Total Maximum Daily Load
for *E. coli* in
Deer, Little Deer, and Beaver Creeks

Ottawa and Muskegon Counties

Michigan Department of Environmental Quality
Water Resources Division
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1. INTRODUCTION

Section 303(d) of the federal Clean Water Act and the United States Environmental Protection Agency's (USEPA) 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 a basis for determining the pollutant reductions necessary from both point and nonpoint sources to restore and maintain the quality of water resources. The purpose of this TMDL is to identify the allowable levels of *Escherichia coli* (*E. coli)* that will result in the attainment of the applicable WQS in the Deer, Little Deer, and Beaver Creeks, located in Ottawa and Muskegon Counties, Michigan (Figure M-1).

1.1 PROBLEM STATEMENT

This TMDL addresses the assessment units (AUIDs) and listings that appear on the 2012 Section 303(d) list (Goodwin et al., 2012 [draft]) as:

Beaver Creek, Deer Creek, and Little Deer Creek **AUID**: 040500060704-01
County: Ottawa and Muskegon SIZE: 63.6 Miles
Location: Tributary to the Lower Grand River
Use impairments: Total and partial body contact recreation.
Cause: *E. coli*
Source: Unknown.
TMDL Year(s): 2012

Monitoring data collected by the Michigan Department of Environmental Quality (MDEQ) in 2009 and 2010 in the Deer, Little Deer, and Beaver Creeks, including tributaries, 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 (Tables 1-3). According to the MDEQ methodology for listing water bodies as impaired in the Integrated Report (Goodwin et al., 2012 [draft]), all sites are not attaining the TBC and PBC WQS. This TMDL addresses the entire Deer, Little Deer, and Beaver Creeks watersheds (Figure M-1).

1.2 BACKGROUND

Little Deer and Beaver Creeks are tributaries to Deer Creek, which flows through the city of Coopersville, Michigan (Figure M-1). Deer Creek is composed of about 64 miles of stream, over a watershed of about 34 square miles. Deer Creek is part of the Grand River watershed, which outlets to Lake Michigan. The Grand River is the longest river and second largest watershed (about 5,572 square miles in area) in Michigan.

The TMDL source area lies within the Jamestown (VI.3.3) subsubsection of the regional Landscape Ecosystem Classification of Michigan (Albert, 1995). The TMDL area is within an area of broad, gently sloping ridges with clayey soils, which generally have high water holding capacity and low permeability. Topography in the TMDL area is fine textured ground and end moraines, with no steep slopes and no large lakes. Prior to European colonization, the forests were equal parts hemlock and beech, with lesser amounts of sugar and red maples, basswood, and birch. Currently, the majority of the uplands have been converted to crop production, while woodlots exist on sites deemed too wet or steep for agriculture. Hydrology has been altered by historic and current efforts to quickly drain water from agricultural production areas via ditches.

According to 2006-Era Land Cover Data (NOAA, 2008), the TMDL source area is 79 percent agricultural, 9 percent developed, 5 percent natural upland ecosystems (forests and grasslands combined) 6 percent wetland, and 1 percent other cover types (Figure M-2). The TMDL area has a human population of approximately 6,400 people, according to the 2010 U.S. Census Bureau (U.S. Census Bureau, 2010a and 2010b). The city of Coopersville has a population of about 4,275 people, and according to past population estimates, the population grows by about 1.5-2.0 percent annually (www.cityofcoopersville.com).

1.3 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.

Sanitary wastewater discharges have an additional target:

> Rule 62. (3) Discharges containing treated or untreated human sewage shall not contain more than 200 fecal coliform bacteria per 100 ml, based on the geometric mean of all of five or more samples taken over a 30-day period, nor more than 400 fecal coliform bacteria per 100 ml, based on the geometric mean of all of three or more samples taken during any period of discharge not to exceed seven days. Other indicators of adequate disinfection may be utilized where approved by the Department.

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 1,000 *E. coli* per 100 mL as a daily maximum year-round to protect the PBC use. The 2009 monitoring data indicated daily maximum and 30-day geometric mean WQS exceedances at all sites.

2. 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 1,000 *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 has 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. 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 1,000 *E. coli* per 100 mL as a daily maximum year-round. The existence of multiple sources of *E. coli* to a water body results in a variety of critical conditions (e.g., high flow is the critical condition for storm water-related sources and low flow is the critical condition for dry weather sources such as illicit connections); therefore, no single critical condition is applicable for this TMDL. Expressing the TMDL as a concentration equal to the WQS ensures that the WQS will be met under all critical flow and loading conditions.

2.1 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, 300 *E. coli* per 100 mL as a daily maximum during the recreation season, and PBC WQS of 1,000 *E. coli* per 100 mL as a daily maximum year-round.

2.1.a WLAs

The WLA for the facilities listed in Table 4 is 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 1,000 *E. coli* per 100 mL as a daily maximum the remainder of the year. There are two individual National Pollutant Discharge Elimination System (NPDES) permits included in the WLA: Beaver Creek Dairy Concentrated Animal Feeding Operation (CAFO) and Michigan Department of Transportation (MDOT) Statewide Municipal Separate Storm Sewers. Certificates of Coverage (COCs) under general NPDES permits include: one CAFO and two storm water from industrial activities (MIS110000).

2.1.b LAs

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 1,000 *E. coli* per 100 mL as a daily maximum year-round. This LA is based on the assumption that the drainage from 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. Six minor civil divisions have land area within the Deer, Little Deer, and Beaver Creeks TMDL source area (Table 5).

2.1.c MOS

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 pollutant decay was used. Pathogen organisms ordinarily have a limited capability of surviving outside of their hosts, and therefore, a rate of pollutant decay could be developed. However, applying a rate of pollutant decay could result in an allocation that would be greater than the WQS, thus no rate of decay is applied to provide for a greater protection of water quality. The use of the TBC (130 *E. coli* per 100 mL as a 30-day geometric mean and 300 *E. coli* per 100 mL during the recreational season) and PBC (1,000 *E. coli* per 100 mL as a daily maximum the remainder of the year) WQS as a WLA and LA is a more conservative approach than developing an explicit MOS. This approach 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 pollutant decay. Applying the WQS to be met under all flow conditions also adds to the assurance that an explicit MOS is unnecessary.

3. DATA DISCUSSION

Weekly *E. coli* data to support this TMDL were collected for 16 weeks; from May 19 to August 31, 2009. Generally, the MDEQ weekly samples were taken on Mondays, between 9:00 a.m. and 12:30 p.m. At all sites, single samples were collected from the left bank, center, and right bank portions of the streams. Samples were not collected from a site if the water was not flowing at the time of sampling. The geometric mean of the three samples was calculated to compare with the daily maximum TBC WQS and the PBC WQS. All samples, duplicates, and blanks were collected and analyzed according to an approved Quality Assurance Project Plan (Great Lakes Environmental Center and Limnotech, Inc., 2009).

The number of WQS exceedances at each sampling site and site geometric means are summarized in Table 1. *E. coli* daily geometric means and 30-day geometric means are shown in relation to precipitation events in Table 2 and Figures 1-4. All sites exceeded the daily maximum TBC WQS and 30-day geometric mean WQS, indicating that the TBC WQS designated use is not being met throughout the watershed. Sites 2 and 3, on Beaver Creek, had the greatest number of daily maximum TBC WQS exceedances of all sites, with 16 exceedances, followed by site 11 (Little Deer Creek and 48th) and site 12 (Deer Creek at Mill Road) with 15 exceedances each, and site 1 (Beaver Creek) with 14 exceedances. Site 13 (Deer Creek at Leonard) had the fewest daily maximum TBC WQS exceedances (4). The 30-day geometric mean TBC WQS was exceeded 100 percent of the time during the sampling period at all sites (Table 2 and Figures 5-8).

Site 11, on Little Deer Creek and 48th, had the greatest number of PBC WQS exceedances (9) of all sites in the entire TMDL source area. All sites exceeded the PBC WQS more than twice (Table 2), indicating that the PBC designated use is not being met throughout the watershed.

Site geometric means were calculated by incorporating all the weekly data for each site into a geometric mean calculation (Table 1). Site geometric means are intended to facilitate comparison among sites and to help in the determination of priority areas, but are not to be compared with the numeric WQS. Site 3, located on Beaver Creek, had the highest site geometric mean (1,794 *E. coli* per 100 mL). Site 13, the site nearest the Grand River confluence, had the lowest site geometric mean (306 *E. coli* per 100 mL), and the fewest exceedances of the daily maximum TBC (4) and PBC (2) WQS. Of sites located directly on the mainstem of Deer Creek (sites 5, 7, 8, 9, 12, and 13), site 5 (the furthest upstream) had the highest site geometric mean, followed by site 12 (Figure 9). The site geometric mean (site 12) was considerably higher than the sites immediately upstream (site 9), indicating that a source may be located between sites 9 and 12 causing *E. coli* to be more elevated at site 12.

Precipitation data for the 24-hours prior to each MDEQ sampling event were obtained from a weather site at Sparta, located about 7 miles northeast of Coopersville, Michigan (Enviro-Weather, 2011) (Tables 2-3 and Figures 1-4). The MDEQ weekly sampling did not target wet weather deliberately, but did correspond with four significant (>0.5 inches) rain events; May 27 (0.57 inches), June 8 (0.70 inches), July 19 (0.97 inches) and August 8-10 (1.31 inches). The May 27, June 8, and August 10 events occurred within 12 hours prior to sampling and coincided with increased concentrations of *E. coli* in samples, and likely caused wet weather exceedances of the WQS at some of the sites. The July 19 rain event ended about 18 hours prior to the sampling on July 20, 2009, and did not coincide with a notable increase in *E. coli* concentrations at any of the sites. The highest daily geometric mean detected in this study was 263,041 *E. coli* per 100 mL, at site 3 (Beaver Creek at 56th), following the rain event on August 8-10, 2009. Following the precipitation event on August 8-10, 2009, all sites exceeded the PBC WQS. Using a Pearsons Correlation, sites 2-5, 9, 11, and 12 had a significant relationship ($r^2 \geq 0.5$, using a 95% confidence interval) between daily geometric means of *E. coli* and precipitation amount in the prior 24 hours (Table 1). At these sites, *E. coli* generally increased with prior precipitation amount. At the remainder of the sites, there was little statistical relationship between *E. coli* and precipitation.

Samples from selected sites were sent to Helix Biological Laboratory for Bacterial Source Tracking (BST) analysis. This process entails filtration of the samples, followed by incubation of the filtered residue to increase bacterial populations. Bacterial deoxyribonucleic acid (DNA) is then extracted and amplified using qualitative polymerase chain reaction (PCR). The resulting product is compared to known target DNA sequences (controls) of selected potential fecal source animals (such as human, cattle, pig, and horse). A positive result on the target marker implies that the target animal is a source at the time and location the sample was taken. A negative result implies that the target source animal is not a source of *E. coli* at the time and place of the sampling, but from a broader perspective, does not exclude that animal as a potential source to the water body. This is because *E. coli* concentrations in a flowing water body are highly variable throughout both space and time due to the variable nature of sources and moving water. Sources of this variation include mobile animals, intermittent discharges from illicit connections, and flushes of storm water either carrying or diluting contamination. BST analysis was conducted during weekly monitoring at sites 2 and 11 on August 3 and August 17, 2009. These sites were selected based on their consistently high *E. coli* concentrations. Results are summarized in Table 3. Positive results for human bacteroides were found at site 11 on both August 3 and August 17, 2009, implying that a human source of fecal contamination was present at this site at the time of sampling. The same human biomarkers were not found at site 2; however, as stated above, this does not exclude the existence of human sources in the watersheds these sites represent.

To supplement the weekly sampling, wet-weather targeted monitoring was conducted at selected sites following two rain events (June 2 and June 23, 2010) (Table 3). *E. coli* and BST analyses were conducted on the wet weather samples from sites 1, 3, 5, 6, 10, and 11. The June 2 wet weather samples were collected after 0.59 inches of rain and *E. coli* concentrations ranged from 3,100 to 8,600 *E. coli* per 100 mL. On June 2, bovine bacteroides and enterococci were positively identified at sites 5 and 11. The June 23 wet-weather samples were collected after 0.34 inches of rain and *E. coli* concentrations of the samples ranged from 1,300 to a high of 82,000 *E. coli* per 100 mL (site 3; Beaver Creek). On this sampling date, bovine bacteroides and enterococci was positively identified at sites 1, 6, and 11. These results indicate that at the time of these two rain events, fecal contamination from cattle was a source of *E. coli* contamination at sites 1,5, 6, and 11. Neither bovine bacteroides nor enterococci were found in wet weather samples from sites 3 or 10 during either wet weather sampling event, indicating that another animal was likely a source at the time that samples were collected.

4. SOURCE ASSESSMENT

Potential sources to the TMDL area include illicit connections, failing on-site sewage disposal systems (OSDS), agricultural operations, NPDES discharges, biosolids land applications, leaking sanitary sewer lines, wildlife and pet waste, dumping of trash, contaminated runoff, and storm sewer outflow. The source assessment for the Deer Creek TMDL includes a load duration curve analysis for each site, an inventory of NPDES permitted discharges (Table 4), and a nonpoint source assessment, which included spatial and stressor analyses.

For the purposes of locating target areas for implementation activities and to facilitate discussion, the TMDL source area has been subdivided at two levels: individual catchments (1-29); and catchment groupings (A-K) (Figure M-3). The catchments were defined by using the catchment layer of the National Hydrography Dataset (USDA-NRCS, USGS, and USEPA, 2009), with some modifications made when the catchments were too small to be practical. The 29 catchments were then merged into 11 groupings (A-K) based on larger subwatersheds.

4.1 Load Duration Curve Analysis

To assist in determining potential sources to TMDL water bodies, the MDEQ conducted a load duration curve analysis for all sites (Cleland, 2002). A load duration curve considers how stream flow conditions relate to a variety of pollutant sources (point and nonpoint sources). The load duration curves for each site show the flow conditions that occurred during sampling and can be used to make rough determinations as to what flow conditions result in exceedances of the WQS. The load duration curves for each site sampled in the Deer, Little Deer, and Beaver Creeks TMDL area are included in Appendix 1. United States Geologic Survey (USGS) gauge No. 04118500 (located on the Lower Grand River, near Rockford, Michigan) was used to develop the load duration curves for this TMDL. The drainage area ratio, a ratio of the drainage area of the site locations to the drainage area of the gauged watershed, was calculated for each of the 13 sites for this TMDL. The curves were generated by applying these drainage area ratios to gauged flows for the period of record of the gauge (60 years). The flow information used in load duration curve development was determined on each sampling date at sites 1-13 by collecting water level elevation data. Water level elevation is a relative measure of water depth in the channel, determined by measuring the distance from a fixed point (such as a culvert edge) to the water's surface using a weighted tape. MDEQ hydrology staff also visited sites to collect reference flows for correlating the water level elevation data with actual gauged flows (USGS, 2007).

Exceedances of the *E. coli* WQS that occur during high flows are generally linked with rainfall events, such as surface runoff contaminated with fecal material, a flush of accumulated wildlife feces, or trash from the storm sewers or septic tank failures involving failing drainage fields that no longer percolate properly (surface failures). Exceedances that occur during low flows or dry conditions can generally be attributed to a constant source that is independent of the weather. Examples of constant sources include illicit connections (either directly to surface waters or to storm sewers), some types of OSDS failures, groundwater contamination, and pasture animals with direct stream access. Groundwater contamination of surface water with *E. coli* can occur in areas where OSDS are too close to surface waters or in areas where livestock or animal waste is allowed to accumulate in close proximity to surface waters. According to the load duration curves, low flow and high flow conditions were not represented during the 2009 weekly sampling.

The load duration curves for Beaver Creek (sites 1-3) show an interesting difference between the most upstream site (1) and the two downstream sites (2-3). *E. coli* concentrations during dry weather were higher at sites 2 and 3, than at site 1. This increase in magnitude of dry condition exceedances implies that additional dry weather-related sources are entering Beaver Creek between sites 1 and 2 (Catchments 2, 4, 6, and portions of 1 and 7).

The load duration curves for the two sites on Little Deer Creek (sites 10 and 11) vary considerably. The most upstream site (site 10) exceeds the daily maximum TBC mainly in the moist and mid-range flow conditions, while further downstream, at site 11, daily maximum TBC and PBC WQS are also common at dry conditions flows. This implies that a constant dry weather source is entering Little Deer Creek between sites 10 and 11 (Catchments 25, 26, 27, and portions of 28). Exceedances at high flows were evident at both sites 10 and 11.

Many exceedances of the daily maximum TBC WQS were found at all sites during the lowest flow conditions that were sampled in 2009 (dry conditions). This trend is less marked at the most downstream site on mainstem Deer Creek (site 13). While TBC WQS exceedances were common at lower flows at all sites, several sites (6, 7, 10, and 13) only exceeded the PBC WQS under higher flows. High *E. coli* concentrations at high flows indicate that an influx of *E. coli* occurred with the influx of storm water. During dry conditions, PBC WQS exceedances occurred at sites 1-5, 8, 9, 11, and 12 and were especially frequent at sites 2 and 11.

4.2 NPDES Discharges

There are five NPDES permitted facilities discharging within the TMDL source area (Table 4 and Figure M-1). Treated municipal wastewater from the Coopersville Wastewater Treatment Plant (MI0022730) is discharged to the Lower Grand River. Therefore, this discharge is not a potential source to the TMDL area and not listed in Table 4. There are no Combined Sewer Overflow facilities or outfalls, or chronic sanitary sewer overflow issues within the TMDL source area. Occasional sanitary sewer overflows from the Coopersville sanitary sewers are a potential source of *E. coli* to the TMDL area, although none have been reported since 2003. Additionally, any sanitary sewer collection system, especially older systems, have the potential to leak. Leaking sanitary sewer lines from Coopersville are therefore a potential source. Illicit connections to the storm sewers regulated under the MDOT statewide MS4 permit are a potential source of *E. coli* to the source area. The only state road covered under the MDOT statewide MS4 permit, which may discharge to the TMDL source area, is I-96 (Figure M-1). The discharge of storm water that contains *E. coli* in quantities exceeding the WQS is prohibited by the Industrial Storm Water General Permits (MIS510000 and MIS520000); however, all regulated and unregulated storm water can be contaminated by a flush of waste from pets, feral animals, wildlife attracted by human habitation (such as raccoons), and improper garbage disposal (such as diapers or cat litter). Because landfills may attract wildlife such as raccoons and seagulls, the Ottawa County Farms Landfill (MIS111226), which discharges storm water to an unnamed tributary to Deer Creek (individual catchment 17, grouping F), may be a potential source of *E. coli* to the TMDL area during wet weather.

Grand Haven-Spring Lake, Allendale, and Allegan Wastewater Treatment Plants are permitted to land apply biosolids within the TMDL watershed, via a licensed hauler and applicator. Biosolids are the residuals settled out of municipal and commercial sanitary sewage during the treatment process, and are also known as sewage sludge. Biosolids are treated to reduce pathogens, and can then be land applied to agricultural fields. The land application sites within the TMDL watershed are located within catchments 1-3, 8, 12, 14, 25, and 29.

Beaver Creek Dairy CAFO (MI0058138) houses approximately 2,600 adult cows under a roofed confinement area. Beaver Creek Dairy manifested about 5,746,500 gallons of liquid waste and 1,100 tons of solid waste in 2009. Manifested manure is waste that is sold or transferred to another entity, other than the facility producing the waste. Since manifested manure is no longer the legal responsibility of the CAFO permittee, it is considered a nonpoint source when it is land applied. A total of 27,004,921 gallons of liquid waste, and 2,179 tons of solid waste were not manifested, and were spread by Beaver Creek Dairy CAFO. The Comprehensive Nutrient Management Plan (CNMP), 2009 Annual Report, has identified 2,729 acres of land as available for the spreading of their non-manifested waste (Beaver Creek Dairy, 2010). Approximately 573 of these identified available acres are within the Deer Creek TMDL Source Area (Figure M-4). During 2009, Beaver Creek Dairy land applied waste upstream of sites 4, 5, and 7, on 97 acres in catchment 3, 376 acres in catchment 12, 79 acres in catchment 13, and 21 acres in catchment 15. In particular, manure applications to areas in catchment 12 were made from July 31 through August 7 and had the potential to contribute to exceedances at site 5 on the August 10 sampling event (which was preceded by a heavy rainfall).

The River Ridge CAFO (MIG010127) houses approximately 2,800 cattle under a roofed confinement area and in open confinement. River Ridge Dairy manifested about 2,000,000 gallons of liquid waste and 5,000 tons of solid waste in 2009. The CNMP identified 2,507 acres of land as available for the spreading of their non-manifested waste (River Ridge Farm, 2010). Approximately 1,033 of the available acres are within the Deer Creek TMDL Source Area. A total of 8,760,292 gallons of liquid waste, and 12,900 tons of solid waste were not manifested, and were spread by the River Ridge CAFO (Figure M-4). During 2009, River Ridge land applied manure on about 50 acres of land within catchment 22 during late August through September. Any potential surface water contamination from these manure applications would not have been evident in MDEQ sampling because no rain events preceded sampling.

4.3 Nonpoint Sources

Nonpoint sources of *E. coli* contamination include any source that is not regulated by an NPDES permit, including failing OSDS, unregulated storm water, livestock, manure applications to agricultural fields, and pet and wildlife waste.

Unregulated storm water includes storm runoff from rural areas from all land cover types, including agriculture and natural land covers, as well as storm water from storm sewers located in Coopersville and other residential developments (subdivisions and mobile home parks [MHPs]). Unregulated storm water can be contaminated by the same potential sources as regulated storm water (see Section 4.2). As the amount of developed land in a watershed increases, the amount of impervious surfaces also increases. Impervious surfaces, such as roads and rooftops, do not allow storm water to infiltrate the ground, and thus increases runoff. The risk of surface water contamination increases as the amount of runoff increases, because the capture of pollutants by infiltration is lessened or eliminated prior to the discharge of the runoff into a surface water. Higher concentrations of pathogens are associated with increased relative cover of developed and urbanized land cover (Schoonover and Lockaby, 2006). Road density (length of roadway per unit land area) and the amount of developed land (relative to total land area) is highest in areas surrounding Coopersville (Catchments 13, 15, 16, 17, and 19). Generally, a significant contributor to urban storm water contamination is pet waste. According to the American Veterinary Medical Association (2007) an average of 37.2 percent of households own dogs, and households with dogs have an average of 1.7 dogs. Given these statistics, and the occupied housing unit data from the 2010 U.S. Census, the dog population in the source area is an estimated 1,584 (Table 8). An estimate of cat ownership was not conducted for this TMDL, due to the limitations on cat ownership statistics available. Cats, unlike dogs, can defecate in litter boxes indoors, in which case their feces may be disposed of in a landfill, making the numbers of cat ownership more unreliable in association with *E. coli* contamination. However, feral and outdoor cats and dogs are a potential source to this TMDL water body and should be considered in any effort to reduce contamination by encouraging people to clean up after their pets.

There are two areas with a high density of human population in the TMDL source area, including the city of Coopersville and village of Conklin. Most areas of Coopersville are served by sanitary sewers, but runoff and storm sewer issues remain a potential source. Given the high density of human population in this area, illicit connections (either to storm sewers or direct to water bodies) and failing OSDS in unsewered areas are potential sources to Deer Creek and other tributaries which flow through the city of Coopersville. Storm water discharges from Coopersville are a potential source to sites 6, 7, and 8, in particular, but also to downstream sites on the mainstem of Deer Creek (sites 9, 12, and 13). The village of Conklin is served by the sanitary system of Chester Township, which discharges the treated wastewater outside of the TMDL watershed. Storm water from the village of Conklin may discharge to the TMDL watershed, and if so, would be a potential source to site 1 and also affect downstream sites.

The Country Village MHP is located on the line between catchments 28 and 18, on 32nd Ave, north of Hayes Road in Wright Township (Figure M-1). This community of around 30 housing units is served by a lagoon treatment system, which discharges to groundwater and is permitted under the Michigan Groundwater Discharge Program (permit number GW1510146). The MHP lagoon system is aging and leakage may be a potential source of *E. coli* to Little Deer and Deer Creeks. In 2009, the lagoons were found to be leaking due to lining issues and animal activity. Recent complaints by neighbors indicate that the lagoons may be leaking again after actions were taken in 2009 to address the leakage. The MHP discharge to groundwater consists of a perforated discharge pipe, which slowly discharges up to 10,000 gallons per day to the ground surface in an adjacent agricultural field. The permit intends for the wastewater to enter the ground for further treatment by filtration through the soil before reaching the groundwater or venting to surface waters. Because of this premise, the effluent disinfection or bacterial monitoring of the lagoon treated wastewater is not required by the permit. The Groundwater Discharge Permit prohibits the discharge of the lagoon treated wastewater during the winter months. Sites 10 and 11 are downstream of this discharge, and could potentially be affected during wet weather if lagoon leakage is occurring.

The OSDS are used to provide treatment of sanitary waste when a building is not connected to sanitary sewers. The OSDS treat sewage by settling out solids allowing liquid waste to percolate downward in the septic field. This downward percolation provides both filtration and time for natural processes to treat the waste. According to USEPA estimates, each person generates 70 gallons of wastewater per day (USEPA, 2000). Based on 2010 Census estimates in areas of the TMDL watershed that are estimated to have no sanitary sewer service, the MDEQ estimates that there are approximately 840 housing units with 2,300 occupants that rely on OSDS in the TMDL area, resulting in the treatment of approximately 0.16 million gallons of sanitary wastewater per day by OSDS (2,300 people x 70 gallons per day). When the septic field does not allow downward percolation because soil or water-table characteristics inhibit movement, OSDS do not provide proper treatment and pose a contamination risk to either groundwater, surface water, or both (Figure M-5). Where soils are poor, illicit connections and failing or poorly designed OSDS may be more common. Homes with illicit connections can be a long distance from the actual water body they are contaminating, when they are discharging to buried tile lines or road side ditches, which eventually connect to surface water. An illicit connection of this type may cause both wet and dry weather exceedances. Failing OSDS and illicit connections to water bodies are considered a potential source in all catchments and sampled sites. Data from site 11, on Little Deer Creek, showed many more dry weather exceedances than the nearby upstream site (10), indicating that a dry weather source, such as illicit connections or failed OSDS, may be contributing to *E. coli* issues in this area. Site 11 also tested positive for human bacteroides on August 3 and 17, 2009.

In rural areas, livestock are a more likely source of contamination to storm water. Agriculture, including hay/pasture, accounts for approximately 79 percent of the land use in the entire TMDL source area and as much as 94 percent of the land area in individual catchments (Table 8, Figure M-2). Runoff and discharges from artificial drainage, such as tiles, from pastureland and the land application of manure to cultivated land are sources of *E. coli* to surface waters (Abu-Ashour and Lee, 2000). Many factors affect the amount of *E. coli* transported from fields when manure is land applied or deposited by grazing animals; chief among them is the amount of *E. coli* present in the manure at the time of application. Liquid cattle manure has been shown to contain *E. coli* concentrations from 4,500 to 15,000,000 *E. coli* per mL (Unc and Goss, 2004).

Manure applications on no-till, tile drained fields may pose an especially high risk of surface water contamination by *E. coli*, given that fissures in the natural soil structure can provide a relatively unimpeded pathway for contaminated water to reach tiles, then surface water, without the benefits of filtration through soil or riparian buffer strips (Shipitalo and Gibbs, 2000; Cook and Baker, 2001). Throughout the entire Midwest, approximately 20 percent of all agricultural lands are tile drained (Zucker and Brown, 1998). Subsurface drainage tiles reduce the amount of surface runoff up to 45 percent (Busman and Sands, 2002), but reroute precipitation through the soil vadose zone (3- to 5-feet depth) and into a permeable tile, which then routes directly to surface water bypassing buffer strips. In fields where water infiltration rates are slow due to already saturated conditions or poorly drained soil types, runoff can be enhanced, causing sheet-flow of contaminated storm water if manure has been applied. The end result in a field with poorly drained soil types, either tiled or not tiled, is an increased risk of contaminated storm water to a surface water body if manure is applied prior to rainfall. Farmed, poorly drained soils are represented in Figure M-4. Tillage practices in the Deer Creek watershed are unknown.

For the purposes of this TMDL, all livestock within the source area are considered potential sources of *E. coli*, although larger operations and operations directly adjacent to water bodies are more likely to create contamination issues. A complete list of livestock operations, ranging in size from a single animal up to larger dairy and meat operations, are included in Table 6 and Figure M-7. Individual AFOs and active pasture lands are labeled with identification (ID) numbers to facilitate discussion. Sixty-three farms were identified within the watershed through driving reconnaissance and remote sensing. Table 6 also indicates the type of livestock, type of AFO (pasture or feedlot), and whether the operation is located within 1,000 feet of Deer Creek or its tributaries. Livestock farms close in proximity, or adjacent to, water bodies are more likely to contaminate surface waters from barnyard or pasture runoff, particularly if animal areas slope towards water bodies without buffer vegetation or embankments to contain runoff. Where livestock type, and/or AFO size is listed as unknown, the existence or number of animals could not be confirmed visually from the road. Smaller farms, such as hobby horse farms and small family farms (<12 animals), can also contaminate surface water if the pastures slope into adjacent water bodies, animals have direct access, or if manure is stockpiled upslope of a water body. Hobby horse farms were found in 11 of the 29 catchments. Livestock in the watershed appear to be mainly cattle and horses, although sheep and goats were noted. Large cattle operations will generally spread manure in the early spring and late fall on fields available to them for land application as near as possible to their operations. Manure spreading, resulting from large farms or AFOs in and near the source area, is a likely source of *E. coli*. Based on the land cover analysis (Tables 7 and 8) and locations of identified livestock farms (Table 6 and Figure M-7), livestock manure stockpiled near streams or land applied is likely a significant source to all sites monitored for this TMDL.

Site 11, on Little Deer Creek, demonstrates exceedances during all flow conditions sampled (see Section 4.1), indicating a constant source of *E. coli* present during dry weather and low flows, in addition to the wet weather sources that were indicated at all sampling sites. Site 10, about 2 miles upstream of site 11, did not exceed the WQS consistently during dry weather as site 11 did. BST results indicate the presence of both human and bovine sources to site 11 (no human BST analyses were conducted at site 10). The area on the southwest quarter of section 5 (Tallmadge Township) has a number of homes that are situated near Little Deer Creek, located in catchment 26, although these homes appear to be newer construction, making improperly designed OSDS less likely, but still possible. Another potential source is a mid- to large-sized cattle AFO (ID 58) located less than 1,000 feet from the tributary to Little Deer Creek in catchment 27.

Sites 2 and 3, on Beaver Creek (catchment grouping A), had the highest site geometric means of any sampled site. Illicit connections, failing OSDS, or livestock with direct stream access are potential sources for exceedances of the WQS during low flow or dry conditions. In Beaver Creek, 88 percent of the watershed is agricultural land cover (the highest of any catchment grouping) and 7 AFOs (mainly cattle) were found to be within 1,000 feet of Beaver Creek and its tributaries. Positive BST analysis results for bovine bacteroides and enterococci in wet weather sampling (site 1) affirms agricultural runoff as a potential source to Beaver Creek.

Positive BST analysis results for bovine bacteroides and enterococci in wet weather sampling (site 6) affirms agricultural runoff as a potential source to the unnamed tributary to Deer Creek, located just north of Coopersville. A large cattle AFO was noted in this catchment, situated more than 1,000 feet from the tributary, making land application of cattle manure a likely source to site 6. Additionally, a hobby horse farm (ID 23) with direct animal access to the tributary was noted. Site 6 is also likely impacted by storm water from residential areas of Coopersville.

4.4 Spatial Analysis

A spatial analysis of each individual catchment was conducted to characterize the potential sources that may contribute to *E. coli* WQS exceedances. The land cover, soil characteristics, and human habitation patterns in each catchment all may indicate potential sources and conditions unique to each catchment and can be used to aid source assessment.

Coastal Change Analysis Program 2006-Era Land Cover Data (NOAA, 2008) characterizes an area by land cover type (i.e., cultivated land, hay/pasture, developed land). Each land cover type has potential sources of *E. coli* particular to that land cover type (i.e., cultivated land may have livestock manure applied to it, but developed land likely does not). The 2006-Era Land Cover Data dataset is a raster dataset made up of a 30-square meter (1/4-acre) grid with an 85 percent accuracy rate. A 15 percent error is expected with an 85 percent accuracy rate. In areas where development of agricultural lands has occurred between 2006 and the present (2011), land cover data may be out of date. However, this is the most up-to-date land cover data available. The 2006-Era Land Cover Data was edited within the city of Coopersville to match aerial imagery dated 2011, to reflect recent urban development in that area. Results of the land cover analysis can be found in Table 7 at the catchment grouping level, and Table 9 at the individual catchment level.

The Soil Survey Geographic (SSURGO) Database was used to obtain the drainage characteristics of soils in the TMDL source area (USDA-NRCS, 2011). Soil drainage characteristics can have a significant effect on the quantity of runoff and infiltration, both of which can affect *E. coli* contamination of surface waters. Within the SSURGO dataset, mapped soil units are further broken down into more specific soil components, which are based on multiple additional soil characteristics (such as drainage capacity). As a result, some map units have many different soil characteristics that have been aggregated by soil survey staff to facilitate mapping. The resulting table, Mapunit Aggregated Attribute, was used for the spatial analysis, which is the basis for the stressor analysis.

High human population and high density housing either near a water body or connected to a surface water body by storm sewers, poses a significant *E. coli* contamination risk. The increased risk of contamination originates from storm water contamination issues (discussed above), illicit connections to storm sewers or water bodies, and failing OSDS. Occupied housing units and population data from the 2010 Census at the census block level were used to calculate the number of occupied housing units, population numbers, and density (Table 8).

4.5 Stressor Analysis

In order for stakeholders to prioritize actions within the TMDL source area, and to further define nonpoint sources of *E. coli*, a stressor analysis was completed using the results of spatial analyses. Stressors are defined as a set of physical conditions, which would increase the likelihood of *E. coli* contamination to surface waters. For ease of discussion, the 11 stressors selected for this analysis were divided into urban and rural categories.

The urban stressors for each individual catchment include the following stressors:

- Road density.
- Percent cover of developed land served by sanitary sewers.
- Occupied housing units.
- Human population density.
- Total human population.

The rural stressors for each individual catchment include the following stressors:

- Number of large AFOs.
- Number of AFOs in 1,000 foot riparian buffer.

- Percent cover of agricultural land.
- Percent cover of agricultural land with poor drainage.
- Percent cover of developed land with no sanitary sewers.
- Percent cover of soils with poor OSDS absorption characteristics.

For each stressor, the catchment data (e.g., human population or percent land cover) was ranked and divided into the 1st-4th quartiles (the 1st quartile contains the catchments with the bottom 25 percent of the data, the 2nd quartile contains the catchments in the 25th-50th percentile, etc.). The quartile to which each catchment belongs (1st-4th) was translated into the stressor score (1-4), with 4 being the highest environmental stress score for each stressor variable. For each catchment, the stressor scores were then summed to calculate an urban stressor score (5 through 20), a rural stressor score (6 through 24), and the overall stressor score, combining all urban and rural stressors (11 through 44). The methods for calculating the stressors, and the results, are described in detail in Sections 4.5.a through 4.5.f. The results of stressor scoring are shown in Figure M-8 and Table 8, and discussed in Section 6.

4.5.a Urban Stressors: Road Density

Road density was used as an indicator of the area of impervious surface and urban development for the stressor analysis. Impervious surface area is not equivalent or directly related to developed land cover. Therefore, both road density and developed land cover were used separately in the stressor analysis. Road density was calculated by determining the length of roads (in meters), and dividing that length by the area (in acres) of each individual catchment (Table 8). Road density was highest in the highly urbanized catchments in Coopersville, grouping E and F. Catchment 15, in grouping E, had the highest road density (27.3 meters per acre).

4.5.b Urban Stressors: Percent Cover of Developed Land Served by Sanitary Sewers

According to 2006-Era Land Cover Data (NOAA, 2008) 9 percent of the TMDL source area is high, medium, or low density or open developed land. This is a relatively small proportion of the source area, but in terms of *E. coli* contamination from OSDS, pets, and wildlife, it is an important segment. In terms of developed land cover relative to the total catchment area, catchment 15 (within grouping E) was 65 percent developed land (Table 8). This highly developed catchment has sanitary sewers available in most areas, but not all residences may be properly connected to them.

Nearly half (42 percent) of developed land in the TMDL source area is served by sanitary sewers maintained by the city of Coopersville and Chester Township. Sewered and unsewered areas were determined by obtaining maps of sewer systems from the city of Coopersville and Chester Township. Within areas that are largely served by sanitary sewers, illicit connections and failing OSDS remain a potential source of *E. coli* contamination to surface waters.

4.5.c Urban Stressors: Occupied Housing Units, Human Population Density, and Total Human Population

Human population within the source area in 2010 was estimated to be approximately 6,359 people (Table 8) (U.S. Census Bureau, 2010a and 2010b). Catchment 15 had the highest human population and highest human density (people per acre) of any catchment in the source area. In terms of number of occupied housing unit density (units per acre), catchment 15 had the highest density followed by catchments 10 and 17; all are located near the city of Coopersville.

4.5.d Rural Stressors: Number of Large AFOs and AFOs near tributaries

The number of large AFOs, and number of AFOs within 1,000 feet of Deer Creek tributaries in each catchment was used as an indicator of rural stress. AFOs can be potential sources of *E. coli* by contaminating surface runoff at the AFO site, as well as over a wider area if the manure is land applied or stockpiled off-site.

The MDEQ has identified 14 AFOs that appear to be large (50+ livestock animals), and therefore, are important potential nonpoint sources of *E. coli* to the TMDL source area (Table 6). Forty-one AFOs have been identified that are within 1,000 feet of Deer Creek and its tributaries (Tables 6 and 8). Catchments 3 and 22 each contain three large AFOs, the most of any catchment in the watershed. In terms of catchment groupings, grouping B (upper Deer Creek) has the most (9) AFOs within 1,000 feet of tributaries, and the most (5) large AFOs.

4.5.e. Rural Stressors: Percent Cover of Agricultural Land and Agricultural Land with Poor Drainage

Catchments 1, 2, 4, and 6 of grouping A (Beaver Creek), catchments 14 and 27 of grouping J (Little Deer Creek), and catchment 22 of grouping F (tributary to Deer Creek), had the highest percent of land cover in agriculture and were in the upper quartile of all 27 catchments for percent land cover occupied by agriculture (hay/pasture and cultivated land combined). Percent cover in agriculture ranged from 22 to 94 percent of individual catchment area (Table 9). Land application of manure is likely to be a significant source in the entire TMDL watershed, based on land cover analysis, the number of AFOs, and available land for CAFO land application.

The capacity of soils to support agriculture with or without artificial drainage was estimated using the component table of the Farmland Classification System SSURGO dataset: (1) Prime Farmland; and (2) Prime Farmland if Drained (USDA-NRCS, 2011). The Prime Farmland classification (1) is designated after consideration of the water table and flooding frequency and without regard to current land use. Soils categorized as Prime Farmland if Drained (2), could potentially produce crops at a ‘prime farmland’ level if artificial drainage or flood control was installed. The resulting datasets were layered with the 2006-Era Land Cover Data (NOAA, 2008) to produce coverage of soil characteristics by land cover type. Farmland areas (cultivated land and hay/pasture) in the source area where artificial drainage is needed to maximize farmland potential are estimated (by catchment) in Figure M-4. The catchment groupings with the highest proportion of agricultural land having these poor drainage characteristics are B and C, and on the catchment level, catchment 12 had the highest proportion of these soils (within catchment grouping B). These areas may pose a particular surface water contamination risk if manure is applied prior to a heavy rainfall.

4.5.f. Rural Stressors: Percent Cover of Developed Land with No Sanitary Sewers and Soils with Poor OSDS Absorption Characteristics

Developed areas served by sanitary sewers were determined using collection system maps provided by the city of Coopersville. Developed land cover, which is not served by sanitary sewers (about 5 percent of the entire source area) is largely rural housing relying on OSDS for sewage treatment. Individual catchments 17 and 19 had the highest percent of unsewered, developed land, relative to the entire catchment area.

The capacity of the soil to provide the necessary drainage to accommodate a properly functioning OSDS was derived from the 'septic tank absorption field' of the Mapunit Aggregated Attribute table (USDA-NRCS, 2011). About 46 percent of the TMDL source area is made up of soils that limit the ability of OSDS drainage fields to infiltrate properly, due to poor drainage (primarily from high clay content). Catchments with a high proportion of the land area covered by soils that limit OSDS functionality can be seen in Figure M-6, and tend to be concentrated in catchment groupings A, B, C, E, and K. Catchment 12, within grouping B, had the highest percent of soils that limit OSDS functionality (88 percent) but also had a low amount of developed land (3 percent of catchment) and a low number of housing units (18). The OSDS located on these soils with poor, or slow, infiltration rates may lead to a higher rate of surface and seasonal failures.

5. REASONABLE ASSURANCE ACTIVITIES

5.1 NPDES

The COCs for the general industrial storm water permit (MIS110000) listed in Table 4, specify that if a TMDL is established by the Department for the receiving water that 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 provide an estimate of the current annual load of those materials via storm water discharges to the receiving stream. In addition, storm water permit authorization requires facilities to obtain a certified operator who will have supervision and control over the control structures at the facility, eliminate any unauthorized non-storm water discharges, and develop and implement the Storm Water Pollution Prevention Plan for the facility.

The MDOT Statewide Individual Storm Water NPDES Permit (MI0057364) covers storm water discharges from state roads in the watershed (Interstate-96, Figure M-1). This statewide permit requires the permittee to reduce the discharge of pollutants to the maximum extent practicable and employ Best Management Practices to comply with TMDL requirements.

The NPDES CAFO permit (individual and general permits) contains several measures which help to reduce *E. coli* entering surface waters, from the production area, waste (manure) storage sites, and manure land application sites. At production facilities, and associated manure storage sites, the permit requires properly designed, constructed, and maintained manure storage structures. These structures must be designed to store at least six months of generated production area waste, normal precipitation, the 25-year, 24-hour rainfall, and the required freeboard amount. All manure storage structures must be inspected once per week, providing assurance against overflow and potential structural damage. The CAFO permit states that direct contact of animals with the surface waters of the state is prohibited at the production area, and the disposal of dead animals shall not contaminate surface waters.

The CAFO permit requires the development of a CNMP, as well as annual reviews and reports. CNMPs do not specifically address *E. coli*, but by addressing nutrients contained in manure, these plans indirectly assist in controlling the amount of *E. coli* entering surface water. The CNMP does this by preventing over-application of manure and by requiring CAFO operators to plan and record manure applications on an ongoing basis. The CNMP requires the submission of maps to identify land application areas and reports on the quantities and types of manure applied. The permit requires an assessment of land application areas prior to land application, including the condition of all tile outlets, observations of soil cracking, moisture holding capacity of the soil, crop maturity, and the condition of designated conservation practices (i.e., grassed waterways, buffers, diversions). During land application of waste, a 100-foot set-back surrounding waterways and other sensitive areas is required to minimize potential contamination of waterways with manure. The 100-foot set-back may be replaced with a 35-foot vegetated buffer where no land application can occur. After any land application of manure, tile outlets must be inspected. If an inspection reveals a discharge with color, odor, or other characteristics indicative of an unauthorized discharge of CAFO waste, the permit instructs the permittee to immediately notify the MDEQ. CAFO waste may not be land applied if the field is flooded or saturated, it is raining, or if more than 0.5 inches of rain is forecasted within the next 24 hours with an occurrence greater than 70 percent chance. To help minimize contaminated runoff, CAFO waste on tillable fields must be injected or incorporated into the ground within 24 hours of application. The land application of CAFO waste where it may enter surface waters of the state if it cannot be incorporated due to no-till practices, is prohibited. The application of CAFO waste to frozen or snow-covered fields without incorporation is only allowed after a specific field-by-field demonstration is completed to assess and minimize the risk of surface water contamination. The CAFO permit requirements summarized above are designed to minimize the contamination of surface water by CAFO-generated waste by providing record keeping, inspection, and land application requirements and guidance.

The MDEQ encourages the use of biosolids to enhance agricultural and silvicultural production in Michigan. Biosolids applications are regulated by Residuals Management Programs that are required by the provisions of a facility's NPDES discharge permit for wastewater treatment or by a general permit (MIG960000). Michigan's administrative rules require that pathogens in biosolids be significantly reduced through a composting process, prior to land application (R 323.2418 of Part 24, Land Application of Biosolids, of the NREPA). Provisions contained in Part 24 that protect surface and ground waters from contamination by land applied biosolids include: isolation distances from surface water (50 feet for subsurface injection or surface application with incorporation, or 150 feet for surface application without incorporation within 48 hours); sampling to ensure that pathogen density requirements in R 323.2414 are met; and restrictions (but not prohibition) of land application to frozen, saturated, or highly sloped land.

NPDES individual permits, COCs, and general permits are reissued every five years on a rotating schedule, and the requirements within the permits (outlined above) may also change at reissuance. Pursuant to R 323.1207(1)(b)(ii) of the Part 8 rules, and Title 40 of the Code of Federal Regulations, Part 130.7, NPDES permits issued or reissued after the approval of this TMDL are required to be consistent with the goals of this TMDL (described in the Waste Load Allocation Section [2.1.a]).

5.2 Nonpoint Sources

Failing or poorly designed OSDS are likely a significant source of *E. coli* to unsewered areas of Deer, Little Deer, and Beaver Creeks. Michigan is the only state in the United States with no unified statewide sanitary code and with decentralized regulatory authority over OSDS (Sacks and Falardeau, 2004). Instead, Michigan regulatory code (Section 2435 of the Public Health Code, 1978 PA 368, as amended) gives local district health departments the authority to "adopt regulations to properly safeguard the public health and to prevent the spread of diseases and sources of contamination." The state of Michigan does issue design criteria for OSDS that are utilized by more than 2 homes and discharge 1,000-10,000 gallons per day (Michigan Department of Public Health, 1994). For systems that discharge less than 1,000 gallons per day, the system must be approved by the local health department in accordance with local sanitary code (R 323.2210 of the Part 22 rules). Local health departments must be accredited by the state in a process that involves evaluation of the local departments every three years.

Additionally, adopted sanitary codes must meet minimum measures proscribed by the state of Michigan.

Ottawa County has a Real Estate Transfer Evaluation policy (often referred to as a point-of-sale program), which requires an inspection of OSDS prior to the property sale or transfer of ownership (Ottawa County Health Department, 2005). Ottawa County Environmental Health Regulations require that new dwellings connect to available sanitary sewers, and that existing dwellings connect to available sanitary sewers when OSDS are deemed ineffective by the county health officer. Ottawa County regulations also prohibit new OSDS in flood-prone areas or within the ten-year flood plain and existing OSDS in flood-prone areas must be brought to code upon failure or property transfer. Muskegon County has put in place sanitary regulations which require that if a new or existing dwelling is within 200 feet of a sanitary sewer, the building on that property must be connected to the sewer line rather than rely on an OSDS for sanitary sewage treatment (Muskegon County Health Department, 2005). Muskegon County does not require point-of-sale inspections, but does require permit issuance for the repair of existing OSDS and the construction of new OSDS. The permit issuance process contains specific precautions when a new OSDS is proposed within 400 feet of a water body, allowing new construction of an OSDS only when the system can comply with regulations to ensure it is above the seasonal mean high water table. Muskegon County regulations also prohibit new OSDS in flood-prone areas (ten-year flood). OSDS repair permits and permits for new construction of OSDS are issued by the Ottawa and Muskegon County Health Departments. The repair and replacement of failing OSDS, particularly near water bodies, will significantly improve water quality and remove a public health threat.

Unpermitted discharges of pollutants to waters of the state (illicit connections), whether direct or indirect, are illegal in the state of Michigan. Section 3109(1) of Part 31 states that a person shall not directly or indirectly discharge into the waters of the state a substance that is or may become injurious to public health, safety, or welfare, or to domestic, commercial, industrial, agricultural, recreational, or other uses that may be made of such waters. Section 3109(2) further specifically prohibits the discharge of raw sewage of human origin, directly or indirectly, into any waters of the state. The municipality in which that discharge originates is responsible for the violation, unless the discharge is regulated by an NPDES permit issued to another party. The elimination of illicit discharges of raw human sewage to the Deer Creek source area will significantly improve water quality and remove a public health threat.

Nonpoint source pollution from unpermitted agricultural operations is generally not regulated by the MDEQ, but is mitigated through voluntary programs such as Clean Michigan Initiative and federal Clean Water Act Section 319 funded grants for watershed management plan development and implementation. Unregulated AFOs may be required to apply for an NPDES permit in accordance with the circumstances set forth within R 323.2196 of the Part 21 administrative rules. This authority allows the MDEQ to impose pollution controls and conduct inspections, thereby reducing pollutant contamination (i.e., *E. coli*) from agricultural operations that have been determined to be significant contributors of pollutants.

The Michigan Agriculture Environmental Assurance Program (MAEAP) is a voluntary program established by Michigan law (1994 PA 451, MCL 324.3109d) to minimize the environmental risk of farms, and to promote the adherence to Right-to-Farm Generally Accepted Agricultural Management Practices, also known as GAAMPs. To earn MAEAP verification, a farm must demonstrate that they are meeting the requirements geared toward reducing contamination of ground and surface water, as well as the air. Livestock*a*Syst is the portion of the MAEAP verification process that holds the most promise for protecting waters of the state from contamination by *E. coli* and other pathogens, which include: steps to promote the separation of contaminated storm water from clean storm water at the farm site; the completion of a CNMP similar to that required by NPDES permitted CAFOs; runoff control at feedlots and the identification of environmentally sensitive areas; the prevention of manure reaching tile lines; and controlling contamination of runoff through incorporation on land application fields.

Enteric bacteria in agricultural soil where manure has been applied usually declines to preapplication levels within one to six months depending on conditions (Stoddard et al., 1998; Jamieson et al., 2002; Unc and Goss, 2004; and Oliver et al., 2005); however, under laboratory conditions, *E. coli* has survived for 231 days in manure amended soils (Jiang et al., 2002). Even given the potential longevity of enteric bacteria after manure application, studies show that if 4 to 8 days pass between manure application and heavy rainfall, contamination can be reduced (Crane et al., 1978 and Saini et al., 2003). Vegetated riparian buffer strips wide enough to trap sediment have been shown to reduce the enteric bacteria in runoff (Coyne et al., 1998 and Lim et al., 1998). A Vegetated Buffer Index (VBI) was developed for each catchment in the Deer Creek TMDL watershed. The VBI expresses the relative amount of stream miles where 2006 land cover data for natural and wetland land covers intersects with streams. The VBI is only as accurate as the land cover data (15 percent error is expected) and only buffers larger than 30-meters in width and that existed in 2006 would be represented; therefore, the VBI is meant to give only an estimate of which catchments have substantial buffered areas. According to the VBI, 41 percent of the stream miles in the entire Deer Creek TMDL area have a significant vegetative buffer (Table 9). MDEQ staff will continue to promote the maintenance and installation of riparian vegetated buffers in this watershed through programs such as TMDL implementation grants issued using Clean Michigan Initiative and federal Clean Water Act Section 319 grants.

The MDEQ will conduct inspections of the Country Village MHP (permitted under Michigan Groundwater Discharge Program, permit number GW1510146) sewage lagoons and discharge area in 2012. The MDEQ will ensure that all components of the permit requirements are being met and that surface water is not being contaminated by this discharge.

Federal Clean Water Act Section 319 funding was used to develop the Lower Grand Watershed Management Plan (WMP), which was approved by the MDEQ in 2011. Part of the WMP involved field investigations of Deer Creek in 2009, which identified a number of sites where animal access was of concern. Once approved, this TMDL will elevate the priority of the Deer Creek watershed for potential future funding under these programs.

The MDEQ endorses the use of its Landscape Level Wetland Functional Assessment (LLWFA) tool as a means to prioritize areas for wetland restoration and protection. Michigan's LLWFA methodology identifies historically lost wetlands, determines the functions they once provided, and helps to prioritize wetlands for restoration to obtain the most significant water quality improvements. Removal of *E. coli* by wetlands is a function that has not been considered in the LLWFA in the past; however, the MDEQ is working to incorporate this important function of wetlands into the LLWFA. Wetland restoration has the potential to decrease *E. coli* concentrations by slowing the flow of runoff, thus increasing filtration by vegetation and soil. Wetlands that retain water long enough to cause bacterial mortality, and create conditions which increase mortality (such as high levels of sunlight), are also beneficial to reducing *E. coli* in surface waters. Wetlands that are adjacent to surface waters and have high amounts of emergent vegetation (such as wet meadows and emergent marsh) have the most potential to decrease *E. coli*, and also would not attract large amounts of waterfowl. The MDEQ partnered with the Annis Water Resources Institute and produced "The Lower Grand River Watershed Wetlands Initiative," which incorporates the LLWFA. The report can be found on the Annis Water Resources Institute Web site (http://www.gvsu.edu/wri/isc/lower-grand-river-watershed-wetlands-initiative-project-overview-313.htm). The Deer Creek watershed has lost 43 percent of its wetlands since presettlement, according the LLWFA. Lost wetlands, by type, are shown in Figure M-9. The percentage of wetlands lost since presettlement, by catchment, is shown in Table 9.

6. IMPLEMENTATION RECOMMENDATIONS

Implementation of NPDES permit-related point source discharges is regulated as determined by the language contained within each permit, which are updated every five years and must be consistent with this TMDL. The implementation of nonpoint source activities to reach the goal of attaining the WQS is voluntary. Funding is available on a competitive basis through Clean Michigan Initiative and federal Clean Water Act Section 319 grants for TMDL implementation and watershed planning and management activities. Priority catchments were identified using the stressor analysis (Table 8 and Figure M-8). Higher stressor scores indicate a higher priority in terms of the implementation of voluntary nonpoint source activities and can also be used in the TMDL implementation grant application process for prioritization. The top ranked priority catchments to address urban contamination issues are: 10, 13, 15, 17, and 19. Priority catchments to address rural contamination issues are: 1-4, 8, 10, 12, and 13. Catchments that scored above 30 (on a scale of 10 to 40) in their overall/combined stressor scores are: 8, 10, 13, 15, and 17. We recommend the following voluntary activities to make progress in meeting the goal of this TMDL:

Recommended Voluntary Urban Activities:

- Survey of the city of Coopersville and village of Conklin storm sewer outfalls to look for dry-weather discharges or other signs of illicit connections.
- Outreach to educate residents on backyard conservation, which includes proper pet waste management, rain gardens, rain barrels, improving storm water infiltration and storage, and discouragement of congregating wildlife. This effort could be targeted to residents in the city of Coopersville and village of Conklin, as well as riparian land owners throughout the watershed.
- Outreach to educate residents on the signs that their residence may have improper connections to a storm sewer or a surface water body.
- Adoption of pet waste ordinances.

Recommended Voluntary Rural Activities:

- Focused effort by local health departments and other agencies to locate and address failing OSDS throughout the watershed, but particularly upstream of site 11, where human bacteroides was detected. This effort could include BST monitoring in Beaver Creek to determine source of low flow WQS exceedances.
- Outreach to educate residents on the signs that their residence may have a failing OSDS or improper connections to a surface water body.
- Install riparian vegetated buffer strips in agricultural areas that are not artificially drained (tiled). Catchment groupings A, B, C, D, and F had less than 40 percent of their stream miles buffered with natural vegetation (Tables 7 and 9).
- Wetland restoration in areas where historic wetlands have been lost and would be beneficial for removing *E. coli* from runoff (see LLWFA in Section 5.2).
- Conduct agricultural tillage and artificial drainage survey of the watershed, followed by implementing water table management (controlled drainage) where manure is applied to artificially drained land.
- Livestock exclusion from riparian areas and providing vegetated buffers between pasture

and water.

- Outreach to agricultural community to encourage becoming MAEAP verified and/or the use of Best Management Practices on manure storage, composting, and application and the development of nutrient management plans.

7. FUTURE MONITORING

Future monitoring by the MDEQ 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*, as described in this document. When the results of these actions indicate that the water body may have improved to meet 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 1,000 *E. coli* per 100 mL are being met. Requests for future *E. coli* monitoring within this TMDL area may be submitted for consideration via the form found on the MDEQ Web site at http://www.michigan.gov/deq/ then search for “monitoring request form.” Any future data collected by the MDEQ will be accessible to the public via the Beach Guard database at http://www.deq.state.mi.us/beach/.

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Table 1. Summary of sampling site locations, site geometric means, and TBC and PBC WQS exceedances for entire 16-week sampling period in 2009. Note that site geometric means are the geometric means of all sample results for each site, and are calculated to facilitate comparisons among sites and are *not* intended to be compared to the WQS to determine exceedances.

Location	Site Description	Latitude	Longitude	Site Geomeans	TBC exceedances	PBC exceedances	Correlation between precipitation and E. coli (r^2)
1	Beaver Creek @ Elder	43.11671	-85.8968	794	14	5	0.43
2	Beaver Creek @ 48th	43.09305	-85.90701	1767	16	8	0.66*
3	Beaver Creek @ 56th	43.0848	-85.92721	1794	16	8	0.51*
4	Unnamed Trib to Deer Creek (Taft)	43.10393	-85.94188	334	7	5	0.52*
5	Deer Creek @ Roosevelt	43.08936	-85.95142	1262	13	6	0.52*
6	Unnamed Trib to Deer Creek (Cleveland)	43.07455	-85.93723	518	8	3	0.39
7	Deer Creek @ Center St.	43.070983	-85.93705	774	12	3	0.29
8	Deer Creek @ Randall	43.0601	-85.92933	897	12	5	0.42
9	Deer Creek @ Garfield	43.045416	-85.92705	722	13	4	0.63*
10	Little Deer Creek @ Hayes	43.030916	-85.88046	472	7	3	0.39
11	Little Deer Creek @ 48th	43.0258	-85.90655	1355	15	9	0.62*
12	Deer Creek @ Mill (Brucker)	43.02911	-85.92175	1088	15	6	0.64*
13	Deer Creek @ Leonard (Grand River)	43.01366	-85.92496	306	4	2	0.49

* - statistically significant relationship at the 95% confidence level

Table 2. *E. coli* data collected weekly from May 19 through August 31, 2009. “Daily geometric means” are the geometric means of all sample results for a site and given sampling date. Daily geometric means are compared to the daily maximum TBC WQS and the PBC WQS to determine attainment. Gray shading indicates that the daily maximum TBC or 30-day geometric mean WQS was exceeded. A gray shading with a bold outline indicates that both the daily maximum TBC and PBC WQS were exceeded.

		Site 1			Site 2			Site 3			Site 4			Site 5			
		Beaver Creek at Elder			Beaver Creek at 48th			Beaver Creek at 56th			Unnamed Trib at Taft			Deer Creek at Roosevelt			
Date	Location	Sample Results	Daily Geometric Mean	30-day Geomean	Sample Results	Daily Geometric Mean	30-day Geomean	Sample Results	Daily Geometric Mean	30-day Geomean	Sample Results	Daily Geometric Mean	30-day Geomean	Sample Results	Daily Geometric Mean	30-day Geomean	Precipitation in prior 24 hours
	L	320			400			380			30			86			
5/19/2009	C	290			440			260			30			130			
	R	310	306		430	423		350	326		20	26		100	104		0.00
	L	6,900			17,000			7,300			6,500			7,700			
5/27/2009	C	8,100			19,000			6,500			1,800			5,200			
	R	9,800	8,182		15,000	16,921		9,800	7,747		2,600	3,122		5,800	6,147		0.57
	L	170			650			810			30			290			
6/1/2009	C	200			500			1,000			10			270			
	R	220	196		670	602		780	858		20	18		260	273		0.01
	L	16,000			29,000			16,000			9,000			24,000			
6/8/2009	C	13,000			32,000			17,000			6,100			17,000			
	R	17,000	15,235		30,000	30,308		24,000	18,689		8,100	7,633		24,000	21,394		0.70
	L	710			660			1,000			85			690			
6/15/2009	C	1,300			560			790			73			660			
	R	1,100	1,005	1,497	640	618	2,407	850	876	2,041	100	85	250	820	720	1,218	0.00
	L	720			880			1,200			400			770			
6/22/2009	C	370			450			1,100			230			930			
	R	370	462	1,625	630	630	2,606	1,000	1,097	2,602	860	429	437	740	809	1,837	0.00
	L	250			1,900			1,200			230			1,200			
6/29/2009	C	360			1,600			930			120			1,100			
	R	210	266	819	1,700	1,729	1,651	1,500	1,187	1,788	210	180	247	930	1,071	1,295	0.00
	L	480			2,900			800			340			650			
7/7/2009	C	460			2,100			690			400			730			
	R	500	480	980	2,200	2,375	2,173	740	742	1,737	340	359	448	1,000	780	1,598	0.00
	L	260			2,300			870			1,800			560			
7/13/09	C	560			1,800			700			1,300			370			
	R	280	344	459	2,600	2,208	1,287	690	749	913	1,000	1,328	316	600	499	753	0.00
	L	560			860			860			100			840			
7/20/09	C	620			1,000			520			90			560			
	R	700	624	417	620	811	1,359	560	630	855	50	77	309	420	582	722	0.97
	L	580			1,100			1,300			110			2,400			
7/27/09	C	480			1,000			1,900			120			2,100			
	R	400	481	421	900	997	1,489	1,200	1,436	902	110	113	237	1,600	2,005	866	0.00
	L	390			1,000			4,400			4,400			860			
8/3/09	C	370			1,600			3,300			3,300			580			
	R	260	335	441	1,500	1,339	1,415	4,600	4,057	1,153	4,600	4,057	442	820	742	805	0.09
	L	9,200			55,000			250,000			9,200			240,000			
8/10/09	C	6,900			61,000			280,000			7,700			200,000			
	R	8,200	8,044	774	55,000	56,931	2,671	260,000	263,041	3,732	8,700	8,510	832	250,000	228,943	2,507	1.31
	L	1,300			1,000			1,600			250			1,700			
8/17/09	C	1,100			1,100			1,200			170			1,400			
	R	900	1,088	975	1,200	1,097	2,323	1,100	1,283	4,156	160	189	563	1,600	1,562	3,150	0.05
	L	270			1,200			360			320			510			
8/24/09	C	450			140			460			290			520			
	R	360	352	869	940	541	2,142	530	444	3,875	260	289	735	530	520	3,079	0.00
	L	610			550			820			52			190			
8/31/09	C	680			590			870			41			360			
	R	360	531	887	480	538	1,893	760	815	3,460	31	40	598	330	283	2,081	0.00

Table 2. cont.

Date	Location	Site 6 Unnamed Trib at Cleveland			Site 7 Deer Creek at Center			Site 8 Deer Creek at Randall			Site 9 Deer Creek at Garfield			Precipitation in prior 24 hours
		Sample Results	Daily Geometric Mean	30-day Geomean	Sample Results	Daily Geometric Mean	30-day Geomean	Sample Results	Daily Geometric Mean	30-day Geomean	Sample Results	Daily Geometric Mean	30-day Geomean	
5/19/2009	L	330			190			190			190			
	C	260			170			230			180			
	R	280	289		170	176		160	191		170	180		0.00
5/27/2009	L	20,000			22,000			6,400			5,200			
	C	15,000			16,000			7,700			9,200			
	R	16,000	16,869		10,000	15,212		7,300	7,112		6,800	6,878		0.57
6/1/2009	L	360			360			770			380			
	C	460			520			780			330			
	R	390	401		540	466		690	746		360	356		0.01
6/8/2009	L	20,000			20,000			14,000			5,500			
	C	19,000			17,000			13,000			8,100			
	R	24,000	20,893		24,000	20,132		10,000	12,209		6,100	6,477		0.70
6/15/2009	L	310			550			440			260			
	C	300			550			410			430			
	R	210	269	1,615	700	596	1,719	360	402	1,378	400	355	1,002	0.00
6/22/2009	L	310			640			460			530			
	C	300			760			400			460			
	R	275	295	1,622	730	708	2,270	500	451	1,637	390	456	1,208	0.00
6/29/2009	L	150			480			260			320			
	C	230			490			250			180			
	R	200	190	661	500	490	1,142	170	223	819	280	253	624	0.00
7/7/2009	L	270			300			1,600			390			
	C	470			330			1,500			490			
	R	430	379	654	630	397	1,105	2,000	1,687	964	400	424	646	0.00
7/13/09	L	140			270			260			380			
	C	160			280			190			300			
	R	52	105	227	220	255	461	220	222	432	360	345	359	0.00
7/20/09	L	420			210			720			450			
	C	370			430			650			470			
	R	400	396	245	280	294	401	710	693	482	650	516	387	0.97
7/27/09	L	1,000			340			680			450			
	C	700			380			840			630			
	R	600	749	296	450	387	355	930	810	542	490	518	397	0.00
8/3/09	L	340			790			5,500			930			
	C	520			730			5,200			710			
	R	490	442	350	1,200	885	400	5,800	5,495	1,029	770	798	500	0.09
8/10/09	L	11,000			5,200			6,900			10,000			
	C	9,800			7,300			10,000			14,000			
	R	10,000	10,254	676	5,600	5,968	687	6,500	7,655	1,392	5,800	9,329	928	1.31
8/17/09	L	31			670			750			1,600			
	C	20			770			370			1,500			
	R	63	34	539	490	632	824	480	511	1,645	1,800	1,629	1,265	0.05
8/24/09	L	260			280			490			600			
	C	270			300			430			490			
	R	120	203	472	360	312	834	430	449	1,509	670	582	1,296	0.00
8/31/09	L	100			230			170			120			
	C	150			310			160			190			
	R	110	118	326	260	265	773	190	173	1,108	210	169	1,035	0.00

Table 2. cont.

Date	Location	Site 10			Site 11			Site 12			Site 13			Precipitation in prior 24 hours
		Little Deer Creek at Hayes			Little Deer Creek at 48th			Deer Creek at Mill			Deer Creek at Leonard			
		Sample Results	Daily Geometric Mean	30-day Geomean	Sample Results	Daily Geometric Mean	30-day Geomean	Sample Results	Daily Geometric Mean	30-day Geomean	Sample Results	Daily Geometric Mean	30-day Geomean	
5/19/2009	L	64			100			210			130			
	C	200			60			170			100			
	R	210	139		90	81		240	205		150	125		0.00
5/27/2009	L	19,000			4,600			6,500			4,600			
	C	17,000			2,000			8,700			1,200			
	R	12,000	15,708		2,100	2,683		5,500	6,775		800	1,641		0.57
6/1/2009	L	240			310			420			290			
	C	230			310			490			270			
	R	280	249		290	303		360	420		280	280		0.01
6/8/2009	L	1,500			11,000			10,000			300			
	C	1,900			13,000			8,000			200			
	R	2,400	1,898		12,000	11,972		11,000	9,583		800	363		0.70
6/15/2009	L	500			1,600			490			130			
	C	740			1,400			620			120			
	R	690	634	919	1,300	1,428	1,025	630	576	1,263	210	149	315	0.00
6/22/2009	L	430			1,000			470			290			
	C	280			880			680			200			
	R	370	354	1,108	700	851	1,639	760	624	1,579	280	253	363	0.00
6/29/2009	L	230			830			300			170			
	C	180			520			310			110			
	R	170	192	459	680	665	1,240	310	307	850	150	141	222	0.00
7/7/2009	L	330			1,700			660			210			
	C	300			2,000			730			100			
	R	200	271	467	2,200	1,956	1,800	840	740	952	140	143	194	0.00
7/13/09	L	100			2,000			470			310			
	C	63			2,300			440			200			
	R	41	64	237	3,000	2,399	1,305	410	439	514	200	231	177	0.00
7/20/09	L	230			1,700			500			160			
	C	360			1,300			540			180			
	R	150	232	193	2,200	1,694	1,351	490	510	501	170	170	182	0.97
7/27/09	L	240			680			1,600			380			
	C	260			820			1,600			370			
	R	210	236	178	900	795	1,332	900	1,321	582	340	363	196	0.00
8/3/09	L	320			1,400			2,800			100			
	C	350			1,900			5,200			110			
	R	280	315	197	1,800	1,685	1,605	3,900	3,844	966	130	113	187	0.09
8/10/09	L	9,800			20,000			26,000			24,000			
	C	13,000			14,000			29,000			26,000			
	R	12,000	11,520	417	21,000	18,049	2,503	20,000	24,706	1,948	29,000	26,254	531	1.31
8/17/09	L	900			4,100			1,100			270			
	C	1,200			3,700			1,000			340			
	R	800	952	717	4,300	4,025	2,776	1,200	1,097	2,340	290	299	559	0.05
8/24/09	L	220			590			960			330			
	C	330			630			720			330			
	R	280	273	740	560	593	2,250	550	724	2,510	200	279	617	0.00
8/31/09	L	180			400			390			80			
	C	150			450			430			80			
	R	140	156	682	480	442	2,001	320	377	1,954	190	107	483	0.00

Table 3. Results of BST analysis at selected sites and sampling events. Targeted wet weather events are shaded gray. *E. coli* concentrations are the geometric mean of three samples for comparison with the TBC and PBC WQS.

Sample Date	Site	Precipiation in Prior 24-Hours(inches)	E. coli (colonies per 100 mL)	Human Bacteroides	Bovine (Cattle) Bacteroides	Bovine (Cattle) Enterococci
8/3/2009	2	0.09	1,600	-	-	na
8/3/2009	11	0.09	1,900	+	-	na
8/17/2009	2	0.05	1,100	-	-	na
8/17/2009	11	0.05	3,700	+	-	na
6/2/2010	1	0.59	4,200	na	-	-
6/2/2010	3	0.59	4,600	na	-	-
6/2/2010	5	0.59	4,700	na	+	+
6/2/2010	6	0.59	8,600	na	-	-
6/2/2010	10	0.59	3,100	na	-	-
6/2/2010	11	0.59	6,000	na	+	+
6/23/2010	1	0.34	6,700	na	+	+
6/23/2010	3	0.34	82,000	na	-	-
6/23/2010	5	0.34	20,000	na	-	-
6/23/2010	6	0.34	30,000	na	+	+
6/23/2010	10	0.34	1,300	na	-	-
6/23/2010	11	0.34	19,000	na	+	+

na- not analyzed

Table 4. NPDES permitted facilities discharging to the source watershed of the TMDL.

Facility Name	Permit Number	Latitude	Longitude
Individual Permit			
MDOT Statewide - MS4	MI0057364	various	various
Beaver Creek Dairy-CAFO	MI0058138	43.099200	-85.982500
General Concentrated Animal Feeding Operation (CAFO) - MIG010000			
River Ridge Farms-CAFO	MIG010127	43.045833	-85.958333
General Industrial Stormwater - MIS11000			
Ottawa County Farms Landfill	MIS111226	43.045833	-85.950000
Heath Outdoor Products	MIS110206	43.060833	-85.932777

Table 5 The land area (in acres) of each civil division that falls within the TMDL source area, and the percent of TMDL source area for which each division is responsible.

Minor Civil Division	Area (acres)	Percent of TMDL area
Chester Twp	1387	6.3%
Polkton Twp	8819	40.3%
Wright Twp	6470	29.6%
Coopersville	2841	13.0%
Tallmadge Twp	1857	8.5%
Ravenna Twp	499	2.3%
County		
Ottawa	21374	97.7%
Muskegon	499	2.3%

Table 6. List of locations and descriptions of AFOs and active pasture in the source area as determined by remote sensing and visual observations (ground truthing). The size of the operation (small = 1 to 12, medium = 13 to 50, and large = 50+ animals) is intended to be only an estimate and is based solely on visual observations of animals and the size of pasture areas.

ID	Latitude	Longitude	Livestock Type	Operation Size	Type of Operation	Within 1000-ft Riparian Buffer?	Catchment ID	Grouping
1	43.1188	-85.8901	cattle	small	pasture	yes	1	A
2	43.1204	-85.8884	cattle	small	pasture	yes	1	A
3	43.1212	-85.8884	cattle	small	pasture	yes	1	A
4	43.1112	-85.9073	horse	small	pasture		2	A
5	43.1139	-85.9073	cattle	medium	pasture	yes	2	A
6	43.1328	-85.9076	horse	small	pasture		2	A
7	43.1157	-85.9394	cattle	small	pasture	yes	3	B
8	43.1028	-85.9573	horse	small			3	B
9	43.1187	-85.9389	cattle	unknown	pasture	yes	3	B
10	43.1171	-85.9274	horse	small	pasture	yes	3	B
11	43.1009	-85.9472	cattle	large	feedlot	yes	3	B
12	43.1084	-85.9473	cattle	large	feedlot	yes	3	B
13	43.1146	-85.9274	cattle	large	feedlot		3	B
14	43.1003	-85.9069	horse	medium	pasture	yes	4	A
15	43.1003	-85.9072	cattle	large	feedlot	yes	4	A
16	43.1042	-85.9220	horse	small	pasture	yes	5	B
17	43.1109	-85.9274	cattle	large	feedlot		5	B
18	43.0901	-85.9071	cattle	medium	feedlot	yes	7	A
19	43.0885	-85.9071	cattle	small	pasture		7	A
20	43.0894	-85.9462	cattle	small	pasture	yes	8	B
21	43.0987	-85.9274	cattle	large	feedlot	yes	8	B
22	43.0746	-85.9344	horse	small	pasture	yes	10	C
23	43.0772	-85.9272	horse	small	pasture	yes	10	C
24	43.0807	-85.9272	cattle	large	feedlot		10	C
25	43.0981	-85.9572	horse	medium	pasture	yes	12	B
26	43.1040	-85.9753	cattle	small	pasture		12	B
27	43.0952	-85.9677	cattle	large	feedlot	yes	12	B
28	43.0969	-85.9667	unknown	unknown	pasture	yes	12	B
29	43.0795	-85.9470	cattle	unknown	pasture	yes	13	E
30	43.0796	-85.9470	horse	small	pasture	yes	13	E
31	43.0746	-85.9490	cattle	large	feedlot	yes	13	E
32	43.0599	-85.8830	horse	small	pasture	yes	14	J
33	43.0601	-85.8690	cattle	small	pasture		14	J
34	43.0569	-85.8873	cattle	small	pasture		14	J
35	43.0569	-85.8866	cattle	medium	pasture	yes	14	J
36	43.0601	-85.9100	cattle	small	pasture	yes	16	D
37	43.0642	-85.9071	cattle	medium	pasture		16	D
38	43.0602	-85.9087	cattle	small	pasture	yes	16	D
39	43.0453	-85.9316	cattle	small	feedlot	yes	17	F
40	43.0511	-85.9569	cattle	large	feedlot		17	F
41	43.0450	-85.8547	unknown	small	pasture		18	J

Table 6 (continued).

ID	Latitude	Longitude	Livestock Type	Operation Size	Type of Operation	Within 1000-ft Riparian Buffer?	Catchment ID	Grouping
42	43.0353	-85.8674	cattle	small	pasture	yes	18	J
43	43.0443	-85.9068	cattle	large	pasture	yes	20	H
44	43.0454	-85.8927	cattle	medium	pasture		20	H
45	43.0455	-85.9167	cattle	large	feedlot	yes	20	H
46	43.0453	-85.9284	horse	small	pasture	yes	21	G
47	43.0377	-85.9367	cattle	large	feedlot	yes	22	F
48	43.0278	-85.9365	cattle	large	feedlot		22	F
49	43.0320	-85.9366	cattle	large	feedlot	yes	22	F
50	43.0367	-85.9068	cattle	small	pasture		23	I
51	43.0335	-85.9172	goat	small	pasture	yes	23	I
52	43.0272	-85.9270	horse	unknown	pasture	yes	23	I
53	43.0283	-85.8881	horse	small	pasture		25	J
54	43.0286	-85.9066	horse	small	pasture	yes	25	J
55	43.0309	-85.8967	horse	unknown	pasture	yes	25	J
56	43.0309	-85.9040	horse	small	pasture		25	J
57	43.0262	-85.8737	horse	small	pasture		26	J
58	43.0248	-85.8701	cattle	large	pasture	yes	27	J
59	43.0308	-85.8747	unknown	small	pasture	yes	28	J
60	43.0309	-85.8731	horse	small	pasture	yes	28	J
61	43.0160	-85.9021	horse	small	pasture		29	K
62	43.0155	-85.9321	horse	small	pasture		29	K
63	43.0112	-85.9179	cattle	small	pasture		29	K
64	43.1334	-85.9033	horse	small	pasture			
65	43.1235	-85.9475	cattle	large	feedlot			
66	43.0831	-85.9664	cattle	large	feedlot			
67	43.0943	-85.9877	cattle	large	feedlot			
68	43.0981	-85.9867	cattle	large	feedlot			

Table 7. 2006-Era Land Cover (NOAA, 2008), soil characteristics (USDA-NRCS, 2011), and population and housing data from the 2010 U.S. Census (U.S. Census Bureau, 2010a and 2010b) at the grouping level.

Grouping	Total Area (acres)	River Length (kilometers)	Number of Animal Feeding Operations in 1000 ft buffer	Number of Large Animal Feeding Operations	Cultivated Land and Hay/Pasture with poor drainage	Soils with Very Limited OSDS Percolation	Human Population (2010)	Occupied Housing Units (2010)	Road Density (meters per acre)	Agricultural land (gridcodes 6 and 7)	Developed Land (gridcodes 2-5)	Natural areas (gridcodes 8-11)	Wetland (gridcodes 12-18)	Vegetated Buffer Index (percent of river miles with adjacent natural land cover)
A	4286	20.5	7	1	38%	56%	387	149	7	88%	3%	3%	4%	31%
B	4229	17.5	9	5	45%	63%	357	131	6	82%	3%	8%	7%	37%
C	1992	9.7	2	1	44%	61%	967	341	7	82%	17%	4%	4%	33%
D	1184	4.9	2	0	25%	33%	158	59	11	81%	5%	3%	5%	35%
E	1588	6.2	3	1	24%	60%	3000	1250	20	44%	79%	6%	5%	60%
F	1683	7.7	3	3	15%	24%	427	196	10	74%	12%	2%	2%	31%
G	175	1.6	1	0	17%	23%	13	4	6	86%	2%	3%	6%	38%
H	667	2.7	2	2	10%	15%	48	18	5	87%	3%	1%	6%	54%
I	948	6.1	2	0	7%	22%	82	30	4	76%	3%	9%	12%	70%
J	4310	21.8	8	1	19%	30%	683	241	7	86%	6%	4%	5%	41%
K	812	3.5	0	0	31%	67%	239	85	8	60%	10%	11%	24%	84%

Table 8. 2006-Era Land Cover (NOAA, 2008) soil characteristics (USDA-NRCS, 2011), population, housing, and pet information derived from the 2010 U.S. Census (U.S. Census Bureau, 2010a and 2010b) for each catchment (1 through 29), as the number of acres, percent of each catchment, and stressor score.

Catchment ID	Grouping	Total Area	Unsewered Developed Land			Sewered Developed Land			Road Density		Number of Large Animal Feeding Operations		Number of Animal Feeding Operations within 1000 ft riparian buffer		Soils with Very Limited OSDS Percolation			Cultivated Land and Hay/Pasture with poor drainage (artificial draining recommended)		
		Acres	Acres	Percent	Stressor Score	Acres	Percent	Stressor Score	Meters of Road per Acre	Stressor Score	Number	Stressor Score	Number	Stressor Score	Acres	Percent	Stressor Score	Acres	Percent	Stressor Score
1	A	1497	75	5.0%	3	11	0.7%	4	8.1	3	0	1	3	4	764	51%	3	607	41%	3
2	A	459	26	5.7%	4	0	0.0%	1	8.1	3	0	1	1	2	248	54%	3	203	44%	4
3	B	1453	52	3.6%	2	0	0.0%	1	5.3	2	3	4	5	4	758	52%	3	525	36%	3
4	A	572	16	2.8%	2	0	0.0%	1	6.7	2	1	3	2	3	302	53%	3	210	37%	3
5	B	899	29	3.2%	2	0	0.0%	1	5.1	2	1	3	1	2	418	46%	2	329	37%	3
6	A	388	15	3.9%	3	0	0.0%	1	7.3	3	0	1	0	1	286	74%	4	176	46%	4
7	A	1371	38	2.8%	1	0	0.0%	1	4.1	1	0	1	1	2	786	57%	3	446	32%	3
8	B	348	15	4.2%	3	0	0.0%	1	7.8	3	1	3	2	3	207	59%	3	133	38%	3
9	B	400	15	3.8%	3	0	0.0%	1	6.8	2	0	1	0	1	291	73%	4	164	41%	4
10	C	1992	56	2.8%	1	170	8.5%	4	7.1	3	1	3	2	3	1223	61%	4	873	44%	4
11	B	148	5	3.3%	2	0	0.0%	1	5.3	2	0	1	0	1	128	86%	4	73	49%	4
12	B	980	25	2.5%	1	0	0.0%	1	4.9	1	0	1	1	2	860	88%	4	659	67%	4
13	E	535	32	6.1%	4	40	7.5%	4	10.1	4	1	3	3	4	398	74%	4	272	51%	4
14	J	1379	76	5.5%	3	0	0.0%	1	8.5	4	0	1	2	3	377	27%	1	288	21%	2
15	E	822	1	0.1%	1	531	64.6%	4	27.3	4	0	1	0	1	487	59%	3	99	12%	1
16	D	1184	108	9.1%	4	18	1.5%	4	11.4	4	0	1	2	3	388	33%	2	299	25%	2
17	F	877	134	15.3%	4	103	11.7%	4	16.2	4	0	1	1	2	233	27%	1	150	17%	2
18	J	992	70	7.1%	4	0	0.0%	1	8.0	3	0	1	1	2	375	38%	2	199	20%	2
19	E	232	31	13.5%	4	22	9.5%	4	16.9	4	0	1	0	1	61	26%	1	8	3%	1
20	H	667	29	4.3%	3	0	0.0%	1	5.0	1	2	4	2	3	98	15%	1	65	10%	1
21	G	175	6	3.6%	2	0	0.0%	1	5.8	2	0	1	1	2	40	23%	1	30	17%	2
22	F	748	22	2.9%	2	0	0.0%	1	4.4	1	3	4	2	3	146	20%	1	100	13%	1
23	I	948	21	2.2%	1	0	0.0%	1	3.6	1	0	1	2	3	211	22%	1	69	7%	1
24	F	58	0	0.0%	1	0	0.0%	1	0.0	1	0	1	0	1	24	41%	2	7	13%	1
25	J	810	22	2.7%	1	0	0.0%	1	5.9	2	0	1	2	3	223	28%	2	123	15%	1
26	J	113	3	2.9%	2	0	0.0%	1	4.2	1	0	1	0	1	37	33%	2	13	11%	1
27	J	497	6	1.3%	1	0	0.0%	1	2.8	1	1	3	1	2	163	33%	2	107	22%	2
28	J	519	49	9.5%	4	0	0.0%	1	9.0	4	0	1	2	3	130	25%	1	80	15%	2
29	K	812	40	4.9%	3	0	0.0%	1	8.0	3	0	1	0	1	545	67%	4	251	31%	3
Entire Watershed		21,873	1018	4.7%		895	4.1%		8		14		39		10208	47%		6558	30%	

Table 8. Cont.

Catchment ID	Grouping	Agricultural land (gridcodes 6 and 7)			Human Population (2010)		Human Population Density (2010)		Occupied Housing Units (2010)			Estimated number of pet Dogs	Urban Stressor Score	Rural Stressor Score	Overall Stressor Score	Stressor Score Rank
		Acres	Percent	Stressor Score	Persons	Stressor Score	Persons per acre	Stressor Score	Units	Density (units/acre)	Stressor Score	Dogs				
1	A	1344	90%	4	152	3	0.10	2	57	0.04	3	36	15	19	34	3
2	A	427	93%	4	27	1	0.06	1	10	0.02	1	6	7	17	24	13
3	B	1153	79%	2	106	3	0.07	1	40	0.03	3	25	10	17	27	11
4	A	530	93%	4	40	1	0.07	1	15	0.03	1	10	6	17	23	18
5	B	767	85%	3	76	2	0.08	1	27	0.03	2	17	8	16	24	13
6	A	356	92%	4	35	1	0.09	2	13	0.03	1	8	8	16	24	13
7	A	1121	82%	2	134	3	0.10	2	54	0.04	3	34	10	13	23	18
8	B	301	86%	3	53	2	0.15	3	19	0.05	2	12	11	19	30	5
9	B	278	70%	1	46	1	0.12	2	17	0.04	2	11	8	13	21	23
10	C	1582	79%	2	967	4	0.49	4	341	0.17	4	216	19	19	38	1
11	B	102	68%	1	29	1	0.20	3	10	0.07	1	6	8	15	23	18
12	B	860	88%	3	46	2	0.05	1	18	0.02	2	11	7	17	24	13
13	E	417	78%	2	306	4	0.57	4	111	0.21	4	70	20	18	38	1
14	J	1236	90%	4	189	4	0.14	3	66	0.05	4	42	16	13	29	7
15	E	182	22%	1	2545	4	3.10	4	1077	1.31	4	681	20	10	30	5
16	D	952	80%	2	158	3	0.13	3	59	0.05	3	37	17	11	28	9
17	F	531	61%	1	373	4	0.43	4	178	0.20	4	112	20	11	31	4
18	J	822	83%	3	201	4	0.20	4	71	0.07	4	45	16	13	29	7
19	E	89	38%	1	149	3	0.64	4	61	0.26	3	39	18	6	24	13
20	H	583	87%	3	48	2	0.07	1	18	0.03	2	12	7	14	21	23
21	G	151	86%	3	13	1	0.07	1	4	0.02	1	3	6	13	19	26
22	F	679	91%	4	48	2	0.06	1	16	0.02	1	10	6	15	21	23
23	I	719	76%	2	82	3	0.09	2	30	0.03	3	19	10	9	19	26
24	F	41	70%	1	5	1	0.09	2	2	0.03	1	1	6	10	16	28
25	J	655	81%	2	153	3	0.19	3	56	0.07	3	36	12	13	25	12
26	J	83	73%	1	14	1	0.13	3	5	0.05	1	3	7	6	13	29
27	J	465	94%	4	62	2	0.13	3	21	0.04	2	13	9	13	22	21
28	J	456	88%	3	62	2	0.12	2	22	0.04	2	14	11	11	22	21
29	K	483	60%	1	239	4	0.29	4	85	0.10	4	54	16	12	28	9
Entire Watershed		17362	79%		6359		0.28		2505	0.11		1584				

Table 9. 2006-Era Land Cover (NOAA, 2008), wetlands lost since presettlement, and the calculated VBI (percent of river miles adjacent to natural/wetland land cover), for each catchment.

Catchment ID	Grouping	Total Area	Agriculture (gridcodes 6 and 7)		Developed Land (gridcodes 2-5)		Natural areas (gridcodes 8-11)		Wetland (gridcodes 12-18)		Wetland Lost since Pre-Settlement		Vegetated Buffer Index (percent of river miles with adjacent natural land cover)
		Acres	Acres	Percent	Acres	Percent	Acres	Percent	Acres	Percent	Acres	Percent of Original Wetland Area Lost	Percent
1	A	1497	1344	90%	86	6%	37	2%	30	2%	132	74%	11%
2	A	459	427	93%	26	6%	0	0%	6	1%	40	68%	0%
3	B	1453	1153	79%	52	4%	146	10%	103	7%	196	63%	37%
4	A	572	530	93%	16	3%	10	2%	15	3%	16	23%	36%
5	B	899	767	85%	29	3%	68	8%	34	4%	53	47%	25%
6	A	388	356	92%	15	4%	8	2%	9	2%	10	28%	21%
7	A	1371	1121	82%	38	3%	85	6%	115	8%	72	31%	59%
8	B	348	301	86%	15	4%	18	5%	15	4%	21	49%	26%
9	B	400	278	70%	15	4%	54	13%	53	13%	23	30%	98%
10	C	1992	1582	79%	226	11%	70	4%	84	4%	134	53%	33%
11	B	148	102	68%	5	3%	30	20%	12	8%	5	30%	91%
12	B	980	860	88%	25	3%	33	3%	63	6%	108	60%	30%
13	E	535	417	78%	72	14%	27	5%	17	3%	29	58%	47%
14	J	1379	1236	90%	76	5%	40	3%	21	2%	78	53%	14%
15	E	822	182	22%	532	65%	57	7%	38	5%	99	64%	64%
16	D	1184	952	80%	126	11%	35	3%	64	5%	40	27%	35%
17	F	877	531	61%	237	27%	4	0%	5	1%	67	69%	15%
18	J	992	822	83%	70	7%	44	4%	54	5%	26	34%	42%
19	E	232	89	38%	53	23%	18	8%	29	12%	3	16%	86%
20	H	667	583	87%	29	4%	8	1%	38	6%	15	23%	54%
21	G	175	151	86%	6	4%	6	3%	11	6%	7	30%	38%
22	F	748	679	91%	22	3%	32	4%	15	2%	32	52%	35%
23	I	948	719	76%	21	2%	89	9%	116	12%	19	13%	70%
24	F	58	41	70%	0	0%	1	2%	16	27%	1	7%	86%
25	J	810	655	81%	22	3%	52	6%	81	10%	38	30%	71%
26	J	113	83	73%	0	0%	14	12%	16	15%	8	40%	71%
27	J	497	465	94%	3	1%	13	3%	16	3%	9	25%	29%
28	J	519	456	88%	16	3%	24	5%	22	4%	12	32%	37%
29	K	812	483	60%	40	5%	88	11%	198	24%	35	14%	84%
Entire Watershed		21,873	17362	79%	1873	9%	1111	5%	1296	6%	1328	43%	41%

Figure 1. Daily geometric means for sampling sites on Beaver Creek (sites 1, 2, and 3) and precipitation (in inches) for the 24-hour period prior to sampling.

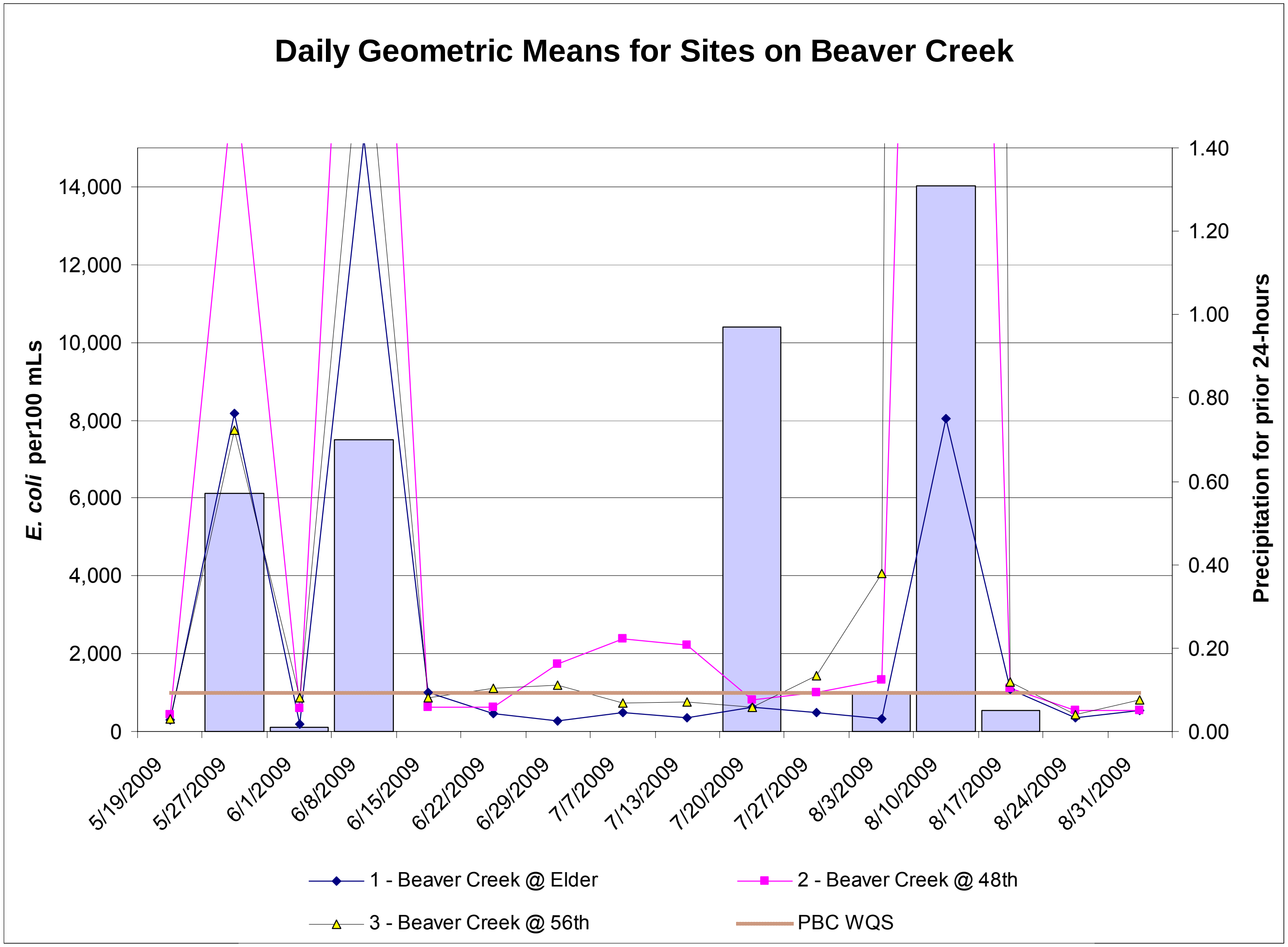

Figure 2. Daily geometric means for sampling sites on Deer Creek (sites 5, 7, 8, 9, 12, and 13) and precipitation (in inches) for the 24-hour period prior to sampling

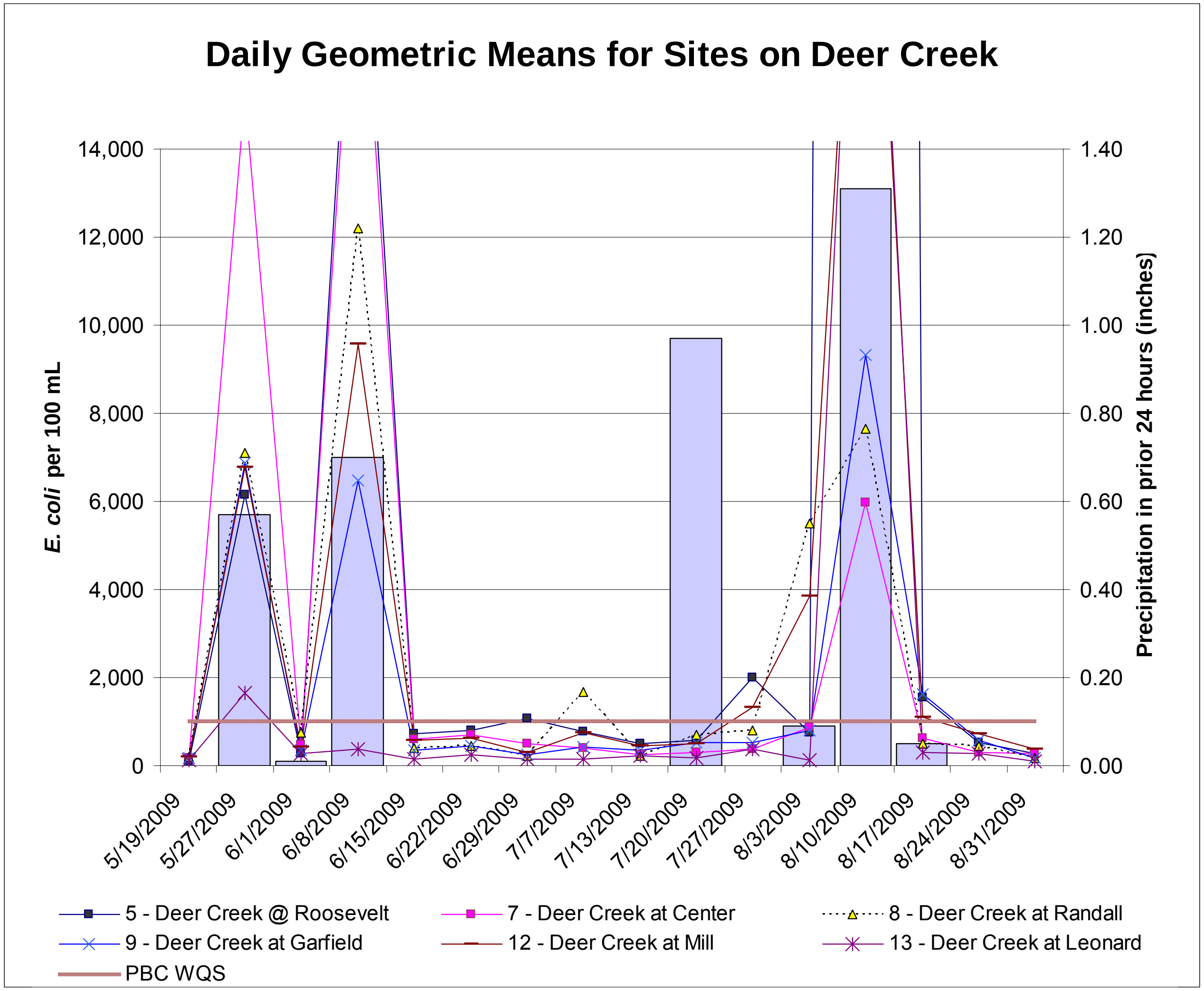

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Figure 3. Daily geometric means for sampling sites on Little Deer Creek (sites 10 and 11), and precipitation (in inches) for the 24-hour period prior to sampling.

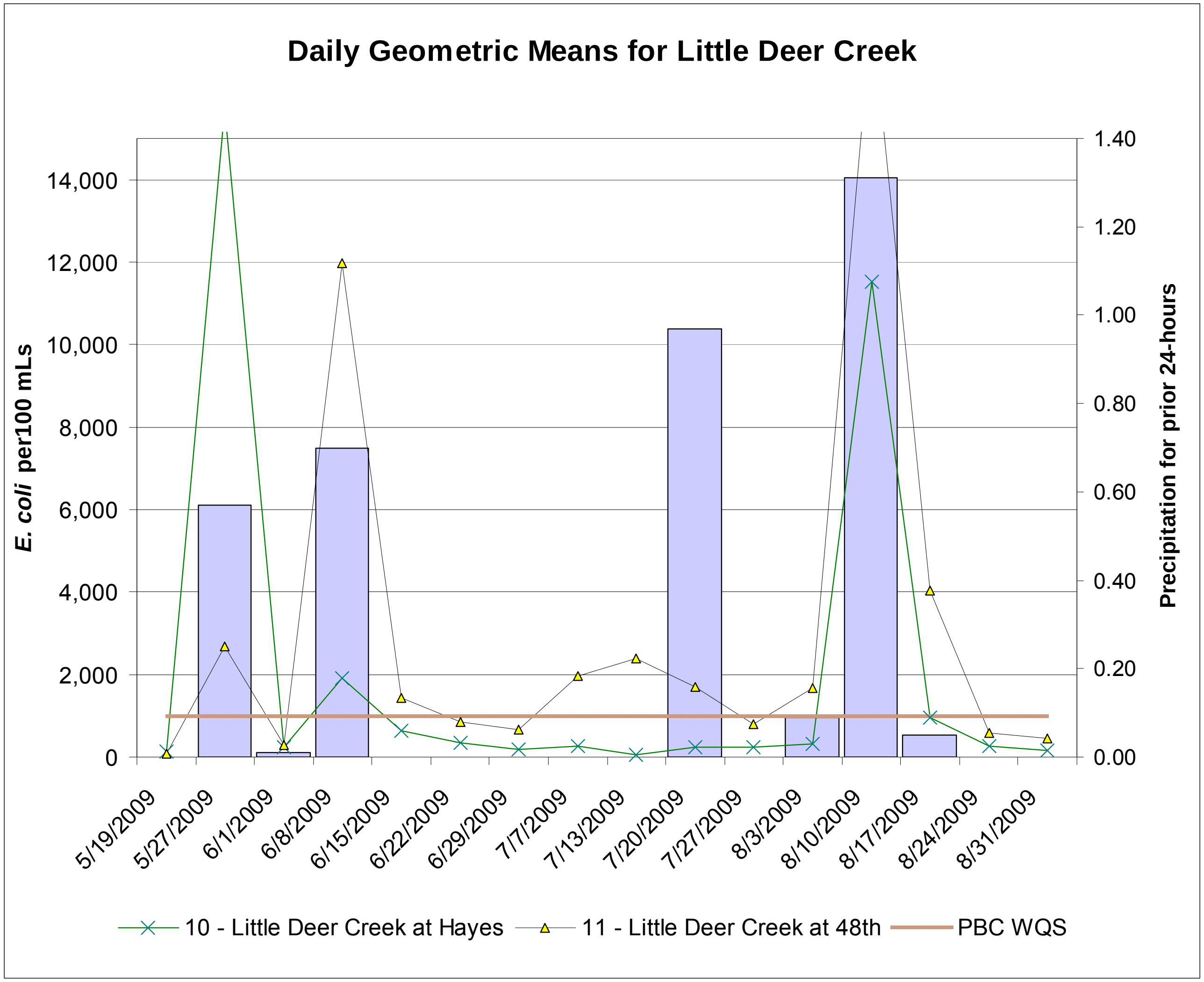


Figure 4. Daily geometric means for sampling sites on tributaries to Deer Creek (sites 4 and 6), and precipitation (in inches) for the 24-hour period prior to sampling.

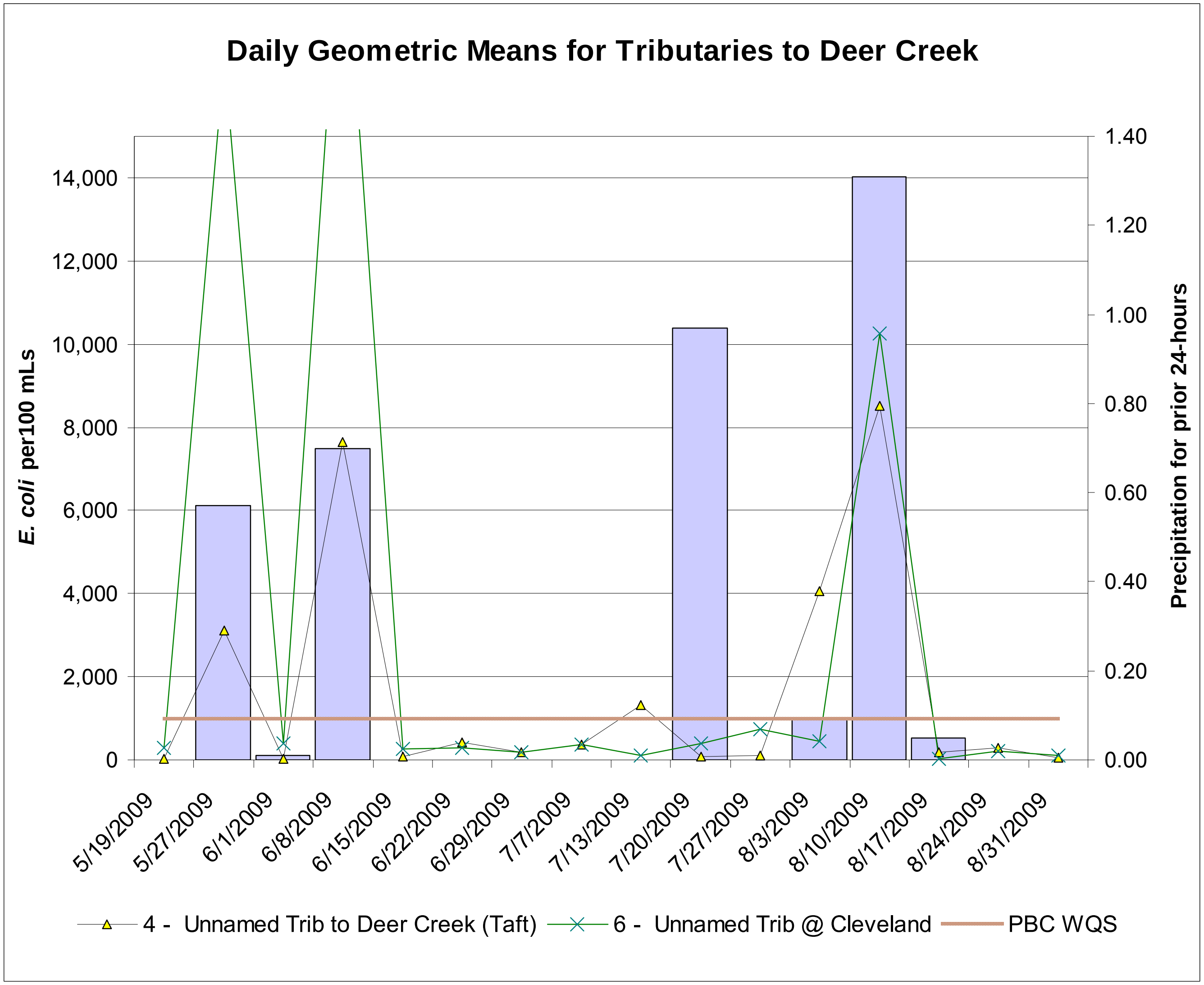


Figure 5. Thirty-day geometric means for sampling sites on Beaver Creek (sites 1, 2, and 3).

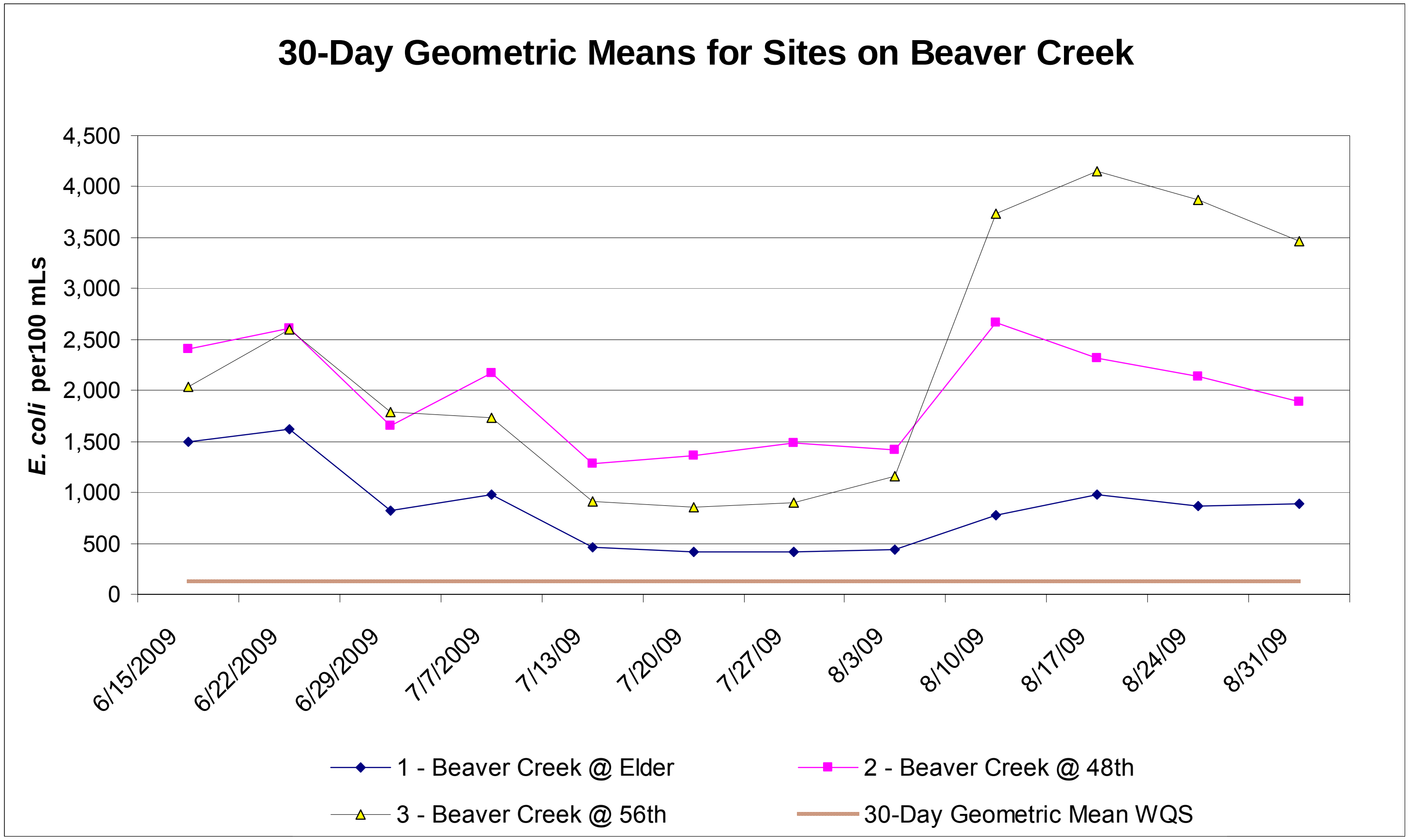


Figure 6. Thirty-day geometric means for sampling sites on Deer Creek (sites 5, 7, 8, 9, 12, and 13).

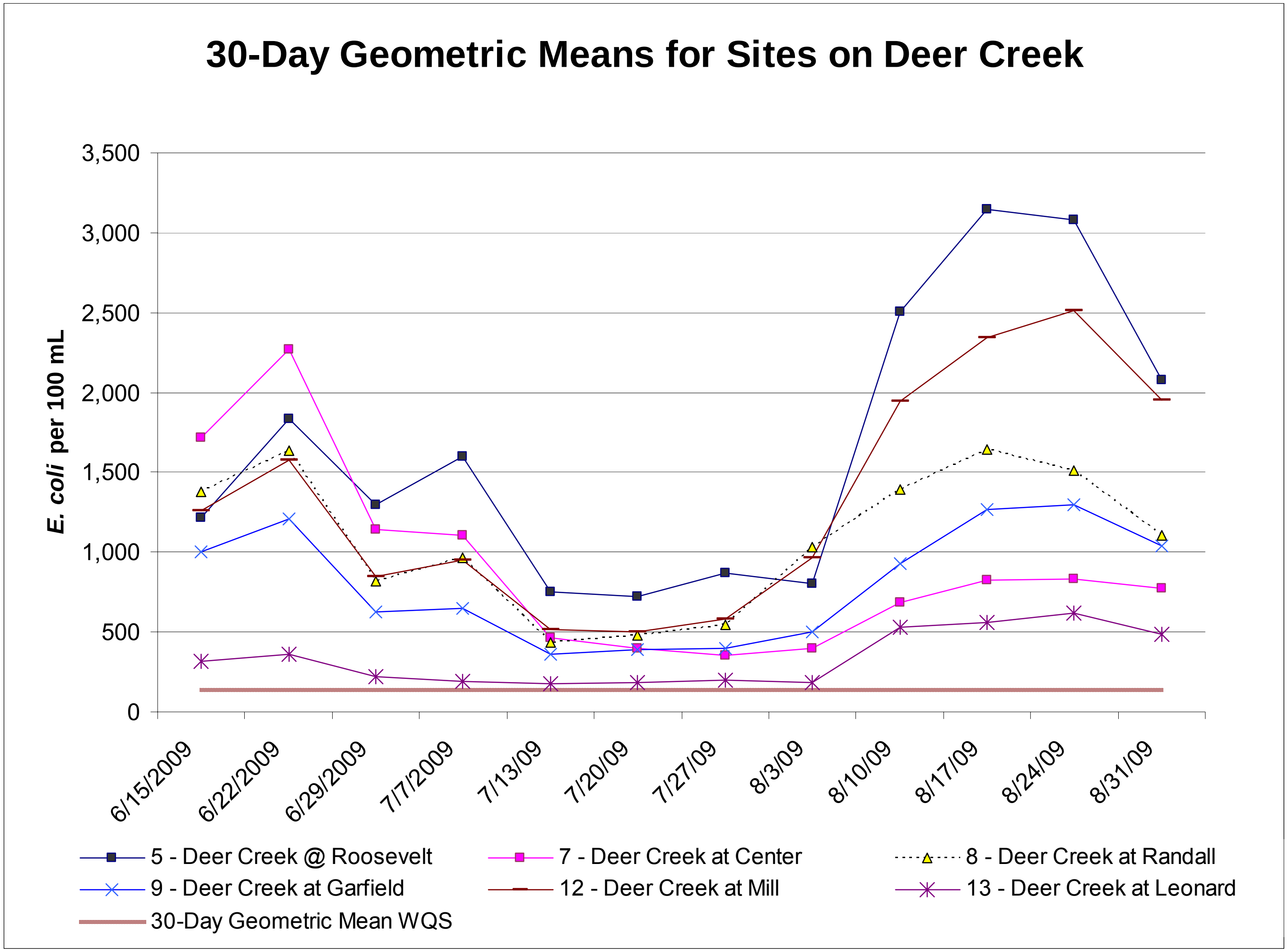


Figure 7. Thirty-day geometric means for sampling sites on Little Deer Creek (sites 10 and 11).

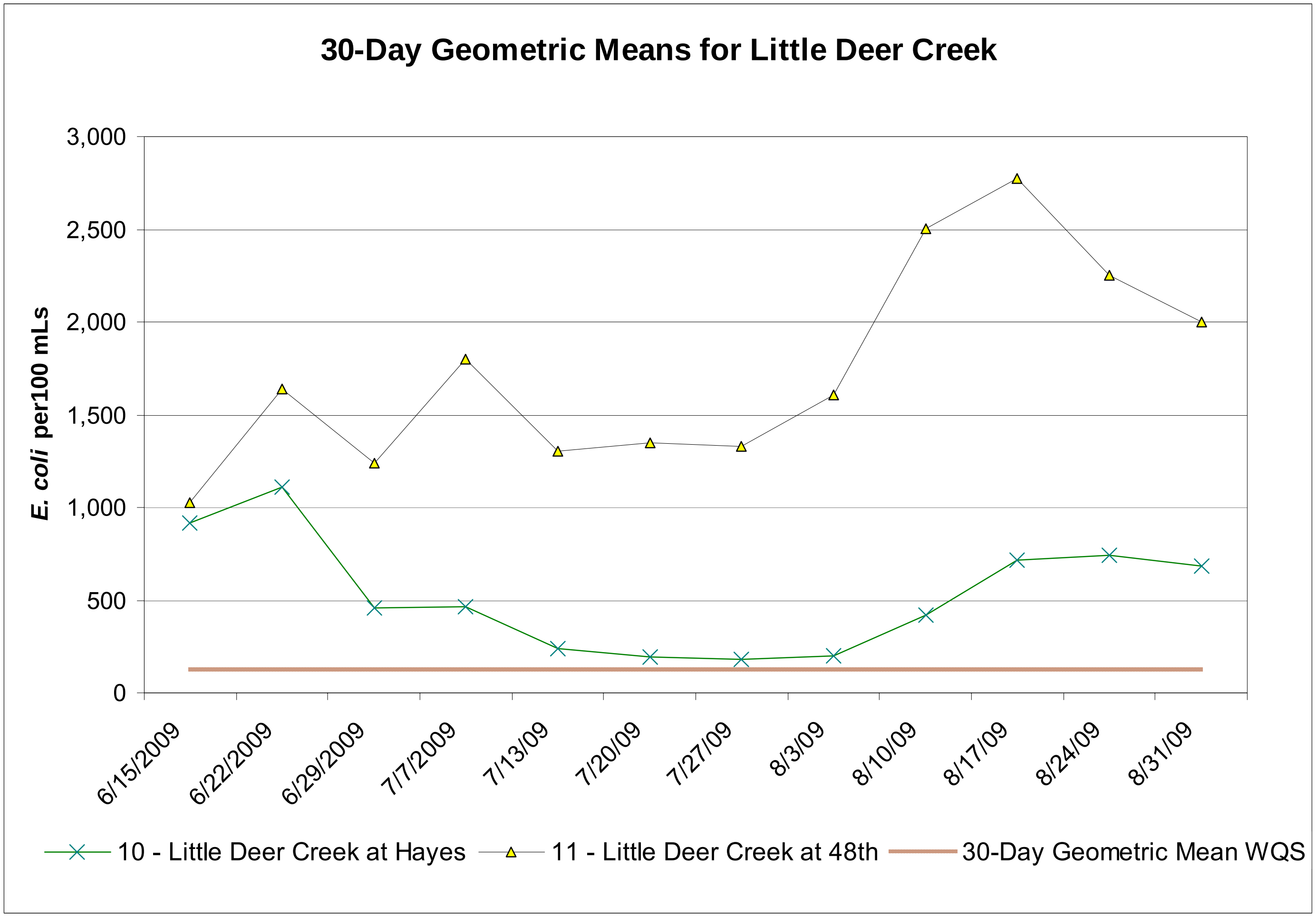


Figure 8. Thirty-day geometric means for sampling sites on tributaries to Deer Creek (sites 4 and 6).

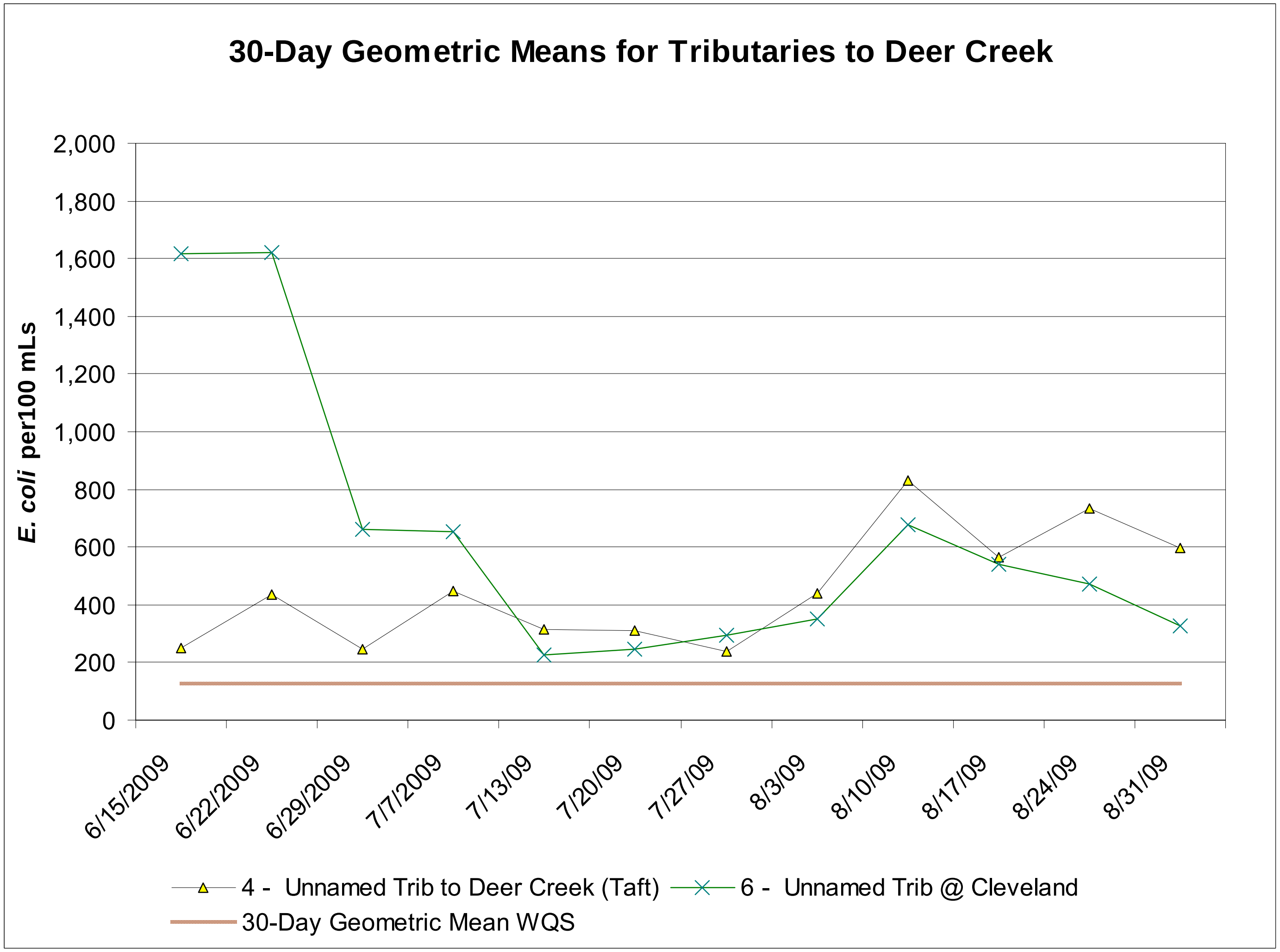
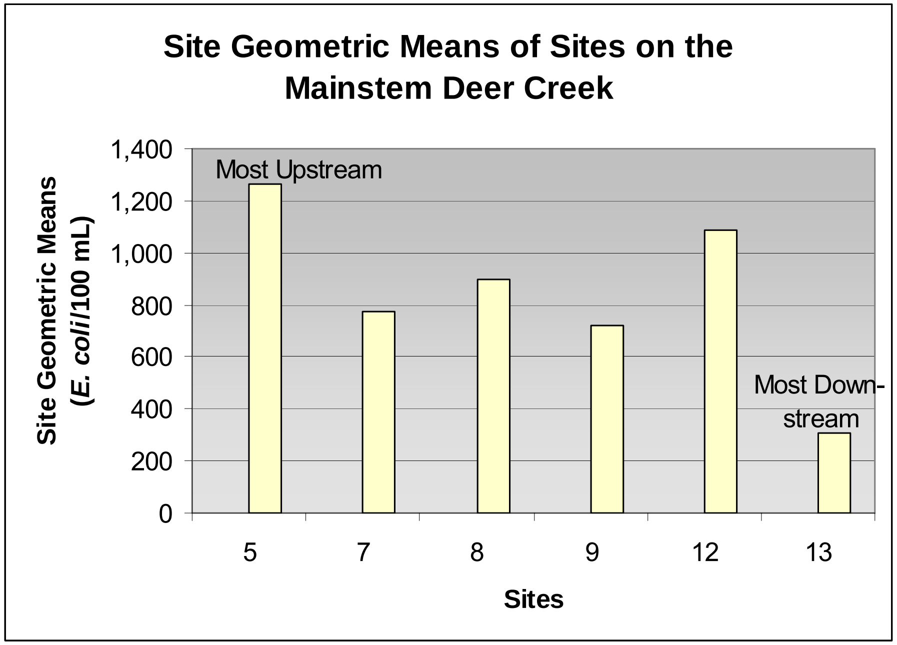
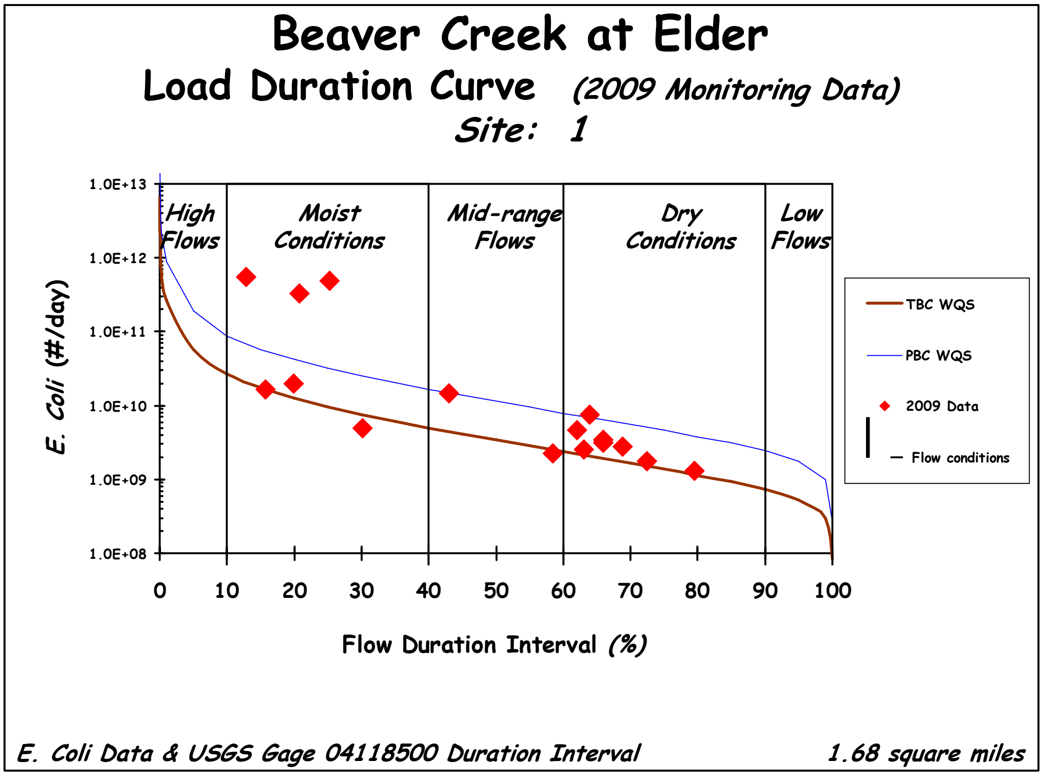
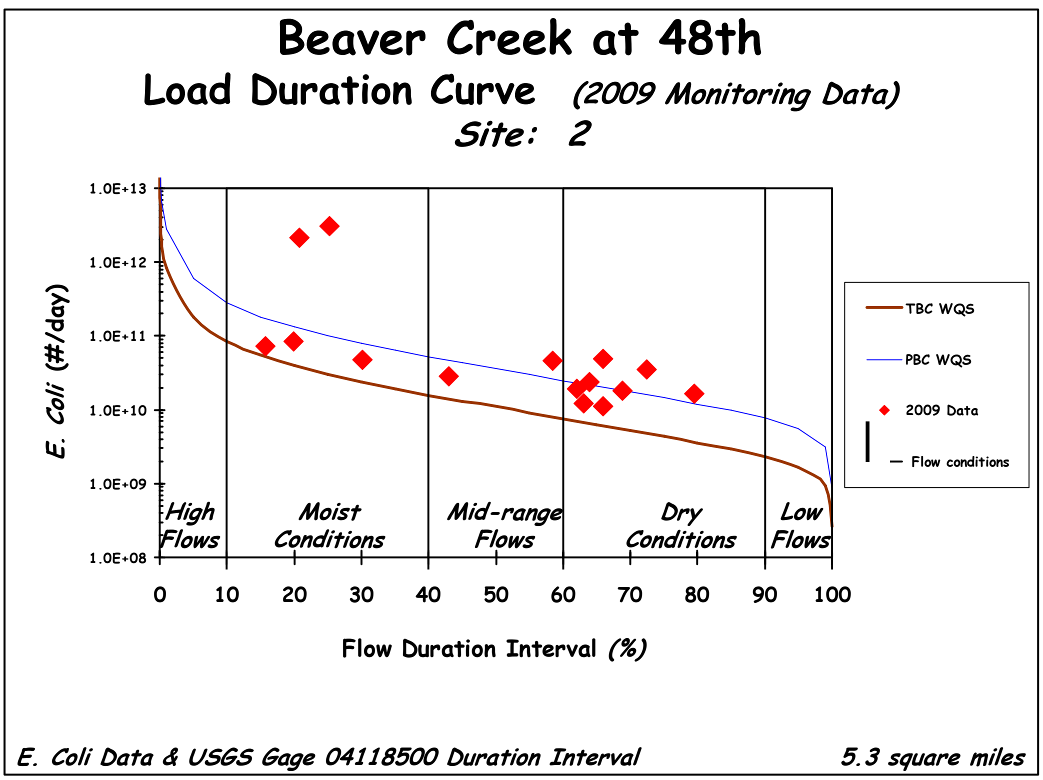


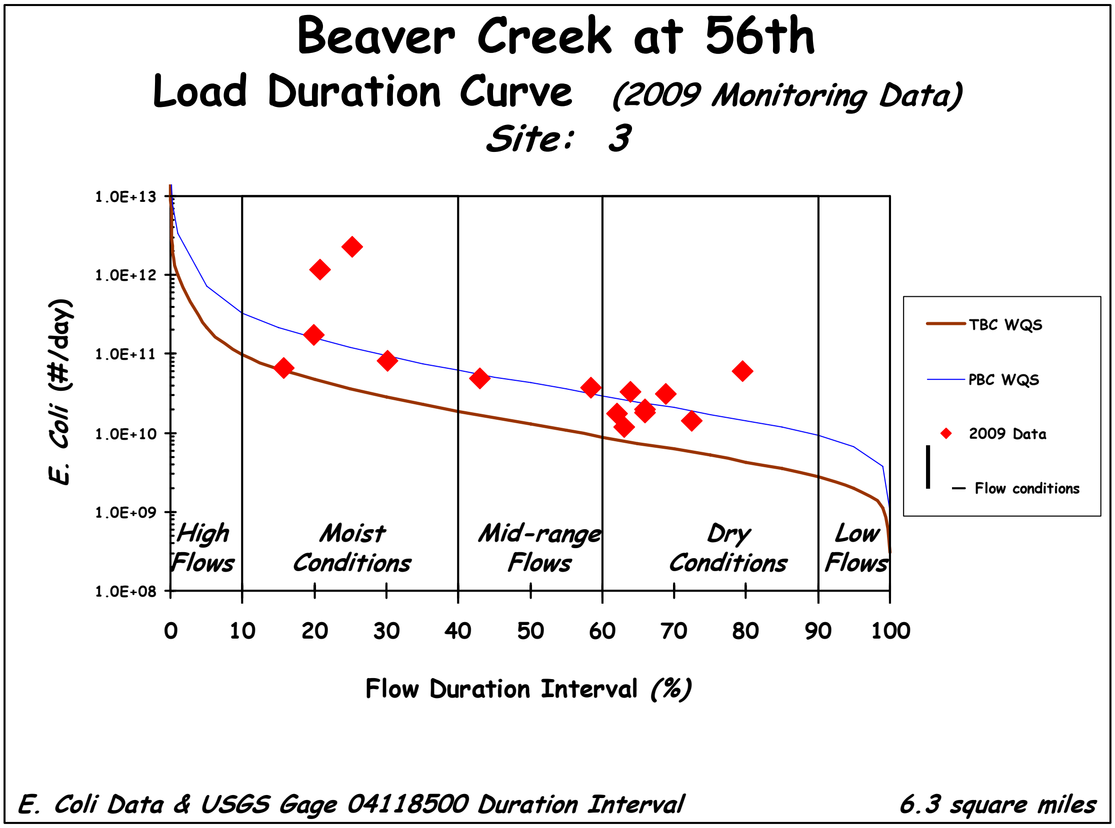
Figure 9. Site geometric means for all sites on the mainstem of Deer Creek (5, 7, 8, 9, 12, and 13) shown in downstream order. Site geometric means are the geometric means of all data for each site and cannot be compared to the WQS.

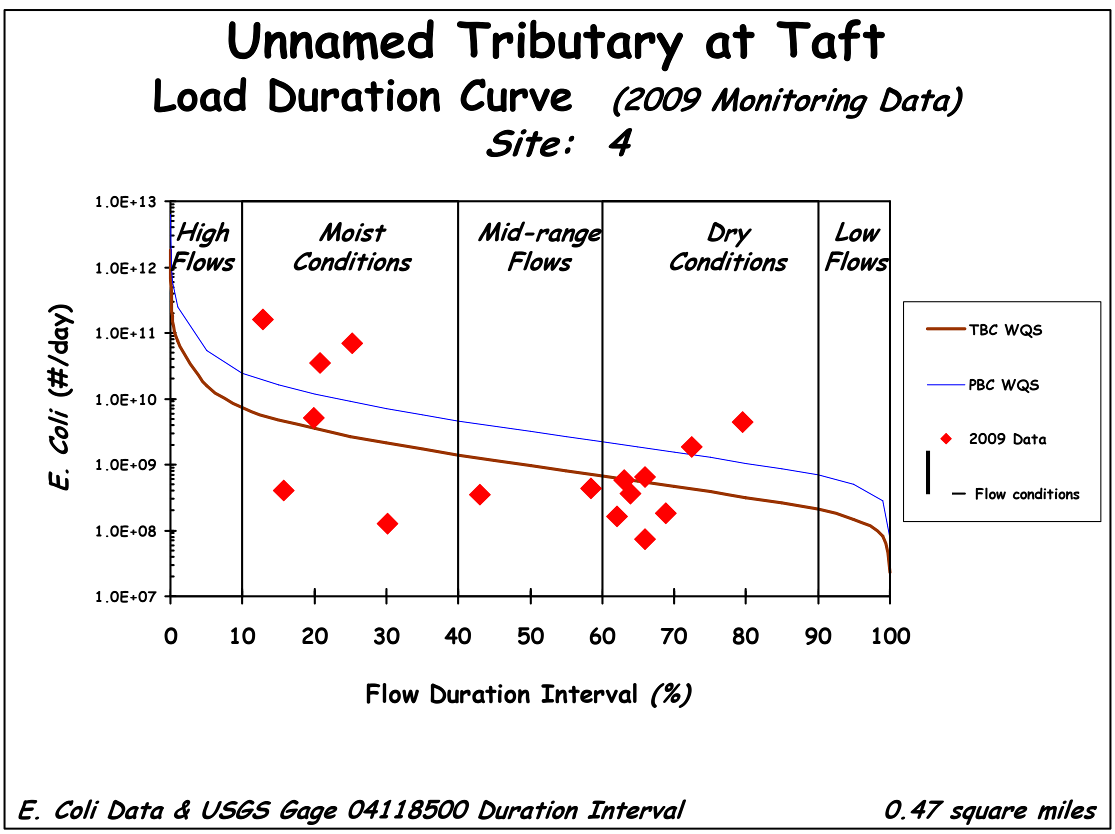


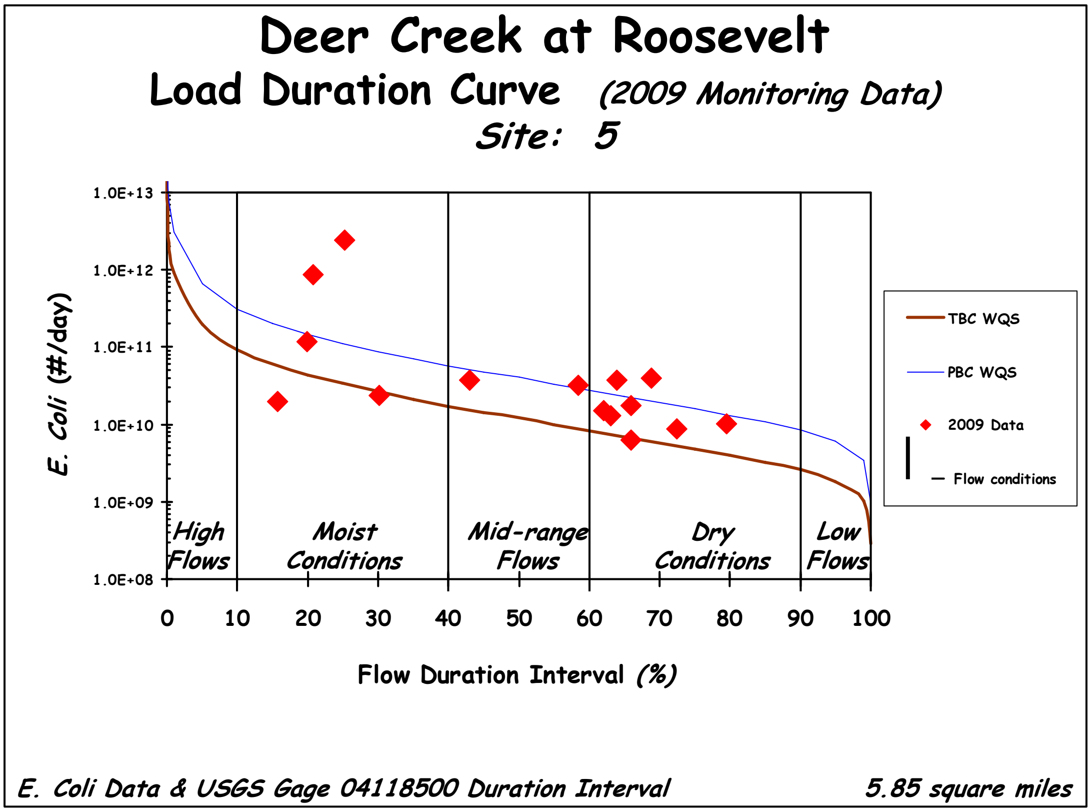
Appendix 1. Load Duration Curves for 2009 monitoring data at sites 1-13. Flows were calculated from USGS gage No. 04118500 (located on the Lower Grand River, near Rockford, Michigan). Flows associated with exceedances of the daily maximum TBC and PBC WQS are indicated where 2010 data points are above the red and blue curved lines, which represent the WQS.



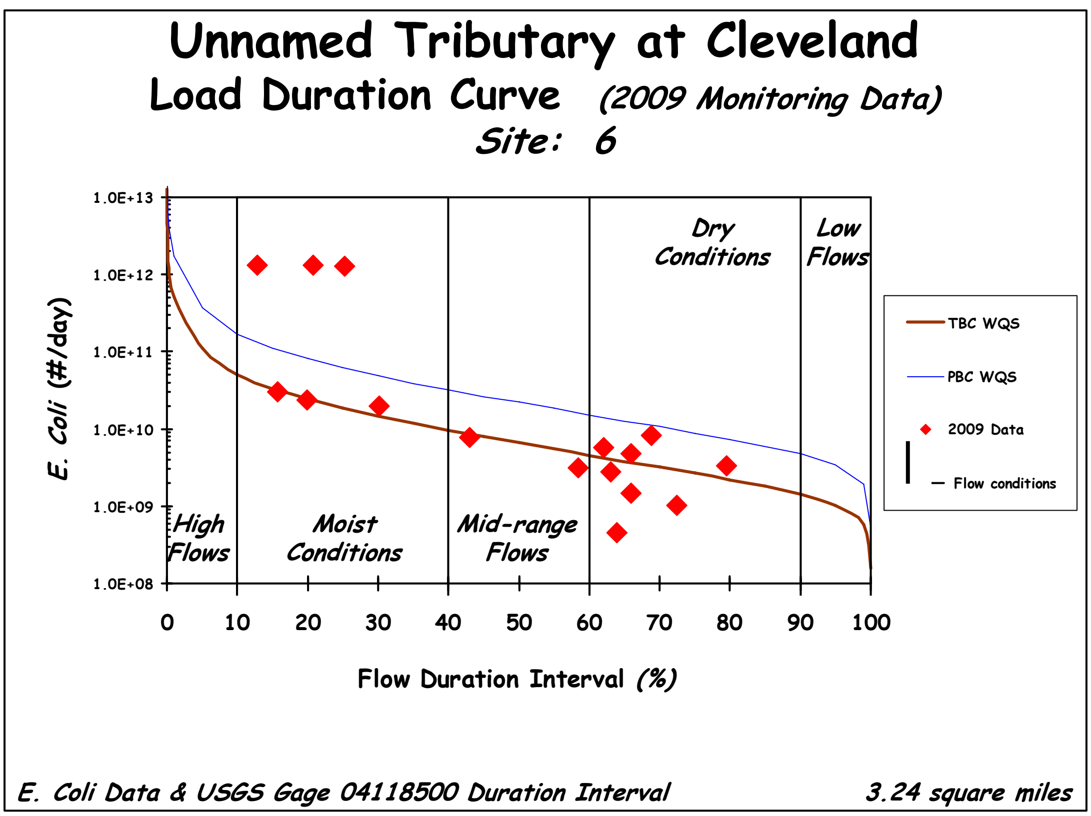



Beaver Creek at 56th
Load Duration Curve (2009 Monitoring Data)
Site: 3
1.0E+13
1.0E+12
1.0E+11
1.0E+10
1.0E+09
1.0E+08
E. Coli (#/day)
High Flows
Moist Conditions
Mid-range Flows
Dry Conditions
Low Flows
0
10
20
30
40
50
60
70
80
90
100
Flow Duration Interval (%)
TBC WQS
PBC WQS
2009 Data
Flow conditions
E. Coli Data & USGS Gage 04118500 Duration Interval
6.3 square miles

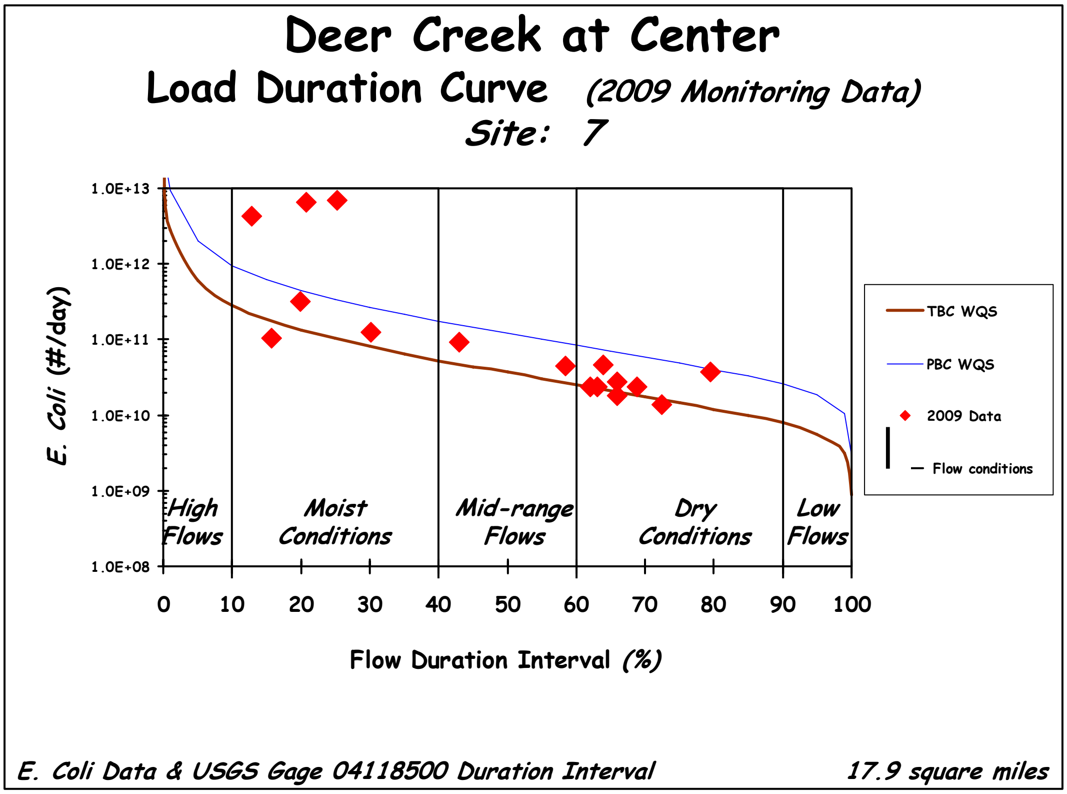

Unnamed Tributary at Taft
Load Duration Curve (2009 Monitoring Data)
Site: 4
1.0E+13
1.0E+12
1.0E+11
1.0E+10
1.0E+09
1.0E+08
1.0E+07
E. Coli (#/day)
High Flows
Moist Conditions
Mid-range Flows
Dry Conditions
Low Flows
0
10
20
30
40
50
60
70
80
90
100
Flow Duration Interval (%)
TBC WQS
PBC WQS
2009 Data
Flow conditions
E. Coli Data & USGS Gage 04118500 Duration Interval
0.47 square miles

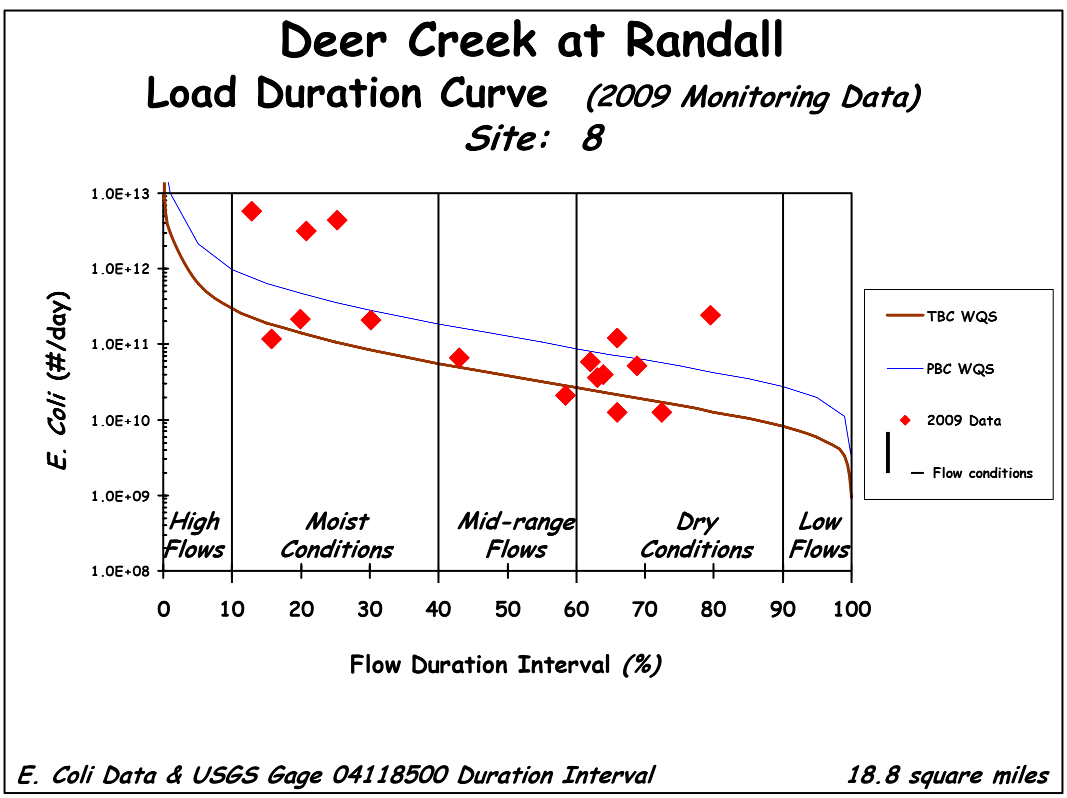


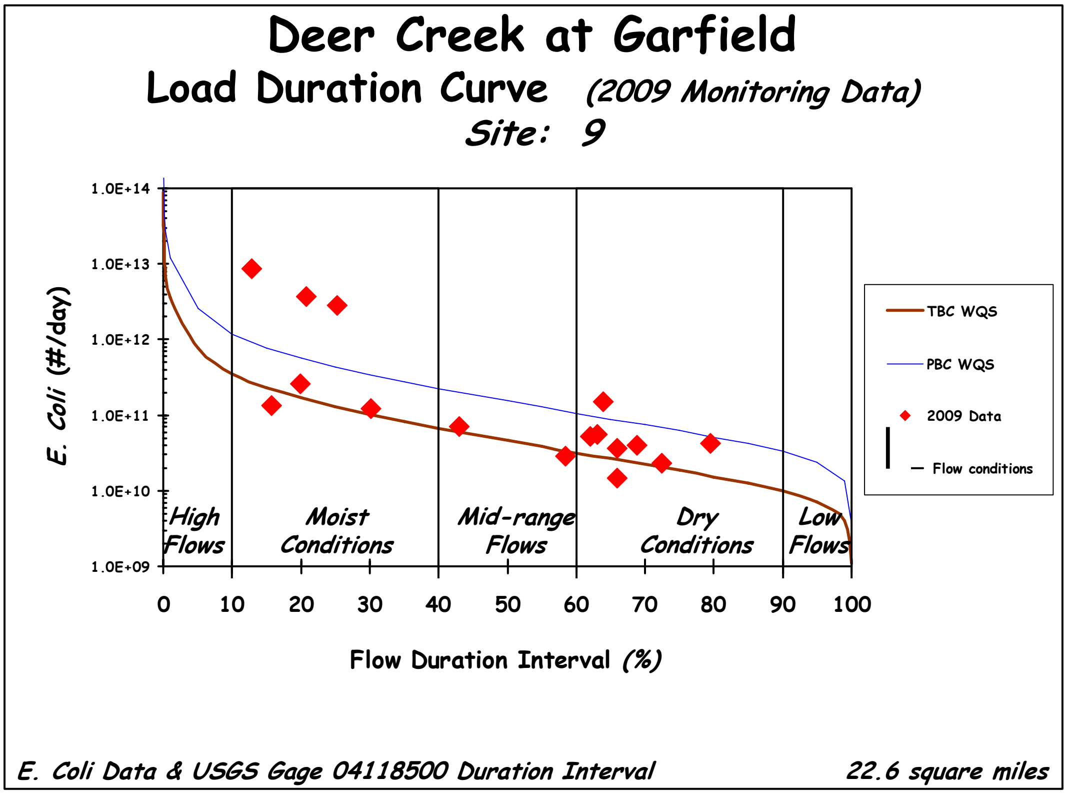
Deer Creek at Roosevelt
Load Duration Curve (2009 Monitoring Data)
Site: 5
E. Coli (#/day)
1.0E+13
1.0E+12
1.0E+11
1.0E+10
1.0E+09
1.0E+08
High Flows
Moist Conditions
Mid-range Flows
Dry Conditions
Low Flows
0 10 20 30 40 50 60 70 80 90 100
Flow Duration Interval (%)
TBC WQS
PBC WQS
2009 Data
Flow conditions
E. Coli Data & USGS Gage 04118500 Duration Interval
5.85 square miles

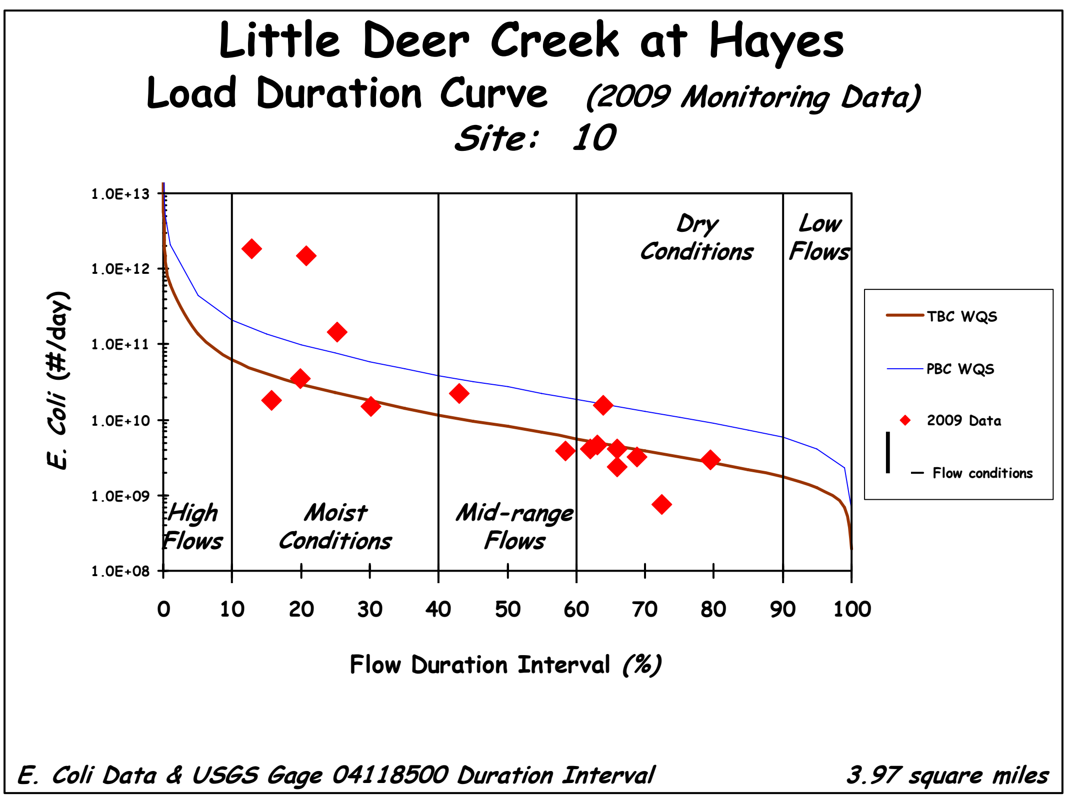


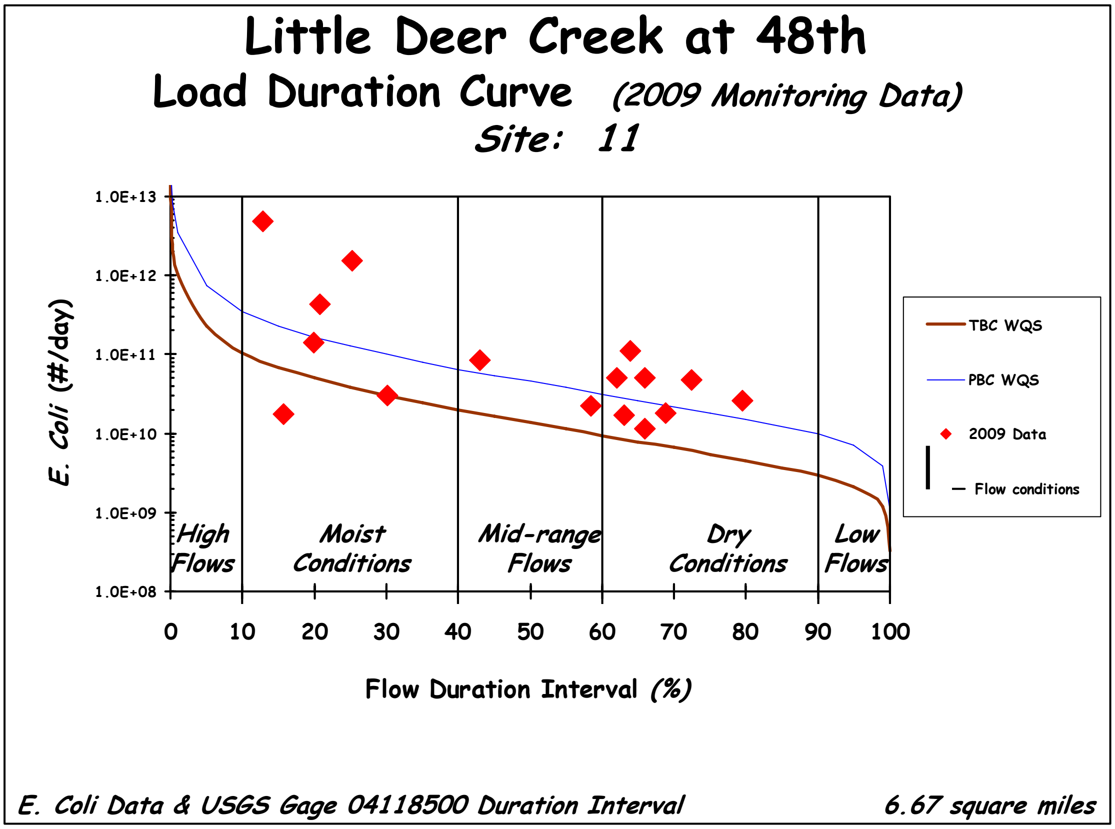
Unnamed Tributary at Cleveland
Load Duration Curve (2009 Monitoring Data)
Site: 6
E. Coli (#/day)
1.0E+13
1.0E+12
1.0E+11
1.0E+10
1.0E+09
1.0E+08
High Flows
Moist Conditions
Mid-range Flows
Dry Conditions
Low Flows
0 10 20 30 40 50 60 70 80 90 100
Flow Duration Interval (%)
TBC WQS
PBC WQS
2009 Data
Flow conditions
E. Coli Data & USGS Gage 04118500 Duration Interval
3.24 square miles

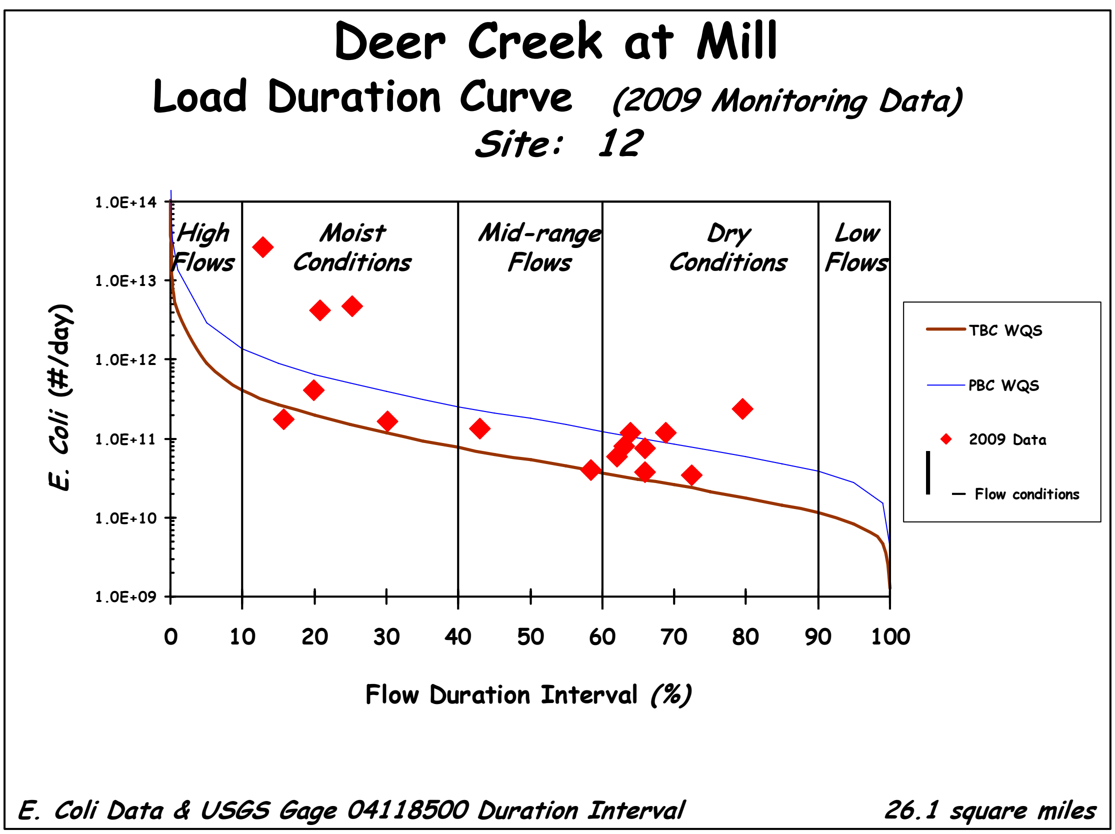

Deer Creek at Center
Load Duration Curve (2009 Monitoring Data)
Site: 7
1.0E+13
1.0E+12
1.0E+11
1.0E+10
1.0E+09
1.0E+08
E. Coli (#/day)
High Flows
Moist Conditions
Mid-range Flows
Dry Conditions
Low Flows
0
10
20
30
40
50
60
70
80
90
100
Flow Duration Interval (%)
TBC WQS
PBC WQS
2009 Data
Flow conditions
E. Coli Data & USGS Gage 04118500 Duration Interval
17.9 square miles

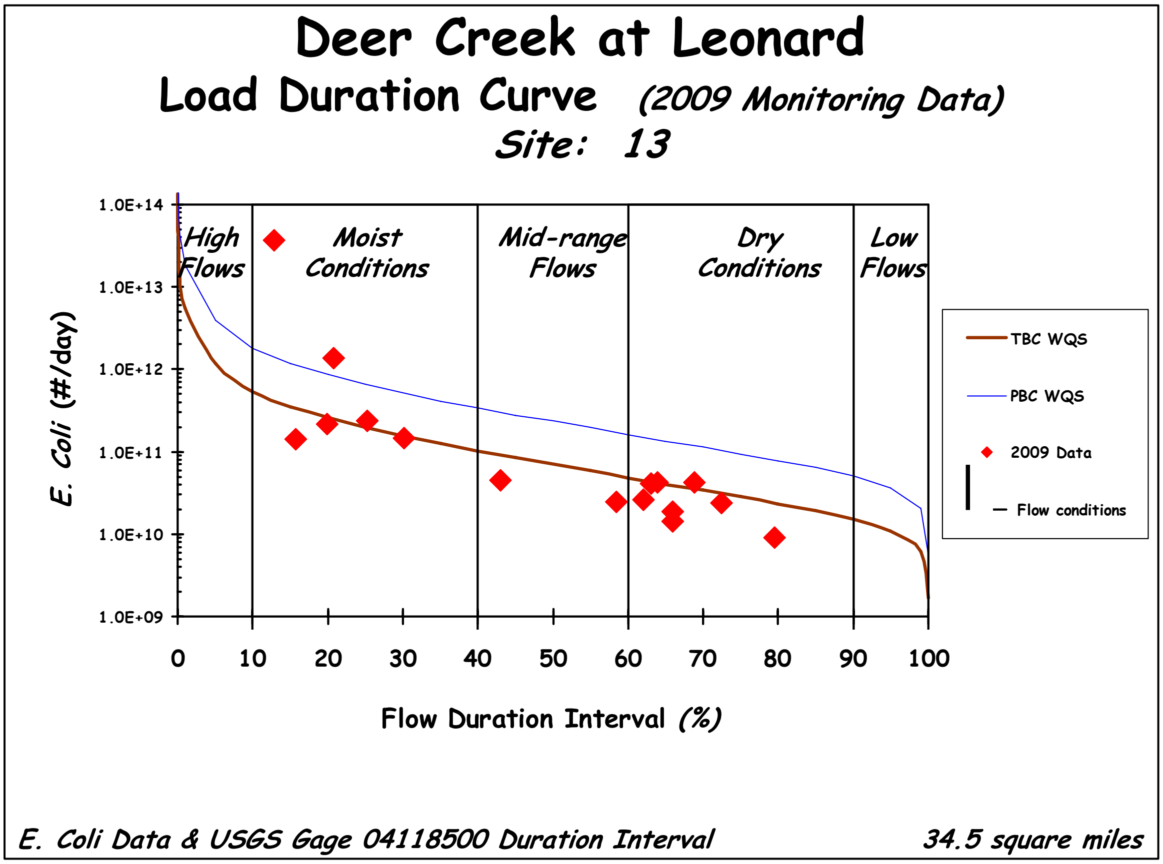

Deer Creek at Randall
Load Duration Curve (2009 Monitoring Data)
Site: 8
1.0E+13
1.0E+12
1.0E+11
1.0E+10
1.0E+09
1.0E+08
E. Coli (#/day)
High Flows
Moist Conditions
Mid-range Flows
Dry Conditions
Low Flows
0
10
20
30
40
50
60
70
80
90
100
Flow Duration Interval (%)
TBC WQS
PBC WQS
2009 Data
Flow conditions
E. Coli Data & USGS Gage 04118500 Duration Interval
18.8 square miles


Deer Creek at Garfield
Load Duration Curve (2009 Monitoring Data)
Site: 9
1.0E+14
1.0E+13
1.0E+12
1.0E+11
1.0E+10
1.0E+09
E. Coli (#/day)
High Flows
Moist Conditions
Mid-range Flows
Dry Conditions
Low Flows
0
10
20
30
40
50
60
70
80
90
100
Flow Duration Interval (%)
TBC WQS
PBC WQS
2009 Data
Flow conditions
E. Coli Data & USGS Gage 04118500 Duration Interval
22.6 square miles


Little Deer Creek at Hayes
Load Duration Curve (2009 Monitoring Data)
Site: 10
1.0E+13
1.0E+12
1.0E+11
1.0E+10
1.0E+09
1.0E+08
E. Coli (#/day)
Dry Conditions
Low Flows
High Flows
Moist Conditions
Mid-range Flows
0
10
20
30
40
50
60
70
80
90
100
Flow Duration Interval (%)
TBC WQS
PBC WQS
2009 Data
Flow conditions
E. Coli Data & USGS Gage 04118500 Duration Interval
3.97 square miles


Little Deer Creek at 48th
Load Duration Curve (2009 Monitoring Data)
Site: 11
1.0E+13
1.0E+12
1.0E+11
1.0E+10
1.0E+09
1.0E+08
E. Coli (#/day)
High Flows
Moist Conditions
Mid-range Flows
Dry Conditions
Low Flows
0
10
20
30
40
50
60
70
80
90
100
Flow Duration Interval (%)
TBC WQS
PBC WQS
2009 Data
Flow conditions
E. Coli Data & USGS Gage 04118500 Duration Interval
6.67 square miles


Deer Creek at Mill
Load Duration Curve (2009 Monitoring Data)
Site: 12
1.0E+14
1.0E+13
1.0E+12
1.0E+11
1.0E+10
1.0E+09
E. Coli (#/day)
High Flows
Moist Conditions
Mid-range Flows
Dry Conditions
Low Flows
0
10
20
30
40
50
60
70
80
90
100
Flow Duration Interval (%)
TBC WQS
PBC WQS
2009 Data
Flow conditions
E. Coli Data & USGS Gage 04118500 Duration Interval
26.1 square miles


Deer Creek at Leonard
Load Duration Curve (2009 Monitoring Data)
Site: 13
High Flows
Moist Conditions
Mid-range Flows
Dry Conditions
Low Flows
1.0E+14
1.0E+13
1.0E+12
1.0E+11
1.0E+10
1.0E+09
E. Coli (#/day)
0
10
20
30
40
50
60
70
80
90
100
Flow Duration Interval (%)
TBC WQS
PBC WQS
2009 Data
Flow conditions
E. Coli Data & USGS Gage 04118500 Duration Interval
34.5 square miles

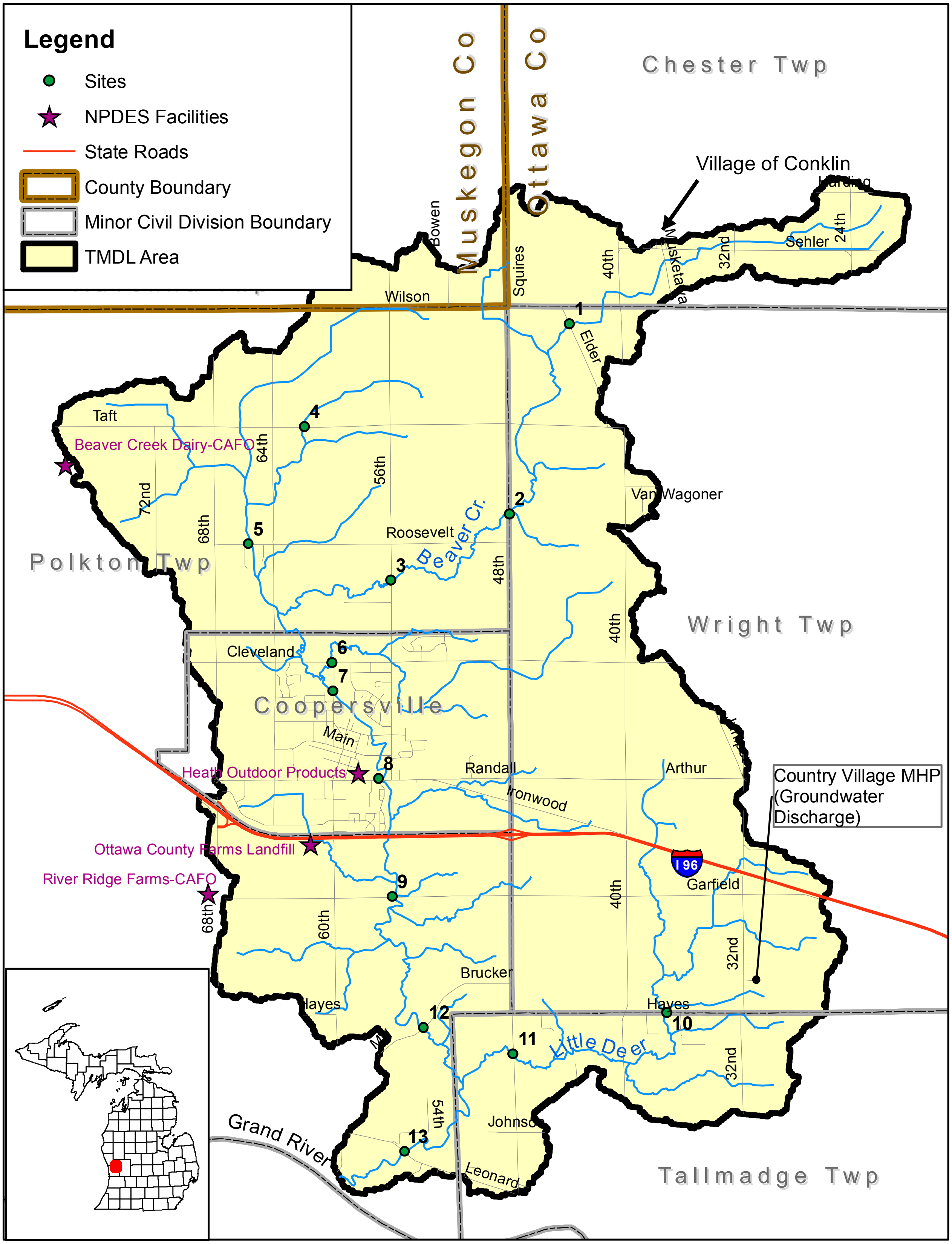


Figure M-1. Locations of sampling sites, NPDES permitted facilities, state roads, minor divisions and counties within the Deer Creek TMDL area.

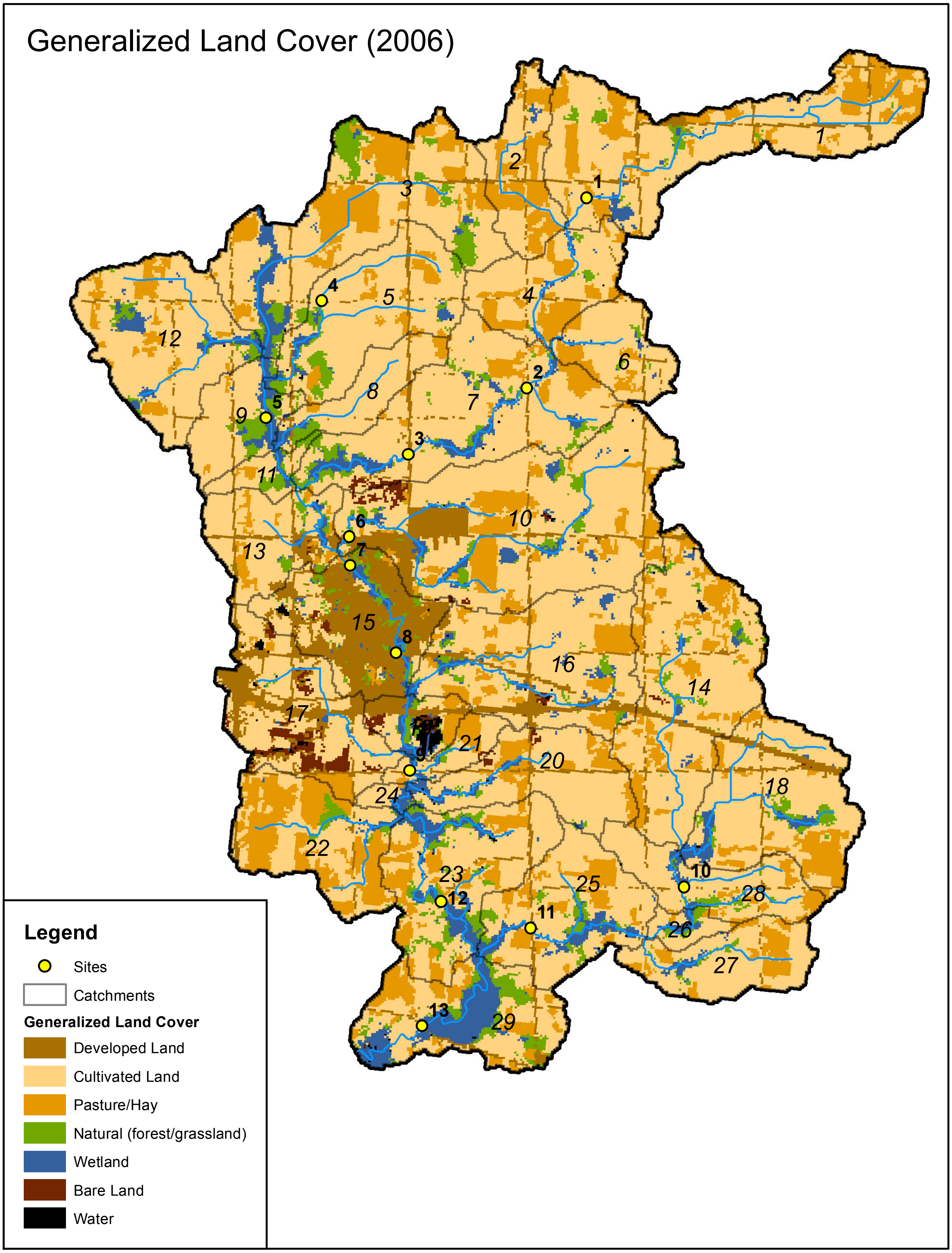


Figure M-2. Generalized 2006-Era Land Cover Data (NOAA, 2008b) by catchment.

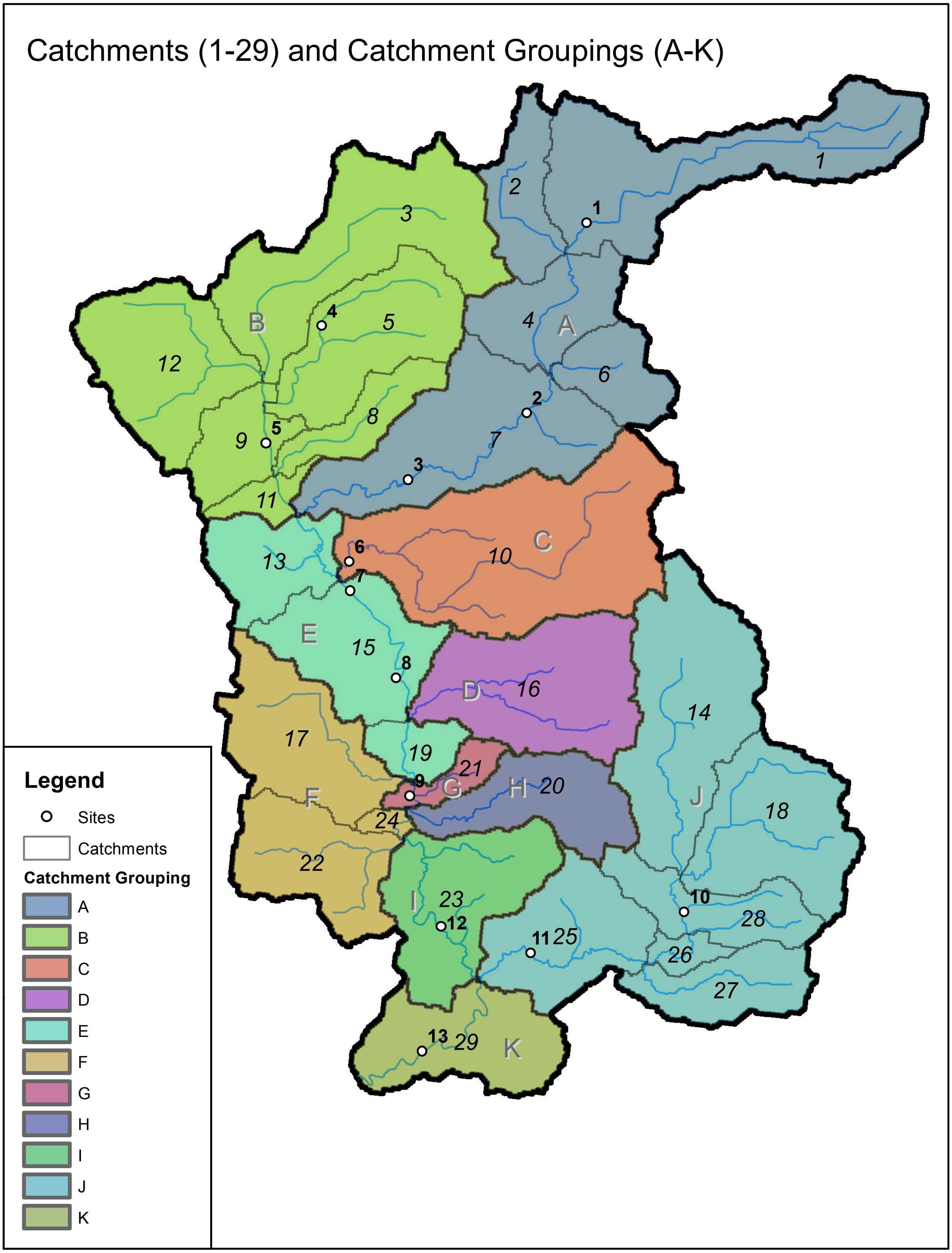


Figure M-3. Locations of catchments (1 through 29), catchment groupings (A through K), and sampling sites within the source area.

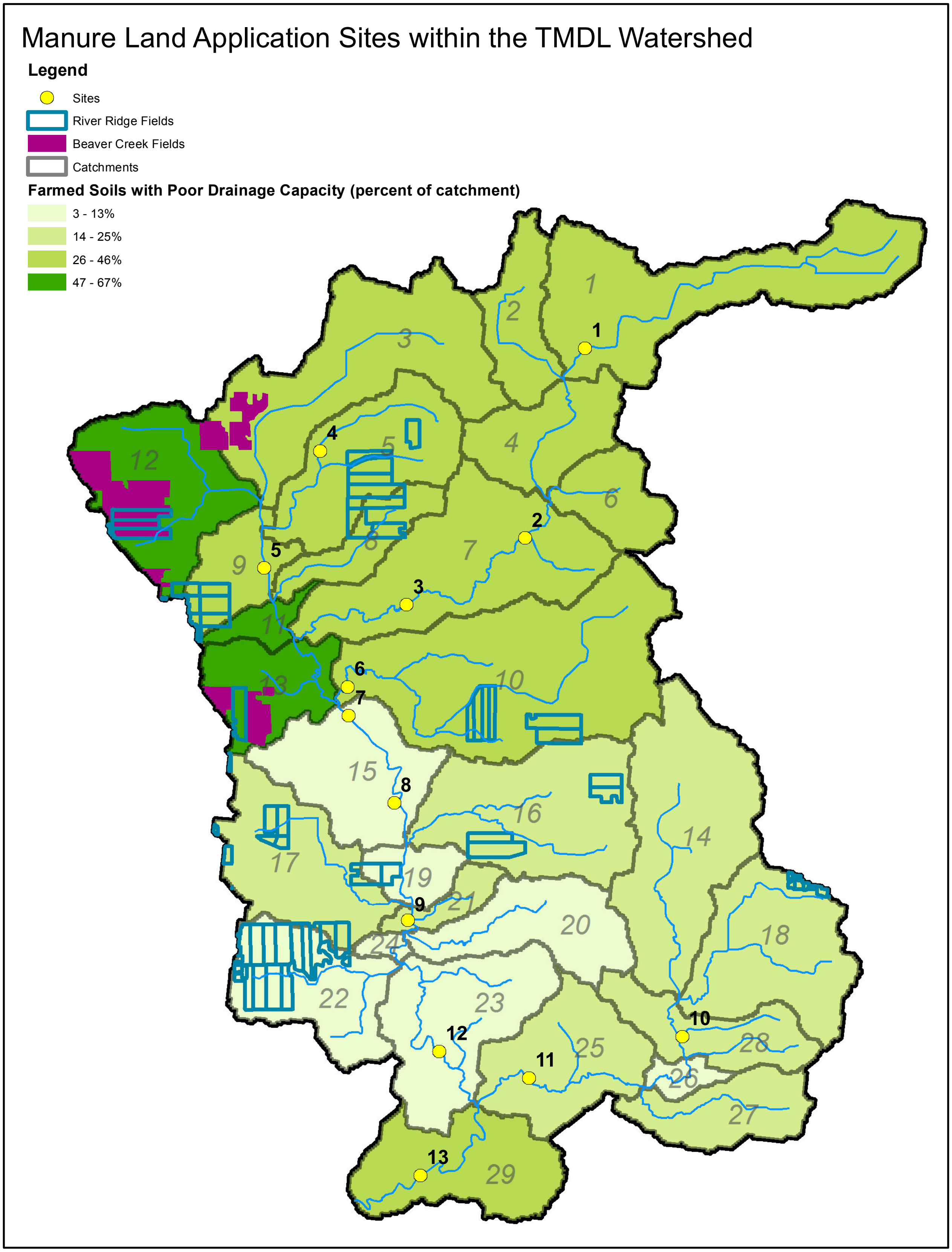


Figure M-4. Potential manure land application sites for Beaver Creek Dairy and River Ridge Farms are represented in this map, as is the percent of each catchment that is farmed on poorly drained soils (indicated by varying shades of green). For the purposes of crop production, poorly drained soils are defined as requiring artificial drainage to obtain prime farmland condition.

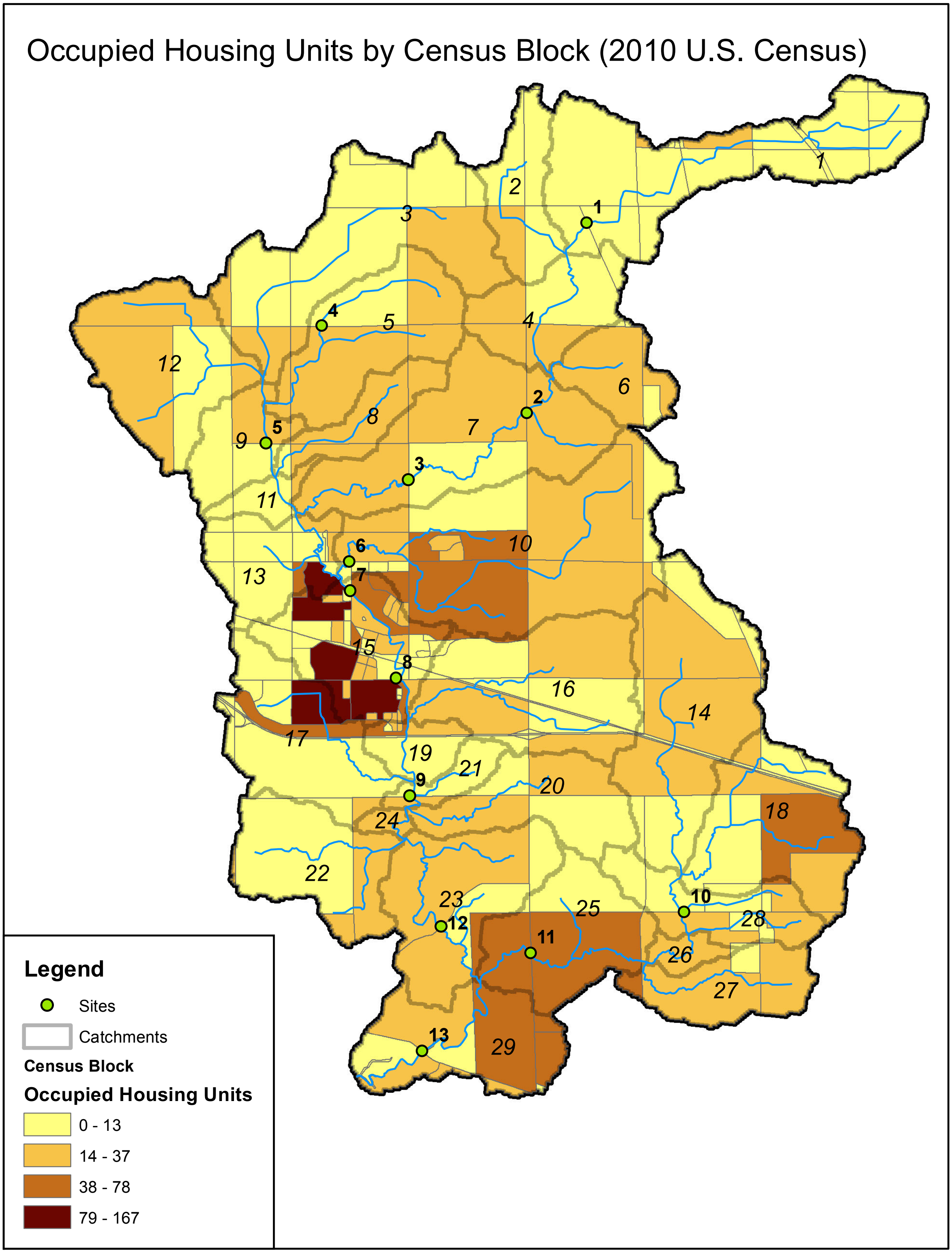
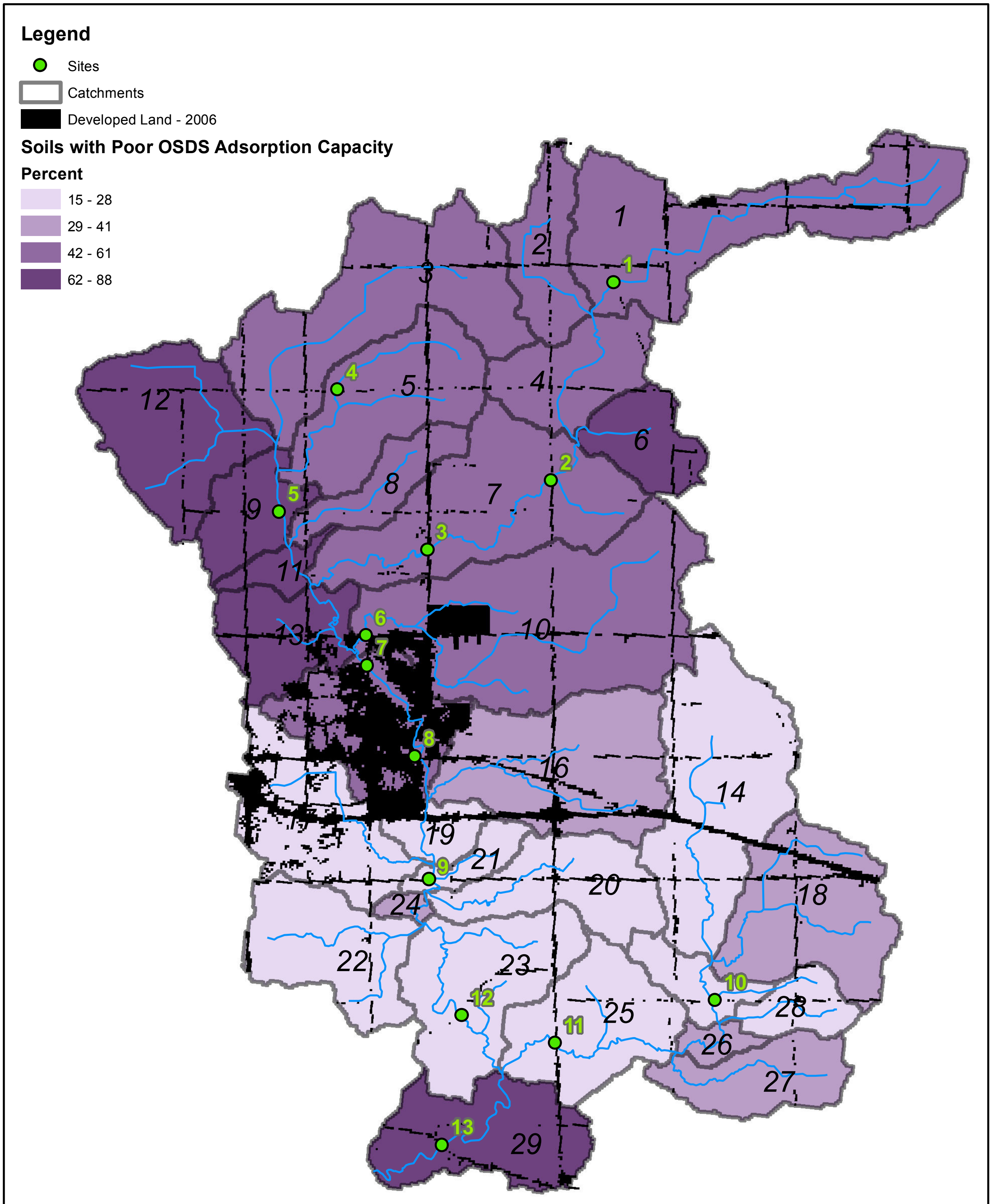


Figure M-5. Number of occupied housing units by census block in the TMDL source area (U.S. Census Bureau, 2010a and 2010b)



Developed Land and Percent of Soils with Poor OSDS Adsorbtion Capacity for Each Catchment

Figure M-6. Percentage of soils with very limited capacity for OSDS absorption fields (poor drainage) and developed land in each catchment. The location of a housing unit with an OSDS on these poorly drained soils may indicate an increased risk for certain types of OSDS failures.

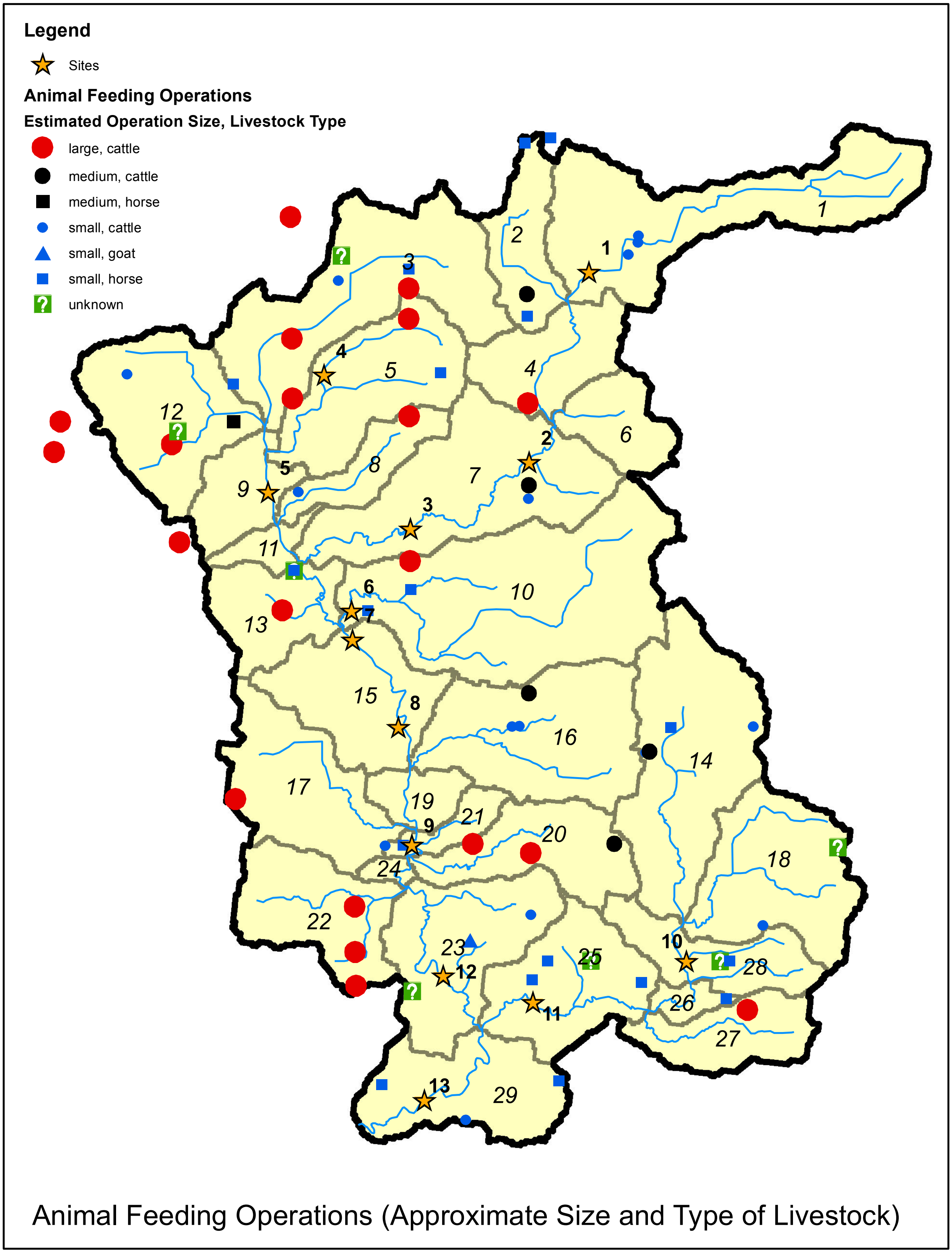
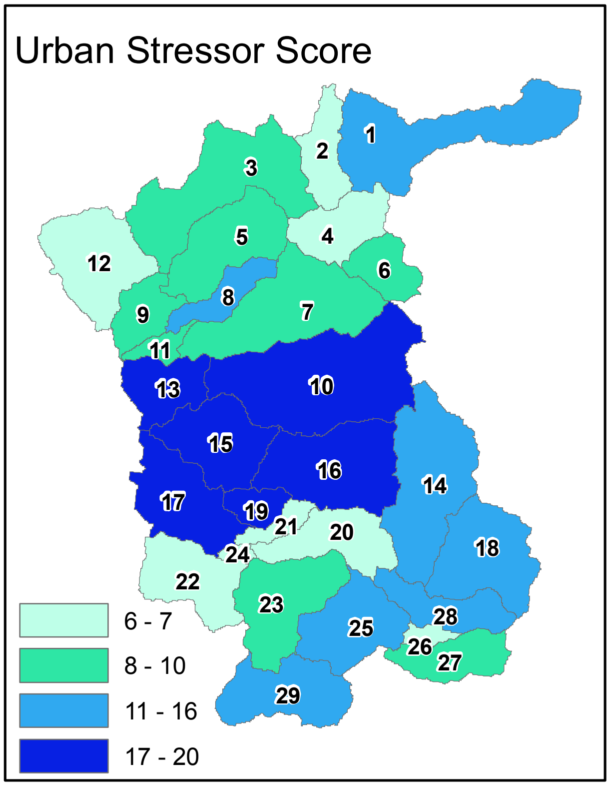


Figure M-7. Animal feeding operations by type of livestock and estimated operation size, based on visual observations.



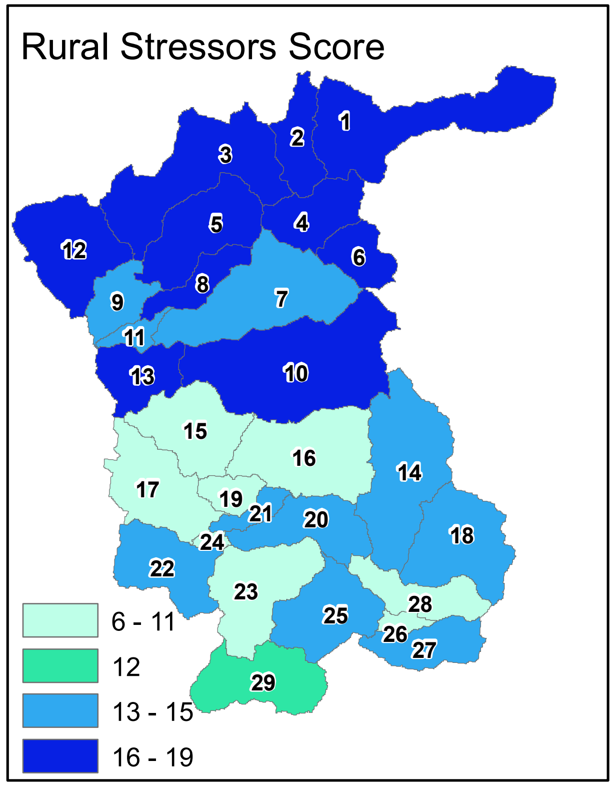
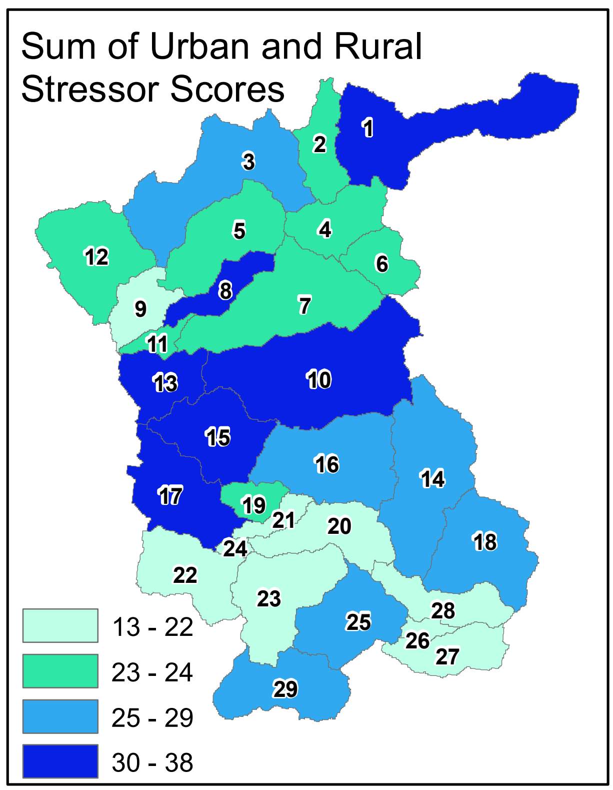


Figure M-8. Rural, urban, and overall stressor scores for each catchment were calculated as described in section 4.5, and in Table 8. A higher stressor score (dark blue) indicates that a catchment has a number of risk factors, which make the area a likely contributor to E. coli contamination, and could therefore be a priority for potential future implementation activities



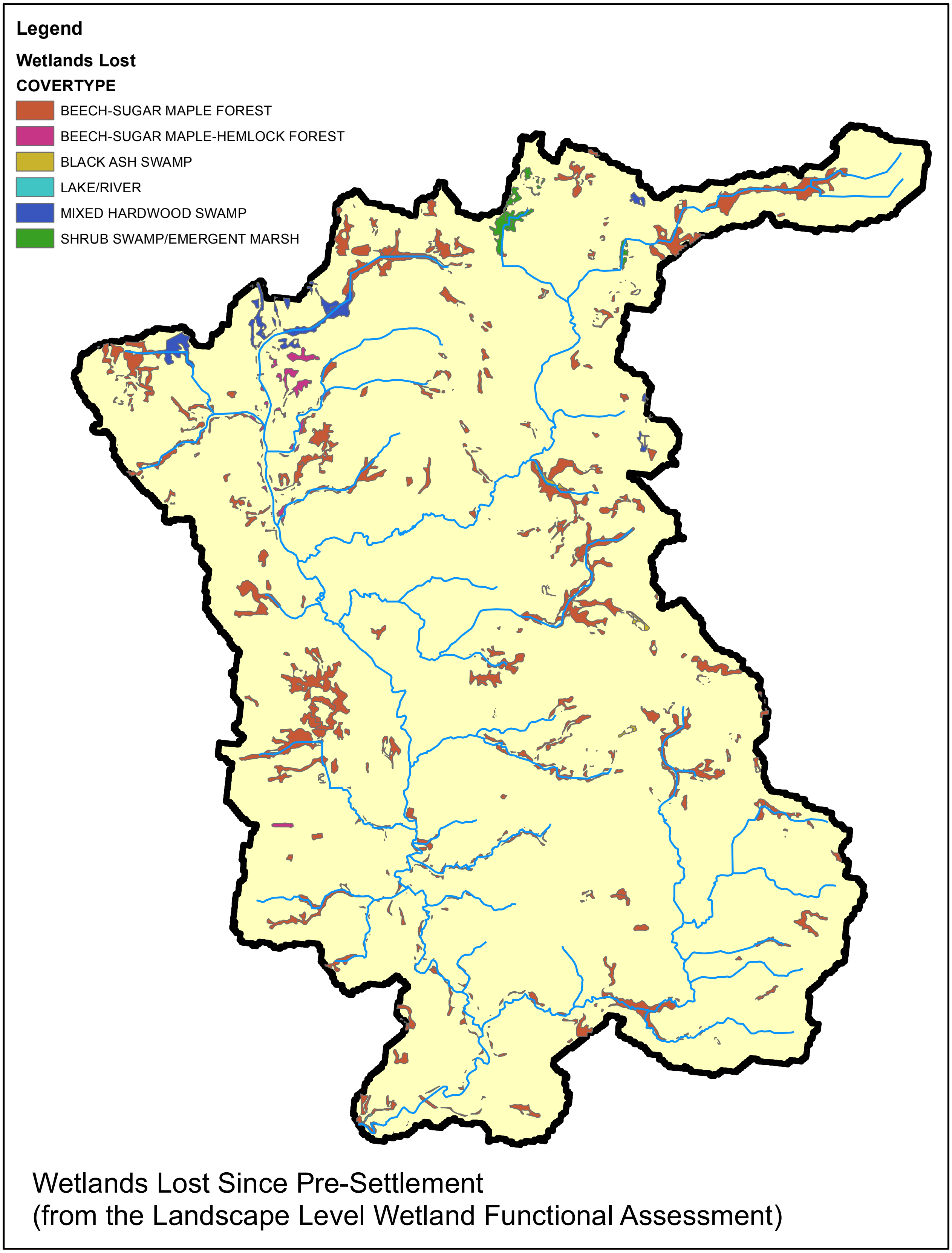


Figure M-9. Wetlands lost (by type) since pre-settlement, which was calculated from the Landscape Level Wetland Functional Assessment (LLWFA) methodology.