Michigan Department of Natural Resources and Environment
Water Bureau
May 2010

Total Maximum Daily Load for *E. coli* for Ruddiman Creek Muskegon County

INTRODUCTION

Section 303(d) of the federal Clean Water Act and the United States Environmental Protection Agency's (USEPA's) Water Quality Planning and Management Regulations (Title 40 of the Code of Federal Regulations, Part 130) require states to develop Total Maximum Daily Loads (TMDLs) for water bodies that are not meeting water quality standards (WQS). The TMDL process establishes the allowable loadings of pollutants for a water body based on the relationship between pollution sources and in-stream water quality conditions. TMDLs provide states a basis for determining the pollutant reductions necessary from both point and nonpoint sources to restore and maintain the quality of their water resources. The purpose of this TMDL is to identify the allowable levels of *E. coli* that will result in the attainment of the applicable WQS in Ruddiman Creek, located in Muskegon County, Michigan (Figure 1).

PROBLEM STATEMENT

This TMDL addresses the listing that appears on the 2008 Section 303(d) list (LeSage and Smith, 2008) as:

RUDDIMAN CREEK **AUID**: 040601021004-04
County: MUSKEGON SIZE: 1.96 M
Location: Main branch of Ruddiman Creek upstream of pond to headwaters.
Use impairments: Total and partial body contact recreation.
Cause: *E. coli*
Source: Sewage discharges in unsewered areas
TMDL Year(s): 2010

Ruddiman Creek was first placed on the Section 303(d) list in 1998 due to impairment of recreational uses by *E. coli* (Creal and Wuycheck, 1998). Illicit sewage discharges to storm sewers were suspected based on high levels of *E. coli* found in 1996 and 1997. Monitoring data collected by the Michigan Department of Natural Resources and Environment (DNRE) in 2009 documented multiple exceedances of the daily maximum and 30-day geometric mean WQS for *E. coli* during the total body contact (TBC) recreational season of May 1 through October 31, and periodic exceedances of the partial body contact (PBC) WQS (Table 1; Figures 2a-2c and 3). Many illicit discharges from older neighborhoods had been corrected prior to DNRE sampling in 2009. Sampling in 2009 of the west branch of Ruddiman Creek (Station 3), and at the outlet to Muskegon Lake (Station 4), indicate that the entirety of Ruddiman Creek is impaired; therefore, this TMDL addresses the entire watershed (Figure 1). The expanded TMDL reach includes Assessment Units 040601021004-08 (listed in the 2010 Section 303(d) list) and 040601021004-10 (listing proposed for the 2012 Section 303(d) list) as follows:

RUDDIMAN POND **AUID**: 040601021004-08
County: MUSKEGON SIZE: 21 acres
Location: Impoundment of Ruddiman Creek
Use impairments: Total and partial body contact recreation.
Cause: *E. coli*
Source: Sewage discharges in unsewered areas
TMDL Year(s): 2010

RUDDIMAN CREEK **AUID**: 040601021004-10
County: MUSKEGON SIZE: 1.6 M
Location: West and North Branches of Ruddiman Creek
Use impairments: Total and partial body contact recreation.
Cause: *E. coli*
Source: Sewage discharges in unsewered areas.
TMDL Year(s): 2010

The TMDL reach is located in the Ruddiman Creek watershed, which flows into Muskegon Lake, and finally, Lake Michigan (Hydrologic Unit Code 04060102 [Figure 1]). The Ruddiman Creek watershed covers 4,125 acres (about 6.5 square miles) of Muskegon County. Muskegon Lake is a large drowned-river mouth lake, located in the Southern Lake Michigan Lake Plain ecosystem type, which is characterized by lacustrine clay and silt soils, and prior to colonization by non-native Americans, white oak-white pine forest (Albert, 1995). The Ruddiman Creek TMDL watershed is composed of four municipalities, which include the city of Muskegon, Muskegon Heights, Roosevelt Park, and Norton Shores (Table 5). Ruddiman Creek has been highly modified to maintain drainage for the greater Muskegon-Norton Shores Metropolitan Statistical Area and about 60 percent of the Ruddiman Creek waterway is below ground, as storm sewers, in the upper watershed. The above-ground portion of Ruddiman Creek begins as a 60-inch storm sewer outfall, just upstream of Barclay Avenue (Figure 1). The Ruddiman Creek watershed is home to a population of about 23,000 people (based on a population density estimate from the United States Census Bureau [2000]) and is approximately 33 percent covered by impervious surfaces (Purdue University and USEPA, 2001). Land use is predominately residential and commercial. Land cover as a percentage of the watershed in 2006 was predominately low intensity developed land (37 percent), followed by medium intensity (27 percent), and high intensity (15 percent) (NOAA, 2008). Only about 3 percent of the watershed drains naturally to the creek without entering storm sewers (NOAA, 2008).

NUMERIC TARGET

The impaired designated uses addressed by this TMDL are TBC and PBC recreation. The designated use rule (Rule 100 [R 323.1100] of the Part 4 rules, WQS, promulgated under Part 31, Water Resources Protection, of the Natural Resources and Environmental Protection Act, 1994 PA 451, as amended) states that this water body be protected for TBC recreation from May 1 through October 31 and PBC recreation year-round. The target levels for these designated uses are the ambient *E. coli* standards established in Rule 62 of the WQS as follows:

> R 323.1062 Microorganisms.
> Rule 62. (1) All waters of the state protected for total body contact recreation shall not contain more than 130 *E. coli* per 100 milliliters (mL), as a 30-day geometric mean. Compliance shall be based on the geometric mean of all individual samples taken during five or more sampling events representatively spread over a 30-day period. Each

sampling event shall consist of three or more samples taken at representative locations within a defined sampling area. At no time shall the waters of the state protected for total body contact recreation contain more than a maximum of 300 *E. coli* per 100 mL. Compliance shall be based on the geometric mean of three or more samples taken during the same sampling event at representative locations within a defined sampling area.

(2) All surface waters of the state protected for partial body contact recreation shall not contain more than a maximum of 1,000 *E. coli* per 100 ml. Compliance shall be based on the geometric mean of 3 or more samples, taken during the same sampling event, at representative locations within a defined sampling area.

For this TMDL, the WQS of 130 *E. coli* per 100 mL as a 30-day geometric mean and 300 *E. coli* per 100 mL as a daily maximum to protect the TBC use are the target levels for the TMDL reach from May 1 through October 31, and 1000 *E. coli* per 100 ml as a daily maximum year-round to protect the PBC use. The 2009 monitoring data indicated daily maximum TBC WQS exceedances at Stations 1-4, and monthly average TBC WQS exceedances at Stations 1-3. The PBC WQS was exceeded frequently on main branch Stations 1 and 2, and periodically at Stations 3 and 4.

DATA DISCUSSION

Weekly *E. coli* data were collected by the DNRE from four sites in the above-ground portion of Ruddiman Creek from May 19 to September 1, 2009 (Figure 1). Precipitation data for the two days prior to each DNRE sampling event were obtained from a weather station at the Annis Water Resources Institute, Muskegon (Table 1). *E. coli* daily maximum and 30-day geometric mean data for 2009 are shown in Table 1 and Figure 3. Station 1 is located immediately downstream of the 60-inch city of Muskegon storm sewer outfall, which also has storm sewer connections from Muskegon Heights. Station 2 is located downstream of Station 1 on the main branch of Ruddiman Creek downstream of Barclay Road. Station 3 is located on the west branch of Ruddiman Creek and Station 4 is located below the weir at the outlet of Ruddiman pond (an impoundment of Ruddiman Creek). The highest daily maximum *E. coli* concentration of 30,429 *E. coli* per 100 mL was recorded at Station 2 on June 30, 2009, following a rainfall of 0.15 inches. This small amount of rainfall was preceded by 7 days of no measurable rainfall, potentially accounting for high *E. coli* levels in the flush of the storm sewers. The daily maximum TBC standard (300 *E. coli* per 100 mL) was exceeded at Station 1 on 100 percent of sampling dates, at Station 2 on 87 percent of sampling dates, at Station 3 on 94 percent of sampling dates, and at Station 4 on 13 percent of sampling dates. The PBC recreation daily maximum standard (1000 *E. coli* per 100 mL) was exceeded at Station 1 on 75 percent of sampling dates, at Station 2 on 63 percent of sampling dates, at Station 3 on 13 percent of sampling dates, and at Station 4 on 6 percent of sampling dates. Based on the geometric means of all weekly samples at each site, Station 1 had the highest concentrations of *E. coli* while Station 4 had the lowest concentrations. Concentrations of *E. coli* exiting the pond (Station 4) only exceeded the TBC standard on 2 of the weekly sampling dates, and both were following heavy rains. Based on this, it appears that either through mortality of the *E. coli* due to conditions in the pond, settling, or dilution, the concentrations of *E. coli* entering Muskegon Lake tend to be much lower, particularly during dry weather, than those upstream of Ruddiman Pond (Stations 1-3).

Weekly *E. coli* concentrations at Station 3 had a positive correlation with measured flow (R^2=0.61); but no relationship between daily *E. coli* concentration and flow was found at the other stations. Higher flows resulting in higher *E. coli* concentrations at Station 3 may indicate that the *E. coli* source to the west branch is related to runoff from storm events; whereas, at Stations 1 and 2, *E. coli* concentrations are unrelated to flow or storm events indicating a more constant source may be affecting the main branch, such as illicit connections. Flows from rain events on July 25 and August 20, 2009, also indicate that the west branch Ruddiman Creek is considerably flashier than the main branch, with flows in the west branch increasing by a factor of 10 due to these storm events (Table 4).

Targeted wet weather sampling was conducted at Stations 1-4, and storm sewer sites S1 and S2 (Figure 1). S1 is located in a trunkline collecting storm water from the city of Muskegon, and S2 collects storm water from the city of Muskegon and Muskegon Heights. Monitoring occurred during 3 rain events (July 15, August 20, and August 25, 2009). Rain events with more than 0.5 inches of rain in less than 24 hours were targeted. Stations 1-4 were sampled once per storm event, and storm sewer stations were sampled three times during each event during the rise and fall of the hydrograph (Tables 2 and 3). A maximum concentration of 37,609 *E. coli* per 100 mL was found in S2 at the onset of the August 20, 2009, rain event. The wet weather results from the west branch, Station 3, during the July 15, 2009, wet weather event found a concentration of 20,132 *E. coli* per 100 mL about 4.5 hours after the rain event began, which is considerably higher than the highest daily maximum recorded during weekly sampling at the same site (2,964 *E. coli* per 100 mL). The highest concentration from Station 4 (the pond outlet), 8,053 *E. coli* per 100 mL, was also captured during a targeted wet weather event about 7 hours after rain began on August 20, 2009. The *E. coli* storm event mean and maximum concentrations in S2 were higher than the concentrations in S1 during all three storm events.

Two sets of samples from Stations 1 and 2 were collected for bacterial source identification. The first set was collected on July 21, 2009, and was analyzed for fecal *Bacteriodetes* human gene biomarker by polymerase chain reaction; both samples tested positive. These results indicate that on July 21, 2009, the water samples collected at Stations 1 and 2 were contaminated by human fecal material. Since *Bacteriodetes* are strict anaerobes and cannot survive extended periods of time outside the human host, the detection of this biomarker indicates recent, or nearby, fecal pollution. No rain occurred for 5 days prior to July 21, 2009, so flows were correspondingly low at the time of sampling, suggesting illicit sanitary connections to the city of Muskegon's storm sewer (or a municipality connected to the city of Muskegon's sewer system). The second set of samples from Stations 1 and 2 was collected on September 9, 2009, and analyzed for human *Enterococcus faecium* biomarkers; both samples tested negative for this biomarker. For unknown reasons, potentially the colder weather at the end of August 2009, the levels of *E. coli* in Stations 1-3 steadily declined towards the end of the season, which may have been a factor in the lack of the *Enterococcus faecium* biomarker in September.

SOURCE ASSESSMENT

Positive detections of human *Bacteroidetes* at Stations 1 and 2 suggest that illicit connections are a source of pathogens to the main branch of Ruddiman Creek. The detection of this human biomarker immediately downstream of the city of Muskegon sewer outfall (Station 1), the origin of the main branch of Ruddiman Creek, indicates that the human fecal contamination originates in the storm sewers of either, or both, the city of Muskegon and Muskegon Heights. Illicit connections are also a potential source of pathogens to the west branch of Ruddiman Creek, where the city of Muskegon, Norton Shores, and Roosevelt Park have storm sewer inputs; however, human sources were not verified at Station 3.

Land-use data (2006) shows that there is no land in agricultural use within the TMDL watershed; thus livestock and manure spreading are not a potential source of *E. coli*. On-site sewage treatment systems (septic systems) are not known to exist in the Ruddiman Creek watershed due to the urbanized nature of the area and the availability of sanitary sewers. The Muskegon County Health Department does not require point-of-sale inspections on existing septic systems; therefore, there are no estimates of the number of systems or failure rates in the TMDL watershed.

On March 2, 2007, a Sanitary Sewer Overflow (SSO) occurred due to a force main break resulting in 1.08 million gallons of raw sewage being discharged to Ruddiman Creek. The SSO occurred under the jurisdiction of Muskegon County. The problems leading to this SSO have been corrected by upgrading the pump station and improving the sanitary sewer line, which parallels Ruddiman Creek. The sanitary sewers in the Ruddiman Creek watershed are all separated from storm sewers; thus Combined Sewer Overflows are not a source.

The high amount of impervious surfaces within the Ruddiman Creek watershed causes a flush of storm water following precipitation, which can cause storm water to become contaminated with *E. coli* from human litter (such as diapers) and pet and wildlife fecal waste. In addition to pet and wildlife fecal waste on the ground surface, approximately 60 percent of the TMDL watershed is a complex of underground storm sewers, which are residence for numerous wildlife, including raccoons, opossums, rats, and mice. Bacteria from these warm-blooded mammals are a certain contributor to the WQS exceedances observed in the creek.

There are no permitted Concentrated Animal Feeding Operations in the Ruddiman Creek watershed and application of animal manure to agricultural fields and direct cattle access are not considered sources of *E. coli* to Ruddiman Creek.

LOADING CAPACITY (LC) DEVELOPMENT

The LC represents the maximum loading that can be assimilated by the water body while still achieving WQS. As indicated in the Numeric Target section, the targets for this pathogen TMDL are the TBC 30-day geometric mean WQS of 130 *E. coli* per 100 mL, daily maximum of 300 *E. coli* per 100 mL, and the PBC daily maximum WQS of 1000 *E. coli* per 100 ml. Concurrent with the selection of a numeric concentration endpoint, development of the LC requires identification of the critical condition. The "critical condition" is defined as the set of environmental conditions (e.g., flow) used in development of the TMDL that result in attaining WQS and have an acceptably low frequency of occurrence.

For most pollutants, TMDLs are expressed on a mass loading basis (e.g., pounds per day). For *E. coli*, however, mass is not an appropriate measure, and the USEPA allows pathogen TMDLs to be expressed in terms of organism counts (or resulting concentration). Therefore, this pathogen TMDL is concentration-based, consistent with R 323.1062, and the TMDL is equal to the TBC target concentrations of 130 *E. coli* per 100 mL as a 30-day geometric mean and daily maximum of 300 *E. coli* per 100 mL in all portions of the TMDL reach for each month of the recreational season (May through October) and PBC target concentration of 1000 *E. coli* per 100 mL as a daily maximum year-round. Expressing the TMDL as a concentration equal to the WQS ensures that the WQS will be met under all flow and loading conditions; therefore, a critical condition is not applicable for this TMDL.

LC

The LC is the sum of individual waste load allocations (WLAs) for point sources and load allocations (LAs) for nonpoint sources and natural background levels. In addition, the LC must include a margin of safety (MOS), either implicitly within the WLA or LA, or explicitly, that accounts for uncertainty in the relation between pollutant loads and the quality of the receiving water body. Conceptually, this definition is denoted by the equation:

$$LC = \sum WLAs + \sum LAs + MOS$$

The LC represents the maximum loading that can be assimilated by the receiving water while still achieving WQS. Because this TMDL is concentration-based, the total loading for this TMDL is equal to the TBC WQS of 130 *E. coli* per 100 mL as a 30-day geometric mean and 300 *E. coli* per 100 mL as a daily maximum during the recreation season and PBC WQS of 1000 *E. coli* per 100 mL as a daily maximum the remainder of the year.

<u>WLAs</u>

The WLA for the facilities listed in Table 6 are equal to 130 *E. coli* per 100 mL as a 30-day geometric mean and 300 *E. coli* per 100 mL as a daily maximum during the recreational season between May 1 and October 31, and 1000 *E. coli* per 100 mL as a daily maximum the remainder of the year. Illicit connections to the storm sewers of Municipal Separate Storm Sewer Systems (MS4) permittees listed in Table 6 are illegal, and therefore, have a WLA of zero.

<u>LAs</u>

Because this TMDL is concentration-based, the LA is also equal to 130 *E. coli* per 100 mL as a 30-day geometric mean and 300 *E. coli* per 100 mL as a daily maximum during the recreational season and 1000 *E. coli* per 100 mL as a daily maximum for the remainder of the year. This LA is based on the assumption that all land, regardless of use, will be required to meet the WQS. Therefore, the relative responsibility for achieving the necessary reductions of bacteria and maintaining acceptable conditions will be determined by the amount of land under the jurisdiction of the local unit of government in the watershed (Table 5). Four municipalities have land area within the Ruddiman Creek TMDL watershed.

<u>MOS</u>

This section addresses the incorporation of a MOS in the TMDL analysis. The MOS accounts for any uncertainty or lack of knowledge concerning the relationship between pollutant loading and water quality, including the pollutant decay rate, if applicable. The MOS can be either implicit (i.e., incorporated into the WLA or LA through conservative assumptions) or explicit (i.e., expressed in the TMDL as a portion of the loadings). This TMDL uses an implicit MOS because no rate of decay was used. Pathogen organisms ordinarily have a limited capability of surviving outside of their hosts and a rate of decay could be developed. However, applying a rate of decay could result in an allocation that would be greater than the WQS, thus no rate of decay is applied to provide for greater protection of water quality. The DNRE has determined that the use of the TBC WQS of 130 *E. coli* per 100 mL as a 30-day geometric mean and 300 *E. coli* per 100 mL as a daily maximum during the recreational season, and the PBC WQS of 1000 *E. coli* per 100 mL as a daily maximum year-round for the WLA and LA is a more conservative approach than developing an explicit MOS. This accounts for the uncertainty in the relationship between pollutant loading and water quality, based on available data and the assumption to not use a rate of decay. Applying the WQS to be met under all flow conditions also adds to the assurance that an explicit MOS is unnecessary.

SEASONALITY

The WQS for *E. coli* are expressed in terms of seasons, e.g., TBC from May 1 through October 31 and PBC year-round. Allocations and controls developed for the more protective TBC season are also expected to assure attainment of the daily maximum PBC WQS of 1000 *E. coli* per 100 mL, year-round. Because this is a concentration-based TMDL, WQS must be met regardless of flow conditions in the applicable season.

REASONABLE ASSURANCE ACTIVITIES

The TMDL watershed receives storm water discharges from Phase II communities (a complete list of the regulated MS4s within the TMDL watershed is included in Table 6). These regulated MS4s are required to obtain permit coverage under Michigan's NPDES MS4 Jurisdictional-Based or Watershed-Based Storm Water General Permits. Under the Jurisdictional or Watershed MS4 permits, permittees are required to reduce the discharge of pollutants (including *E. coli*) from their MS4 to the maximum extent practicable through the development and implementation of a Public Involvement and Participation Process, a storm water-related Public Education Plan, an Illicit Discharge Elimination Program (IDEP), a post-construction Storm Water Control Program for new development and redevelopment projects, a Construction Storm Water Runoff Control Program, and a Pollution Prevention/Good Housekeeping Program for municipal operations. The MS4 communities in the Muskegon Lake watershed are cooperating under a watershed-based program called the Muskegon Area Municipal Storm Water Committee, which includes all MS4 permits listed in Table 6.

In particular, the IDEP and TMDL requirements of the permits have the greatest potential to contribute to the reduction of *E. coli* levels in Ruddiman Creek. The IDEP requirements of the MS4 storm water permits require permittees to develop a program to find and eliminate illicit connections and discharges to their MS4. This includes a plan to conduct dry-weather screening of each MS4 discharge point at least once every five years (unless an alternative schedule or approach is approved by the DNRE or the permittee opts to pursue the elective option). Dry-weather screening does not require *E. coli* sampling; however, if a permittee observes evidence of any illicit connection or discharge, they are required to investigate and eliminate them. Each of the MS4 municipalities in Table 6 has adopted ordinances to allow for the enforcement and correction of illicit connections to the storm sewers. As for the TMDL requirements, permittees are required to identify and prioritize actions to be consistent with the requirements and assumptions of the TMDL. Through prioritizing TMDL actions, permittees are able to focus their efforts, which will help to make progress towards meeting Michigan's WQS.

The Certificates of Coverage for the general industrial storm water permit (MIS310000) listed in Table 6 specify that if a TMDL is established by the Department for the receiving water, which restricts the discharge of any of the identified significant materials or constituents of those materials, then the Storm Water Pollution Prevention Plan shall identify the level of control for those materials necessary to comply with the TMDL and an estimate of the current annual load of those materials via storm water discharges to the receiving stream.

Reducing pathogens and meeting the *E. coli* WQS in Ruddiman Creek are listed as goals in the Muskegon Lake Watershed Management Plan; approved in 2005 and updated in 2007. Ruddiman Creek does not currently have a dedicated subwatershed plan. Additionally, Ruddiman Creek is designated as part of the Muskegon Lake Great Lakes Area of Concern (AOC), first designated by the International Joint Commission in 1985. In 2002, beach closings were listed as a beneficial use impairment in the Remedial Action Plan, which was developed by the Muskegon Lake Watershed Partnership (formerly the Muskegon Lake Public Advisory Council) and the DNRE. The goal of the Remedial Action Plan is to identify environmental problems, establish water use goals, and provide cleanup solutions that will restore the AOC's beneficial uses. Due to Ruddiman Creek's status as part of an AOC, funding for implementation projects to reduce *E. coli* and pathogens in Ruddiman Creek may be available in the future.

The problems leading to the March 2, 2007, SSO have been corrected by upgrading the pump station and improving the sewer line that parallels Ruddiman Creek. The sewer line was televised and inspected in 2007 and no evidence of leakage was observed. In 2008, Muskegon County relined at-risk stretches of the sewer line and repaired potentially problematic manholes. In the future, internal televised inspection of the pipe and cleaning will be conducted by Muskegon County every five years (personal communication with Mr. Mark Eisenbarth, Deputy Director, Muskegon County Department of Public Works). In addition, Muskegon County is required, by law, to report any sewage spills or leakage from their collection system within 24 hours of detection of the spill or SSO.

MONITORING

Future monitoring will take place as part of the five-year rotating basin monitoring, as resources allow, once actions have occurred to address sources of *E. coli.* When these results indicate that the water body may be meeting WQS, sampling will be conducted at the appropriate frequency to determine if the 30-day geometric mean value of 130 *E. coli* per 100 ml and daily maximum values of 300 *E. coli* per 100 ml and 1000 *E. coli* per 100 ml are being met.

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Figure 1. Location of Ruddiman Creek monitoring sites (Stations 1-4), storm sewer sites (S1 and S2), MS4 outfalls, and NPDES permitted facilities within the TMDL watershed.

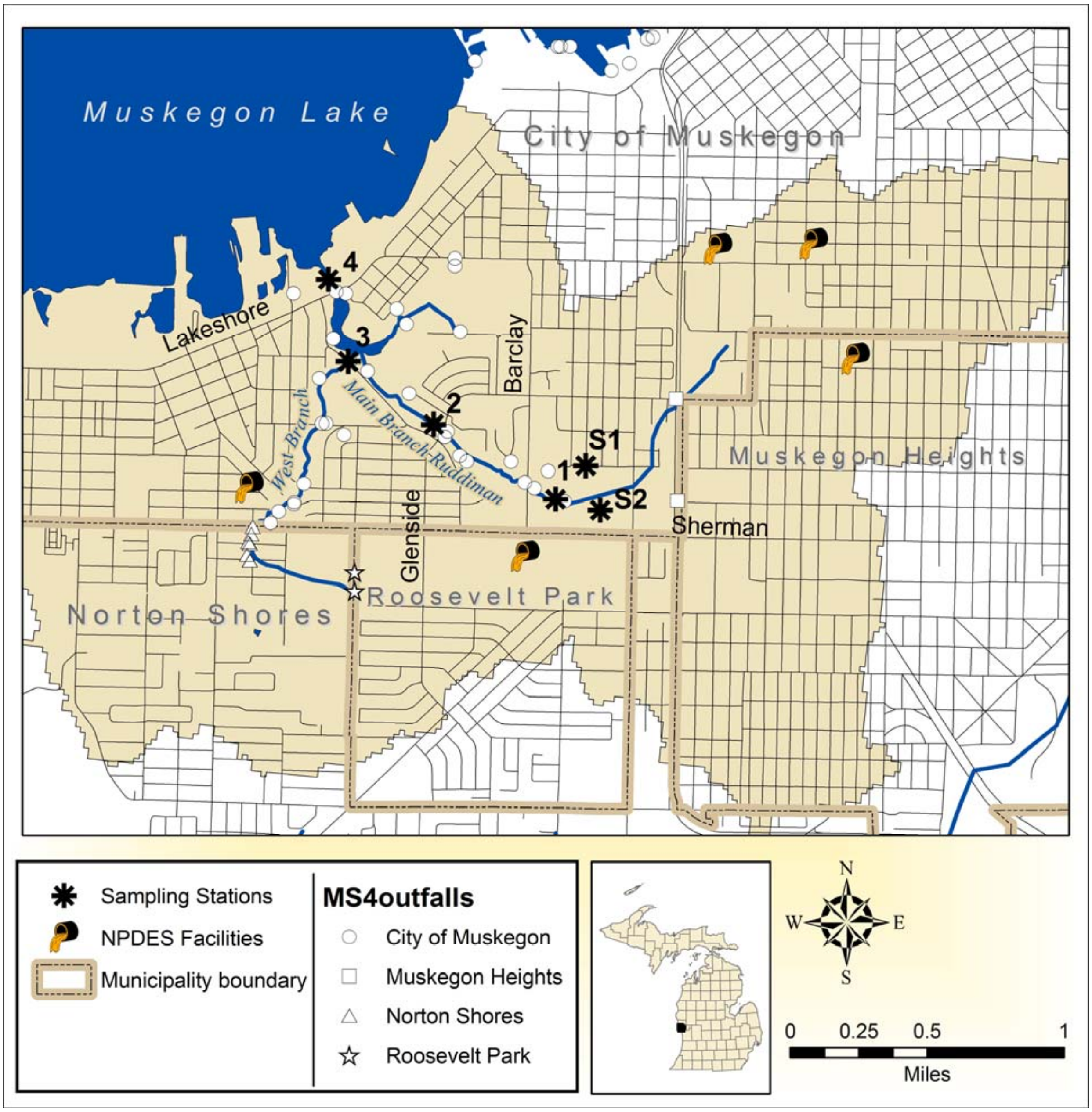

Figure 2a. Daily Maximum *E. coli* sampling results from the main branch Ruddiman Creek (Stations 1-2).

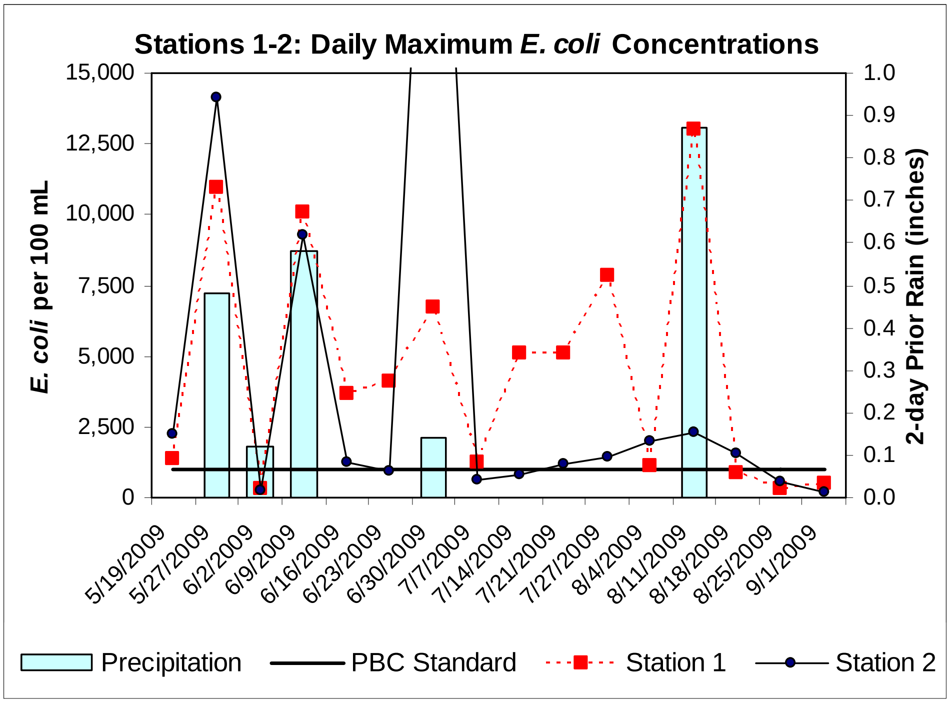

Figure 2b. Daily Maximum *E. coli* sampling results from the west branch Ruddiman Creek (Station 3).

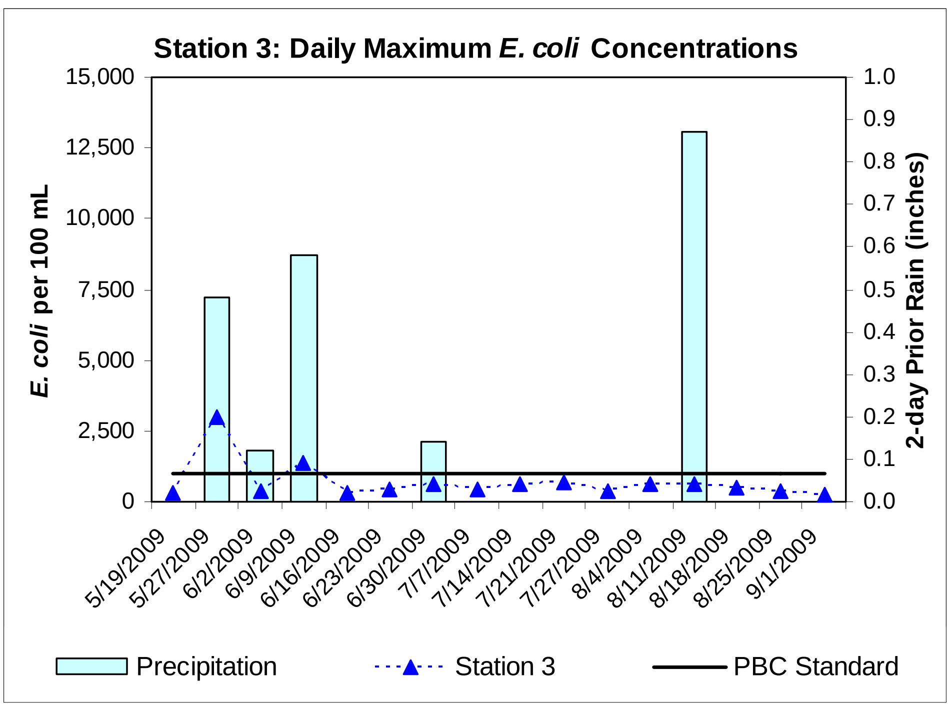

Figure 2c. Daily Maximum *E. coli* sampling results from the outlet of the impoundment of Ruddiman Creek (Station 4).

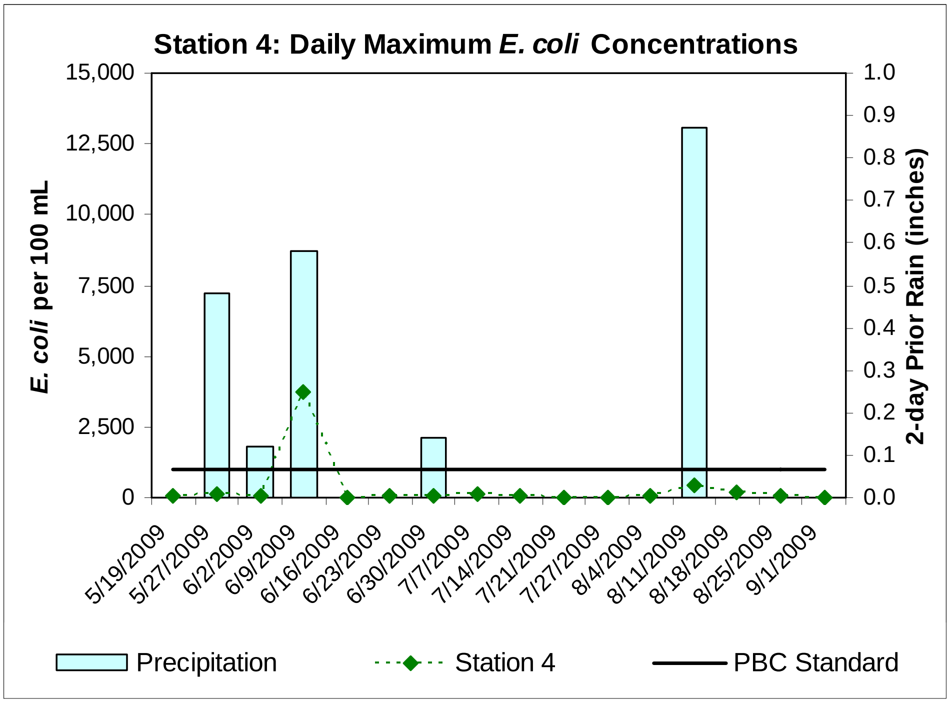

Figure 3. Thirty-day geometric mean *E. coli* sampling results from Ruddiman Creek (Stations 1-4) in relation to the TBC WQS of 130 *E. coli* per 100 mL as a 30-day geometric mean.

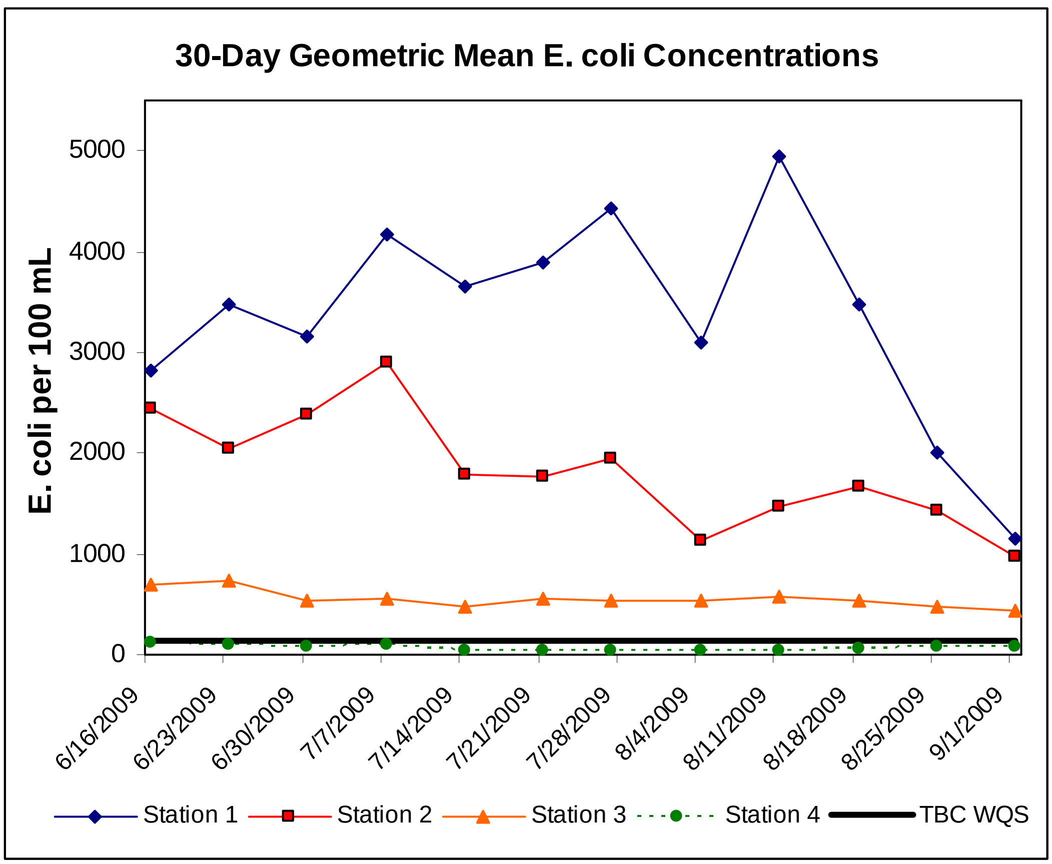

Table 1. Weekly *E. coli* sampling results (counts per 100 mL) from Ruddiman Creek (Stations 1-4). Exceedances of the TBC WQS are shaded gray and PBC exceedances are outlined in bold. The daily maximum is the geometric mean of the sample results. The 30-day geometric mean is a rolling geometric mean of the associated daily maximum and the four preceding daily maxima.

Date	Transect location	Station 1 Main Branch at 60" Outfall Sample Results	Daily Max.	30-day Geomean	Station 2 Main Branch at Glenside Sample Results	Daily Max.	30-day Geomean	Station 3 West Branch at McGraft Park Sample Results	Daily Max.	30-day Geomean	Station 4 Pond Outlet Sample Results	Daily Max.	30-day Geomean	Notes
5/19/2009	L	1400			2000			340			50			
	C	1500			2400			290			30			
	R	1300	1398		2300	2227		320	316		110	55		
5/27/2009	L	9200			16000			3100			100			0.48" on 5/27/09
	C	12000			11000			2800			120			
	R	12000	10983		16000	14121		3000	2964		110	110		
6/2/2009	L	270			300			420			60			0.12" rain on 6/01/09
	C	280			200			320			30			
	R	380	306		210	233		380	371		50	45		
6/9/2009	L	8600			9800			1400			5200			0.58" rain on 6/08/09
	C	10000			10000			1300			3400			
	R	12000	10106		8100	9259		1400	1366		3000	3757		
6/16/2009	L	4100			1300			280			10			
	C	3600			990			420			30			
	R	3400	3689	2810	1600	1272	2438	330	339	694	14	16	110	
6/23/2009	L	3600			990			480			30			
	C	4600			880			330			75			
	R	4100	4080	3482	860	908	2038	430	408	730	52	49	108	
6/30/2009	L	6500			23000			660			74			0.14" rain on 6/29/09
	C	5500			35000			600			21			
	R	8500	6723	3156	35000	30429	2376	610	623	535	41	40	88	
7/7/2009	L	1600			640			400			120			
	C	1100			700			480			150			
	R	1100	1246	4179	550	627	2897	490	455	557	120	129	109	
7/14/2009	L	4900			860			610			31			
	C	5200			960			570			30			
	R	5200	5098	3644	700	833	1790	720	630	477	52	36	43	
7/21/2009	L	5200			1100			640			1			
	C	5800			1400			700			10			
	R	4400	5101	3888	1100	1192	1767	700	679	548	20	6	35	
7/27/2009	L	8600			1300			330			30			
	C	7700			1700			330			38			
	R	7300	7848	4432	1400	1457	1942	450	366	536	20	28	32	
8/4/2009	L	1400			1700			450			40			
	C	1000			2300			770			48			
	R	1000	1119	3096	2100	2017	1128	720	630	538	34	40	22	
8/11/2009	L	14000			2100			520			310			0.87" rain on 8/10/09
	C	16000			2400			660			610			
	R	9800	12996	4948	2500	2327	1467	680	616	571	440	437	41	
8/18/2009	L	1100			1900			400			680			
	C	850			2000			550			100			
	R	710	872	3476	1000	1560	1663	490	476	540	110	196	56	
8/25/2009	L	390			540			470			60			
	C	320			460			470			80			
	R	270	323	2002	670	550	1425	270	391	483	30	52	87	
9/1/2009	L	520			180			260			6			
	C	500			200			270			18			
	R	500	507	1157	260	211	968	210	245	446	14	11	73	

Table 2. Wet weather results at Stations 1-4. Exceedances of the TBC WQS are shaded gray and PBC exceedances are outlined in bold. The daily maximum is the geometric mean of the sample results.

Date	Transect location	Station 1 Main Branch at 60" Sample Results	Daily Max.	Station 2 Main Branch at Sample Results	Daily Max.	Station 3 West Branch at Sample Results	Daily Max.	Station 4 Pond Outlet Sample Results	Daily Max.	Notes
7/15/2009	L	8600		9200		20000		52		0.47" rain
	C	10000		8700		24000		41		
	R	7300	8563	10000	9285	17000	20132	10	28	
8/20/2009	L	14000		22000		8100		6900		0.54" rain
	C	15000		14000		7500		8700		
	R	20000	16134	13000	15879	12000	9000	8700	8053	
8/25/2009	L	990		780		610		70		0.41" rain
	C	1200		800		750		60		
	R	1300	1156	690	755	700	684	80	70	

Table 3. Results from targeted wet weather sampling events in storm sewer sites (see Figure 1 for locations). The daily maximum is the geometric mean of the sample results.

Date and rainfall amount	S 1 West side trunk			S 2 Main trunk		
	Time	Sample Results	Geometric Mean	Time	Sample Results	Geometric Mean
July 15, 2009 - 0.47 inches rain	7:12	1800		7:23	600	
		3000			1000	
		2200	2282		650	731
	8:00	5500		8:10	8700	
		4400			11000	
		3900	4553		9200	9584
	9:15	2200		9:26	5500	
		1500			5800	
		2000	1876		9800	6787
August 20, 2009 - 0.54 inches rain	10:16	6100		10:05	44000	
		7300			31000	
		8700	7290		39000	37609
	11:04	1700		10:55	25000	
		2200			22000	
		2400	2078		31000	25738
	12:22	7200		12:15	19000	
		7000			16000	
		8700	7597		13000	15810
August 25, 2009 - 0.41 inches rain	21:00	900		21:20	1250	
		860			1600	
		780	845		1400	1409
	22:00	1100		22:20	2100	
		1200			2200	
		1300	1197		2500	2260
	23:00	980		23:20	1500	
		1000			1600	
		890	955		1900	1658

Table 4. Flow results, in cubic feet per second, from routine weekly monitoring and wet weather sampling events (denoted by *).

	Flows (cubic feet per second)			
Date	Station 1	Station 2	Station 3	Station 4
5/19/2009	1.41	2.47	2.12	1.77
5/26/2009	1.77	2.83	3.18	5.3
6/2/2009	0.71	1.06	1.77	6
6/9/2009	1.06	2.12	2.12	7.77
6/16/2009	1.41	1.77	1.77	4.94
6/23/2009	1.06	2.12	1.77	4.24
6/30/2009	1.06	2.12	1.77	8.48
7/7/2009	1.41	2.12	1.77	2.47
7/14/2009	1.77	2.47	1.77	3.18
7/15/2009 *	2.29	4.06	10.1	19.8
7/28/2009	2.12	2.12	1.06	4.59
8/4/2009	1.77	1.77	1.06	4.94
8/11/2009	1.77	2.47	1.77	NA
8/18/2009	1.06	1.77	1.41	3.53
8/20/2009 *	3.18	6	15.19	64.27
8/25/2009 *	0.71	1.41	1.06	0.71
8/25/2009	1.7	2.64	6.46	8.36
9/1/2009	1.77	1.41	1.06	4.59
* Rain Event				

Table 5. Percent of land area in Ruddiman Creek TMDL watershed located within each municipality.

Municipality	Percent of Watershed Area
City of Muskegon	53%
Muskegon Heights	20%
Norton Shores	17%
Roosevelt Park	10%

Table 6. NPDES facilities discharging to the Ruddiman Creek watershed.

Designated Name	Permit No.	Township	Latitude	Longitude
MAHLE Inc-Muskegon Hts Complex	MI0004057	Muskegon	43.214722	-86.246944
Federal Mogul Corp-Muskegon	MI0055247	Laketon	43.220833	-86.25
MIG250000: Non-Contact Cooling Water				
CWC-Textron	MIG250337	Norton Shores	43.204166	-86.270833
MIG610000: Storm Water Discharges from Municipal Separate Storm Sewer Systems (MS4s)				
Roosevelt Park MS4-Muskegon	MIG610146	various		
Norton Shores MS4-Muskegon	MIG610147	various		
Muskegon Heights MS4-Muskegon	MIG610149	various		
Muskegon CDC MS4	MIG610151	various		
Muskegon MS4-Muskegon	MIG610152	various		
MIS310000: Storm Water from Industrial Facilities in Cycle 3 Watersheds				
Brunswick Corp	MIS310149	Muskegon	43.220555	-86.256944
J&M Machine Products-Sherman	MIS310270	Laketon	43.207777	-86.290833
CWC-Textron	MIS310486	Norton Shores	43.204166	-86.270833