Frederick County Stream Survey
2013-2016 Four-year Report

Prepared for

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1 INTRODUCTION

Freshwater streams are highly valued natural ecosystems that provide clean water and support fish and other aquatic life. Frederick County, Maryland, performs a stream monitoring and assessment program to collect information on the health of the County's streams. Findings are used to help guide the County's Office of Sustainability and Environmental Resource's (OSER) watershed management programs to better protect and restore local waters.

The Frederick County Stream Survey (FCSS) is a program designed to assess the status of County streams in terms of water quality, and biological and habitat conditions. The survey, at the countywide scale, employs a stratified random statistical design to allow inferences on stream condition and stressors in each of the County's 20 watersheds (Figure 1 and Table 1). Site selection and sampling methods are based on Maryland Department of Natural Resources' Maryland Biological Stream Survey (MBSS); however, the County is monitoring stream conditions at a finer scale than the MBSS, which enables the County to make assessments for smaller watersheds than MBSS.

Table 1. List of abbreviations for Frederick County watersheds

Watershed Name	Abbreviation
Ballenger Creek	BALL
Bennett Creek	BENN
Lower Bush Creek	BUSL
Upper Bush Creek	BUSU
Carroll Creek	CARR
Catoctin Creek	CATO
Fishing Creek	FISH
Glade Creek	GLAD
Hunting Creek	HUNT
Israel Creek	ISRA
Little Catoctin Creek South	LCCS
Lower Linganore Creek	LINL
Upper Linganore Creek	LINU
Little Pipe Creek	LIPI
Middle Creek	MIDD
Monocacy Direct Southwest	MODS
Owens Creek	OWEN
Potomac Direct	POTD
Toms Creek	TOMS
Tuscarora Creek	TUSC

In 2007, a Pilot Study was launched in the Bennett Creek and Catoctin Creek watersheds to help develop, test, and refine the sampling design and protocols for the full FCSS (Versar Inc. 2009). The first round of the FCSS began in 2008 and continued through 2011. Round 2 of the FCSS began in 2013 and finished its fourth year in 2016. Since its inception the FCSS has sampled over 400 stream locations in Frederick County. For each of the sampling years, field crews contacted landowners and sampled 50 randomly selected sites stratified across the 20 watersheds in the County. Following methods detailed in the design report (Perot et al. 2008), data were collected on water quality, physical habitat, and biological communities (benthic macroinvertebrates) at each of the stream sites. This information was used to make assessments of stream conditions Countywide as these sites were randomly selected and statistical estimates of the extent of streams (percentage of stream miles) in different condition classes for each assessment measured can be made. These results, including the raw data for each site sampled, can be found in the yearly FCSS reports on the Frederick County website (Versar, Inc. 2010a, 2010b, 2011, 2012, 2014, 2015, 2016, and 2017). The final Round 1 FCSS report (Versar Inc., 2013), summarizing results at the 20-

watershed scale, as well as the yearly reports, is available online at www.frederickcountymd.gov/7578/Water-Quality-Monitoring

Stream conditions can be affected by a variety of key stressors including land use, habitat, and water quality factors. This report summarizes FCSS Round 2 results at the 20-watershed scale and examines the differences between Round 1 and Round 2 stream conditions and assess any trends, if present, in Frederick County water quality. It also looks at estimates of condition within the County's portion of the Maryland DNR 8-digit watersheds to inform decisions related to Total Maximum Daily Loads (TMDLs). The Appendices provide more detailed results of watershed condition and assessment scores.

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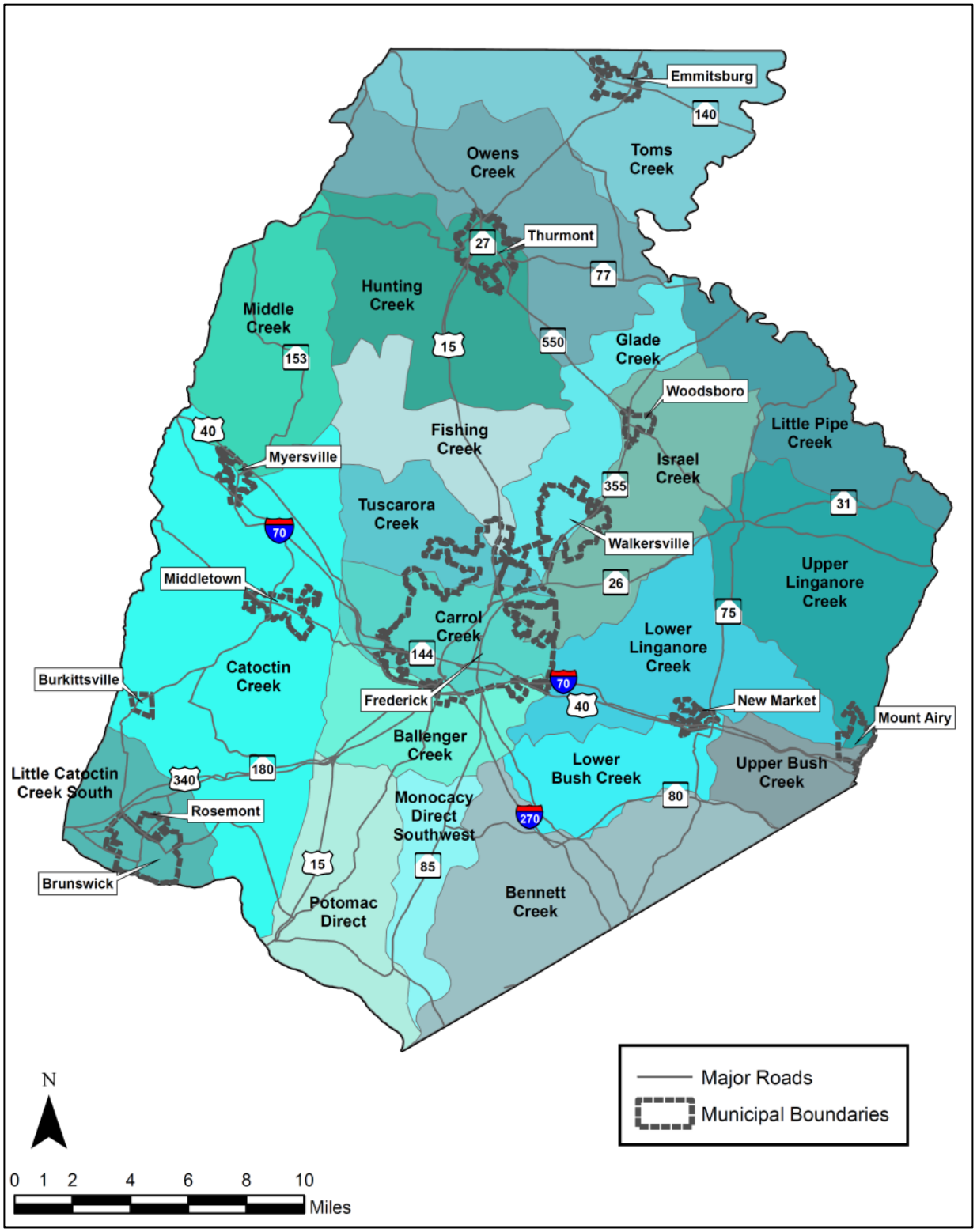

Figure 1. Frederick County Watersheds

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2 LAND USE

Watershed land use is an indicator of how human activities and natural processes affect a stream. A watershed is an area of land that drains to a particular body of water. Watersheds form natural geographic units for assessing impacts on streams because land use within the watershed upstream of a specific stream site is representative of many of the human activities and natural processes affecting the stream at that point.

Conversion of naturally vegetated lands to urban and agricultural uses can result in serious impacts to streams and their aquatic inhabitants. In urban and suburban areas, impervious surfaces, such as roads, parking lots, sidewalks, and rooftops, cause a rapid increase in the rate that water is transported from the watershed to its stream channels. Effects include an increase in the variability of stream flows (more "flashy" flows), increased streambank erosion, habitat degradation caused by channel instability, increased pollutant runoff, elevated temperatures, and losses of biological diversity. Reviews of stream research in numerous watersheds indicate that impacts on stream quality are commonly noted at about 10% coverage by impervious surfaces (Schueler et al. 2009 and Stranko et al. 2008). Effects on sensitive species may occur at even lower impervious levels (Roth et al. 1999). Agricultural impacts on stream resources can include sediment, nutrient, and other pollutant runoff. Impacts from agriculture also include increased erosion leading to habitat and water quality degradation. However, agricultural effects may be complex, as they may include contributions of lime (which can neutralize harmful acid rain inputs) and nutrients (which can, in some cases, enhance stream productivity).

Frederick County has a diverse mix of land uses (Figure 2). Overall, 48% of the County is agriculture, 33% is forest, and 17% is urban/suburban (2% is "other," including wetlands/water and barren lands).

In the FCSS, land uses were characterized within the individual catchment areas upstream of sampled sites. Table 2 shows the percent of each land class found in each of the 20 County watersheds.

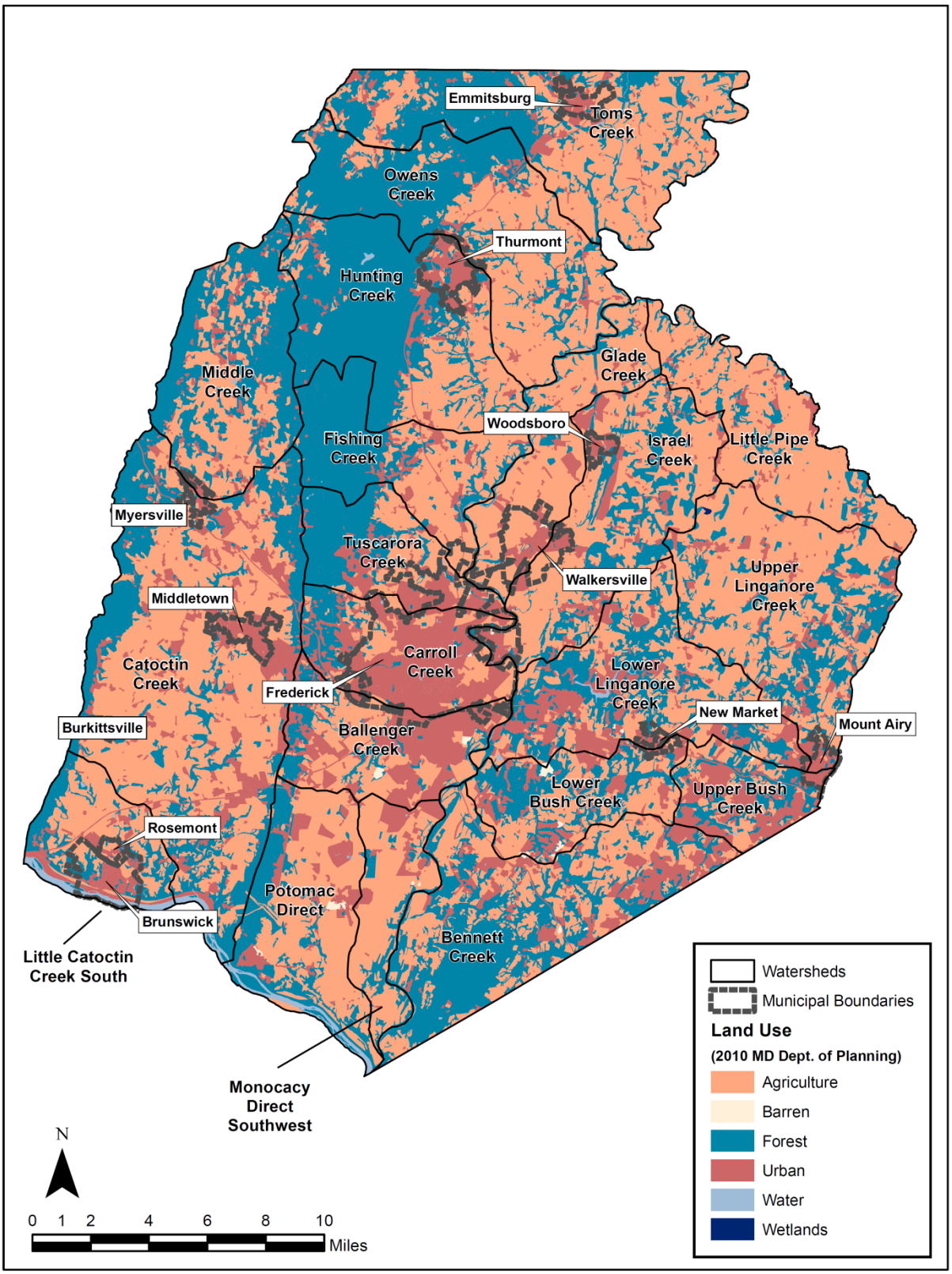

Figure 2. Land use in Frederick County (based on 2010 Maryland Department of Planning Land Use)

Fishing Creek, Hunting Creek, Middle Creek, and Owens Creek watersheds, in the northwest portion of the County, had the highest percentages of forested land use. In contrast, Glade Creek, Carroll Creek, and Ballenger Creek watersheds had the lowest percentages of forested land use in the County.

The Glade Creek, Little Pipe Creek, and Monocacy Direct Southwest watersheds had the highest percentage of agricultural land use in the County

The watersheds most impacted by urban land use are Carroll Creek, Upper Bush Creek, and Ballenger Creek.

Table 2. Percent land use in Frederick County watersheds

Watershed	Agriculture	Forest	Urban
BALL	34.4	13.6	51.8
BENN	37.3	40.5	21.7
BUSL	40.2	31.2	28.5
BUSU	23.8	22.9	53.2
CARR	19.8	10.3	69.7
CATO	51.7	22.6	25.0
FISH	35.1	47.2	17.5
GLAD	71.4	9.6	17.5
HUNT	26.4	56.8	16.6
ISRA	54.7	22.3	22.7
LCCS	44.0	25.7	23.3
LINL	37.1	29.7	32.0
LINU	55.7	22.8	21.3
LIPI	58.9	20.9	19.8
MIDD	31.8	45.1	23.0
MODS	66.6	14.6	18.3
OWEN	44.8	41.7	13.1
POTD	55.1	23.3	17.6
TOMS	57.9	27.4	14.2
TUSC	24.5	39.5	35.7

Impervious Surface

Impervious surfaces are mainly constructed surfaces – rooftops, sidewalks, roads/driveways, and parking lots – covered by impenetrable materials such as asphalt, concrete, brick, and stone. These materials seal surfaces, repel water and prevent precipitation and meltwater from infiltrating soils. Soils compacted by urban development are also highly impervious. Impervious surfaces increase runoff, reduce evapotranspiration, have high thermal conductivities, and contribute to non-point source pollution problems. As a rule, water quality decreases as impervious surface cover increases, leading to degraded stream conditions. Based on Schueler et al. (2009), five categories of urban streams are defined based on how much impervious surface exists in their upstream catchment:

- Excellent – less than 4% impervious surface in the upstream catchment. Stranko et. al (2008), indicate that brook trout are almost never found in streams with upstream impervious cover greater than 4%;
- Sensitive – 4 to 10% impervious surface in the upstream catchment, are generally able to maintain their hydrologic function and support good to excellent aquatic diversity;
- Impacted – 10 to 25% impervious surface in the upstream catchment, show clear signs of declining stream health;
- Non-supporting – 25 to 60% impervious surface, no longer support their designated uses in terms of hydrology, channel stability, habitat, water quality, or biological

diversity. They have become so degraded that it may be difficult to fully recover predevelopment stream function; and

- Urban drainage – greater than 60% impervious surface and basically just function as conduits for floodwater, they consistently have poor habitat and biodiversity scores.

In the Round 2 FCSS, the average percent imperviousness in catchments upstream of sampled sites was 5.4%, well below the threshold for sensitive streams (Appendix Table A1) and approximates the mean Countywide of 4.8%, as derived from the 2014 impervious surface planimetrics. Throughout the 200 sites monitored, the percent impervious surface values ranged from less than one percent to thirty percent.

Based on the catchments upstream of sites sampled, 12 of the 20 watersheds in the County have all of their stream miles in the "Excellent" or "Sensitive" categories. In fact, estimates based on sites sampled showed that 5 of the watersheds have 90% or greater of stream miles categorized as "Excellent." No watersheds have stream miles in the "Urban Drainage" category, however, Lower Bush Creek has 20% of its stream miles classified as "Non-Supporting".

According to the Lower Monocacy Watershed Restoration Action Strategy (Hunicke and Moore, 2008) brook trout are found in streams in Middle Creek, Owens Creek, Hunting Creek, Fishing Creek, Tuscarora Creek, and in one stream in Bennett Creek watershed. According to the map of impervious surface by catchment, that is based on 2014 aerial imagery (Figure 3), these six watersheds have a large amount of land with impervious surfaces below the brook trout threshold; however, other portions of these watersheds have areas with impervious surfaces in the "Impacted" category. Owens Creek and Hunting Creek have higher impervious surfaces near Thurmont, while Tuscarora Creek is affected by the northwestern outskirts of the City of Frederick. Bennett Creek, which contains the southernmost brook trout stream in the Lower Monocacy watershed, also has higher levels of impervious surface in the eastern portion of the watershed.

Overall, between 2005 and 2014, impervious surface area in Frederick County has increased slightly (Figure 4), however, some of these reported differences may be due to different imagery classification methodologies used in the creation of the impervious surface cover GIS layers.

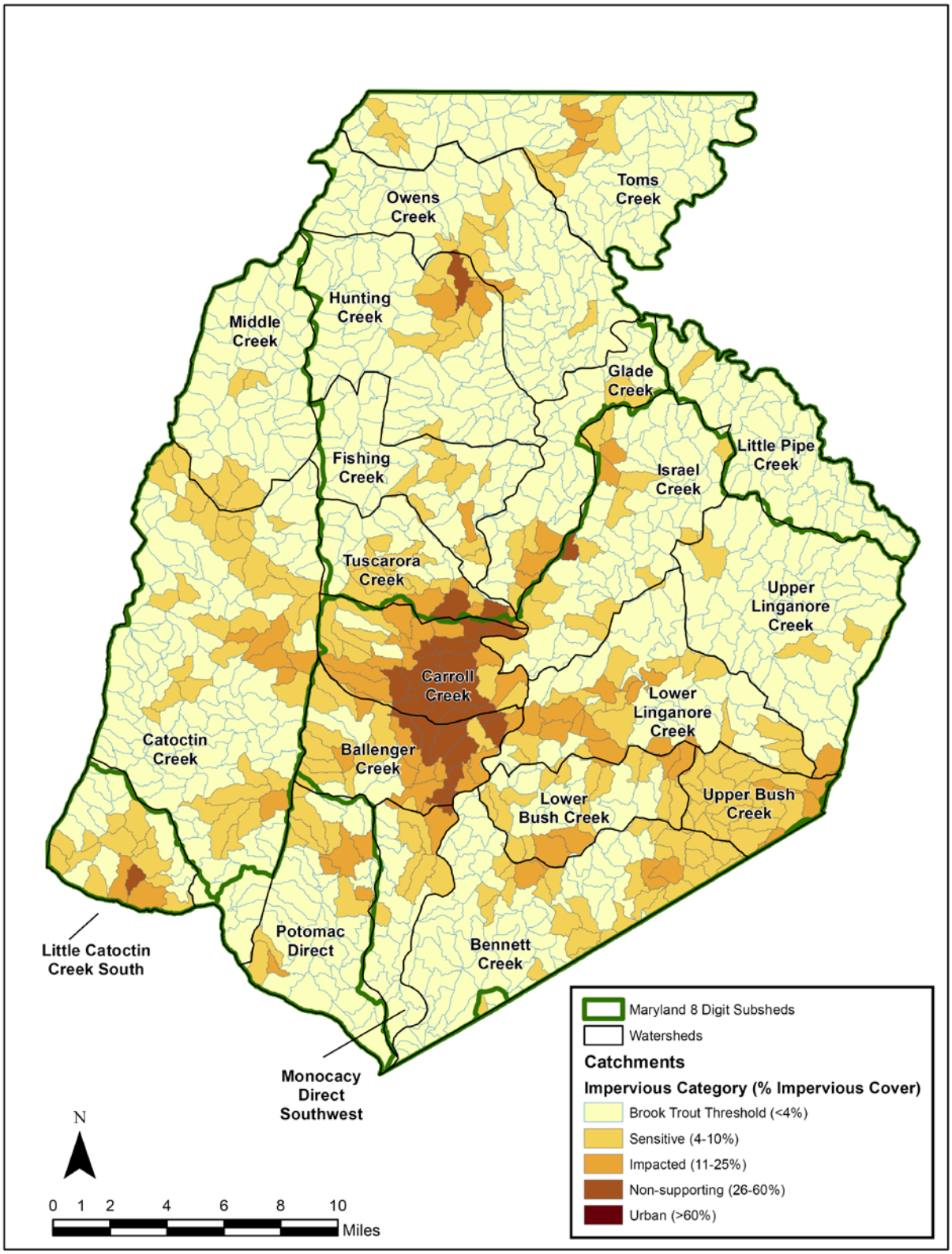

Figure 3. Impervious category for each catchment in Frederick County (based on 2005 planimetrics)

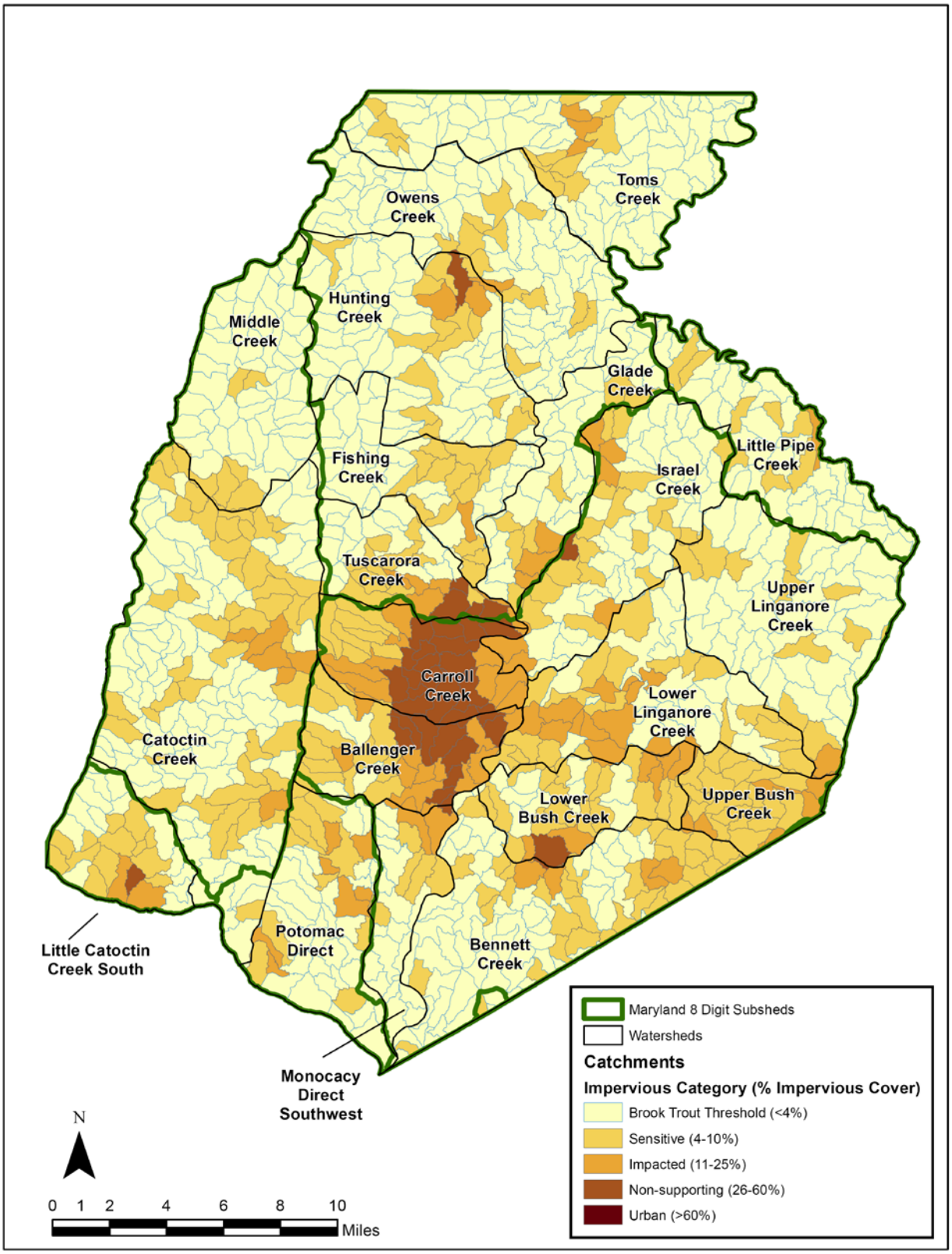

Figure 4. Impervious category for each catchment in Frederick County (based on 2014 planimetrics)

3 HABITAT

Stream health, as characterized by the condition of biological communities, is often directly correlated to the quality of physical habitat within a stream. Habitat loss and degradation have been identified as critical factors affecting biological diversity in streams worldwide. Habitat degradation can result from a variety of impacts occurring within the stream itself or in the surrounding watershed. Typical instream impacts include sedimentation, channelization, and bank erosion. Urban development, timber harvesting, agriculture, livestock grazing, and the draining or filling of wetlands are well-known examples of human activities affecting stream habitat at the watershed scale.

These human activities may cause changes in vegetative cover, sediment loads, and hydrology influence stream habitat quality. The amount of forest, meadow, and other vegetative cover in a watershed regulates the flow of water, nutrients, and sediments to adjacent streams. In watersheds addected by human land uses, riparian (streamside) forests can act as a filter, reducing the amounts of nutrients, sediments, and other pollutants reaching streams. They also provide local benefits of shade, leaf litter to feed the aquatic food web, and large woody debris, which in turn provides complex habitat and cover and creates pool and riffle microhabitats preferred by fish and other aquatic animals. Loss of watershed or riparian vegetation increases the potential for overland and channel erosion, often increasing the siltation of stream bottoms and obliterating clean gravel surfaces used by many fish species as spawning habitat. Stream bottoms that become embedded with increased sediment offer poor habitat for many bottom-dwelling species. The impervious surfaces of urban areas and the direct connection of runoff to stormwater pipes or channelized streams alter runoff patterns and create "flashy" streams with extreme high and low flows, increased scouring, and streambank erosion. Altered flow patterns accelerate downcutting and widening of stream channels.

The FCSS collects data on many aspects of physical habitat, including the extent and type of vegetated riparian buffer, the severity of bank erosion observed, and other metrics that can be combined and used as an overall indicator of habitat quality called the Physical Habitat Index (PHI). The PHI for Maryland streams was developed using data from the Maryland Biological Stream Survey (Paul et al. 2002). This index combines several measures of physical habitat characteristics listed below into one value that is then compared to minimally impacted (“reference”) sites throughout the state.

Physical Habitat Index

To calculate the Physical Habitat Index (PHI) at each site, six parameters were given a numerical score and a categorical rating: instream habitat, epibenthic substrate, remoteness, instream woody debris and rootwads, shading, and bank stability. The raw six categorical scores were converted into a scaled score (0-100 scale) as described in Paul et al. (2002) and averaged together into an aggregate final PHI score. Benthic Index of Biotic Integrity (BIBI) (see Section 5) and PHI categories are described in Table 3.

Table 3. Condition class thresholds for BIBI and PHI scores in accordance with MBSS methodology.

Condition Class	BIBI Range	PHI Range	Description (Roth et al. 1999)
Good/Marginally Degraded	4.00 – 5.00	81 – 100	Comparable to reference streams considered to be minimally impacted.
Fair/ Partially Degraded	3.00 – 3.99	66-80	Comparable to reference conditions, but some aspects of biological integrity may not resemble the qualities of minimally impacted streams.
Poor/ Degraded	2.00 – 2.99	51-65	Significant deviation from reference conditions, with many aspects of biological integrity not resembling the qualities of minimally impacted streams.
Very Poor/Severely Degraded	1.00 – 1.99	0-50	Strong deviation from reference conditions, with most aspects of biological integrity not resembling the qualities of minimally impacted streams.

PHI scores during Round 1 of the FCSS classified 20% of County stream miles as "Severely Degraded" and 19% as "Minimally Degraded". Roughly the same percentage of stream miles in Round 2 were classified as "Severely Degraded" as in Round 1 (Figure 5). Round 2 PHI scores show that only 13% of stream miles were classified as "Minimally Degraded", indicating a decrease in physical habitat quality for 6% of the stream miles in the County (Figures 5 and 6). However, this did not result in a statistically significant difference in mean PHI scores between rounds at the countywide scale (Table 4, two-sided t-test p-value > 0.05), and countywide summary statistics are largely similar for both Rounds (Table 4). The Catoctin Creek watershed had significantly higher mean PHI scores in Round 1 as compared to Round 2 (one-sided t-test p-value = 0.004); the mean Round 1 PHI score was 79.1 and 57.0 in Round 2 (Appendix Table A2). Statistically significant differences between Round 1 and Round 2 mean PHI scores were not identified for any other watershed (two-sided t-test, all p-values > 0.05). Distribution of PHI score categories for each Round are illustrated in Figures 7 and 8.

Table 4. Summary PHI score statistics.

	Mean	Median	Minimum	Maximum
Round 1	65.5	67.24	17.5	95.7
Round 2	64.4	65.77	28.1	94.4

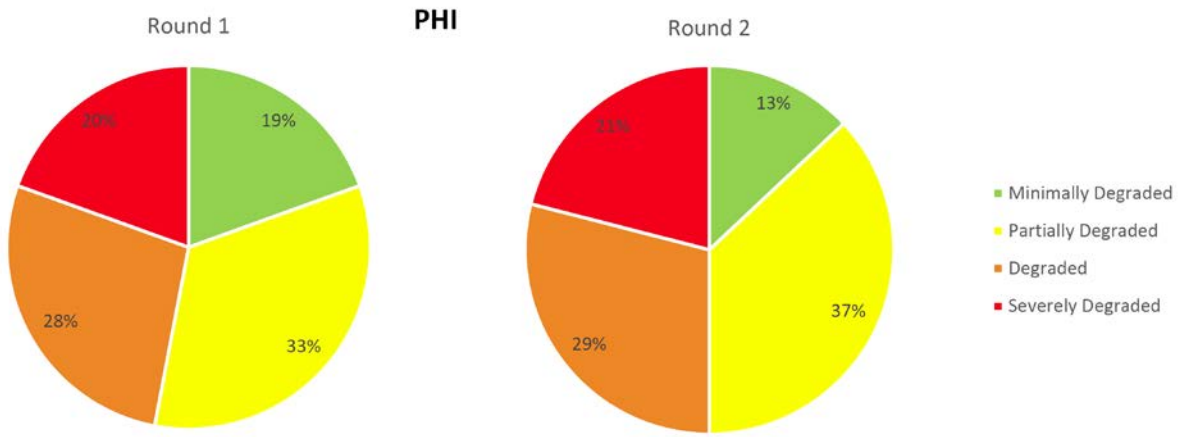

Figure 5. Percentages of Round 1 and Round 2 stream miles in each PHI score category Round 1 and Round 2 FCSS.

In Round 1, Catoctin Creek and Bennett Creek had the greatest percentage of stream miles with PHI scores in the top category, "Marginally Degraded" (60% and 50%, respectively). Little Pipe Creek (60%) and the Potomac River Direct Watershed (50%) had the highest percentages of stream miles in the "Severely Degraded" category. In fact, Little Pipe Creek, Glade Creek, and Lower Linganore Creek contained zero stream miles that were "Marginally Degraded" according to the PHI (Figure 6).

Round 2 PHI scores show that Hunting Creek had the greatest percentage of stream miles in the "Marginally Degraded" category (50%). No sites categorized as "Severely Degraded" were sampled in the Bennett Creek, Little Catoctin Creek South, and the Tuscarora Creek watersheds. Glade Creek (60%) and Catoctin Creek (40%) watersheds had the greatest percentage of stream miles in the "Severely Degraded" category (Figure 6).

Ten watersheds in Round 1 had average PHI ratings of "Partially Degraded", while in Round 2, only 8 watersheds received ratings of "Partially Degraded." For both rounds, average PHI ratings for all other watershed were in the "Degraded" category (Figures 7 and 8 and Appendix Table A-2).

Figure 6. Percentage of stream miles in Physical Habitat Indicator (PHI) categories for each of the five 8-digit watersheds in Frederick County for FCSS sampling Rounds 1 and 2.

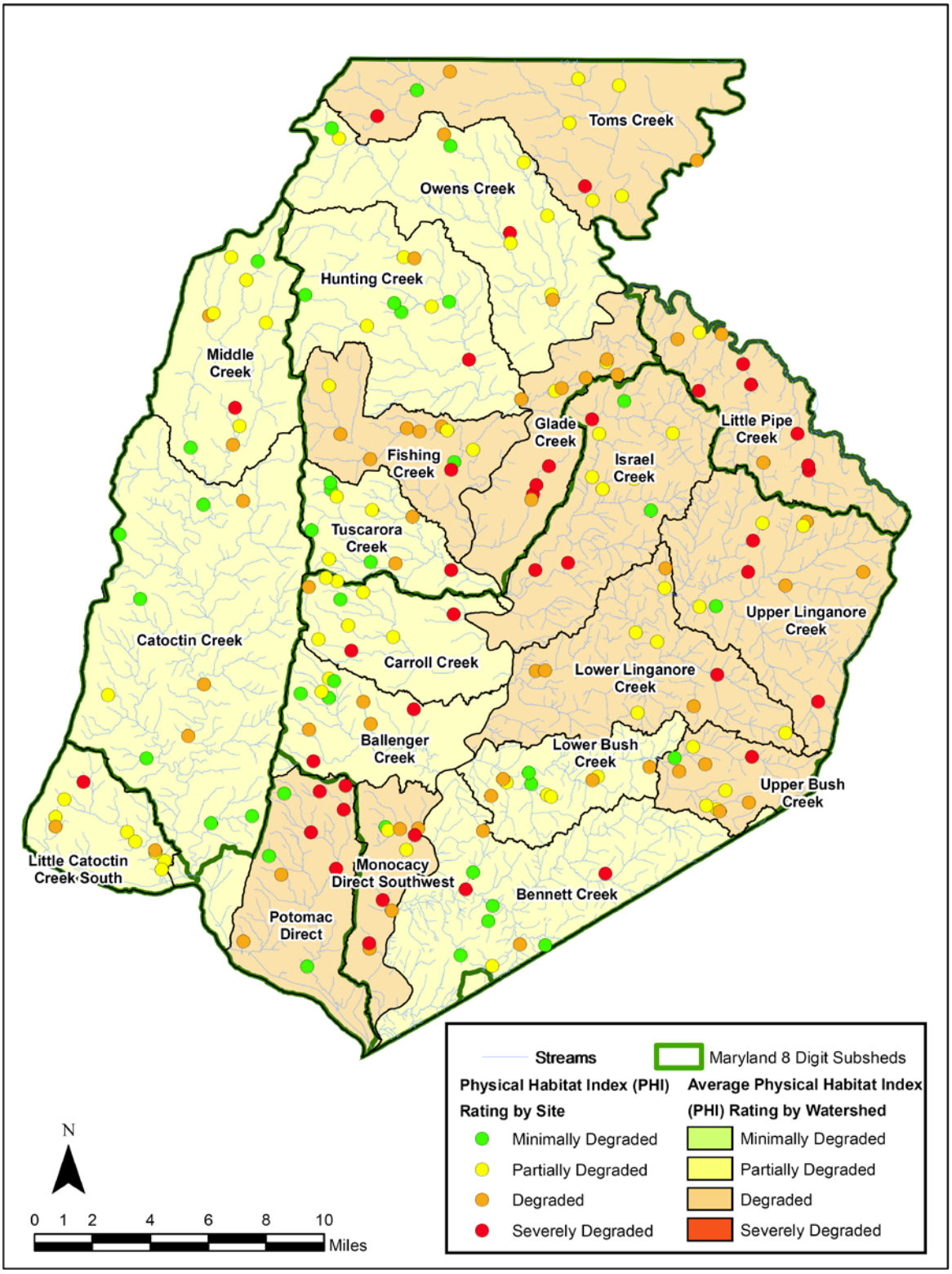

Figure 7. Map of Frederick County watersheds shaded according to average Physical Habitat Indicator (PHI) category, with PHI category also shown per site, for Round 1 of the Frederick County Stream Survey.

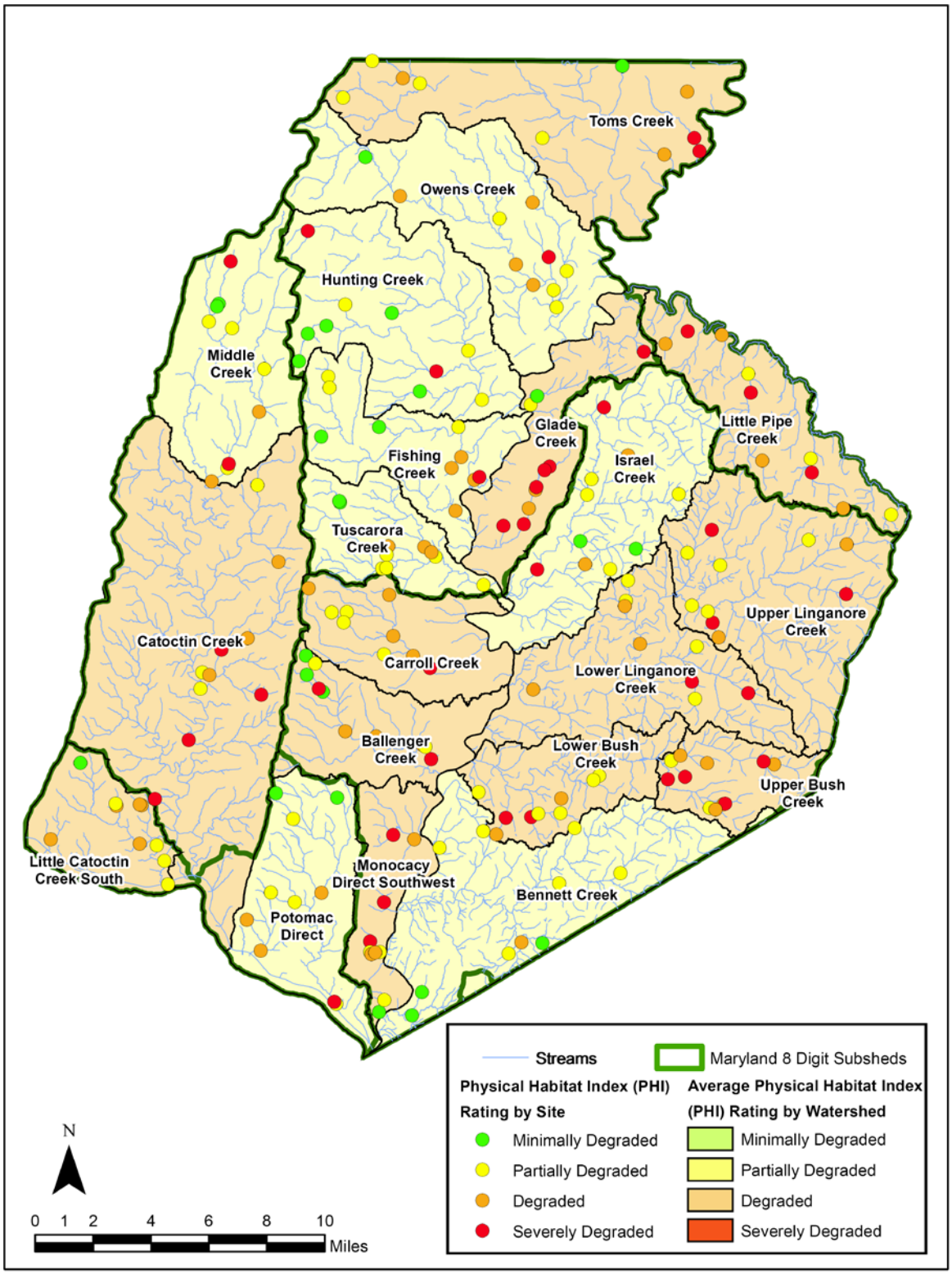

Figure 8. Map of Frederick County watersheds shaded according to average Physical Habitat Indicator (PHI) category, with PHI category also shown per site, for Round 2 of the Frederick County Stream Survey.

Bank Erosion

Bank erosion was scored on a scale of 0 to 3; associated narrative ratings for these scores are described in Table 5. During Round 2 of the FCSS, bank erosion observed in the County's streams ranged from none to severe (Table 6 and Appendix Table A3). Countywide erosion scores were significantly worse in Round 1 than in Round 2 (one-sided t-test p-value < 0.001); however, Cohen's effect size was small (0.325) and indicates that this difference is of little practical significance. It can not be stated with statistical certainty that Round 2 erosion scores were worse than Round 1. Fewer sites sampled in Round 2 (5%) fell into the "Severe" erosion category as compared to sites sampled in Round 1 (20%) (Figure 9). Forty-seven percent of Round 2 sites fell into "Minimum" erosion categories compared to 32% in Round 1. Results varied by watershed (Figures 10-12 and Appendix Table A3), and only 2 watersheds had mean erosion scores that differed significantly between rounds. Little Catoctin Creek South and Lower Linganore Creek watersheds had significantly lower mean erosion scores in Round 2 than in Round 1 (one-sided t-test p-values of 0.012 and 0.005, respectively). All other watersheds had one-sided t-test p-values > 0.025).

Table 5. Erosion severity classes

Erosion Severity Class	Score
None	0
Minimum	1
Moderate	2
Severe	3

Table 6. Summary erosion statistics in meters.

	Mean	Median	Minimum	Maximum
Round 1	1.6	2	0	3
Round 2	1.4	1	0	3

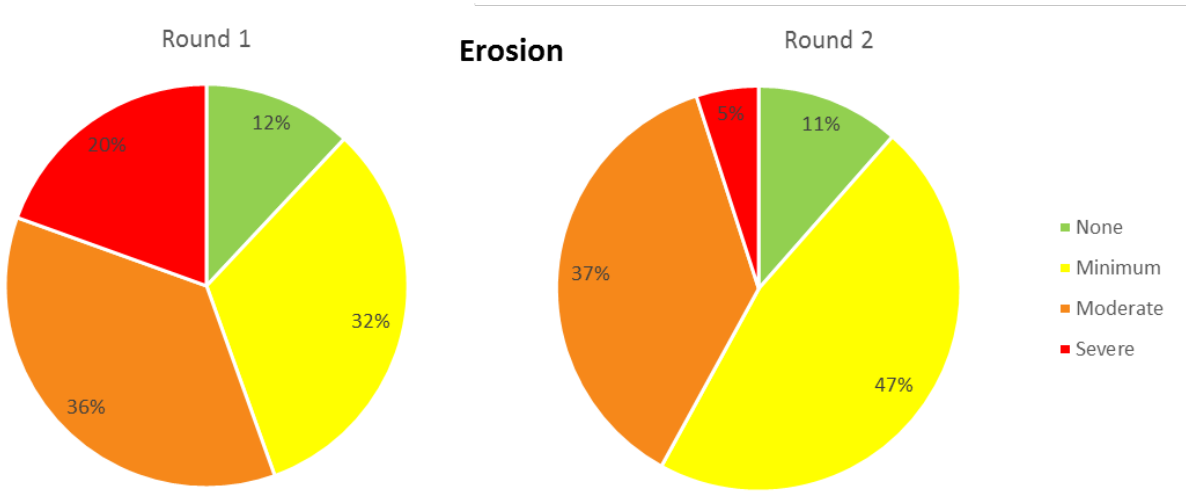

Figure 9. Percentages of Round 1 and Round 2 stream miles in each erosion severity class for Round 1 and Round 2 FCSS.

Figure 10. Percentage of stream miles in erosion severity classes for each of the five 8-digit watersheds in Frederick County for FCSS sampling Rounds 1 and 2.

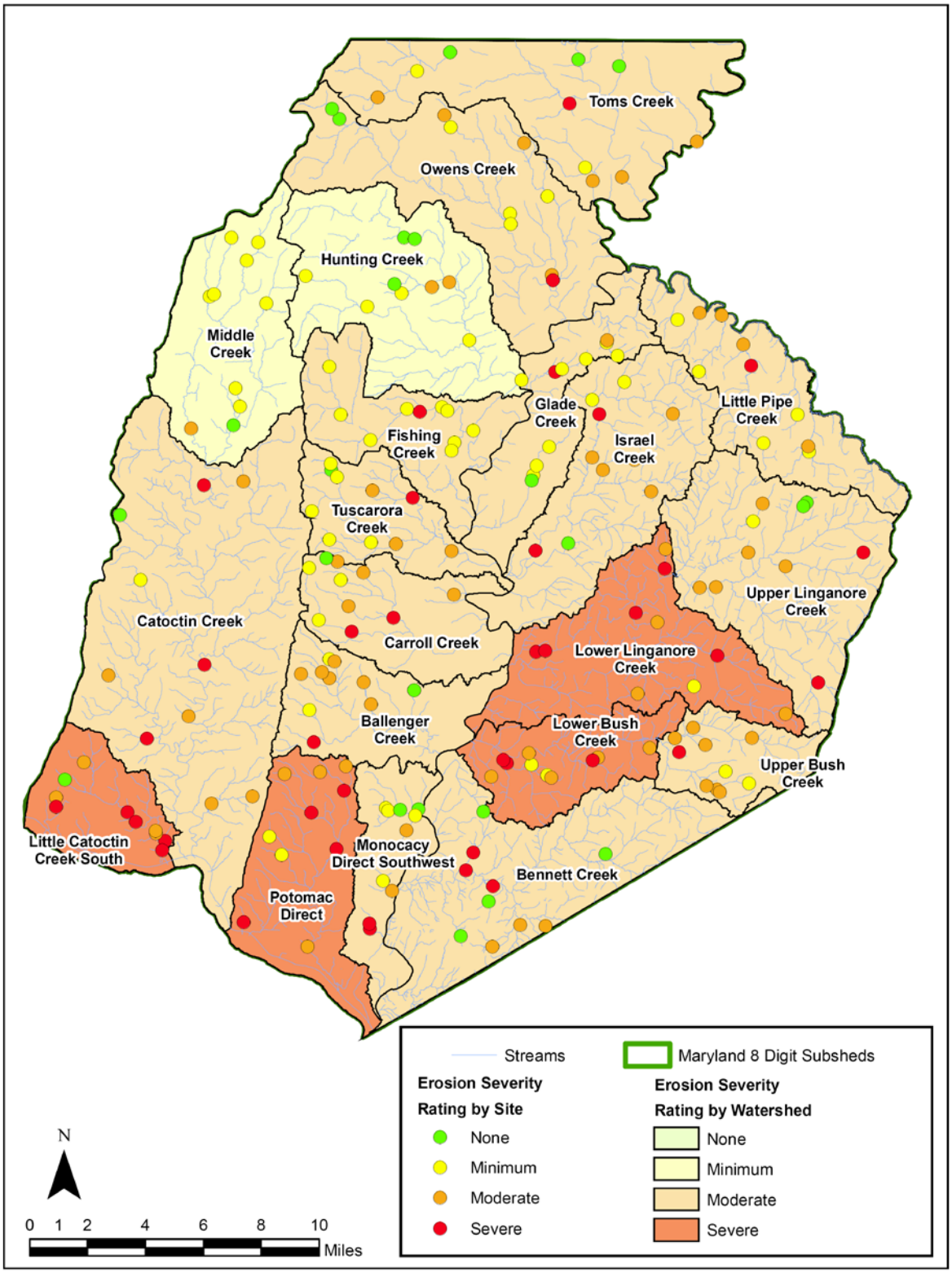

Figure 11. Map of Frederick County watersheds shaded according to average erosion severity class, with erosion class also shown per site, for Round 1 of the Frederick County Stream Survey.

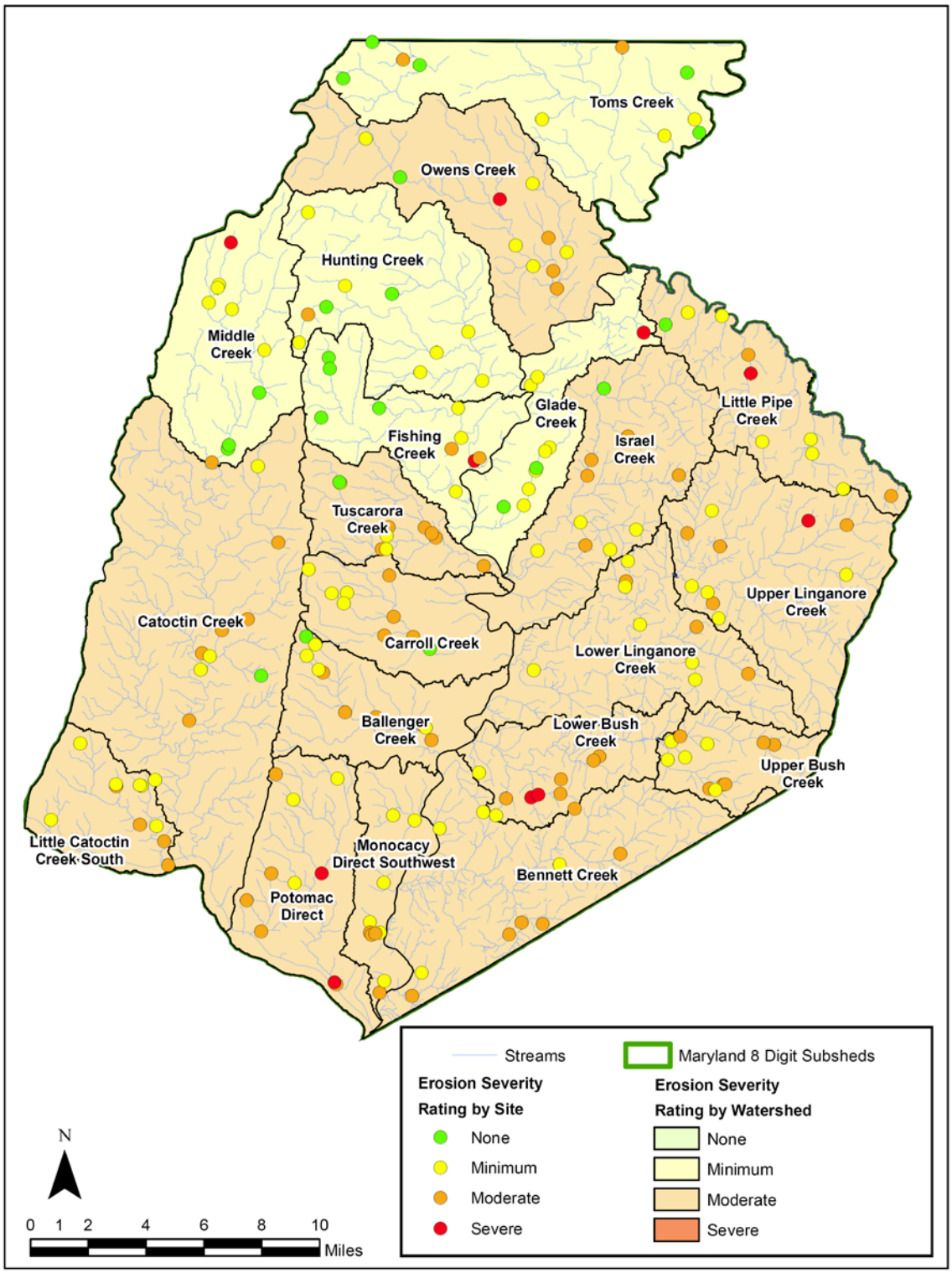

Figure 12. Map of Frederick County watersheds shaded according to average erosion severity class, with erosion class also shown per site, for Round 2 of the Frederick County Stream Survey.

Riparian Buffer

For the purposes of this report, the riparian buffer width on both sides of the stream were summed together as a measure of riparian buffer integrity. According to a literature review (U.S. Army Corps of Engineers 1991, Wenger 1999, Fischer and Fischenich 2000, Broadmeadow and Nisbet 2004), the riparian buffer widths required to adequately provide specific functions vary, for example:

- For erosion control, buffers should be between 30 and 98 feet (9-30 meters) on each side of the stream;
- For the removal of nitrogen and phosphorus, 16-164 feet (5-50 meters);
- For pesticide removal, 49-328 feet (15-100 meters);
- For the protection of aquatic wildlife, 33-164 feet (10-50 meters); and
- To provide adequate shading, 30-320 feet (9-98 meters).

Riparian buffer categories were assigned based on natural breaks in the data (Table 7). During Round 2, 12% of County stream miles had vegetated riparian buffer widths less than 15 meters, while 65% of stream miles in the County had vegetated riparian buffers of at least 60 meters (Figure 13). Countywide average riparian buffer widths did not vary significantly between Rounds 1 and 2 (two-sided t-test p-value > 0.05) and mean buffer width was similar for both rounds (Table 8).

Table 7. Riparian width sum classes

Category	Riparian Width Sum
1	≤ 15 m
2	15 m to ≤ 30 m
3	30 m to ≤ 60 m
4	> 60 m

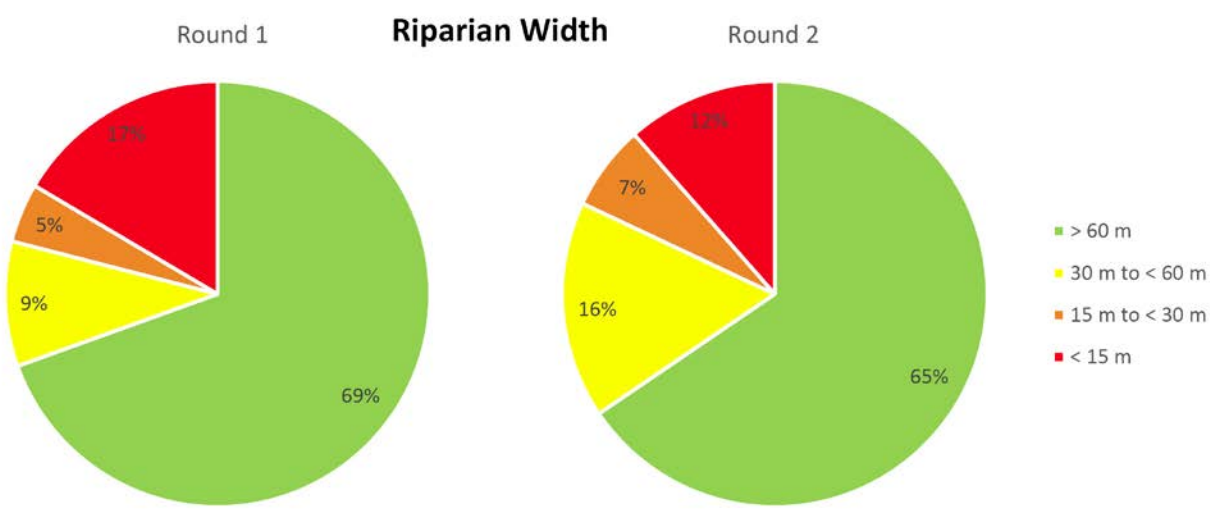

Figure 13. Percentages of Round 1 and Round 2 stream miles in each riparian buffer width category.

Average riparian buffer widths at the watershed scale in Round 1 compared to Round 2 were not significantly different (two-sided t-test p-values > 0.05) for all but two watersheds; Fishing Creek and Catoctin Creek watersheds (Appendix Table A4). Round 1 mean riparian buffer width in the Fishing Creek watershed was significantly lower than in Round 2 (one-sided t-test p-value = 0.022). Sites sampled in the Catoctin Creek watershed in Round 2 had significantly less mean riparian buffer width in than in Round 1 (one-sided t-test p-value = 0.018).

Table 8. Summary total riparian width statistics in meters.

	Mean	**Median**	**Minimum**	**Maximum**
Round 1	71	90	0	100
Round 2	72	80	0	100

Except for Catoctin Creek, Glade Creek, Lower Linganore Creek, and Little Pipe Creek watersheds, all other watersheds in Frederick County had average riparian buffer widths of more than 60 meters along their stream banks. Glade Creek and Little Pipe Creek watersheds had the greatest percentage of stream miles with less than 15 meters of riparian buffer along their banks (Figure 14). While no watershed had an average riparian buffer value less than 30 meters for either sampling round, there were many individual sites scattered throughout the County that had less than 15 meters of vegetated riparian buffer (Figures 15 and 16).

Figure 14. Percentage of stream miles in riparian buffer width categories for each of the five 8-digit watersheds in Frederick County for FCSS sampling Rounds 1 and 2.

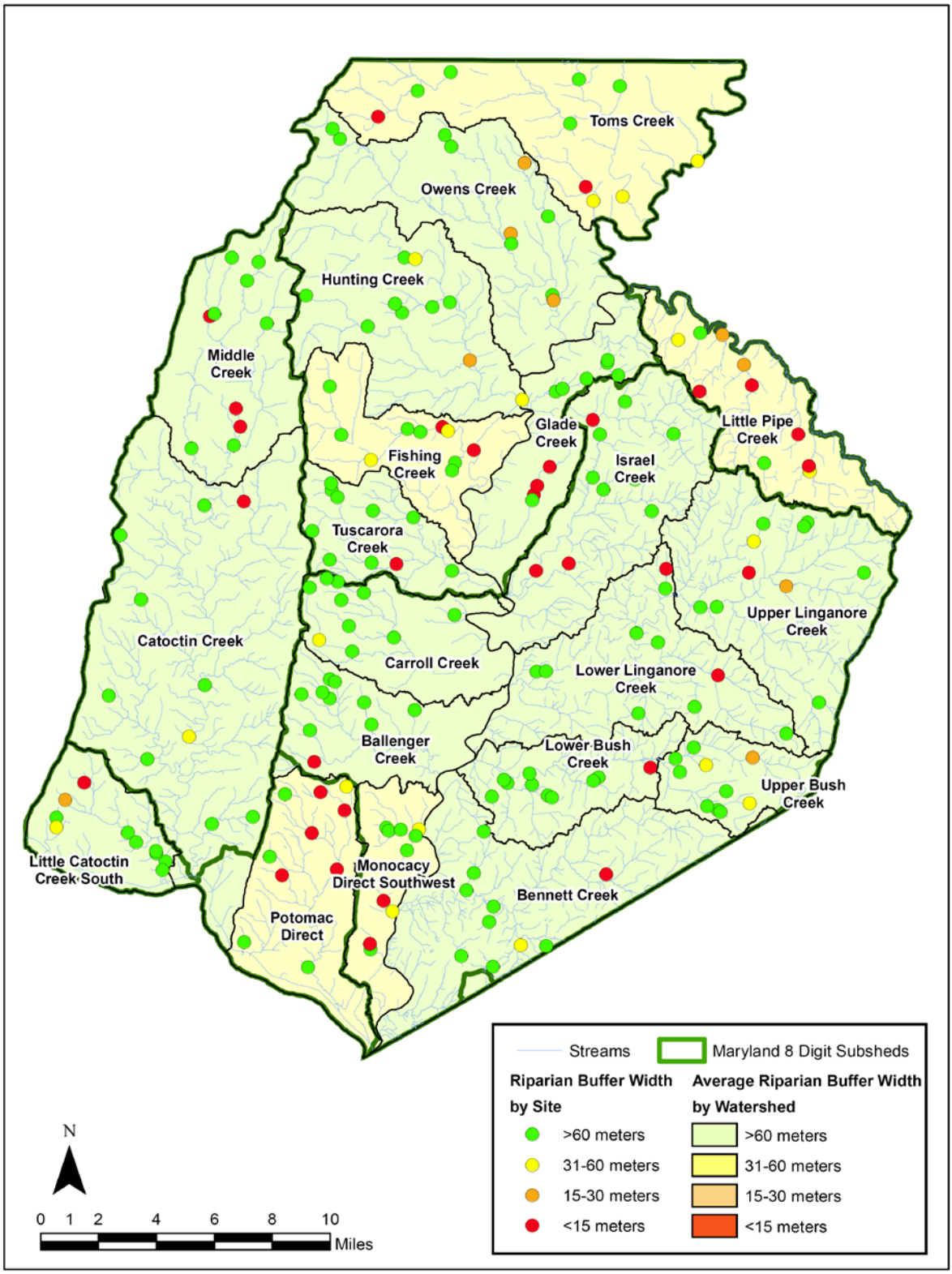

Figure 15. Map of Frederick County watersheds shaded according to average riparian buffer width category, with riparian buffer width category per site also shown, for Round 1 of the Frederick County Stream Survey.

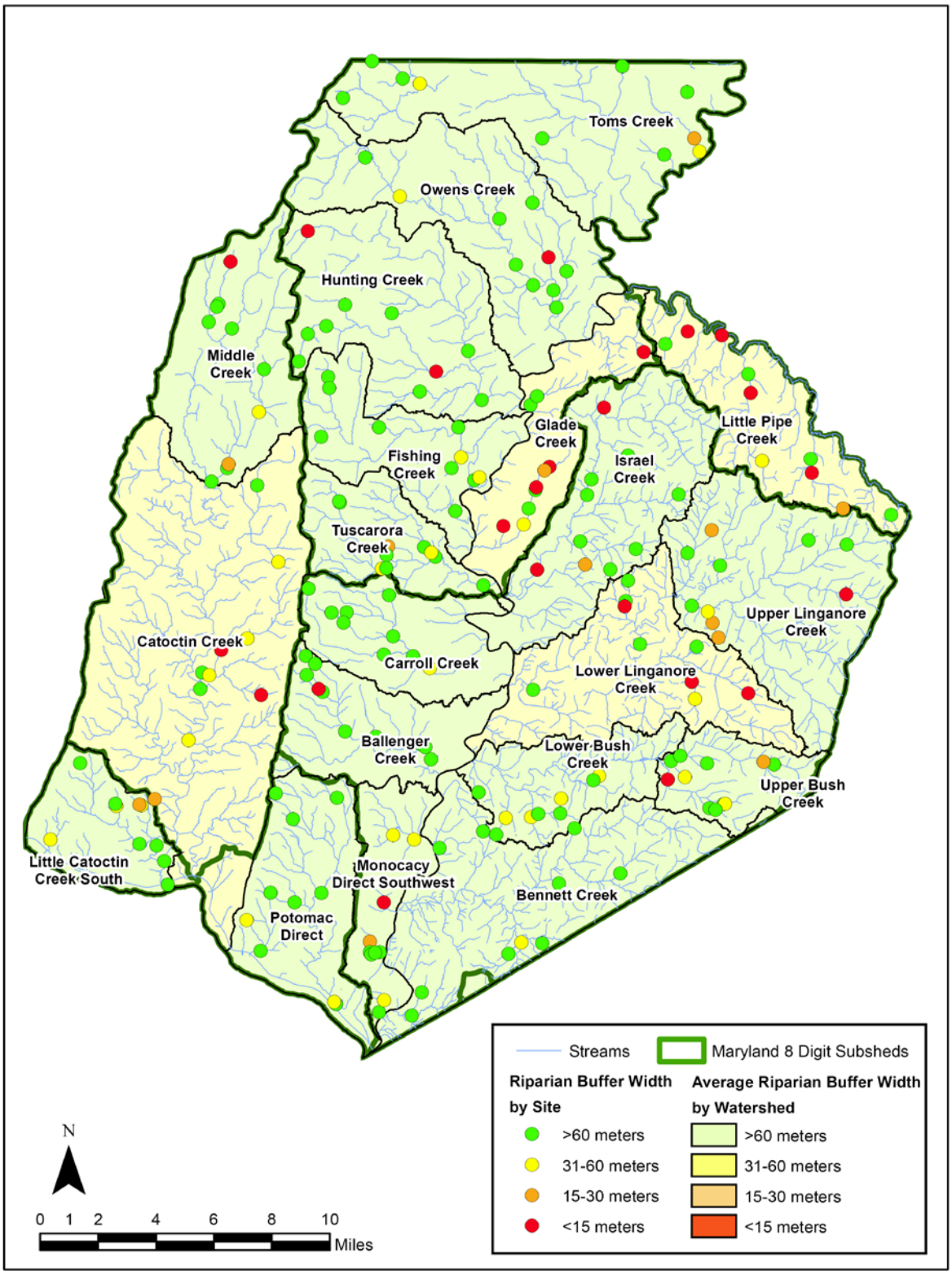

Figure 16. Map of Frederick County watersheds shaded according to average riparian buffer width category, with riparian buffer width category per site also shown, for Round 2 of the Frederick County Stream Survey.

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4 WATER QUALITY

Nutrients, such as nitrogen and phosphorus, are important for life in all aquatic systems. In the absence of human influence, streams contain low background levels of nutrients that are essential for aquatic plant and animal survival. However, since European settlement, concentrations of nitrogen and phosphorus in many North American streams has increased. Anthropogenic activities such as agriculture and urbanization result in nutrient-rich runoff from fertilization, wastewater discharge, and storm-water flow over impervious and pervious surfaces into streams.

Phosphorus and nitrogen are the primary nutrients that pollute streams. Nitrogen can enter the ecosystem in several chemical dissolved and particulate forms. Phosphorus is vital for cellular growth and division. Plants also require this chemical to convert sunlight into usable energy. Under natural aquatic conditions phosphorus is typically only present in low concentrations. In the late 1960s, scientists determined that anthropogenic phosphorous is a major cause of excessive algae growth and degraded water quality in downstream estuaries.

Elevated nitrogen and phosphorus concentrations are major contributors to nutrient over-enrichment in Frederick County streams. Excessive nutrient-loading in aquatic systems can cause eutrophication, or excessive plant growth, and precipitate anoxic conditions, particularly in downstream estuaries like the Potomac River and Chesapeake Bay. For example, eutrophication can cause algal blooms that lead to decreased concentrations of dissolved oxygen which, after prolonged exposure, can asphyxiate fish, shellfish, and other animals.

Estimates of nitrogen sources in Maryland, as presented in the Chesapeake Bay TMDL (Chesapeake Bay Phase 5.3.2 Watershed model), are 38% from agricultural sources, 25% from developed land, 10% from forest, and 27% from wastewater treatment plants.

Threshold categories for total nitrogen (TN) and total phosphorus (TP) concentrations can be found in Table 9. These thresholds are used by the MBSS and derived from expert judgement and literature (Ray Morgan, University of Maryland Frostburg, personal communication; and Morgan et al. 2007).

Table 9. Water quality thresholds (mg/L) for nutrients measured at sites sampled during the FCSS (Southerland et al. 2007)

Parameter	Low	Moderate	High
Total Nitrogen	< 1.5	1.5 – 7.0	> 7.0
Total Phosphorus	< 0.025	0.025 – 0.070	> 0.070

Nitrogen

Mean countywide Round 1 and 2 TN concentrations were similar (Table 10) and did not statistically differ (two-sided t-test p-value > 0.05). The percentage of sites with "Moderate" concentrations of TN increased from Round 1 to Round 2 (Figure 17 and Appendix A-5), while percentages of sites in both the "Low" and "High" concentration categories decreased between Round 1 and Round 2 (Figure 17). The percentage of stream miles in each TN category per round is illustrated in Figure 18. At the individual watershed scale, mean TN concentrations significantly decreased from Round 1 to Round 2 in the Little Catoctin Creek South watershed (one-sided t-test p-value = 0.006). Mean TN concentration significantly increased in the Ballenger Creek and Carrol Creek watersheds from Round 1 to Round 2 (one-sided t-test p-values of 0.017 and 0.020, respectively).

Generally, the majority stream miles in each watershed, in both Round 1 and 2, were in the "Moderate" concentration category for total nitrogen (Figure 18). Nitrogen levels within the watersheds in Frederick County varied geographically (Figures 19 and 20). Watersheds in the north-west portion of the County had average concentrations of total nitrogen in the "Low" category (Figure 19 and 20).

Table 10. Summary total nitrogen concentration statistics in mg/L.

	Mean	**Median**	**Minimum**	**Maximum**
Round 1	2.99	2.30	0.10	15.50
Round 2	3.03	2.65	0.10	16.00

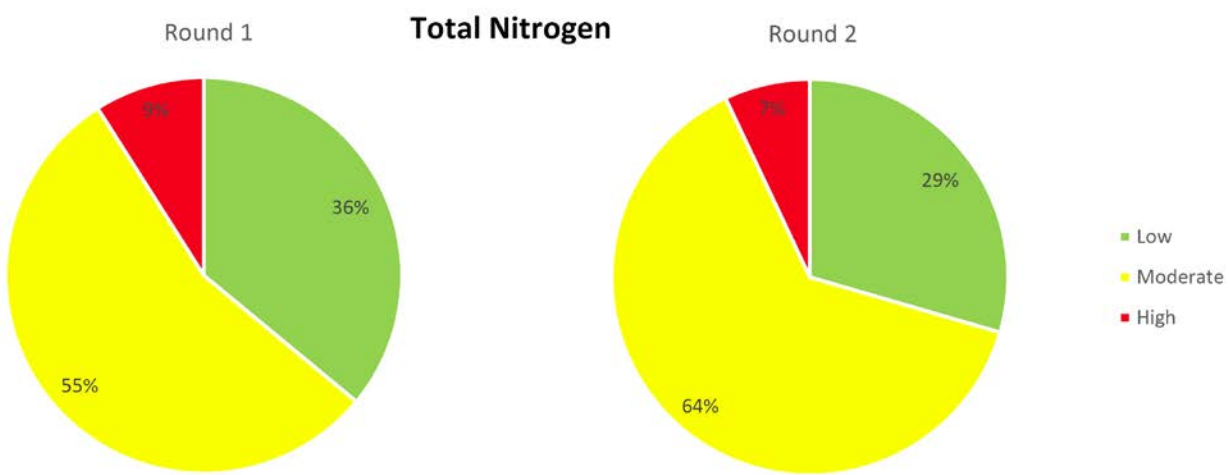


Figure 17. Percentages of Round 1 and Round 2 stream miles in each total nitrogen concentration category.

Figure 18. Percentage of stream miles in total nitrogen concentration categories for each of the five 8-digit watersheds in Frederick County for FCSS sampling Rounds 1 and 2.

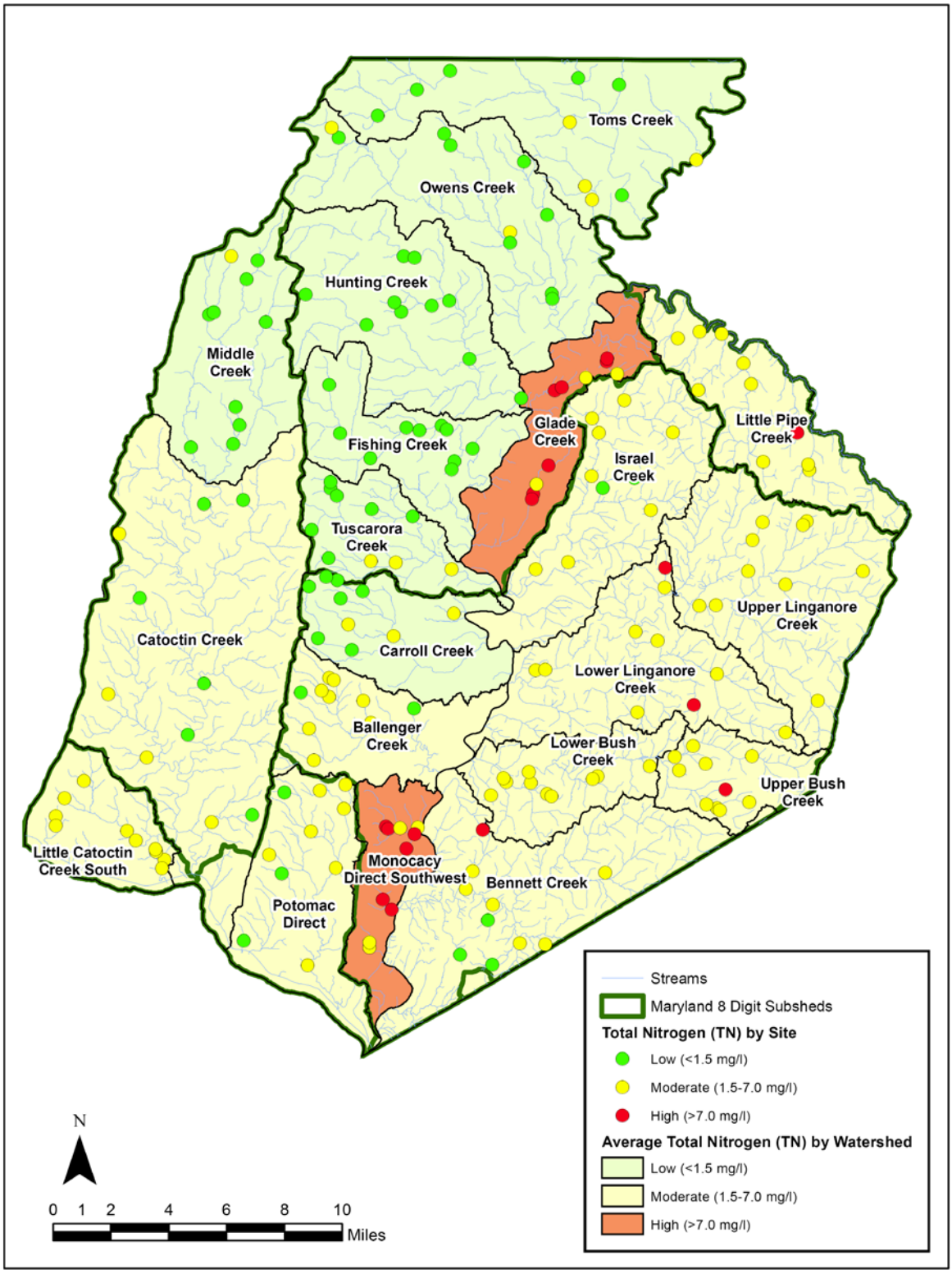


Figure 19. Map of Frederick County watersheds shaded according to average total nitrogen (mg/l) concentration category, with total nitrogen category per site also shown, for Round 1 Frederick County Stream Survey.

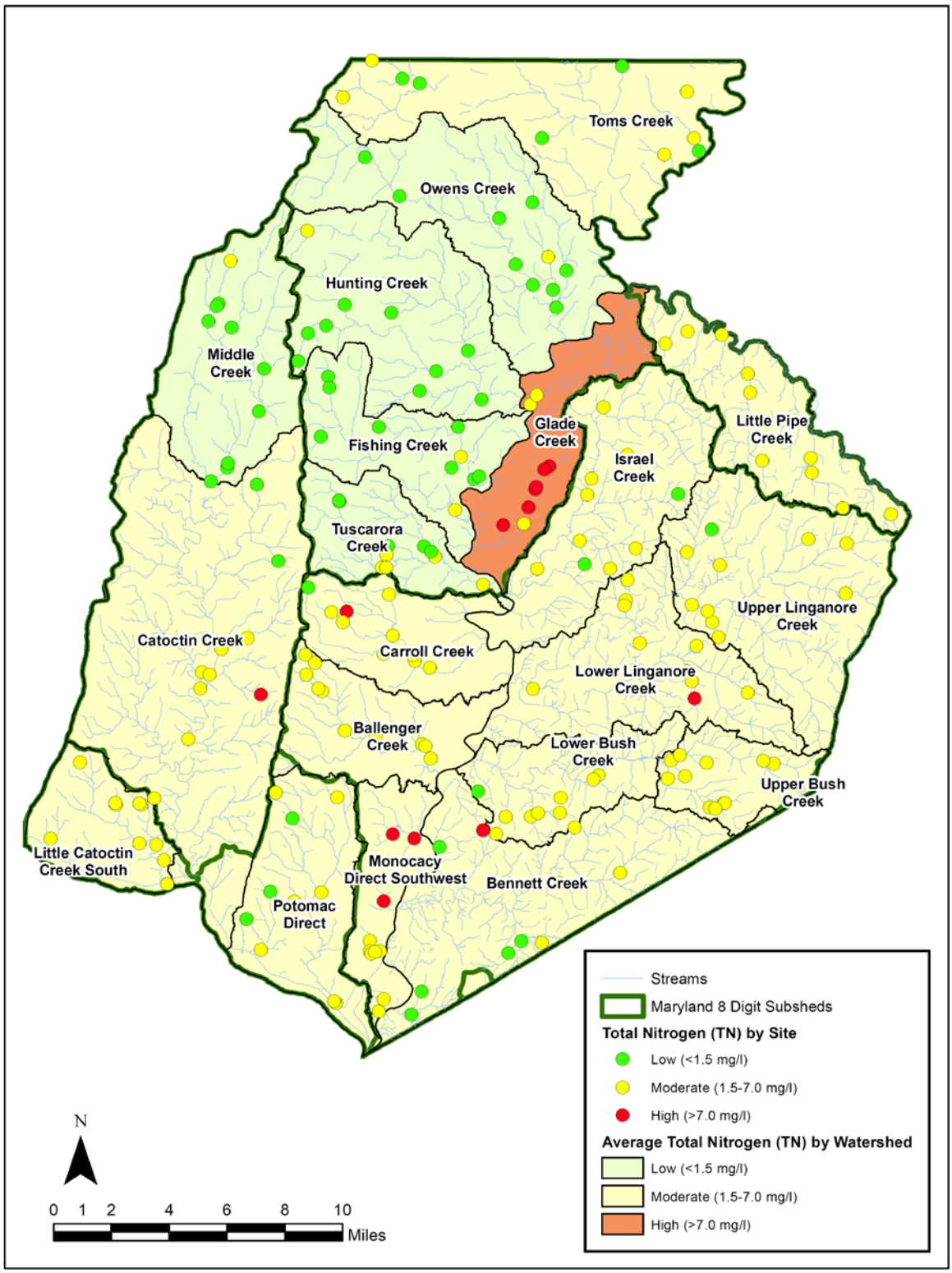


Figure 20. Map of Frederick County watersheds shaded according to average total nitrogen (mg/l) concentration category, with total nitrogen category per site also shown, for Round 2 Frederick County Stream Survey.

Phosphorus

Round 2 sampling shows a smaller percentage of County stream miles in "High" and "Moderate" categories for TP as compared to Round 1 concentrations (Figure 21). While Round 2 summary statistics indicate a slight increase in mean TP concentrations compared to Round 1, this value is likely driven by the outlier maximum TP value and is supported by a lower Round 2 median TP concentration (Table 11). Countywide mean TP concentrations were significantly lower in Round 2 than in Round 1 (one-sided t-test p-value < 0.001); however, the magnitude of effect size indicates that the statistical difference is of little practical significance (Cohen's effect size = -0.033).

At the watershed scale, significant decreases in mean TP concentrations between Rounds 1 and 2 were identified using one-sided t-tests in the Ballenger Creek (p-value = 0.0.18), Little Catoctin Creek South (p-value = 0.008) and Potomac Direct (p-value = 0.022) watersheds. There was no significant difference in Round 1 vs. Round 2 mean TP concentrations for all other watersheds. Overall, there was a marked decrease in the percentage of stream miles for each watershed in the "High" concentration category (Figure 22). In Round 1, five watersheds had average TP concentrations in the "High" category whereas Round 2 had only two watersheds (Catoctin Creek and Glade Creek) with an average TP rating of "High" (Figures 23 and 24). TP results by watershed and site are shown in Figures 23 and 24.

Table 11. Summary total phosphorous concentration statistics in mg/L.

	Mean	**Median**	**Minimum**	**Maximum**
Round 1	0.048	0.025	0.004	1.078
Round 2	0.057	0.016	0.006	5.462

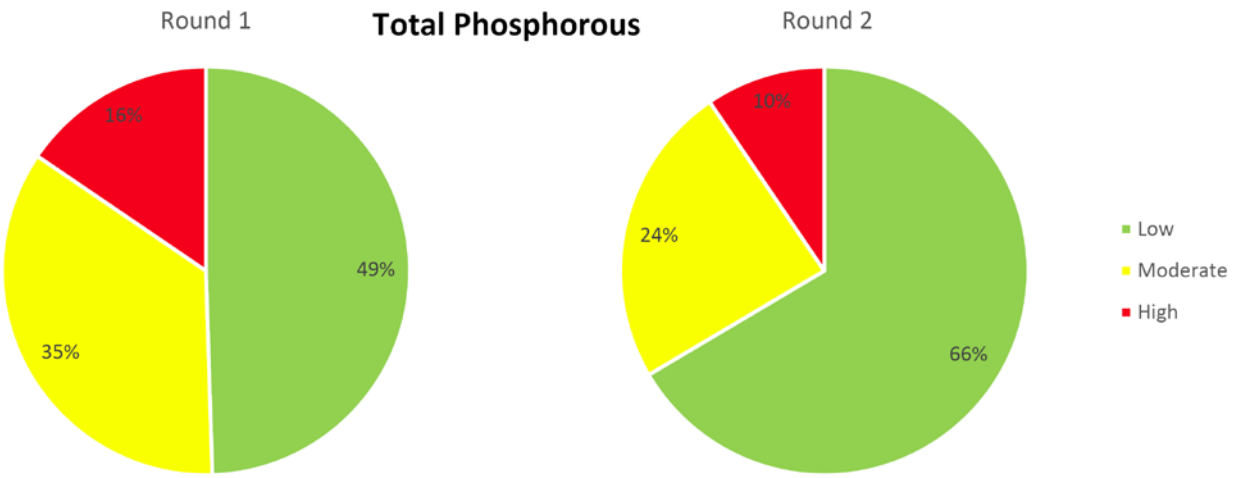


Figure 21. Percentages of Round 1 and Round 2 stream miles in each total phosphorous concentration category.

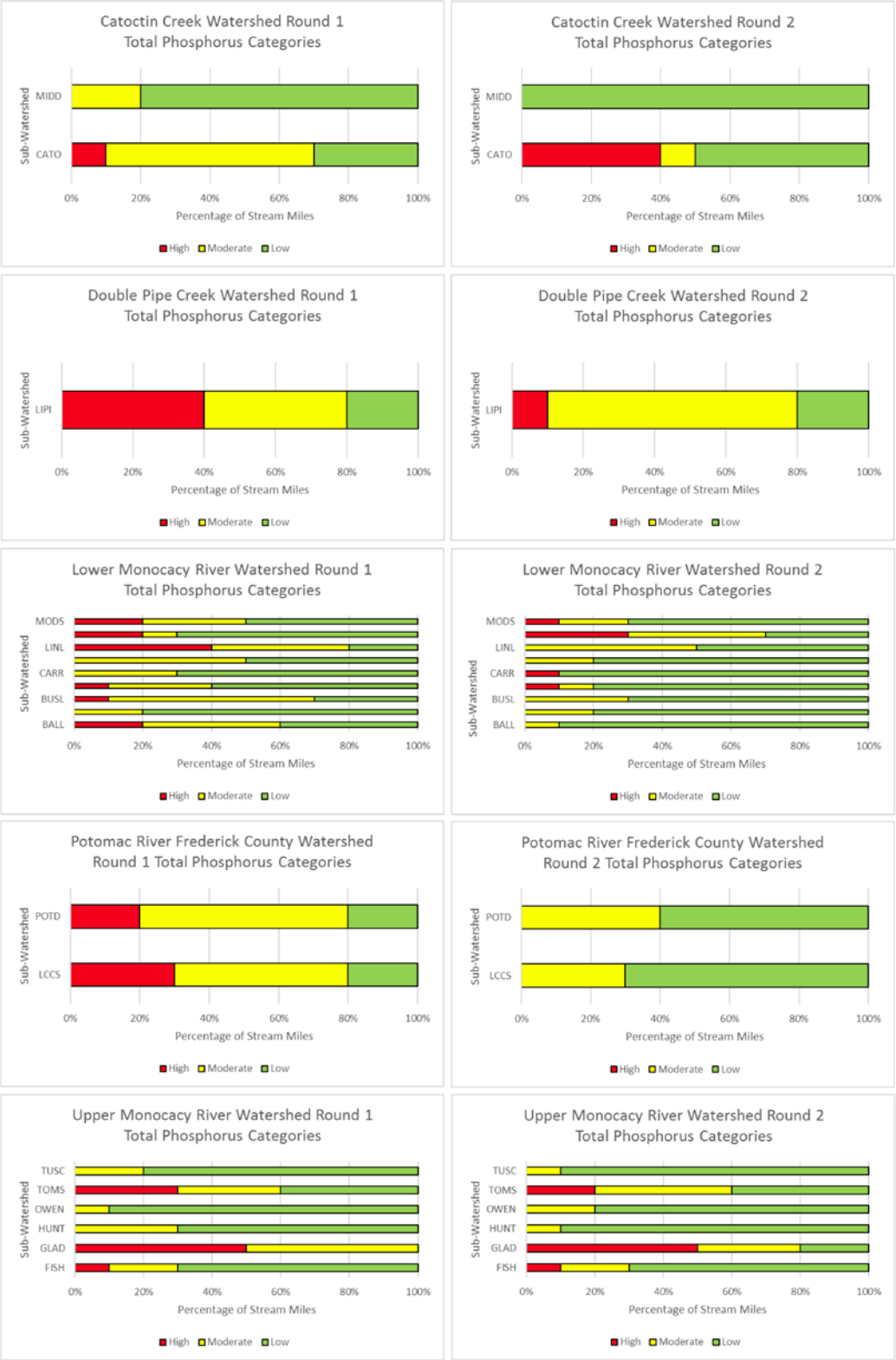


Figure 22. Percentage of stream miles in total phosphorous concentration categories for each of the five 8-digit watersheds in Frederick County for FCSS sampling Rounds 1 and 2.

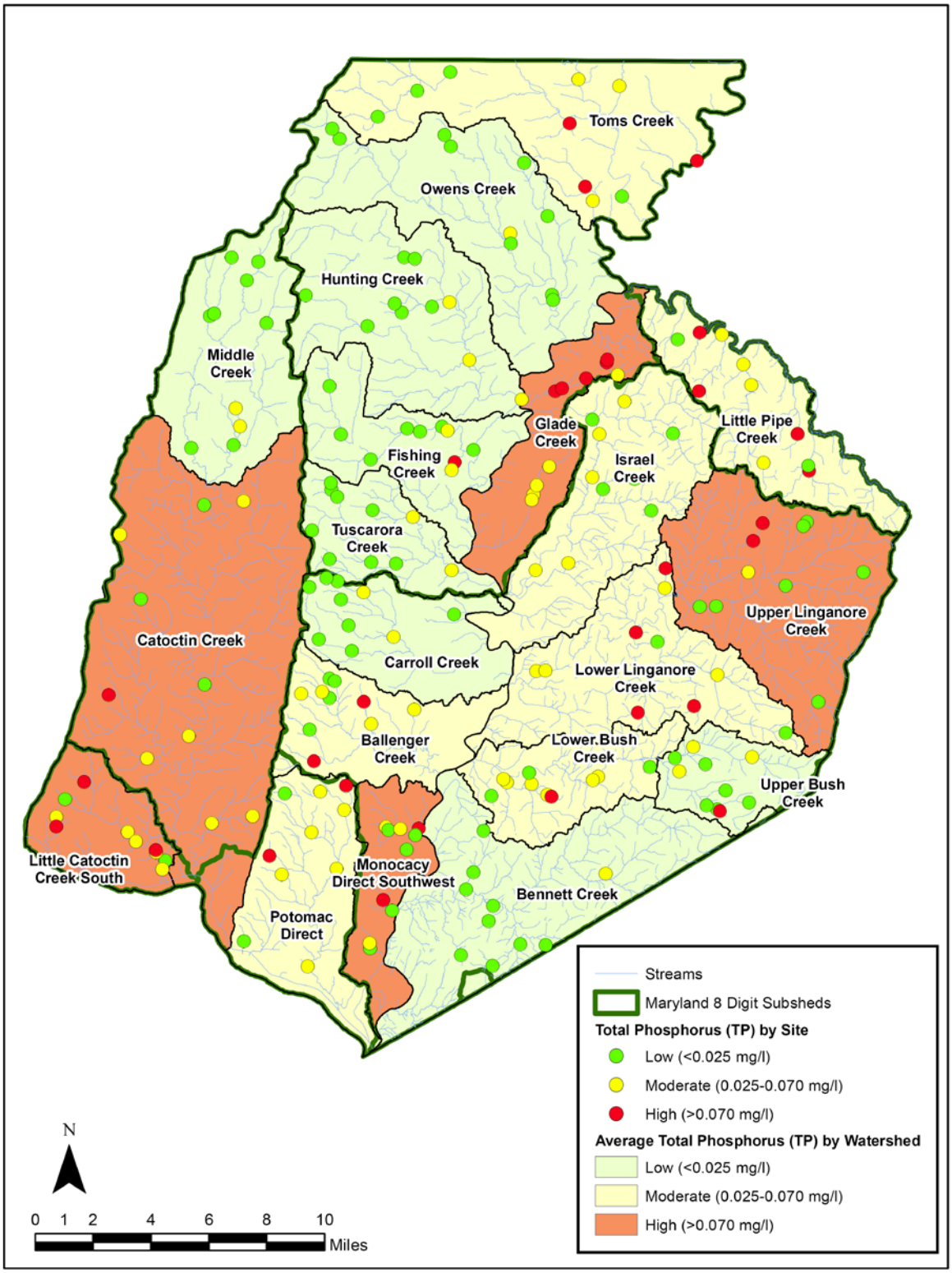


Figure 23. Map of Frederick County watersheds shaded according to average total phosphorous (mg/l) concentration category, with total phosphorous category also shown per site, for Round 1 Frederick County Stream Survey.

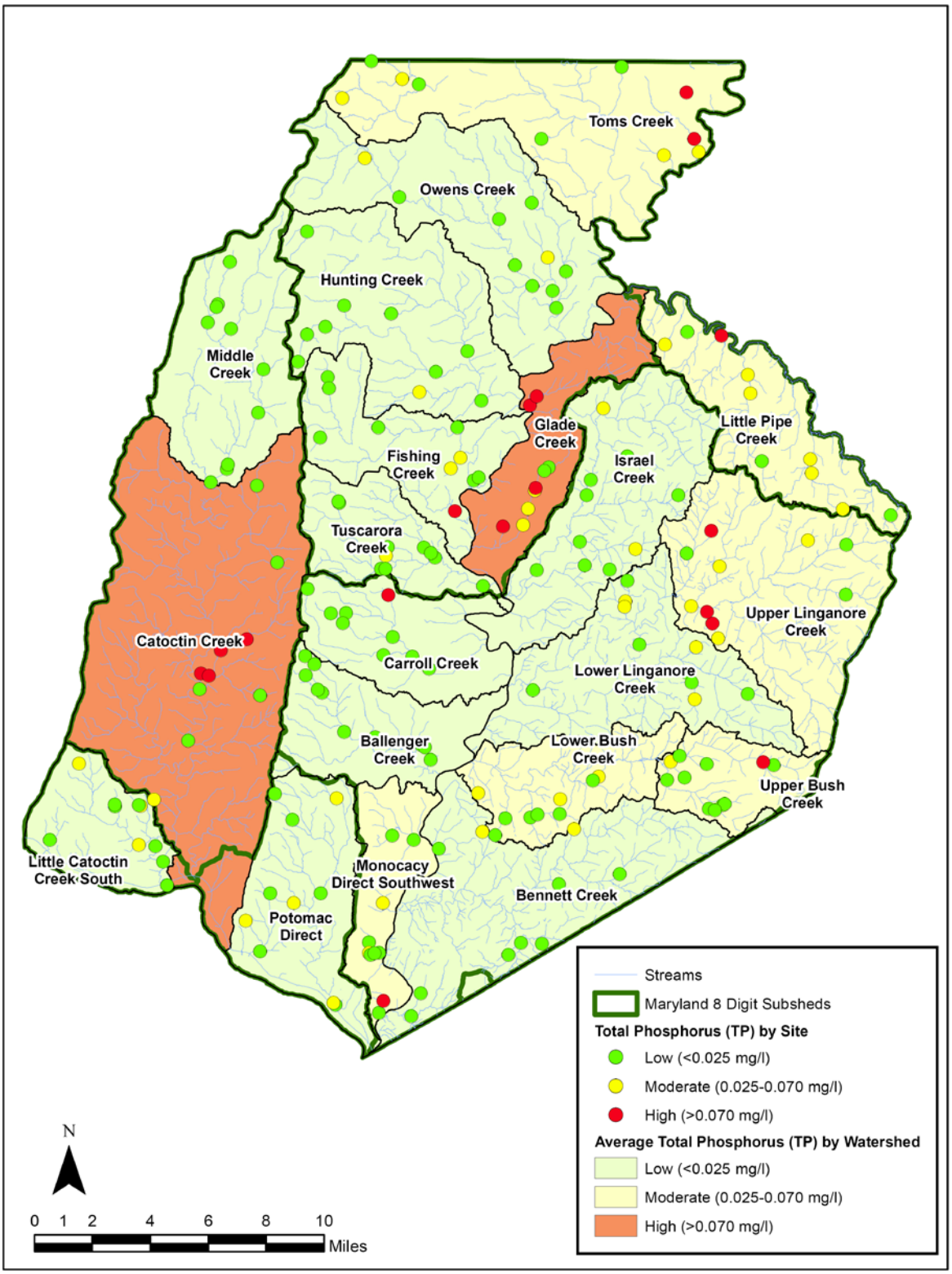


Figure 24. Map of Frederick County watersheds shaded according to average total phosphorous (mg/l) concentration category, with total phosphorous category also shown per site, for Round 2 Frederick County Stream Survey.

5 BIOLOGICAL CONDITION

Freshwater benthic macroinvertebrates are bottom-dwelling aquatic invertebrates greater than 0.5 millimeters in length. These animals live in water during some stage of their lifecycle, and dwell on rocks, logs, sediment, debris and aquatic plants. Stream benthic macroinvertebrates include crustaceans (i.e. crayfish), mollusks (i.e., clams and snails), aquatic worms, and immature forms of aquatic insects such as stonefly and mayfly nymphs.

Benthic macroinvertebrates are an important part of the food chain. Many invertebrates feed on algae and bacteria that are in lower trophic levels. Some invertebrates shred and eat leaves and other organic matter that enters the water. Because of their abundance and position as "middlemen" in the aquatic food chain, benthic macroinvertebrates play a critical role in the natural processing of energy and nutrients. As these invertebrates die and decay they leave behind nutrients that are reused by aquatic plants and other animals in the food chain.

Benthic macroinvertebrates represent an extremely diverse group of aquatic animals, with over 600 taxa known to occur in Maryland (Jessup et al. 2003). These insects have a wide range of recognized responses to stressors such as organic pollutants, sediments, and toxic chemicals and can serve as an early warning sign of declines in environmental quality. Benthos are relatively stationary, and their migrations come largely in the form of downstream drift, so they are less able to escape the effects of sediment and other pollutants that diminish water quality and degrade habitat. Therefore, benthic macroinvertebrates can serve as reliable indicators of stream condition.

The Benthic Index of Biotic Integrity (benthic IBI or BIBI) is a stream assessment tool that evaluates stream biological integrity based on characteristics of the various benthic organisms present at a site. Biological integrity is defined as the ability to support and maintain a balanced, integrated, adaptive community of organisms having a species composition, diversity, and functional organization comparable to that of the natural habitat of the region (Karr and Dudley 1981).

Frederick County sites were evaluated using the benthic IBI developed for the Maryland Biological Stream Survey (for detailed methods, see Southerland, et al. 2007). IBI scores are determined by comparing the benthic assemblages at each site to those found at minimally impacted ("reference") sites within the same region. Site-specific IBI results were used to estimate the extent of streams within the study watersheds that were in" Good," "Fair," "Poor," and Very Poor" condition with respect to the biotic integrity of the benthic community (see Table 3).

Mean countywide BIBI scores significantly decreased from Round 1 to Round 2 with a small level of practical significance (one-sided t-test p-value = 0.016, effect size = 0.217; Table 12). In Round 1, 7% of stream miles were classified as "Very Poor" while 17% of stream miles classified in Round 2 were considered "Very Poor," however, there was little change in the

percentage of stream miles in the "Poor" and "Good" categories between Rounds 1 and 2 (Figure 25). Generally, BIBI scores showed a downward trajectory for most watersheds in the County (Figures 26, 27 and 28). Particularly in the Glade Creek and Little Catoctin Creek South watersheds, where BIBI scores significantly decreased between Rounds 1 and 2 (two-sided t-test p-values 0.014 and 0.036 respectively).

Table 12. Summary BIBI score statistics.

	Mean	**Median**	**Minimum**	**Maximum**
Round 1	3.04	3.00	1.50	5.00
Round 2	2.85	2.75	1.25	4.75

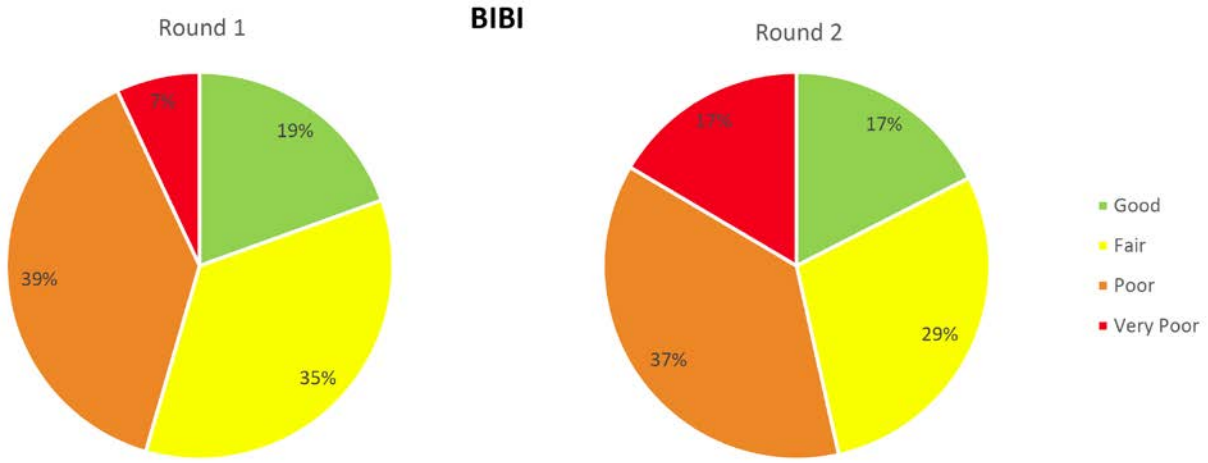


Figure 25. Percentages of Round 1 and Round 2 stream miles in each BIBI score category

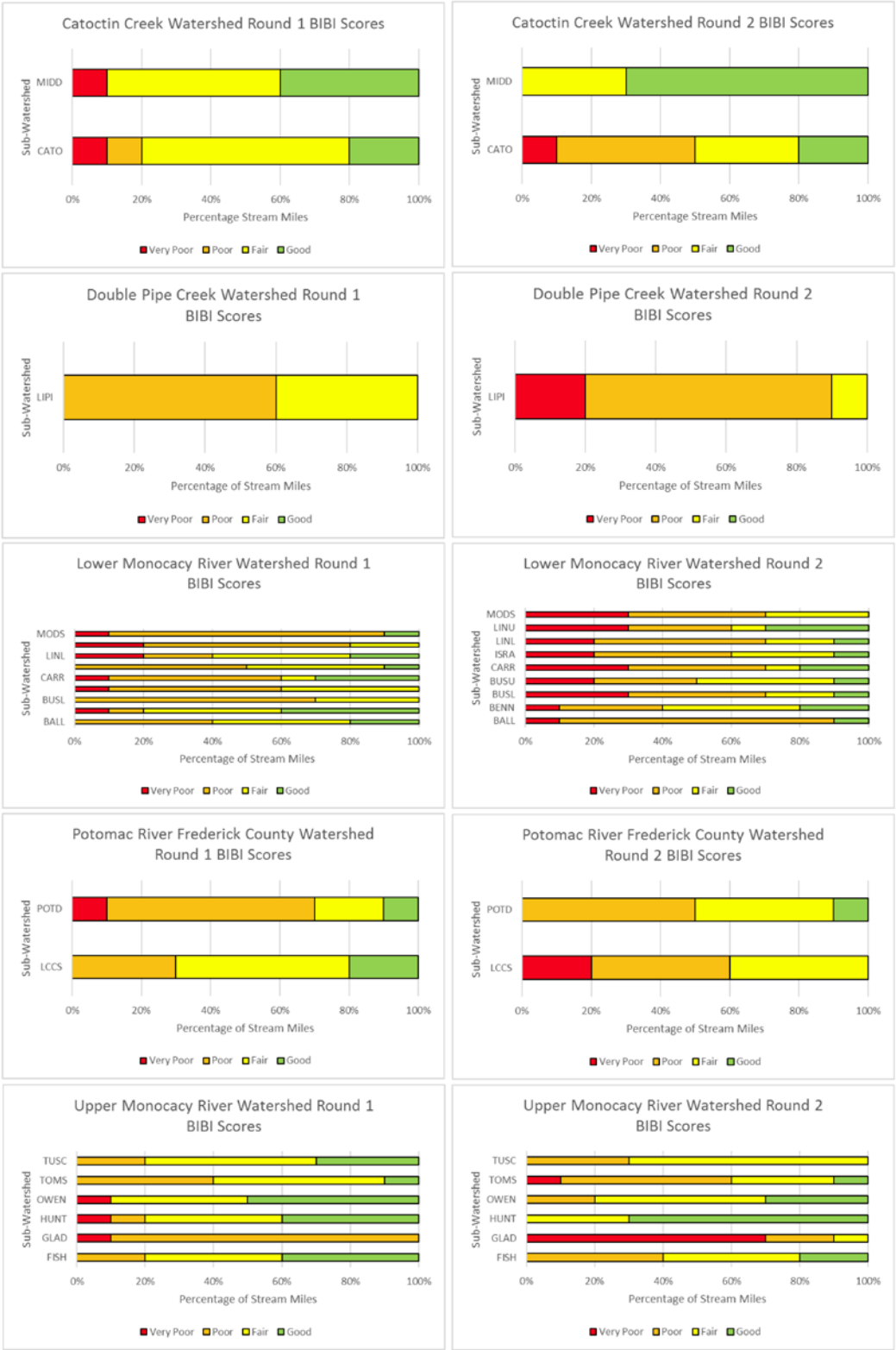


Figure 26. Percentage of stream miles in BIBI score categories for each of the five 8-digit watersheds in Frederick County for FCSS sampling Rounds 1 and 2.

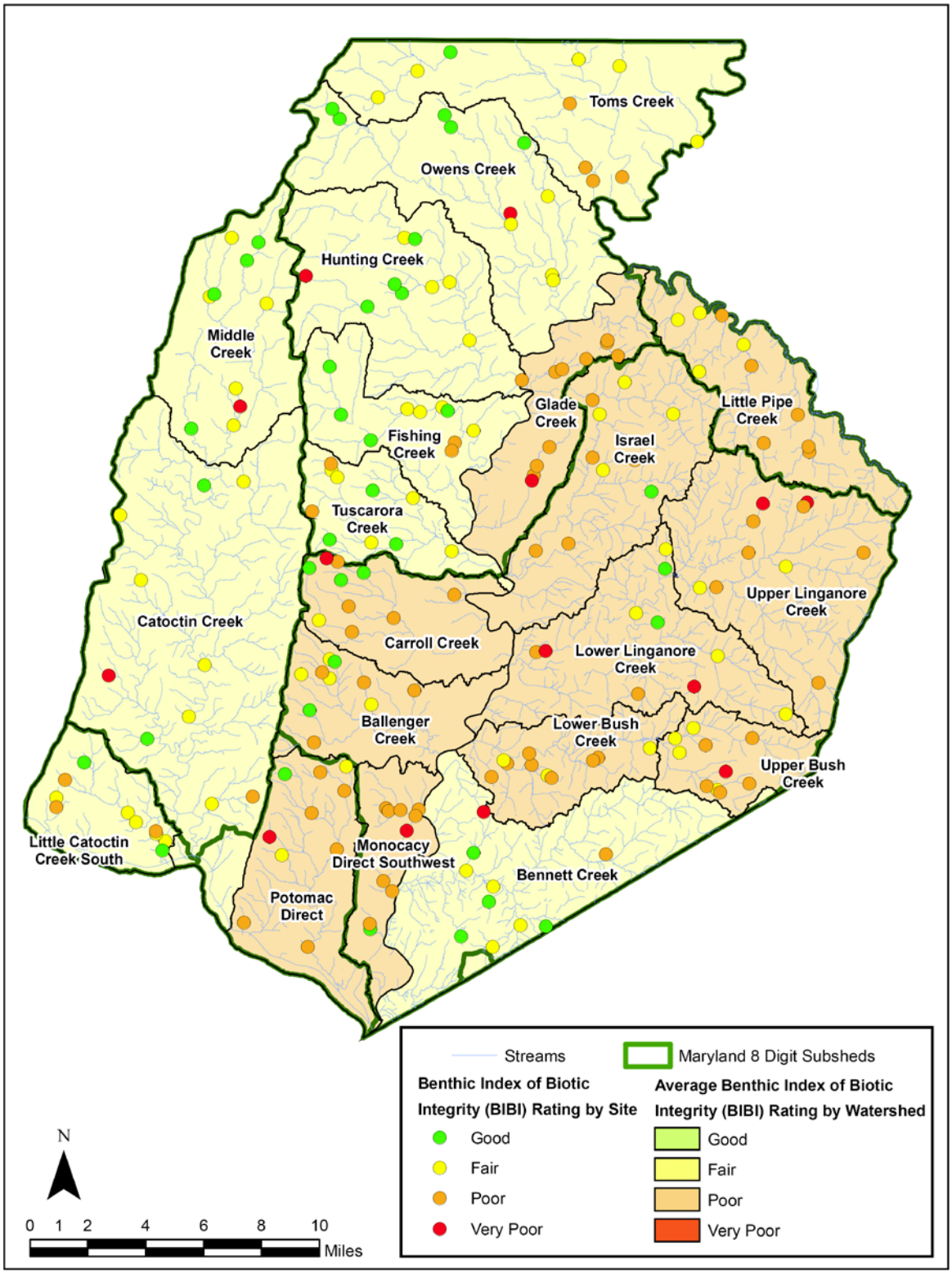


Figure 27. Map of Frederick County watersheds shaded according to average BIBI score category, with BIBI score category per site also shown, for Round 1 of the Frederick County Stream Survey.

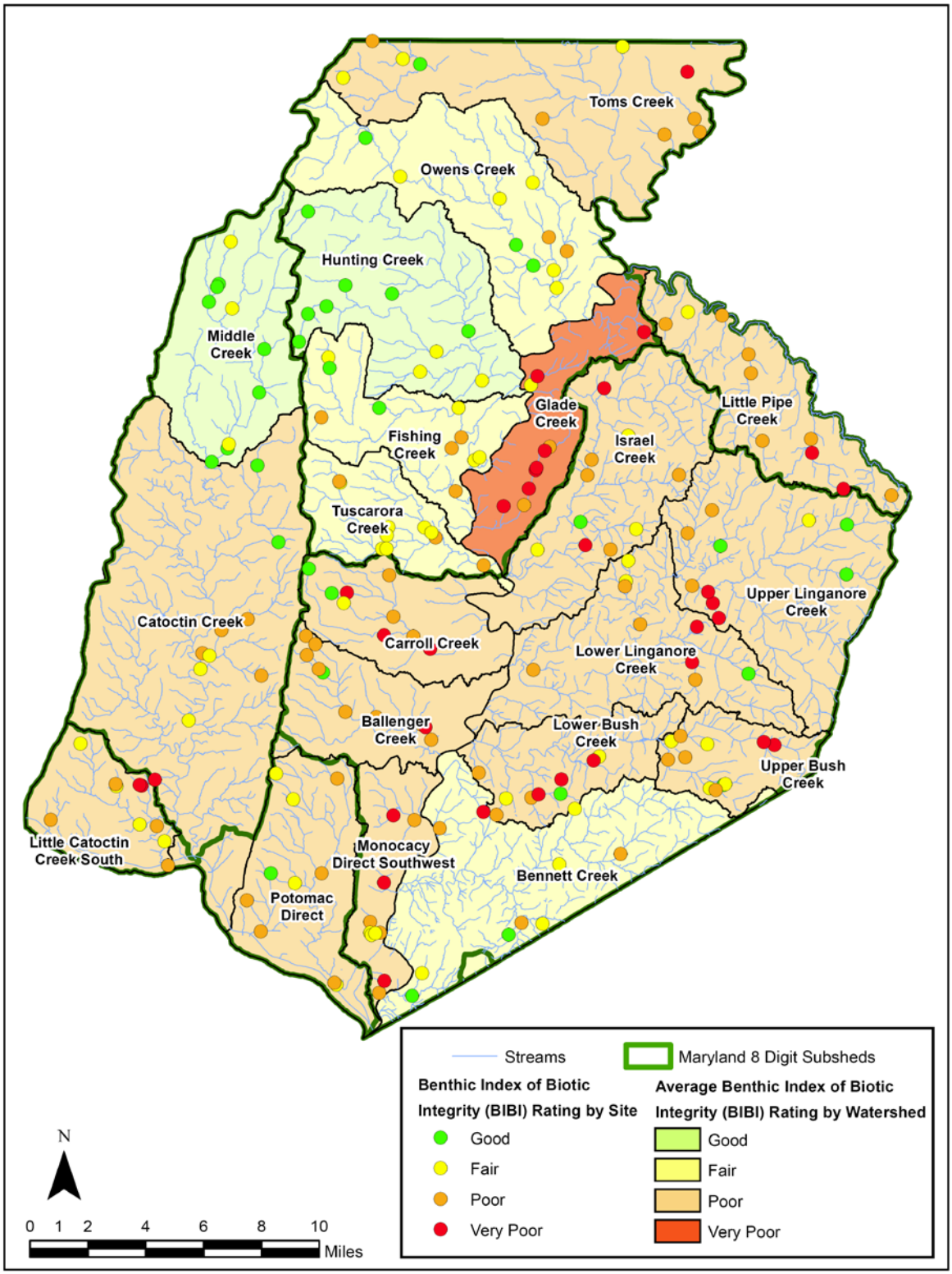


Figure 28. Map of Frederick County watersheds shaded according to average BIBI score category, with BIBI score category per site also shown, for Round 2 of the Frederick County Stream Survey.

6 SCATTER PLOTS

Relationships Among Biological, Physical, and Land Use Data

Land use, habitat, and water chemistry parameters were regressed against the benthic macroinvertebrate IBI scores for each site sampled in both Round 1 and Round 2 (n = 400) to examine the relationship of those parameters to the biological health of the stream. All reported R^2 values are the adjusted R^2.

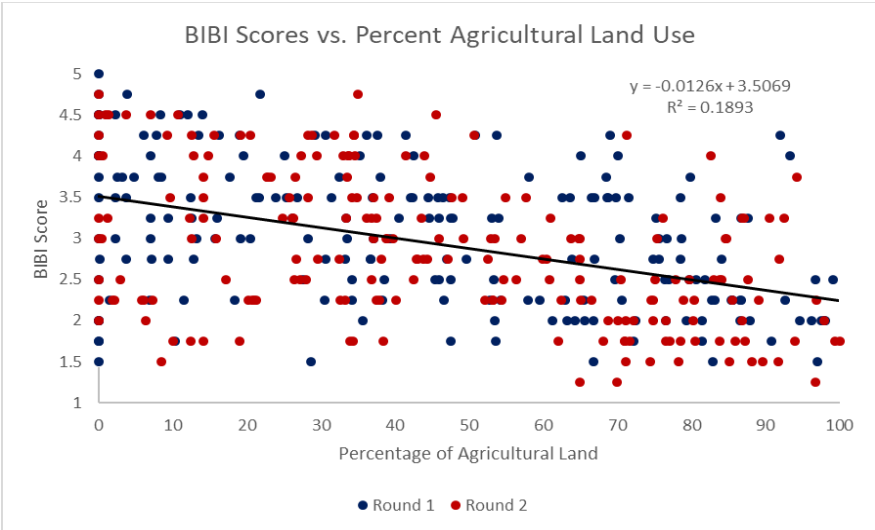
While the relationship of the BIBI to land use in the catchments upstream of the sample sites was not very strong, BIBI scores did significantly decrease with both increasing agricultural and urban land use ($R^2 = 0.19$, $p < 0.001$; $R^2 = 0.04$, $p < 0.001$). BIBI scores showed a significant increase with increasing forested land use ($R^2 = 0.32$, $p < 0.001$) (Figure 29). BIBI scores showed a significant decrease with increased urban land cover (Figure 29).

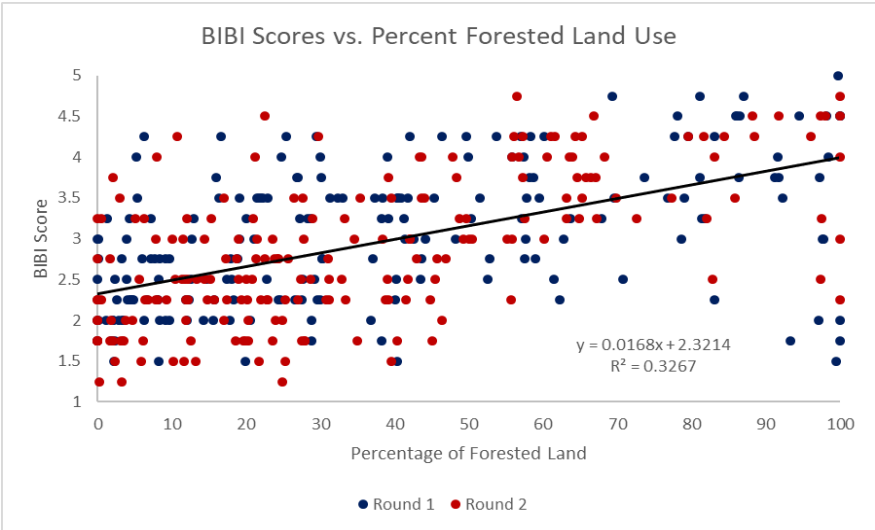
There was a significant positive relationship between PHI and BIBI scores ($R^2 = 0.13$, $p < 0.001$). The result is consistent with the prediction that as physical habitat quality increases, the quality of the benthic community also increases (Figure 30).

There is a significant negative relationship between BIBI scores and both TN and TP ($R^2 = 0.22$, $p < 0.001$ for TN and $R^2 < 0.01$, $p = 0.019$ for TP; Figure 31). The weak relationship between BIBI and TP concentrations is likely due to outliers.

Figure 32 shows regression relationships between land use in the catchments upstream of sites and TN. The relationship between agricultural land use and TN is significant ($R^2 = 0.35$, $p < 0.001$); as agricultural land use increases, TN increases as well. The relationship between forested land use and total nitrogen was also significant and strong ($R^2 = 0.42$, $p < 0.001$); increased forested land use corresponds to a decrease in TN at the sampled site. The relationship between upstream urban land use and TN was not significant ($R^2 < 0.01$, $p = 0.101$).

The regression relationships between land use in the catchments upstream of sites and TP were not strong (Figure 33), but showed patterns similar to TN. There was a significant positive relationship between upstream agricultural land use and TP ($R^2 < 0.01$, $p = 0.037$). Forested and urban land use do not have a significant relationship to TP concentrations ($R^2 < 0.01$, $p = 0.123$ for forest and $R^2 < 0.01$, $p = 0.400$).





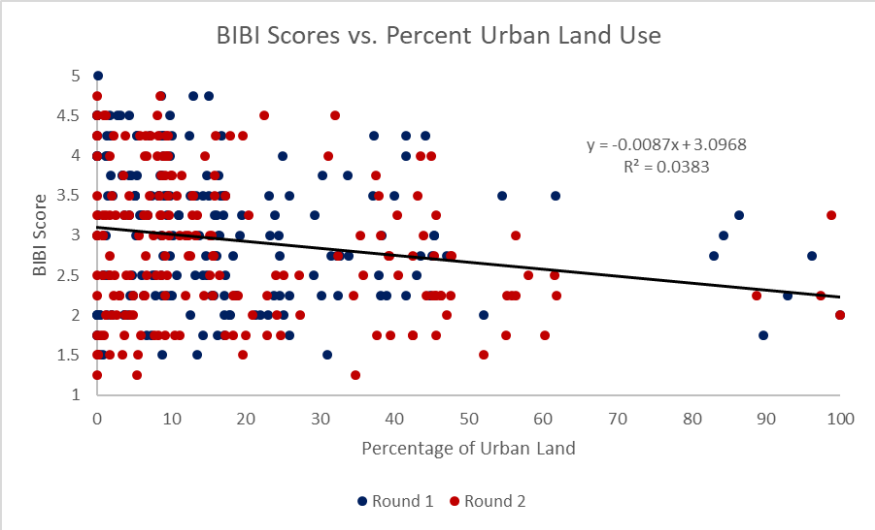


Figure 29. Regression relationships between the Benthic Index of Biotic Integrity (BIBI) and agricultural, forested, and urban land use in upstream catchments for Rounds 1 and 2 of the Frederick County Stream Survey

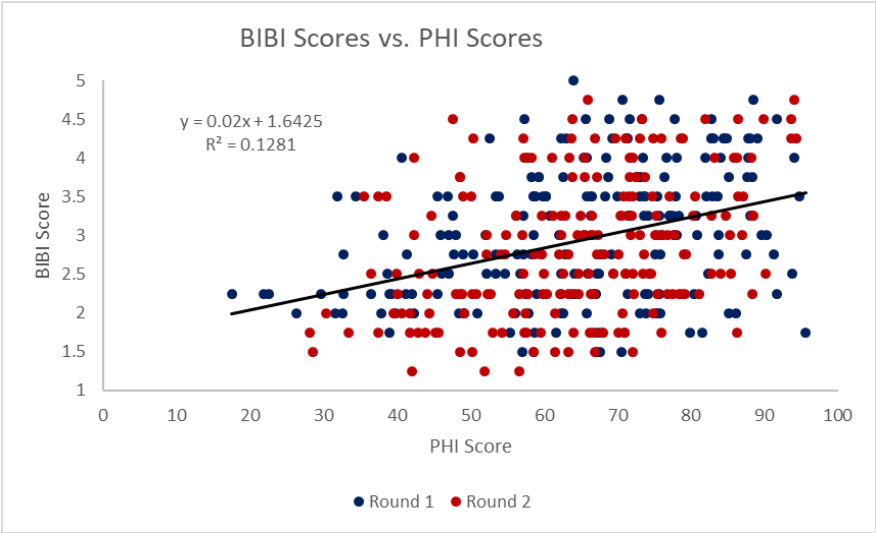
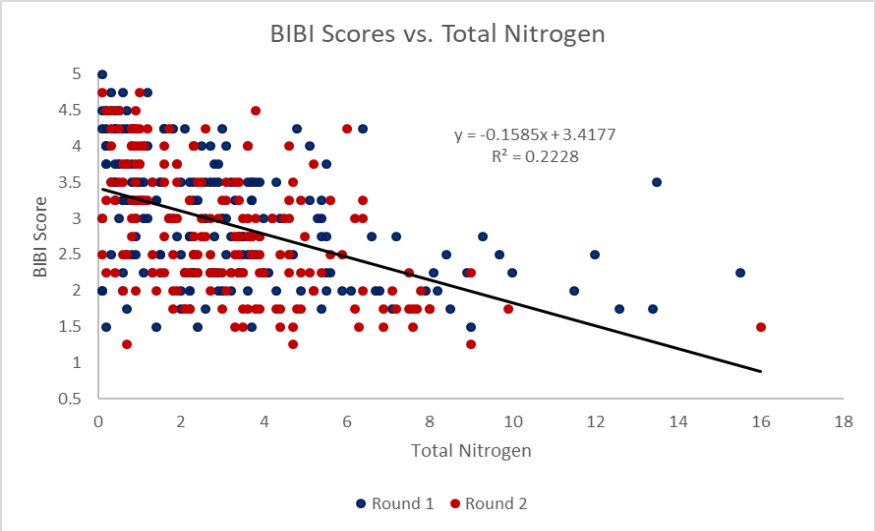


Figure 30. Regression relationship between the Benthic Index of Biotic Integrity (BIBI) and Physical Habitat Indicator (PHI) for Rounds 1 and 2 of the Frederick County Stream Survey



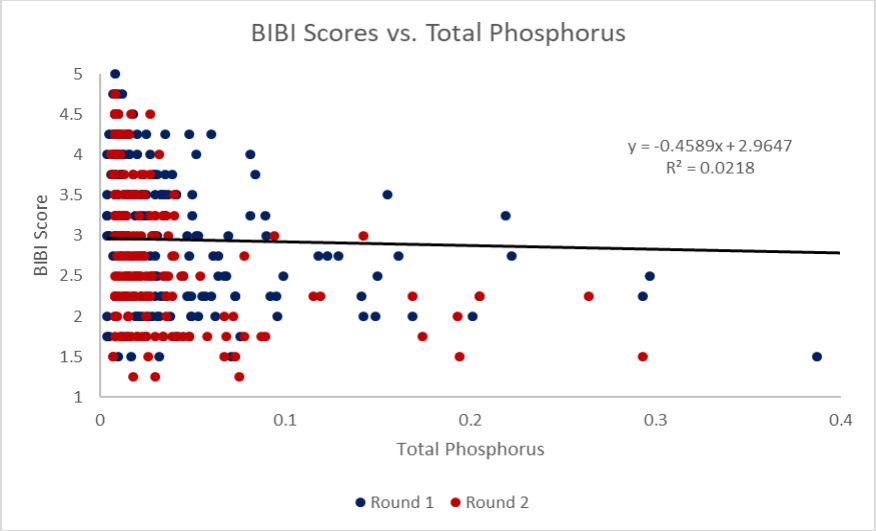
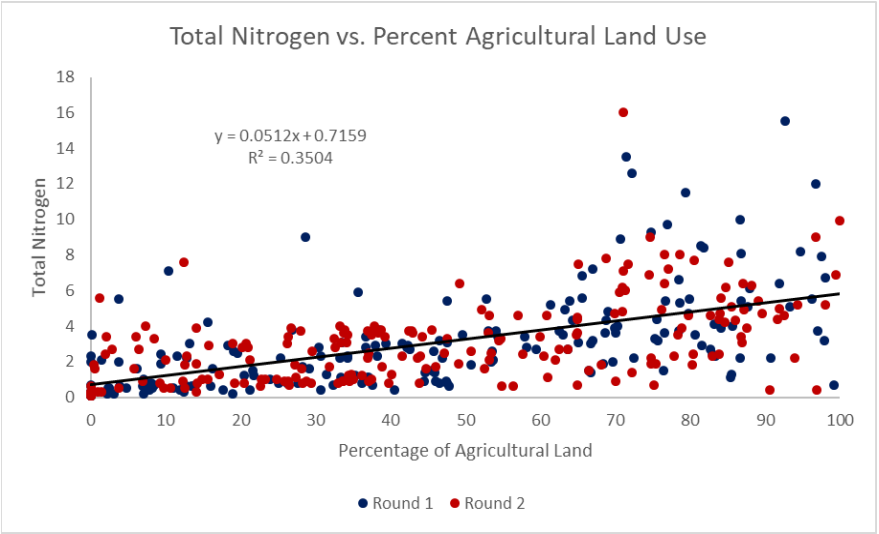
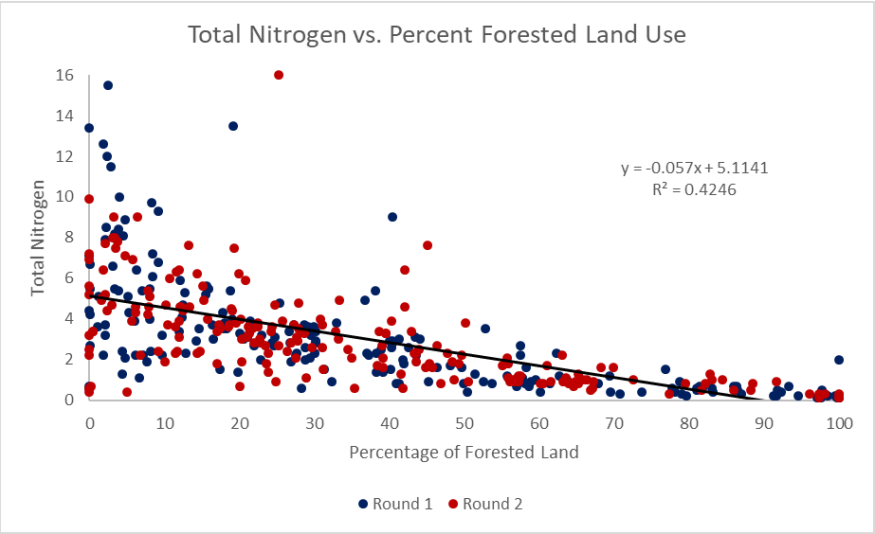


Figure 31. Regression relationships between the Benthic Index of Biotic Integrity and total nitrogen (mg/l) and total phosphorus (mg/ l) for Rounds 1 and 2 of the Frederick County Stream Survey





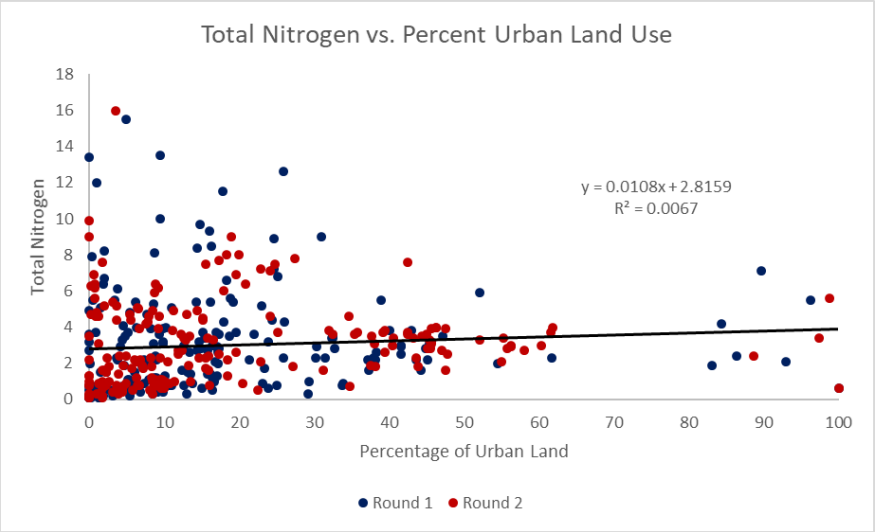
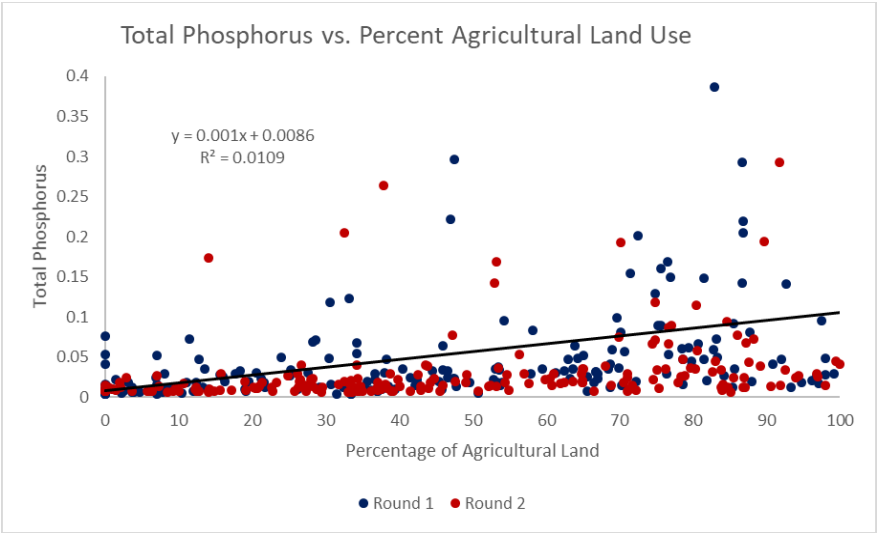
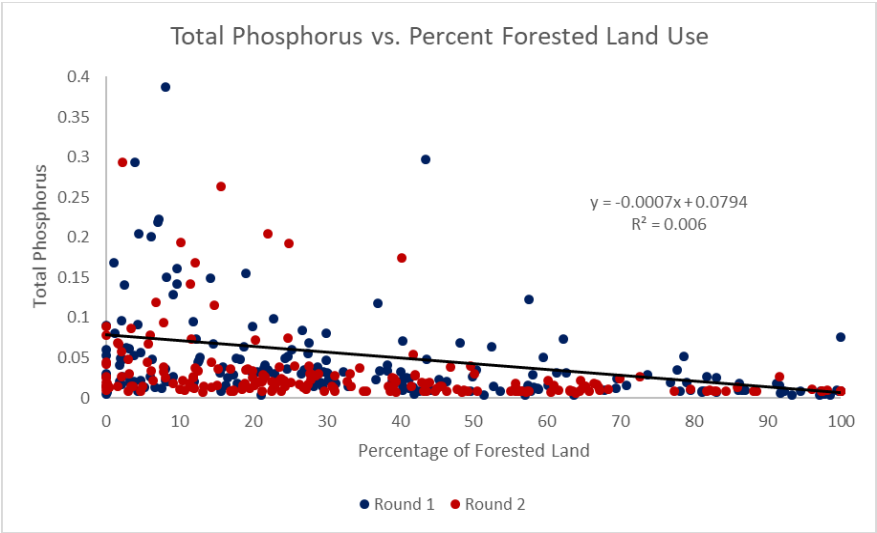


Figure 32. Regression relationships between total nitrogen (mg/l) and upstream land use for Rounds 1 and 2 of the Frederick County Stream Survey





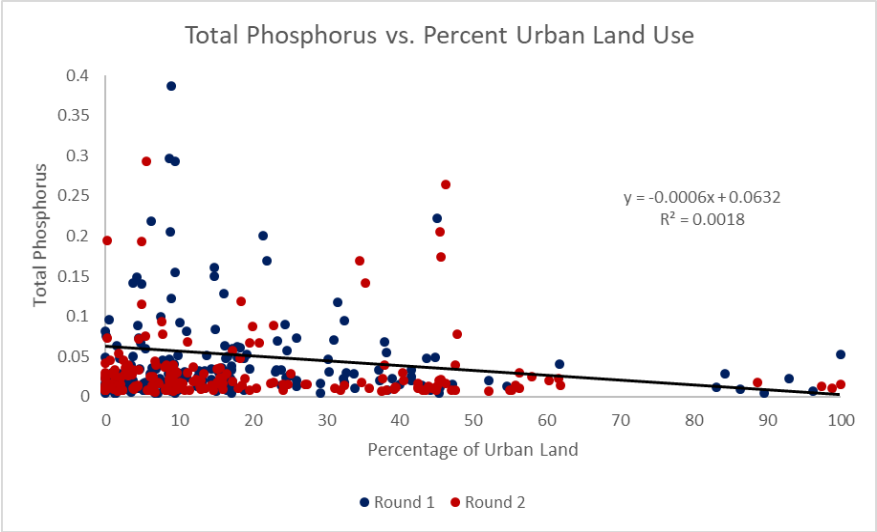


Figure 33. Regression relationships between total phosphorus (mg/l) and upstream land use for Rounds 1 and 2 of the Frederick County Stream Survey

7 8-DIGIT WATERSHED RESULTS

FCSS Results Summarized for TMDL Watersheds

Within Frederick County, the Maryland Department of the Environment (MDE) has several established Total Maximum Daily Loads (TMDLs) which set limits for certain pollutants. The watersheds containing these TMDLs and their status as of 2017are:

- Lower Monocacy – sediment, fecal coliform, phosphorus TMDLs are approved;
- Upper Monocacy – sediment, fecal coliform, phosphorus TMDLs are approved;
- Double Pipe Creek – sediment, fecal coliform, phosphorus TMDLs are approved
- Catoctin Creek – sediment and phosphorus TMDL are approved;
- Lake Linganore – sediment and phosphorus TMDLs are approved;
- Potomac River Frederick County – sediment TMDL has been approved

In order for the County to begin to assess water quality at the 8-digit scale, results from the 20 County subwatersheds can be nested to the 8-digit watersheds located within the County. Results for the parameters sampled by the FCSS for both Round 1 and Round 2 are presented in Tables 13 and 14. Going forward, the County may decide to shift its focus from reporting on the subwatershed scale to the 8-digit watersheds to better evaluate TMDL effectiveness.

Table 13. Percentage Frederick County portions of the Maryland DNR 8-digit watersheds in land use categories.

Watershed	% Agricultural Land Use	% Forested Land Use	% Urban Land Use	% Impervious Surface
Catoctin Creek	35.94	51.05	13.02	3.9
Double Pipe Creek	80.7	12.31	6.99	3.1
Lower Monocacy River	46.36	27.5	26.3	8.2
Potomac River Frederick County	53.37	34.9	13.56	4.7
Upper Monocacy River	32.43	57.78	9.54	3.8

Table 14. Mean Round 1 vs Round 2 values for sites sampled in Frederick County portions of the Maryland DNR 8-digit watersheds.

	Bank Erosion		Riparian Buffer Width (m)		PHI Score		Total Nitrogen (mg/l)		Total Phosphorus (mg/l)		BIBI Score	
Watershed	**Round 1**	**Round 2**	**Round 1**	**Round 2**	**Round 1**	**Round 2**	**Round 1**	**Round 2**	**Round 1**	**Round 2**	**Round 1**	**Round 2**
Catoctin Creek	2.6	2.1	74	63	74.08	63.25	1.64	2.07	0.075	0.050	3.46	3.49
Double Pipe Creek	2.8	2.4	34	46	50.25	54.58	4.91	4.47	0.069	0.039	2.60	2.38
Lower Monocacy River	3.3	2.8	77	73	65.38	63.70	3.65	3.71	0.042	0.029	2.85	2.66
Potomac River Frederick County	4.2	3.1	62	81	60.54	66.92	3.34	2.76	0.059	0.023	2.99	2.76
Upper Monocacy River	2.2	1.9	71	74	66.94	66.63	2.01	2.20	0.040	0.116	3.26	3.02

8 CONCLUSIONS

Now that two Rounds of the FCSS are complete, trends in the condition of stream quality can begin to be examined. While the average biological condition for Frederick County in Round 2 decreased slightly from Fair Condition to Poor Condition, it is clear that condition varied greatly within and among the watersheds of the County. Biological condition is dependent on the location of the watershed within the County. Biological condition in Hunting Creek and Middle Creek improved between Round 1 and Round 2, while it worsened in Glade Creek. In general, streams in forested areas tend to score higher than other streams.

Total phosphorus concentration improved dramatically between Round 1 and Round 2. The state of Maryland banned the use of phosphorus in dishwasher detergent in 2010 and in fertilizers in 2011. The positive impact of this regulations could be reflected in the decreased phosphorus levels in in Frederick County streams.

There are a variety of factors affecting biological condition that make it difficult to identify any single major stressor to stream condition. In some areas, bank erosion maybe the predominant stressor, while in others the total inputs of nitrogen or phosphorus may have a stronger influence on biological condition. The FCSS provides data on a broad suite of land use, habitat, and water quality conditions that together affect Fredrick County's streams. As more data are collected in future sampling by the Survey, relationships between potential stressors and biological condition may become more readily apparent.

As the County prepares to begin Round 3 of the FCSS and looks to the future, it plans to utilize results from the FCSS both assess the effectiveness of TMDL regulations and to better target restoration opportunities at the watershed level. Continuing comparisons can be made between the biological, physical, and chemical characteristics of streams in the County, allowing further conclusions to be drawn about the changes in condition over time. Also during Round 3, the County will implement additional changes including:

- A partial replacement survey design that includes 40% fixed sites from previous rounds and 60% of new randomly-selected sites in each watershed to allow the County to perform more intense trend analysis.
- Increased the water quality grab sampling parameters for laboratory analysis from 10 analytes in previous rounds to 15 analytes to be consistent with MBSS parameters and add additional metals and chlorides analytes which may be of interest to the County in the future.

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APPENDIX A: SUMMARY TABLES

Table A1. Percentage of stream miles in impervious land use categories and the watershed mean for the FCSS Rounds 1 and 2

Watershed	Excellent	Sensitive	Impacted	Non-Supporting	Urban Drainage	Mean Percent Impervious in Site Catchment	Excellent	Sensitive	Impacted	Non-Supporting	Urban Drainage	Mean Percent Impervious in Site Catchment
	Round 1						**Round 2**					
Ballenger Creek	0	90	0	10	0	8.56	0	50	50	0	0	10.62
Bennett Creek	80	10	0	0	0	1.65	70	20	10	0	0	3.35
Lower Bush Creek	0	100	0	0	0	6.00	10	50	20	20	0	13.57
Upper Bush Creek	0	70	30	0	0	8.97	0	60	40	0	0	9.52
Carroll Creek	50	30	20	0	0	6.93	10	30	60	0	0	14.00
Catoctin Creek	80	20	0	0	0	2.71	20	60	20	0	0	6.21
Fishing Creek	100	0	0	0	0	1.66	70	30	0	0	0	3.04
Glade Creek	70	30	0	0	0	3.29	80	20	0	0	0	3.57
Hunting Creek	70	20	0	0	0	2.70	90	10	0	0	0	2.61
Israel Creek	80	20	0	0	0	3.38	50	50	0	0	0	3.67
Lower Catoctin Creek South	100	0	0	0	0	2.35	80	20	0	0	0	3.39
Lower Linganore Creek	60	30	10	0	0	4.54	40	50	10	0	0	6.09
Upper Linganore Creek	90	10	0	0	0	2.79	90	10	0	0	0	2.46
Little Pipe Creek	90	10	0	0	0	2.62	80	20	0	0	0	3.51
Middle Creek	100	0	0	0	0	2.01	100	0	0	0	0	2.34
Monocacy Direct Southwest	70	20	10	0	0	4.71	90	10	0	0	0	2.97
Owens Creek	100	0	0	0	0	2.10	100	0	0	0	0	2.37
Potomac Direct	40	60	0	0	0	3.92	50	50	0	0	0	4.19
Toms Creek	90	10	0	0	0	2.65	80	10	10	0	0	4.34
Tuscarora Creek	70	30	0	0	0	2.59	50	50	0	0	0	4.77

Table A-1. Percentage of stream miles in Physical Habitat Indicator (PHI) classes and the watershed mean for the FCSS Round 1 and Round 2

	> 60 m	30-60 m	15-30 m	< 15 m	Mean PHI Score	> 60 m	30-60 m	15-30 m	< 15 m	Mean PHI Score
Watershed	**Round 1**					**Round 2**				
Ballenger Creek	30	30	30	10	66.9	30	20	30	20	65.9
Bennett Creek	50	20	10	20	72.3	30	60	10	0	74.9
Lower Bush Creek	20	50	30	0	72.9	0	50	20	30	61.3
Upper Bush Creek	10	40	30	20	63.9	0	20	50	30	60.3
Carroll Creek	10	70	0	20	66.9	0	40	40	20	60.9
Catoctin Creek	60	10	30	0	79.1	0	30	30	40	57.0
Fishing Creek	10	30	50	10	65.8	20	30	40	10	68.6
Glade Creek	0	20	60	20	55.7	10	10	20	60	51.8
Hunting Creek	40	30	20	10	73.9	50	30	0	20	76.0
Israel Creek	20	50	10	20	64.9	20	40	20	20	66.7
Little Catoctin Creek South	10	60	20	10	68.7	10	40	50	0	65.9
Lower Linganore Creek	0	50	40	10	63.7	0	50	30	20	60.9
Upper Linganore Creek	10	30	30	30	57.6	0	50	20	30	61.7
Little Pipe Creek	0	10	30	60	50.3	0	30	40	30	54.6
Middle Creek	20	50	20	10	69.1	20	40	20	20	69.5
Monocacy Direct Southwest	10	30	30	30	59.3	10	30	30	30	60.8
Owens Creek	30	40	20	10	70.3	10	40	40	10	67.4
Potomac Direct	30	0	20	50	52.4	20	40	30	10	67.9
Toms Creek	10	50	20	20	64.3	10	40	30	20	64.0
Tuscarora Creek	40	30	20	10	71.9	20	50	30	0	72.1

Table A3. Percentage of stream miles in impervious land use categories and the watershed mean for the FCSS Rounds 1 and 2

	None	Minimum	Moderate	Severe	Mean Bank Erosion Score	None	Minimum	Moderate	Severe	Mean Bank Erosion Score
Watershed	**Round 1**					**Round 2**				
Ballenger Creek	10	20	60	10	1.7	10	40	50	0	1.4
Bennett Creek	40	0	30	30	1.5	0	40	60	0	1.6
Lower Bush Creek	0	20	50	30	2.1	0	30	50	20	1.9
Upper Bush Creek	0	20	70	10	1.9	0	40	60	0	1.6
Carroll Creek	10	30	40	20	1.7	10	50	40	0	1.3
Catoctin Creek	10	10	50	30	2	10	40	50	0	1.4
Fishing Creek	0	90	0	10	1.2	40	30	20	10	1
Glade Creek	10	70	10	10	1.2	20	70	0	10	1
Hunting Creek	30	50	20	0	0.9	20	70	10	0	0.9
Israel Creek	10	20	50	20	1.8	10	40	50	0	1.4
Lower Catoctin Creek South	10	0	40	50	2.3	0	60	40	0	1.4
Lower Linganore Creek	0	10	40	50	2.4	0	60	40	0	1.4
Upper Linganore Creek	20	10	50	20	1.7	0	50	40	10	1.6
Little Pipe Creek	0	50	40	10	1.6	10	60	20	10	1.3
Middle Creek	10	80	10	0	1	30	50	10	10	1
Monocacy Direct Southwest	20	40	20	20	1.4	0	60	40	0	1.4
Owens Creek	20	40	30	10	1.3	10	50	30	10	1.4
Potomac Direct	0	20	40	40	2.2	0	30	50	20	1.9
Toms Creek	30	20	40	10	1.3	50	30	20	0	0.7
Tuscarora Creek	10	50	30	10	1.4	10	30	60	0	1.5

Table A-4. Percentage of stream miles in riparian buffer classes and the watershed mean for the FCSS Round 1 and Round 2

	> 60 m	30-60 m	15-30 m	< 15 m	Mean Riparian Buffer Width (m)	> 60 m	30-60 m	15-30 m	< 15 m	Mean Riparian Buffer Width (m)
Watershed	**Round 1**					**Round 2**				
Ballenger Creek	90	0	0	10	79	90	0	0	10	83
Bennett Creek	90	0	0	10	81	90	10	0	0	92
Lower Bush Creek	90	0	0	10	83	50	40	0	10	70
Upper Bush Creek	90	0	10	0	83	70	20	10	0	77
Carroll Creek	100	0	0	0	68	80	20	0	0	81
Catoctin Creek	80	10	0	10	83	30	40	10	20	53
Fishing Creek	70	10	0	20	58	80	20	0	0	83
Glade Creek	70	0	0	30	61	40	10	10	40	45
Hunting Creek	70	20	10	0	77	80	0	0	20	78
Israel Creek	70	0	0	30	65	70	0	10	20	70
Little Catoctin Creek South	70	10	10	10	78	60	30	10	0	74
Lower Linganore Creek	80	0	0	20	73	60	10	0	30	55
Upper Linganore Creek	70	20	0	10	71	50	10	30	10	63
Little Pipe Creek	30	20	10	40	34	40	10	10	40	46
Middle Creek	70	0	0	30	63	70	10	10	10	74
Monocacy Direct Southwest	60	20	0	20	43	50	30	10	10	66
Owens Creek	70	0	30	0	72	80	10	0	10	79
Potomac Direct	40	10	10	40	46	80	20	0	0	88
Toms Creek	50	30	0	20	60	70	20	10	0	78
Tuscarora Creek	90	0	0	10	89	70	20	10	0	82

Table A-5. Percentage of stream miles in total nitrogen classes and the watershed mean for the FCSS Round 1 and Round 2

	Low	Moderate	High	Mean Total Nitrogen Concentration (mg/L)	Low	Moderate	High	Mean Total Nitrogen Concentration (mg/L)
Watershed	**Round 1**				**Round 2**			
Ballenger Creek	20	80	0	2.45	0	100	0	3.32
Bennett Creek	30	60	10	2.93	40	50	10	3.03
Lower Bush Creek	0	100	0	2.83	10	90	0	3.66
Upper Bush Creek	0	90	10	3.79	0	100	0	3.64
Carroll Creek	70	30	0	1.28	10	80	10	2.82
Catoctin Creek	60	40	0	2.36	20	70	10	3.08
Fishing Creek	100	0	0	0.43	80	20	0	0.83
Glade Creek	0	30	70	7.98	0	30	70	7.64
Hunting Creek	100	0	0	0.59	90	10	0	0.65
Israel Creek	20	80	0	2.69	20	80	0	2.64
Little Catoctin Creek South	0	100	0	3.71	0	100	0	2.62
Lower Linganore Creek	0	80	20	4.56	0	90	10	4.49
Upper Linganore Creek	0	100	0	3.89	10	90	0	3.83
Little Pipe Creek	0	90	10	4.91	0	100	0	4.47
Middle Creek	90	10	0	0.93	90	10	0	1.05
Monocacy Direct Southwest	0	30	70	8.47	0	70	30	5.92
Owens Creek	80	20	0	0.99	90	10	0	1.02
Potomac Direct	30	70	0	2.96	30	70	0	2.9
Toms Creek	60	40	0	1.42	50	50	0	1.67
Tuscarora Creek	70	30	0	0.66	50	50	0	1.37

Table A-6. Percentage of stream miles in total phosphorus classes and the watershed mean for the FCSS Round 1 and Round 2

	Low	Moderate	High	Mean Total Phosphorous Concentration (mg/L)	Low	Moderate	High	Mean Total Phosphorous Concentration (mg/L)
Watershed	**Round 1**				**Round 2**			
Ballenger Creek	40	50	10	0.047	90	10	0	0.013
Bennett Creek	90	10	0	0.015	80	20	0	0.018
Lower Bush Creek	30	60	10	0.047	70	30	0	0.026
Upper Bush Creek	60	30	10	0.025	80	10	10	0.030
Carroll Creek	80	20	0	0.019	90	0	10	0.020
Catoctin Creek	30	60	10	0.136	50	10	40	0.090
Fishing Creek	70	30	0	0.024	70	20	10	0.025
Glade Creek	0	50	50	0.121	20	30	50	0.601
Hunting Creek	70	30	0	0.017	90	10	0	0.012
Israel Creek	50	50	0	0.027	80	20	0	0.022
Little Catoctin Creek South	20	50	30	0.074	70	30	0	0.023
Lower Linganore Creek	20	40	40	0.069	50	50	0	0.024
Upper Linganore Creek	60	20	20	0.071	30	40	30	0.060
Little Pipe Creek	20	40	40	0.069	20	70	10	0.039
Middle Creek	80	20	0	0.014	100	0	0	0.010
Monocacy Direct Southwest	50	30	20	0.542	70	20	10	0.045
Owens Creek	90	10	0	0.015	80	20	0	0.015
Potomac Direct	20	60	20	0.045	60	40	0	0.022
Toms Creek	40	30	30	0.046	40	40	20	0.032
Tuscarora Creek	80	20	0	0.017	90	10	0	0.014

Table A-7. Percentage of stream miles in benthic IBI categories and watershed mean for the FCSS Round 1 and Round 2

	Good	Fair	Poor	Very Poor	Mean BIBI Score	Good	Fair	Poor	Very Poor	Mean BIBI Score
Watershed	**Round 1**					**Round 2**				
Ballenger Creek	10	40	50	0	2.95	10	0	80	10	2.50
Bennett Creek	30	40	20	10	3.30	20	40	30	10	3.05
Lower Bush Creek	0	30	70	0	2.78	10	20	40	30	2.58
Upper Bush Creek	0	40	50	10	2.68	10	40	30	20	2.80
Carroll Creek	20	20	50	10	2.95	20	10	40	30	2.65
Catoctin Creek	20	50	20	10	3.15	20	30	40	10	2.93
Fishing Creek	30	50	20	0	3.53	20	40	40	0	3.13
Glade Creek	0	0	90	10	2.25	0	10	20	70	1.90
Hunting Creek	20	60	10	10	3.38	70	30	0	0	4.08
Israel Creek	10	40	50	0	2.93	10	30	40	20	2.70
Little Catoctin Creek South	20	40	40	0	3.10	0	40	40	20	2.60
Lower Linganore Creek	20	40	20	20	2.93	10	20	50	20	2.65
Upper Linganore Creek	0	20	60	20	2.28	30	10	30	30	2.73
Little Pipe Creek	0	40	60	0	2.60	0	10	70	20	2.38
Middle Creek	40	50	0	10	3.50	70	30	0	0	4.05
Monocacy Direct Southwest	0	10	80	10	2.43	0	30	40	30	2.28
Owens Creek	50	40	0	10	3.63	30	50	20	0	3.35
Potomac Direct	10	20	60	10	2.68	10	40	50	0	2.93
Toms Creek	10	50	40	0	3.10	10	30	50	10	2.55
Tuscarora Creek	30	50	20	0	3.35	0	70	30	0	3.13

APPENDIX B: STRESSOR ID

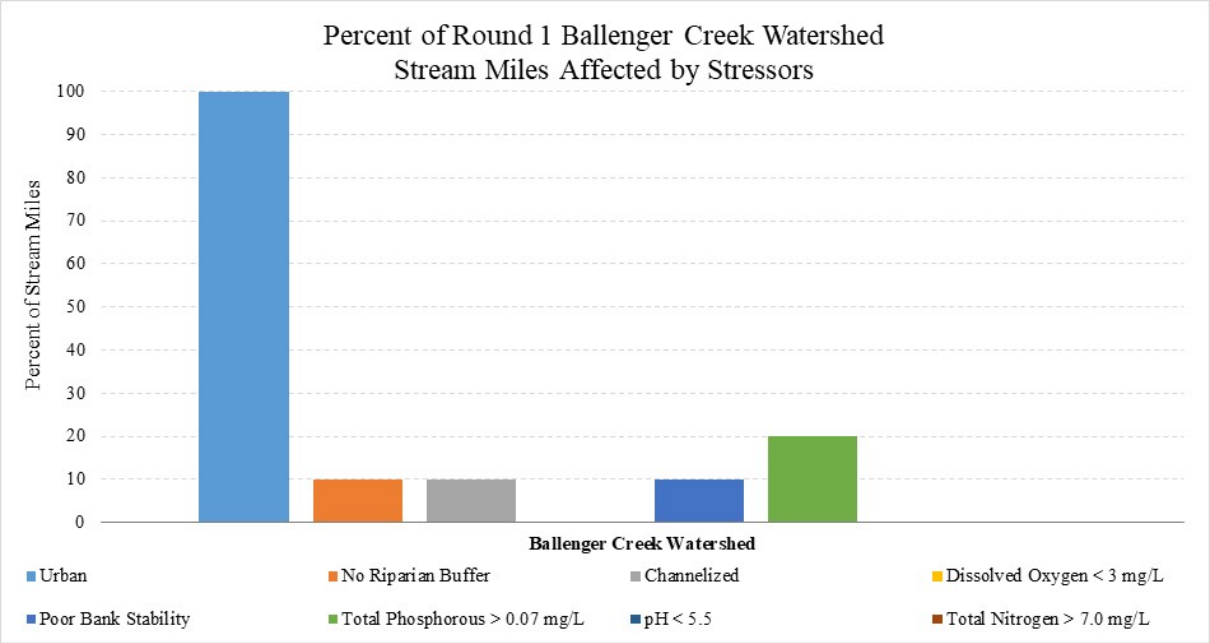
Watershed Stressor Identification

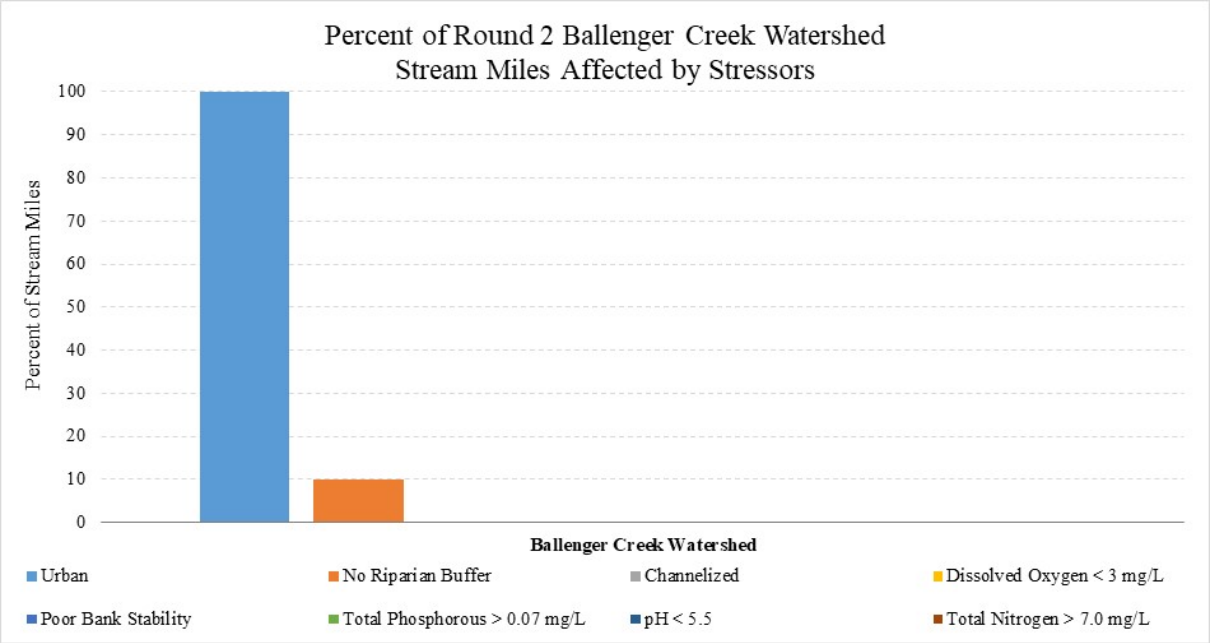
Watershed stressors in Frederick County were identified using criteria developed in the MBSS Round 3 report (Maryland DNR MBSS 2011). The following watershed stressors have been evaluated for Frederick County watersheds:

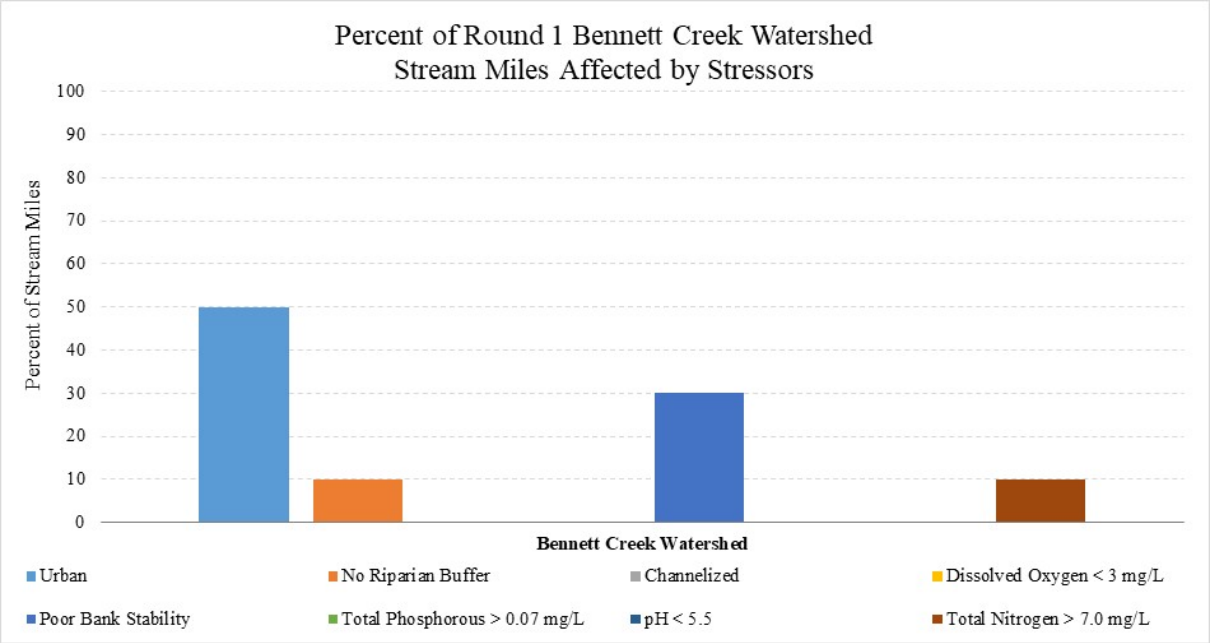
- Urban land use > 5%
- No riparian buffer
- Channelized stream
- Total Nitrogen > 7.0 mg/L
- DO < 3 mg/L
- Total Phosphorous > 0.07 mg/L
- pH < 5.5
- Poor stream bank stability and highly eroded banks

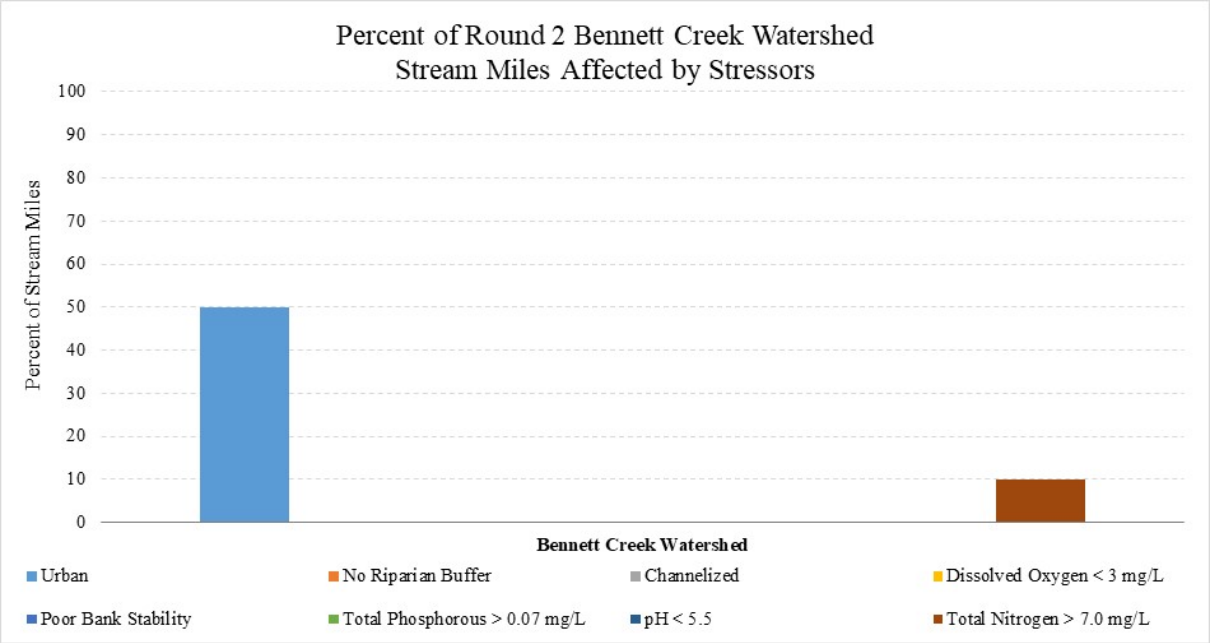
The extent of impact of each factor is depicted by the percentage of stream miles influenced by each stressor. The following bar charts show the percentage of stream miles of each stressor the County's watersheds in both Round 1 and Round 2. The County intends to use this information to better target restoration opportunities at the watershed scale.

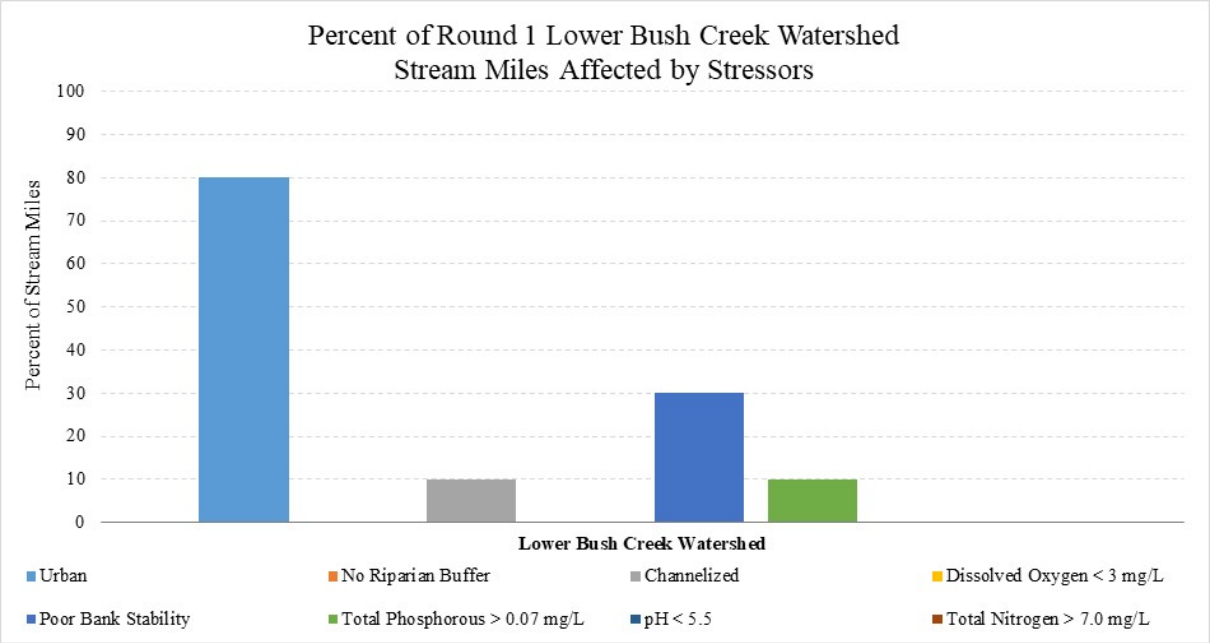
The most common stressors in all Frederick County watersheds are urbanization and elevated total phosphorous concentrations, followed by poor bank stability, lack of riparian buffer and elevated total nitrogen concentrations. No watersheds are "stressed" by DO in either round.

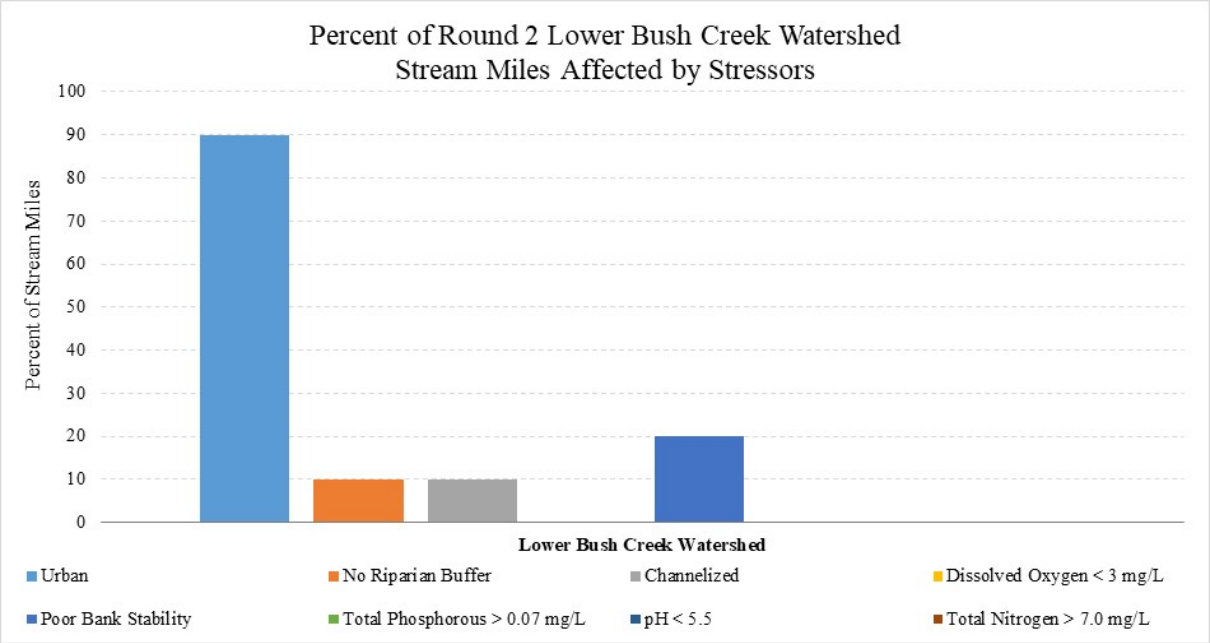

Percent of Round 1 Ballenger Creek Watershed
Stream Miles Affected by Stressors
Percent of Stream Miles
100
90
80
70
60
50
40
30
20
10
0
Ballenger Creek Watershed
Urban
No Riparian Buffer
Channelized
Dissolved Oxygen < 3 mg/L
Poor Bank Stability
Total Phosphorous > 0.07 mg/L
pH < 5.5
Total Nitrogen > 7.0 mg/L

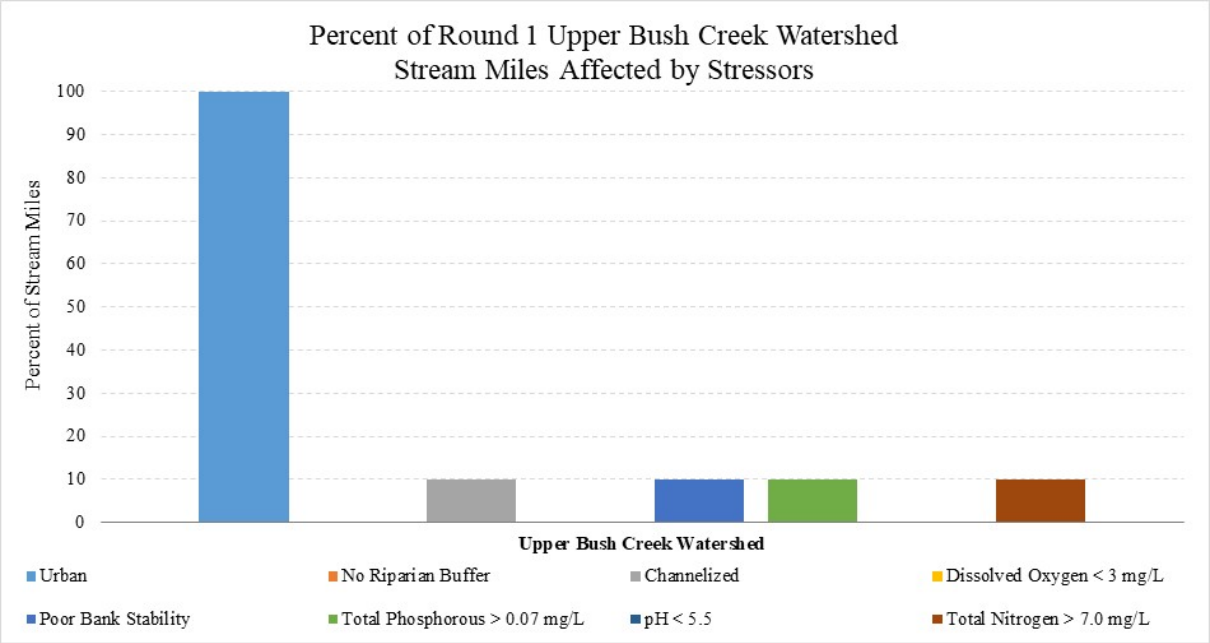

Percent of Round 2 Ballenger Creek Watershed
Stream Miles Affected by Stressors
Percent of Stream Miles
100
90
80
70
60
50
40
30
20
10
0
Ballenger Creek Watershed
Urban
No Riparian Buffer
Channelized
Dissolved Oxygen < 3 mg/L
Poor Bank Stability
Total Phosphorous > 0.07 mg/L
pH < 5.5
Total Nitrogen > 7.0 mg/L

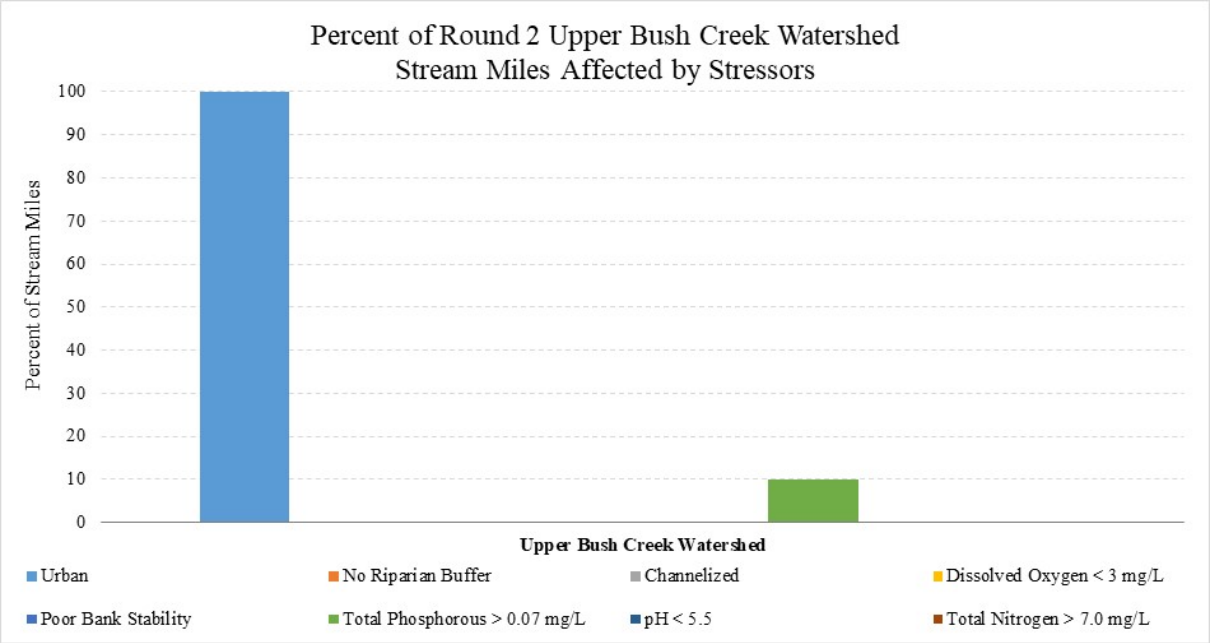

Percent of Round 1 Bennett Creek Watershed
Stream Miles Affected by Stressors
Percent of Stream Miles
100
90
80
70
60
50
40
30
20
10
0
Bennett Creek Watershed
Urban
No Riparian Buffer
Channelized
Dissolved Oxygen < 3 mg/L
Poor Bank Stability
Total Phosphorous > 0.07 mg/L
pH < 5.5
Total Nitrogen > 7.0 mg/L

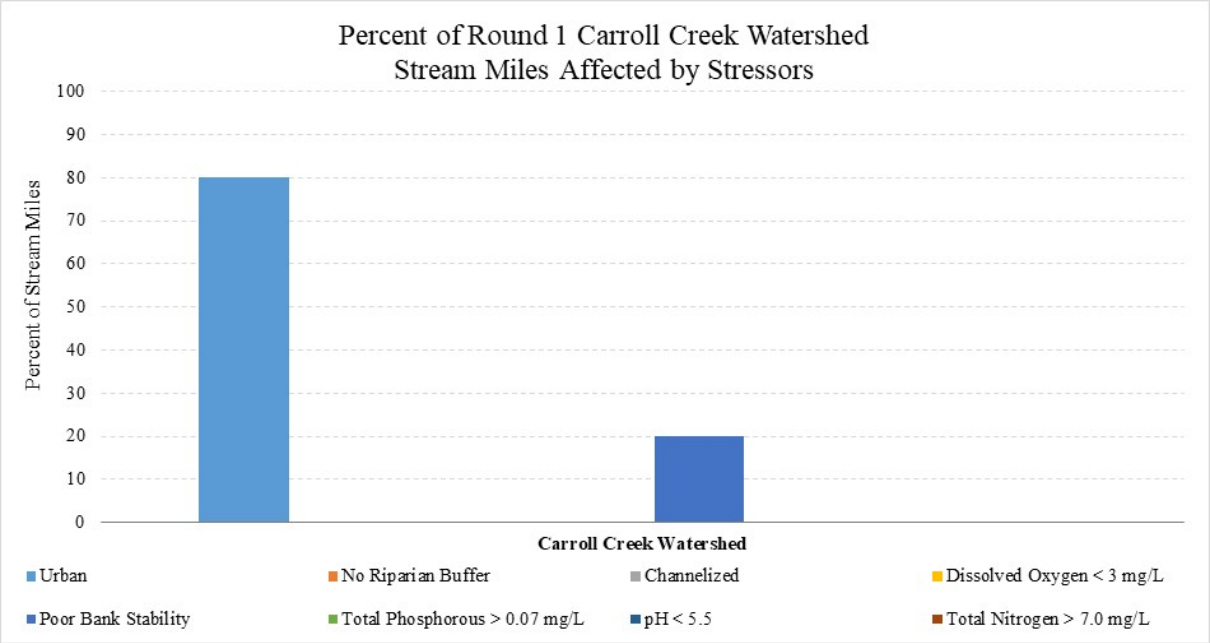

Percent of Round 2 Bennett Creek Watershed
Stream Miles Affected by Stressors
Percent of Stream Miles
100
90
80
70
60
50
40
30
20
10
0
Bennett Creek Watershed
Urban
No Riparian Buffer
Channelized
Dissolved Oxygen < 3 mg/L
Poor Bank Stability
Total Phosphorous > 0.07 mg/L
pH < 5.5
Total Nitrogen > 7.0 mg/L

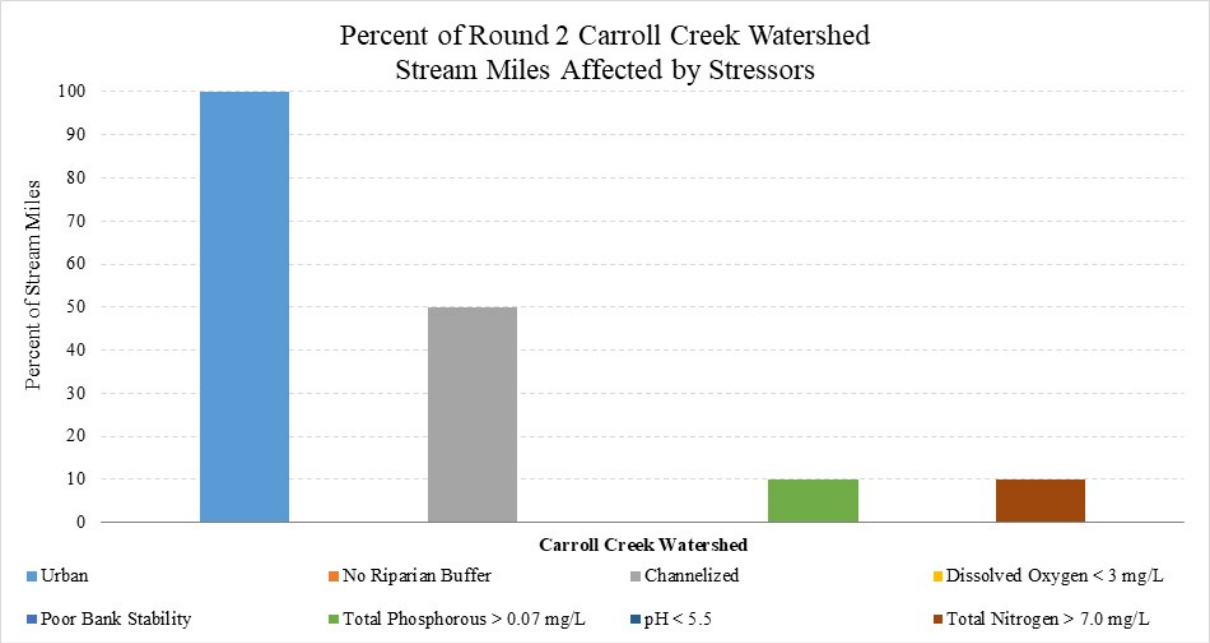

Percent of Round 1 Lower Bush Creek Watershed
Stream Miles Affected by Stressors
Percent of Stream Miles
100
90
80
70
60
50
40
30
20
10
0
Lower Bush Creek Watershed
Urban
No Riparian Buffer
Channelized
Dissolved Oxygen < 3 mg/L
Poor Bank Stability
Total Phosphorous > 0.07 mg/L
pH < 5.5
Total Nitrogen > 7.0 mg/L

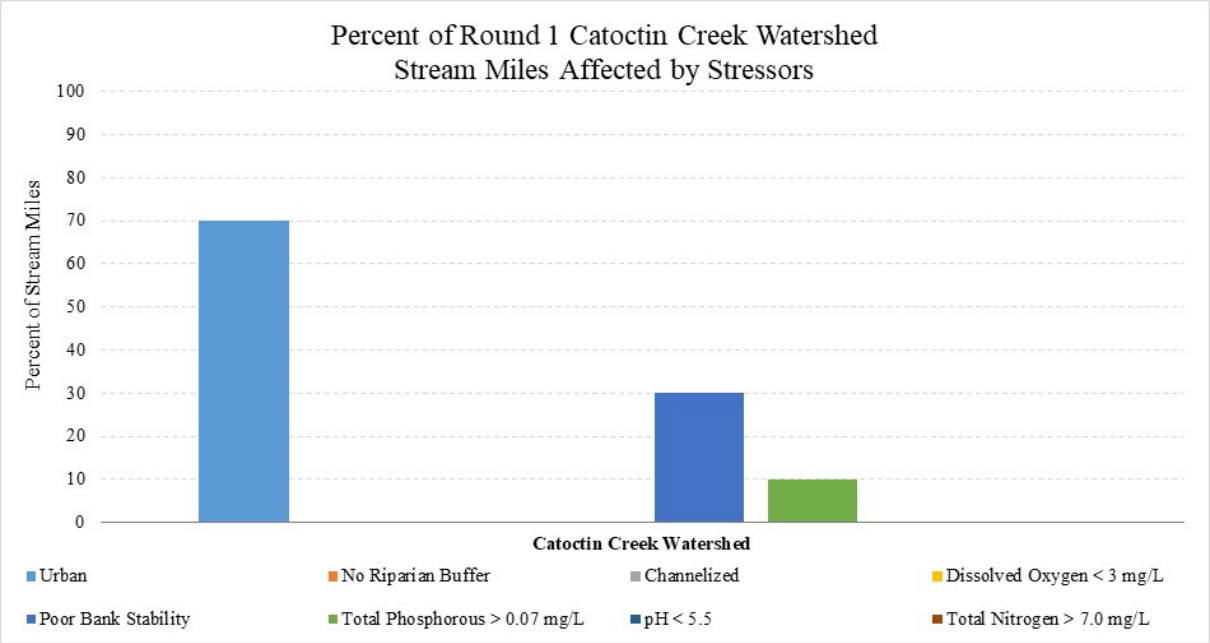

Percent of Round 2 Lower Bush Creek Watershed
Stream Miles Affected by Stressors
Percent of Stream Miles
100
90
80
70
60
50
40
30
20
10
0
Lower Bush Creek Watershed
Urban
No Riparian Buffer
Channelized
Dissolved Oxygen < 3 mg/L
Poor Bank Stability
Total Phosphorous > 0.07 mg/L
pH < 5.5
Total Nitrogen > 7.0 mg/L

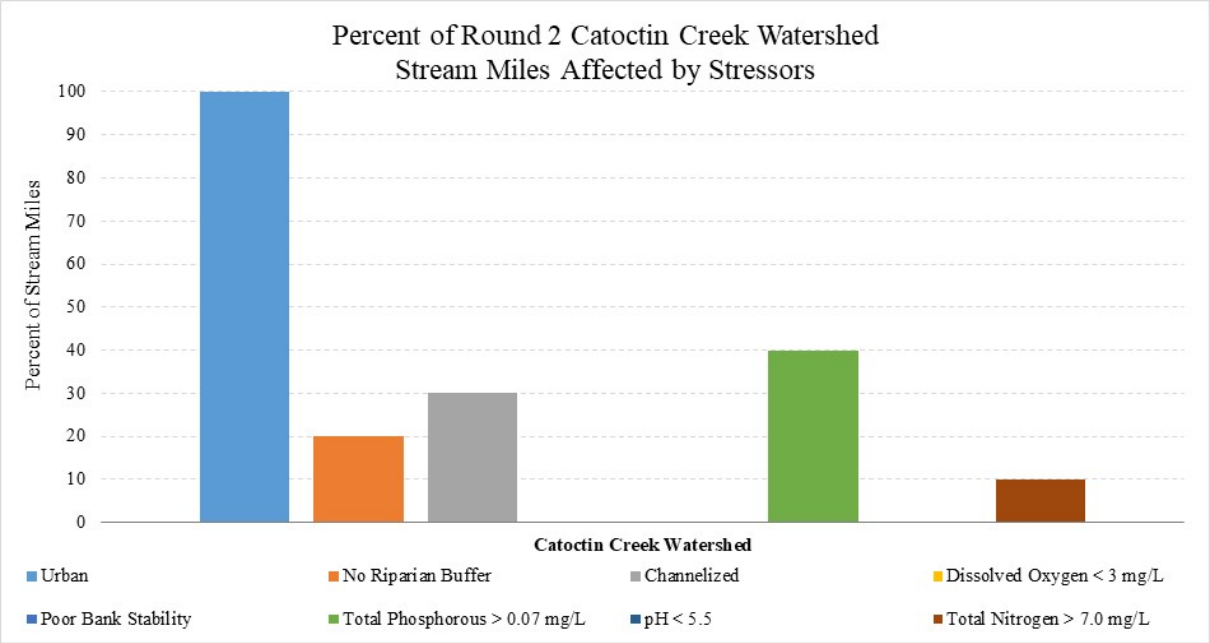

Percent of Round 1 Upper Bush Creek Watershed
Stream Miles Affected by Stressors
Percent of Stream Miles
100
90
80
70
60
50
40
30
20
10
0
Upper Bush Creek Watershed
Urban
No Riparian Buffer
Channelized
Dissolved Oxygen < 3 mg/L
Poor Bank Stability
Total Phosphorous > 0.07 mg/L
pH < 5.5
Total Nitrogen > 7.0 mg/L

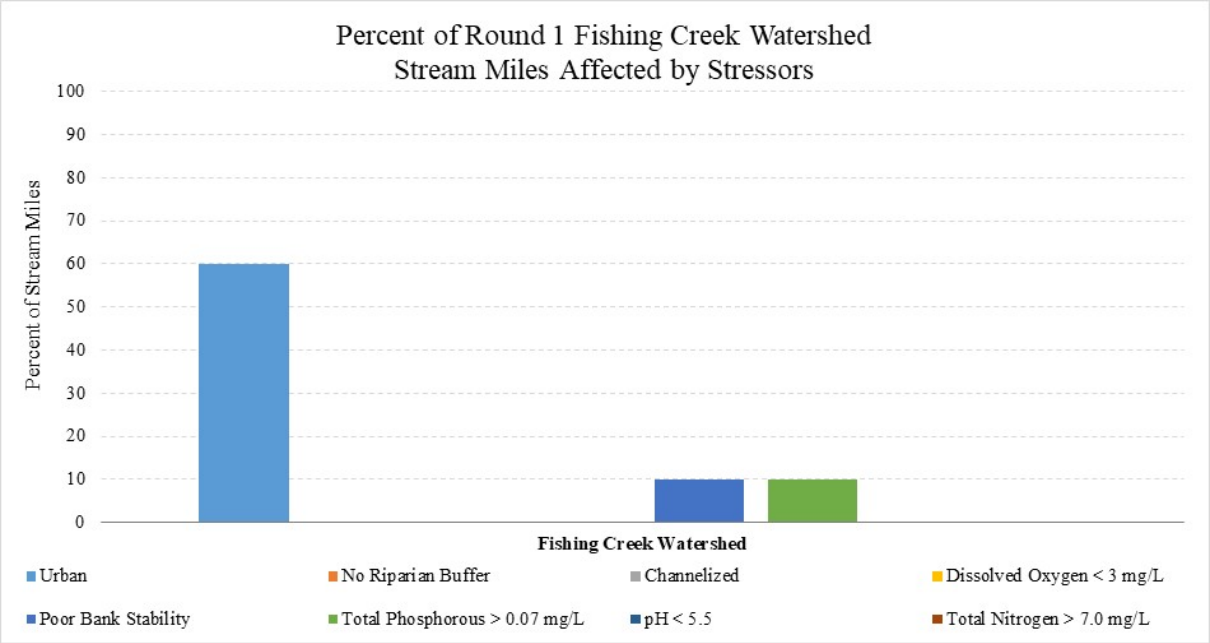

Percent of Round 2 Upper Bush Creek Watershed
Stream Miles Affected by Stressors
Percent of Stream Miles
100
90
80
70
60
50
40
30
20
10
0
Upper Bush Creek Watershed
Urban
No Riparian Buffer
Channelized
Dissolved Oxygen < 3 mg/L
Poor Bank Stability
Total Phosphorous > 0.07 mg/L
pH < 5.5
Total Nitrogen > 7.0 mg/L

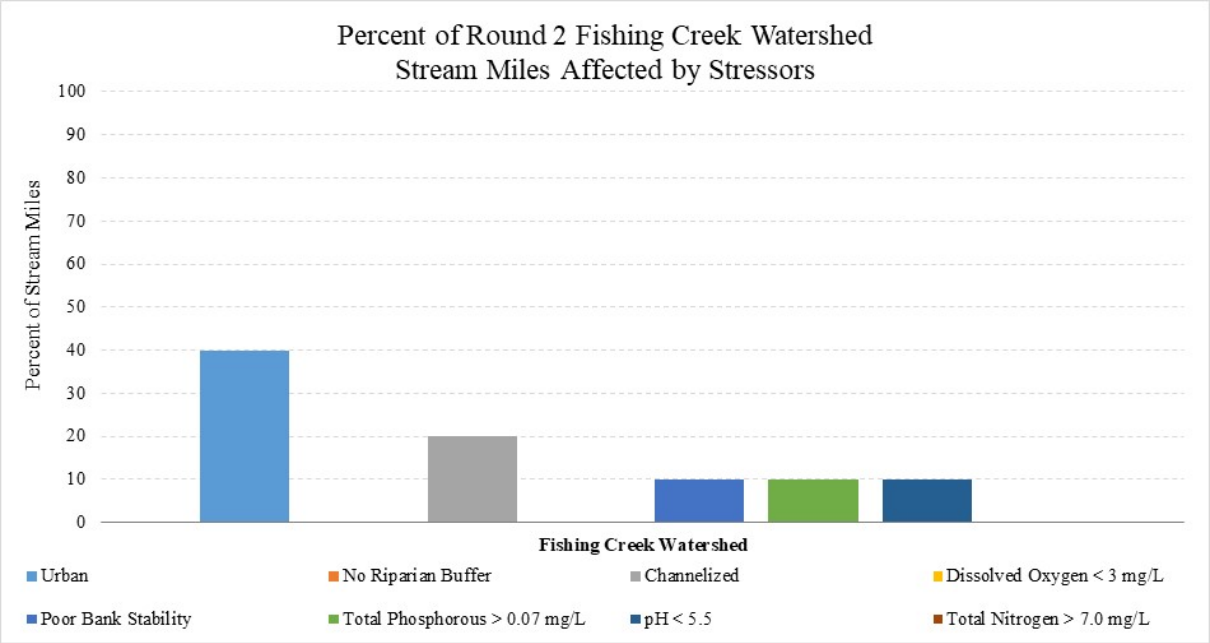

Percent of Round 1 Carroll Creek Watershed
Stream Miles Affected by Stressors
Percent of Stream Miles
100
90
80
70
60
50
40
30
20
10
0
Carroll Creek Watershed
Urban
No Riparian Buffer
Channelized
Dissolved Oxygen < 3 mg/L
Poor Bank Stability
Total Phosphorous > 0.07 mg/L
pH < 5.5
Total Nitrogen > 7.0 mg/L

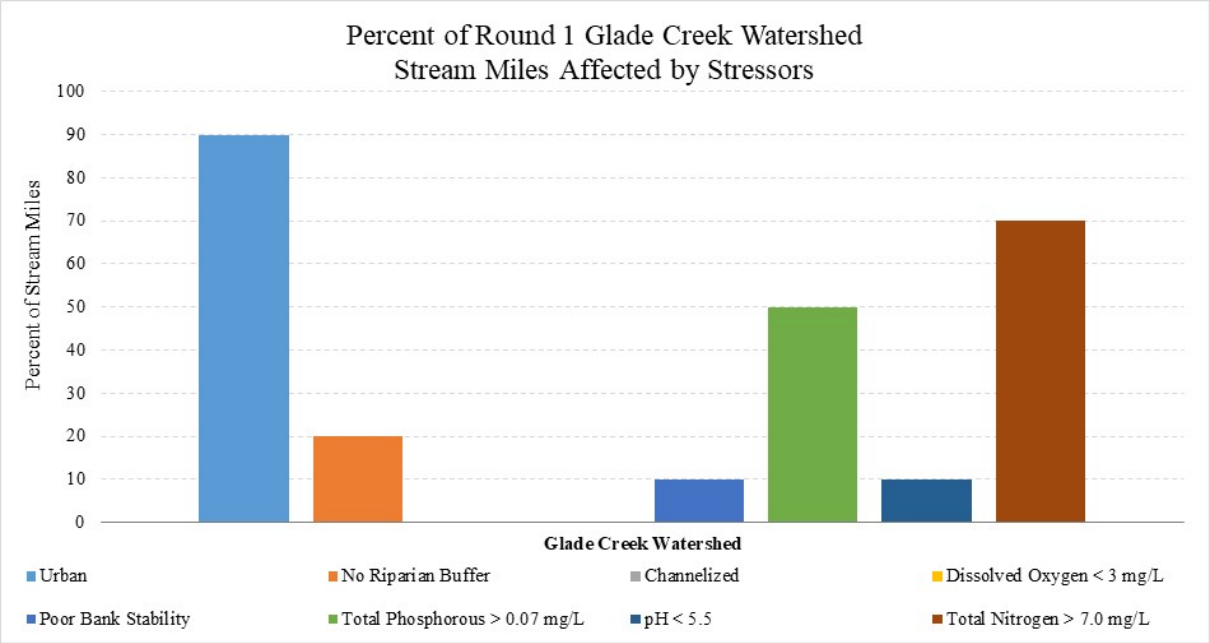

Percent of Round 2 Carroll Creek Watershed
Stream Miles Affected by Stressors
Percent of Stream Miles
100
90
80
70
60
50
40
30
20
10
0
Carroll Creek Watershed
Urban
No Riparian Buffer
Channelized
Dissolved Oxygen < 3 mg/L
Poor Bank Stability
Total Phosphorous > 0.07 mg/L
pH < 5.5
Total Nitrogen > 7.0 mg/L

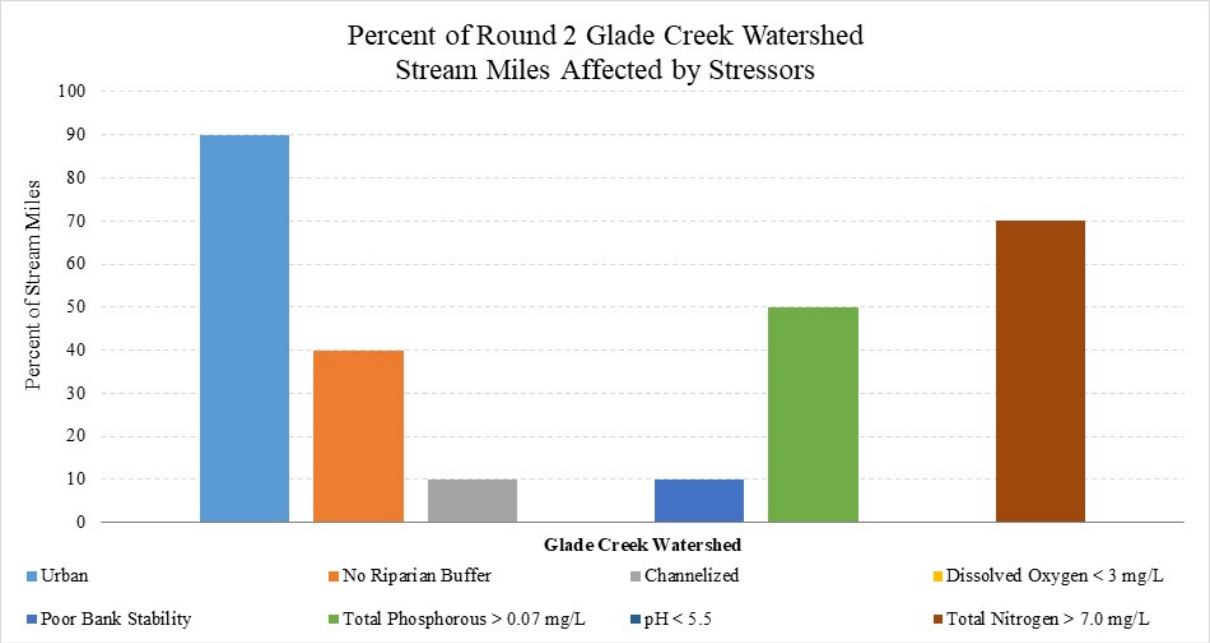

Percent of Round 1 Catoctin Creek Watershed
Stream Miles Affected by Stressors
Percent of Stream Miles
100
90
80
70
60
50
40
30
20
10
0
Catoctin Creek Watershed
Urban
No Riparian Buffer
Channelized
Dissolved Oxygen < 3 mg/L
Poor Bank Stability
Total Phosphorous > 0.07 mg/L
pH < 5.5
Total Nitrogen > 7.0 mg/L

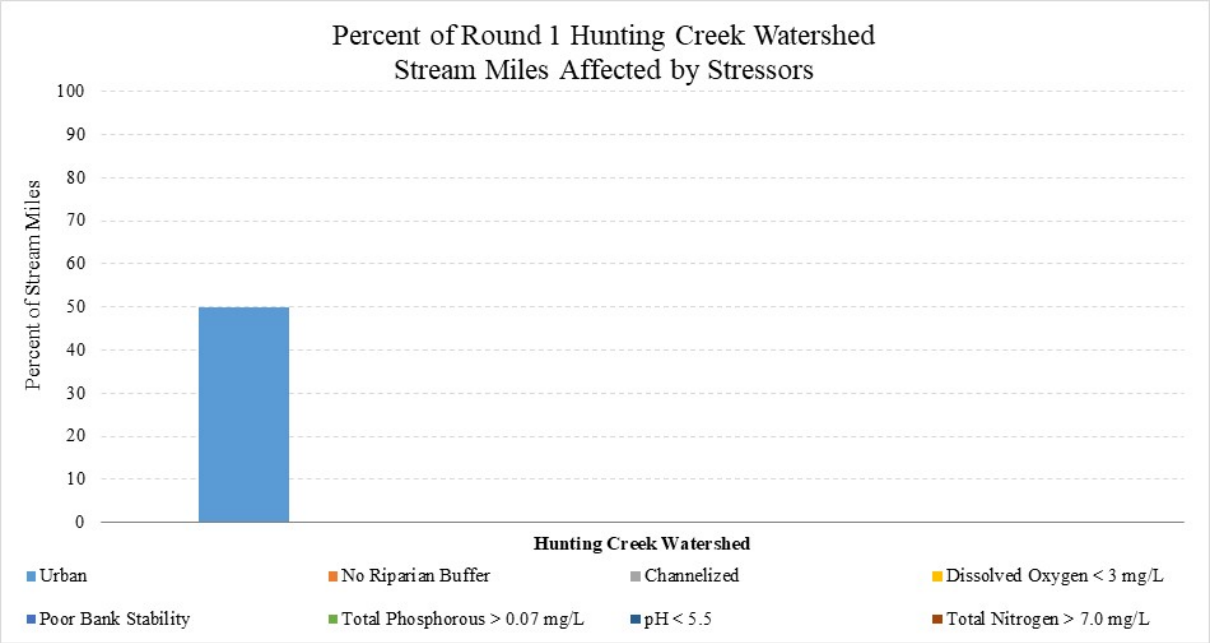

Percent of Round 2 Catoctin Creek Watershed
Stream Miles Affected by Stressors
Percent of Stream Miles
100
90
80
70
60
50
40
30
20
10
0
Catoctin Creek Watershed
Urban
No Riparian Buffer
Channelized
Dissolved Oxygen < 3 mg/L
Poor Bank Stability
Total Phosphorous > 0.07 mg/L
pH < 5.5
Total Nitrogen > 7.0 mg/L

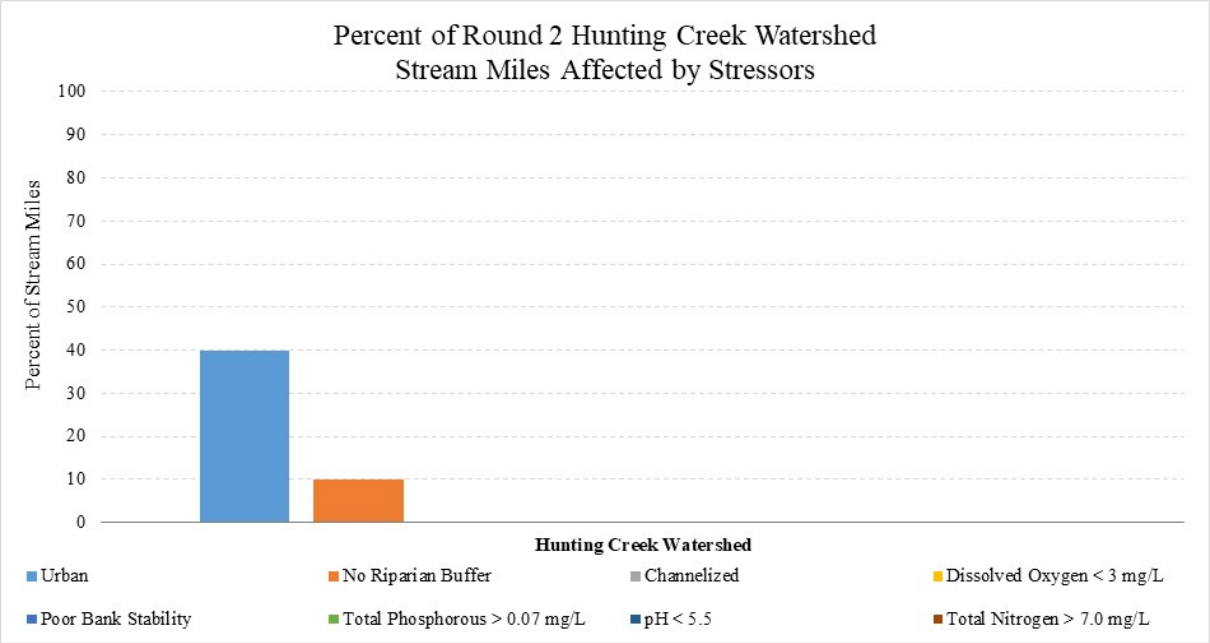

Percent of Round 1 Fishing Creek Watershed
Stream Miles Affected by Stressors
Percent of Stream Miles
100
90
80
70
60
50
40
30
20
10
0
Fishing Creek Watershed
Urban
No Riparian Buffer
Channelized
Dissolved Oxygen < 3 mg/L
Poor Bank Stability
Total Phosphorous > 0.07 mg/L
pH < 5.5
Total Nitrogen > 7.0 mg/L

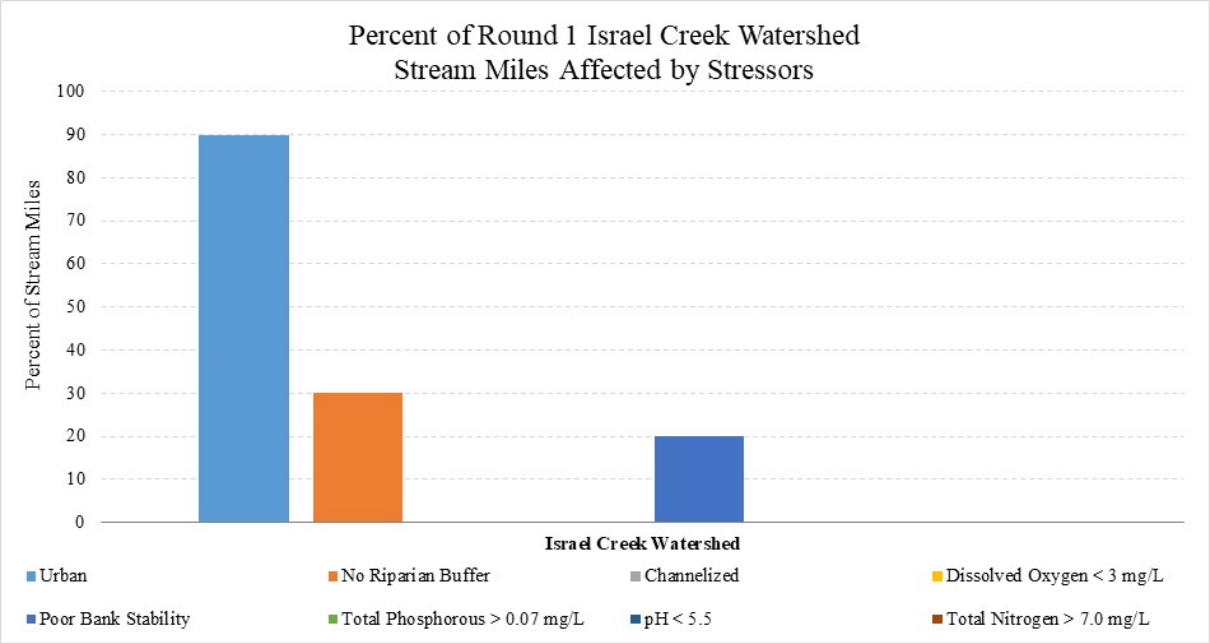

Percent of Round 2 Fishing Creek Watershed
Stream Miles Affected by Stressors
Percent of Stream Miles
100
90
80
70
60
50
40
30
20
10
0
Fishing Creek Watershed
Urban
No Riparian Buffer
Channelized
Dissolved Oxygen < 3 mg/L
Poor Bank Stability
Total Phosphorous > 0.07 mg/L
pH < 5.5
Total Nitrogen > 7.0 mg/L

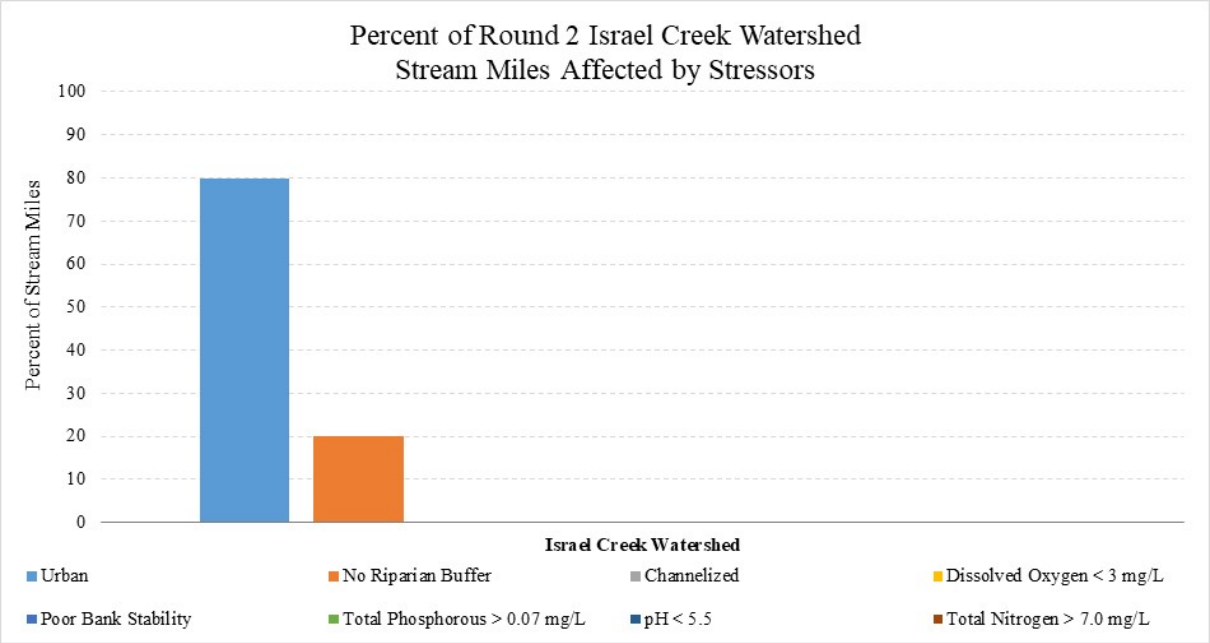

Percent of Round 1 Glade Creek Watershed
Stream Miles Affected by Stressors
Percent of Stream Miles
100
90
80
70
60
50
40
30
20
10
0
Glade Creek Watershed
Urban
No Riparian Buffer
Channelized
Dissolved Oxygen < 3 mg/L
Poor Bank Stability
Total Phosphorous > 0.07 mg/L
pH < 5.5
Total Nitrogen > 7.0 mg/L

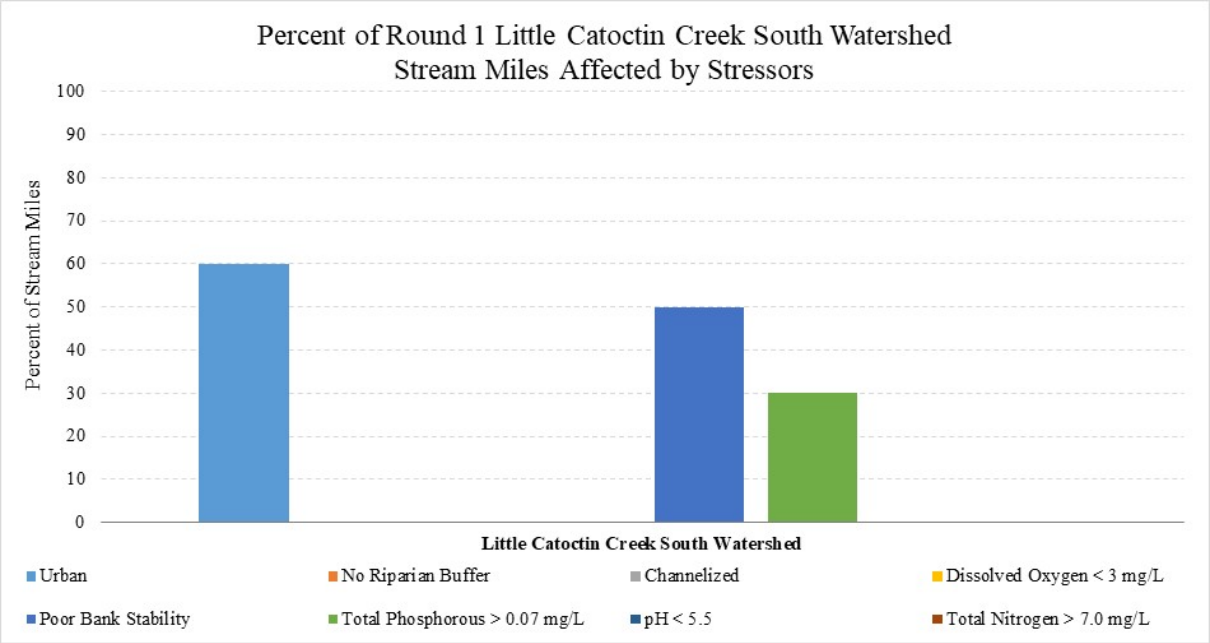

Percent of Round 2 Glade Creek Watershed
Stream Miles Affected by Stressors
Percent of Stream Miles
100
90
80
70
60
50
40
30
20
10
0
Glade Creek Watershed
Urban
No Riparian Buffer
Channelized
Dissolved Oxygen < 3 mg/L
Poor Bank Stability
Total Phosphorous > 0.07 mg/L
pH < 5.5
Total Nitrogen > 7.0 mg/L

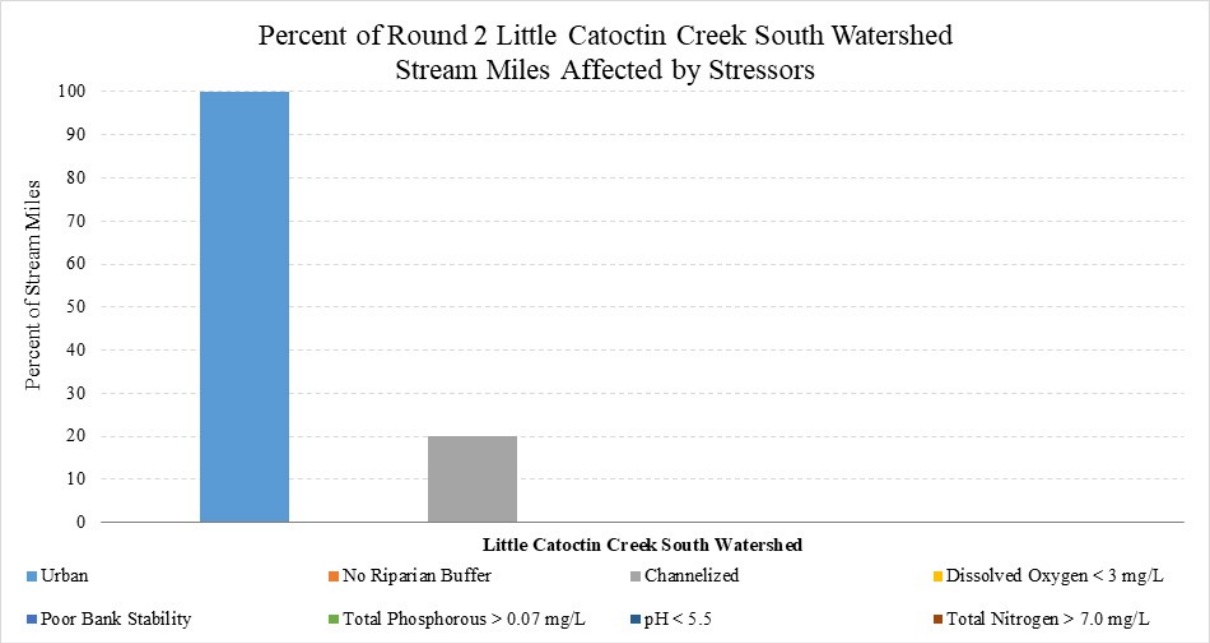

Percent of Round 1 Hunting Creek Watershed
Stream Miles Affected by Stressors
Percent of Stream Miles
100
90
80
70
60
50
40
30
20
10
0
Hunting Creek Watershed
Urban
No Riparian Buffer
Channelized
Dissolved Oxygen < 3 mg/L
Poor Bank Stability
Total Phosphorous > 0.07 mg/L
pH < 5.5
Total Nitrogen > 7.0 mg/L

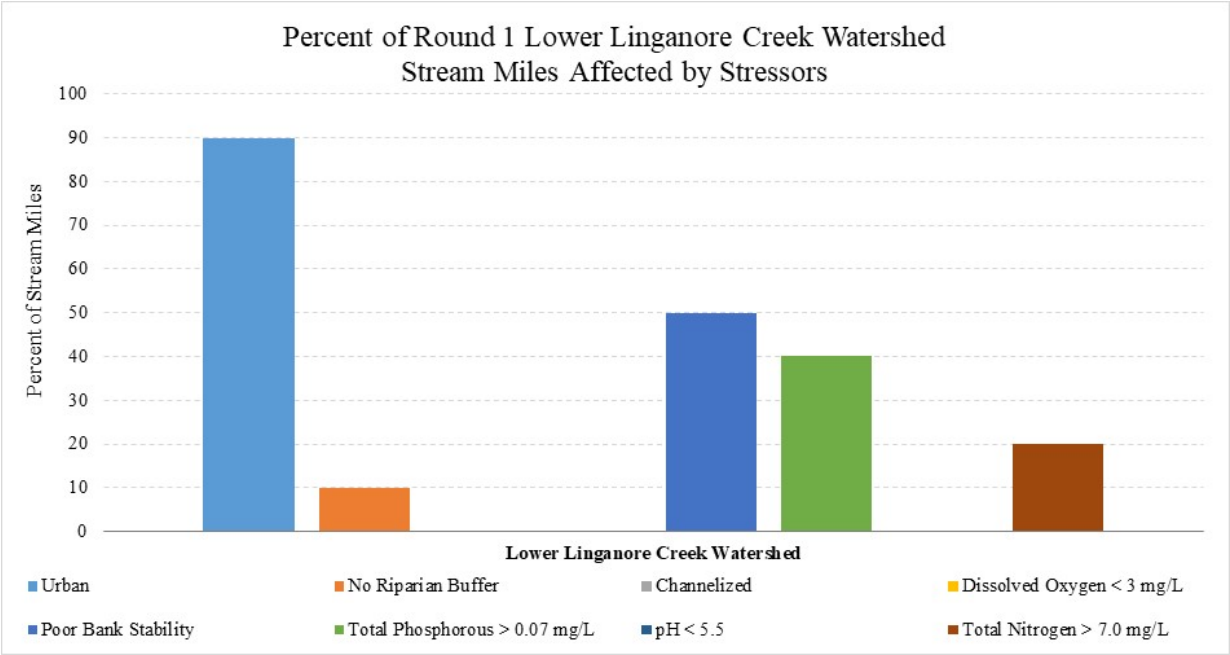

Percent of Round 2 Hunting Creek Watershed
Stream Miles Affected by Stressors
Percent of Stream Miles
100
90
80
70
60
50
40
30
20
10
0
Hunting Creek Watershed
Urban
No Riparian Buffer
Channelized
Dissolved Oxygen < 3 mg/L
Poor Bank Stability
Total Phosphorous > 0.07 mg/L
pH < 5.5
Total Nitrogen > 7.0 mg/L

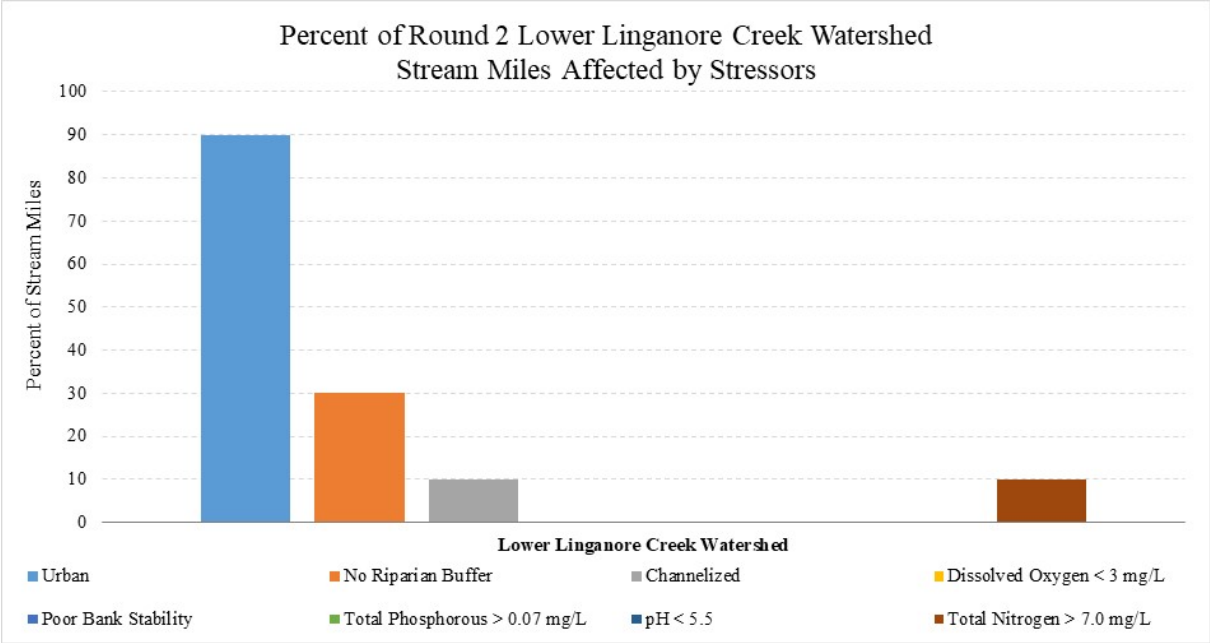

Percent of Round 1 Israel Creek Watershed
Stream Miles Affected by Stressors
Percent of Stream Miles
100
90
80
70
60
50
40
30
20
10
0
Israel Creek Watershed
Urban
No Riparian Buffer
Channelized
Dissolved Oxygen < 3 mg/L
Poor Bank Stability
Total Phosphorous > 0.07 mg/L
pH < 5.5
Total Nitrogen > 7.0 mg/L

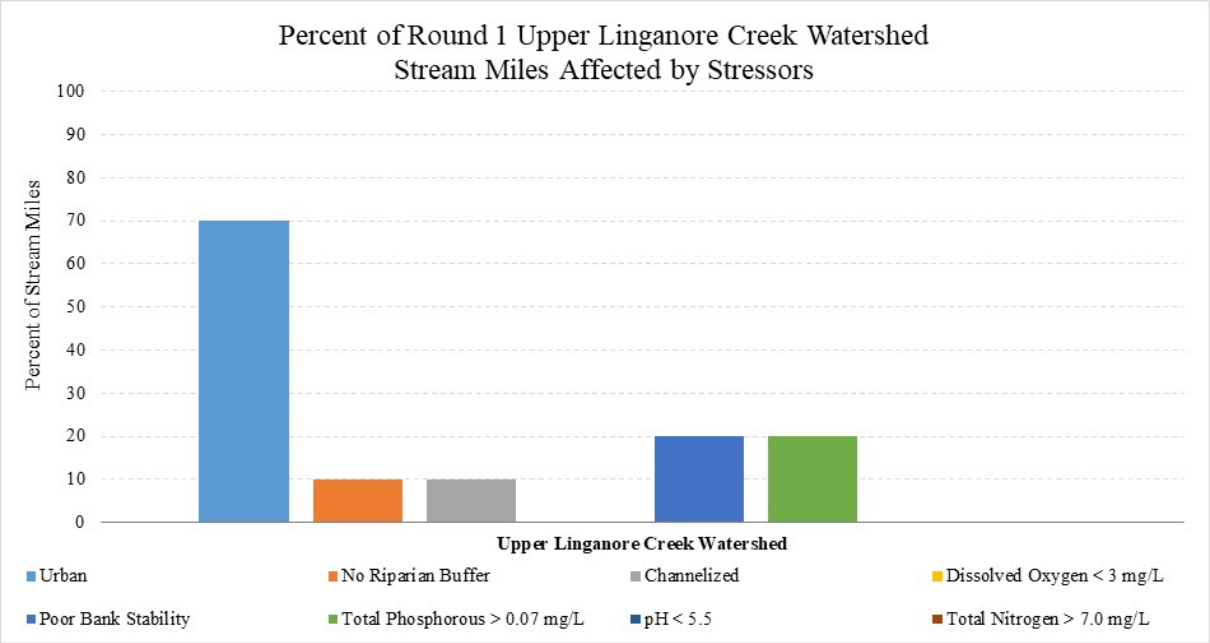

Percent of Round 2 Israel Creek Watershed
Stream Miles Affected by Stressors
Percent of Stream Miles
100
90
80
70
60
50
40
30
20
10
0
Israel Creek Watershed
Urban
No Riparian Buffer
Channelized
Dissolved Oxygen < 3 mg/L
Poor Bank Stability
Total Phosphorous > 0.07 mg/L
pH < 5.5
Total Nitrogen > 7.0 mg/L

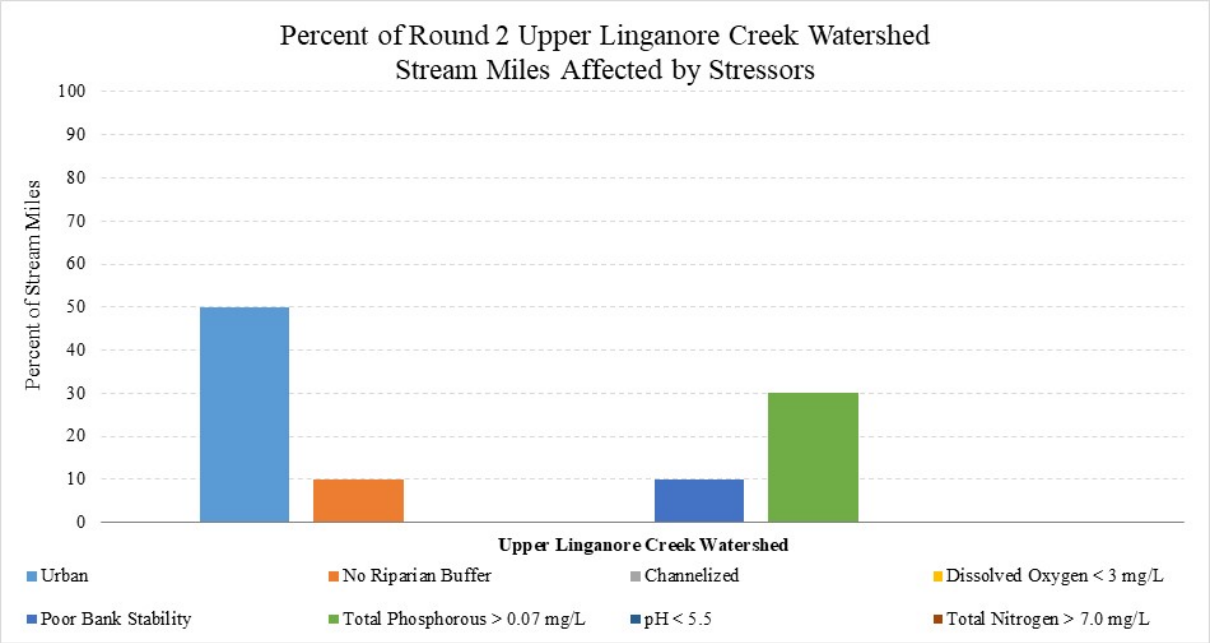

Percent of Round 1 Little Catoctin Creek South Watershed
Stream Miles Affected by Stressors
Percent of Stream Miles
100
90
80
70
60
50
40
30
20
10
0
Little Catoctin Creek South Watershed
Urban
No Riparian Buffer
Channelized
Dissolved Oxygen < 3 mg/L
Poor Bank Stability
Total Phosphorous > 0.07 mg/L
pH < 5.5
Total Nitrogen > 7.0 mg/L

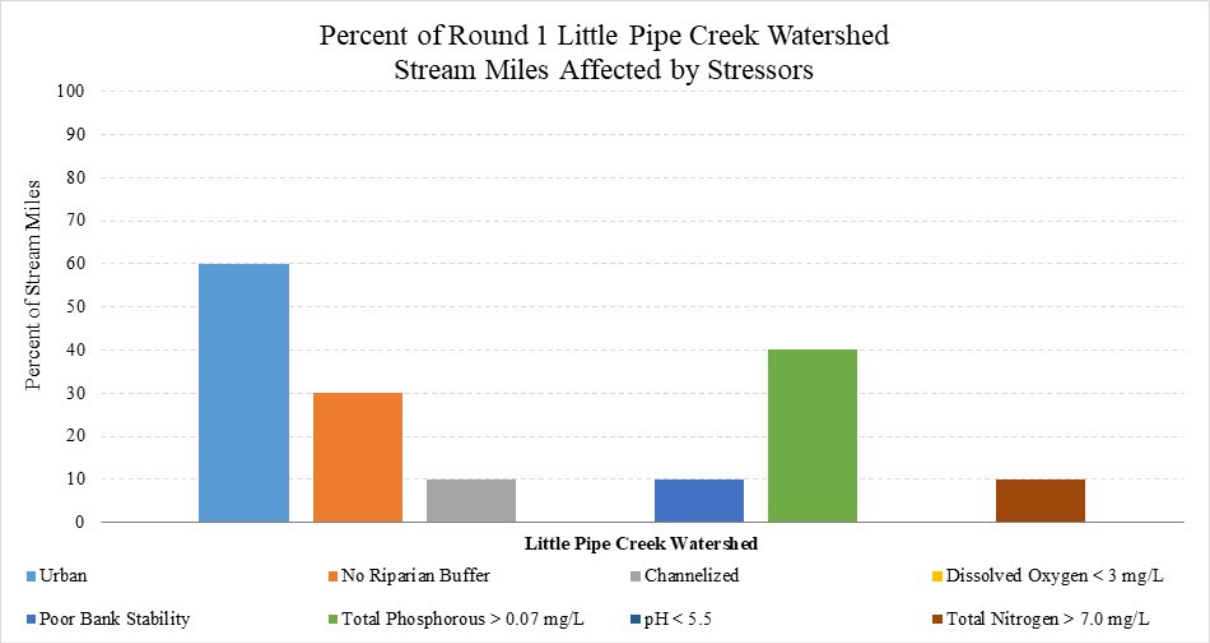

Percent of Round 2 Little Catoctin Creek South Watershed
Stream Miles Affected by Stressors
Percent of Stream Miles
100
90
80
70
60
50
40
30
20
10
0
Little Catoctin Creek South Watershed
Urban
No Riparian Buffer
Channelized
Dissolved Oxygen < 3 mg/L
Poor Bank Stability
Total Phosphorous > 0.07 mg/L
pH < 5.5
Total Nitrogen > 7.0 mg/L

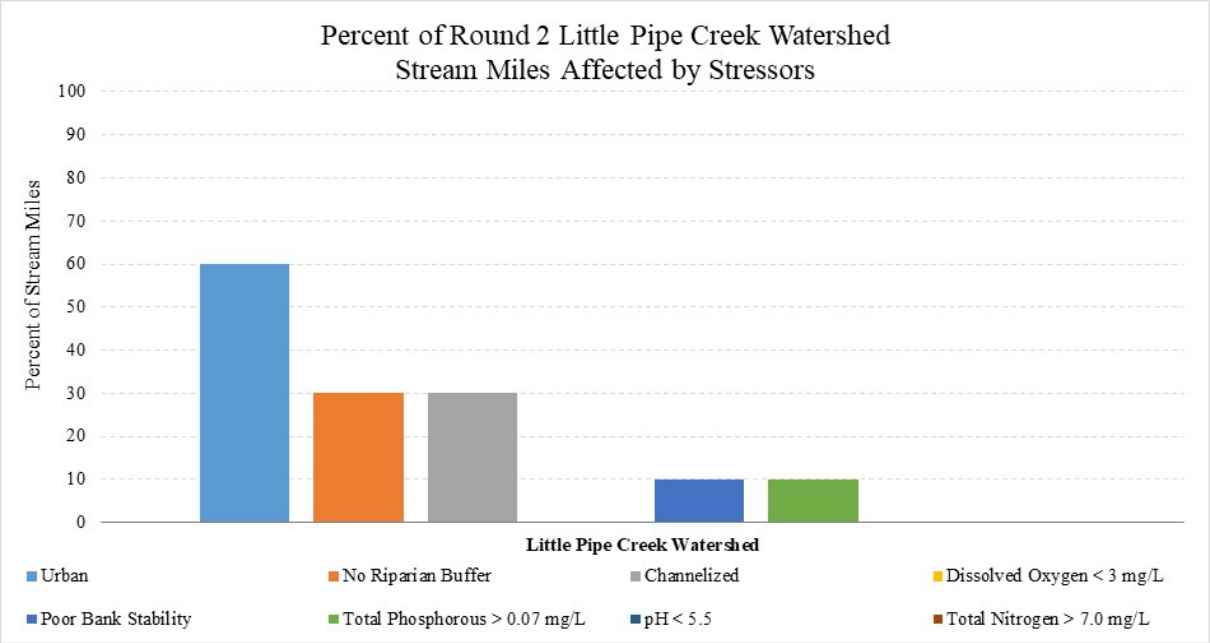

Percent of Round 1 Lower Linganore Creek Watershed
Stream Miles Affected by Stressors
Percent of Stream Miles
100
90
80
70
60
50
40
30
20
10
0
Lower Linganore Creek Watershed
Urban
No Riparian Buffer
Channelized
Dissolved Oxygen < 3 mg/L
Poor Bank Stability
Total Phosphorous > 0.07 mg/L
pH < 5.5
Total Nitrogen > 7.0 mg/L

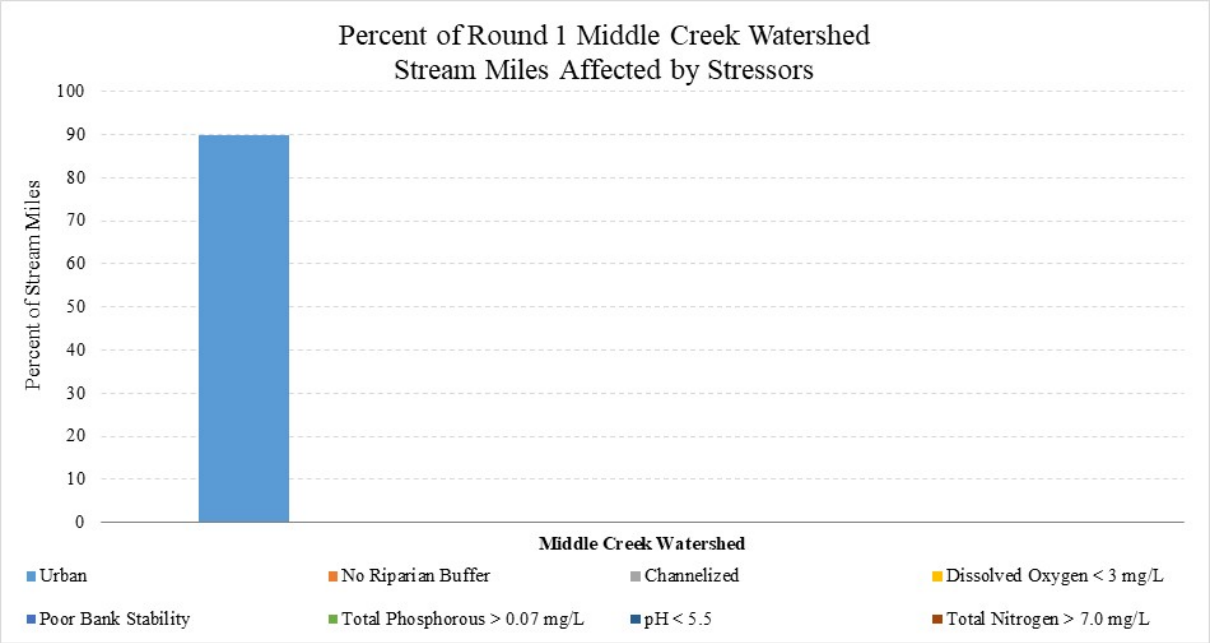

Percent of Round 2 Lower Linganore Creek Watershed
Stream Miles Affected by Stressors
Percent of Stream Miles
100
90
80
70
60
50
40
30
20
10
0
Lower Linganore Creek Watershed
Urban
No Riparian Buffer
Channelized
Dissolved Oxygen < 3 mg/L
Poor Bank Stability
Total Phosphorous > 0.07 mg/L
pH < 5.5
Total Nitrogen > 7.0 mg/L

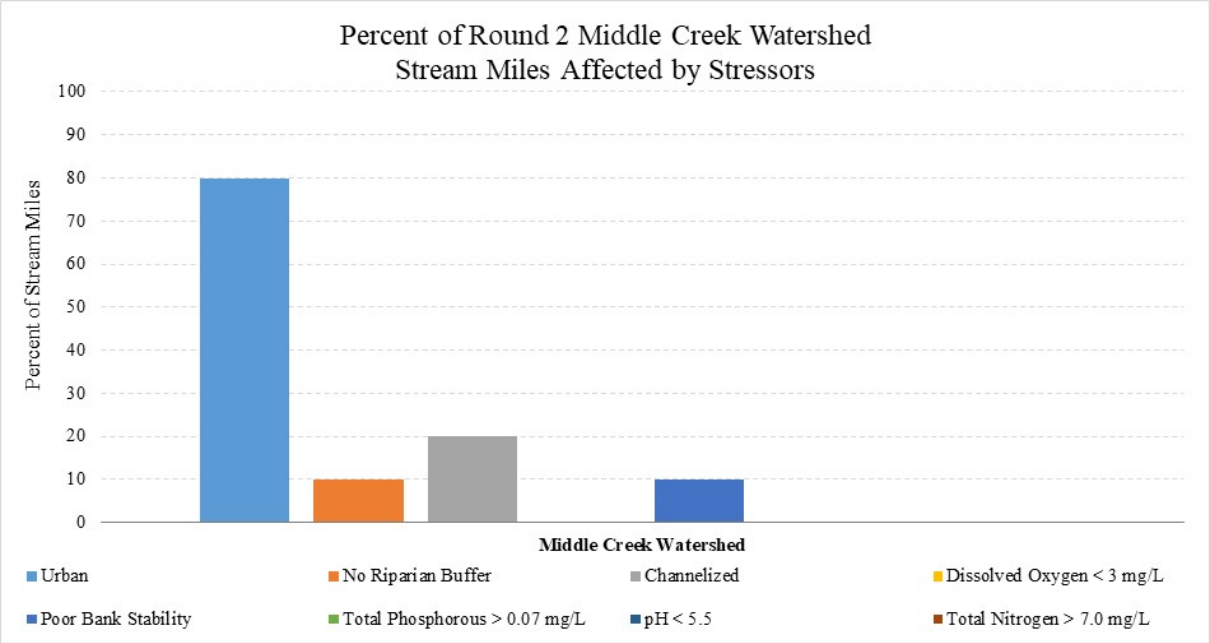

Percent of Round 1 Upper Linganore Creek Watershed
Stream Miles Affected by Stressors
Percent of Stream Miles
100
90
80
70
60
50
40
30
20
10
0
Upper Linganore Creek Watershed
Urban
No Riparian Buffer
Channelized
Dissolved Oxygen < 3 mg/L
Poor Bank Stability
Total Phosphorous > 0.07 mg/L
pH < 5.5
Total Nitrogen > 7.0 mg/L

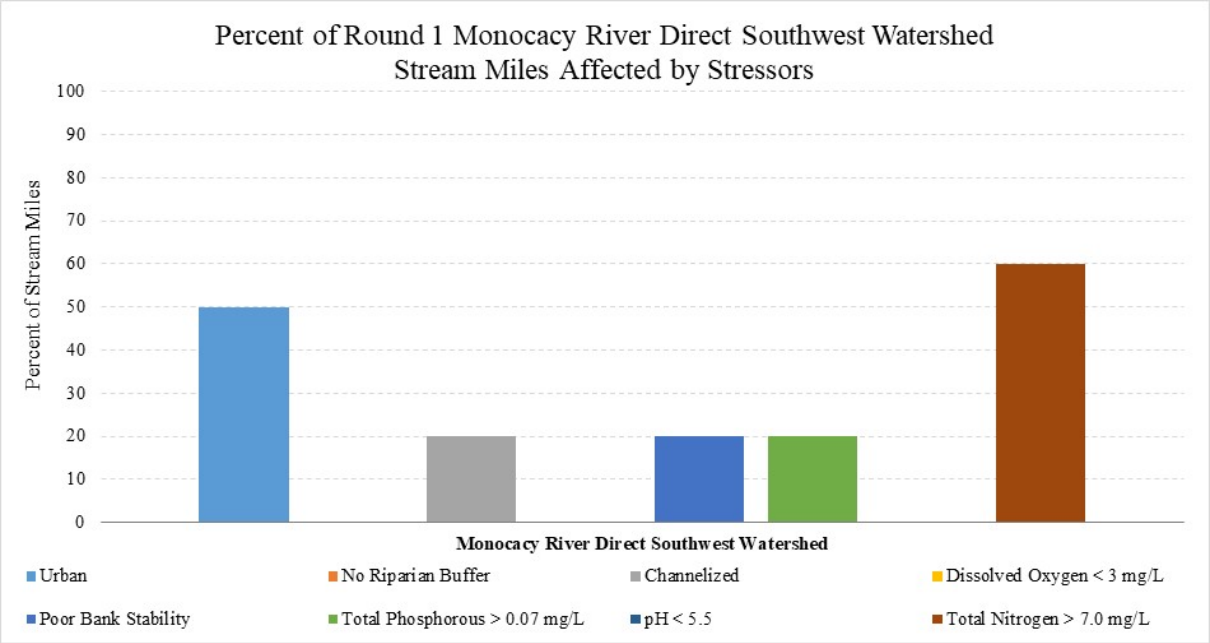

Percent of Round 2 Upper Linganore Creek Watershed
Stream Miles Affected by Stressors
Percent of Stream Miles
100
90
80
70
60
50
40
30
20
10
0
Upper Linganore Creek Watershed
Urban
No Riparian Buffer
Channelized
Dissolved Oxygen < 3 mg/L
Poor Bank Stability
Total Phosphorous > 0.07 mg/L
pH < 5.5
Total Nitrogen > 7.0 mg/L

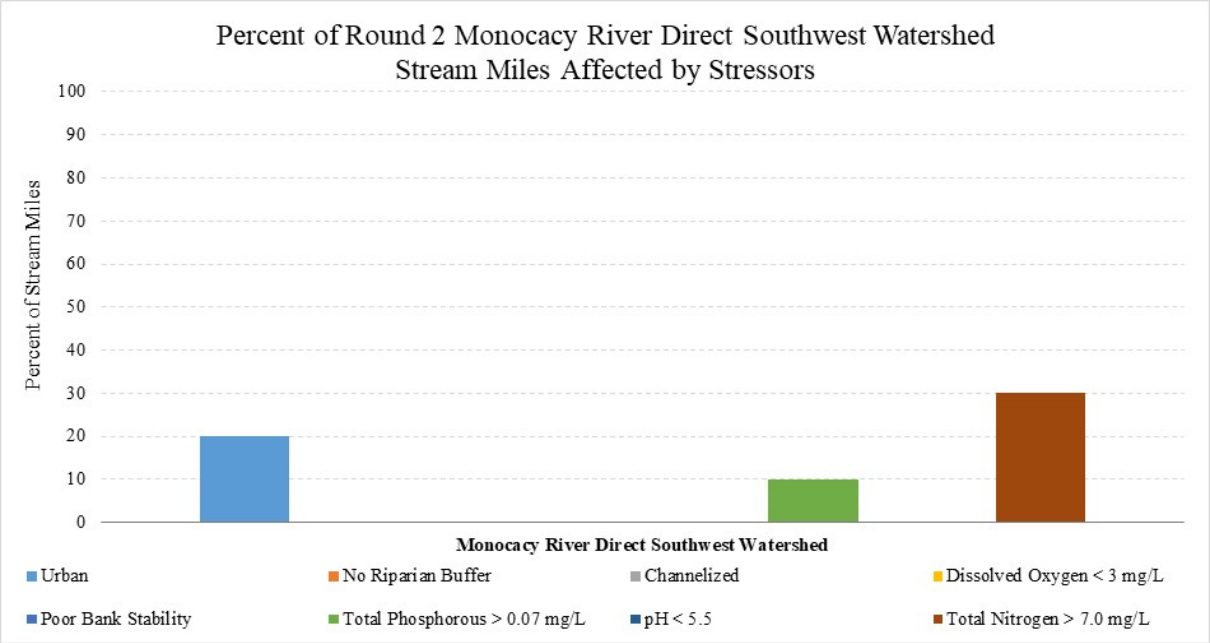

Percent of Round 1 Little Pipe Creek Watershed
Stream Miles Affected by Stressors
Percent of Stream Miles
100
90
80
70
60
50
40
30
20
10
0
Little Pipe Creek Watershed
Urban
No Riparian Buffer
Channelized
Dissolved Oxygen < 3 mg/L
Poor Bank Stability
Total Phosphorous > 0.07 mg/L
pH < 5.5
Total Nitrogen > 7.0 mg/L

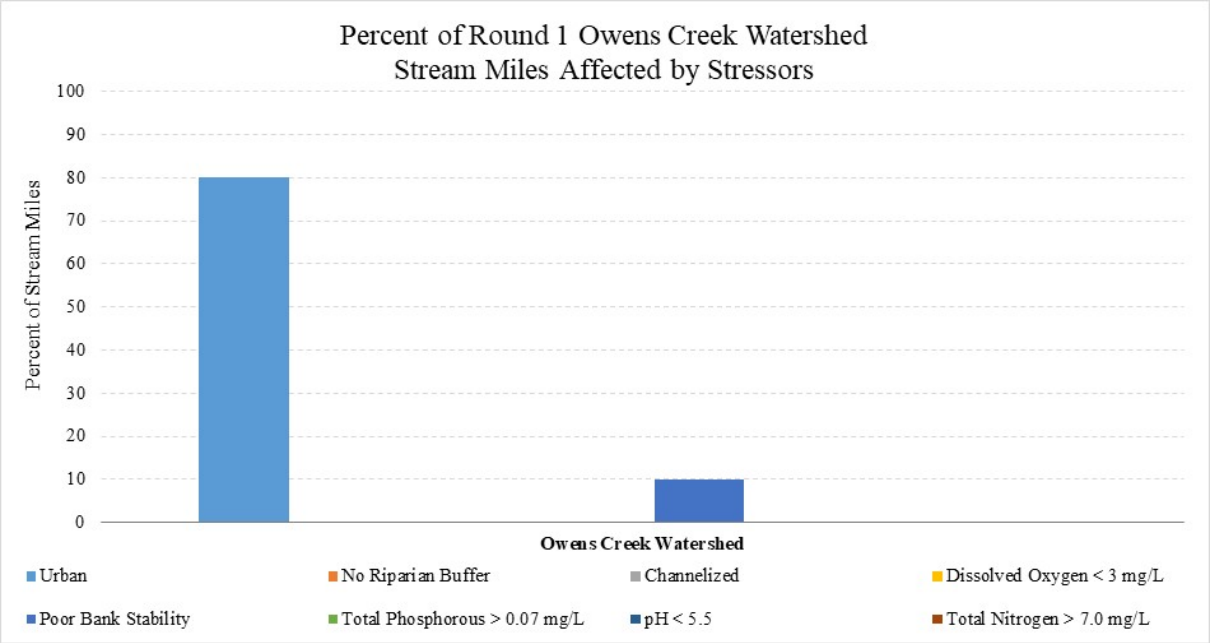

Percent of Round 2 Little Pipe Creek Watershed
Stream Miles Affected by Stressors
Percent of Stream Miles
100
90
80
70
60
50
40
30
20
10
0
Little Pipe Creek Watershed
Urban
No Riparian Buffer
Channelized
Dissolved Oxygen < 3 mg/L
Poor Bank Stability
Total Phosphorous > 0.07 mg/L
pH < 5.5
Total Nitrogen > 7.0 mg/L

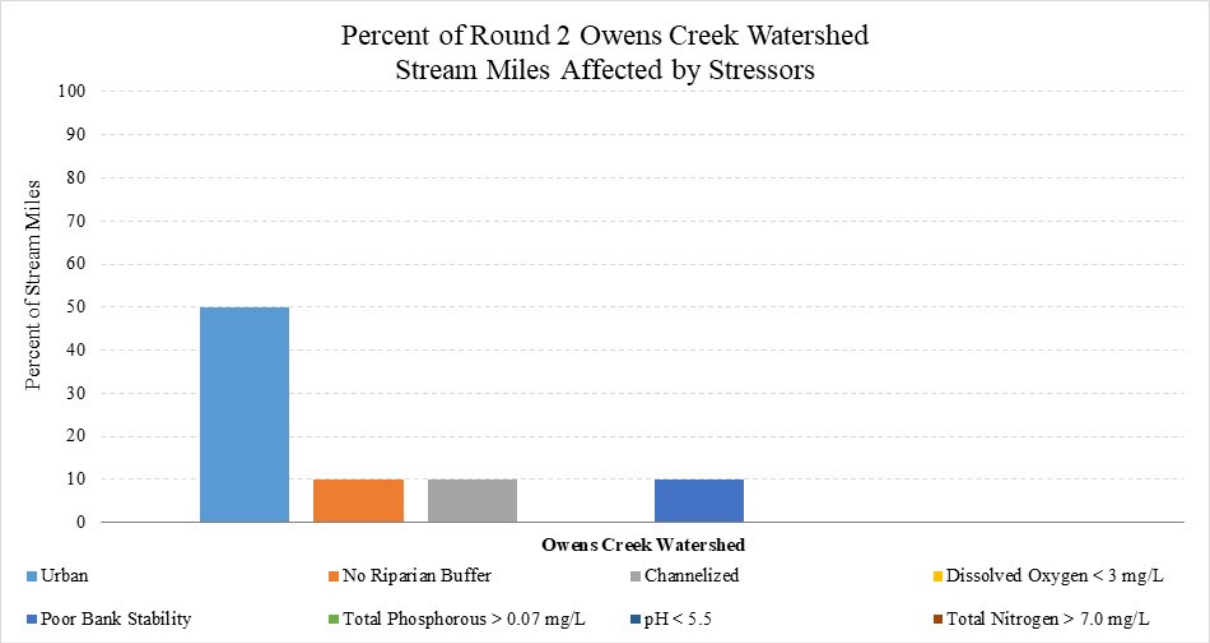

Percent of Round 1 Middle Creek Watershed
Stream Miles Affected by Stressors
Percent of Stream Miles
100
90
80
70
60
50
40
30
20
10
0
Middle Creek Watershed
Urban
No Riparian Buffer
Channelized
Dissolved Oxygen < 3 mg/L
Poor Bank Stability
Total Phosphorous > 0.07 mg/L
pH < 5.5
Total Nitrogen > 7.0 mg/L

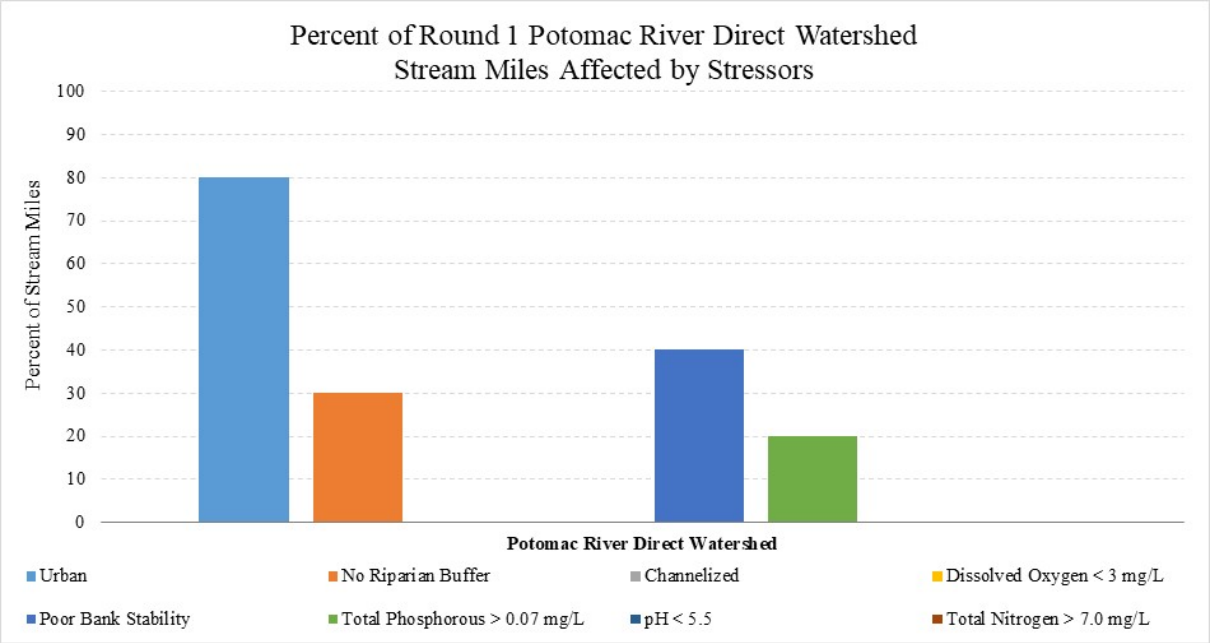

Percent of Round 2 Middle Creek Watershed
Stream Miles Affected by Stressors
Percent of Stream Miles
100
90
80
70
60
50
40
30
20
10
0
Middle Creek Watershed
Urban
No Riparian Buffer
Channelized
Dissolved Oxygen < 3 mg/L
Poor Bank Stability
Total Phosphorous > 0.07 mg/L
pH < 5.5
Total Nitrogen > 7.0 mg/L

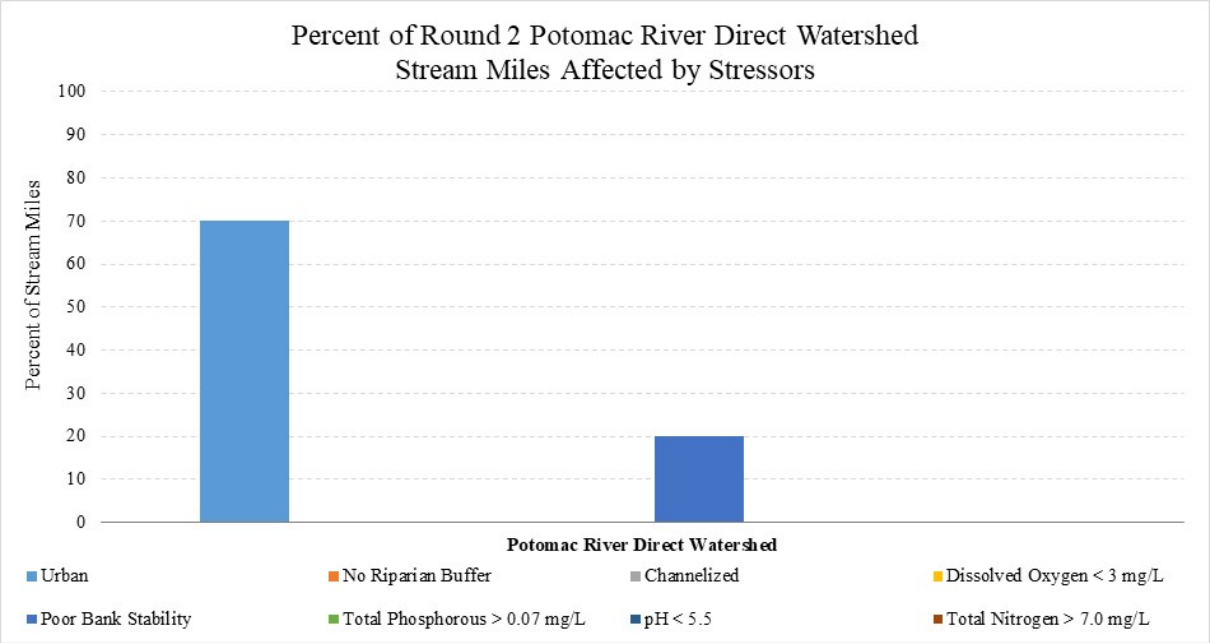

Percent of Round 1 Monocacy River Direct Southwest Watershed
Stream Miles Affected by Stressors
Percent of Stream Miles
100
90
80
70
60
50
40
30
20
10
0
Monocacy River Direct Southwest Watershed
Urban
No Riparian Buffer
Channelized
Dissolved Oxygen < 3 mg/L
Poor Bank Stability
Total Phosphorous > 0.07 mg/L
pH < 5.5
Total Nitrogen > 7.0 mg/L

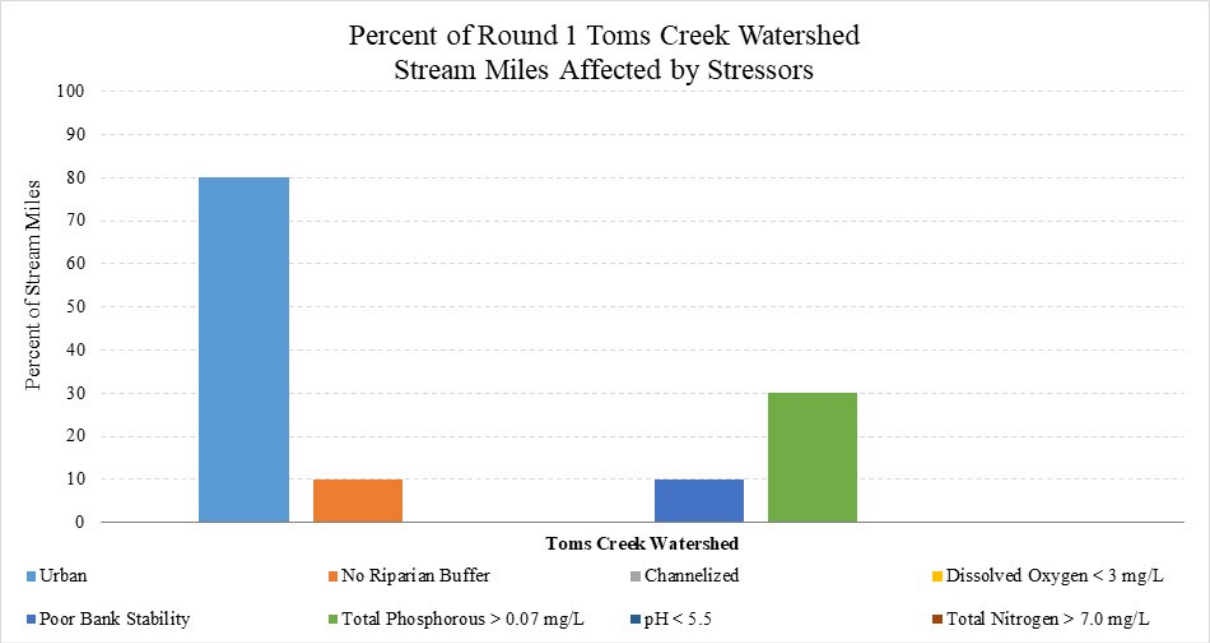

Percent of Round 2 Monocacy River Direct Southwest Watershed
Stream Miles Affected by Stressors
Percent of Stream Miles
100
90
80
70
60
50
40
30
20
10
0
Monocacy River Direct Southwest Watershed
Urban
No Riparian Buffer
Channelized
Dissolved Oxygen < 3 mg/L
Poor Bank Stability
Total Phosphorous > 0.07 mg/L
pH < 5.5
Total Nitrogen > 7.0 mg/L

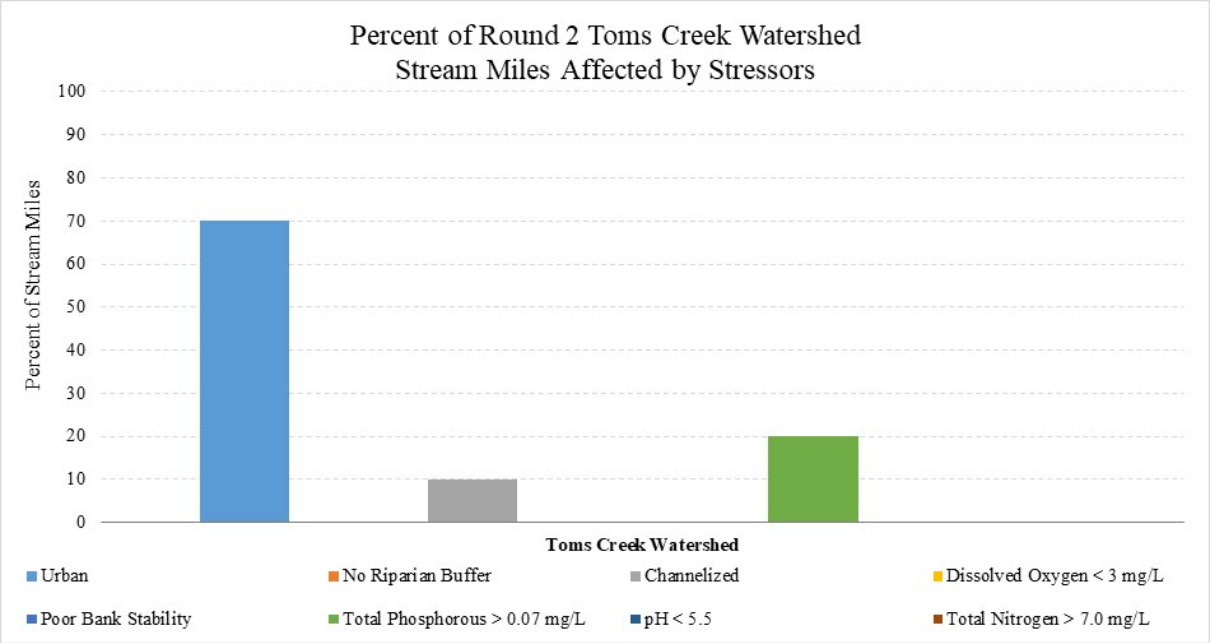

Percent of Round 1 Owens Creek Watershed
Stream Miles Affected by Stressors
Percent of Stream Miles
100
90
80
70
60
50
40
30
20
10
0
Owens Creek Watershed
Urban
No Riparian Buffer
Channelized
Dissolved Oxygen < 3 mg/L
Poor Bank Stability
Total Phosphorous > 0.07 mg/L
pH < 5.5
Total Nitrogen > 7.0 mg/L

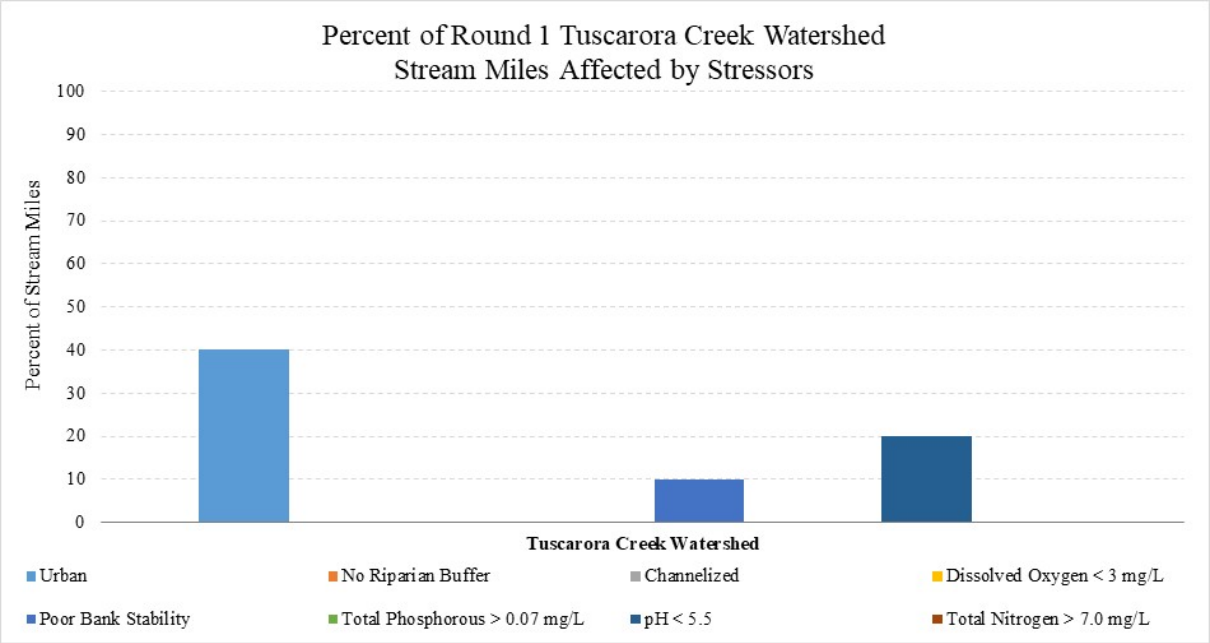

Percent of Round 2 Owens Creek Watershed
Stream Miles Affected by Stressors
Percent of Stream Miles
100
90
80
70
60
50
40
30
20
10
0
Owens Creek Watershed
Urban
No Riparian Buffer
Channelized
Dissolved Oxygen < 3 mg/L
Poor Bank Stability
Total Phosphorous > 0.07 mg/L
pH < 5.5
Total Nitrogen > 7.0 mg/L

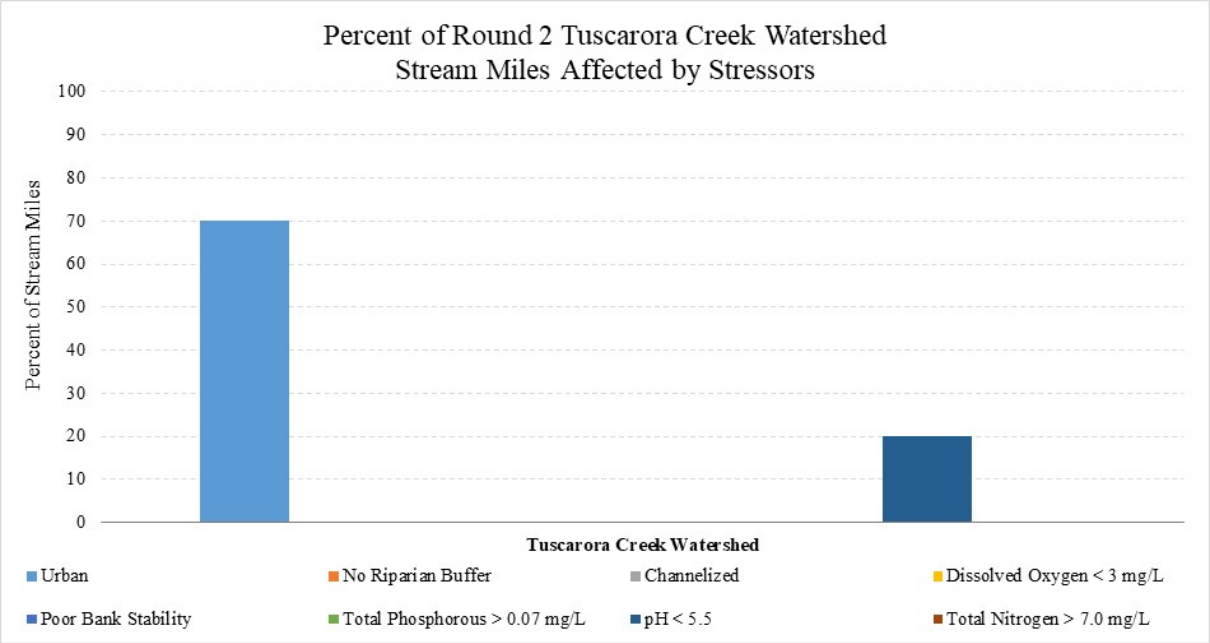

Percent of Round 1 Potomac River Direct Watershed
Stream Miles Affected by Stressors
Percent of Stream Miles
100
90
80
70
60
50
40
30
20
10
0
Potomac River Direct Watershed
Urban
No Riparian Buffer
Channelized
Dissolved Oxygen < 3 mg/L
Poor Bank Stability
Total Phosphorous > 0.07 mg/L
pH < 5.5
Total Nitrogen > 7.0 mg/L


Percent of Round 2 Potomac River Direct Watershed
Stream Miles Affected by Stressors
Percent of Stream Miles
100
90
80
70
60
50
40
30
20
10
0
Potomac River Direct Watershed
Urban
No Riparian Buffer
Channelized
Dissolved Oxygen < 3 mg/L
Poor Bank Stability
Total Phosphorous > 0.07 mg/L
pH < 5.5
Total Nitrogen > 7.0 mg/L


Percent of Round 1 Toms Creek Watershed
Stream Miles Affected by Stressors
Percent of Stream Miles
100
90
80
70
60
50
40
30
20
10
0
Toms Creek Watershed
Urban
No Riparian Buffer
Channelized
Dissolved Oxygen < 3 mg/L
Poor Bank Stability
Total Phosphorous > 0.07 mg/L
pH < 5.5
Total Nitrogen > 7.0 mg/L


Percent of Round 2 Toms Creek Watershed
Stream Miles Affected by Stressors
Percent of Stream Miles
100
90
80
70
60
50
40
30
20
10
0
Toms Creek Watershed
Urban
No Riparian Buffer
Channelized
Dissolved Oxygen < 3 mg/L
Poor Bank Stability
Total Phosphorous > 0.07 mg/L
pH < 5.5
Total Nitrogen > 7.0 mg/L


Percent of Round 1 Tuscarora Creek Watershed
Stream Miles Affected by Stressors
Percent of Stream Miles
100
90
80
70
60
50
40
30
20
10
0
Tuscarora Creek Watershed
Urban
No Riparian Buffer
Channelized
Dissolved Oxygen < 3 mg/L
Poor Bank Stability
Total Phosphorous > 0.07 mg/L
pH < 5.5
Total Nitrogen > 7.0 mg/L

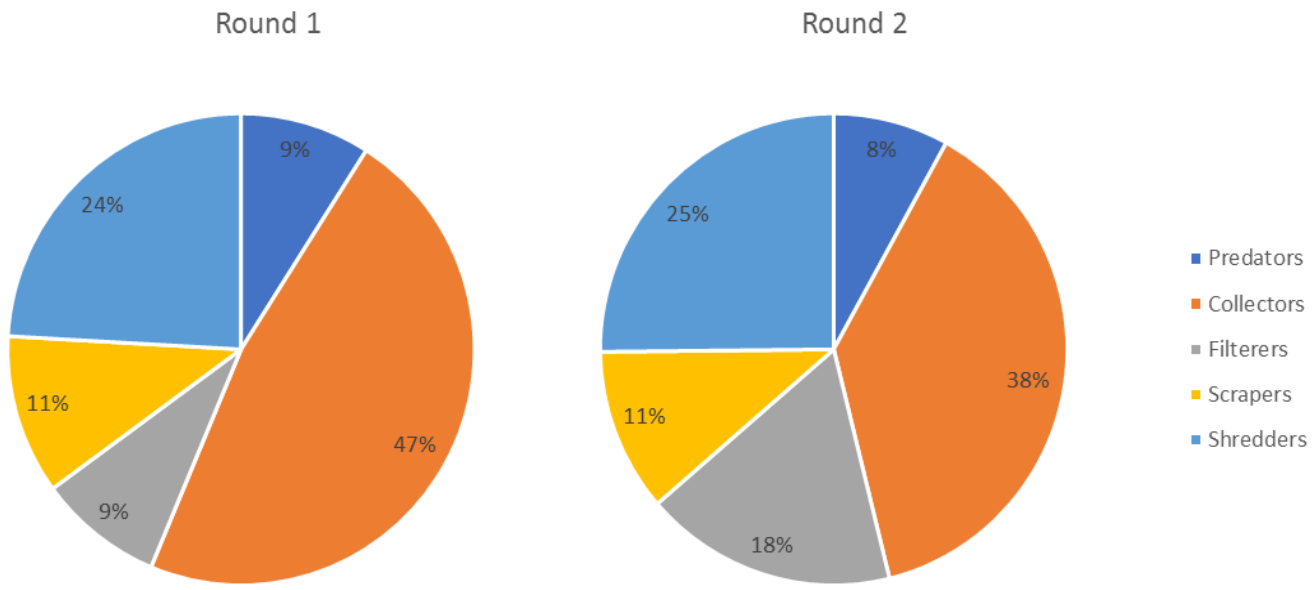

Percent of Round 2 Tuscarora Creek Watershed
Stream Miles Affected by Stressors
Percent of Stream Miles
100
90
80
70
60
50
40
30
20
10
0
Tuscarora Creek Watershed
Urban
No Riparian Buffer
Channelized
Dissolved Oxygen < 3 mg/L
Poor Bank Stability
Total Phosphorous > 0.07 mg/L
pH < 5.5
Total Nitrogen > 7.0 mg/L

APPENDIX C: BENTHIC PIE CHARTS

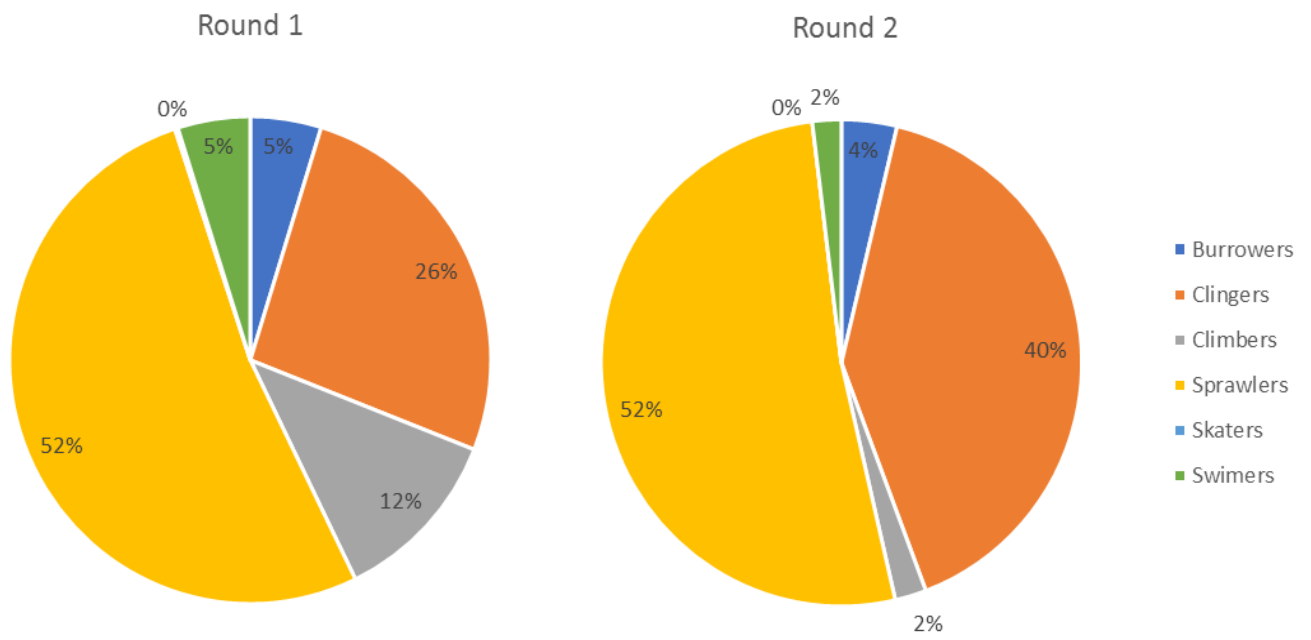
Benthic Macroinvertebrate Taxonomic Grouping

While the benthic macroinvertebrate IBI is a robust means of assessing stream quality, there is some evidence that examining the metrics that make up the IBI may provide more insight into watershed condition (Roy, et al 2003, Hawkins et al 2000). To that purpose, the County looked at the percentage of taxa found in the Functional Feeding Groups and in the Benthic Habit Groups used in the IBI , by watershed for both Round 1 and Round 2. The results are included in this appendix.

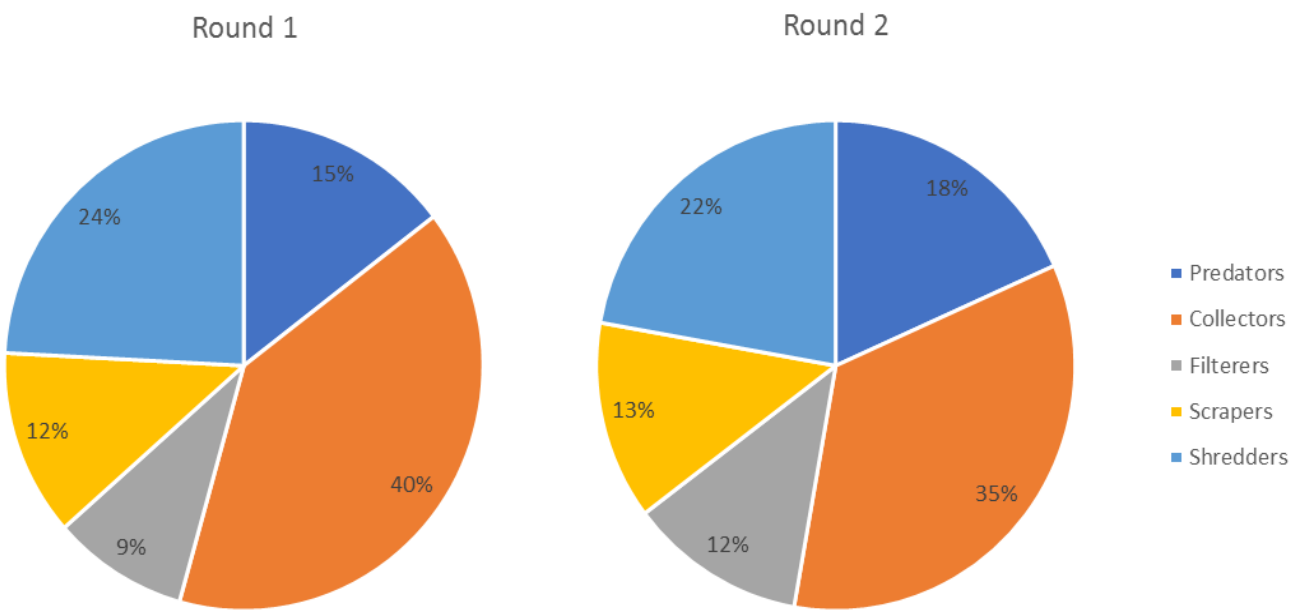
Ballenger Creek Watershed Functional Feeding Groups



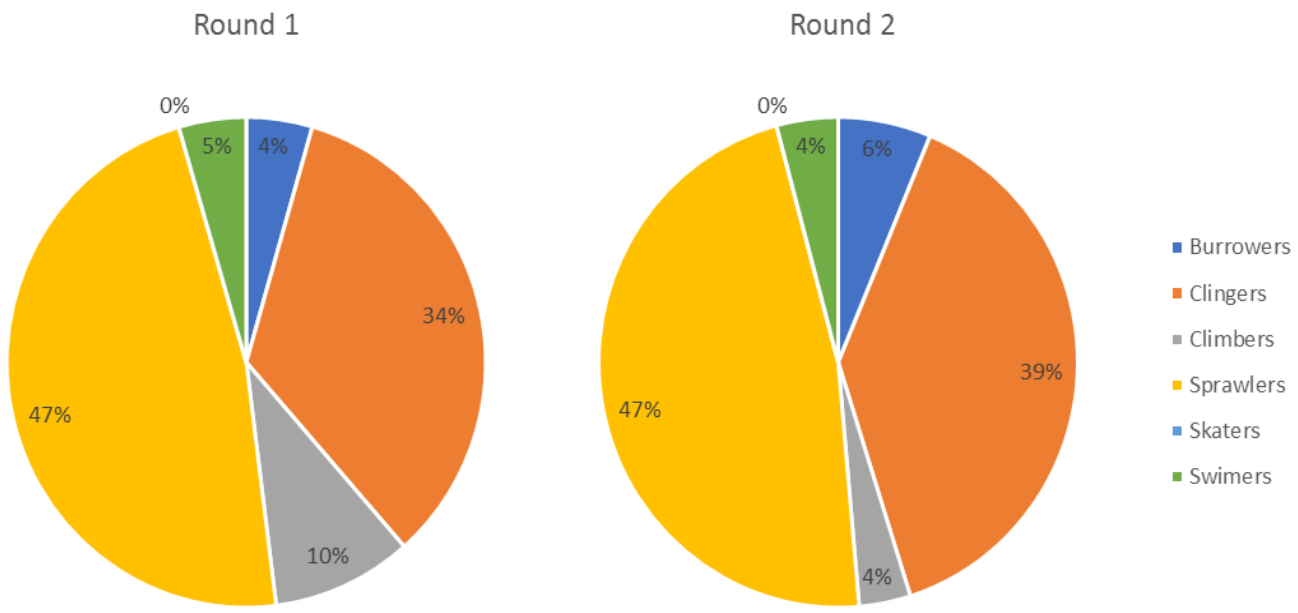
Ballenger Creek Watershed Benthic Habit Groups



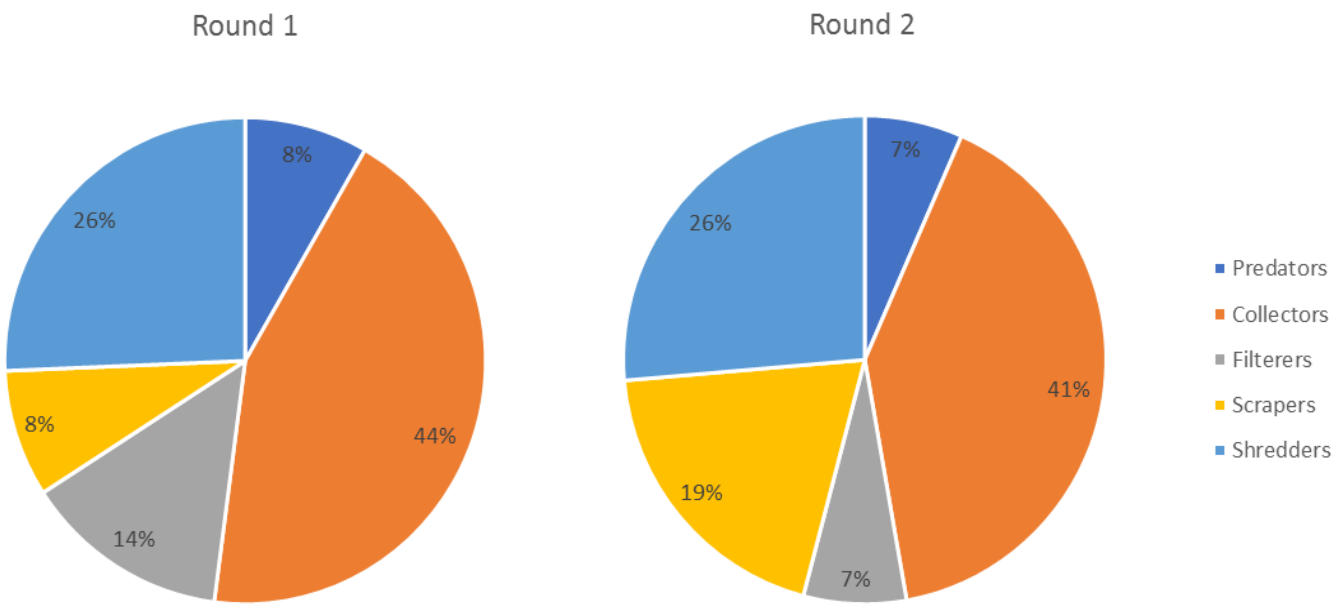
Bennett Creek Watershed Functional Feeding Groups



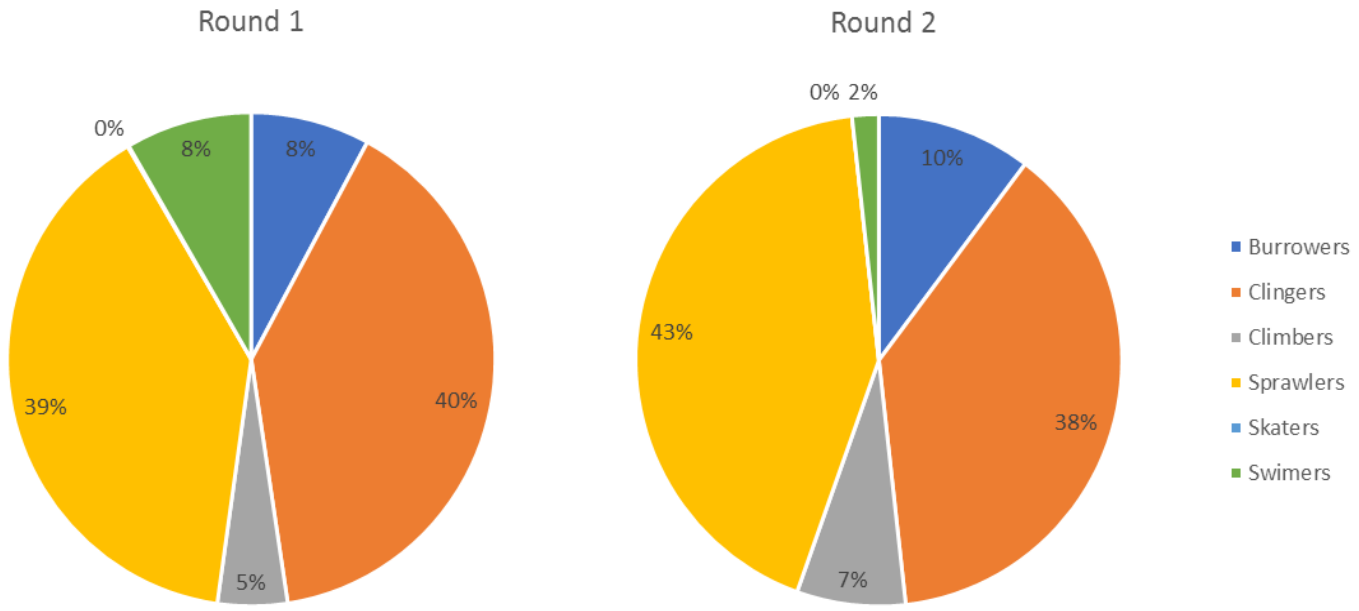
Bennett Creek Watershed Benthic Habit Groups



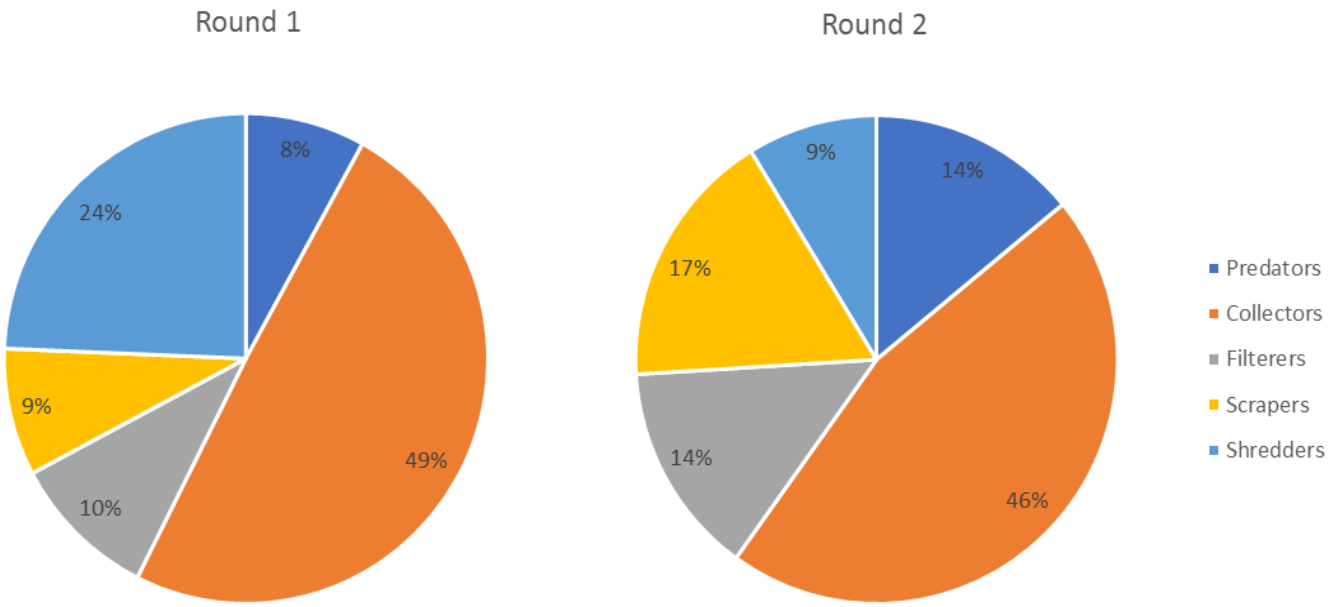
Carroll Creek Watershed Functional Feeding Groups



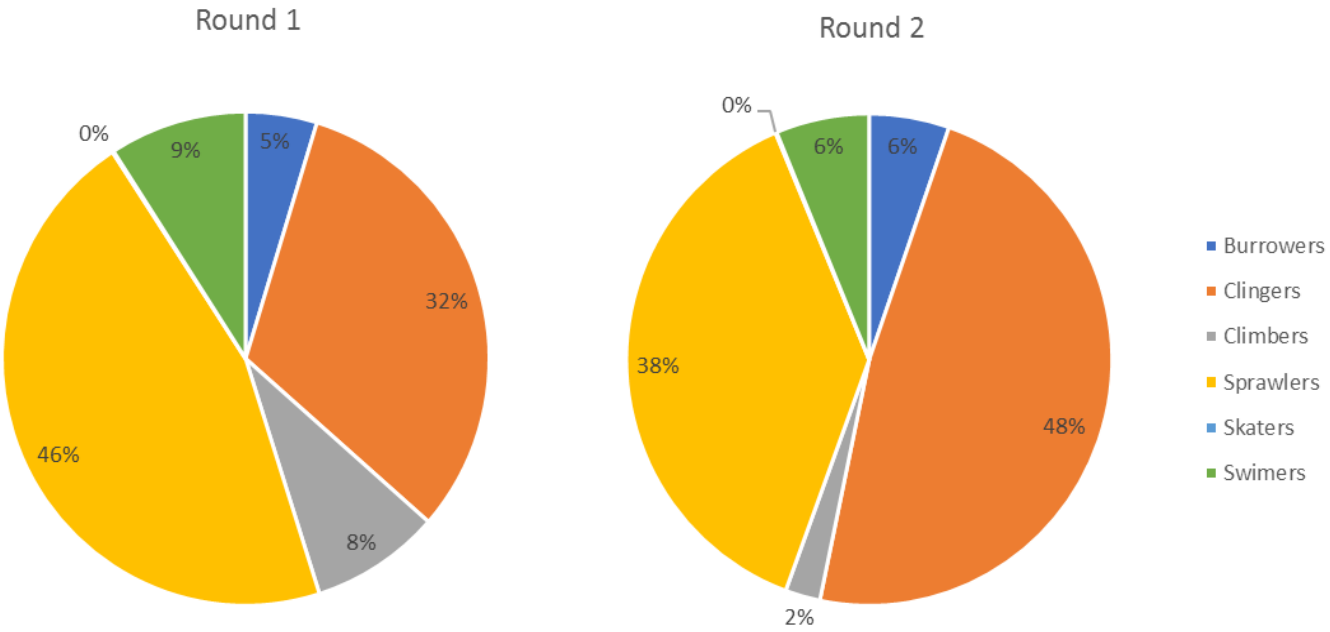
Carroll Creek Watershed Benthic Habit Groups



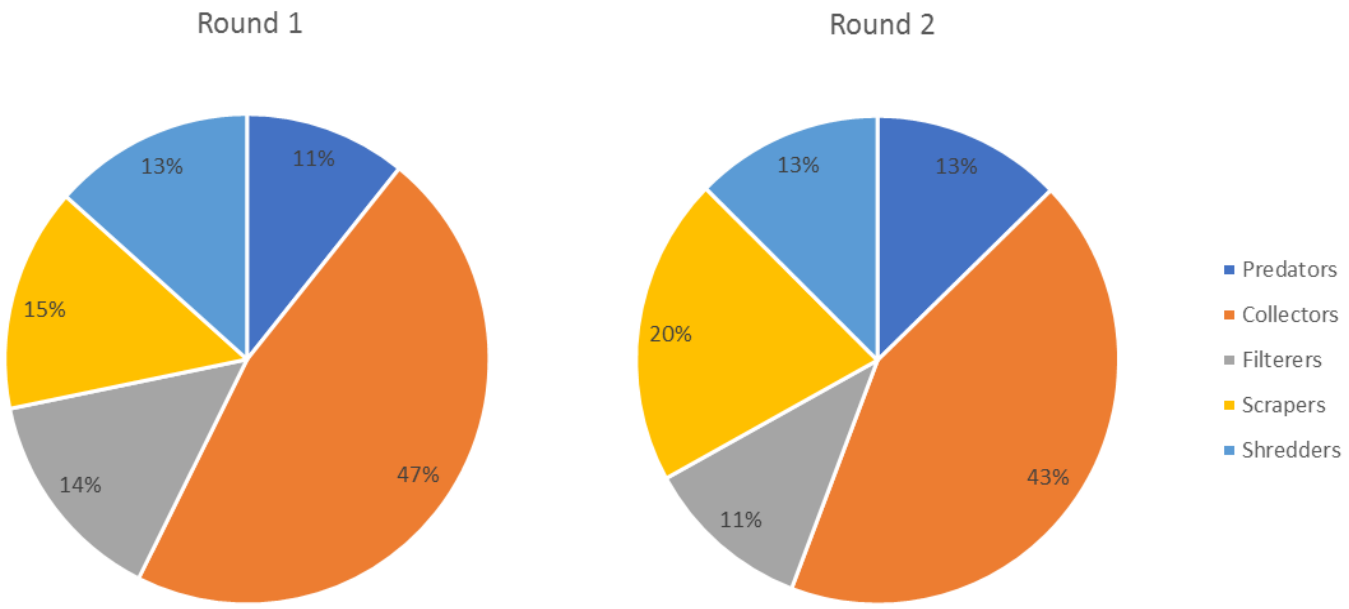
Catoctin Creek Watershed Functional Feeding Groups



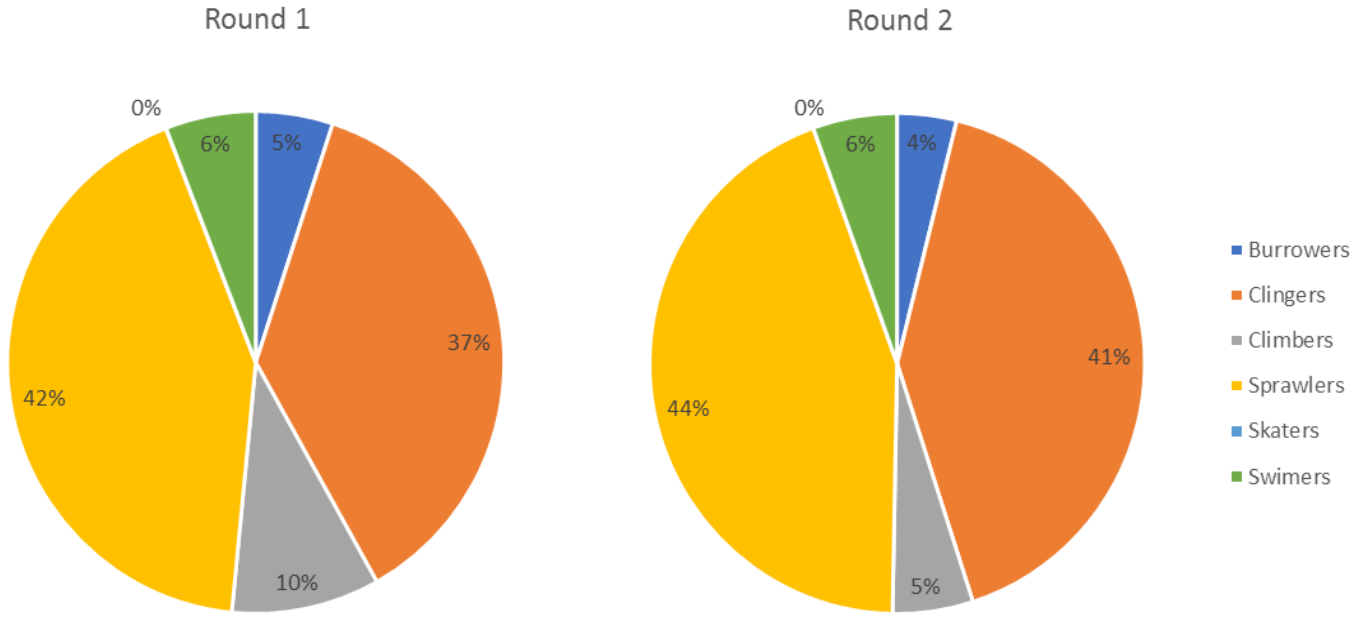
Catoctin Creek Watershed Benthic Habit Groups



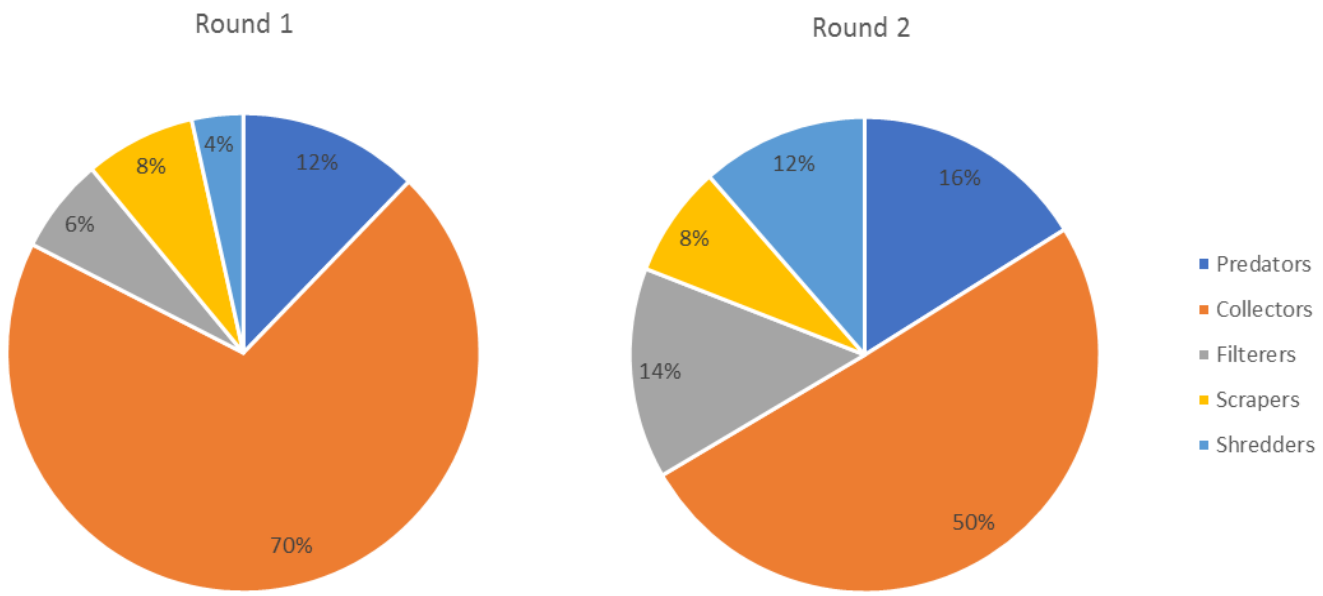
Fishing Creek Watershed Functional Feeding Groups



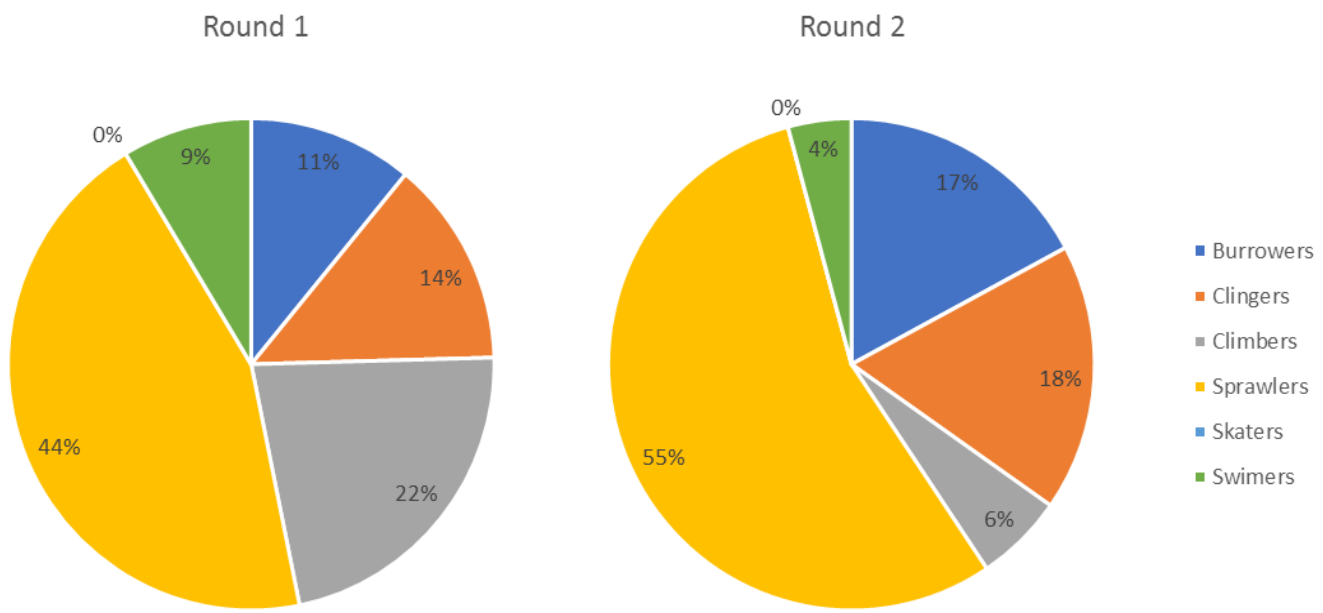
Fishing Creek Watershed Benthic Habit Groups



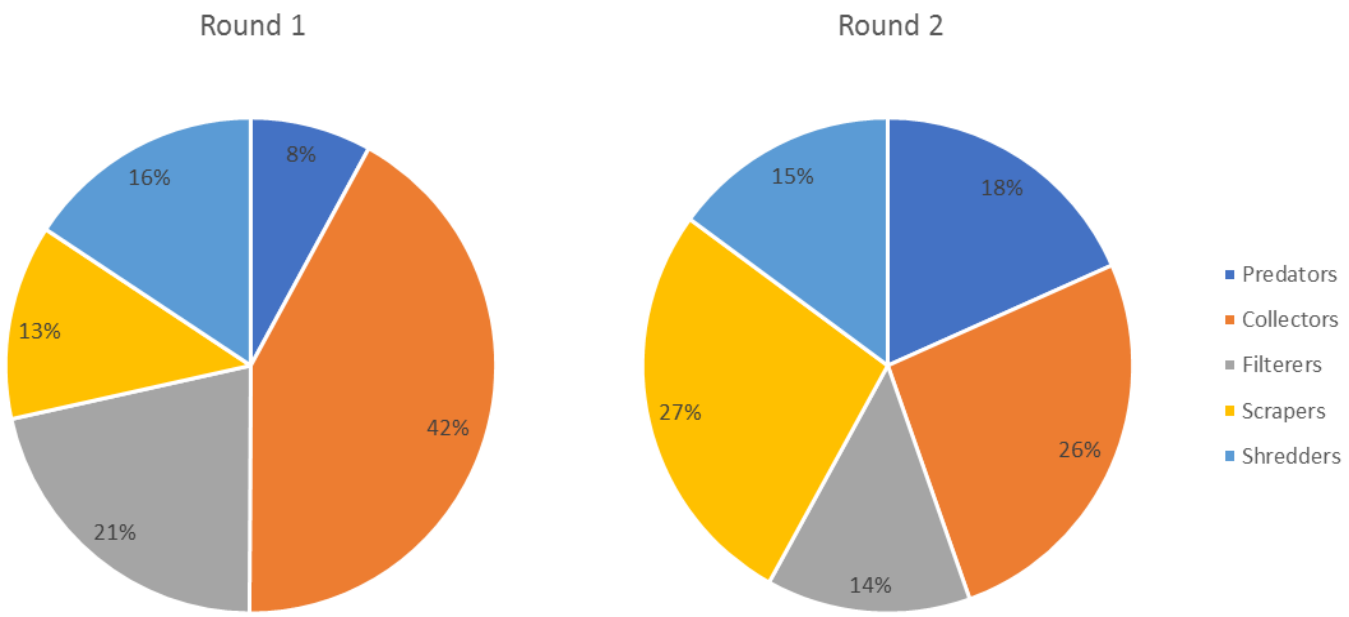
Glade Creek Watershed Functional Feeding Groups



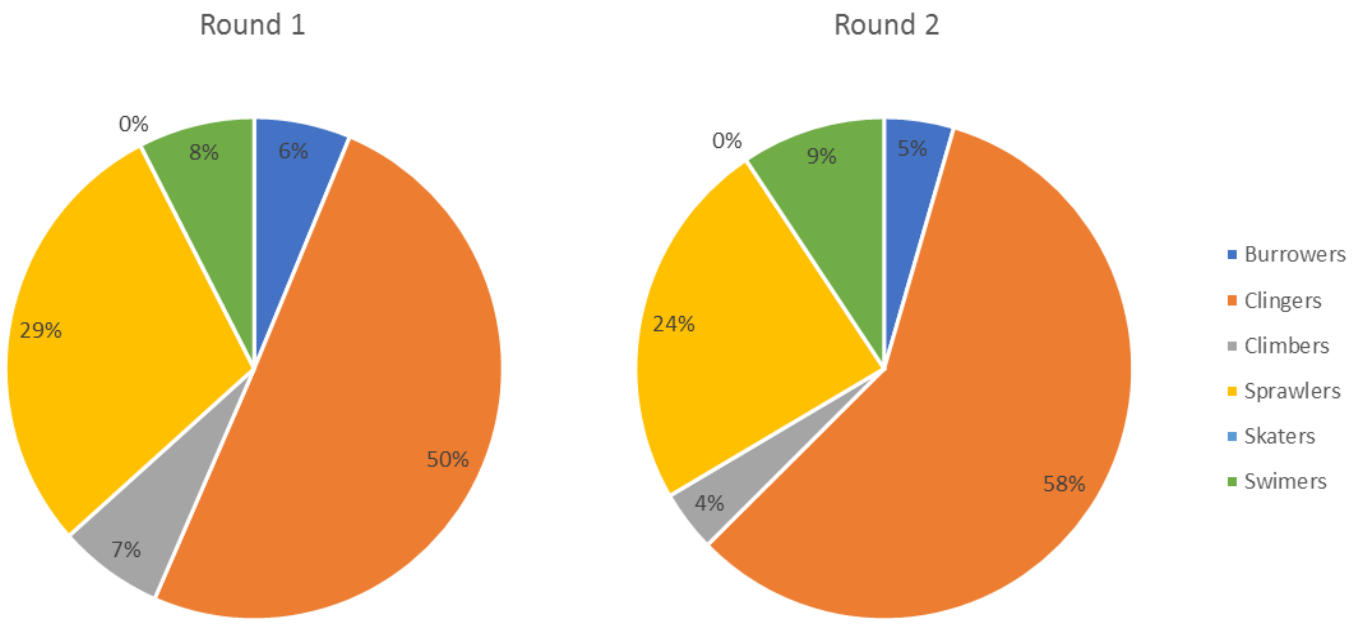
Glade Creek Watershed Benthic Habit Groups



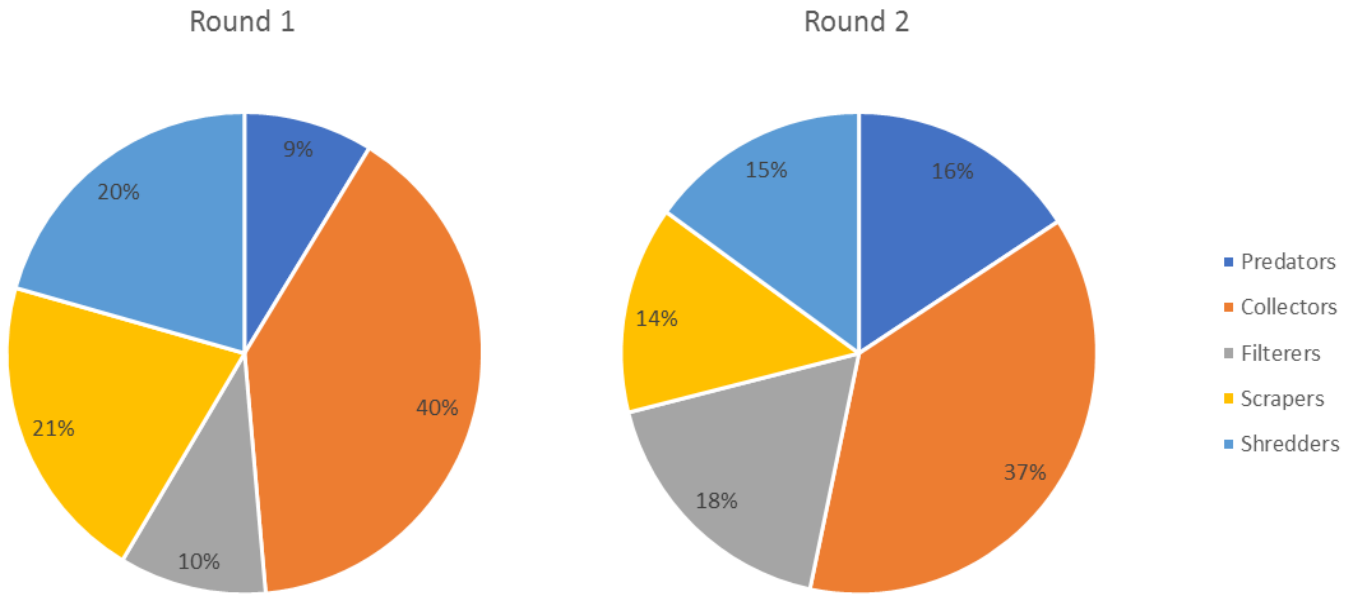
Hunting Creek Watershed Functional Feeding Groups



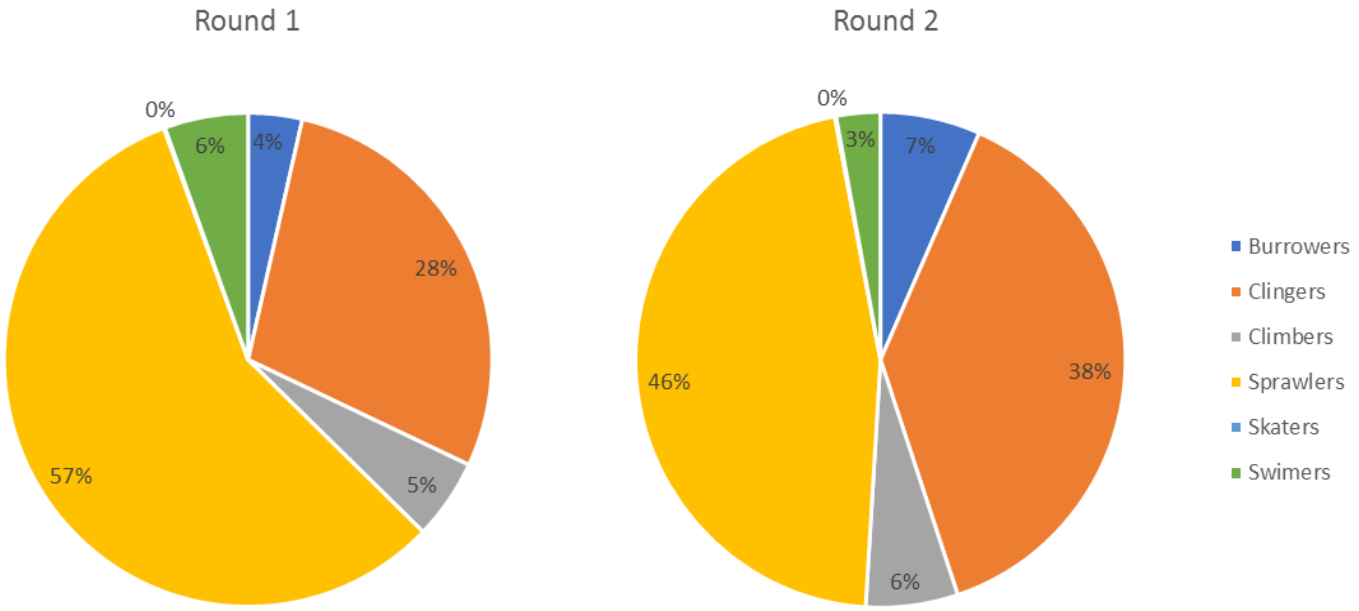
Hunting Creek Watershed Benthic Habit Groups



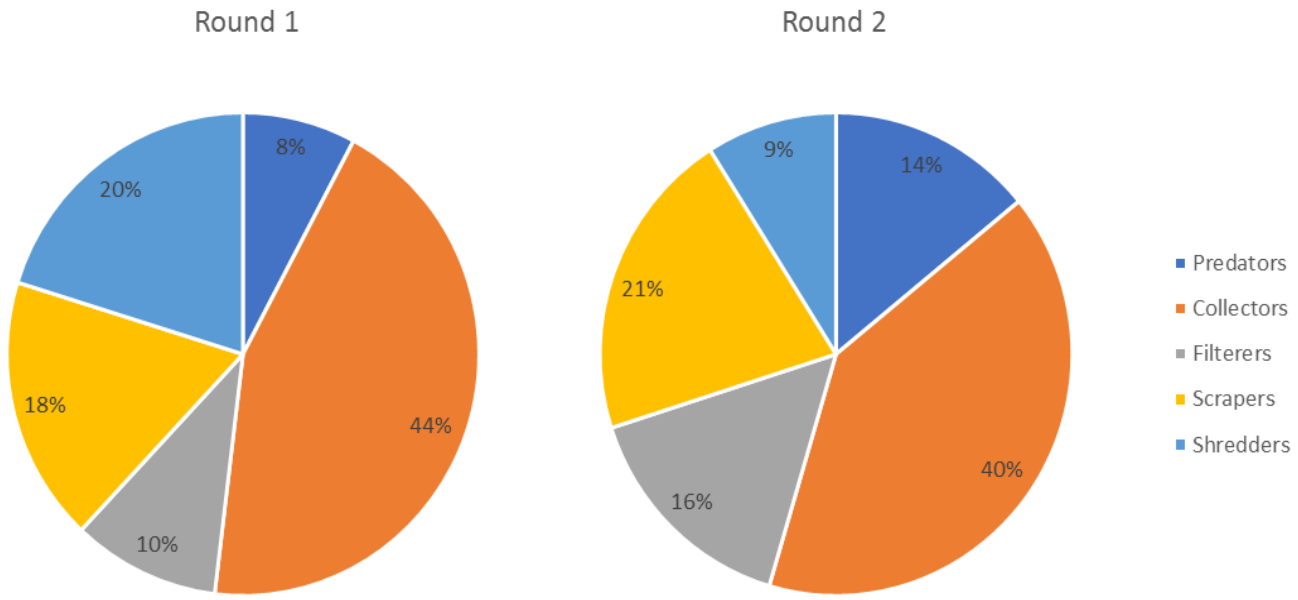
Israel Creek Watershed Functional Feeding Groups



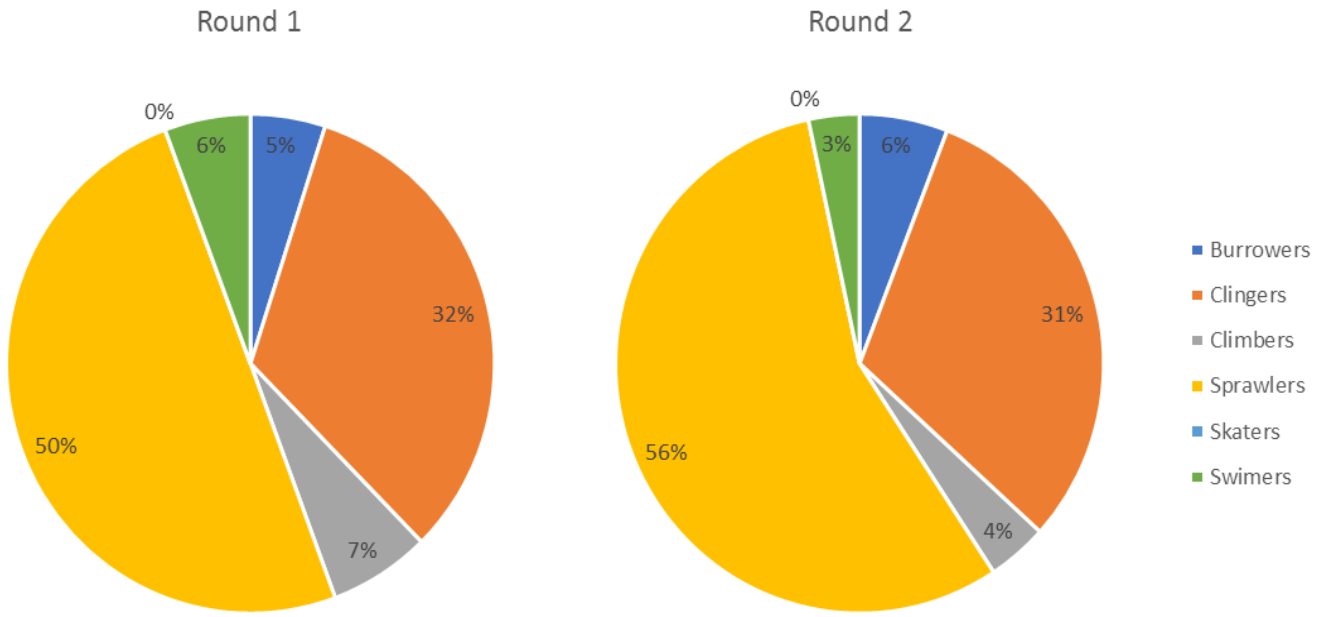
Israel Creek Watershed Benthic Habit Groups



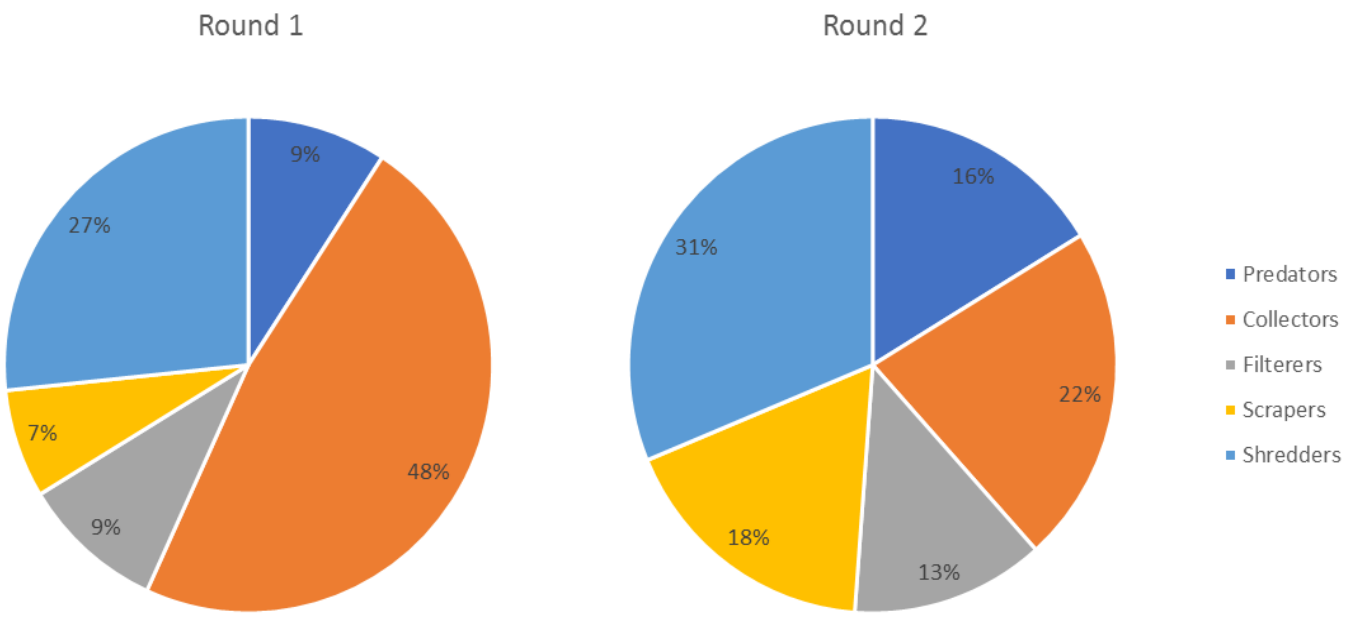
Little Catoctin Creek South Watershed Functional Feeding Groups



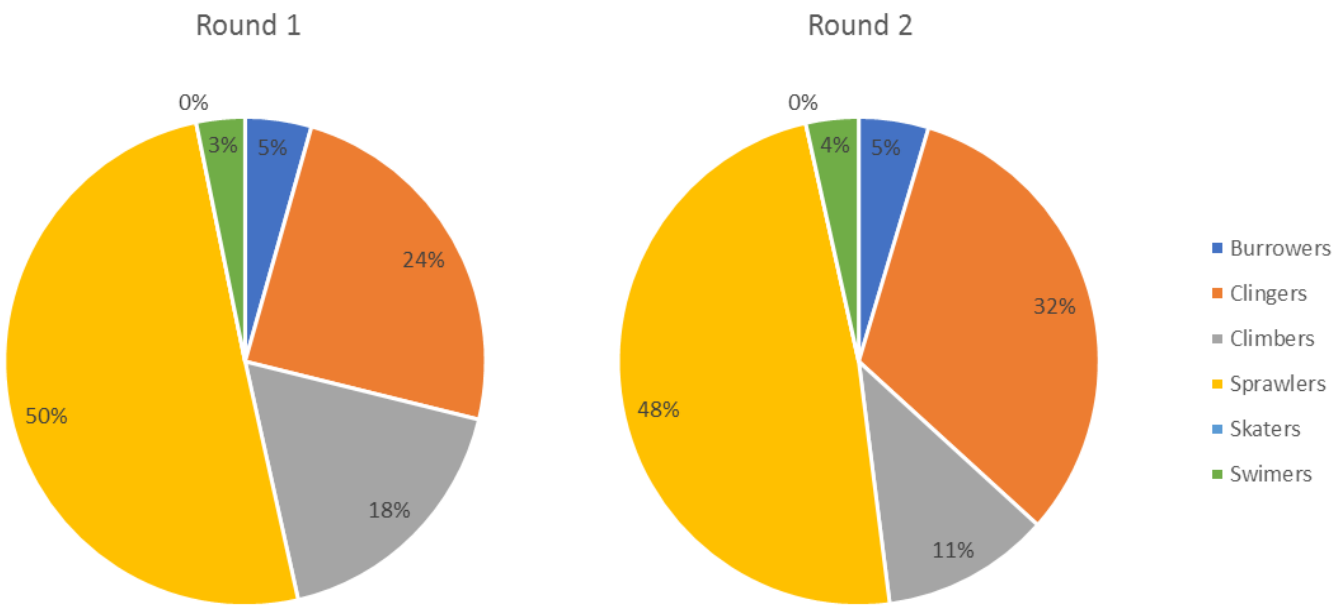
Little Catoctin Creek South Watershed Benthic Habit Groups



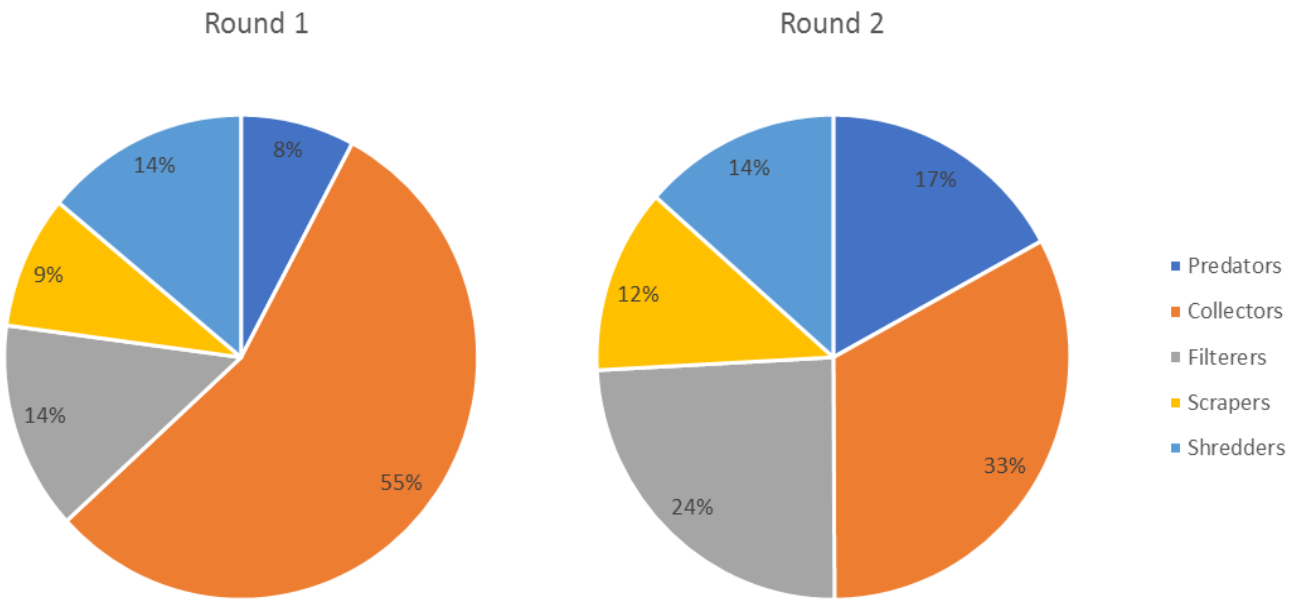
Little Pipe Creek Watershed Functional Feeding Groups



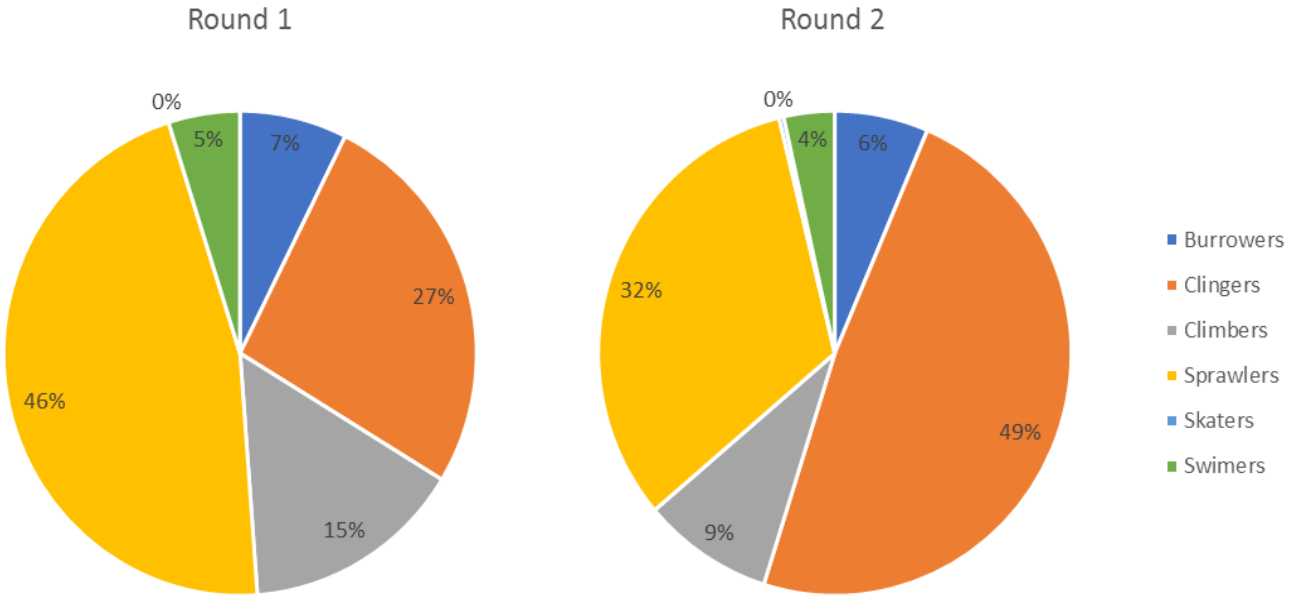
Little Pipe Creek Watershed Benthic Habit Groups



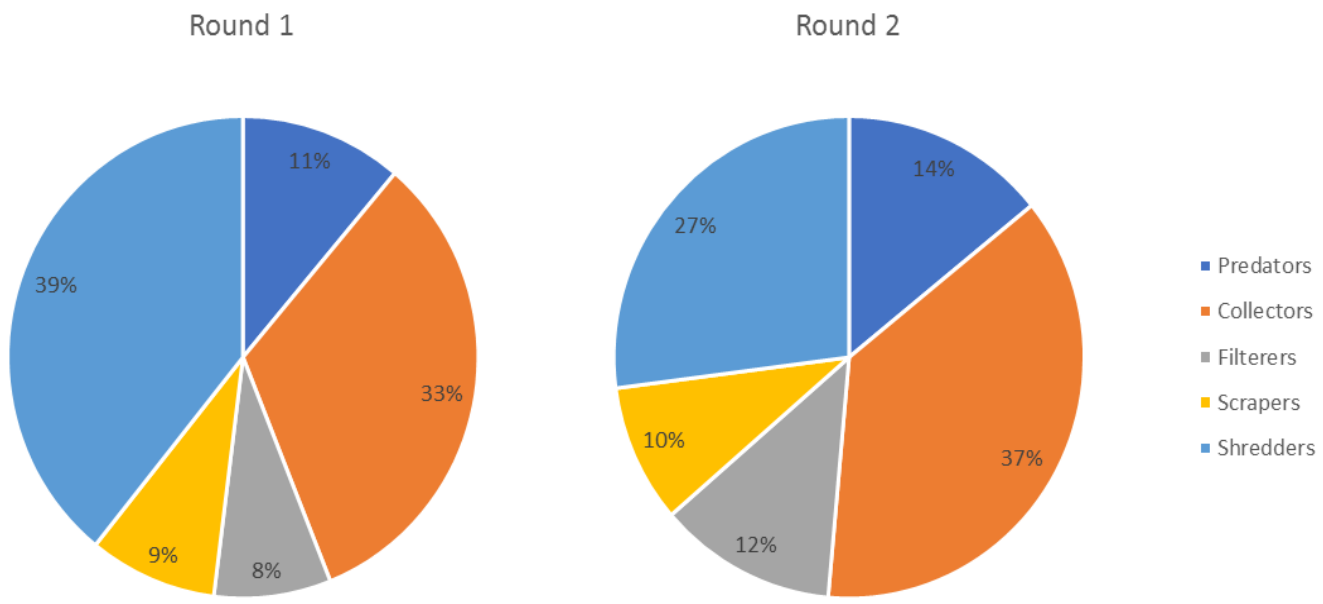
Lower Bush Creek Watershed Functional Feeding Groups



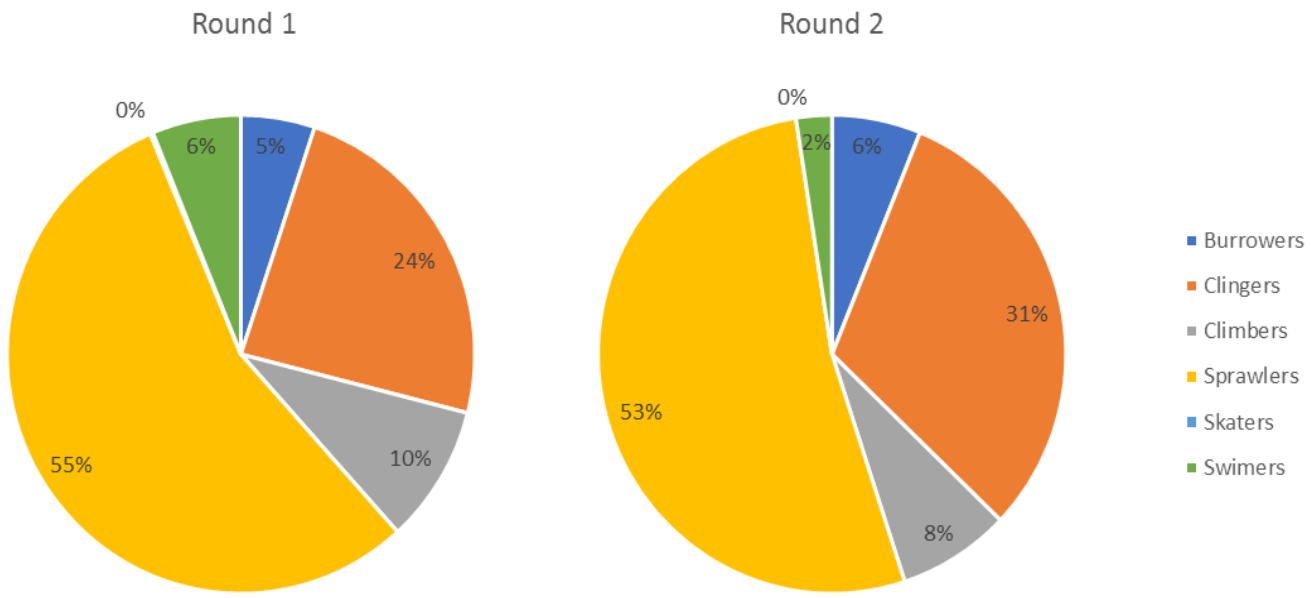
Lower Bush Creek Watershed Benthic Habit Groups



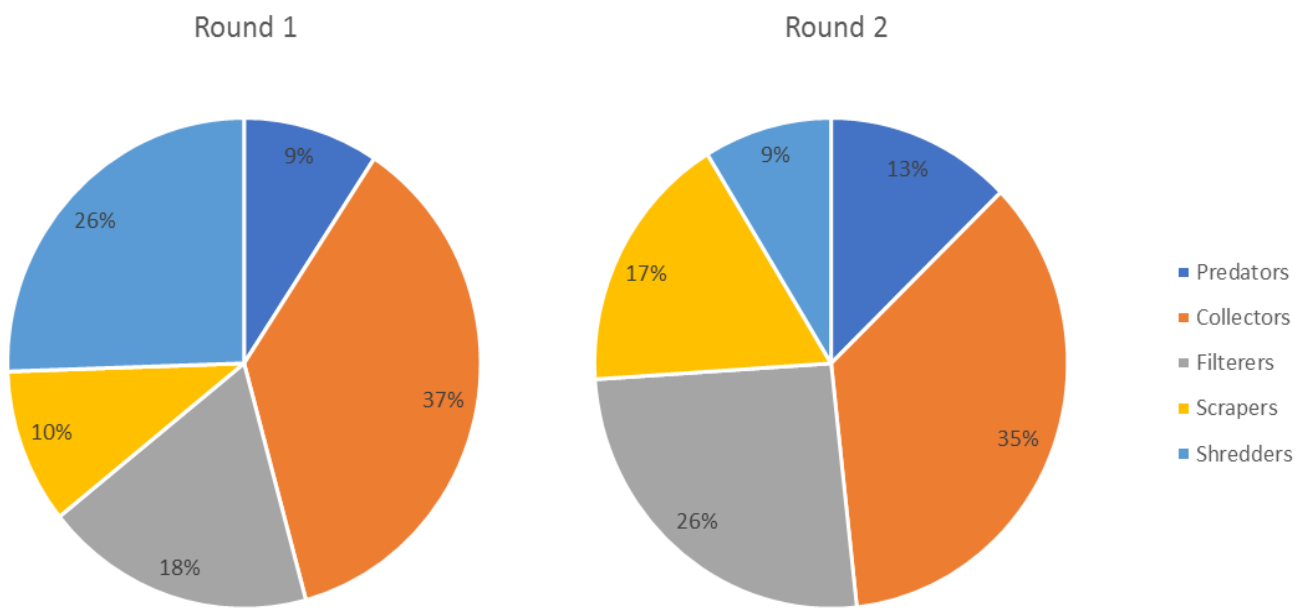
Lower Linganore Creek Watershed Functional Feeding Groups



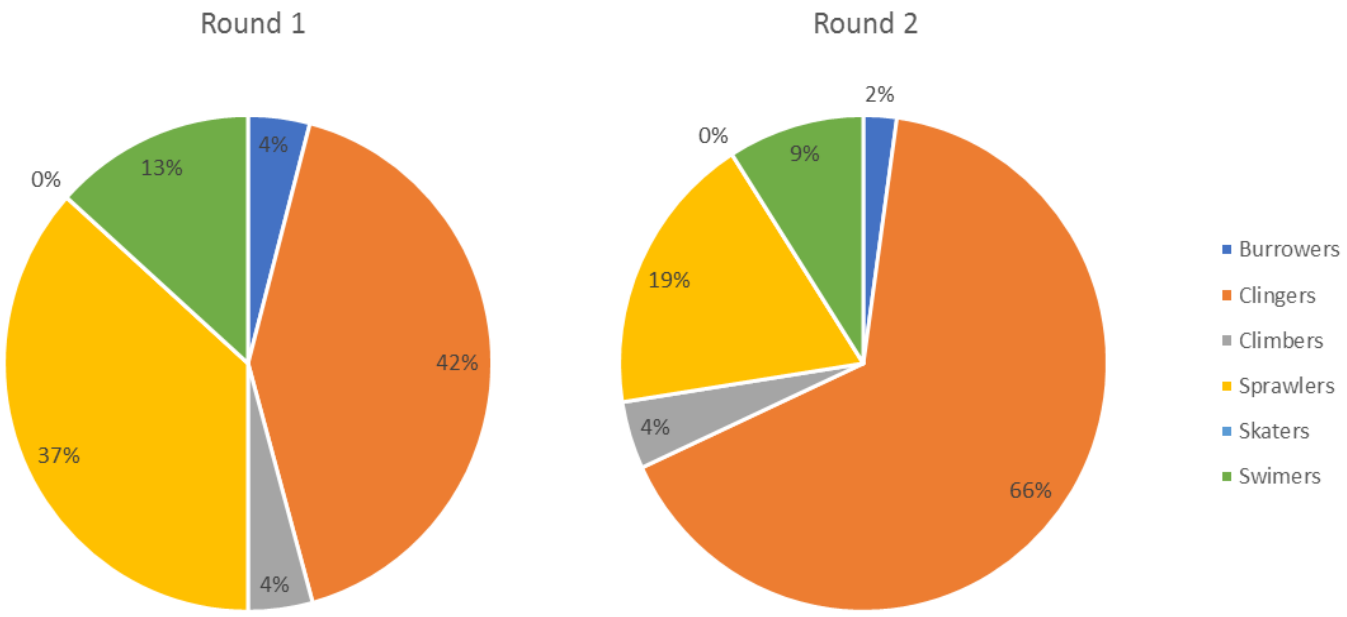
Lower Linganore Creek Watershed Benthic Habit Groups



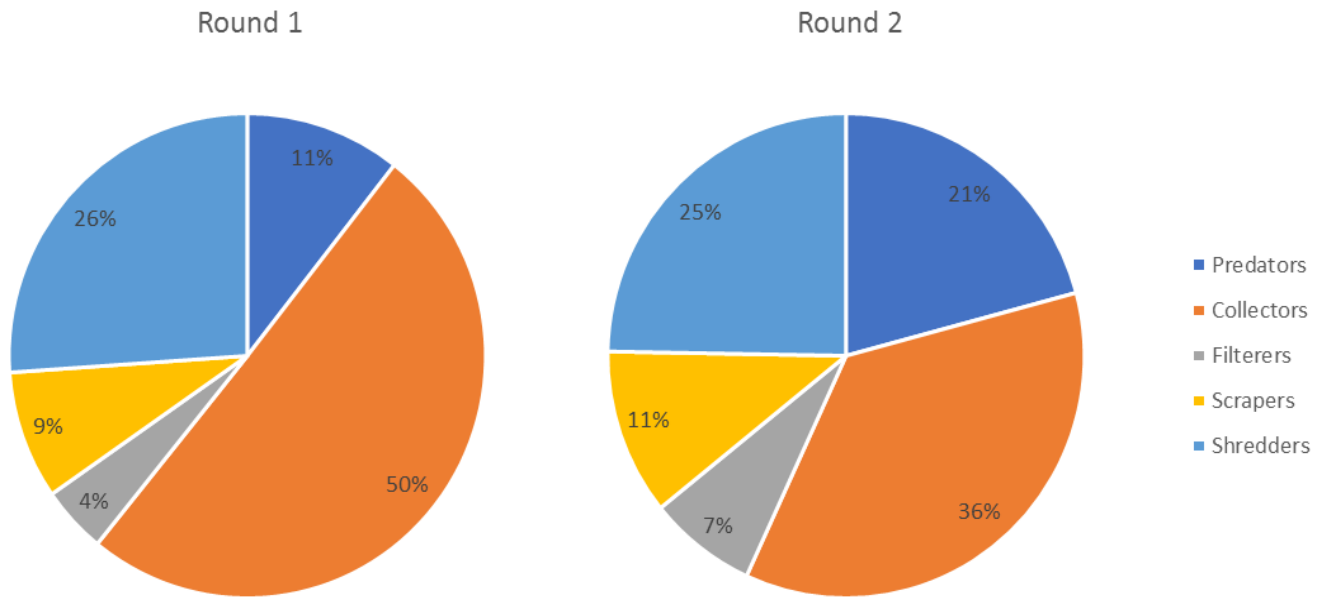
Middle Creek Watershed Functional Feeding Groups



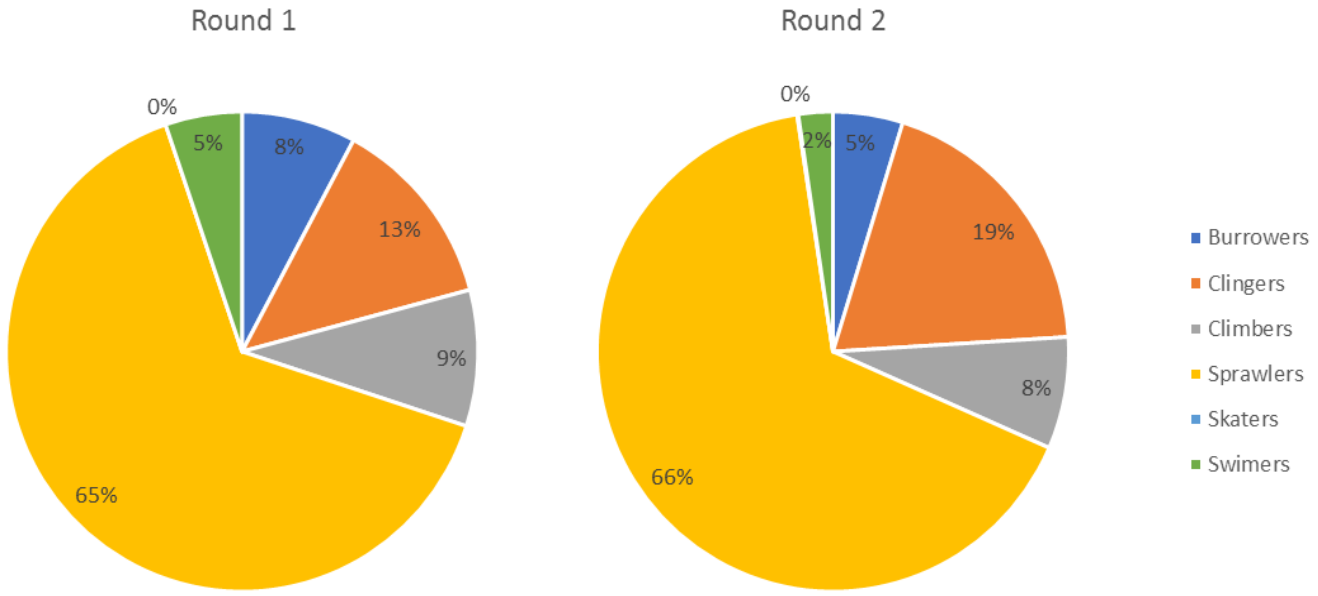
Middle Creek Watershed Benthic Habit Groups



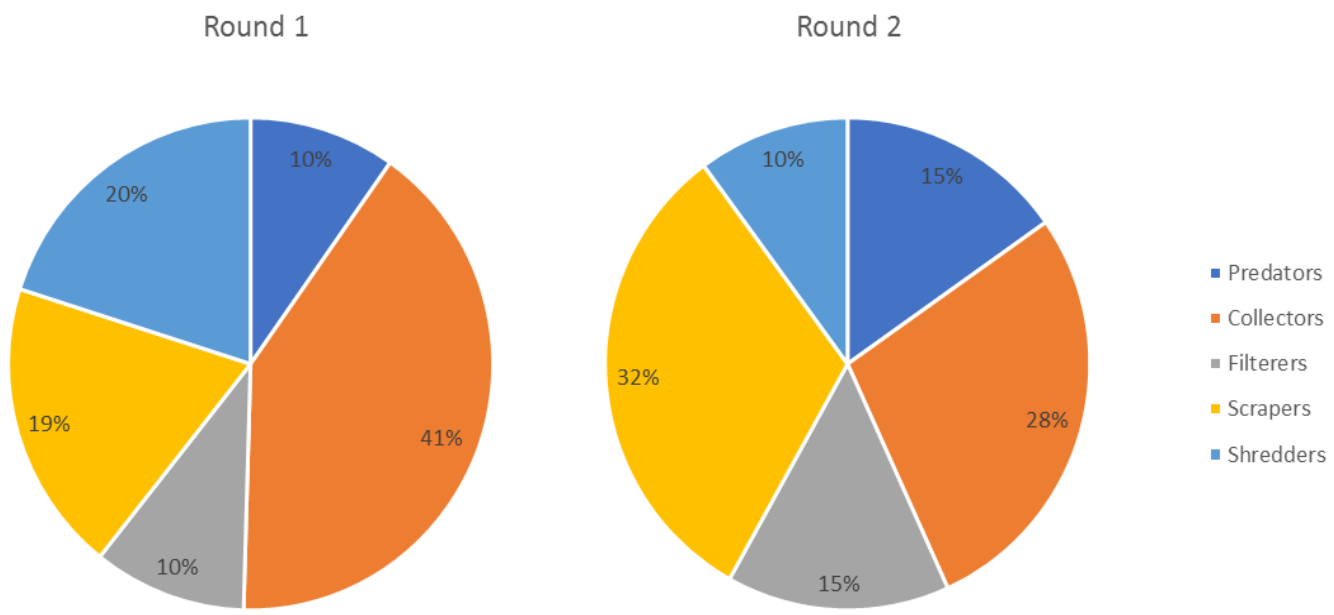
Monocacy Direct Southwest Watershed Functional Feeding Groups



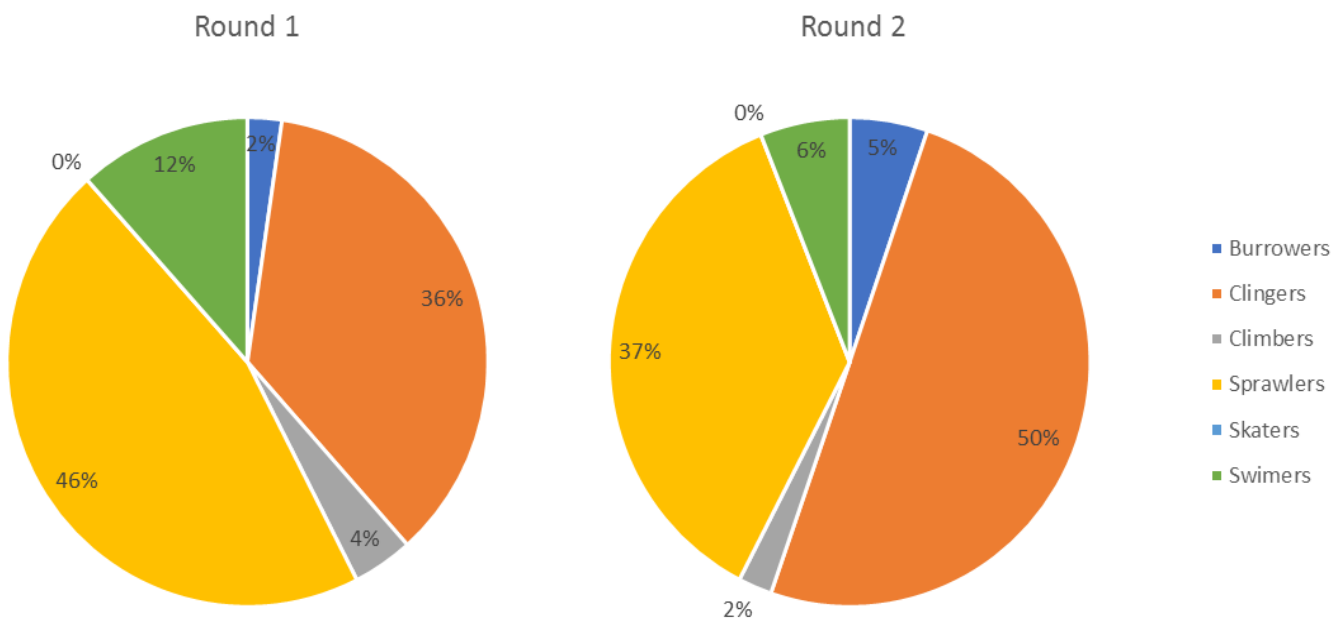
Monocacy Direct Southwest Watershed Benthic Habit Groups



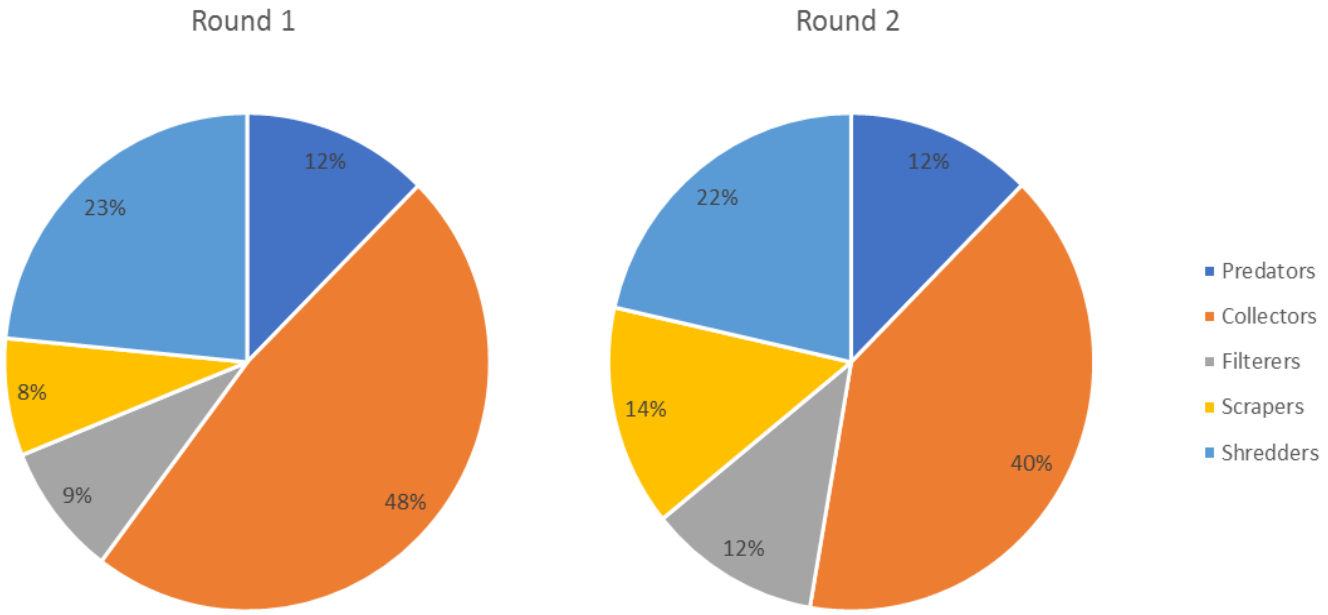
Owens Creek Watershed Functional Feeding Groups



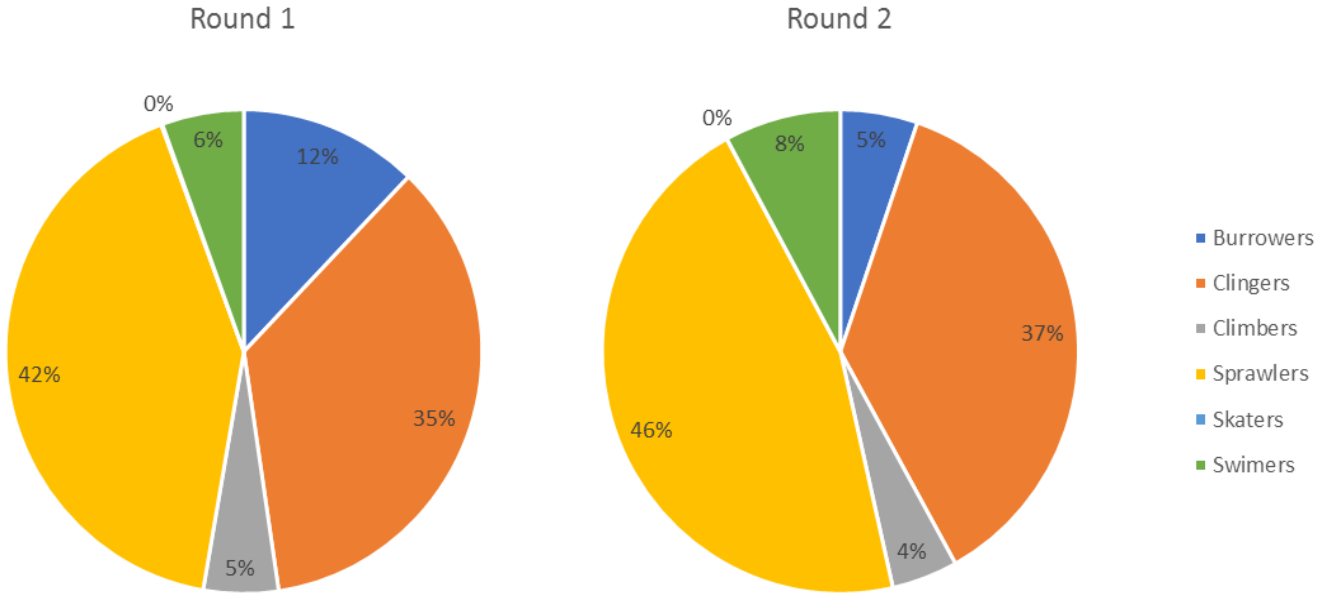
Owens Creek Watershed Benthic Habit Groups



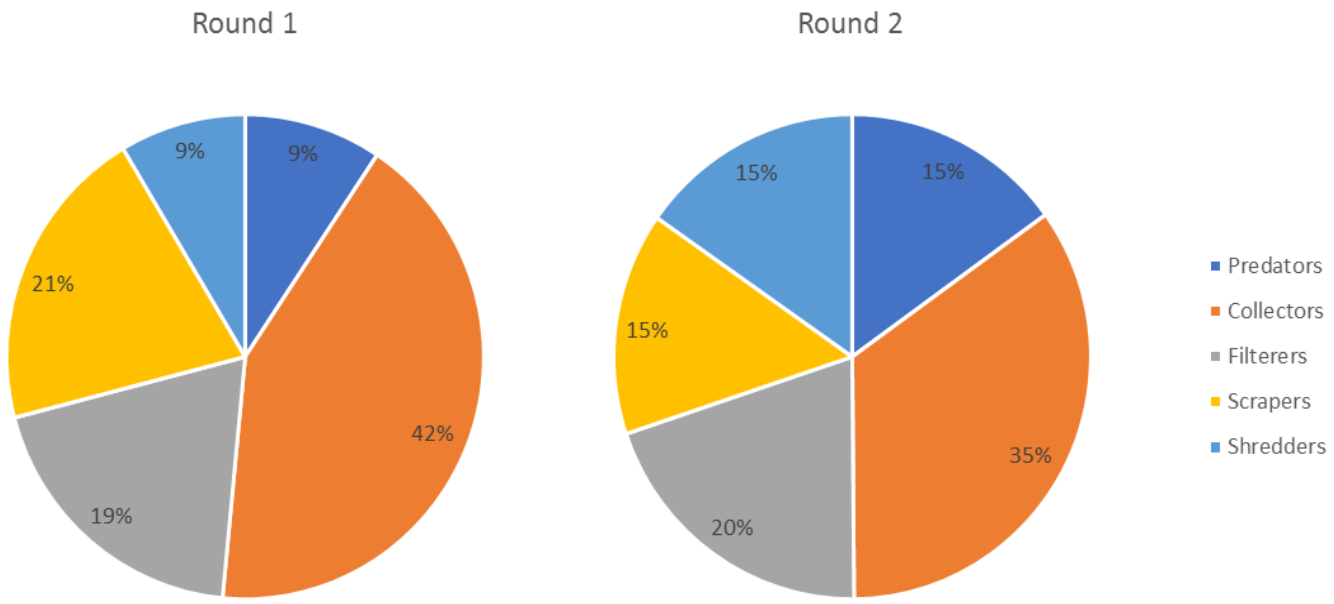
Potomac Direct Watershed Functional Feeding Groups



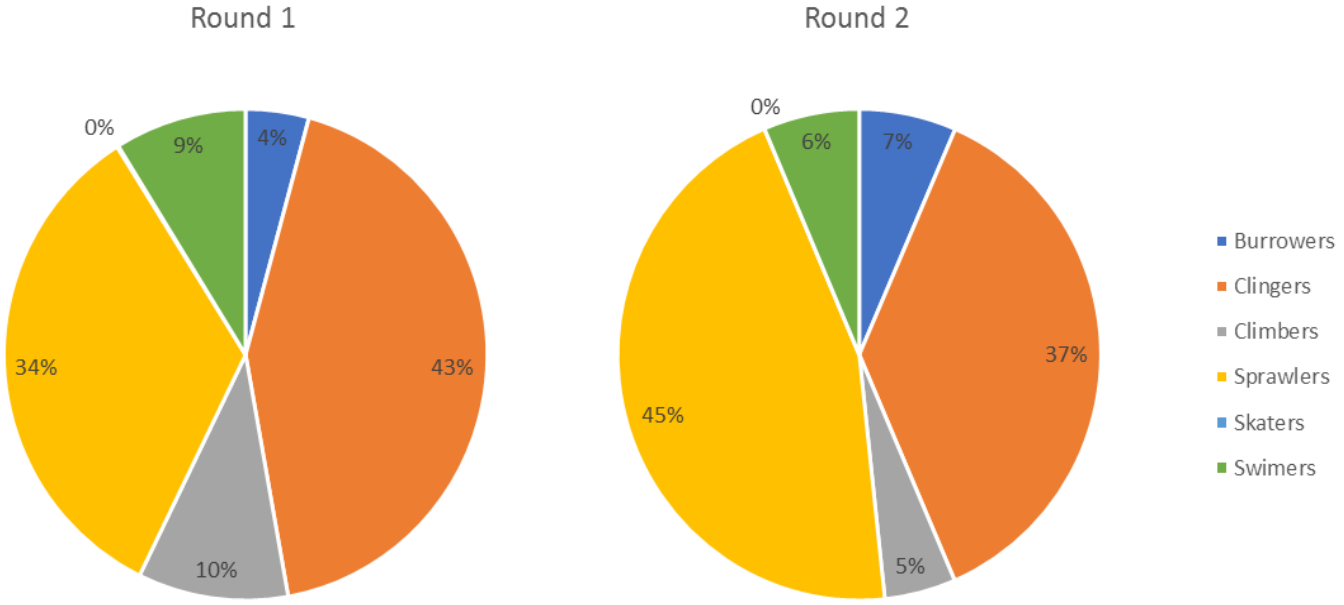
Potomac Direct Watershed Benthic Habit Groups

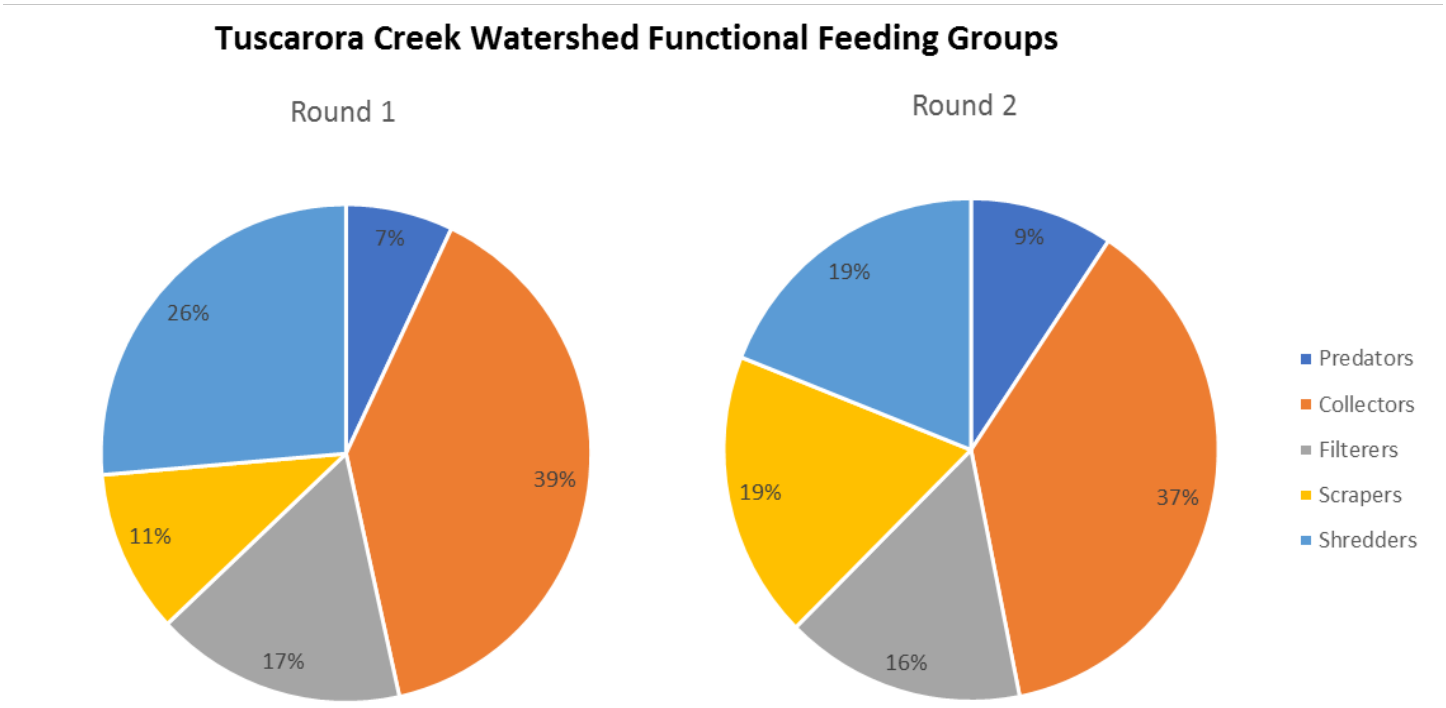


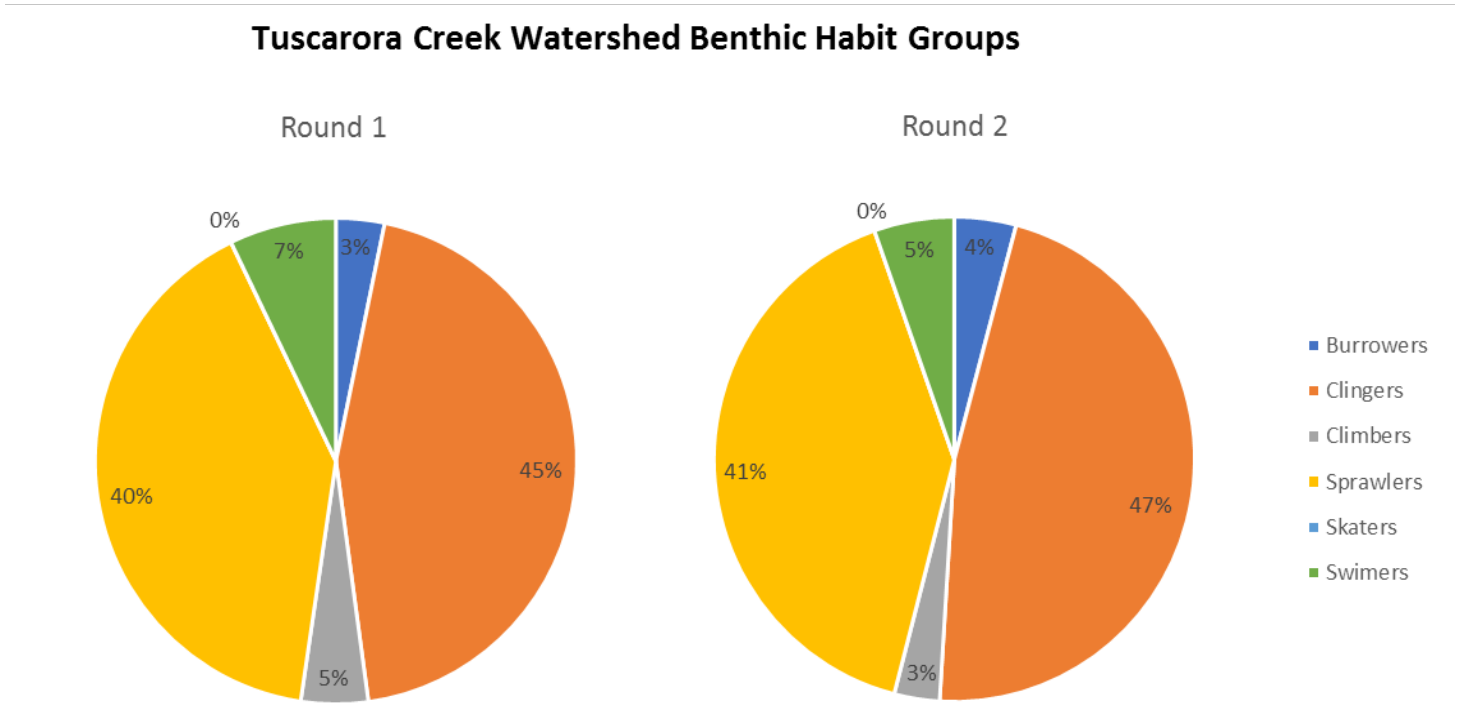
Toms Creek Watershed Functional Feeding Groups



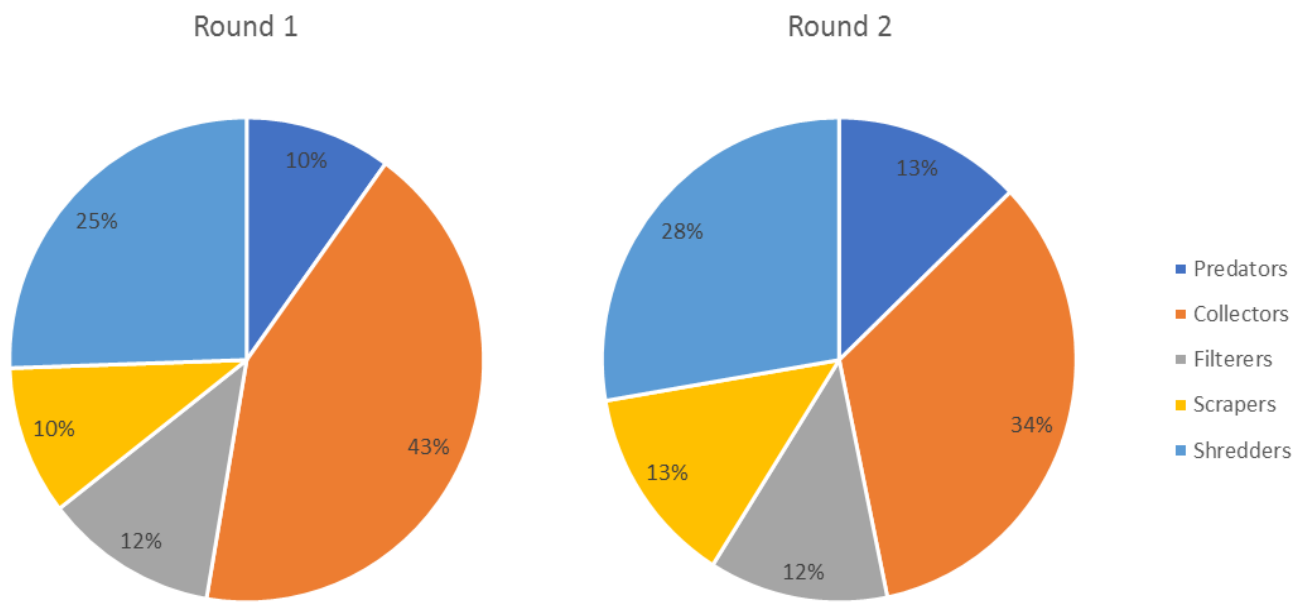
Toms Creek Watershed Benthic Habit Groups



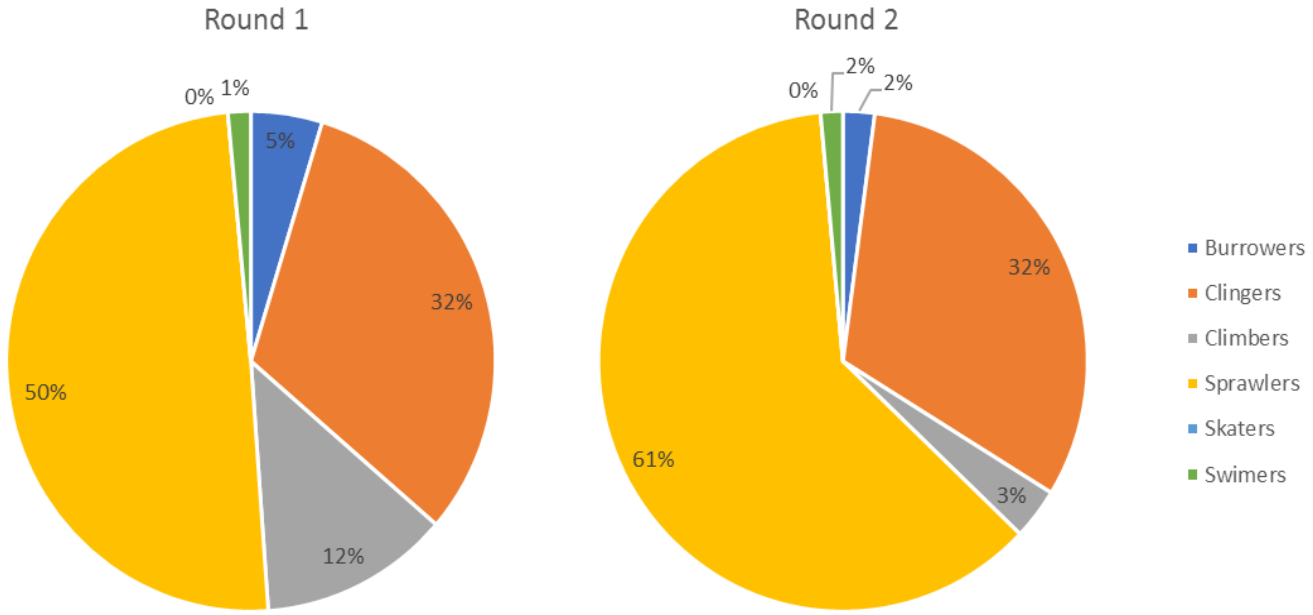

Tuscarora Creek Watershed Functional Feeding Groups
Round 1
7%
39%
17%
11%
26%
Round 2
9%
37%
16%
19%
19%
Predators
Collectors
Filterers
Scrapers
Shredders


Tuscarora Creek Watershed Benthic Habit Groups
Round 1
0%
7%
3%
45%
5%
40%
Round 2
0%
5%
4%
47%
3%
41%
Burrowers
Clingers
Climbers
Sprawlers
Skaters
Swimers

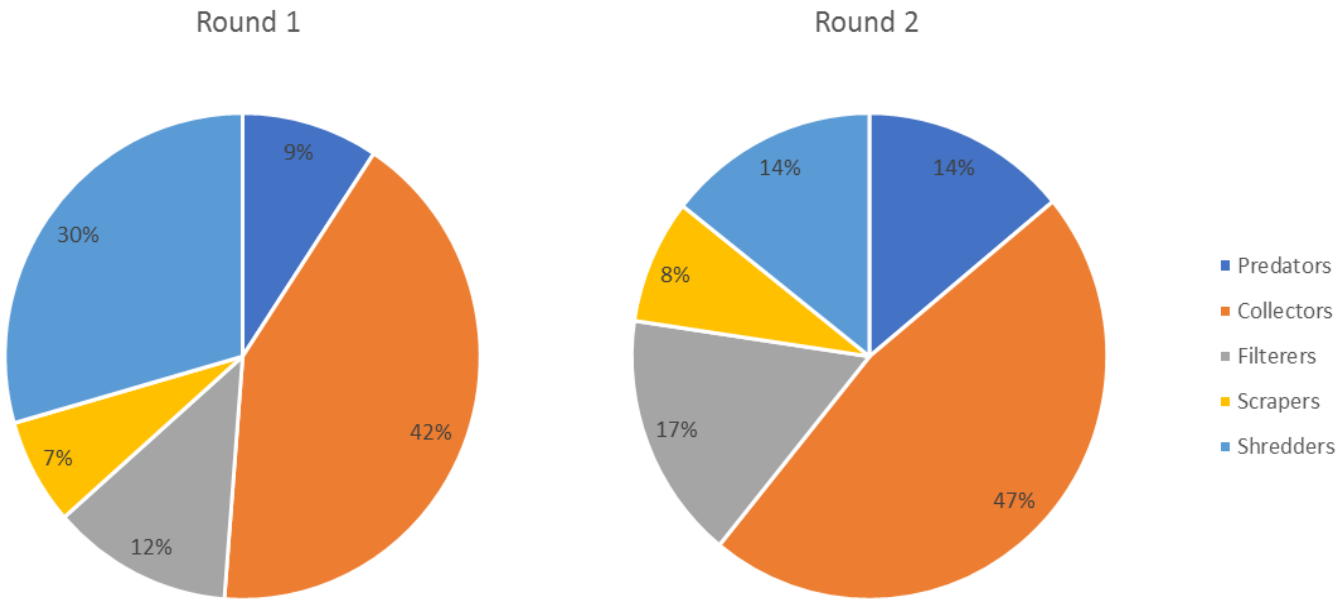
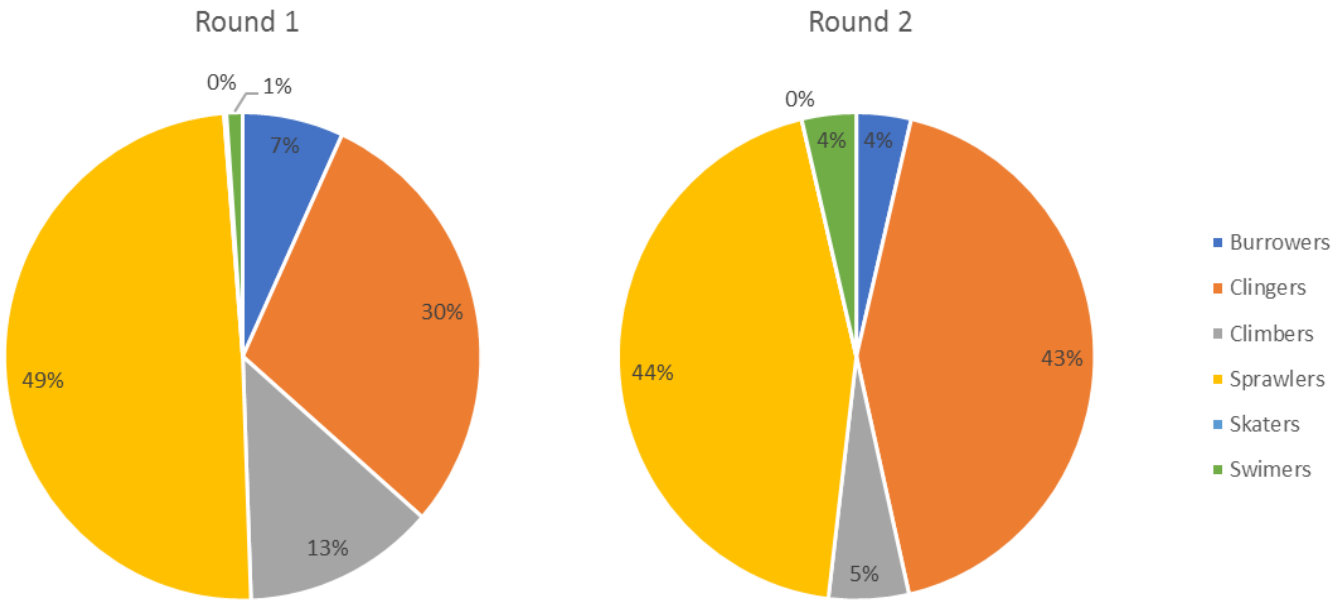
Upper Bush Creek Watershed Functional Feeding Groups



Upper Bush Creek Watershed Benthic Habit Groups



Upper Linganore Creek Watershed Functional Feeding Groups



Upper Linganore Creek Watershed Benthic Habit Groups