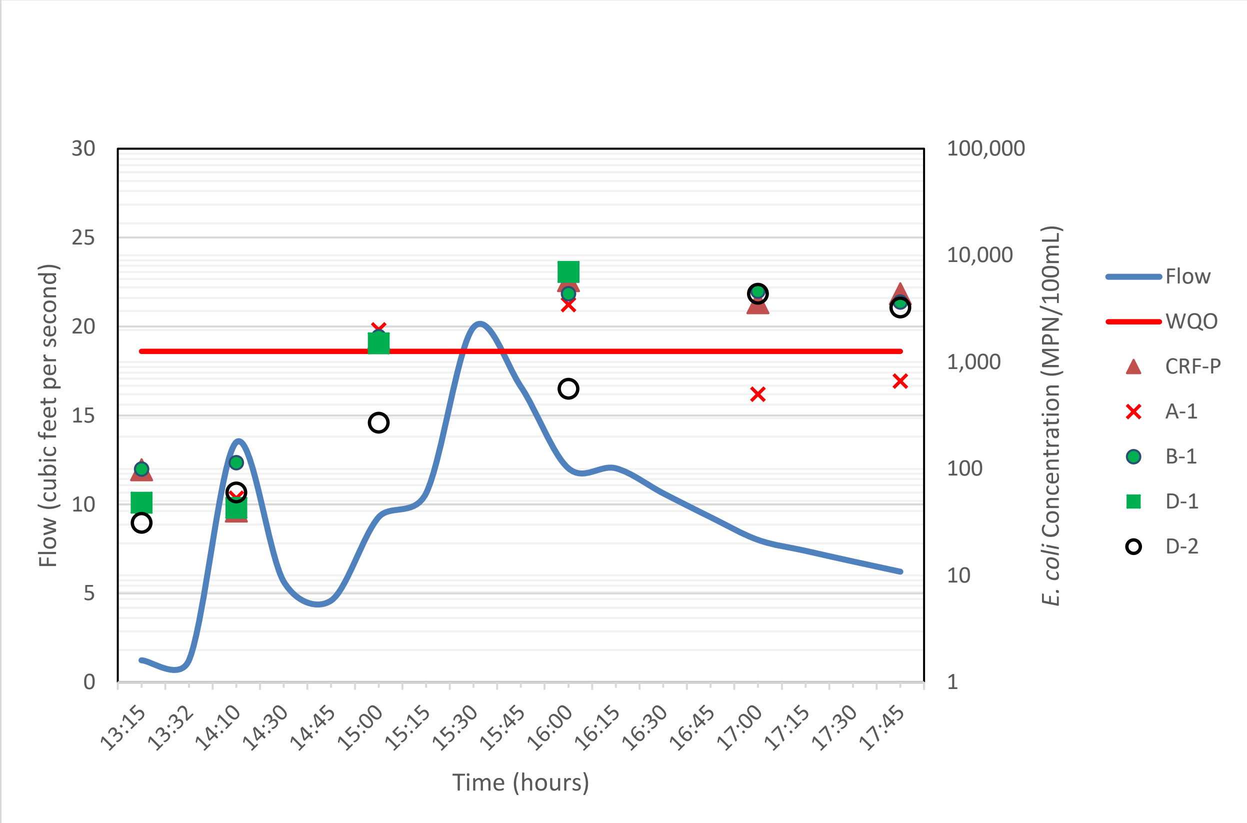
Instantaneous flow was measured at CRF-P by monitoring stream stage at the weir during storm event(s) and converting stream stage values to flow using the Manning Equation (as described in Section 3.3, above). One storm event was monitored on 7/27/2016 in which 0.66 inches of rain fell over the course of three hours. Seventeen flow measurements were taken during the storm event, the first at 13:32 and the last at 18:00. Flow measurements ranged from 1.23 ft^3/s at the beginning of the storm event to 19.95 ft^3/s during peak flow. Flow measurements were used to produce hydrographs to analyze the concentrations of *E. coli* during storm events.

4.2.2.6 *E. coli* Monitoring

E. coli samples were collected at CRF-P, CRF-A1, CRF-B1, CRF-B2, CRF-D1, and CRF-D2 during the storm event on 7/27/2016. Pollutograph monitoring was conducted at CRF-P, CRF-A1, CRF-B1, CRF-D1, and CRF-D2, and spot samples were collected at CRF-B2.

Results from the pollutograph monitoring of the storm event (7/27/2016) can be found on Figure 4-11 below.

Figure 4-11: Pollutograph of *E. coli* Concentrations and Flow in the County Road F Drainage During the Storm Event on 7/27/2016



4.2.2.7 Human Origin Assessment

Human origin assessment was performed to address the question of whether *E. coli* in the County Road F drainage originates from human sources. Six samples were collected from sites CRF-P and CRF-D2 during a storm event on 7/27/2016 and analyzed for the Human Marker. All six samples were negative. The results are presented in Table 4-13.

Table 4-13: Results of Human Marker Assays at Monitoring Sites CRF-P1 and CRF-D2

Date	Site	Human Marker
7/27/2016	CRF-P1-1	Negative
	CRF-D2-1	Negative
	CRF-P1-2	Negative
	CRF-D2-2	Negative
	CRF-P1-3	Negative
	CRF-D2-3	Negative

4.2.2.8 Non-human Origin Assessment

Non-human origin assessment was done to address the question of whether *E. coli* in the County Road F drainage originates from non-human sources. Six samples were collected from sites CRF-P and CRF-D2 during a storm event on 7/27/2016 and analyzed for the Avian and Canine Marker. All six samples were positive for the Avian Marker. Two of the six samples were positive for the Canine Marker. The results are presented in Table 4-14, below.

Table 4-14: Results of Non-human Marker Assays at Monitoring Sites CRF-P1 and CRF-D2

Date	Site	Avian Marker	Canine Marker
7/27/2016	CRF-P1-1	Positive	Negative
	CRF-D2-1	Positive	Negative
	CRF-P1-2	Positive	Negative
	CRF-D2-2	Positive	Positive
	CRF-P1-3	Positive	Negative
	CRF-D2-3	Positive	Positive

4.3 Goose Drainage

The Goose Drainage lies south of the Whitaker Drainage and is the smallest of the five drainages in the Lambert Creek Watershed (Figure 1-1). The Drainage is dominated by Goose Lake, which is bisected by US Highway 61, forming East Goose Lake and West Goose Lake (Figure 4-12). The Primary Monitoring Site for the Goose Drainage (Gos-P) lies at the northern end of West Goose Lake. The main inputs into West Goose Lake are from two culverts that extend under Highway 61 and connect West Goose Lake to East Goose Lake (Sites Gos-A1, A2, A3, and A4). In addition, there is a storm drain outfall at the southern end of West Goose Lake that discharges to a small forebay (Site Gos-A5). During the site reconnaissance conducted in May 2014, it was observed that very warm water was flowing from the outfall into the forebay. VLAWMO staff indicated that flows from this outfall were from a permitted discharger just upstream of the outfall. Water in this drainage flows west from East Goose Lake to West Goose Lake (through the two culverts identified above), then north toward the Primary Monitoring Site.

A potential source of *E. coli* that was observed during the site reconnaissance was the canal that discharges to the south side of East Goose Lake. Large grassy areas that go directly to the water's edge are a likely source of bacteria to the canal, which may be transported to West Goose Lake via the southern culvert (Figure 4-12). During the site reconnaissance, several geese were observed along the grassy banks of the canal and large amounts of fecal matter were observed on the grass.

In addition, there is a restaurant and bar along the northern end of West Goose Lake along the western shore called Don's Little Bar. In the rear of the bar is a grassy bank where geese and goose fecal material were observed during the site reconnaissance. This is a potential source of *E. coli* at the Primary Monitoring Site, which is located approximately 400 feet to the North.

Figure 4-12: Map of the Goose Drainage Monitoring Sites

4.3.1 Monitoring Locations

Site selection for the bacterial source identification in the Goose Drainage was based on historical data available for the drainage and the results of the site reconnaissance conducted throughout 2014, 2015, and the spring of 2016. The monitoring sites are shown graphically on Figure 4-12 and described in Table 4-15.

Table 4-15. Monitoring Site Identifications, Locations, and Drainage Area Descriptions for the Goose Drainage

Site ID	Site Name / Sample Location	Site Drainage Description
Gos-P	Primary Monitoring Site at North end of West Goose Lake	The entire Goose Drainage
Gos-A1	In front of entrance to culvert at northern end of East Goose Lake, which conveys water to West Goose Lake	Inflow from northern portion of East Goose Lake
Gos-A2	In front of exit to culvert at northern end of West Goose Lake, which receives water from East Goose Lake	Outflow from culvert that conveys flow from northern portion of East Goose Lake
Gos-A3	In front of entrance to culvert at southern end of East Goose Lake, which conveys water to West Goose Lake	Inflow from southern portion of East Goose Lake
Gos-A4	In front of exit to culvert at southern end of West Goose Lake, which receives water from East Goose Lake	Outflow from culvert that conveys flow from southern portion of East Goose Lake
Gos-A5	In front of storm drain outfall in forebay at the southern end of West Goose Lake from permitted discharge	Permitted discharge from light industrial facility

4.3.2 Results

2015 Dry Weather Assessment

4.3.2.1 Visual Observations

A total of 13 observations were made in the Goose Drainage in 2015 during the dry weather assessment. During all observation days, flow in Lambert Creek was observed at the weir at the west end of West

Goose Lake. However, flow fluctuated very little throughout the study period at the weir during dry weather monitoring and there were no observations of flow entering West Goose Lake from shoreline sources, except at the far south end of West Goose Lake at Site Gos-A5.

There was no evidence of human waste at any of the Goose sites over the Monitoring Period (no signs of homeless encampments, sewage leaks, odors, etc.). Birds were observed along the shoreline of West Goose Lake, including a large number of geese and large amounts of goose waste at Site Gos-A2; and at East Goose Lake at the east side of Highway 61 and County Road F.

4.3.2.2 Flow Monitoring

Instantaneous flow measurements were attempted by VLAWMO staff at Site Gos-P several times over the Monitoring Period by observing the water level on the stream gauge at this site, but water level barely changed throughout the course of the Study and accurate flow measurements were not able to be recorded from this site.

4.3.2.3 *E. coli* Monitoring

In the Goose Drainage, a total of 13 samples were collected and analyzed for *E. coli* from the primary monitoring site (Gos-P) (Figure 4-12 and Table 4-15). Samples were also collected from the West Goose Lake side of two culverts that convey water from East Goose Lake to the west side (sites Gos-A2 and Gos-A4) and from the south end of West Goose Lake at an outfall from a permitted discharge (Site Gos-A5). All but one of the samples collected in front of the permitted outfall had *E. coli* concentrations below the detection limit (Table 4-16). All samples collected over the course of the assessment had *E. coli* concentrations well below the acute water quality standard of 1,260 MPN/100 mL. Elevated concentrations of *E. coli* were observed along the east shore of West Goose Lake adjacent to a dirt parking lot, just upstream of (Gos-P). Erosion next to the shoreline was observed in this area as well as large numbers of waterfowl and goose excrement.

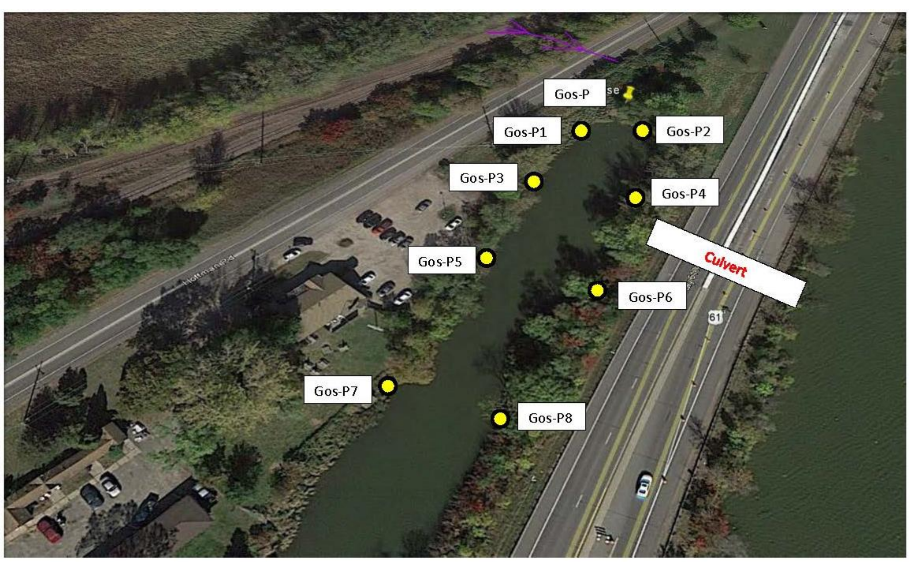
Table 4-16: *E. coli* Concentrations at the Goose Drainage Sites by Date

Date	*E. coli* Concentrations (MPN / 100 mL)			
	Gos-P	Gos-A2	Gos-A4	Gos-A5
4/30/15	111	3.1	12	<1
5/21/15	19	4	63	<1
6/2/15	93	8	15	<1
6/10/15	192	6	4	<1
6/24/15	44	58	27	2
6/25/15	59	26	81	<1
7/8/15	75	22	223	--
7/9/15	63	6	99	--
7/22/15	26	3	1	--
7/23/15	42	5	5	--
7/26/15	72	--	--	--
7/27/15	63	--	--	--
9/1/15	68	--	--	--
Geometric mean	**61**	**8**	**20**	**2**

-- No sample collected

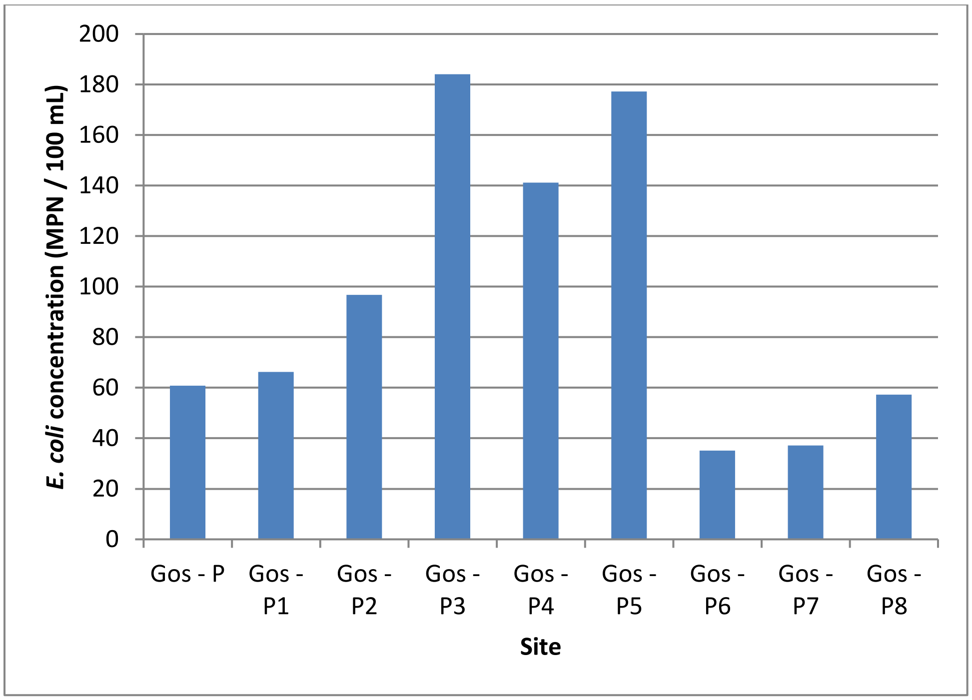
In order to further assess potential sources of *E. coli* associated with the large number of geese near the primary monitoring site, a small Special Study was conducted in the Goose Drainage. Several sites close to the primary monitoring site (Gos-P1) were monitored for *E. coli* over a period of three days from August 26 through September 1, 2015, as shown on Figure 4-13.

Figure 4-13: Map of Goose Drainage Monitoring Sites Samples in the Goose Special Study



A total of 27 samples were collected during dry weather over the course of the Special Study. The results are represented as geometric mean *E. coli* concentrations on Figure 4-14. During the monitoring, goose and goose excrement were observed in the grassy area adjacent to Gos-P7 (in front of Don's Little Bar) and waterfowl were observed along the shoreline at Gos-P2. The greatest *E. coli* concentrations during the Special Study were observed at sites Gos-P3 and Gos-P5 adjacent to a dirt parking lot of a local bar (Figure 4-13) with geometric mean concentrations of 184 MPN/100 mL and 177 MPN/100 mL, respectively. Concentrations were also elevated at Site Gos-P4 in front of the culvert that connects West Goose Lake with East Goose Lake (geometric mean concentration of 141 MPN/100 mL).

Figure 4-14: Results from Goose Drainage Special Study



4.3.2.4 Human and Non-human Origin Assessment

Four samples were collected from the Goose Drainage and analyzed for the molecular markers (Table 4-17). None of the samples were positive for the human marker and one was positive for the bird marker.

Table 4-17: Results of Human and Non-human Genetic Marker Assays at Monitoring Sites Oak-P and Oak-C1

Date	Site	Human Marker	Bird Marker
8/26/2015	Gos-P	Negative	Positive
8/27/2015	Gos-P	Negative	Negative
9/1/2015	Gos-P	Negative	Negative

2017 Wet Weather Assessment

Wet weather Monitoring of the Goose Drainage was conducted during a storm event on June 28, 2017. Three sites were monitored during the course of the storm: Gos-P (the primary monitoring site), Gos-A2 (in front of the northern culvert that connects West Goose Lake to East Goose Lake), and Gos-A4 (in front of the southern culvert that connects West Goose Lake to East Goose Lake). The sites are shown on Figure 4-12. Flow measurements and samples for *E. coli* analyses were collected from each site a total of seven times over the course of the storm from 3:30 to 7:50 p.m.

4.3.2.5 Flow Monitoring

Instantaneous flow was measured at all three sites with a hand-held flow meter; however, fluctuations in water level were not discernable at the stream stage at Gos-P and therefore flow could not be calculated and pollutographs could not be produced. Instantaneous flow at Site Gos-P ranged from 0.16 feet per second (ft/s) at the onset of the storm to a peak rate of 0.93 ft/s approximately two hours later as the storm peaked, then gradually subsided to 0.44 ft/s (Table 4-18). At Site Gos-A2 in front of the northern culvert, no flow could be measured with the hand-held flow meter. At Site Gos-A4 in front of the southern culvert, instantaneous flow was erratic, ranging from 0.04 ft/s at the onset of the storm to 0.17 ft/s at the storm's peak.

4.3.2.6 *E. coli* Monitoring

Samples for *E. coli* enumeration were collected at each of the three sites at the same times that flow was measured (Table 4-18). Among the three sites monitored, *E. coli* concentrations were lowest at Site Gos-A4, ranging from 69 MPN/100 mL to 138 MPN/100mL, which are similar to concentrations in samples collected during dry weather. At Site Gos-P, the primary monitoring site, *E. coli* concentrations were higher than those at Gos-A-4, ranging from 435 MPN/100 mL to 980 MPN/100 mL; however, none of the samples collected from Gos-P nor Gos-A4 exceeded the Acute Water Quality Standard of 1,260 MPN/100 mL. *E. coli* concentrations at Site Gos-A2 (geometric mean of 6,344 MPN/100 mL) were one to two orders of magnitude greater than those at sites Gos-P and Gos-A4 (geometric mean concentrations of 695 MPN/100 mL and 86 MPN/100 mL, respectively). All of the samples collected from Site Gos-A2 had *E. coli* concentrations that were at or above the Acute Water Quality Standard. Concentrations during the second half of the storm event were two times greater than those during the first half of the storm.

Table 4-18: Wet Weather Flow and *E. coli* Results from the Goose Drainage During the June 28, 2017 Storm Event

Site	Sample Number	Time (hours)	Flow (ft/s)	*E. coli* (MPN/100 mL)
Gos-P	1	15:30	0.16	579
	2	16:30	0.2	435
	3	17:20	0.93	866
	4	18:00	0.3	980
	5	18:45	0.6	866
	6	19:20	0.47	770
	7	19:45	0.44	548
			Geometric Mean:	**695**
Gos-A2	1	15:30	0	3,080
	2	16:30	0	6,130
	3	17:20	0	1,260
	4	18:00	0	5,170
	5	18:45	0	11,200
	6	19:20	0	17,330
	7	19:45	0	17,330
			Geometric Mean:	**6,344**
Gos-A4	1	15:40	0.04	83
	2	16:40	0.06	138
	3	17:30	0.12	80
	4	18:10	0.06	120
	5	18:55	0.17	69
	6	19:30	0.07	62
	7	19:50	0.09	73
			Geometric Mean:	**86**

Note: Values in red met or exceeded the Acute Water Quality Standard of 1,260 MPN/100 mL

4.3.2.7 Human and Non-Human Origin Assessment

During the June 28, 2017 storm event, a total of nine samples were collected for molecular marker analyses: three samples each from the primary monitoring site (Gos-P) and the West Goose Lake side of the two culverts (Gos-A-2, and Gos-A4) (Table 4-20). All nine samples were negative for the human and canine marker, but all nine samples were positive for the avian marker.

Table 4-19: Results of Human and Non-human Marker Assays at Goose Drainage Monitoring Sites During the June 28, 2017 Storm Event

Site	Sample Number	Time Sampled	Human Marker	Avian Marker	Canine Marker
Gos-P	1	03:30	Negative	Positive	Negative
	2	06:00	Negative	Positive	Negative
	3	07:45	Negative	Positive	Negative
Gos-A2	1	03:35	Negative	Positive	Negative
	2	06:00	Negative	Positive	Negative
	3	07:45	Negative	Positive	Negative
Gos-A4	1	03:30	Negative	Positive	Negative
	2	06:10	Negative	Positive	Negative
	3	07:50	Negative	Positive	Negative

4.4 Whitaker Drainage

The Whitaker Drainage lies at the top of the Lambert Creek Watershed (Figure 1 1). The drainage consists entirely of urban land use, primarily single family residential with several large ball fields associated with parks and schools in the upper part of the drainage. There is an extensive MS4 infrastructure in the drainage that conveys storm water flows from the Whitaker Drainage to the Primary Monitoring Site (Wht-P). The MS4 is underground for the entirety of the Whitaker Drainage and there are no surface canals or open ditches where flows in the MS4 are exposed.

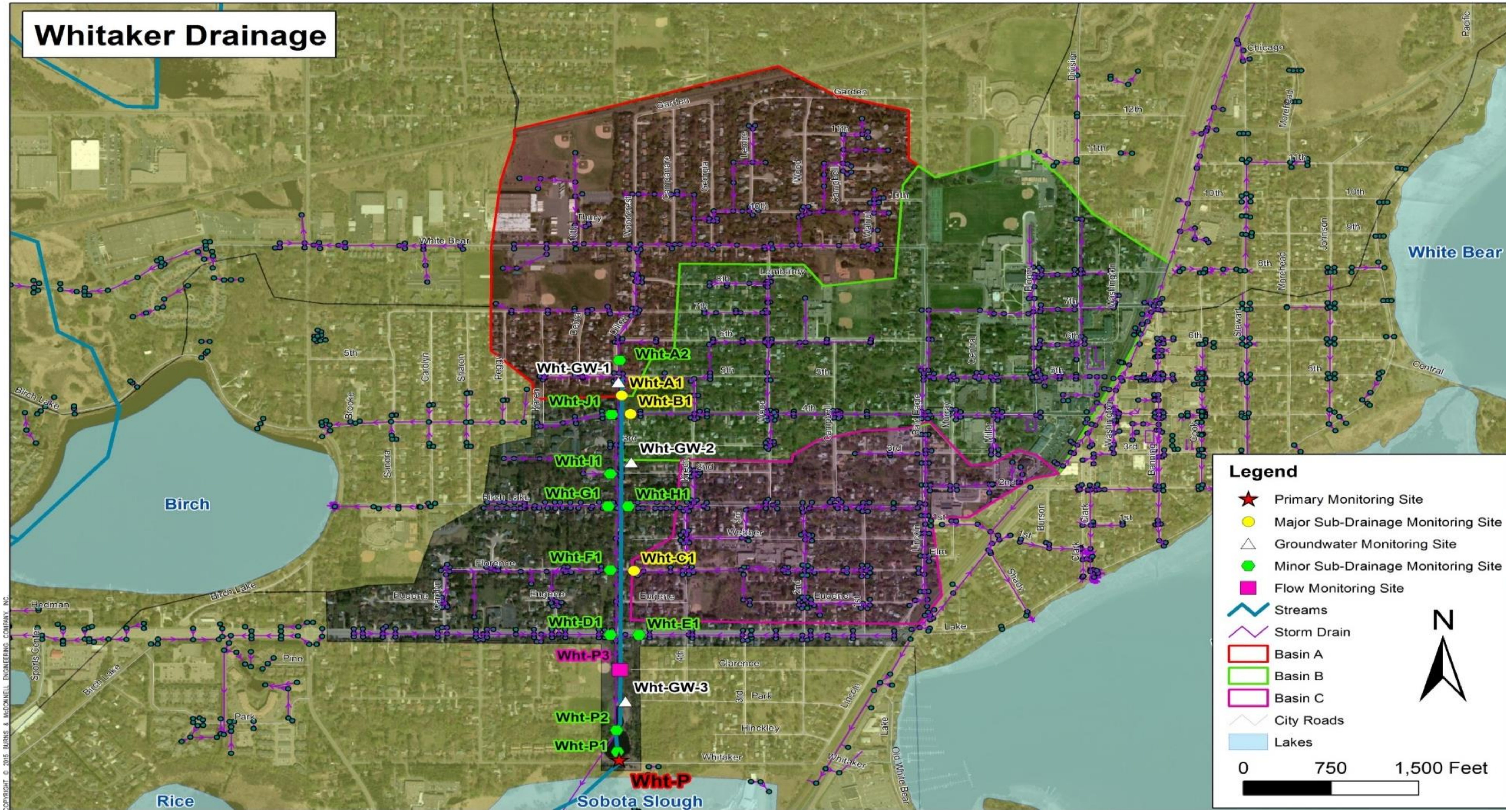
Preliminary maps of the MS4 infrastructure within the Whitaker Drainage were created from GIS files made available by VLAWMO. The preliminary maps were used in the field during a site reconnaissance that was conducted on May 15, 2014 in the Whitaker drainage to identify potential sources of bacteria that may be contributing to elevated concentrations at the Primary Monitoring Site. Following the reconnaissance, the preliminary maps were adjusted based on observations of flow and potential inputs to the Primary Monitoring Site. Based on the observations and maps of the MS4 infrastructure, it was determined that within the Whitaker Drainage there are three Major Sub-drainages that each drain to discrete sampling locations. The locations are identified on Figure 4-15 and described below:

- Major Sub-drainage A – located on Dillon Street, just north of 4th Street;
- Major Sub-drainage B – located on 4th Street at Campbell Avenue; and
- Major Sub-drainage C – located on Florence Street between 4th Street and 2nd Street.

Flows from each of these Major Sub-drainages are directed to the Mainstem MS4, which flows south from 5th Street to the storm drain outfall then discharges to the Whitaker Detention Basin (Figure 4-15).

The Mainstem MS4 is designated as a blue-line stream on Figure 4-15 and prior to development of the Whitaker Drainage was an open channel known as the Dillon Ditch. In addition to the Major Sub-drainages A, B, and C, there are a series of smaller MS4 pipes that convey flows to the Mainstem MS4 from the east and west sides of the Whitaker Drainage. These Minor Sub-drainages drain surface streets that run perpendicular to the Mainstem MS4. The location where the Minor Sub-drainages connect to the Mainstem MS4 are designated in green as Minor Sub-drainage Monitoring Sites D through J on Figure 4-15.

Figure 4-15. Map of the Whitaker Drainage Showing Surface Water and Groundwater Monitoring Sites



4.4.1 Monitoring Locations

Site selection for the bacterial source identification in the Whitaker Drainage was based on historical data available for the drainage and the results of the site reconnaissance conducted throughout 2014, 2015, and the spring of 2016. The monitoring sites are shown graphically on Figure 4-15 and described in Table 4-20.

Table 4-20. Monitoring site IDs, locations, and drainage area descriptions for the Whitaker Drainage

Site ID	Site Name / Sample Location	Site Drainage Description
Wht-P	Primary Monitoring Site at Base of Whitaker Drainage just upstream of Whitaker Road	The entire Whitaker Drainage
Wht-P1	Downstream side of the Middle Forebay of the Whitaker Detention Basin, upstream of the weir	Upper and Middle Forebays of the Whitaker Detention Basin
Wht-P2	At the Storm drain outfall just upstream of where the MS4 discharges to the Upper Forebay	The entire Whitaker Drainage except the Whitaker Detention Basin
Wht-P3	Mainstem MS4 in Columbia Park off Clarence Street	The entire Whitaker Drainage except the Whitaker Detention Basin and ~ 750 feet upstream of the basin
Wht-A1	On Dillon Street just upstream of 4th Street	Upper northwest corner of the Whitaker Drainage above 4th Street
Wht-B1	East side of the Mainstem MS4 on 4th Street	Upper northeastern and central portion of the Whitaker Drainage upstream of 3rd Street
Wht-C1	East side of the Mainstem MS4 on Florence Street	Lower southeastern portion of the Whitaker Drainage between 3rd Street and Highway 96E
Wht-D1	West side of the Mainstem MS4 at Highway 96E Street	Highway 96E from the western drainage boundary to the Mainstem MS4
Wht-E1	East side of the Mainstem MS4 at Highway 96E Street	Highway 96E from the eastern drainage boundary to the Mainstem MS4
Wht-F1	West side of the Mainstem MS4 at Florence Street	Florence Street from the west side of the drainage boundary to the MS4 Mainstem
Wht-G1	West side of the Mainstem MS4 at Birch Lake Avenue	Birch Lake Avenue from the western watershed boundary to the Mainstem MS4
Wht-H1	East side of the Mainstem MS4 at Birch Lake Avenue	Birch Lake Avenue from the Sub-drainage C boundary to the Mainstem MS4

Site ID	Site Name / Sample Location	Site Drainage Description
Wht-I1	West side of the Mainstem MS4 at 2nd Street	2nd Street from the western watershed boundary to the Mainstem MS4
Wht-J1	West side of the Mainstem MS4 at 4th Street	4th Street from the western watershed boundary to the Mainstem MS4
Wht-GW-1	Groundwater Monitoring Well on the South side of 5th Street at and of Dillon Street	NA
Wht-GW-2	Groundwater Monitoring Well North of 2nd Street along Dillon Ditch	NA
Wht-GW-3	Groundwater Monitoring Well in Columbia Park, just West of Park Street	NA

4.4.2 Groundwater Monitoring

In order to assess the extent to which groundwater may be influencing *E. coli* concentrations in the surface receiving waters of Lambert Creek, three temporary groundwater monitoring wells were installed in the Whitaker Drainage to monitor the groundwater table and to measure concentrations of *E. coli*. The wells were positioned adjacent to the Mainstem MS4 in line with a drainage formerly known as the Dillon Ditch. Wells were installed in March 2015 using direct push technology. Each well was drilled to a depth of approximately 20 feet below ground surface (bgs), which is below the depth of the bottom of the MS4 channel. Polyvinyl chloride (PVC) casings (1.5 inches inside diameter) were installed to maintain the integrity of the bore-holes and each casing was fitted with a removable PVC cap. The wells were in place for a period of up to three years.

Groundwater samples for bacterial analyses were collected from the wells using a sterile plastic bailer and sterile techniques described in Section 3. The bailer was lowered from the top of the casing with a nylon line to just below groundwater level. For each sampling event, three well casing volumes were purged from the well hole prior to sample collection. Initial depth data were used to verify that purging rates did not exceed the recharge capacity of the well. The process was considered complete when water quality parameters and monitoring water levels stabilized. A new, sterile bailer was used for each sampling event and the purging process described above was followed. After purging, groundwater samples were collected from the well with the bailer and decanted directly into a 100-mL sterile, pre-labelled plastic bottle. The sample was stored on ice until transport to the laboratory within the required holding time.

4.4.3 Results

In 2015, a dry weather assessment of the Whitaker Drainage was conducted. Similar to the Oakmede, County Road F, and Goose Drainage assessments, the objective of dry weather monitoring in the Whitaker Drainage was to determine the potential sources and pathways of *E. coli* to the receiving waters within the drainages, identify spatial patterns with the drainages to identify specific areas within each drainage that might be a substantial contributor of *E. coli*, and identify the extent to which *E.coli* from human origin impact the receiving waters. In addition, A small-scale groundwater study was conducted in the Whitaker Drainage to determine if *E. coli* was present in groundwater, which could affect bacteria levels in the storm drain infrastructure via infiltration.

2015 Dry Weather Assessment

4.4.3.1 Visual Observations

A total of 13 dry weather observations were made in the Whitaker Drainage in 2015. During all observation days, flow in Lambert Creek was observed at the MS4 outfall (Site Wht-P2) and the weir at the far end of Whitaker Pond (Figure 4-15) and were able to collect dry weather samples from these locations and others within the MS (Wht-C1, Wht-B1, and Wht-A1). In general, flowing water was observed in the MS4 within the Whitaker Drainage downstream of 4th Street. Above 4th Street, the MS4 was generally dry during dry weather conditions.

There was no evidence of human waste at any of the Whitaker sites over the Monitoring Period (no signs of homeless encampments, sewage leaks, odors, etc.). Birds were observed throughout the Whitaker Drainage, particularly in the parks and ballfield, such as Podvin Park and Lincoln Elementary ballfield.

4.4.3.2 Flow Monitoring

The Whitaker Drainage is the only drainage in Lambert Creek with an installed flow meter. The meter is installed within the MS4 in Columbia Park off Clarence Street, accessed via a manhole. Flow is measured continuously at this site and recorded on a datalogger on site.

4.4.3.3 *E. coli* Monitoring

In the Whitaker Drainage, a total of 66 dry weather samples were collected and analyzed for *E. coli* between April and September 2015; 13 from the primary monitoring site (Wht-P1) and the remainder from the Whitaker Pond area and upstream tributaries. In general, dry weather *E. coli* concentrations were low over the course of the study throughout the drainage and there was only one exceedance of the Acute Water Quality Standard (1,987 MPN/100 mL at the MS4 outfall that discharges to Whitaker Pond).

Spatially, *E. coli* concentrations were greatest in Sub-drainage A (northwest) (see Figure 4-15), followed by Sub-drainage B (northeast), and Sub-drainage C (southeast). *E. coli* concentrations were low in all three sub-drainages during dry weather, with geometric mean concentrations of 47, 32, and 13 MPN/100 mL, respectively.

Table 4-21: *E. coli* Concentrations at the Whitaker Drainage Sites by Date During Dry Weather

Date	*E. coli* Concentrations (MPN / 100 mL)					
	Wht-P	**Wht-P1**	**Wht-P2**	**Wht-C1**	**Wht-B1**	**Wht-A1**
4/30/2015	2	2	13	--	--	--
5/21/2015	93	178	150	4	142	54
6/2/2015	172	147	6	<1	25	24
6/10/2015	51	26	11	2	12	8
6/24/2015	130	9	194	91	55	308
6/25/2015	236	10	82	7	236	45
7/8/2015	76	28	56	12	19	36
7/9/2015	115	16	115	7	8	27
7/22/2015	15	3	19	10	16	70
7/23/2015	16	6	160	155	29	105
7/26/2015	49	1,987	135	--	--	--
7/27/2015	55	22	435	--	--	--
9/1/2015	65	52	579	--	--	--
Geometric Mean	**52**	**26**	**72**	**13**	**32**	**47**

-- No sample collected
Note: Values in red exceeded the Acute Water Quality Standard of 1,260 MPN/100 mL

4.4.3.4 Human and Non-human Origin Assessment

A limited number of samples for molecular analyses were collected from sites Wht-P (located at the weir at the end of Whitaker Pond), and the outfall that discharges into Whitaker Pond (Wht-P2). Among the nine samples collected, none were positive for the human marker, two were positive for the bird marker, and three were positive for the dog marker.

4.4.3.5 Groundwater Assessment

Three temporary groundwater wells were drilled in the Whitaker Drainage (see Figure 4-15). Each well was monitored three times from April through July 2015 and *E. coli* concentrations were below detection limit in all samples (Table 4-22).

Table 4-22: *E. coli* Concentrations (MPN/100 mL) from Groundwater in the Whitaker Drainage

Date	Site		
	Wht-GW-1	**Wht-GW-2**	**Wht-GW-3**
4/28/2015	< 1	< 1	< 1
6/2/2015	< 1	< 1	< 1
7/8/2015	< 1	< 1	< 1

2017 Wet Weather Assessment

4.4.3.6 Flow Monitoring

Instantaneous flow was measured during a storm event on August 9, 2017 in the Whitaker Drainage. Instantaneous flow was measured at five sites over the course of the storm event: the primary monitoring site (Wht-P), the storm drain outfall that drains to Whitaker Pond (Wht-P2), and the base of the three main Subdrainages (Wht-C1, Wht-B1, and Wht-A1) (see Figure 4-15). Flow was measured six times over the course of the storm at sites Wht-P and Wht-P2, and three times at sites Wht-C1, Wht-B1, and Wht-A1. Flow measurements were paired with the collection of a grab sample at each site for *E. coli* analysis (see Table 4-23). At Site Wht-P, flow was negligible during the first half of the storm event, but increased to 0.31 ft/s approximately two hours after the onset of rain. Flow at Site Wht-P2 showed a similar pattern, but greater magnitude, suggesting that flow dissipates as the stormwater flows through Whitaker Pond. Instantaneous flow was much greater in the subdrainages, with peak flows approaching 2.0 ft/s.

4.4.3.7 *E. coli* Monitoring

In general, *E. coli* concentrations were greatest with the peak in flow at all of the sites during the storm event (Table 4-23). At the primary monitoring site (Wht-P), concentrations were relatively low, but two of the six samples exceeded the Acute Water Quality Standard. Concentrations at Wht-P were substantially lower than those at Wht-P2 where the creek discharge from the storm drain on the opposite side of Whitaker Pond, suggesting that the pond may be an effective means of reducing *E. coli* concentrations. Similar relative results were observed at these two sites during dry weather as well. *E. coli* concentration at the mouths of the subdrainages (Wht-C1, Wht-B1, and Wht-A1) within the MS4 were similar to those at Wht-P2 where the MS4 discharges to Whitaker Pond. Two thirds of the samples collected from the subdrainage MS4 exceeded the Acute Water Quality Standard.

Table 4-23: Wet Weather Flow and *E. coli* Results from the Whitaker Drainage During the August 9, 2017 Storm Event

Site	Sample Number	Time (hours)	flow (ft/s)	*E. coli* (MPN/100 mL)
Wht-P	1	12:00	0.00	44
	2	12:45	0.00	39
	3	1:15	0.09	387
	4	2:00	0.31	1,300
	5	2:30	0.24	1,553
	6	3:00	0.19	980
			Geometric Mean:	**330**
Wht-P2	1	12:15	0.04	113
	2	12:55	0.10	2,420
	3	1:20	0.98	12,997
	4	2:05	0.34	3,448
	5	2:35	0.33	3,076
	6	3:05	0.21	2,420
			Geometric Mean:	**2,120**
Wht-C1	1	12:20	0.1	980
	2	1:25	1.81	17,329
	3	3:10	1.31	1,733
			Geometric Mean:	**3,088**
Wht-B1	1	12:30	0.21	1,120
	2	1:30	1.68	4,106
	3	3:15	1.91	1,515
			Geometric Mean:	**1,910**
Wht-A1	1	12:40	0.01	140
	2	1:35	1.48	3,873
	3	3:20	1.47	4,106
			Geometric Mean:	**1,305**

Note: Values in red met or exceeded the Acute Water Quality Standard of 1,260 MPN/100 mL

4.4.3.8 Human and Non-human Origin Assessment

Human origin assessment was done to address the question of whether *E. coli* in the Whitaker Drainage originates from human sources. A total of 15 samples were collected during the August 9, 2017 storm event from several sites in the Whitaker Drainage, including the primary monitoring site (Wht-P), the storm drain outfall into Whitaker Pond (Wht-P2), and the bottom of the three major sub-drainages (Wht-C1, Wht-B1, and Wht-A1) (see Figure 4-15).

The results are presented in Table 4-24. Among the 27 analyses conducted, 0% were positive for the human marker, 100 percent were positive for the avian marker, and 53% (eight of the 15 samples) were positive for the canine marker.

Table 4-24: Results of Human and Non-human Marker Assays at Whitaker Drainage Monitoring Sites During the August 9, 2017 Storm Event

Site	Sample Number	Time Sampled	Human Marker	Avian Marker	Canine Marker
Wht-P	1	12:00	Negative	Positive	Negative
	2	13:15	Negative	Positive	Negative
	3	15:00	Negative	Positive	Negative
Wht-P2	1	12:15	Negative	Positive	Negative
	2	13:20	Negative	Positive	Positive
	3	15:05	Negative	Positive	Positive
Wht-C1	1	12:20	Negative	Positive	Negative
	2	13:25	Negative	Positive	Positive
	3	15:10	Negative	Positive	Positive
Wht-B1	1	12:30	Negative	Positive	Negative
	2	13:30	Negative	Positive	Positive
	3	15:15	Negative	Positive	Positive
Wht-A1	1	12:40	Negative	Positive	Negative
	2	13:35	Negative	Positive	Positive
	3	15:20	Negative	Positive	Positive

5.0 CONCLUSIONS

Based on the results of the Lambert Creek Bacterial Source Identification Study, the following conclusions can be made:

- During dry weather, *E. coli* concentrations were low throughout the watershed, with only one exceedance over of the course of the dry weather sampling at all four drainages.
- There were no samples that were positive for the human marker during dry weather over the course of the study, suggesting that human fecal matter is not a source of *E. coli* to the receiving waters of Lambert Creek during dry weather.
- There was no evidence of homeless encampments, leaking sewage pipes, or other potential sources of *E. coli* that might enter Lambert Creek from human origin.
- Based on limited sampling in the Whitaker Drainage, groundwater does not appear to be a sources of *E. coli* to Lambert Creek.
- Birds are a likely source of *E. coli* in Lambert Creek during both dry and wet weather. Birds and bird fecal matter were frequently observed in all four drainages over the course of the multi-year study and nearly all the samples collected during both dry and wet weather conditions were positive for the bird molecular marker.
- Fecal matter from dogs is also a potential source of *E. coli* to Lambert Creek, based on the moderate frequency of positive results for the dog marker.
- During storm events, *E. coli* concentrations mirrored the hydrograph at all sites (although this signal was muted in the Goose Drainage) with concentrations peaking during the greatest flow.
- *E. coli* concentrations increased dramatically at all sites with the onset of rain. In general, meaningful spatial patterns could not be determined during the storm events – *E. coli* concentrations were elevated at all sites monitored and concentrations remained elevated after the hydrograph had fallen to near-baseline levels.
- Restoration efforts in the Oakmede Drainage appear to have been successful in reducing *E. coli* concentrations in the receiving waters. This is likely due to a combination of streambank stabilization, (which reduces the inputs of bacteria associated with sediment particles) and the clearing of vegetation in the riparian zone (which enhances solar radiation on the surface waters of the creek).
- Observations made during pollutograph monitoring identified potential areas where BMPs could be introduced to reduce the input of *E. coli* to Lambert Creek during storm events.

6.0 RECOMMENDATIONS

Based on the results of the study presented above, the following recommendations are submitted for consideration.

General Recommendations for the Lambert Creek Watershed.

- Assess and consider enhancing the street sweeping program to remove leaf litter and soil in street gutters, which were shown to be sources of *E. coli*.
- Implement and/or enforce BMPs for construction crews (contractor and City) to prevent construction-related soil from entering the storm drain system.
- Implement inlet protection at parks and other public facilities (particularly in the Whitaker Drainage) to prevent flow from grassy areas from entering the storm drain system during irrigation activities and storm events.
- Assess the use of fertilizer on properties within the watershed managed by municipalities and replace manure-based fertilizers with synthetic fertilizers, as appropriate.
- Implement and/or continue education and outreach BMPs that focus on preventing *E. coli* from entering the MS4. Messaging may include dog waste control (e.g., dog waste dispensers and signage), water conservation (preventing irrigation overflow from entering the MS4), and minimizing the accumulation of organic debris (leaf litter and grass clippings) in street gutters.
- Develop or enhance existing illicit discharge programs to identify sources of *E. coli* in dry weather flows within the watershed and implement BMPs as appropriate.
- Continue monitoring the primary monitoring sites at the base of each of the drainages identified in this Study. Monthly monitoring from May through October is recommended. Use the baseline data from the Study and subsequent monitoring to assess BMP effectiveness and TMDL milestones.
- Consider additional studies to better understand the potential health risks associated with *E. coli* in the watershed (such as a quantitative microbial risk assessment) and an associated assessment of the applicability of the existing standards (particularly as it related to the differences in *E. coli* concentrations during dry versus wet weather periods).

Oakmede Drainage

- Continue monitoring Oak-P for *E. coli* and flow during dry weather on a monthly basis (minimum) from May through October in subsequent years to determine if the results obtained in this study remain consistent over time.
- Use data collected in future monitoring years to continue to assess the effectiveness of the restoration of the Lambert Creek reach at Oakmede by comparing *E. coli* concentrations before and after restoration (2013). Assessments conducted with additional data collected in the future will help determine the effectiveness of stream restoration as a viable BMP for reducing E. coli concentrations at other locations in the Lambert Creek Watershed.
- Identify areas of erosion, degraded BMPs, or discharge from storm drains that cause hydromodification (e.g., in the area around Rice Lake) and stabilize the associated soils to prevent E. coli adsorbed to the soil particles from entering the receiving waters.

Country Road F Drainage

- Continue monitoring CRF-P for *E. coli* and flow during dry weather on a monthly basis (minimum) from May through October in subsequent years to determine if the results obtained in this study remain consistent over time.
- Consider assessing the storm drain ponds at the top of the drainage for potential BMP enhancement. Visual observations suggested that these ponds may be a source of continuous dry weather flow to the primary monitoring site.

Goose Drainage

- Consider goose management BMPs to eliminate or minimize the goose population and associated fecal matter near Don's Little Bar on West Goose Lake.
- Implement BMPs at the parking lot in this area to prevention erosion events from transporting soil and associated E. coli to the receiving waters
- Consider vegetation-management BMPs in the area around the primary monitoring site to decrease stagnation and make the area less attractive to waterfowl.

Whitaker Drainage

- Consider assessing the weir at the bottom of Whitaker Pond (Site Wht-P) for improvements that would minimize stagnation of water that may lead to elevated bacterial levels.
- Provide inlet protection BMPs in city-owend parks within the drainage to prevent runoff from the grassy areas of the parks to the receiving waters.

7.0 LITERATURE CITED

Southern California Coastal Water Research Project (SCCWRP). (2013). *The California Microbial Source Identification Manual: A Tiered Approach to Identifying Fecal Pollution Sources to Beaches*.

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