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E. coli Results and Source Assessment: Portions of the Lower Cass River and Tributaries, including Millington, Cole, Perry, and Dead Creeks

Genesee, Saginaw, and Tuscola Counties

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1. INTRODUCTION

1.1 WATER QUALITY PROBLEM

Monitoring data collected in 2010 and 2012 by staff of the Michigan Department of Environmental Quality (MDEQ) in the Cass River and tributaries (including Cole, Perry, Dead, and Millington Creeks) documented 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 1-4, Figures 1-4). These water bodies (Figure 5) are listed as impaired by *E. coli* in Michigan's 2016 Federal Clean Water Act Sections 303(d), 305(b), and 314 Integrated Report (Goodwin et al, 2016), and are included in the draft Statewide *E. coli* TMDL (www.Michigan.gov/ecolitmdl).

1.2 BACKGROUND

The Cass River flows into the Saginaw River and eventually into Saginaw Bay (Figure 6). The Cass River watershed covers an area of about 908 square miles and contains about 1,352 miles of rivers, streams, and drains. The current major land cover types of the study area are: 42 percent cultivated crops, 17 percent pasture/hay, 6 percent developed land, and 27 percent upland natural (forest and grassland) (Figure 7 and Table 5). The study watershed is home to about 18,500 people, mainly living in the city of Frankenmuth and outlying areas of the city of Bridgeport and village of Millington, Michigan. According to the Regional Landscape Ecosystem Classification system, the study watershed is located in the Saginaw Bay Lake Plain (sub-subsection VI.6), Sandusky Lake Plain (VI.5.1), and Lum Interlobate (VI.5.2) (Albert, 1995). The Sandusky and Saginaw Lake Plains are clay lake plains that gradually slope (0-2 percent slopes) toward Lake Huron and Saginaw Bay. There are end-moraines in the Lake Plain sub-subsections, which radiate concentrically from the shore of Saginaw Bay. The main stem of the Cass River approximately parallels the shore of Saginaw Bay, about 15 miles away, between two end-moraines before cutting across the plain to the bay. Lakes are uncommon in the Lake Plain, and soils were wet before drainage for agriculture. Lum Interlobate sub-subsection is located in the headwaters (southern) areas of Dead and Perry Creeks, and the majority of Millington Creek and is characterized by steeper terrain composed of end-moraines, with sandy loam outwash plain located between the moraines. The outwash plain is characterized by frequent kettle lakes and kettle (pocket) wetlands, which were largely alder and pine-cedar swamps before settlement. Due to the high water table in the Lake Plain, extensive drainage was necessary to enable agriculture. Currently, the area is considered important farm land for corn, soybeans, and sugar beets. Streams within the Lake Plains (photo 1) and the Lum Interlobate (photo 2) have a completely different character, flow, and substrate due to their surficial geology.

The seasonally high water table approaches the ground surface in 35 percent of the watershed, although this high water table condition is locally more common in basins such as Cole Creek. A seasonally high water table can cause On-Site Sewage Disposal System (OSDS) failures in early spring, including 'ground failures,' where wastewater can pool on the ground surface and run off into nearby surface waters. As a clay alluvial plain, the soils generally have very low hydraulic conductivity and stream flows are mainly driven by storm water and subsurface infiltration, rather than groundwater influence. The area that is occupied by these poorly drained soils with a seasonally high water table is roughly equivalent to the area that was once occupied by wetland, that has since been drained for agriculture and settlement activities (34 percent of the study watershed). Prior to European colonization of the area, the study watershed was approximately 39 percent wetland, but is currently only about 5-7 percent wetland (a net loss of about 28,600 acres of wetland). The study watershed on a whole has lost 88 percent of its presettlement wetland area.

Photo 1: Much of the Sandusky and Saginaw Lake Plain area was wetland, but has been drained for agriculture, resulting in linear 'dicthes' such as this one (located north of the mainstem Cass River, just east of Frankenmuth, MI).

Photo 2: Lum Lobate area streams, such as Millington Creek, have more flow and are generally less modified than Lake Plain tributaries because drainage occurred naturally.

For the purposes of identifying sources and characterizing drainage areas, the study watershed was divided at three spatial scales: basin, subbasin, and catchment (Figure 8). The basin level is akin to a 12-digit hydrologic unit code, with each basin encompassing each of the major tributaries (Dead, Cole, Perry, and Millington Creeks), as well as direct drainage to the Cass River. Each of the basins was further divided into subbasins at the 2010 and 2012 monitoring sites. Each subbasin is named after the monitoring site immediately downstream of it. For example, Site S1 receives flow from subbasin S1, and Site 6 receives flow from subbasin 6, but also S1 and D1 further upstream. Beyond this, the national hydrograph dataset catchment layer (United States Department of Agriculture [USDA]-NRCS et al., 2009) was edited to match the subbasin boundaries, and used to assign smaller catchments (1-98). Each basin has its own appendices (2-6) with maps (Figures A-G) specific to that basin.

1.3 WATER QUALITY STANDARD

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 [NREPA]) states that these water bodies 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.

3. DATA DISCUSSION

Weekly *E. coli* data were collected for 16 weeks at 10 sites (from May 19 to September 1, 2010), and 5 weeks of weekly samples were collected at 9 different sites on tributaries to the Cass River (from July 23 to August 21, 2012). The sites sampled in 2012 were located in lower order tributaries than the sites that were sampled in 2010, and were intended to pinpoint areas within the tributary watersheds that may be contributing to higher *E. coli* concentrations. The locations and results of the 2010 sites are described in Tables 1 and 2, and shown in Figures 1-4. The locations and results of the 2012 sites are described in Tables 3 and 4. For a detailed map of site locations, which includes roads, see Figure B in Appendices 2-6. Generally, the MDEQ weekly samples were taken on Mondays between 9:00 a.m. and 12:30 p.m. Precipitation data from 24 hours prior to sample collection can be found in Tables 2 and 4. Precipitation data was observed at the MSU Saginaw Valley Beet and Bean Research Farm near Frankenmuth, Michigan (Enviro-Weather, 2012).

At all sites in both years of sampling, 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., 2010 and 2012).

The number of WQS exceedances at each sampling site and site geometric means are summarized in Tables 1 and 3. Site geometric means were calculated by incorporating all the weekly data for each site into a geometric mean calculation (Tables 1 and 3). 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.

E. coli concentrations at tributary sampling sites were notably higher than the main stem of the Cass River. Of the tributaries to the Cass River sampled in 2010 (Sites 6-10), Dead Creek (Site 6) had the most daily maximum TBC WQS exceedances (14), followed by sites on Cole Creek (Site 7) and Millington Creek (Site 9), each with 11 exceedances. The MDEQ weekly sampling did not target wet weather deliberately, but did correspond with one significant (>0.5 inches) rain event on June 3, 2010 (0.58 inches) (Table 2). This rain event appears to have led to an increase in *E. coli* concentrations in the main stem sites (1-5), and possibly in Sites 6-8, although an increase was not apparent in the remaining sites (9-10). No precipitation events occurred within 48 hours prior to any of the sampling events in 2012 (Table 4). Samples from each 2012 site were analyzed for general and human bacteroidese (human specific) biomarkers. 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. 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.

Results of the bacterial source tracking analyses were positive for human bacteroidese at all sites and all dates where the analysis was conducted (Table 3). This indicates that contamination by human fecal material existed at the time of sampling upstream of each 2012 site.

Results by basin are summarized below:

<u>Cass River</u>: In 2010, no exceedances of the PBC WQS were found at the sites on the main stem Cass River (Sites 1-5) indicating that the PBC WQS were being met. Very few, if any, exceedances of the daily maximum TBC WQS were found in the main stem Cass River, with Sites 2, 3, and 4 having only one exceedance, and Sites 1 and 5 having no daily maximum exceedances. Sites on the main stem did exceed the 30-day geometric mean TBC WQS occasionally, although Sites 1 and 2 exceeded very few times and by a very low magnitude. Site 5, the most downstream site on the Cass River main stem, never exceeded the daily maximum or 30-day geometric mean TBC WQS. Site 10, on a small unnamed tributary east of the city of Frankenmuth, had the most PBC WQS exceedances of any site sampled in 2010 (7), although this tributary became stagnant and then dry in the latter part of the sampling season. As a result, sampling results may be artificially high in the final weeks prior to the cessation of

sampling at that location. Using a Pearson's Correlation, every site on the main stem Cass River (except Site 1) had a significant relationship ($r^2 \geq 0.5$, using a 95 percent confidence interval) between daily geometric means of *E. coli* and precipitation amount in the prior 24 hours (Table 1). The Cass River main stem was not sampled in 2012, and no bacterial source tracking was conducted at Sites 1-5, or 10.

Dead Creek: In 2010, the Dead Creek site (6) had the third highest site geometric mean of all sites. Site 6 exceeded the daily maximum TBC WQS more than any other site during 2010 (14 out of 16 sampling dates). Of all sites sampled in 2012, the site with the most PBC WQS exceedances sampled was S1 (Smith Drain, within Dead Creek), which exceeded the PBC WQS 100 percent of the dates sampled. Site S1 also had the highest site geometric mean of all the 2012 sites. The other site on Dead Creek (Site D1) exceeded the daily maximum TBC WQS continuously, but concentrations never exceeded the PBC WQS during sampling. Human biomarkers were found at Site D1 (July 23 and 30, 2012) and Site S1 (July 23, July 30, and August 6, 2012).

Cole Creek: In 2010, the Cole Creek site (7) had the 2nd highest site geometric mean of all sites. Site 7 exceeded the daily maximum TBC WQS on 11 out of 16 sampling dates in 2010. Of the sites monitored on Cole Creek in 2012 (C1 and C2), C2 had notably higher *E. coli* concentrations than C1, with 4 exceedances of the PBC WQS and 5 exceedances of the daily maximum TBC WQS. In 2012, Site C2 ranked second of all sites, while Site C1 ranked eighth, in terms of site geometric means. The highest daily geometric mean found during 2012 occurred at Site C1, on August 21, 2012. Human biomarkers were found at Site C1 (July 23, 2012) and Site C2 (July 23, July 30, and August 6, 2012).

Perry Creek: In 2010, the Perry Creek site (8) had the fifth highest site geometric mean of all sites. Site 8 exceeded the daily maximum TBC WQS on 9 out of 16 sampling dates in 2010. Using a Pearson's Correlation, Site 8 showed more of a relationship between 2010 *E. coli* concentrations and 24-hour prior precipitation ($r^2 = 0.49$) than the other sites monitored in 2012, although not statistically significant using a 95 percent confidence interval (Table 1). In 2012, Site P1 (Burns Drain) had lower concentrations than Sites P2 or P3, but still exceeded the daily max TBC WQS twice. Sites P2 and P3 each exceeded the PBC WQS once, and the daily maximum TBC WQS at all 5 sampling events. Human biomarkers were found at Site P1 (July 30, 2012), P2 (July 23 and August 13, 2012), and P3 (July 23, July 30, and August 6, 2012).

Millington Creek: In 2010, Millington Creek site (6) had the fourth highest site geometric mean of all sites. Site 6 exceeded the daily maximum TBC WQS on 11 out of 16 sampling dates in 2010. Of the 2 sites within Millington Creek sampled in 2012, the site upstream of the village of Millington (M1) had more exceedances than the site downstream of the village (M2). Human biomarkers were found at Site M1 (July 23 and August 6, 2012) and Site M2 (August 13, 2012).

4. SOURCE ASSESSMENT

Potential sources of *E. coli* to this area include illicit sanitary connections from residences and businesses, failing OSDS, NPDES discharges, groundwater discharges, biosolids land applications, agricultural operations, wildlife and pet waste, dumping of trash, contaminated runoff, and storm sewer discharges. This report includes a load duration curve analysis for each MDEQ site sampled, general information on point sources, and a nonpoint source assessment that included spatial and stressor analysis.

4.1 Load Duration Curve Analysis

To assist in determining potential sources to these impaired water bodies, the MDEQ conducted a load duration curve analysis for all sites (Cleland, 2002). The load duration curves for each MDEQ site sampled in the study area are included in Appendix 1. 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. On each load duration curve, 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 water quality standards.

The United States Geologic Survey (USGS) gauge No. 04150500 (located on the Cass River, in Frankenmuth, Michigan) was used to develop the load duration curves for Sites 1-10. Gauge No. 04150500 had a period of record of 73 years, and a drainage area of 842 square miles. A ratio of the drainage area of the site locations to the drainage area of the gauged watershed (defined as the drainage area ratio) was calculated for each of the sites for this study. The curves were generated by applying these drainage area ratios to gauged flows for the period of record of each gauge. The flow information used in load duration curve development was determined on each sampling date at all sites by collecting water level elevation data. Calculated flows for the 2010 stations are shown in Table 6, and the 2012 flows are in Table 7. 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 the 2010 sites (1-10) to collect reference flows for correlating the water level elevation data with actual gauged flows (USGS, 2007). Flow duration data are daily mean flow values measured over a specified time interval that have been exceeded various percentages of the specified time interval. For example, a 5 percent exceedance probability represents a high flow that has been exceeded only 5 percent of all days of the flow record. Conversely, a 95 percent exceedance probability would characterize low flow conditions in a stream, because 95 percent of all daily mean flows in the record are greater than that amount.

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 in runoff or storm sewers (regulated and unregulated), 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, continuous NPDES discharges, 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, high flow conditions were not represented during the 2010 sampling period. Sites (1-5) on the mainstem Cass River rarely exceeded the daily maximum TBC WQS or load target. At Sites 3 and 4, the exceedances followed a rainfall event of 0.53 inches, which occurred during mid-range flows. At Site 2, the only exceedance occurred after a 0.33-inch rainfall event, which occurred during a time of low flow.

Among the sites located on tributaries to the Cass River (Sites 6-10), exceedances were frequently occurring, and were distributed across all flow intervals sampled. Notably, exceedances of the daily maximum TBC WQS occurred during dry and low flow conditions at

Sites 6-9 (Site 10 was rarely sampled under low flow conditions due to a lack of water in that tributary), indicating a constant source is present in Cole, Perry, Dead, and Millington Creeks.

Load duration curves were not constructed for sites sampled only in 2012, due to a limited sampling period (5 weeks) resulting in few samples. Flows were estimated for these sites based on the drainage area ratio and flows at the USGS gauge No. 04150500 (Table 7). On the dates sampled in 2012, the flow exceedance probability ranged from 85 percent (dry conditions) on July 23, 2012, to less than 5 percent (high flows) on August 13, 2012. The sampling date with the lowest flows (July 23, 2012) resulted in the most TBC and PBC exceedances across all sites, indicating a constant source of *E. coli* was affecting the sampled water bodies on that date.

4.2 Point Sources

Potential point sources of *E. coli* are addressed in the draft Statewide *E. coli* TMDL. Point sources for the purpose of the Statewide E. coli TMDL, generally are permitted by National Pollutant Discharge Elimination System Permits, and include; Concentrated Animal Feeding Operations (CAFOs), Industrial Storm Water discharges, Municipal Separate Storm Sewer Systems, wastewater treatment facilities, and biosolids land-application areas. The general locations of potential point sources can be found by using Michigan's Pollution and Solution Mapper. Both the draft TMDL document and mapper can be accessed at www.Michigan.gov/ecolitmdl. Although every NPDES discharge or land-application site within this study area is considered a potential source of *E. coli*, each permit contains specific language designed to protect surface water from exceeding the TBC and PBC WQS.

4.3 Nonpoint Sources

Of the approximately 18,500 people living in the study watershed, about 6,200 are served by municipally operated or privately owned sanitary sewers and wastewater treatment. Within the study area, there are an estimated 4,600 OSDS serving 12,500 persons in areas not served by sanitary sewer collection systems. Subbasin D1, within the Dead Creek basin, had the highest density of OSDS (0.11 OSDS per acre) and also the highest number of OSDS (794 systems). The approximate distribution of OSDS on the catchment level can be seen in Figure F of Appendices 2-6, along with unsewered developed land cover. According to USEPA estimates, each person generates 70 gallons of wastewater per day (USEPA, 2000), resulting in the treatment of approximately 875,000 gallons of sanitary wastewater per day by OSDS (12,500 people x 70 gallons per day) in the study area.

When the OSDS 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. OSDS located on these soils with poor, or slow, infiltration rates may lead to a higher rate of surface and seasonal failures. About 30 percent of the study 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); but, on a smaller scale these soils are much more common. On the basin level, Cole Creek has the highest proportion of these soils (77 percent). Catchment 41 (Millington Creek) and Catchment 45 (Cole Creek) have upwards of 85 percent of their area composed of these soils.

The consistency and magnitude of the *E. coli* exceedances at Site S1 (Smith Drain, within Cole Creek), are indicative of illicit connections or another constant source of contamination. Site S1 has 3 AFOs within 1,000 feet of the creek, but no animal access issues were noted in a survey of aerial imagery (Figure D, Appendix 4). This subbasin has an estimated 91 housing units relying on OSDS for treatment (Appendix 8), with OSDS being the most dense in

Catchments 33 and 34 (the headwaters area) (Figure F, Appendix 4). Human bacteroides was also detected at Site S1 on three occasions, suggesting that OSDS issues or illicit connections are the constant source of *E. coli* at that site.

Domestic septage is defined as the solids that settle out in an OSDS tank, which must be pumped and hauled away. Septage can be hauled to a licensed facility for disposal or land applied. Use the interactive mapper at www.Michigan.gov/ecolitmdl to determine if septage is land applied in the study watershed.

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 urban storm sewers located in Frankenmuth, Millington, and other residential developments (subdivisions and MHPs). Urban storm water can be contaminated by illicit sanitary connections, failing OSDS leaching into storm sewers, trash, pets, and wildlife. Spatial areas of high human population density near surface waters may be especially prone to contaminating surface waters through OSDS failures, illicit connections, trash, and pet waste. One such area of concern is a high density housing development located in Catchment 27 (off of Willard Road, southeast quarter of Section 33 in Arbela Township), adjacent to a tributary of Dead Creek (Figure B, Appendix 4). This housing development is older with a relatively small lot size, and ditched to promote drainage. During a cold winter day, at least one pipe was observed by MDEQ staff to be discharging to a ditch with ice-free water. The OSDS may be aging and failing due to soil conditions as well as having potential for illicit connections. In addition to concerns about failing OSDS and illicit connections, a high density human population as found in this subdivision has a higher density of other nonpoint sources of pollution, such as trash and pet waste. Site D1 would be affected by storm water or any OSDS issues from this housing development.

As the amount of developed land in a watershed increases, the amount of impervious surface 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 Frankenmuth. Overall, developed land cover in the study watershed is 7 percent of the land area, but in individual catchments it is as high as 57 percent (Catchment 3) and 47 percent (Catchment 35) in Frankenmuth. The sites that would be most affected by storm water from Frankenmuth would be Sites 2 and 3 on the main stem of the Cass River. Of all the sites on the main stem, Site 3 had the highest *E. coli*, particularly during wet weather, which could potentially be attributed to a flush of storm water from Dead Creek or the city of Frankenmuth, among other potential sources.

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 (OHU) data from the 2010 U.S. Census, the dog population in the study area is an estimated 4,630 (Appendix 7). Upstream of Site 10, on an unnamed tributary to the Cass River, is a Frankenmuth city park (Memorial Park) with short mowed grass and a fenced dog park. This dog park (known as Hund Platz) may be a potential source of *E. coli* in Subbasin 10, along with the potential to attract waterfowl on the mowed area adjacent to the stream. There is a considerable amount of residential area upstream of the park, so there are other potential sources for the high *E. coli* concentrations found at Site 10. Another city park (Heritage Park) is adjacent to the Cass River in Subbasin 2. This park may also attract pet owners and congregating waterfowl. Feral and outdoor cats and dogs, as well as urban wildlife (such as geese and raccoons) are a potential source and should be considered in any effort to reduce contamination by encouraging people to clean up after their pets and discouraging wildlife congregation.

In rural areas, livestock are a likely source of contamination to storm water. Agriculture, including hay/pasture, accounts for approximately 59 percent of the land use in the entire study area and as much as 93 percent of the land area in individual catchments (12 and 48, in Dead and Perry Creeks, respectively). Upstream of Site P1, in Perry Creek, the subbasin is 84 percent agricultural land cover. The percent of each catchment in agricultural land uses can be found in Appendix 7 and mapped for each basin in Figure D in Appendices 2-6. 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). In the study watershed, it is estimated that 62 percent of the agricultural land may be tile drained, or heavily ditched, based on soils data (Section 4.5.e). 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. Tillage practices in the watershed were partially surveyed for the watershed management planning process (Section 5.2).

For the purposes of this study, all livestock within the watershed are considered potential sources of *E. coli*. Two-hundred and sixteen farms were identified within the watershed through driving reconnaissance and remote sensing which took place in January, 2013. A complete list of livestock operations, ranging in size from a single animal up to larger dairy and meat operations, are included in Table 8 and are mapped in Figure 10 on a watershed scale, and Figure D in Appendices 2-6 on a basin scale. Table 8 also indicates the type of livestock, type of AFO (pasture or feedlot), and whether the operation is located within 1,000 feet of a water body. 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. Appendices 7 and 8 detail the numbers of AFOs at the subbasin and catchment levels.

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. 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 by medium and large farms or AFOs in and near the source area is a likely source of *E. coli*. 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. One hundred and four hobby horse farms were found in the watershed. The Perry Creek Basin contained the most (55) hobby horse farms, and in general, these farms were concentrated in the upper reaches of the Perry, Dead, and Millington Creeks basins. Livestock in the watershed appear to be mainly cattle and horses, although sheep, elk, and goats were noted.

At the basin level, Dead Creek had the most large AFOs, and Perry Creek had the most AFOs within 1,000 feet of water bodies. Subbasins 6 (in Dead Creek) and P1 (Perry Creek) each had 20 AFOs within the buffer, making livestock a likely significant source to Sites 6 and P1 (Figure D, Appendices 4 and 6). During watershed reconnaissance, several AFOs were found that had potential runoff or direct animal access issues. These AFOs were located in Catchments 45 (Cole Creek), 83 and 39 (Perry Creek), and 34 and 21 (Dead Creek) (Figure D, Appendices 3, 4, and 6). Any contamination from these farms would have affected the sample results at Sites 6, 7, and 8 in 2010, and C2, P2, and S1 in 2012. Based on the land cover analysis (Table 5) and locations of identified livestock farms (Table 8 and Appendices 7 and 8), livestock manure stockpiled near streams or land applied is likely a significant source to all sites monitored for this study.

4.4 Spatial Analysis

In an attempt to quantify the potential sources, soil conditions, and land cover types at large and small scales, a spatial analysis was completed for basins, subbasins, and catchments. Results of the spatial analyses are contained in Table 5 (landcover), and Appendices 7 and 8. Visual representations of some of the data contained in these tables are organized at the basin level in appendices 2-6. Each of these appendices contains 7 maps specific to that basin (Figures A-G).

Coastal Change Analysis Program 2006-Era Land Cover Data (NOAA, 2008) characterizes an area by land cover type (i.e., cultivated land, hay/pasture, and 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 (2018), land cover data may be out of date. Results of the land cover analysis can be found at the basin, subbasin, and catchment level.

The Soil Survey Geographic Database was used to obtain the drainage characteristics of soils in the watershed (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 Soil Survey Geographic 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 in Sections 4.5.e and 4.5.i.

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. OHUs and population data from the 2010 Census at the census block level were used to calculate the number of OHUs, population numbers, and density at the subbasin and catchment level (Appendices 7 and 8).

4.5 Stressor Analysis

In order for stakeholders to prioritize actions within the study 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 that would increase the likelihood of *E. coli* contamination to surface waters.

The stressors for each individual catchment include the following:

- Road density.
- Percent cover of developed land.
- Estimated OSDS.
- Human population density.
- OHU density.
- Number of AFOs per area.
- Number of AFOs in 1,000 foot riparian buffer per area.
- Percent cover of agricultural land.
- Percent cover of agricultural land with poor drainage.
- Percent cover of soils with poor OSDS absorption characteristics.
- Percent of presettlement wetlands that have been lost.
- Percent of river miles with no significant vegetated riparian buffer.

The stressors for each subbasin were the same as the catchment stressors, with the addition of the number of approved biosolids land application sites.

For each stressor, the catchment or subbasin 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 or subbasin belongs (1st-4th) was translated into the stressor score (1-4), with 4 being the highest environmental stress score for each stressor variable, and 1 being the lowest amount of stress relative to other catchments. In some cases, the data were so abnormally distributed (such as biosolids sites), that quartiles could not reasonably be calculated. In these cases the stressors were included at the subbasin level, but not the catchment level. For each catchment and subbasin, the stressor scores were then summed to calculate total stressor score (12-48). The methods for calculating the stressors, and the results, are described in detail in Sections 4.5.a through 4.5.i. The results of stressor scoring are shown on maps in Figures 12 and 13 and in tables in Appendices 7 and 8, and discussed in Section 6.

4.5.a 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 or subbasin (Appendices 7 and 8). Road density was highest in the highly urbanized catchments in Frankenmuth. Subbasin 10 had the highest road density (15.6 meters/acre) at the subbasin level, while Catchment 3 (in Subbasin 3) had the highest road density

(20.4 meters/acre) at the catchment level.

4.5.b Stressors: Percent Cover of Developed Land

According to 2006-Era Land Cover Data (NOAA, 2008), 7 percent of the watershed is open, high, medium, and low density developed land. This is a relatively small proportion of the area, but in terms of *E. coli* contamination from OSDS, and runoff from pets and urban wildlife, it is an important segment. Percent developed land cover relative to the total catchment area ranged from 57 percent (Catchment 3 within the Cass River basin) and 0 percent (Catchment 88 in Millington Creek and Catchment 28 in Dead Creek) (Appendix 7). The most highly developed catchments are in the city of Frankenmuth and have sanitary sewers available in most areas, but not all residences may be properly connected to them.

4.5.c Stressors: OHU Density and Human Population Density

Human population within the source area in 2010 was estimated to be approximately 18,500 (U.S. Census Bureau, 2010a and 2010b). Catchments 3 and 35 had the highest human population, human density (people per acre), number of OHUs, and OHU density of all the catchments in the source area (Appendix 7). Not surprisingly, these catchments are located in the city of Frankenmuth. Outside of the relatively urban and suburban areas of Frankenmuth, Catchments 46 and 54 (both encompassing portions of the village of Millington) had notably high human population and OHU numbers and density. Human population density ranged from a low of 0.02 persons per acre (equivalent to 1 person for every 50 acres), to 2 persons per acre on a per-catchment basis. Housing unit density ranged from 0.01 OHU per acre (or 1 OHU per 100 acres) in Catchment 41 in the Millington Creek basin, to 0.92 OHU per acre (or 92 OHUs per 100 acres) in Catchment 3 of the Cass River basin.

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

The number of AFOs, and number of AFOs within 1,000 feet of water bodies in each catchment, was used as an indicator of 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. Because the size of the catchments varied widely, the absolute number of AFOs and AFOs within 1,000 feet of tributaries was converted to a relative value of density of AFOs per acre of catchment land.

The MDEQ has identified 216 AFOs, with 124 (including one CAFO) that are within 1,000 feet of water bodies (Table 8). Catchment 21 in Dead Creek has the most (9) AFOs within 1,000 feet of tributaries, and Catchment 50 (Perry Creek) had the most overall (15) AFOs.

In terms of basins, Perry Creek had the most (95) AFOs, and the most (50) AFOs within 1,000 feet of its tributaries. At the subbasin level, P2 had the most (47) AFOs and the highest density of AFOs; while subbasins P2 and 6 each had 20 AFOs within 1,000 feet of the tributaries.

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

In the entire study area, 59 percent of land area is in agricultural land cover (pasture/hay and cultivated land); however, percent cover in agriculture ranged from 5 to 93 percent of individual catchment area. Catchment 48 (in the Perry Creek basin) had the highest percent of land cover in agriculture of all 98 catchments (Appendix 7). At the subbasin level, percent cover of agriculture ranged from 37 to 84 (Appendix 8). The subbasin with the highest percent agriculture per land area is Subbasin P1, in Perry Creek.

The capacity of soils to support agriculture with or without artificial drainage was estimated using the component table of the Farmland Classification System, Soil Survey Geographic 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 and subbasin) in Appendices 7 and 8. Individual Catchment 7 (within Subbasin 2, in the Cass basin) had the highest proportion of poorly drained agricultural land (91 percent). Of the subbasins, C1 (Cole Creek basin) had the highest (77 percent). Land application of manure is likely to be a significant source in areas where agricultural land cover is a significant portion of the watershed.

4.5.f Stressors: Number of OSDS and Soils with Poor OSDS Absorption Characteristics

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).

The number of OSDS was estimated by obtaining maps of sanitary sewer service areas from the city of Frankenmuth, Bridgeport, and the village of Millington, and assuming that all housing units within the Peach Tree Manor MHP were served by that WWTP. OHUs from the 2010 Census in the sewered areas were excluded, resulting in an estimate of homes not served by sanitary sewers. Based on this analysis, there are an estimated 4,600 OSDS in the study watershed. Of all the individual catchments, 71 (in the Dead Creek basin) had the most OSDS, with an estimated 271 OSDS, followed by Catchment 39 (Perry Creek basin) and Catchment 90 (Cass basin) each with an estimated 180 OSDS. The distance from a home relying on an OSDS to surface water may play a role in the likelihood of the OSDS contaminating surface water by failure, or by illicit connection, but was not considered in this analysis.

4.5.g Stressors: Percent of River Miles without Vegetated Riparian Buffers

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 source area (Figure 10). The VBI expresses the relative amount of stream miles where 2006-era land cover data for natural and wetland land cover types do not intersect with streams, indicating the percent of stream length that has <u>no</u> substantial natural buffer present. The VBI is only as accurate as the land cover data (15 percent error is expected). 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 do not have substantial buffered areas. Catchments 48 (Perry basin) and 94 (Cass basin) had 100 percent of stream miles with no buffer, while Catchment 13 (Dead Creek basin) had the lowest (0 percent with no buffer, or 100 percent with a buffer) (Appendix 7). At the subbasin level, Subbasins C1 (in Cole Creek) and 10 (unnamed tributary to the Cass River) had 90 percent or more of the stream miles with no buffer (Appendix 8). It is estimated that 60 percent of the stream miles in this study had no substantial vegetated riparian buffer.

4.5.h Stressors: Percent/Acres of Presettlement Wetlands Lost

Area where presettlement wetlands have been lost has been determined by the MDEQ by comparing the presettlement extent to the current extent of wetland land cover (Figure 10 and Figure G in Appendices 2-6). Lost wetlands are an indication of a change in hydrology and a loss of wetland function that may once have been fulfilled, which can include the removal of *E. coli*. The loss of presettlement wetland area was examined as a percent of presettlement wetlands lost.

Twenty of the 98 catchments have lost 100 percent of their presettlement wetlands and the vast majority have lost more than 80 percent (Appendix 7). At the subbasin level, C1 (within Cole Creek) and 10 (within the Cass basin) have lost 100 percent of their presettlement wetland area (Appendix 7).

4.5.i Stressors: Number of Biosolids Land Application Sites

The number of approved biosolids land application sites was used to indicate areas within the study watershed where manure spreading by AFOs may also be a common practice. Biosolids land applications are tightly regulated by the MDEQ and therefore should not pose a threat to water quality.

Subbasin 8, in Perry Creek, had the most (46) biosolids land application sites of any subbasin.

6. IMPLEMENTATION RECOMMENDATIONS

NPDES permit-related point source discharges are regulated as determined by the language contained within each permit, and they must be consistent with the goals and assumptions of the draft Statewide *E. coli* TMDL (when approved by the USEPA).

Funding for nonpoint source activities is available on a competitive basis through federal Clean Water Act Section 319 grants for implementation and watershed planning and management activities (www.Michigan.gov/nps). Grants or loans for sewage treatment and storm water planning and infrastructure may be available to eligible organizations through the Storm Water, Asset Management, and Wastewater Program (for more information, go to www.michigan.gov/EGLE and search for “SAW”).

Priority catchments and subbasins were identified using the stressor analysis (Section 4.5). Higher stressor scores indicate a higher priority in terms of the implementation of nonpoint source activities and may also be used in grant application processes for prioritization. This type of prioritization may work best for determining areas to focus on Best Management Practices such as agricultural practices, wetland restoration, or riparian buffer installation. The top ranked subbasins in the study area to address nonpoint source *E. coli* contamination issues are: P1 and P3 in Perry Creek, and 6 in Dead Creek (Figure 11). The top ranked priority catchments in the study area are 5, 91, 92, and 94 (in Cass Basin), 11, 16, 18, 27, 68, and 69 (in Dead Creek Basin), 49, 56, 79, and 81 (in Perry Creek Basin), and 37 and 45 (in Cole Creek Basin) (Figure 12). Complete rankings based on the stressor scoring are located in Appendices 7 and 8.

Rather than using the total stressor score for selecting priority watersheds for implementation activities, the stakeholder may choose to use the relevant individual stressors or groupings of relevant stressors. For example, to locate areas where failing OSDS work should be conducted, the OSDS and poor OSDS soils stressors may be most appropriate, where for agricultural Best Management Practices, the number of AFOs within 1,000 feet of surface water and VBI stressors may be appropriate.

E. coli levels from 2010 and 2012 sampling can also be used to prioritize watersheds within the study area. This method of prioritization may work best when stakeholders are seeking to conduct source-specific work to address constant *E. coli* sources, such as illicit discharge elimination. The 2010 and 2012 sites are ranked by overall site geometric means in Tables 1 and 3.

We recommend the following source-specific activities to make progress in meeting the water quality standards for *E. coli*:

Pets and Wildlife:

- Establish a well-vegetated buffer or garden at Memorial Park in Frankenmuth, particularly between the surface water and the Hund Platz (dog park).
- 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.
- Adoption of pet waste ("pooper scooper") ordinances where none exist, and enforcement and education where ordinances are in place. Ordinances may be developed to ensure that both public and private property do not accumulate pet feces. For an example of a pet waste ordinance, see the city of Plymouth, Michigan's ordinance number 2002-02, Sections 14-26 and 14-27.
- Discourage the congregation of geese in riparian areas (such as parks, cemeteries, and golf courses) using tall and dense vegetation where possible. This diminishes short (mowed) green grass cover, which geese prefer for foraging because it provides an unobstructed view. The goal is to displace foraging geese by creating an unfavorable environment, while creating a favorable environment for people to enjoy as well, such as a garden. Heritage Park and Memorial Park are recommended locations for geese discouragement activities. Shoreline buffers can be incorporated into municipal landscaping plans for public lands and adopted on private lands voluntarily or through zoning code requirements.
- Wetland restoration in areas where historic wetlands have been lost can be beneficial for removing *E. coli* from runoff. A properly planned wetland may also function to discourage geese. Figure G in Appendices 2-6 shows areas where wetlands have been lost since presettlement and percent loss by catchment. These areas can also be viewed interactively on the mapper found at www.Michigan.gov/ecolitmdl.
- Installation of vegetated riparian buffer strips to increase infiltration of storm water.

Illicit Connections and Failing OSDS:

- Outreach to educate residents on the signs that their residence may have improper connections to a storm sewer or a surface water body.
- Outreach to educate residents on signs of OSDS failures (particularly in riparian areas) and aspects of local sanitary code that are designed to protect surface water from contamination.

- Education of residents on the importance of clean water to human health and the dangers of surface water contamination by raw sewage.
- If applicable, modify existing OSDS isolation distances to treat open county drains as conservatively as surface waters. Open county drains are waters of the state, and the same WQS apply.
- In the absence of a statewide OSDS inspection requirement, codify local Time-of-Sale ordinances, or ordinances with periodic required inspections in Genessee, Saginaw, and Tuscola Counties.
- Inspect OSDS and conduct Illicit Discharge Elimination Program in areas of high OHU density located near surface water. Figures E (OHU per Census Block) and F (Estimated numbers of OSDS per catchment and the distribution of developed land cover) in Appendices 2-6 may assist in this effort. Effort directed at aging or densely populated housing areas may be the most productive use of resources.
- Use of infra-red satellite imagery to detect OSDS failures (see *[The link provided was broken and has been removed.]*).

Livestock and Agriculture:

- Outreach to the agricultural community to connect them with conservation programs offered by the United States Department of Agriculture and Michigan Department of Agriculture and Rural Development.
- Use of water table management (controlled drainage) where manure is applied to artificially drained land.
- Wetland restoration in areas where historic wetlands have been lost and would be beneficial for removing *E. coli* from runoff (see pets and wildlife section, above).
- Livestock exclusion from riparian areas and providing vegetated buffers between pasture and water.
- Installation of vegetated riparian buffer strips in agricultural areas that are not artificially drained (tiled). See Section 4.5.g for subbasins or catchments with the greatest percent of unbuffered streams, and Figure 10 for a map of these locations throughout the study watershed.
- Outreach to agricultural community to encourage becoming Michigan Agriculture Environmental Assurance Program verified and/or the use of Best Management Practices on manure management (storage, composting, and application) and the development of nutrient management plans.
- Use of aerial imagery, or detailed elevation data, such as LIDaR (LIght Detection and Ranging or Laser Imaging Detection and Ranging) to identify erosion swales where runoff may be directly entering surface waters from fields and pastures. Once identified, these areas can be targeted for Best Management Practice installation to slow the speed, and increasing infiltration, of runoff from manure land application.

7. FUTURE MONITORING

Future monitoring by the MDEQ will take place primarily as part of the five-year rotating basin monitoring, as resources allow, once actions have occurred to address sources of *E. coli*. According to the basin schedule, the Cass River will be monitored in 2021, 2026, etc.

Monitoring Recommendations:

- Based on the high stressor score rankings that were found in the Cass River basin, and the limited monitoring that occurred in the small tributaries in that basin (only one of these tributaries was monitored [Site 10]), we recommend that further monitoring occur on small tributaries in this basin.

- Based on the high levels of *E. coli* that were found in the tributaries to the Cass River, we recommend that monitoring occur at other tributaries not included in this study.
- Given that human bacteroides were detected at all 2012 monitoring sites, we recommend that further bacterial source tracking be conducted in feeder tributaries upstream of the 2012 sites.

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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 2010. 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.

Site ID	Site Description	Latitude	Longitude	Assessment Units	Site Geometric Means	Site geometric mean rank	Number of 30-Day Geometric Mean exceedances	Number of TBC exceedances	Percent TBC exceedances	PBC exceedances	Correlation between Daily *E. coli* and Prior Precipitation (Pearsons Coefficient, r2)
1	Cass River @ Bray Rd.	43.324278	-83.657086	040802050305-01	105	7	2	0	0%	0	0.35
2	Cass River @ Main St.	43.324534	-83.74047	040802050305-03	55	10	1	1	6%	0	** 0.83
3	Cass River @ Dixie Highway	43.330256	-83.829912	040802050306-01	132	6	6	1	6%	0	** 0.94
4	Cass River @ Fort Rd.	43.348779	-83.884129	040802050306-01	85	8	3	1	6%	0	** 0.87
5	Cass River @ M-13	43.364869	-83.954857	040802050306-03	58	9	0	0	0%	0	** 0.79
6	Zehnder/Dead Creek @ Curtis Rd.	43.321714	-83.794014	040802050304-01	463	3	12	14	88%	2	0.38
7	Cole Creek @ Ormes Rd.	43.321461	-83.672808	040802050305-05	470	2	12	11	69%	2	-0.07
8	Perry Creek @ Ormes Rd.	43.321537	-83.652572	040802050302-01	340	5	12	9	56%	0	0.49
9	Millington Creek @ Loren Rd.	43.324419	-83.651514	040802050303-01	376	4	12	11	69%	1	0.34
*10	Unnamed Tributary @ Van Cleve (Tuscola) Rd.	43.331275	-83.731932	040802050305-04	1017	1	7	9	75%	7	-0.05

* - Consistent weekly samples ceased after 11 weeks due to stagnant water conditions.

** - Statistically significant relationship at the 95 percent confidence interval.

Table 2. *E. coli* data collected weekly from May 19 through September 1, 2010. Green shading indicates that the daily maximum TBC or 30-day geometric mean WQS was met, yellow shading indicates that the daily maximum TBC or 30-day geometric mean WQS was exceeded, and red shading indicates that the PBC WQS was exceeded.

		1			2			3			4			5			
	Location	Cass River @ Bray Rd.			Cass River @ Main St.			Cass River @ Dixie Hwy.			Cass River @ Fort Rd.			Cass River @ M13			Precipitation in prior 24 hours
Date		Sample Results	Daily Geometric Mean.	30-day Geometric Mean	Sample Results	Daily Geometric Mean.	30-day Geometric Mean	Sample Results	Daily Geometric Mean.	30-day Geometric Mean	Sample Results	Daily Geometric Mean.	30-day Geometric Mean	Sample Results	Daily Geometric Mean.	30-day Geometric Mean	
	L	120			110			120			80			120			
5/19/2010	C	210			90			140			130			110			
	R	90	131		90	96		140	133		160	118		130	120		0.00
	L	40			10			40			30			40			
5/26/2010	C	60			20			50			20			30			
	R	60	52		40	20		150	67		70	35		100	49		0.00
	L	130			960			660			770			280			
6/3/2010	C	240			140			300			610			250			
	R	220	190		140	266		390	426		900	751		260	263		0.58
	L	140			160			190			200			110			
6/9/2010	C	110			120			180			170			120			
	R	170	138		160	145		270	210		150	172		70	97		0.20
	L	130			60			170			100			60			
6/16/2010	C	110			100			170			120			110			
	R	250	153	122	170	101	94	230	188	172	120	113	143	70	77	103	0.14
	L	100			320			360			150			140			
6/23/2010	C	160			410			230			180			130			
	R	120	124	121	520	409	126	250	275	199	260	191	158	120	130	105	0.33
	L	100			40			140			10			120			
6/30/2010	C	50			60			150			60			100			
	R	150	91	135	10	29	136	60	108	219	70	35	158	80	99	120	0.00
	L	50			< 10			70			40			70			
7/8/2010	C	40			30			30			< 10			110			
	R	110	60	108	30	10	70	20	35	132	10	7	62	90	88	97	0.00
	L	70			100			90			50			< 10			
7/14/2010	C	80			90			90			60			10			
	R	50	65	93	80	90	63	140	104	115	50	53	49	10	5	53	0.00
	L	80			60			420			70			< 10			
7/21/2010	C	60			70			40			20			10			
	R	60	66	78	190	93	62	80	33	103	80	48	42	60	8	34	0.06
	L	30			30			210			40			40			
7/28/2010	C	40			< 10			130			80			40			
	R	90	48	65	30	10	38	60	118	87	80	63	33	40	40	27	0.00
	L	80			20			60			50			150			
8/5/2010	C	110			20			100			60			80			
	R	120	102	66	30	23	28	140	94	85	50	53	36	120	113	27	0.00
	L	140			90			270			110			60			
8/11/2010	C	140			40			200			90			90			
	R	140	140	78	70	63	41	70	156	115	100	100	61	100	81	27	0.01
	L	120			20			180			210			60			
8/18/2010	C	130			100			140			170			50			
	R	160	136	91	50	46	36	140	152	124	190	189	79	< 10	14	34	0.00
	L	70			90			150			180			60			
8/25/2010	C	120			60			130			210			90			
	R	120	100	98	30	55	32	200	157	133	120	166	101	130	89	54	0.00
	L	250			20			120			110			80			
9/1/2010	C	320			20			70			110			90			
	R	270	278	140	70	30	41	190	117	133	60	90	108	90	87	63	0.00

Table 2 (continued).

		6			7			8			9			10			
	Location	Zehnder/Dead Creek @ Curtis Rd.			Cole Creek @ Ormes Rd.			Perry Creek @ Ormes Rd.			Millington Creek @ Loren Rd.			Unnamed Trib @ Van Cleve/ Tuscola Rd.			Precipitation in prior 24 hours
Date		Sample Results	Daily Geometric Mean.	30-day Geometric Mean	Sample Results	Daily Geometric Mean.	30-day Geometric Mean	Sample Results	Daily Geometric Mean.	30-day Geometric Mean	Sample Results	Daily Geometric Mean.	30-day Geometric Mean	Sample Results	Daily Geometric Mean.	30-day Geometric Mean	
	L	390			220			130			490			110			
5/19/2010	C	310			260			150			570			110			
	R	310	335		260	246		190	155		430	493		120	113		0.00
	L	290			610			330			210			5,100			
5/26/2010	C	380			540			240			100			5,000			
	R	380	347		590	579		230	263		250	174		4,000	4672		0.00
	L	960			650			630			380			2,200			
6/3/2010	C	930			800			700			340			2,800			
	R	980	956		780	740		710	679		350	356		2,200	2384		0.58
	L	440			420			370			1,600			3,500			
6/9/2010	C	430			350			290			1,300			3,300			
	R	470	446		440	401		300	318		1,200	1356		3,300	3365		0.20
	L	1,500			820			840			360			900			
6/16/2010	C	800			660			1,600			660			1,300			
	R	1,300	1160	565	660	710	496	720	989	387	520	498	460	1,800	1282	1403	0.14
	L	530			420			330			1,100			580			
6/23/2010	C	570			570			360			1,100			570			
	R	500	533	620	520	499	572	370	353	457	800	989	529	620	590	1952	0.33
	L	390			5,800			230			530			1,500			
6/30/2010	C	550			6,300			210			540			1,300			
	R	370	430	647	4,200	5354	892	250	229	444	500	523	659	1,400	1398	1533	0.00
	L	1,200			350			280			820			230			
7/8/2010	C	1,200			220			340			710			220			
	R	900	1090	664	260	272	730	290	302	378	700	741	763	120	182	917	0.00
	L	530			90			300			340			330			
7/14/2010	C	550			120			190			280			670			
	R	470	516	684	150	117	571	310	260	363	300	306	567	750	549	638	0.00
	L	30			530			450			180			21,000			
7/21/2010	C	130			480			710			210			21,000			
	R	100	73	393	570	525	537	350	482	314	190	193	469	32,000	24166	1148	0.06
	L	210			660			420			180			2,500			
7/28/2010	C	260			570			390			210			3,200			
	R	310	257	340	850	684	572	400	403	323	140	174	331	2,800	2819	1570	0.00
	L	570			190			440			520						
8/5/2010	C	530			220			410			570			no sample			
	R	650	581	361	210	206	298	460	436	367	430	503	329				0.00
	L	420			120			230			130						
8/11/2010	C	540			180			260			170			no sample			
	R	530	494	308	230	171	272	260	250	353	150	149	238				0.01
	L	330			1,500			300			150						
8/18/2010	C	430			900			260			160			no sample			
	R	370	374	289	1,000	1105	426	280	280	358	150	153	208				0.00
	L	560			430			270			600			40			
8/25/2010	C	460			440			360			470			40			
	R	550	521	428	470	446	412	260	293	325	410	487	250	40	40	336	0.00
	L	520			430			400			320						
9/1/2010	C	610			320			300			360			no sample			
	R	610	578	504	340	360	362	320	337	313	350	343	286				0.00

Table 3. Summary of sampling site locations, site geometric means, and TBC and PBC WQS exceedances for 5-week sampling period in 2012. 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.

Site	Site Description	Latitude	Longitude	Assessment Units	30-Day Geometric Mean		Number of WQS exceedances		Tests for Human Bacteroides	Positive Human Bacteroides Detections
					E. coli/ 100 mL	Rank	PBC	TBC		
C1	Cole Creek @ Bray Rd. (north)	43.29386	-83.66242	040802050305-05	253	8	1	1	1	1
C2	Calkins Drain @ Bray Rd. (south)	43.28490	-83.66239	040802050305-05	1981	2	4	5	3	3
S1	Smith Drain @ Murphy Lake Rd.	43.29511	-83.67879	040802050304-01	2344	1	5	5	3	3
D1	Dead Creek @ Lewis Rd.	43.24294	-83.68112	040802050304-01	480	5	0	5	2	2
P1	Burns Drain @ Birch Run Rd.	43.25204	-83.57312	040802050302-01	253	8	0	2	1	1
P2	Perry Creek @ Vassar Rd.	43.26277	-83.58235	040802050302-01	254	7	1	5	2	2
P3	Pedlow Drain / Perry Creek @ Irish Rd.	43.27956	-83.55928	040802050302-01	544	4	1	5	3	3
M1	Millington Creek @ Millington Rd.	43.28139	-83.51720	040802050303-01	920	3	2	5	2	2
M2	Millington Creek @ Murphy Lake Rd.	43.29584	-83.55536	040802050303-01	399	6	1	3	1	1

Table 4. *E. coli* data collected weekly from July 23 through August 21, 2012. “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. Green shading indicates that the daily maximum TBC or 30-day geometric mean WQS was met, yellow shading indicates that the daily maximum TBC or 30-day geometric mean WQS was exceeded, and red shading indicates that the PBC WQS was exceeded.

		C1 Cole Creek at Bray Rd. (north)			C2 Calkins Drain at Bray Rd. (south)			S1 Smith Drain at Murphy Lake Rd.			D1 Dead Creek at Lewis Rd.			P1 Burns Drain at Birch Run Rd.			
Date		Sample Results	Daily Geometric Mean	30-day Geometric Mean	Sample Results	Daily Geometric Mean	30-day Geometric Mean	Sample Results	Daily Geometric	30-day Geometric Mean	Sample Results	Daily Geometric Mean	30-day Geometric Mean	Sample Results	Daily Geometric Mean	30-day Geometric Mean	24-hour Prior Precipitation (inches)
	L	2,800			2,500			6,100			900			450			
7/23/2012	C	3,400			1,700			4,600			610			400			
	R	3,800	**3307**		2,600	**2227**		7,300	**5895**		680	**720**		540	**460**		0.0
	L	70			980			700			650			160			
7/30/2012	C	70			1,000			1,800			820			210			
	R	30	**53**		5,000	**1698**		1,200	**1148**		980	**805**		140	**168**		0.0
	L	100			1,400			8,700			470			150			
8/6/2012	C	220			1,300			7,700			330			150			
	R	260	**179**		2,000	**1538**		6,300	**7501**		360	**382**		140	**147**		0.0
	L	290			560			1,400			340			120			
8/13/2012	C	310			770			950			390			70			
	R	300	**300**		540	**615**		1,400	**1230**		400	**376**		100	**94**		0.0
	L	140			9,000			1,400			370			900			
8/21/2012	C	90			8,300			1,300			240			1,100			
	R	110	**111**	253	8,300	**8527**	1981	800	**1133**	2344	320	**305**	480	1,000	**997**	254	0.0

Table 4 (continued).

Date		P2 Perry Creek at Vassar Rd.			P3 Pedlow Drain / Perry Creek at Irish Rd.			M1 Millington Creek at Millington Rd.			M2 Millington Creek at Murphy Lake Rd.			24-hour Prior Precipitation (inches)
		Sample Results	Daily Geometric Mean	30-day Geometric Mean	Sample Results	Daily Geometric Mean	30-day Geometric Mean	Sample Results	Daily Geometric Mean	30-day Geometric Mean	Sample Results	Daily Geometric Mean	30-day Geometric Mean	
	L	790			1,100			1,900			560			
7/23/2012	C	1,000			1,300			2,000			450			
	R	1,500	**1058**		1,100	**1163**		1,500	**1786**		390	**461**		0.0
	L	430			660			490			300			
7/30/2012	C	530			710			540			480			
	R	560	**503**		460	**600**		360	**457**		230	**321**		0.0
	L	370			970			800			260			
8/6/2012	C	580			600			890			240			
	R	360	**426**		830	**785**		720	**800**		260	**253**		0.0
	L	610			800			380			1,400			
8/13/2012	C	510			560			550			1,200			
	R	520	**545**		790	**707**		530	**480**		1,200	**1263**		0.0
	L	400			460			1,500			150			
8/21/2012	C	370			390			2,700			290			
	R	390	**386**	544	470	**439**	701	2,300	**2104**	920	220	**212**	399	0.0

Table 5. 2006-era land cover allocated by basin and subbasin, including areas upstream (Subbasin 1) and downstream (Subbasin 5) of the study area. Subbasins 1 and 5 are not included in the basin subtotals or study area total.

Basin	Subbasin	Total Area	Cultivated Crops		Pasture/Hay		Developed, High Intensity		Developed, Medium Intensity		Developed, Low Intensity		Developed, Open Space		Developed (total)		Upland Natural		Wetland		Other	
		Acres	Acres	Percent	Acres	Percent	Acres	Percent	Acres	Percent	Acres	Percent	Acres	Percent	Acres	Percent	Acres	Percent	Acres	Percent	Acres	Percent
na	1*	488,937	213,518	44%	78,620	16%	488	0%	1,341	0%	9,869	2%	3,944	1%	15,642	3%	109,789	22%	69,529	14%	1,840	0%
Cass River	2	5,074	3,286	65%	645	13%	39	1%	47	1%	252	5%	113	2%	452	9%	439	9%	117	2%	129	3%
Cass River	3	7,043	3,194	45%	878	12%	79	1%	264	4%	656	9%	432	6%	1,430	20%	1,272	18%	196	3%	60	1%
Cass River	4	5,093	2,198	43%	316	6%	18	0%	81	2%	309	6%	144	3%	552	11%	1,830	36%	165	3%	33	1%
na	5*	7,508	2,913	39%	353	5%	100	1%	196	3%	574	8%	393	5%	1,263	17%	2,209	29%	679	9%	92	1%
Cass River	10	564	262	46%	28	5%	13	2%	37	6%	129	23%	87	15%	265	47%	7	1%	1	0%	0	0%
Cass River Basin Total*		17,774	8,941	50%	1,867	11%	149	1%	429	2%	1,346	8%	776	4%	2,699	15%	3,547	20%	479	3%	222	1%
Cole Creek	7	1,896	714	38%	173	9%	0	0%	2	0%	52	3%	111	6%	164	9%	725	38%	119	6%	1	0%
Cole Creek	C1	1,137	696	61%	245	22%	0	0%	0	0%	25	2%	0	0%	26	2%	162	14%	5	0%	3	0%
Cole Creek	C2	1,935	954	49%	315	16%	0	0%	0	0%	50	3%	1	0%	51	3%	538	28%	74	4%	3	0%
Cole Creek Basin Total		4,968	2,363	48%	733	15%	0	0%	2	0%	127	3%	112	2%	241	5%	1,425	29%	198	4%	7	0%
Dead Creek	6	12,747	6,793	53%	1,917	15%	26	0%	54	0%	437	3%	41	0%	558	4%	3,080	24%	352	3%	30	0%
Dead Creek	D1	7,151	1,406	20%	1,231	17%	3	0%	10	0%	254	4%	122	2%	389	5%	3,423	48%	673	9%	11	0%
Dead Creek	S1	1,493	507	34%	339	23%	0	0%	1	0%	46	3%	3	0%	51	3%	526	35%	65	4%	5	0%
Dead Creek Basin Total		21,391	8,706	41%	3,487	16%	28	0%	65	0%	737	3%	167	1%	997	5%	7,029	33%	1,090	5%	46	0%
Millington Creek	9	5,242	2,223	42%	815	16%	1	0%	8	0%	105	2%	4	0%	118	2%	1,484	28%	586	11%	15	0%
Millington Creek	M1	7,708	1,492	19%	1,706	22%	2	0%	7	0%	97	1%	12	0%	119	2%	2,867	37%	1,477	19%	37	0%
Millington Creek	M2	1,078	174	16%	138	13%	16	2%	36	3%	110	10%	69	6%	231	21%	379	35%	145	13%	9	1%
Millington Creek Basin Total		14,028	3,889	28%	2,660	19%	19	0%	51	0%	313	2%	85	1%	468	3%	4,731	34%	2,208	16%	62	0%
Perry Creek	8	7,375	3,472	47%	1,358	18%	0	0%	2	0%	154	2%	2	0%	158	2%	1,731	23%	637	9%	20	0%
Perry Creek	P1	2,451	1,451	59%	598	24%	2	0%	5	0%	54	2%	2	0%	64	3%	236	10%	102	4%	1	0%
Perry Creek	P2	11,511	4,159	36%	2,686	23%	0	0%	7	0%	215	2%	21	0%	243	2%	3,233	28%	1,038	9%	141	1%
Perry Creek	P3	3,535	1,591	45%	683	19%	12	0%	29	1%	144	4%	37	1%	221	6%	757	21%	276	8%	6	0%
Perry Creek Basin Total		24,872	10,673	43%	5,325	21%	15	0%	42	0%	568	2%	62	0%	686	3%	5,956	24%	2,053	8%	167	1%
Total Area		83,033	34,571	42%	14,072	17%	211	0%	589	1%	3,091	4%	1,201	1%	5,092	6%	22,689	27%	6,027	7%	504	1%

* Subbasins 1 and 5 are not included in TMDL area

Table 6. Estimated stream flow (cubic feet per second), drainage areas (square miles), and probability of flow exceedance at sites and dates monitored in 2010.

Site ID		UGSG Gauge No. 4151500	1	2	3	4	5	6	7	8	9	10	Probability of Flow Exceedance at USGS Station
Site Description		Cass River at Frankenmuth	Cass at Bray	Cass at Main	Cass at Dixie	Cass at Fort	Cass at M-13	Zehnder/Dead Creek at Curtis Rd.	Cole Creek at Ormes Rd.	Perry Creek at Ormes Rd.	Millington Creek at Loren Rd.	Unnamed Trib at Van Cleve/ Tuscola Rd.	
Flows (in cfs) on each sampling date	5/19/2010	907	889	907	912	912	923	26.30	7.89	45.90	23.90	1.06	15%
	5/26/2010	265	260	265	276	276	279	4.50	1.76	13.70	5.41	0.32	42%
	6/3/2010	186	182	186	196	196	198	2.70	1.14	9.70	3.53	0.23	52%
	6/9/2010	450	441	450	462	462	467	9.60	3.35	23.10	10.26	0.54	29%
	6/16/2010	162	159	162	171	171	173	2.20	0.96	8.40	2.99	0.2	56%
	6/23/2010	109	107	109	116	116	118	1.20	0.59	5.70	1.85	0.14	67%
	6/30/2010	164	161	164	173	173	175	2.20	0.98	8.60	3.03	0.2	56%
	7/8/2010	68	67	68	74	74	74	0.60	0.33	3.60	1.05	0.09	82%
	7/14/2010	66	65	66	71	71	72	0.60	0.32	3.50	1.01	0.08	83%
	7/21/2010	119	117	119	127	127	128	1.40	0.66	6.20	2.06	0.15	65%
	7/28/2010	75	74	75	81	81	82	0.70	0.38	4.00	1.18	0.09	79%
	8/5/2010	51	50	51	56	56	56	0.40	0.24	2.70	0.74	0.06	90%
	8/11/2010	49	48	49	54	54	54	0.40	0.22	2.60	0.71	na	91%
	8/18/2010	44	43	44	48	48	49	0.30	0.20	2.30	0.62	na	94%
	8/25/2010	44	43	44	48	48	49	0.30	0.20	2.30	0.62	na	94%
	9/1/2010	42	41	42	46	46	47	0.30	0.19	2.20	0.59	na	94%
Drainage Area (sq mi)		842	825	842	886	855	906	33.40	7.76	38.86	21.92	0.88	

Table 7. Estimated stream flow (cubic feet per second), drainage areas (square miles), and probability of flow exceedance at sites and dates monitored in 2012.

Site ID		UGSG Gauge No. 4151500	C1	C2	S1	D1	P1	P2	P3	M1	M2	Probability of Flow Exceedance at USGS Station
Site Description		Cass River at Frankenmuth	Cole Creek @ Bray Rd. (north)	Calkins Drain @ Bray Rd. (south)	Smith Drain @ Murphy Lake Rd.	Dead Creek @ Lewis Rd.	Burns Drain @ Birch Run Rd.	Perry Creek @ Vassar Rd.	Pedlow Drain/Perry Creek @ Irish Rd.	Millington Creek @ Millington Rd.	Millington Creek @ Murphy Lake Rd.	
Estimated Stream Flow on Sampling Dates (in cubic feet per second)	7/23/2012	49	0.05	0.09	0.03	0.13	0.26	1.21	0.37	0.39	0.44	85%
	7/30/2012	100	0.12	0.21	0.08	0.37	0.52	2.44	0.75	0.92	1.04	30%
	8/6/2012	68	0.08	0.13	0.04	0.21	0.35	1.67	0.51	0.58	0.66	50%
	8/13/2012	385	0.64	1.08	0.53	2.56	1.95	9.16	2.81	4.69	5.31	<5%
	8/21/2012	81	0.09	0.16	0.06	0.27	0.42	1.98	0.61	0.71	0.81	40%
Drainage Area (square miles)		842	1.78	3.02	2.33	11.2	3.83	18	5.52	12.1	13.7	

Table 8. List of locations and descriptions of AFOs and active pasture in the source area as determined by remote sensing and visual observations. 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.
*=CAFO

ID	Latitude	Longitude	Animal	Size of Operation	Type of Operation	Basin	Subbasin	Catchment	Within 1000 feet of stream?
1	43.26600	-83.46124	mixed	small	pasture	millington	M1	58	
2	43.26675	-83.47952	horses	small	pasture	millington	M2	58	
3	43.26651	-83.46751	horses	unknown	pasture	millington	M3	58	yes
4	43.26675	-83.47611	horses	small	pasture	millington	M4	58	yes
5	43.26664	-83.49818	cattle	small	pasture	millington	M5	59	yes
6	43.25220	-83.47068	horses	small	pasture	millington	M6	60	yes
7	43.25730	-83.48088	horses	small	pasture	millington	M7	60	yes
8	43.22287	-83.51569	mixed	small	pasture	millington	M8	90	
9	43.22290	-83.51085	mixed	medium	pasture	millington	M9	90	
10	43.22290	-83.51011	horses	small	pasture	millington	M10	90	
11	43.22299	-83.48658	horses	small	pasture	millington	M11	90	
12	43.22568	-83.48104	horses	small	pasture	millington	M12	90	
13	43.23127	-83.50015	cattle	medium	pasture	millington	M13	90	yes
14	43.23656	-83.48050	horses	small	pasture	millington	M14	90	yes
15	43.23762	-83.47968	horses	small	pasture	millington	M15	90	yes
16	43.30724	-83.59857	cattle	large	pasture	millington	9	42	yes
17	43.29419	-83.58301	horses	small	pasture	millington	9	42	
18	43.29549	-83.59706	horses	small	pasture	millington	9	42	
19	43.29557	-83.57685	horses	small	pasture	millington	9	42	yes
20	43.29966	-83.58318	unknown	small	pasture	millington	9	42	yes
21	43.30059	-83.58321	cattle	medium	pasture	millington	9	42	yes
22	43.30714	-83.61379	cattle	small	pasture	millington	9	42	yes
23	43.30725	-83.59506	horses	small	pasture	millington	9	42	yes
24	43.30666	-83.58338	cattle	large	feedlot	millington	9	77	yes
25	43.31719	-83.58354	horses	large	pasture	millington	9	77	
26	43.31719	-83.58354	unknown	small	pasture	millington	9	77	
27	43.32928	-83.62381	horses	small	pasture	millington	9	77	yes
28	43.30731	-83.58285	cattle	large	feedlot	millington	9	78	yes
29	43.29586	-83.54185	horses	small	pasture	millington	9	78	
30	43.30739	-83.57606	cattle	small	pasture	millington	9	78	yes
31	43.25213	-83.51531	sheep	medium	pasture	perry	P3	54	
32	43.25212	-83.50825	cattle	medium	pasture	perry	P3	54	
33	43.25223	-83.50916	unknown	small	pasture	perry	P3	54	
34	43.26670	-83.52351	unknown	small	pasture	perry	P3	54	yes
35	43.26673	-83.51815	horses	small	pasture	perry	P3	54	
36	43.23945	-83.51976	unknown	small	pasture	perry	P3	56	yes
37	43.24235	-83.52925	cattle	medium	pasture	perry	P3	56	

Table 8 (continued).

ID	Latitude	Longitude	Animal	Size of Operation	Type of Operation	Basin	Subbasin	Catchment	Within 1000 feet of stream?
38	43.25102	-83.52948	horses	small	pasture	perry	P3	56	yes
39	43.25210	-83.52379	horses	small	pasture	perry	P3	56	yes
40	43.25192	-83.54028	poultry	large	feedlot	perry	P3	88	yes
41	43.25332	-83.53875	unknown	large	feedlot	perry	P3	88	yes
42	43.25421	-83.53878	cattle	medium	pasture	perry	P3	88	yes
43*	43.24928	-83.55884	poultry	large	feedlot	perry	P1	47	yes
44	43.24156	-83.53867	horses	medium	pasture	perry	P1	47	yes
45	43.24206	-83.53866	cattle	small	pasture	perry	P1	47	yes
46	43.25191	-83.54508	horses	small	pasture	perry	P1	47	
47	43.23740	-83.57442	horses	small	pasture	perry	P1	48	yes
48	43.22925	-83.55875	cattle	large	feedlot	perry	P1	79	
49	43.22999	-83.56865	horses	small	pasture	perry	P1	79	
50	43.23288	-83.56875	horses	small	pasture	perry	P1	79	
51	43.23654	-83.53859	unknown	unknown	pasture	perry	P1	79	yes
52	43.23720	-83.54501	horses	small	pasture	perry	P1	79	yes
53	43.23725	-83.54022	horses	small	pasture	perry	P1	79	yes
54	43.23820	-83.53861	horses	small	pasture	perry	P1	79	yes
55	43.23928	-83.56887	horses	small	pasture	perry	P1	79	yes
56	43.22281	-83.56780	unknown	small	pasture	perry	P2	49	yes
57	43.22488	-83.56854	horses	small	pasture	perry	P2	49	yes
58	43.19439	-83.57251	horses	small	pasture	perry	P2	50	
59	43.19440	-83.57018	unknown	small	pasture	perry	P2	50	
60	43.20254	-83.56999	horses	small	pasture	perry	P2	50	yes
61	43.20695	-83.60112	horses	small	pasture	perry	P2	50	yes
62	43.20865	-83.59445	cattle	medium	pasture	perry	P2	50	yes
63	43.20871	-83.58693	horses	small	pasture	perry	P2	50	yes
64	43.20911	-83.57737	horses	small	pasture	perry	P2	50	
65	43.20913	-83.57731	unknown	small	pasture	perry	P2	50	
66	43.21361	-83.58130	horses	small	pasture	perry	P2	50	
67	43.21411	-83.60127	horses	small	pasture	perry	P2	50	
68	43.21601	-83.58136	unknown	small	pasture	perry	P2	50	yes
69	43.21657	-83.60133	cattle	small	pasture	perry	P2	50	yes
70	43.22229	-83.61613	horses	small	pasture	perry	P2	50	
71	43.22604	-83.60408	horses	small	pasture	perry	P2	50	
72	43.22798	-83.61126	unknown	small	pasture	perry	P2	50	yes
73	43.21861	-83.55024	horses	small	pasture	perry	P2	51	yes
74	43.19918	-83.56003	horses	small	pasture	perry	P2	52	
75	43.20787	-83.57011	cattle	medium	pasture	perry	P2	52	yes
76	43.20929	-83.56600	horses	small	pasture	perry	P2	52	
77	43.21082	-83.57010	unknown	unknown	pasture	perry	P2	52	yes
78	43.21480	-83.56999	horses	small	pasture	perry	P2	52	yes

Table 8 (continued).

ID	Latitude	Longitude	Animal	Size of Operation	Type of Operation	Basin	Subbasin	Catchment	Within 1000 feet of stream?
79	43.19894	-83.60096	horses	small	pasture	perry	P2	53	yes
80	43.20196	-83.60099	horses	small	pasture	perry	P2	53	yes
81	43.25164	-83.60905	horses	small	pasture	perry	P2	80	
82	43.25164	-83.59282	horses	small	pasture	perry	P2	80	yes
83	43.23706	-83.59435	cattle	large	feedlot	perry	P2	81	yes
84	43.22313	-83.58153	horses	small	pasture	perry	P2	81	
85	43.23078	-83.60139	horses	small	pasture	perry	P2	81	
86	43.23698	-83.60199	horses	small	pasture	perry	P2	81	
87	43.23703	-83.59688	horses	small	pasture	perry	P2	81	yes
88	43.24071	-83.59427	horses	small	pasture	perry	P2	81	
89	43.24433	-83.60362	horses	small	pasture	perry	P2	81	
90	43.23687	-83.62564	cattle	small	pasture	perry	P2	82	
91	43.21299	-83.64119	horses	small	pasture	perry	P2	83	
92	43.21529	-83.64124	horses	small	pasture	perry	P2	83	
93	43.21807	-83.62103	horses	small	pasture	perry	P2	83	
94	43.21860	-83.64116	horses	small	pasture	perry	P2	83	
95	43.22283	-83.54248	horses	small	pasture	perry	P2	84	
96	43.22280	-83.55529	horses	small	pasture	perry	P2	84	yes
97	43.22275	-83.54583	unknown	unknown	pasture	perry	P2	84	yes
98	43.22275	-83.54209	goat	small	pasture	perry	P2	84	
99	43.22283	-83.53752	unknown	small	pasture	perry	P2	84	
100	43.22285	-83.53295	horses	small	pasture	perry	P2	84	
101	43.22286	-83.52825	cattle	large	pasture	perry	P2	84	
102	43.20858	-83.62471	horses	small	pasture	perry	P2	86	yes
103	43.30238	-83.62293	cattle	large	pasture	perry	8	39	yes
104	43.26621	-83.59622	horses	small	pasture	perry	8	39	
105	43.26621	-83.59004	horses	small	pasture	perry	8	39	
106	43.27163	-83.59467	mixed	small	pasture	perry	8	39	yes
107	43.27171	-83.59826	horses	small	pasture	perry	8	39	yes
108	43.27839	-83.60233	cattle	small	pasture	perry	8	39	yes
109	43.28068	-83.58775	horses	small	pasture	perry	8	39	
110	43.28085	-83.59506	horses	medium	pasture	perry	8	39	yes
111	43.28083	-83.59190	horses	small	pasture	perry	8	39	
112	43.28088	-83.59220	horses	small	pasture	perry	8	39	
113	43.28093	-83.57451	horses	small	pasture	perry	8	39	
114	43.28099	-83.57235	cattle	medium	pasture	perry	8	39	yes
115	43.28534	-83.58281	cattle	small	pasture	perry	8	39	yes
116	43.30710	-83.61827	cattle	small	pasture	perry	8	39	
117	43.28129	-83.61012	cattle	small	pasture	perry	8	74	yes
118	43.27494	-83.55919	horses	small	pasture	perry	8	76	
119	43.26651	-83.58018	horses	small	pasture	perry	8	76	yes
120	43.26586	-83.58243	horses	small	pasture	perry	8	76	yes

Table 8 (continued).

ID	Latitude	Longitude	Animal	Size of Operation	Type of Operation	Basin	Subbasin	Catchment	Within 1000 feet of stream?
121	43.25194	-83.57593	cattle	medium	pasture	perry	8	76	yes
122	43.26662	-83.56882	unknown	medium	pasture	perry	8	76	yes
123	43.26764	-83.55910	unknown	small	pasture	perry	8	76	
124	43.27430	-83.55916	horses	small	pasture	perry	8	76	
125	43.27754	-83.55922	horses	small	pasture	perry	8	76	yes
126	43.26626	-83.62966	cattle	small	pasture	cole	C1	37	yes
127	43.28064	-83.65220	unknown	small	pasture	cole	C1	37	
128	43.29284	-83.66255	horses	small	pasture	cole	C1	37	yes
129	43.29542	-83.65147	horses	small	pasture	cole	C1	37	yes
130	43.25164	-83.63131	horses	small	pasture	cole	C2	44	
131	43.26794	-83.64213	unknown	small	pasture	cole	C2	44	yes
132	43.26611	-83.65215	cattle	large	pasture	cole	C2	45	yes
133	43.26609	-83.65401	horses	small	pasture	cole	C2	45	
134	43.26624	-83.64445	unknown	small	pasture	cole	C2	45	yes
135	43.30367	-83.66264	horses	small	pasture	cole	7	36	
136	43.30681	-83.68370	horses	large	pasture	cole	7	36	
137	43.29523	-83.66432	horses	small	pasture	cole	7	99	yes
138	43.35027	-83.70931	cattle	large	feedlot	cass	2	5	yes
139	43.35075	-83.71818	cattle	small	pasture	cass	2	5	yes
140	43.32144	-83.71548	cattle	large	feedlot	cass	2	6	yes
141	43.33622	-83.69229	cattle	large	feedlot	cass	2	7	
142	43.32136	-83.70658	cattle	small	pasture	cass	2	9	
143	43.31809	-83.68329	cattle	medium	pasture	cass	2	97	yes
144	43.22179	-83.65715	horses	small	pasture	dead	D1	27	yes
145	43.23524	-83.64098	cattle	large	pasture	dead	D1	27	yes
146	43.21896	-83.64115	horses	small	pasture	dead	D1	27	
147	43.22943	-83.64089	horses	small	pasture	dead	D1	27	yes
148	43.23677	-83.63119	horses	small	pasture	dead	D1	27	
149	43.23677	-83.63066	horses	small	pasture	dead	D1	27	
150	43.24083	-83.64129	horses	small	pasture	dead	D1	27	
151	43.20820	-83.65713	cattle	small	pasture	dead	D1	30	
152	43.20812	-83.63461	horses	small	pasture	dead	D1	31	yes
153	43.22981	-83.66096	horses	small	pasture	dead	D1	69	yes
154	43.23638	-83.66109	horses	small	pasture	dead	D1	69	yes
155	43.23664	-83.65170	cattle	large	feedlot	dead	D1	69	
156	43.18987	-83.66048	horses	medium	pasture	dead	D1	71	
157	43.19353	-83.65398	unknown	small	pasture	dead	D1	71	
158	43.19584	-83.66070	horses	small	pasture	dead	D1	71	
159	43.20144	-83.66088	horses	small	pasture	dead	D1	71	yes
160	43.18717	-83.64047	elk	medium	pasture	dead	D1	72	yes
161	43.19088	-83.62060	horses	medium	pasture	dead	D1	72	

Table 8 (continued).

ID	Latitude	Longitude	Animal	Size of Operation	Type of Operation	Basin	Subbasin	Catchment	Within 1000 feet of stream?
162	43.19433	-83.61533	horses	medium	pasture	dead	D1	72	
163	43.19544	-83.62078	mixed	medium	pasture	dead	D1	72	
164	43.26589	-83.67078	horses	small	pasture	dead	S1	32	yes
165	43.26102	-83.67163	cattle	large	pasture	dead	S1	34	yes
166	43.24337	-83.66116	horses	small	pasture	dead	S1	34	yes
167	43.31196	-83.73489	mixed	medium	pasture	dead	6	11	yes
168	43.30593	-83.69537	cattle	small	pasture	dead	6	12	yes
169	43.31237	-83.71513	horses	small	pasture	dead	6	12	yes
170	43.30061	-83.76858	unknown	small	pasture	dead	6	16	
171	43.30059	-83.76601	horses	medium	pasture	dead	6	16	
172	43.28877	-83.70533	cattle	large	feedlot	dead	6	17	yes
173	43.30104	-83.79430	cattle	large	feedlot	dead	6	19	
174	43.29479	-83.79431	dogs	small	other	dead	6	19	
175	43.30709	-83.78251	horses	large	pasture	dead	6	20	yes
176	43.30206	-83.77440	horses	small	pasture	dead	6	20	yes
177	43.25901	-83.67473	cattle	large	pasture	dead	6	21	yes
178	43.24379	-83.68112	horses	medium	pasture	dead	6	21	yes
179	43.25118	-83.67483	horses	small	pasture	dead	6	21	yes
180	43.25317	-83.68120	horses	small	pasture	dead	6	21	yes
181	43.25865	-83.68124	cattle	medium	pasture	dead	6	21	
182	43.27168	-83.69575	cattle	large	pasture	dead	6	21	yes
183	43.27538	-83.68133	unknown	small	pasture	dead	6	21	yes
184	43.28036	-83.68993	cattle	medium	pasture	dead	6	21	yes
185	43.28044	-83.67680	cattle	large	feedlot	dead	6	21	
186	43.28368	-83.68147	unknown	small	pasture	dead	6	21	yes
187	43.28716	-83.68149	horses	small	pasture	dead	6	21	yes
188	43.28849	-83.73546	unknown	small	pasture	dead	6	22	
189	43.29326	-83.76176	cattle	small	pasture	dead	6	24	yes
190	43.27891	-83.75191	horses	small	pasture	dead	6	25	yes
191	43.27917	-83.69749	horses	medium	pasture	dead	6	68	yes
192	43.27898	-83.70227	horses	small	pasture	dead	6	68	yes
193	43.28636	-83.70120	horses	small	pasture	dead	6	68	
194	43.28517	-83.77434	horses	small	pasture	dead	6	96	yes
195	43.34363	-83.78866	cattle	large	feedlot	cass	3	2	
196	43.34798	-83.77873	cattle	small	pasture	cass	3	2	
197	43.34936	-83.79888	cattle	medium	pasture	cass	3	2	
198	43.35050	-83.81693	cattle	large	feedlot	cass	3	2	yes
199	43.33221	-83.76279	cattle	small	pasture	cass	3	3	yes
200	43.34560	-83.72823	cattle	large	feedlot	cass	3	3	yes
201	43.32131	-83.80297	horses	medium	pasture	cass	3	93	yes
202	43.31874	-83.82112	horses	small	pasture	cass	3	93	

Table 8 (continued).

ID	Latitude	Longitude	Animal	Size of Operation	Type of Operation	Basin	Subbasin	Catchment	Within 1000 feet of stream?
203	43.32154	-83.83105	horses	small	pasture	cass	3	93	yes
204	43.32154	-83.83017	horses	small	pasture	cass	3	93	yes
205	43.32120	-83.80642	horses	medium	pasture	cass	3	93	yes
206	43.32120	-83.80642	horses	medium	pasture	cass	3	93	yes
207	43.34869	-83.75852	horses	small	pasture	cass	3	95	
208	43.33148	-83.85344	unknown	small	pasture	cass	4	63	yes
209	43.32159	-83.83727	horses	medium	pasture	cass	4	64	
210	43.34017	-83.87571	cattle	small	pasture	cass	4	91	yes
211	43.32193	-83.88187	unknown	small	pasture	cass	4	91	
212	43.32382	-83.88481	horses	unknown	pasture	cass	4	91	yes
213	43.32921	-83.88188	horses	small	pasture	cass	4	91	yes
214	43.33335	-83.85536	cattle	small	pasture	cass	4	91	yes
215	43.34013	-83.87286	unknown	small	pasture	cass	4	91	yes
216	43.35755	-83.84175	horses	small	pasture	cass	4	92	

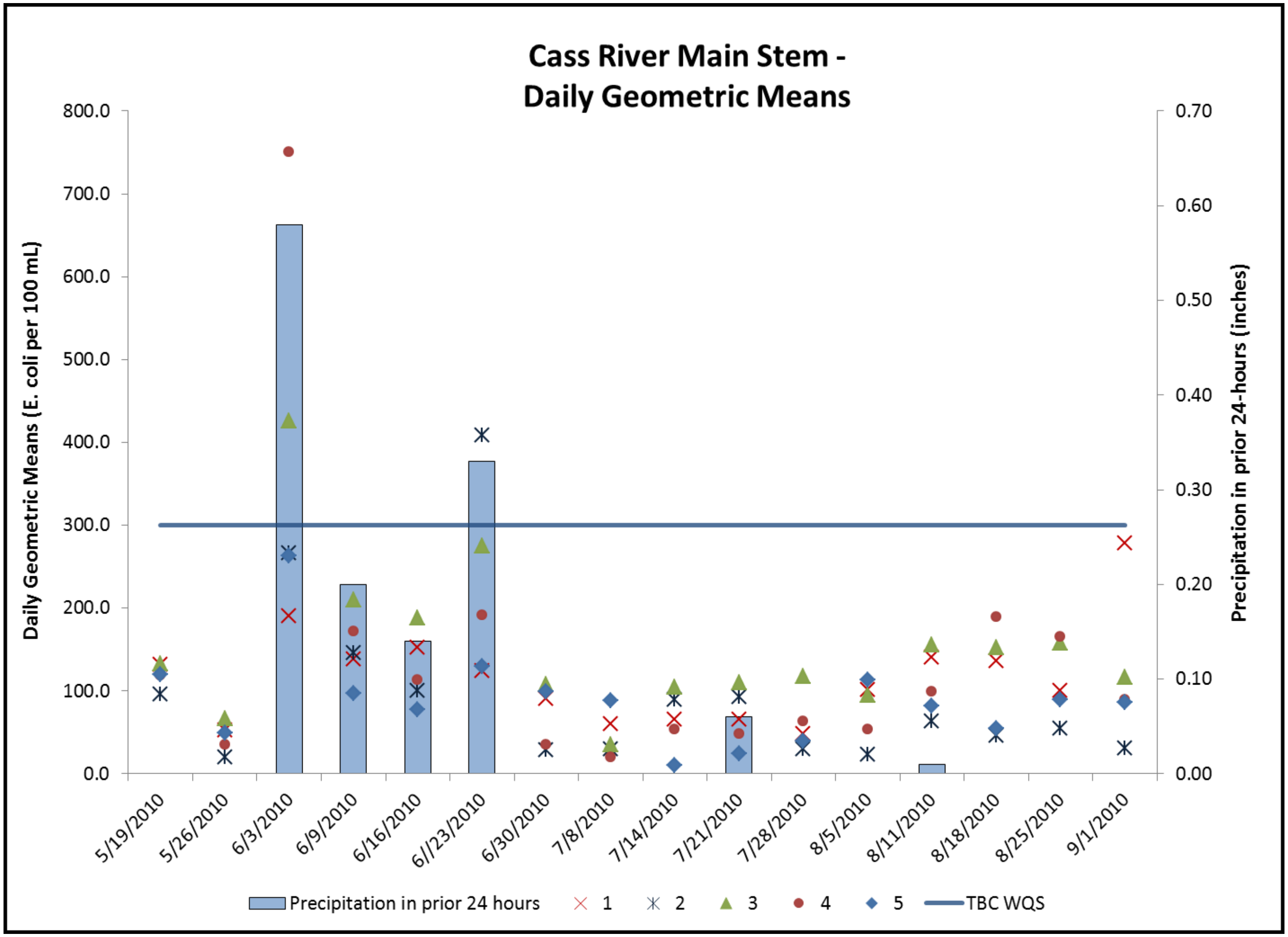


Figure 1. Daily geometric means for mainstem Cass River sites (1-5) and precipitation in the prior 24 hours to sample collection in 2010.

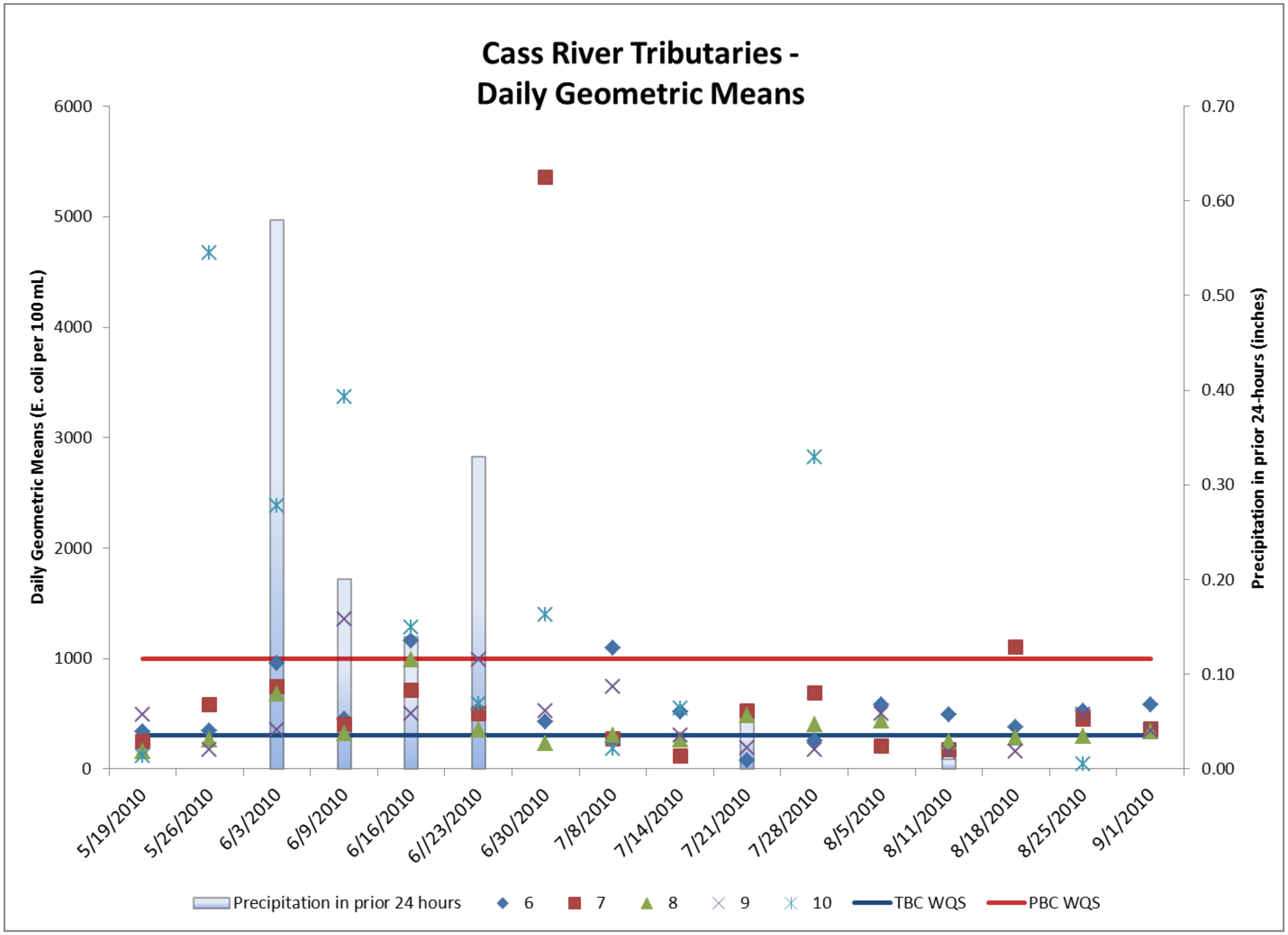


Figure 2. Daily geometric means for tributary sites (6-10) and precipitation in the prior 24 hours to sample collection in 2010. The extremely high result for Site 10, sampled on July 21, 2010 (24,166 *E. coli* per 100 mL) is not shown on the chart.

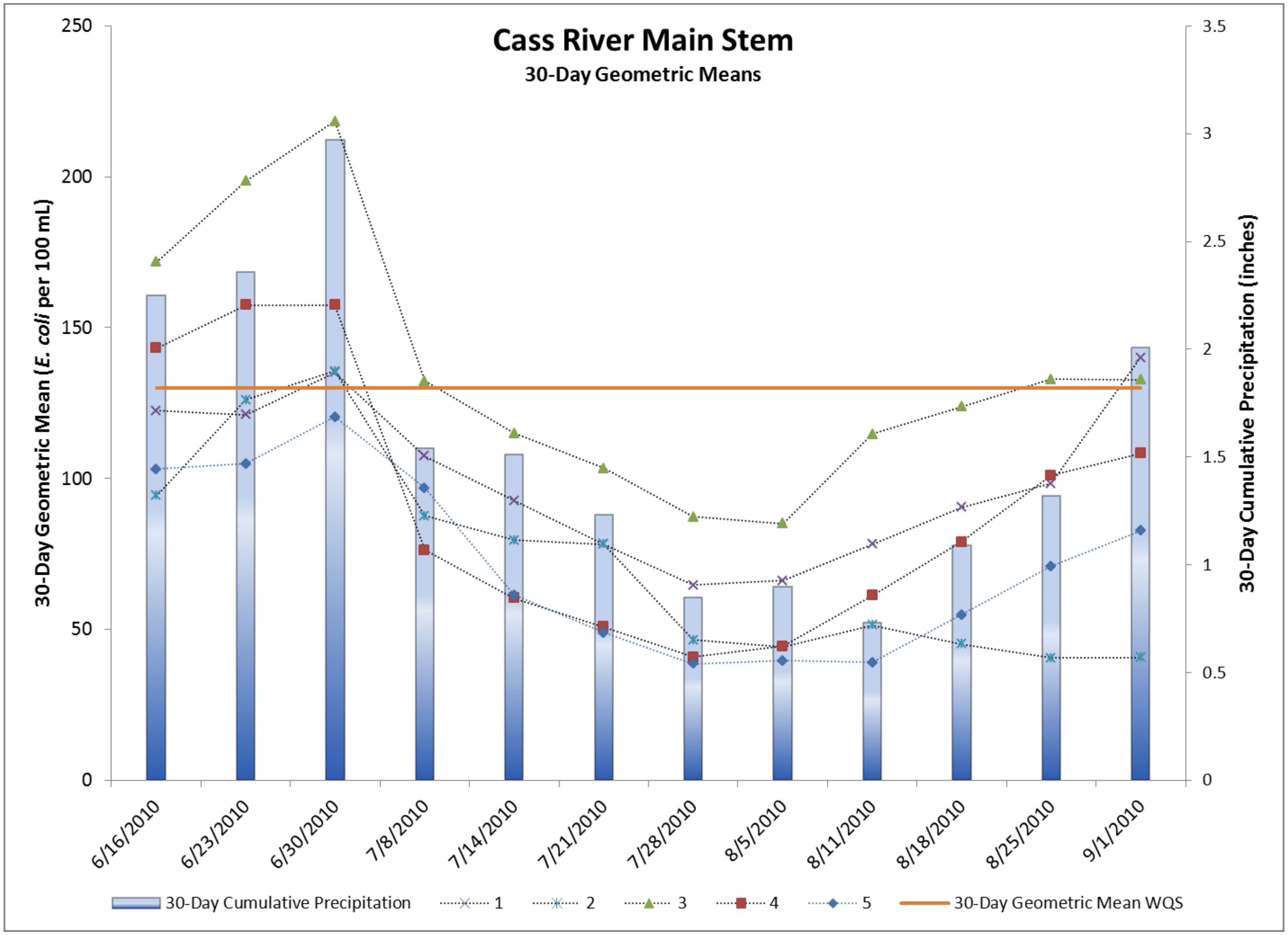


Figure 3. 30-day geometric means for mainstem Cass River sites (1-5) and 30-day cumulative precipitation, collected in 2010.

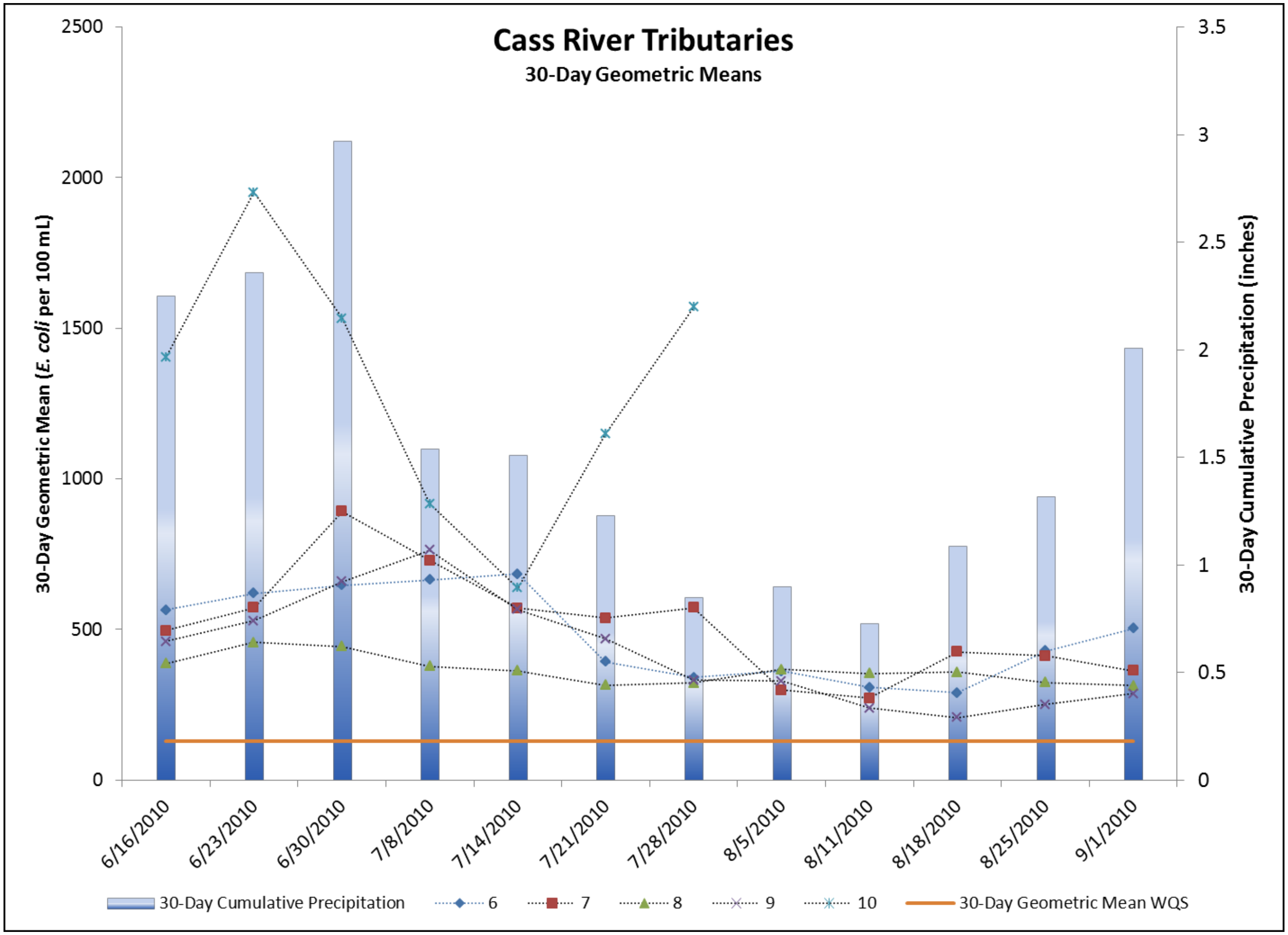


Figure 4. 30-day geometric means for tributary sites (6-10) and 30-day cumulative precipitation, collected in 2010.

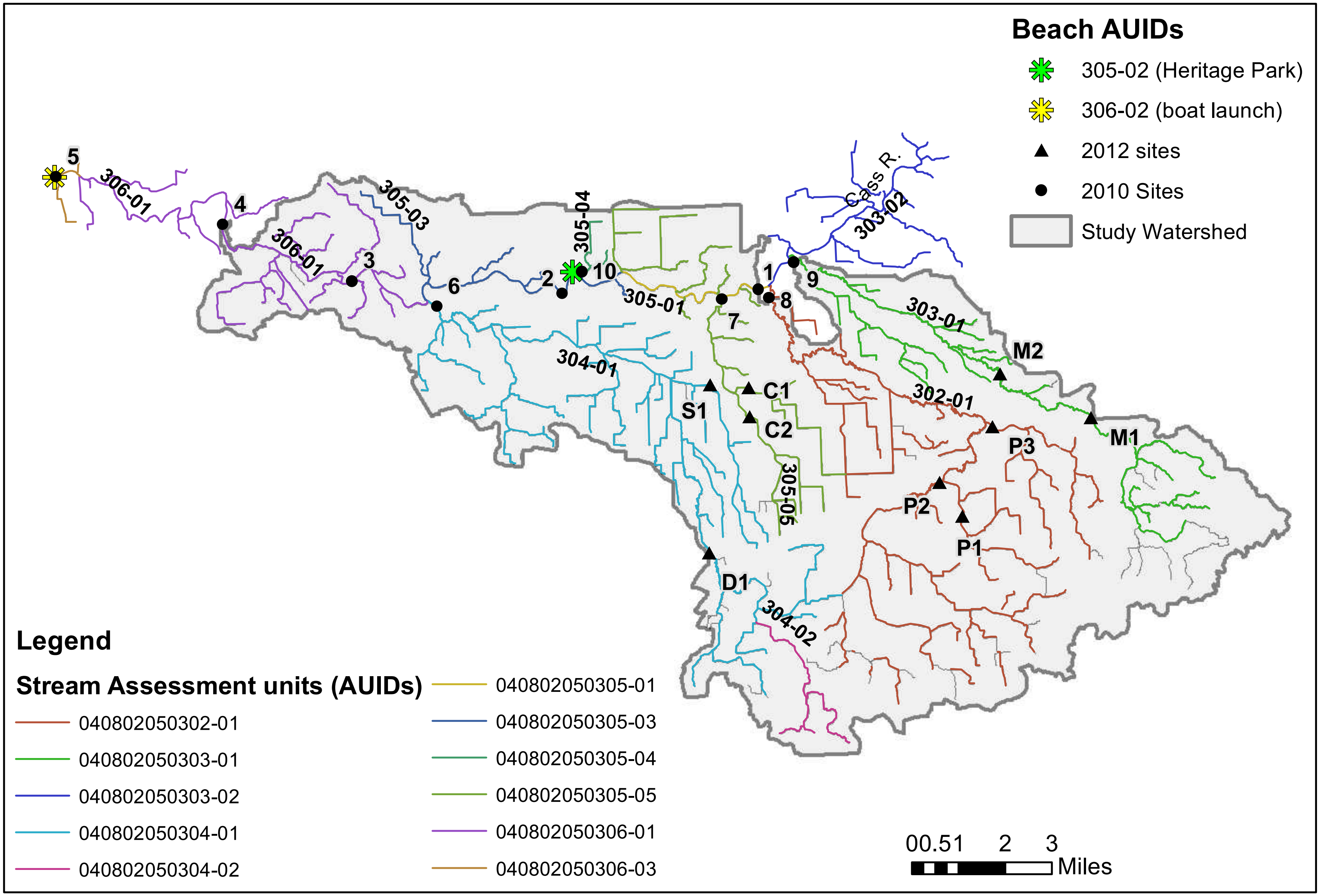


Figure 5. Assessment Unit IDs (AUIDs) in relation to sampling sites in the study watershed.

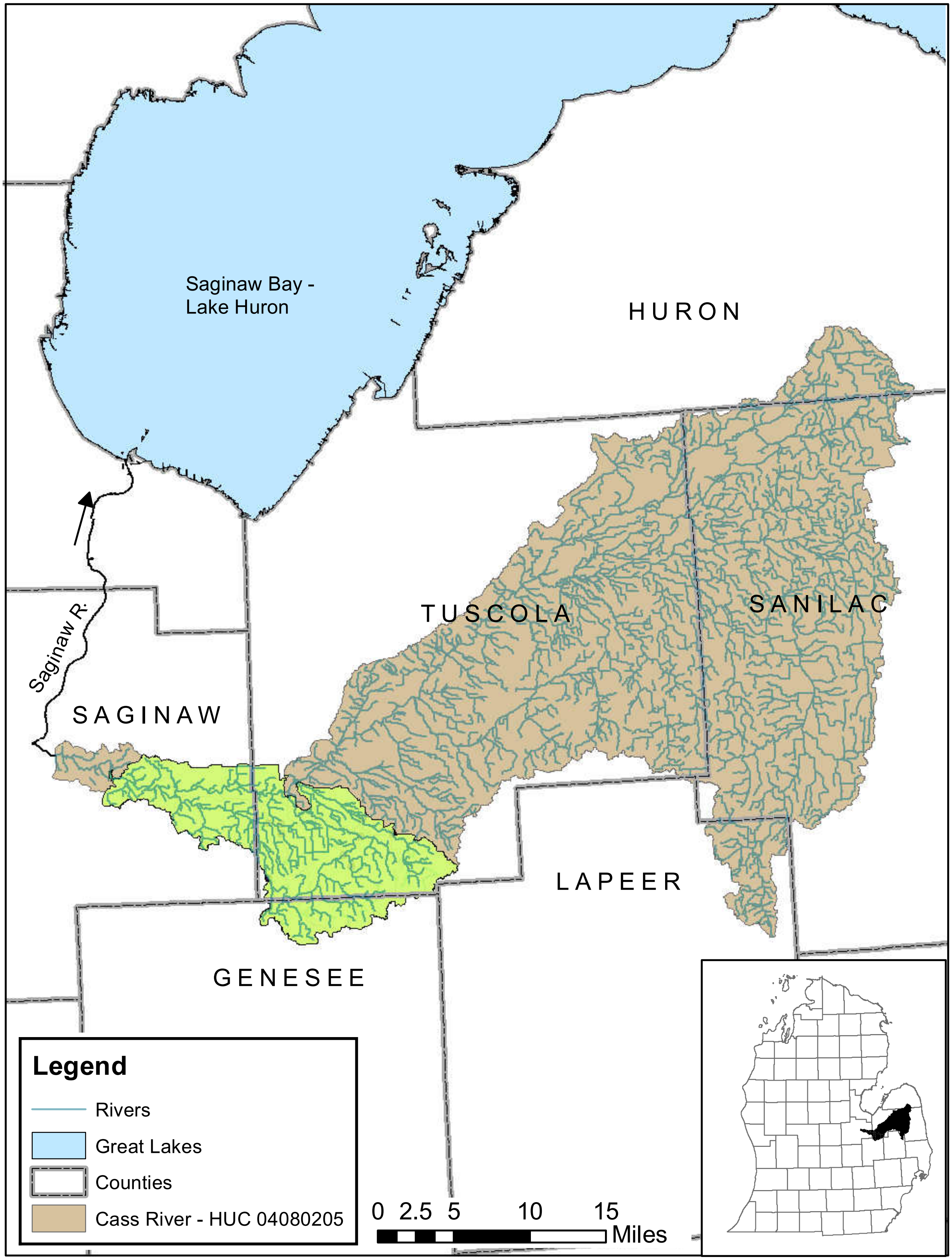


Figure 6. Overview of the Cass River watershed (hydrologic unit code: 4080205), drainage to Saginaw Bay, and location of the study watershed.

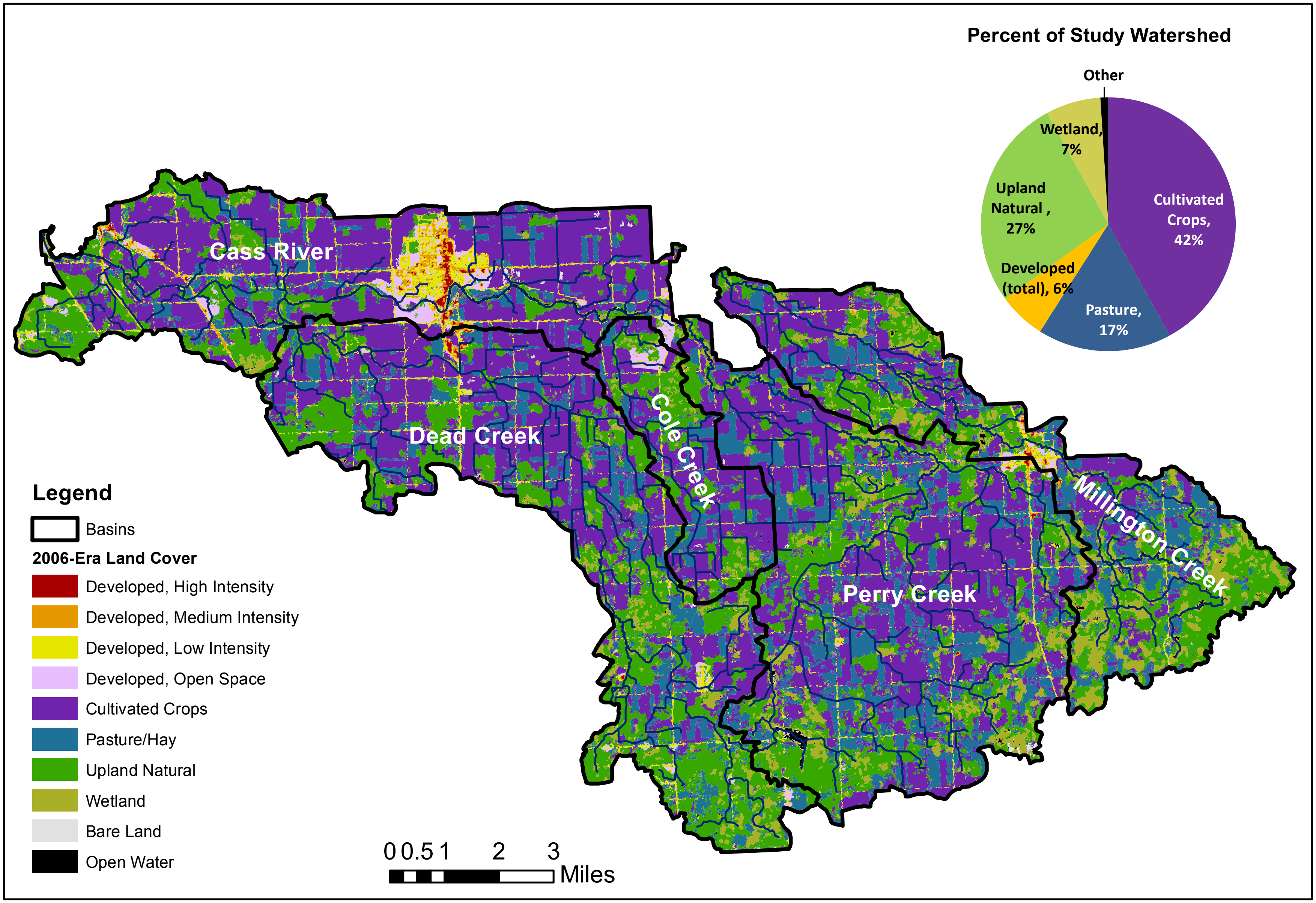


Figure 7. 2006-era land cover data (NOAA, 2008) for the study watershed, and a chart representing the percent coverage of major land types.

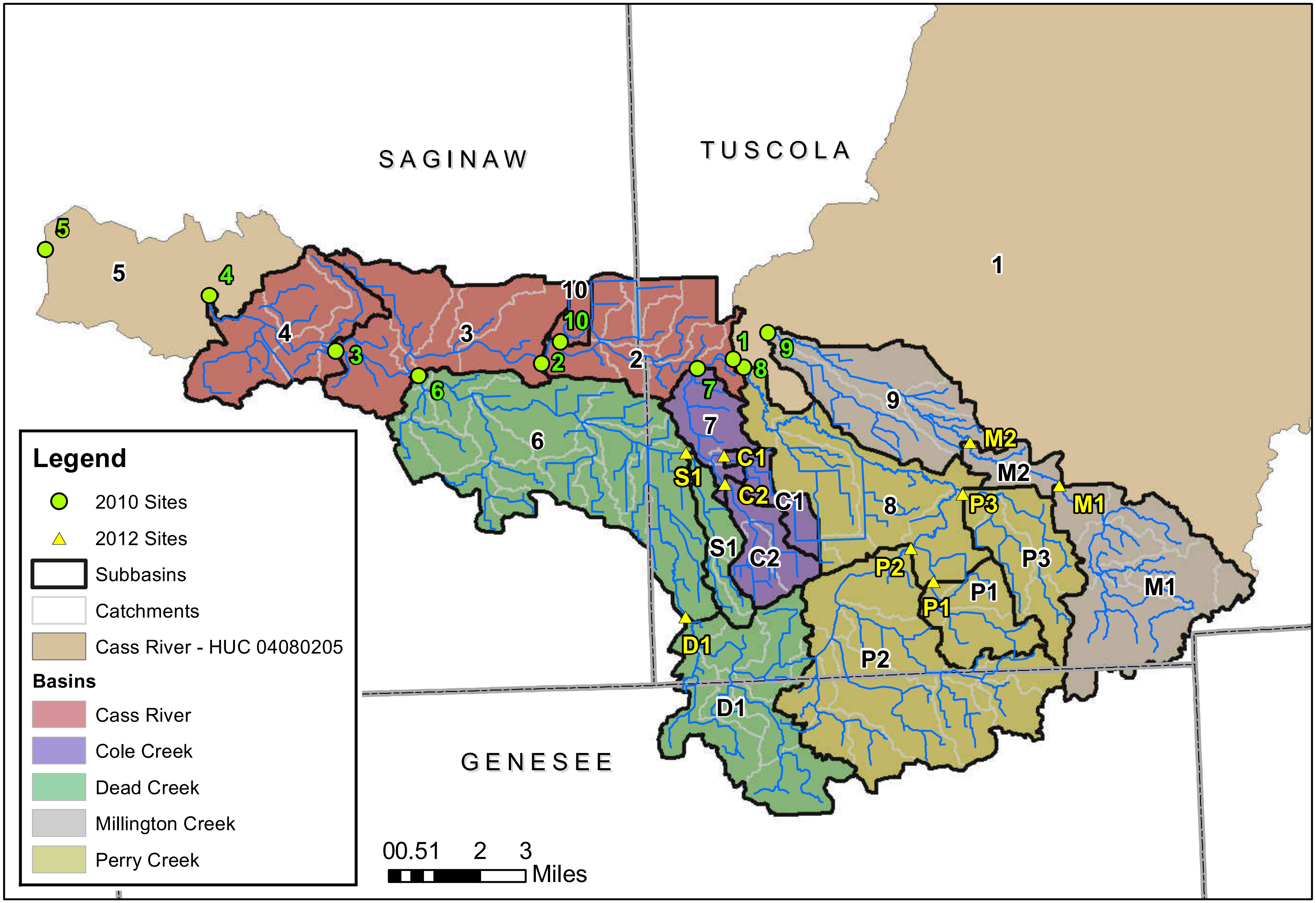


Figure 8: Locations of sampling sites and the watershed delineations of basins, subbasins and catchments. Catchment identification numbers and a closer look at catchment boundaries can be found in Appendices 2-6.

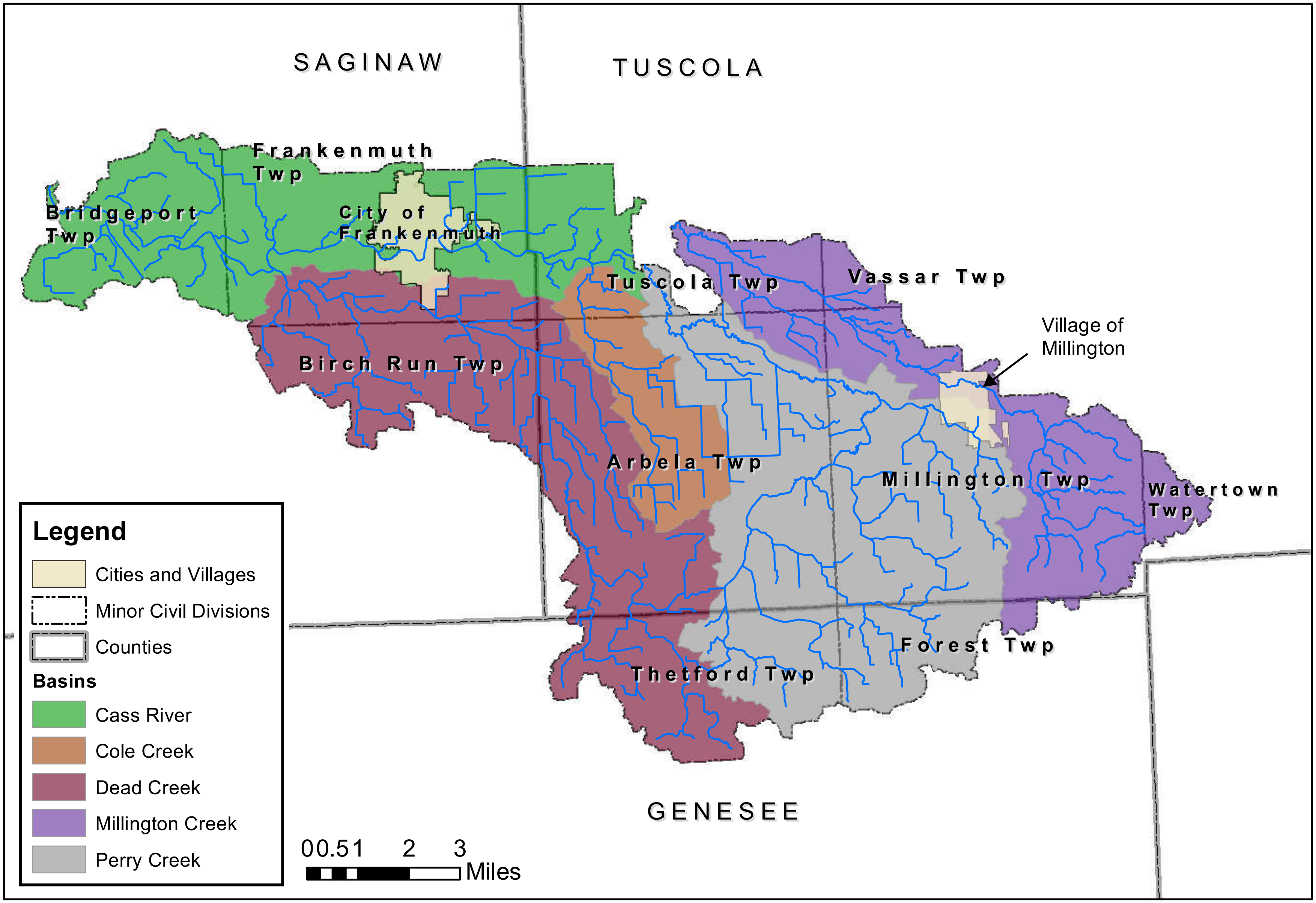


Figure 9. Minor civil divisions and counties.

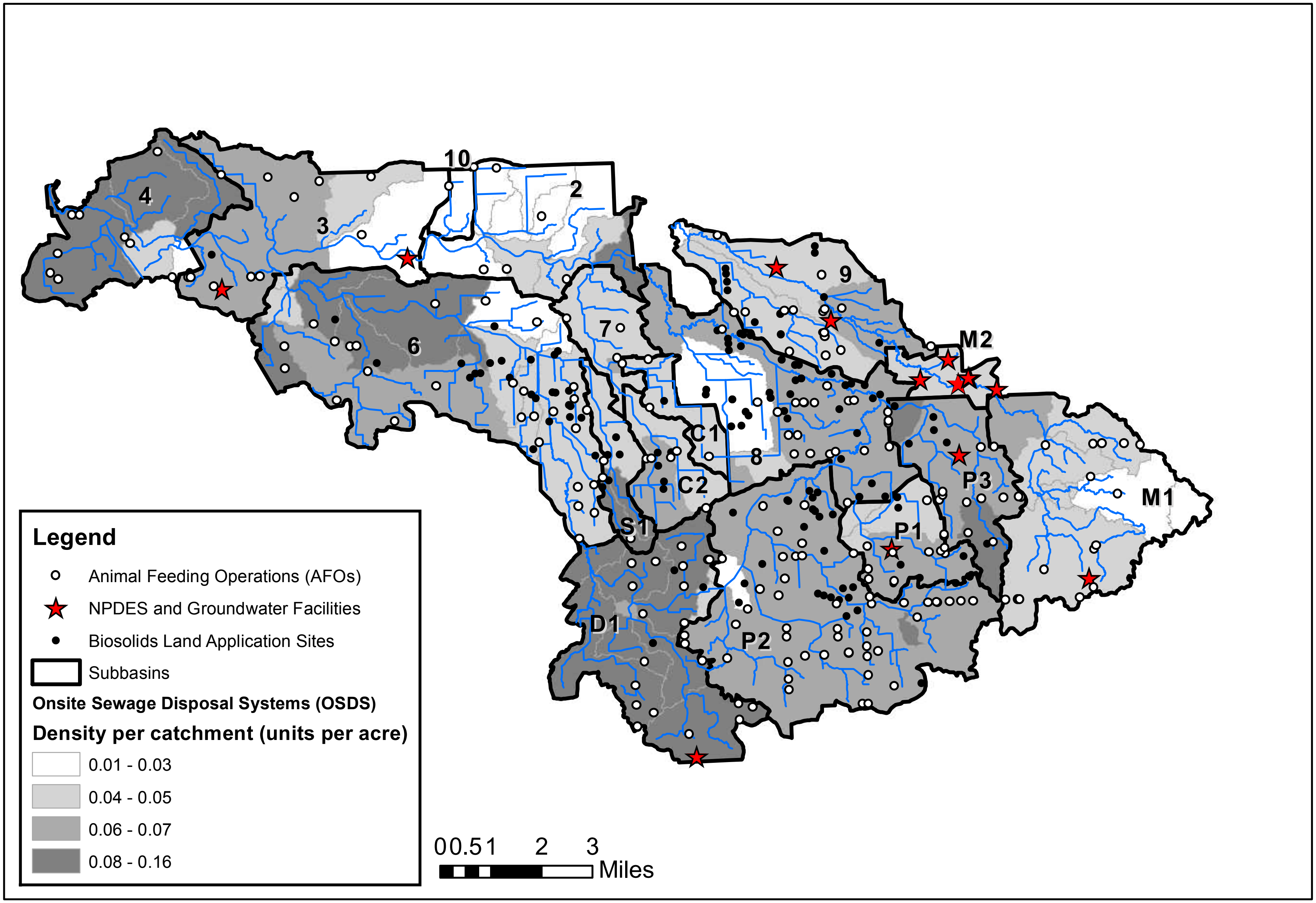


Figure 10. General locations of some types of potential sources (AFOs, NPDES and Groundwater Discharges, biosolids land application sites and OSDS density per catchment (in units per acre). For a detailed look at these potential source locations, see Appendices 2-6.

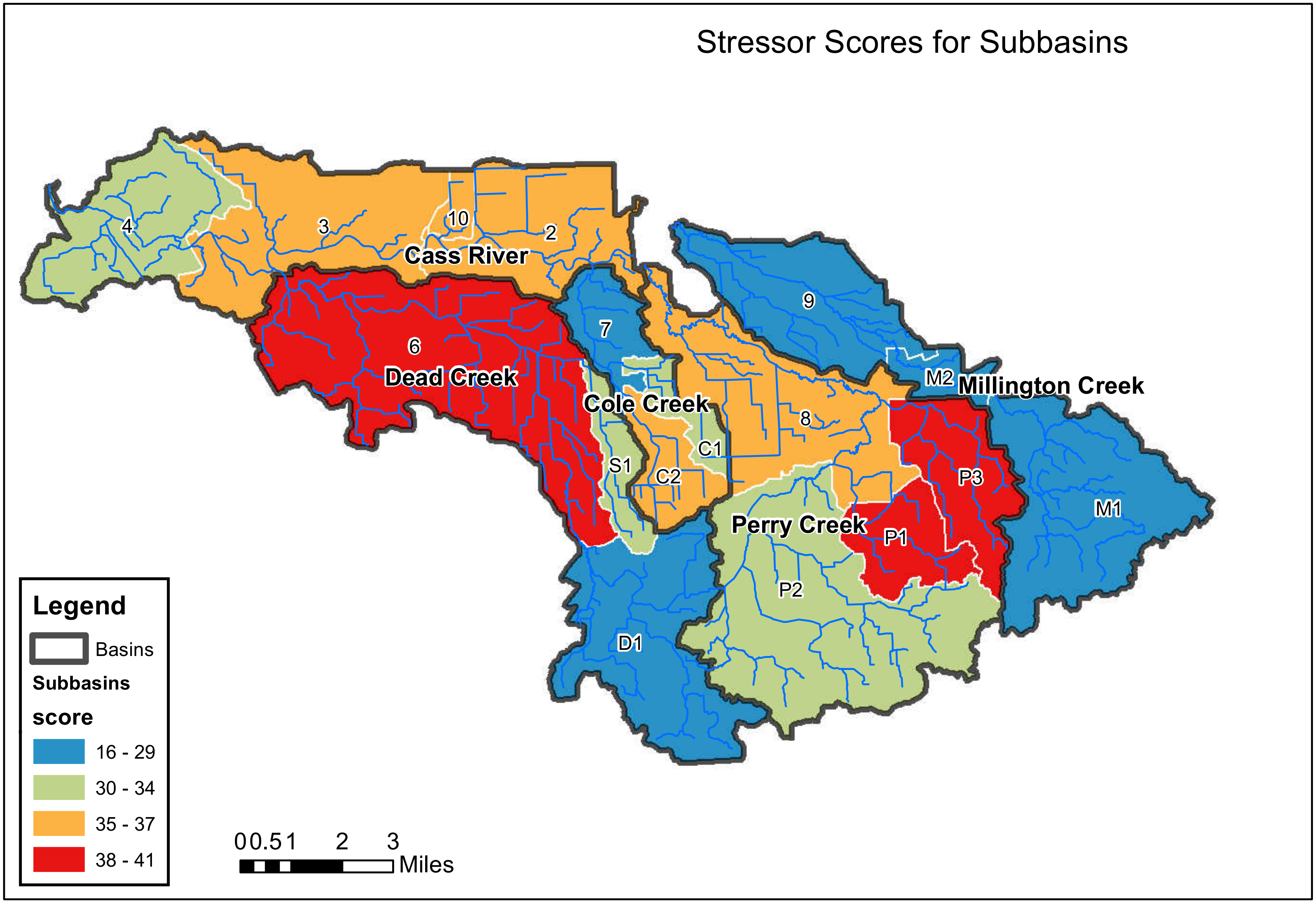


Figure 11. Results of stressor scoring (see Section 4.5) at the subbasin level. A high stressor score indicates that there is more potential for nonpoint sources to contaminate surface water relative to other subbasins. Color coding of stressor scores is based on the 1st-4th quartiles of the data distribution.

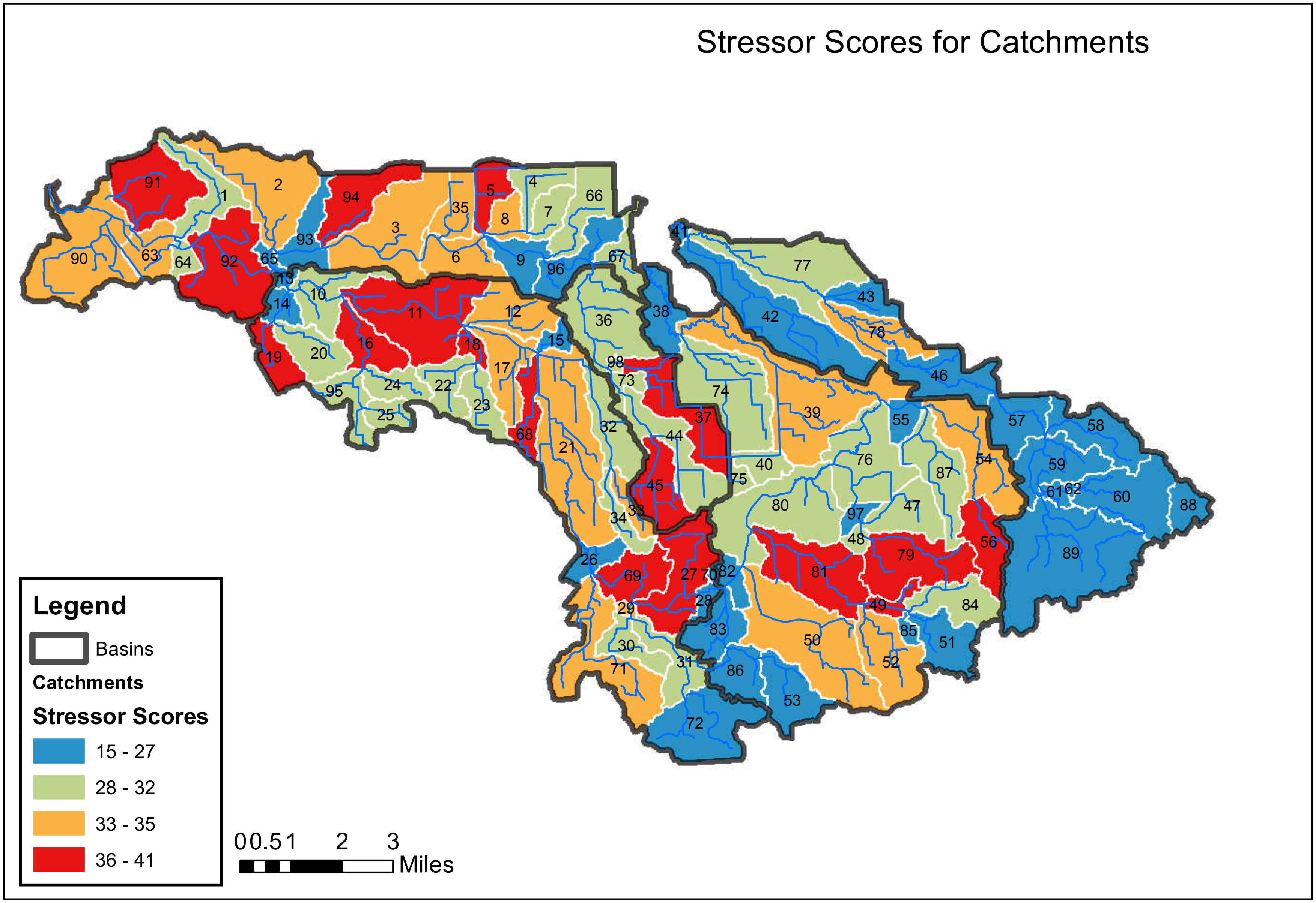
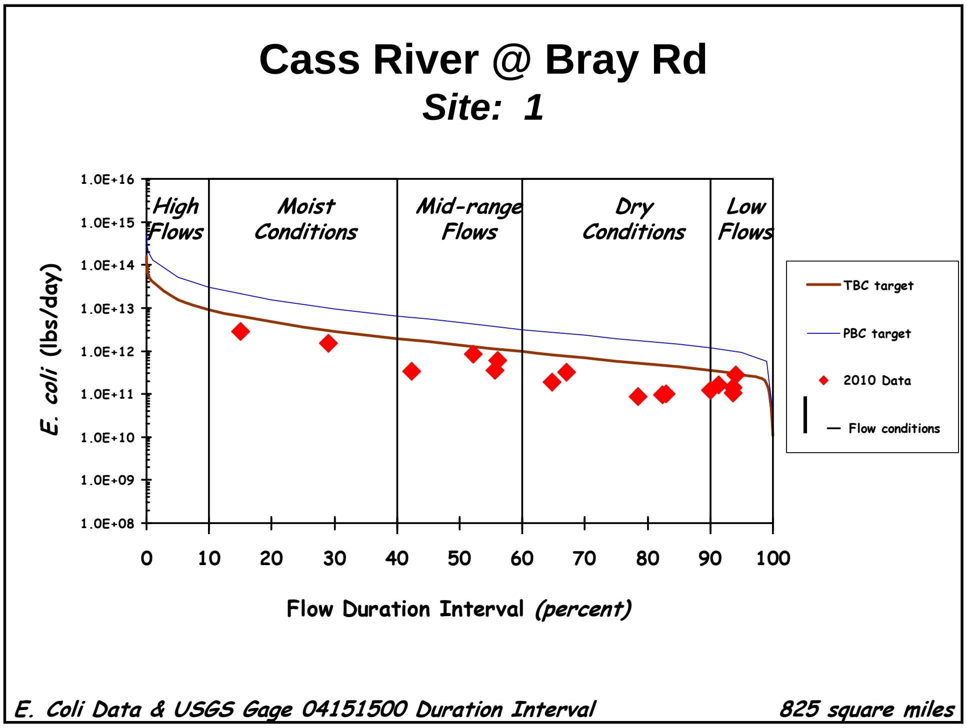
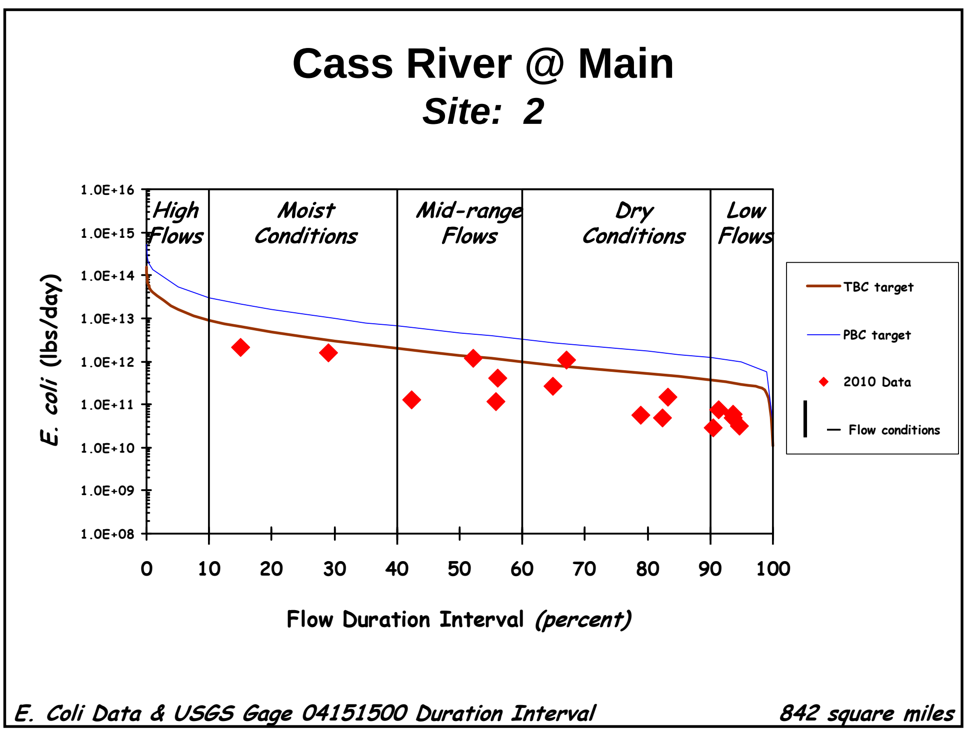
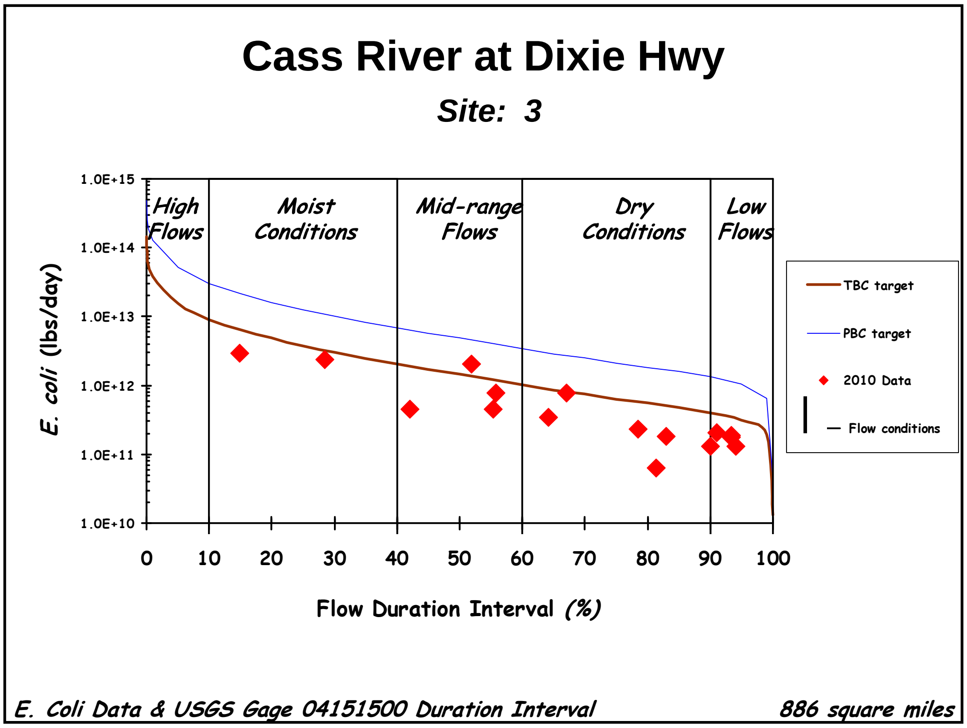


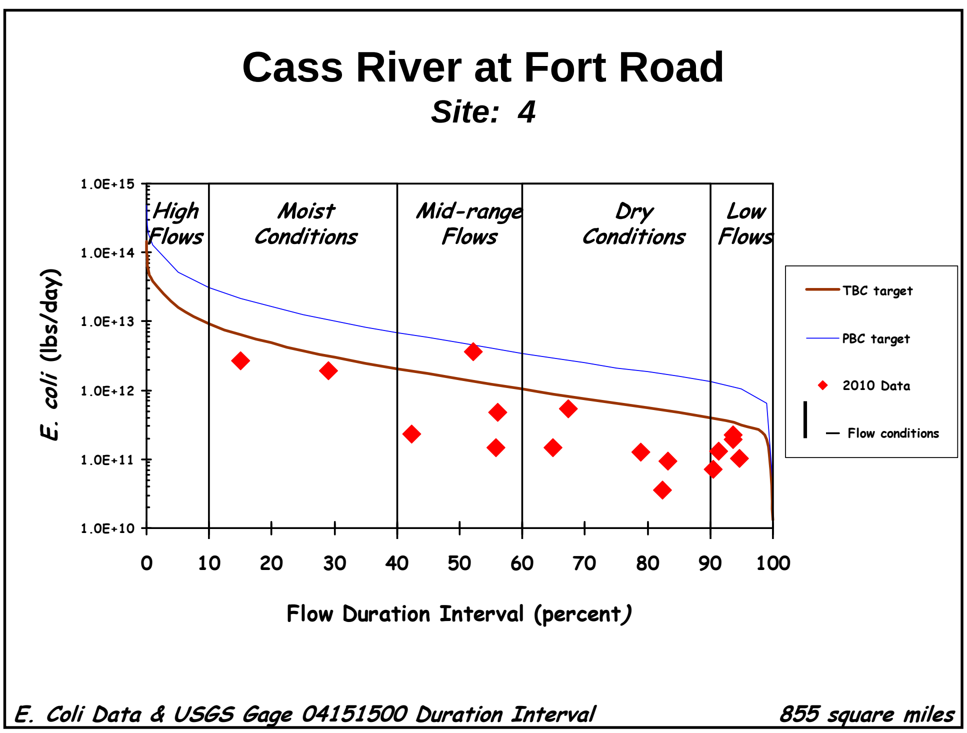
Figure 12. Results of stressor scoring (see Section 4.5) at the catchment level. A high stressor score indicates that there is more potential for nonpoint sources to contaminate surface water relative to other catchments. Color coding of stressor scores is based on the 1st-4th quartiles of the data distribution.

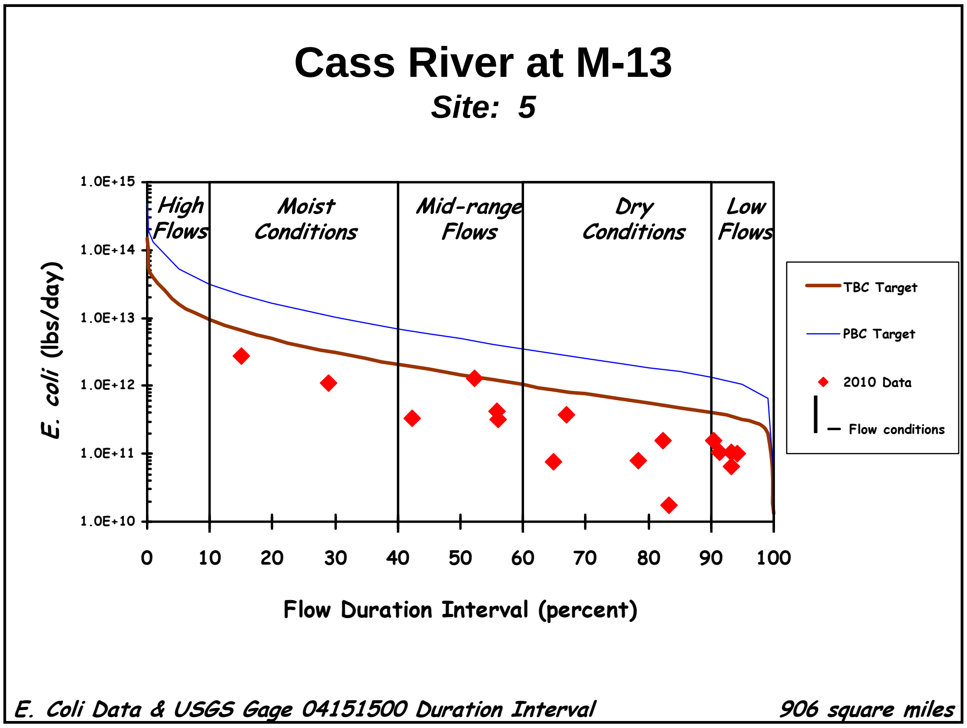
Appendix 1. Load duration curves for 2010 sampling sites (1-10). Methodology is described in Section 4.1.

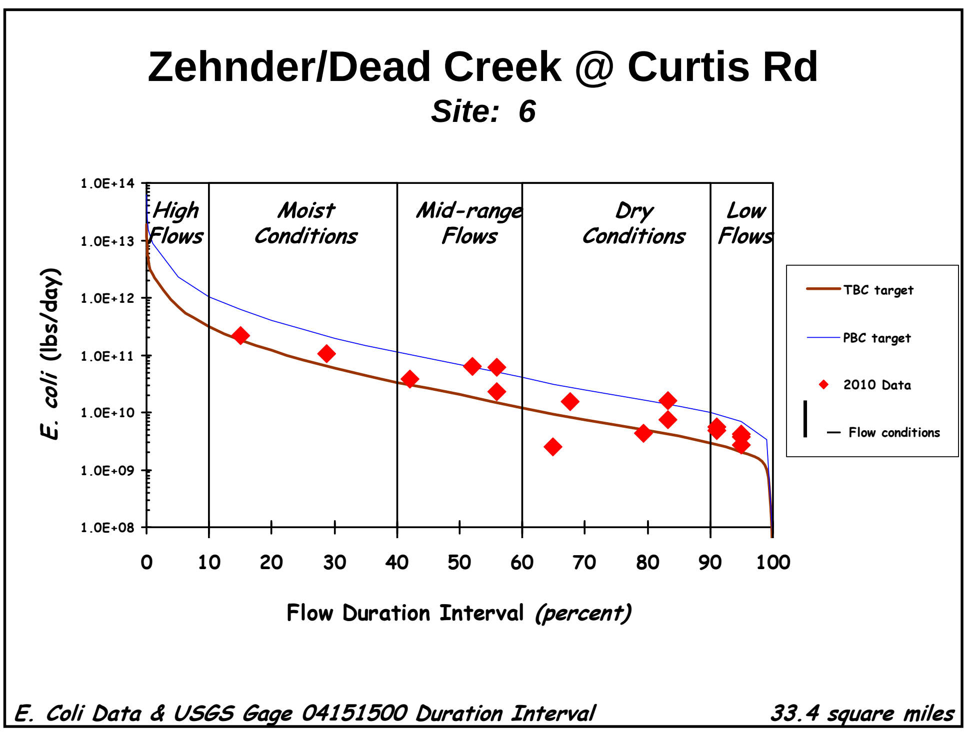


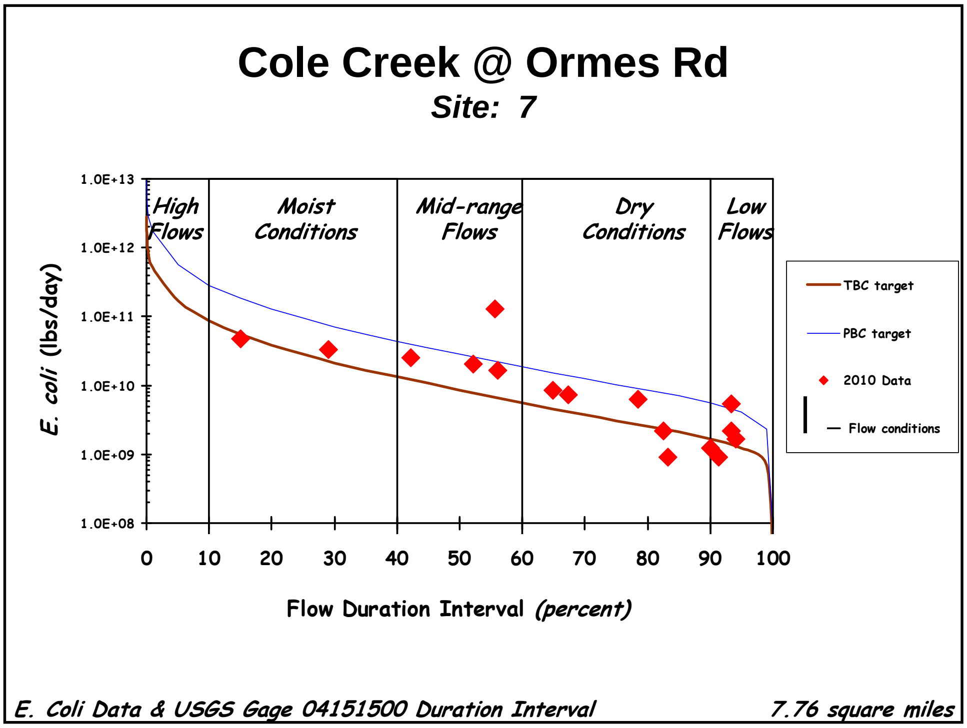


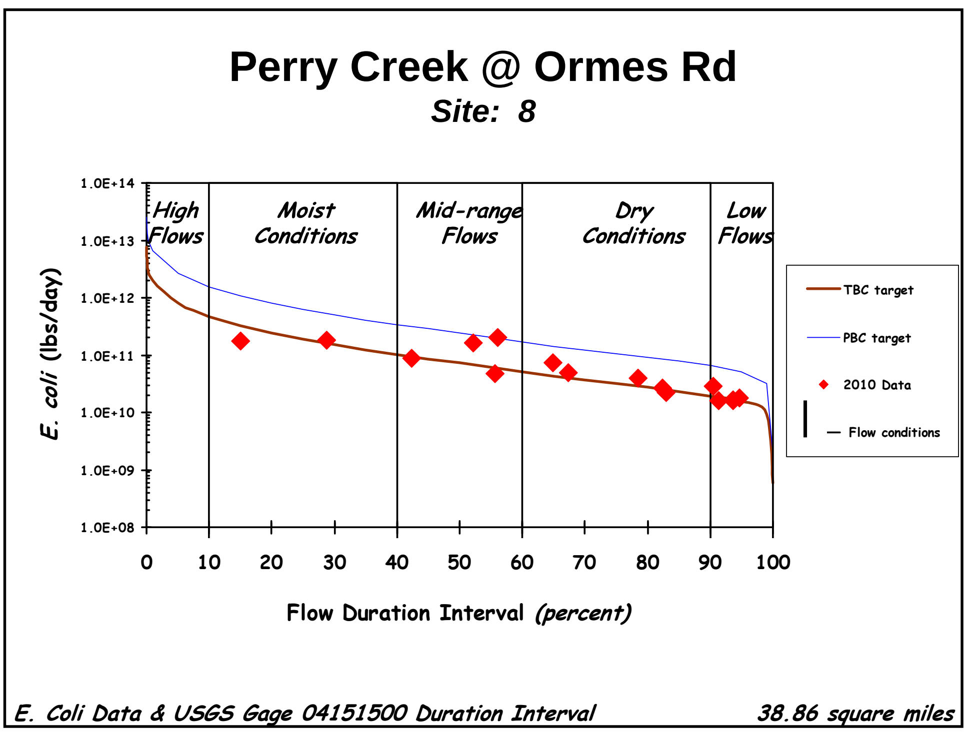

Cass River at Dixie Hwy
Site: 3
1.0E+15
1.0E+14
1.0E+13
1.0E+12
1.0E+11
1.0E+10
E. coli (lbs/day)
High Flows
Moist Conditions
Mid-range Flows
Dry Conditions
Low Flows
0
10
20
30
40
50
60
70
80
90
100
Flow Duration Interval (%)
TBC target
PBC target
2010 Data
Flow conditions
E. Coli Data & USGS Gage 04151500 Duration Interval
886 square miles

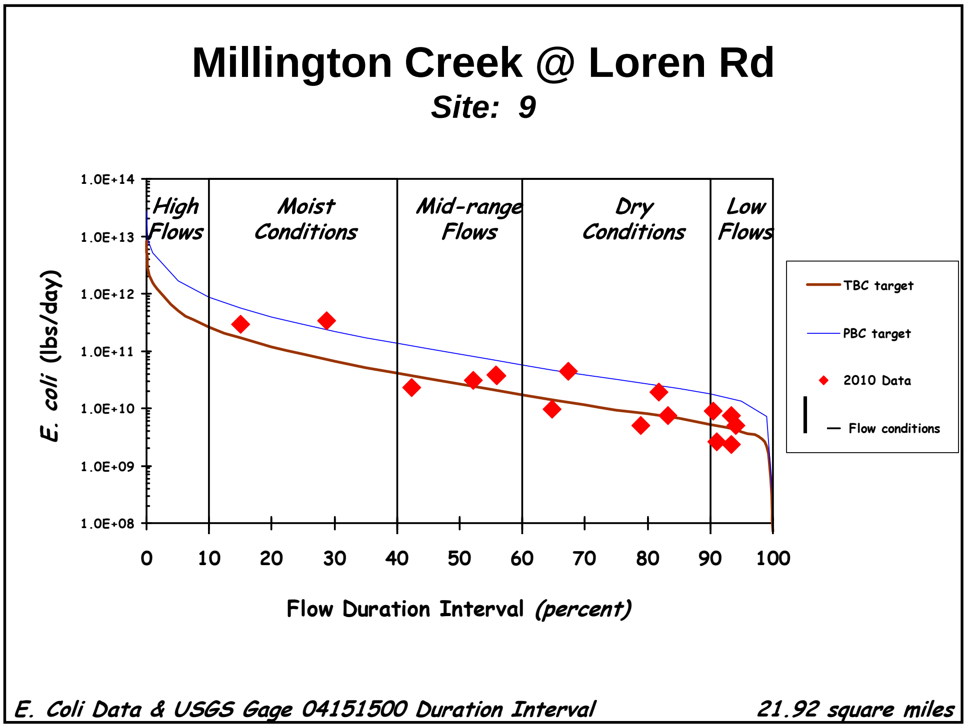

Cass River at Fort Road
Site: 4
1.0E+15
1.0E+14
1.0E+13
1.0E+12
1.0E+11
1.0E+10
E. coli (lbs/day)
High Flows
Moist Conditions
Mid-range Flows
Dry Conditions
Low Flows
0
10
20
30
40
50
60
70
80
90
100
Flow Duration Interval (percent)
TBC target
PBC target
2010 Data
Flow conditions
E. Coli Data & USGS Gage 04151500 Duration Interval
855 square miles


Cass River at M-13
Site: 5
1.0E+15
1.0E+14
1.0E+13
1.0E+12
1.0E+11
1.0E+10
E. coli (lbs/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 (percent)
TBC Target
PBC Target
2010 Data
Flow conditions
E. Coli Data & USGS Gage 04151500 Duration Interval
906 square miles

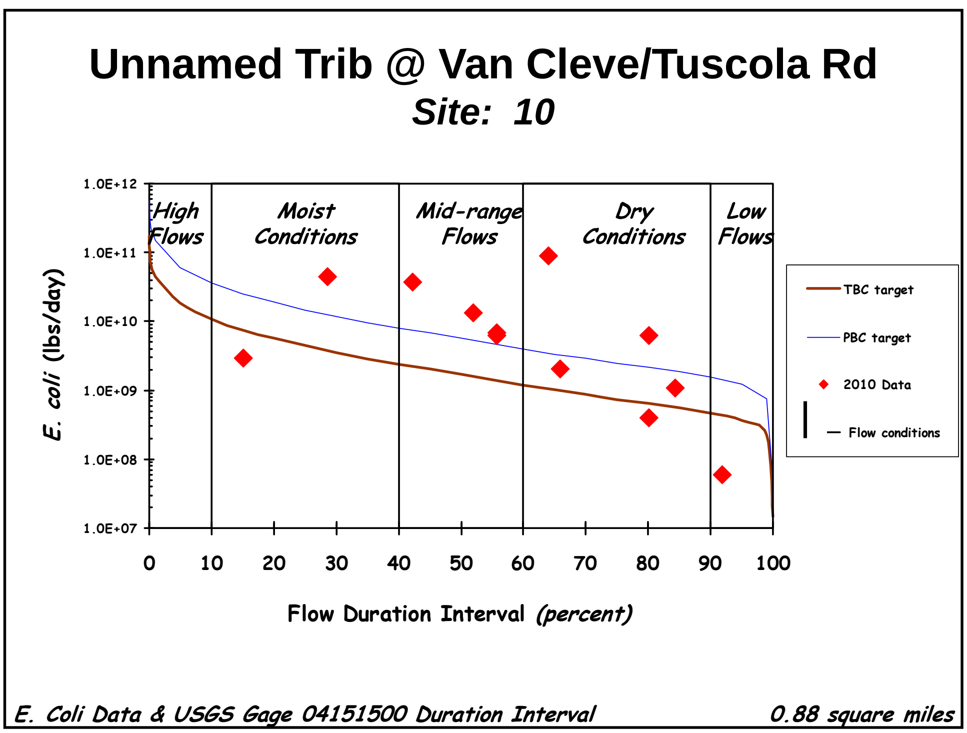

Zehnder/Dead Creek @ Curtis Rd
Site: 6
1.0E+14
1.0E+13
1.0E+12
1.0E+11
1.0E+10
1.0E+09
1.0E+08
E. coli (lbs/day)
High Flows
Moist Conditions
Mid-range Flows
Dry Conditions
Low Flows
0
10
20
30
40
50
60
70
80
90
100
Flow Duration Interval (percent)
TBC target
PBC target
2010 Data
Flow conditions
E. Coli Data & USGS Gage 04151500 Duration Interval
33.4 square miles


Cole Creek @ Ormes Rd
Site: 7
High Flows
Moist Conditions
Mid-range Flows
Dry Conditions
Low Flows
E. coli (lbs/day)
1.0E+13
1.0E+12
1.0E+11
1.0E+10
1.0E+09
1.0E+08
0
10
20
30
40
50
60
70
80
90
100
Flow Duration Interval (percent)
TBC target
PBC target
2010 Data
Flow conditions
E. Coli Data & USGS Gage 04151500 Duration Interval
7.76 square miles


Perry Creek @ Ormes Rd
Site: 8
High Flows
Moist Conditions
Mid-range Flows
Dry Conditions
Low Flows
E. coli (lbs/day)
1.0E+14
1.0E+13
1.0E+12
1.0E+11
1.0E+10
1.0E+09
1.0E+08
0
10
20
30
40
50
60
70
80
90
100
Flow Duration Interval (percent)
TBC target
PBC target
2010 Data
Flow conditions
E. Coli Data & USGS Gage 04151500 Duration Interval
38.86 square miles



Millington Creek @ Loren Rd
Site: 9
1.0E+14
1.0E+13
1.0E+12
1.0E+11
1.0E+10
1.0E+09
1.0E+08
E. coli (lbs/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 (percent)
TBC target
PBC target
2010 Data
Flow conditions
E. Coli Data & USGS Gage 04151500 Duration Interval
21.92 square miles



Unnamed Trib @ Van Cleve/Tuscola Rd
Site: 10
1.0E+12
1.0E+11
1.0E+10
1.0E+09
1.0E+08
1.0E+07
E. coli (lbs/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 (percent)
TBC target
PBC target
2010 Data
Flow conditions
E. Coli Data & USGS Gage 04151500 Duration Interval
0.88 square miles