IMPLEMENTING PRECISION CONSERVATION IN THE SUSQUEHANNA RIVER WATERSHED

Photo by Cotterpin

TECHNICAL REPORT

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Executive Summary

An Innovative Approach to Conservation

Pennsylvania has invested billions of dollars in Chesapeake Bay restoration efforts since 1985 but has yet to meet its nitrogen and sediment goals. In a January 2016 report, *A DEP Strategy to Enhance Pennsylvania's Chesapeake Bay Restoration Effort,* the state called for a new strategy that emphasized "science-based, high-impact, low-cost projects on the ground working with partners in a focused manner."

As a pilot for an innovative approach to conservation, partners proposed to collaborate and harness newly available high-resolution GIS datasets and other technical resources for precision conservation efforts, putting the right restoration and conservation practices in the right places at the right scale while ensuring that they are working as designed. Additionally, efforts would be focused on restoration and the implementation of best management practices (BMPs). The project was designed to demonstrate improved efficiency, effectiveness, and returns on investments through better site selection prioritization while supporting the adoption of innovative GIS analyses to broaden adoption across multiple regions.

Included in this technical report is first a review of the in-stream monitoring that took place to verify mapping as a valid way to prioritize parcels for water quality benefits, and second, applications of targeted BMP siting on agricultural lands that will lead to more cost-effective and efficient restoration work in the Susquehanna River Watershed.

To validate GIS mapping as a method to prioritize parcels for forest buffer restoration, in-stream factors at several sites were measured and compared against five landscape variables. By comparing the five landscape variables to in-stream measurements for fish populations, macroinvertebrate counts, sediment levels, water chemistry, and ecosystem function, we will be testing the hypothesis that states: landscape variables can be reliably used to effectively predict water quality of adjacent streams.

All three selected agriculturally degraded stream segments, representing nine monitoring sites, are located in Centre County, PA. To compare these agriculturally degraded locations to non-degraded systems, Susquehanna and Bloomsburg Universities sampled four additional monitoring sites on forested reference stream reaches in Union and Centre Counties.

Monitoring data were collected between spring 2017 and summer 2019.

Major findings of the landscape analysis include:

1. Nitrogen and phosphorus in streams not only directly pollute water for humans and other living creatures, but also provide nutrients for a number of undesirable consequences including algal blooms. This study found strong and highly significant evidence for reduction of nitrogen and phosphorus by intact upstream riparian forest buffers.
2. Based on this ecological explanation and statistical evidence, a general strategy for management can be implemented to improve water quality. Sites with restoration opportunity areas should be given high priority for forest buffer installation. The data support prioritizing sites with smaller forest buffer planting areas as compared to sites with larger forest buffer planting areas when unfiltered drainage area is held constant.

This is expected as these sites correspond to higher nitrogen in water and lower cost relative to conservation and water quality returns.

3. Chemical composition of sediment is less affected than that of water by short term phenomena like storms. Therefore, sediment analyses provide a more robust proxy of longer term environmental characteristics. The study shows that C:N ratios are stable across three years of sampling at stream sites that have received no modifications. There is significant evidence that larger upstream unfiltered drainage areas correlate to lower C:N ratio in stream sediment. This means that for the same amount of carbon, a larger upstream unfiltered drainage results in higher amount of nitrogen than does a smaller upstream unfiltered drainage. This indicates such sites should be high conservation priorities, since a restoration solution has higher impact on water quality and downstream environment if improvements are made on such sites with higher C:N.
4. Precision conservation landscape variables have the potential to act as a proxy for the community composition of macroinvertebrates. Collectively, these variables explained 42% of the variance in macroinvertebrate communities, although results were not statistically significant. However, among fish communities, the landscape variables show little predictive capability for community composition (7% variance explained).

As a part of the monitoring project, the scientists also took measurements to understand how in-stream and riparian best management practices affect in-stream measurements. In this section, a case study is presented for a single restoration project on Elk Creek, in eastern Centre County, Pennsylvania. The results, discussion, and conclusions discuss pre- and post-restoration data findings.

Restoration practices installed at the Brown site on Elk Creek include a total of 35 in-stream habitat and streambank stabilization structures, 1,500 linear feet of streambank exclusion fencing, an in-stream watering access for livestock, and a 1.5-acre forest riparian buffer planting.

Major findings of the pre- and post- restoration study on Elk Creek include:

1. When looking at macroinvertebrate and fish communities from Elk Creek pre- and post-restoration, there is a clear visual separation between communities sampled prior to restoration taking place and samples taken after restoration, however these results are not significant with such a small sample size.
2. At restoration sites and sites downstream, sediment generally became coarser in the years following in-stream restoration. Coarser stream bottom sediments are better suited to macroinvertebrate and fish habitat than silty sediments that can smother insect and fish eggs. There is a weak trend suggesting the larger the size of the area being restored, the larger the potential for grain size change after stream restoration. However, because of the variability of the measurements at a limited number of sites, this is not a statistically significant trend.
3. There is very little evidence that restoration at this site is having an impact on water chemistry or ecosystem function in the short time period since construction. We did observe a small but statistically significant effect of restoration on total phosphorus. However, the difference in concentrations were unlikely high enough to be biologically important in the long-term and may have been a lingering artifact of the disturbance caused by construction. Gross primary productivity and respiration were higher during the post-construction period, which may have been driven by runoff generated from rain events in 2018. The magnitude of this difference was greatest at the upstream site, producing a significant site x restoration interaction. This difference is best explained by a lack of canopy at the upstream site, which may have allowed for a higher photosynthetic response to 2018 runoff because of greater light availability.

There are some important caveats in this study. The site-level landscape analysis includes a total of 12 data points. With such a small sample size, it is hard to detect a statistically significant signal. Therefore, the signals detected with very small *P*-values represent strong evidence of true signals. On the contrary, trends that are not significant are common. Such trends might have been significant with a larger sample size. Additionally, sites used in the analysis on each stream segment were autocorrelated with one another because of their position downstream of one another. Ideally, sites would have been on different stream segments and the landscape factors would have varied widely.

Using the data to prioritize and implement restoration

The basis of the forest buffer prioritization was a verbal exercise at a workshop in January 2017 where it was identified that partners wanted to work in "places where water quality was degraded by agriculture, but trout populations were nearby and restoration was perceived as attainable." The Conservancy team took that verbal statement and worked with partners over several workshops and webinars to relate the verbal activity back to spatial datasets that would provide a roadmap to key locations for restoration to improve water quality.

The goal of the resulting forest buffer prioritization was to identify at the parcel scale where runoff from agriculture, impervious surfaces, and turf is entering waterways, unfiltered from the landscape upstream, or along agriculturally impaired stream segments. These land use categories were used to represent where high loads of sediment and nutrients are likely originating on the landscape. Agriculturally impaired streams were used to identify where pollutants entering the stream unfiltered are causing degradation of in-stream communities and water quality. By identifying parcels upstream of these impairments, prioritization can inform where restoration should be completed to achieve the greatest water quality improvements.

From the precision conservation analysis through August 2019, 8 high-priority restoration projects were implemented across the four-county study area. These projects resulted in the installation of 70.35 acres of forest riparian buffer, filtering 1,390 total upslope acres, 895 of which contained agriculture, impervious surface, and turf land covers. The average treatment area to forest buffer ratio is 4 upslope acres treated to 1 acre of forest buffer installed. These 11 high-priority projects treat almost 20 upslope acres for every single acre of buffer.

Project Partners

Chesapeake Conservancy, Susquehanna University, Bloomsburg University, the Chesapeake Bay Foundation, and the Pennsylvania Department of Conservation and Natural Resources.

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1. Research Study Overview

To validate GIS mapping as a method to prioritize parcels for forest buffer restoration, in-stream factors at several sites were measured and compared against five landscape variables. By comparing the five landscape variables to in-stream measurements for fish populations, macroinvertebrate counts, sediment levels, water chemistry, and ecosystem function, we will be testing the hypothesis that states: landscape variables can be reliably used to effectively predict water quality of adjacent streams.

2. Study Site Selection

Monitoring locations for the precision conservation project were selected based on four major factors: 1) priority level in the prioritization analysis, 2) proximity to agriculturally degraded streams, 3) planned restoration projects being implemented in 2017 (so stream conditions could be assessed before and after implementation) and 4) landowner willingness to allow access to the stream for monitoring purposes.

All three selected agriculturally degraded stream segments, representing nine monitoring sites, are located in Centre County, PA. To compare these agriculturally degraded locations to non-degraded systems, Susquehanna and Bloomsburg Universities sampled four additional monitoring sites on forested reference stream reaches in Union and Centre Counties. An overview of the in-stream monitoring locations by HUC 12 watershed is shown in Figure 1. Each site reach is described in further detail in the following sections.

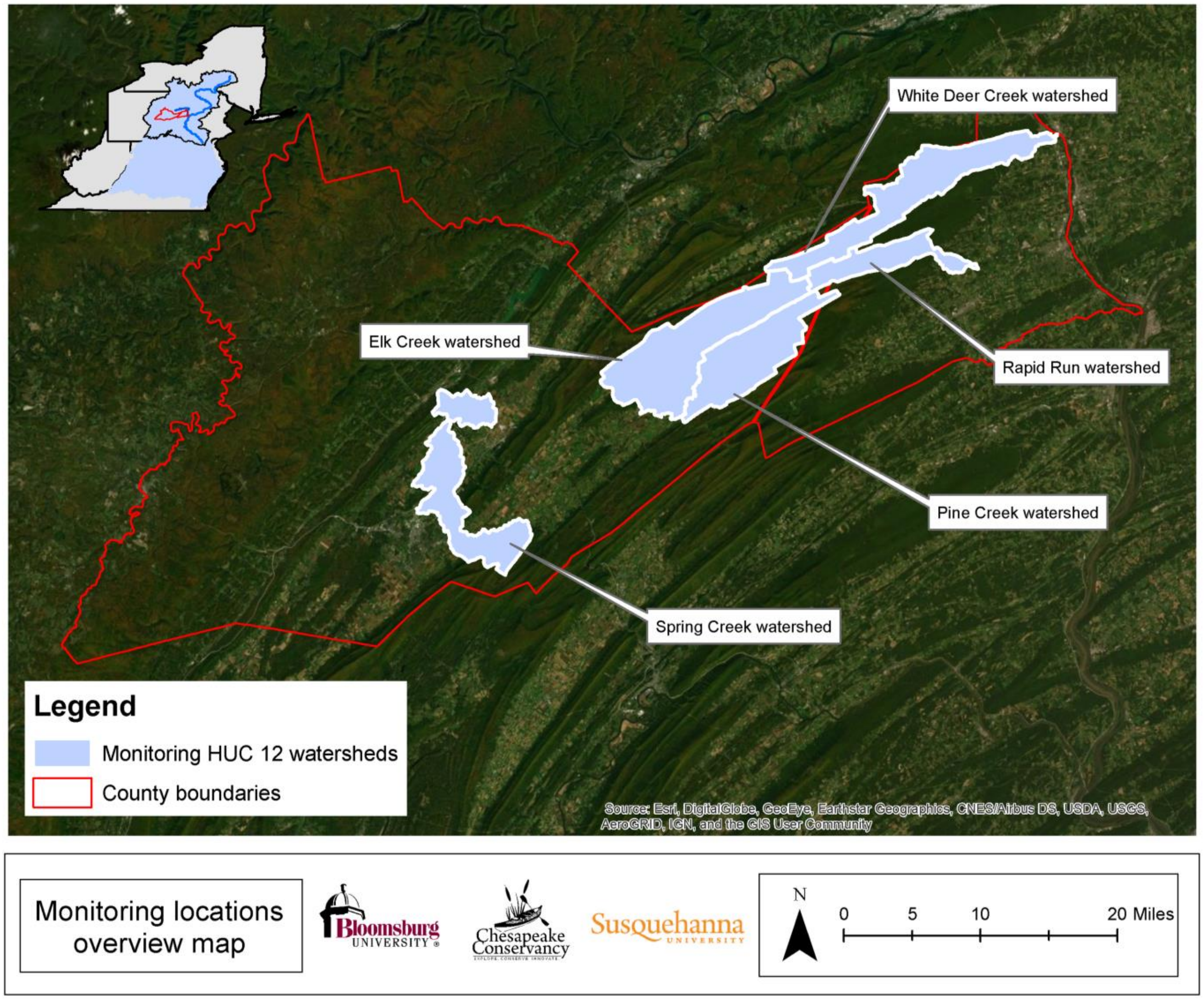

Figure 1. Overview of the in-stream monitoring locations by HUC 12 watershed. Monitoring locations were located across Centre and Union counties within the Susquehanna River Watershed in central Pennsylvania and ranged from forested sites to agriculturally impacted sites.

2.1 Agriculturally Impacted Sites

2.1.1 Elk Creek Watershed Sites

Within Elk Creek there are four agriculturally impacted monitoring sites (Figure 2). The Miller monitoring site is the farthest upstream, approximately five miles from the headwaters of Elk Creek. Land use upstream of the Miller monitoring site includes active crop production, a mix of excluded and unexcluded livestock grazing, and forest. The Brown monitoring site is half a mile downstream of the Miller site. Land use within the Brown monitoring site's watershed includes unexcluded horse pasture grazing and crop production on the North side of Elk Creek, and forest on the South. The Sheats monitoring site is the next site, approximately one half mile downstream of the Brown site. Land use draining into the site includes crop production on the North side of Elk Creek, and fallow fields on the South side. The most downstream monitoring point is the Neff site, which is forested on the North side with crop production on the South side. A full description of the land use draining to each property can be found in Section 6 of the report.

2.1.2 Pine Creek Watershed Sites

The Pine Creek Watershed contains two agriculturally impacted monitoring sites: Bzdil upstream and Bzdil downstream (Figure 3). The tributary to Pine Creek restoration monitoring sites are located within two miles of the headwaters of an Un-named Tributary. The land use of the Bzdil upstream monitoring site includes a mix of forest land and intensive livestock grazing and crop production, often with livestock unexcluded from the stream. Between the upstream and downstream Bzdil sites, land drains from active crop production and fallow fields. A full description of the land use draining to each property can be found in Section 6 of the report.

2.1.3 Spring Creek Watershed Sites

Within Spring Creek are three agriculturally impacted monitoring sites (Figure 4). The Spring Creek restoration monitoring sites are located within one mile of the headwaters of Spring Creek. The Dreibelbis monitoring point is the most upstream monitoring location. The land use upstream of this site is dominated by crop production, with drainage flowing through intact forest buffers. The Middle Dreibelbis monitoring site includes unexcluded livestock grazing of beef cattle throughout 1,500 linear feet of stream. The Mountain View Country Club monitoring site is located approximately 1 mile downstream of the Middle Dreibelbis monitoring site and includes drainage from an additional farm with unexcluded livestock grazing, a large residential development, and part of a golf course with intact forest buffers. A full description of the land use draining to each property can be found in Section 6 of the report. Relative locations of individual monitoring sites within the same stream segment for Elk, Pine, and Spring Creek are depicted in Figure 5.

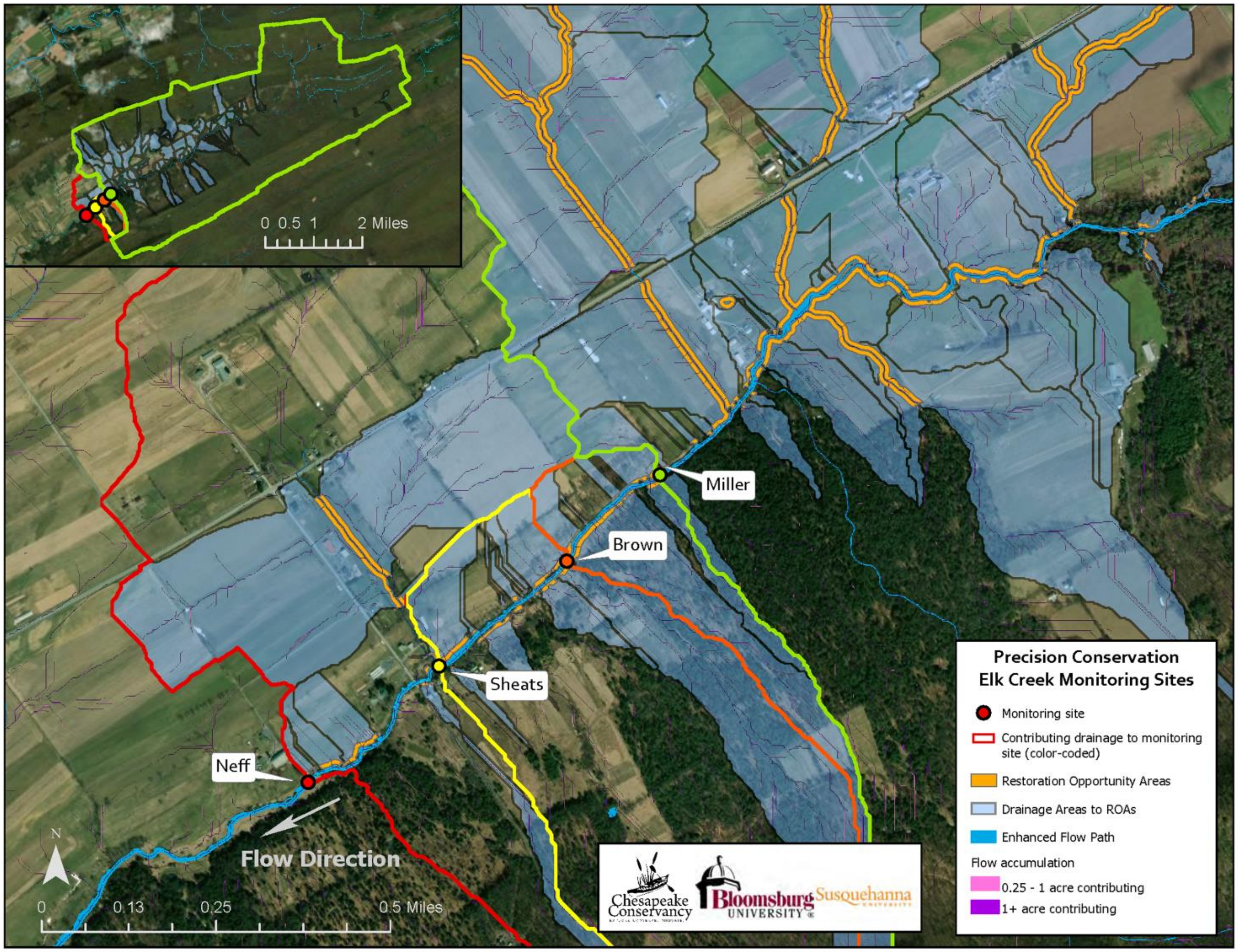

Figure 2. Agriculturally impacted monitoring sites within the Elk Creek HUC 12 Watershed in eastern Centre County, Pennsylvania. The Miller monitoring site is the farthest upstream, approximately 5 miles from the headwaters of Elk Creek. Land use upstream of the Miller monitoring site includes crop production, a mix of excluded and unexcluded livestock grazing, and forest. Monitoring locations start upstream at the Miller location, travel through the Brown and Sheats properties and then farther downstream through the Neff property.

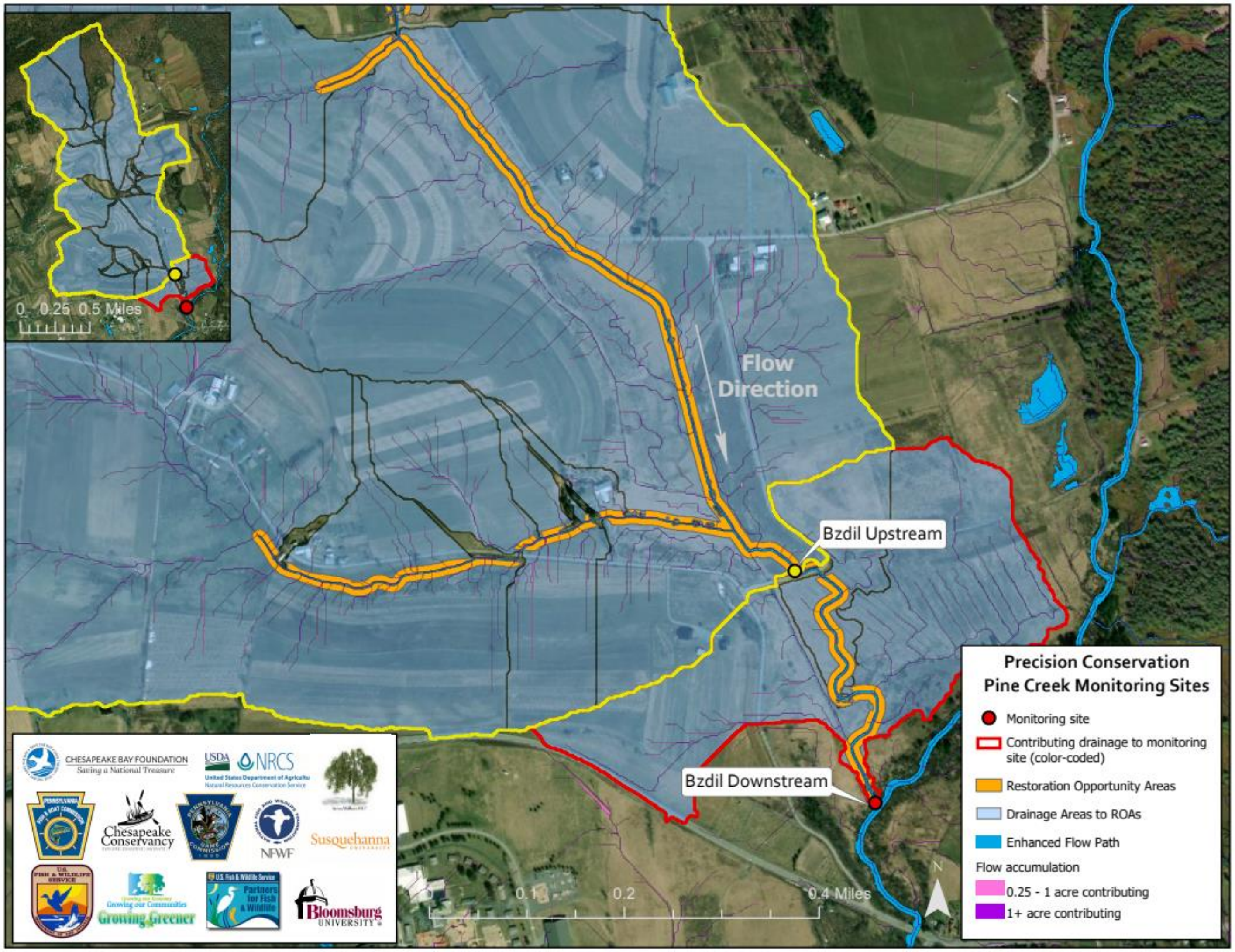

Figure 3. Agriculturally impacted monitoring sites within the Pine Creek HUC 12 Watershed in eastern Centre County, Pennsylvania. The tributary to Pine Creek monitoring sites are located within 2 miles of the headwaters of the unnamed tributary. Upstream of the Bzdil upstream monitoring site is a mix of forest land with intensive livestock grazing and crop production, often with livestock unexcluded from the stream.

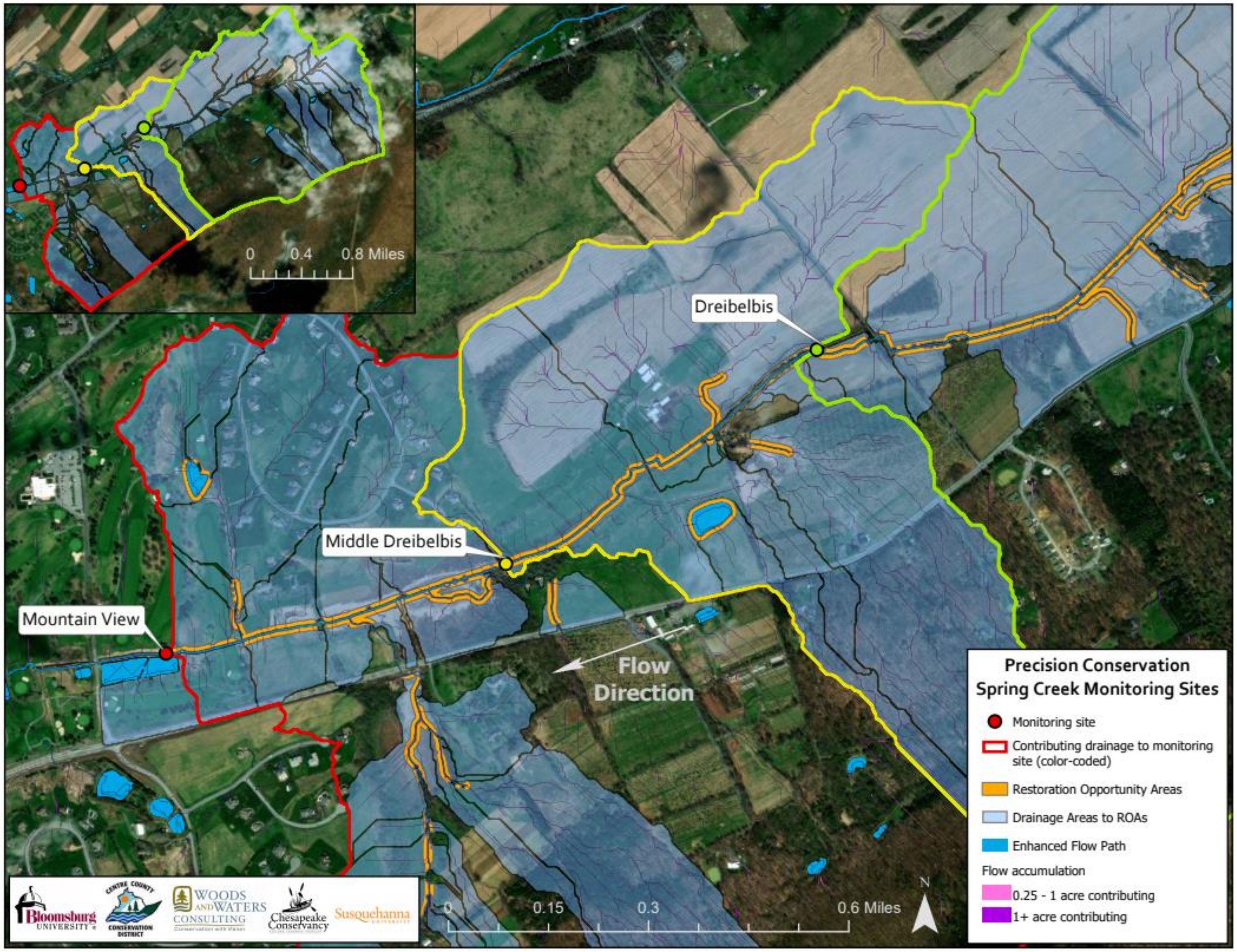

Figure 4. Agriculturally impacted monitoring sites within the Spring Creek HUC 12 Watershed in western Centre County, Pennsylvania. The Spring Creek monitoring sites are located within 1 mile of the headwaters of Spring Creek. The Dreibelbis monitoring point is the most upstream monitoring location. The upstream drainage of this site is dominated by crop production draining through intact forest buffers.

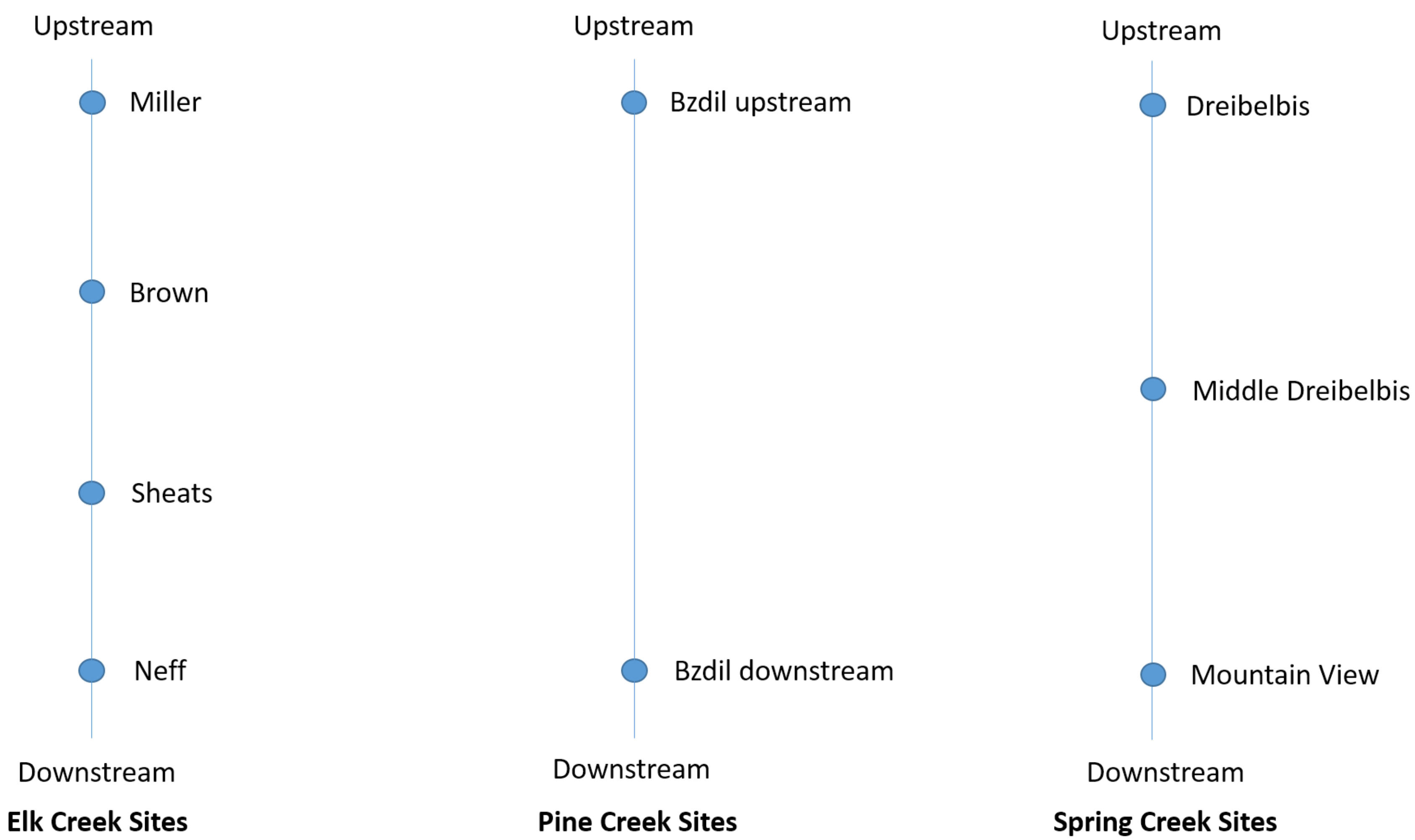

Figure 5. Schematic of upstream-to-downstream orientation for each section of stream with multiple monitoring points (agriculturally impacted sites).

2.2 Forested Reference Sites

2.2.1 Pine Creek Watershed Sites

2.2.1.1 Pine Creek Site

Within the Pine Creek Watershed are two forested reference monitoring sites (Figure 6). The Pine Creek site is located in the main stem of Pine Creek, approximately 1 mile from its headwaters. The land upstream of this site is approximately 80% forested, with some crop production and residential land. A full description of the land use draining to each property can be found in Section 6 of the report.

2.2.1.2 Voneida Run Site

The second forested reference monitoring site is located on Voneida Run, which flows into Pine Creek downstream of the Pine Creek forested reference site (Figure 6). The land use upstream of this site is mostly forested, with a small amount of low intensity crop production. Portions of the forested land were recently selectively logged for timber within the past year. A full description of the land use draining to each property can be found in Section 6 of the report.

2.2.2 Buffalo Creek Watershed Site

The Buffalo Creek Watershed contains the third forested reference monitoring site (Figure 7). This site is located on Yankee Run, a headwater tributary of Buffalo Creek. This forested reference site is located just upstream of Yankee Run’s confluence to Rapid Run. The land use upstream of this site is entirely forested with a mix of deciduous and coniferous trees. An infrequently traveled gravel road runs along this site approximately 125 meters from the stream. A full description of the land use draining to each property can be found in Section 6 of the report.

2.2.3 White Deer Creek Watershed Site

The White Deer Creek Watershed contains the final forested reference monitoring site (Figure 8). This site, on an Un-named Tributary, is located just upstream from the confluence of the tributary and White Deer Creek. The land use upstream of this site is entirely forested and its upstream drainage area contains a mix of deciduous and coniferous forestland. A gravel road runs along this site 75 meters from the stream. A full description of the land use draining to each property can be found in Section 6 of the report.

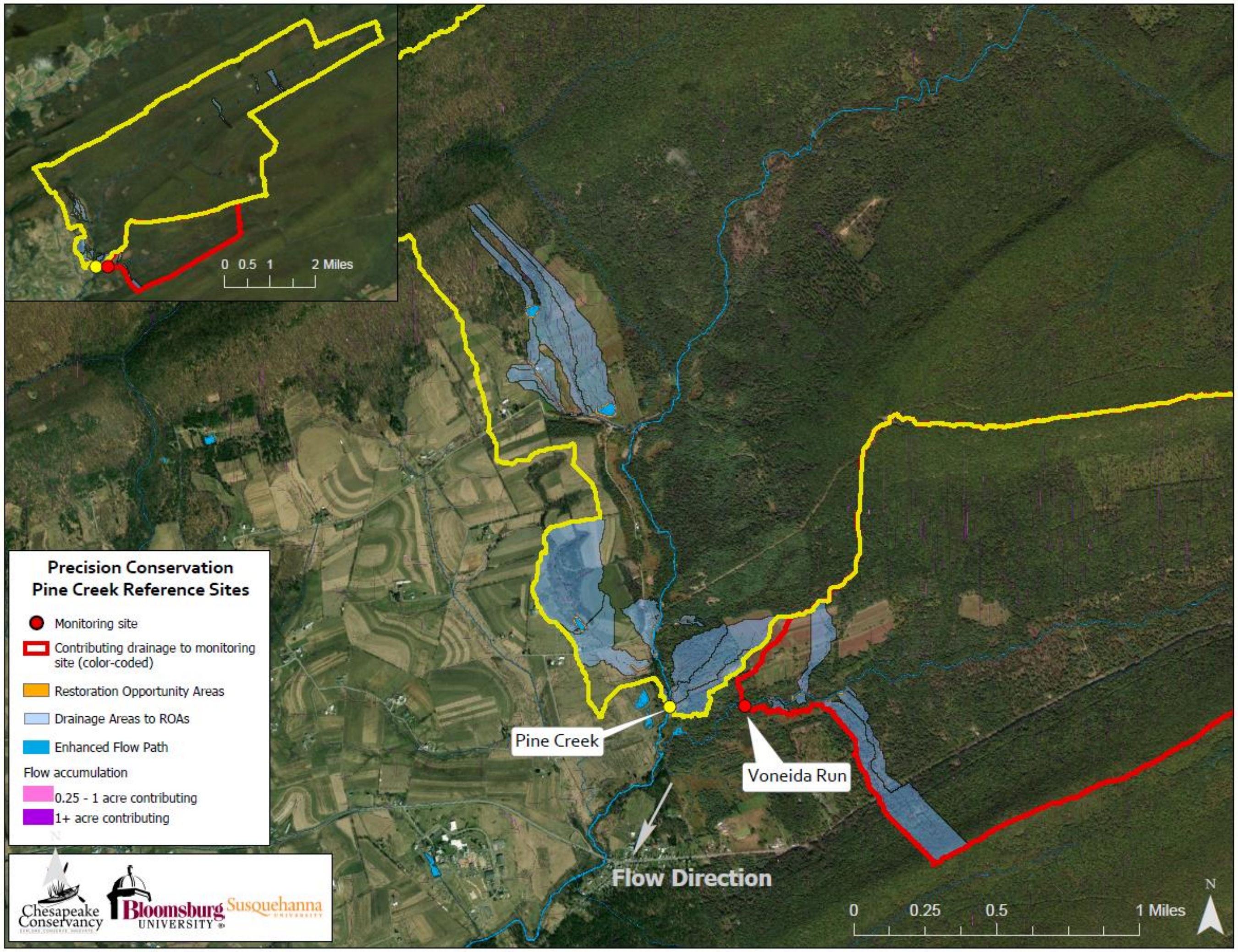

Figure 6. Forested reference monitoring sites in the Pine Creek HUC 12 Watershed in eastern Centre County, Pennsylvania. The Pine Creek monitoring site is located approximately 1 mile from the headwaters of Pine Creek and its drainage area is 80% forested with 20% mixed residential and agriculture. The Voneida Run monitoring site is located approximately 1 mile from the headwaters of Voneida Run and its drainage area is almost all forested with a small section of crop production.

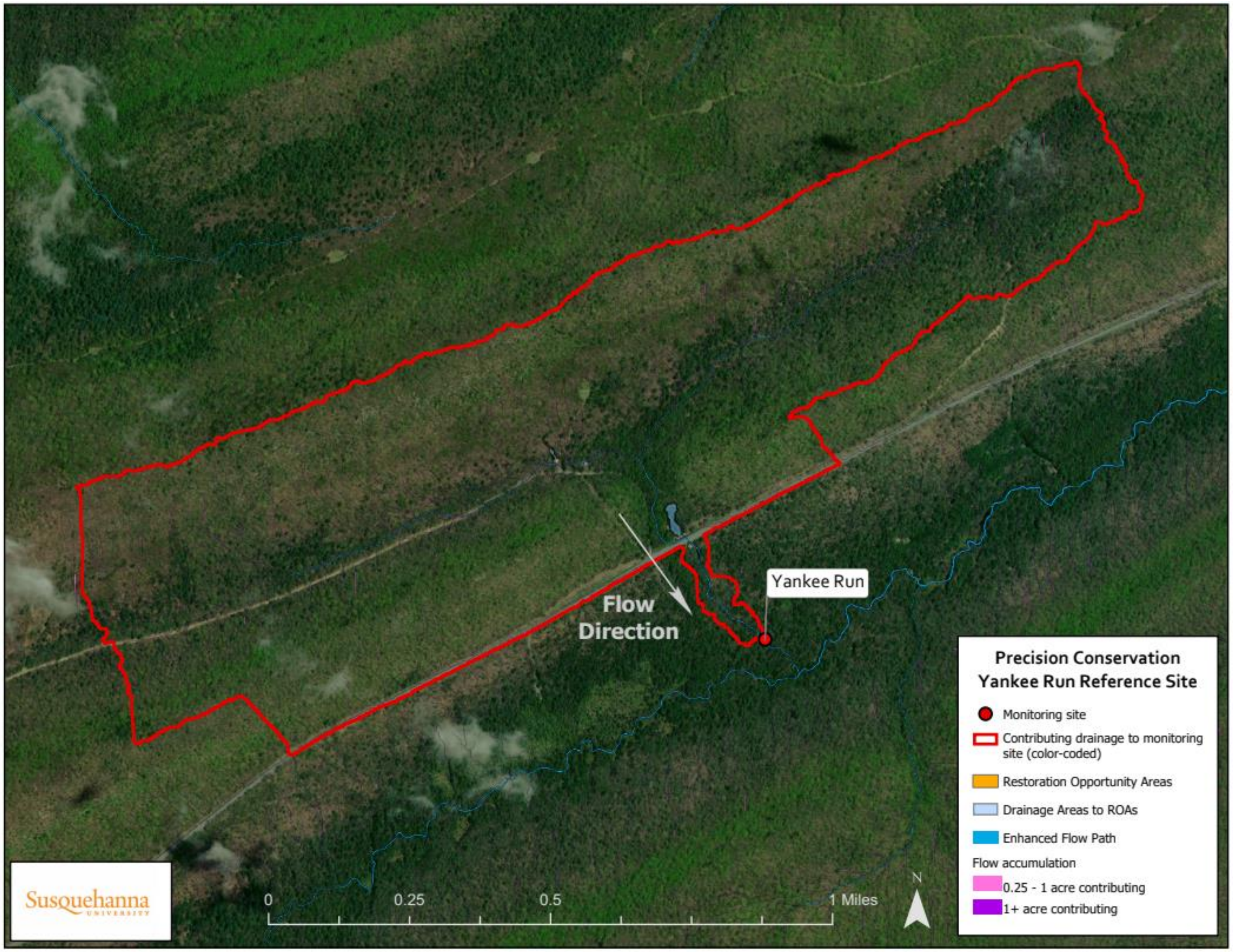

Figure 7. Forested reference monitoring site in the Buffalo Creek HUC 12 Watershed in western Union County, Pennsylvania. The Yankee Run monitoring site is located approximately one mile from the headwaters of Buffalo Creek and its drainage area is completely forested. An infrequently traveled gravel road is located 125 meters from the monitoring site.

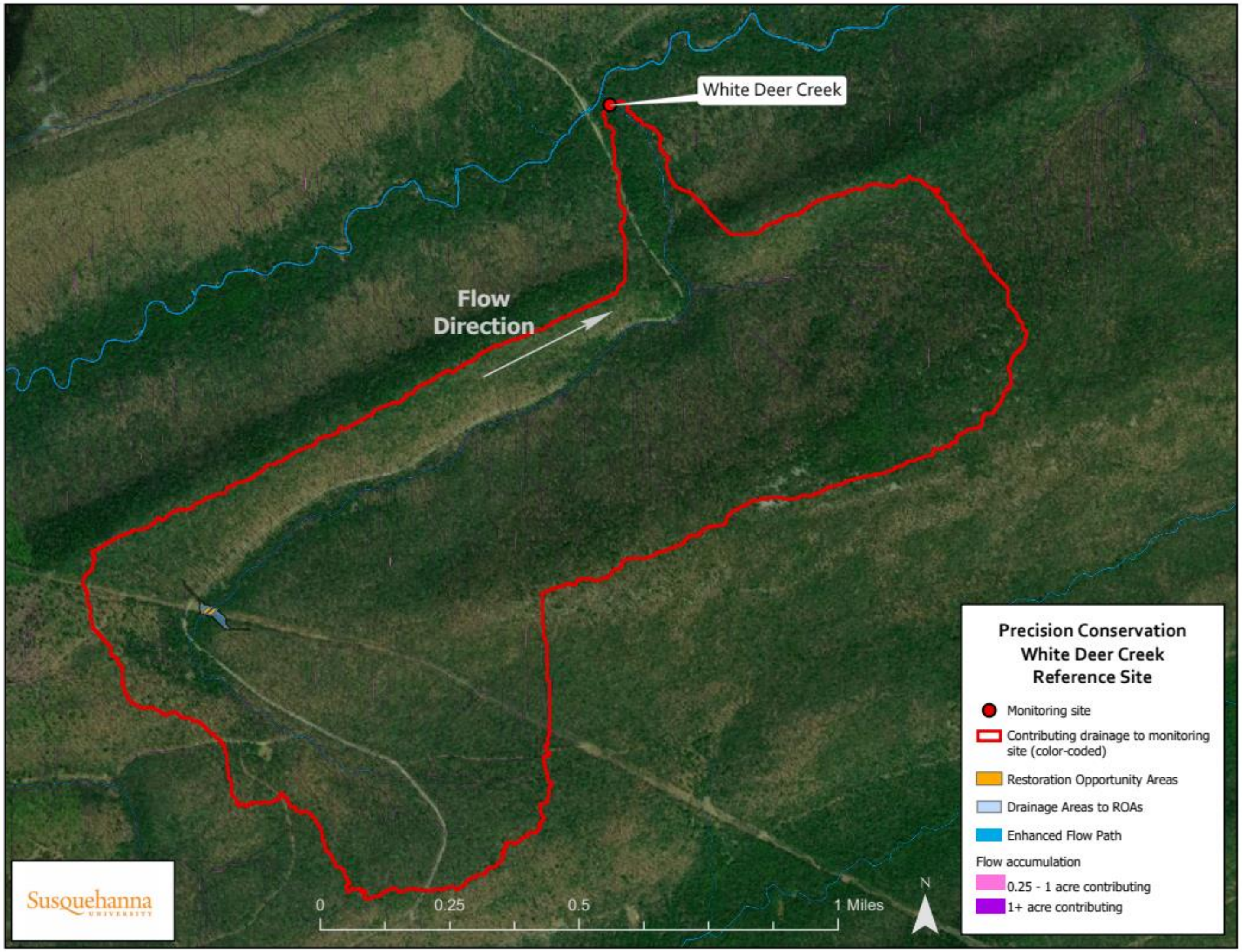

Figure 8. Forested reference monitoring site in the White Deer Creek HUC 12 Watershed in eastern Union County, Pennsylvania. The Un-named Tributary to White Deer Creek site is located within two miles of the headwaters of the tributary and its drainage area is completely forested except for an infrequently used gravel road 75 meters from the stream monitoring site.

3. Field Monitoring Methods

3.1 Fish and Benthic Macroinvertebrates

Fisheries data were collected through electrofishing at each site during the summer of each monitoring year. A 100-meter reach, representing multiple habitats, was electrofished according to standard protocols. By using a single pass of electrofishing, all species were collected, identified, and counted. All game fish were measured to the nearest millimeter and weighed to the nearest 0.1 gram. Changes in the fish community were quantified through various standard fisheries metrics. The Pennsylvania Department of Environmental Protection (DEP) Index of Biotic Integrity (IBI) for the Susquehanna River Watershed was used to assess site and watershed condition. This IBI has been widely used in United States and many countries and has proven to be a reliable means of assessing the effect of human disturbance on streams and watersheds.

Benthic macroinvertebrate samples were collected at each site during the summer of each monitoring year. All collection, processing, and identification of aquatic macroinvertebrates was completed according to Pennsylvania DEP standards, ensuring sampling areas representative of the variety of riffle habitats within the sample reach. Changes in the benthic macroinvertebrate community were quantified through standard benthic macroinvertebrate metrics. The Pennsylvania DEP Protections Index of Biotic Integrity for Wadable Freestone Streams was used to assess site and watershed condition. This index is used by the DEP to establish aquatic life status for streams in Pennsylvania.

3.2 In-situ Water Quality and Ecosystem Function

Water quality factors measured included nutrients (nitrogen and phosphorus), suspended sediments (turbidity), basic probe chemistry, biomass and nutrient status of algae and other microorganisms colonizing cobbles (collectively called periphyton), and two measures of reach-scale ecosystem function (Nitrogen-uptake and ecosystem metabolism). N-uptake and ecosystem metabolism are tied to key ecosystem services associated with healthy streams. All measurements were collected in the Elk Creek, Pine Creek tributary, and in the Pine Creek reference sites throughout the study. Because the Spring Creek headwater site lacked describable flow needed for comparison to the other two streams, measurements of this site were limited to nutrient samples and basic probe chemistry.

Grab samples for nitrogen, phosphorus, and other basic physical and chemical parameters were collected periodically between spring 2017 and summer 2019. Suspended sediments were monitored by periodically deploying continuous loggers that measured depth and turbidity beginning in the summer of 2017. During the three-year period, probe data including temperature, specific conductance, pH, and dissolved oxygen and oxidation reduction potential (ORP) (Eureka Manta sonde) were collected. Samples for total phosphorus (TP), total nitrogen (TN), soluble reactive phosphorus (SRP), nitrate, and ammonium were collected in acid-washed bottles. Samples for soluble nutrients (SRP, nitrate and ammonium) were immediately filtered in the field. All samples were returned to the laboratory on ice, where they were analyzed following standard methods. Alkalinity and stream discharge were also measured on several occasions. These measurements spanned pre- and post-restoration in the upstream reach of Elk Creek.

Nitrogen uptake was measured both pre- and post-restoration in Elk Creek as well as in the Pine Creek tributary, and the Pine Creek reference site. Ambient spiral lengths (the distance a nitrogen atom travels in the water before being immobilized in the stream-bed, $S_{w\text{-}amb}$), ambient uptake velocity (mass transfer coefficient, indicative of nitrogen demand, $V_{f\text{-}amb}$), and ambient areal uptake rates ($U_{\text{-}amb}$) were measured using the Tracer Additions for Spiraling Curve Characterization (TASCC) method (Covino et al. 2010). Durning each sampling occasion, a slug of nitrate solution combined with a conservative tracer (sodium chloride) was briefly introduced at the upstream station.A breakthrough curve was generated by continuously monitoring the concentrations of both solutes at the bottom of the reach.

Scientists also used auto samplers to better characterize nutrient concentrations (TN and TP) that occur during storm events. ISCO samplers were deployed at base-flow immediately prior to a forecasted rain event and set to sample at two-hour intervals. Storm event samples were obtained for upstream and downstream stations on upper Elk Creek and the Pine Creek tributary during the spring of 2017 and for the Pine Creek reference site during the summer of 2019. Record rainfall and equipment malfunctions prevented efforts to obtain additional storm even samples during the 2018 season.

To facilitate the estimation of ecosystem metabolism parameters (gross primary productivity, ecosystem respiration and net ecosystem production) and to characterize oxygen and temperature variability, loggers were deployed that measured dissolved oxygen and temperature at 15-minute intervals (PME MiniDots). These were often deployed for intervals spanning multiple months. Loggers were simultaneously deployed that measured solar radiation at each site. Metabolism parameters were estimated through reverse modeling using the R package StreamMetabolizer (Appling et al. 2018). These measurements spanned pre- and post-restoration in upstream section of Elk Creek.

Periphyton biomass and nutrient status data on 5-10 cobbles were measured from each reach once each year. These measurements spanned pre- and post-restoration in the upstream section of Elk Creek. Initially, pulse amplitude modulating fluorometry (PAM) was used to measure the photosynthetic capacity of algae colonizing the reach. PAM parameters include (F_v/F_m, dark-adapted photosynthetic capacity) and maximum electron transport rate (ETR_m, maximum rate of photosynthesis). These parameters have been shown to be closely related to nitrogen and phosphorus limitation in algae and differences would be expected between pristine and agriculturally-impacted sites. Periphyton was then removed from a known area of each cobble, composited and returned to the laboratory on ice for analysis of biomass (ash free dry mass (AFDM) and chlorophyll *a*), nitrogen and phosphorus content (mat N and mat P) and extracellular enzyme activities related to nutrient status. Enzyme activities measured included alkaline phosphatase (APA), which is indicative of phosphorus limitation, and β-glucosidase (GLU) indicative of labile carbon utilization, such as from an algal or agricultural source. Phenol oxidase (POA), indicative of recalcitrant organic matter utilization, such as carbon originating from forest vegetation, was also measured (Sinsabaugh et al. 1994, Rier et al. 2014). Scientists also calculated a carbon quality index (CQI, Hill et al. 2018), which integrates GLU and POA into a single measure, indicating the quality of carbon being utilized (agricultural inputs = “high quality carbon” while forest inputs = “low quality carbon” from a microbial perspective). In order to obtain additional reference conditions for comparison, scientists measured nutrient chemistry, periphyton nutrient status, and ecosystem metabolism in an additional ten similarly-sized streams throughout central Pennsylvania. Five of these streams are relatively unimpacted by agriculture while five are agriculturally impacted.

3.3 Sediment

Five sediment samples were taken at each site along a 100-meter stream reach, using either a sharpshooter spade, or a handheld bucket dredge, based on the depth of the water. Each sample was taken from a different zone of the stream listed below, assuming the stream had each zone.

- Riffle (shallowest and fastest moving water)
- Pool (deepest and slowest moving water)
- Pool to riffle transition (or run between a pool and riffle)
- Riffle to pool transition (or run between a riffle and pool)
- Eddy (where sedimentation is the greatest)

Each sample was then analyzed for grain size characteristics by mechanical separation using standard sieves and a Bouyoucos Hydrometer (ASTM 152H), a method based on Bouyoucos' 1962 analysis of soil particle size. Sediment grain sizes were classified according to the Udden-Wentworth scale (phi = –log2 of the grain size in millimeters). Sediment characteristics were then calculated by the Folk Graphic method (Folk and Ward 1957).

Organic matter content was calculated through loss on ignition by placing soil samples in an oven at 105°C to account for water loss and then at 550 °C to account for organic matter loss. The C:N ratio was determined by extracting soluble carbon and nitrogen with distilled water in a 1:1 ratio for 24 hours. Extracts were analyzed on a Shimadzu Total Organic Carbon Analyzer that included a Total Nitrogen module (Shimadzu Corp, Kyoto, Japan).

3.4 Monitoring QAPP for Research Methods

Details of all research field and data collection methods can be found in the QAPP in Appendix A.

4. Precision Conservation Mapping Methods

4.1 High-Resolution Land Cover

The high-resolution land cover dataset was created by the Chesapeake Conservancy and partners using 2013 National Agriculture Imagery Program (NAIP) imagery to classify natural and human-made features on the landscape at one-meter resolution. Further details about how the land cover dataset was created and classes included can be found at: http://chesapeakeconservancy.org/conservation-innovation-center/high-resolution-data/land-cover-data-project/

4.2 Enhanced Flow Path Mapping

The enhanced flow path data were created using a Light Detection and Ranging (LiDAR)-derived digital elevation model to identify concentrated flow paths and estimate channel width from flow accumulation. This product was combined with the high-resolution land cover data to create a comprehensive stream network. Further details on the methodology can be found at: http://envisionthesusquehanna.org/wp-content/uploads/2016/12/CC_New_Stream_Dataset_for_Susquehanna.pdf

4.3 Flow Path Buffer Analysis

4.3.1 Identification of Restoration Opportunity Areas

Restoration opportunity areas (ROAs) are defined as areas within a 35' buffer (11 m) of the water network derived from the enhanced flow path analysis, that were classified in the high-resolution land cover as any of the following land cover categories:

- Wetlands
- Low vegetation
- Barren

These land cover categories were considered "readily restorable/plantable," excluding areas with existing vegetation (Tree canopy, Shrubland) and areas with existing infrastructure (Structures, Impervious surfaces, Impervious roads). The area of each ROA was calculated in acres.

4.3.2 Filtering of Restoration Opportunity Areas

Any part of a ROA that intersected with road right of ways (USGS) was erased, as it was considered not "readily restorable/plantable." ROAs that were less than 25 m^2 were filtered out to reduce noise. ROAs were then intersected by parcel boundaries and removed from consideration if they were located on parcels that were less than 0.4 acres in size. The threshold was based on feedback from implementation partners specifying 0.4 acres as a reasonable requisite project area for consideration of a potential property for restoration. After conducting ROA filtering, 6,286 parcels remained, containing a total of 72,371 ROAs.

4.4 Drainage Area Analysis

The Watershed Tool in ESRI's ArcGIS Spatial Analyst extension was used to delineate drainage areas (DA) to each ROA. The area of each DA was calculated in acres, and the total land area within each drainage area was classified as agriculture, impervious, or turf (AIT) from a high-resolution land use dataset. The high-resolution land use dataset was created by the Chesapeake Bay Program, from the high-resolution land cover dataset created by the Chesapeake Conservancy and partners.

4.5 Stream Condition Datasets

Scientists obtained impaired stream data from Pennsylvania Department of Environmental Protection (PA DEP), including the 2017 Integrated List of Non-Attaining (ILNA) streams and 2017 Total Maximum Daily Load (TMDL) streams. The 2017 Designated Use streams data were also obtained from PA DEP.

The ILNA and TMDL streams datasets were combined to create comprehensive datasets of agriculturally impaired streams and non-agriculturally impaired streams. Agriculturally impaired streams were selected out based on the 'Source' attribute. The designated use data were used to identify exceptional value/high quality (EVHQ) streams.

ROAs within 30 meters of an agriculturally impaired stretch, non-agriculturally impaired stretch, or exceptional value/high quality (EVHQ) stretch were selected. The 30-meter buffer was applied to account for lack of spatial overlap between the lower-resolution National Hydrography Dataset (NHD) on which the PA DEP impairment data is based, and the higher-resolution enhanced flow path analysis water network. Any ROAs intersecting the buffered stretches were selected and characterized as on an agriculturally impaired stretch, on a non-agriculturally impaired stretch, or on an EVHQ stretch.

ROAs upstream of agriculturally-impaired or non-agriculturally impaired stretches were also selected. Scientists used a manual process to snap the most downstream endpoint of each impaired tributary segment to the flow accumulation layer derived during the enhanced flow path analysis. Then the Watershed Tool was used to calculate drainage areas or catchments to those downstream points. Any ROAs intersecting those catchments were selected and characterized as upstream of either agriculturally impaired or non-agriculturally impaired stretches.

4.6 Landscape Variables

The spatial location for each monitoring site was snapped to the nearest logical cell in the flow accumulation layer to ensure an accurate delineation of the upland area draining to the site. The Watershed Tool was used to delineate the drainage area corresponding to the monitoring site, and scientists used on-the-ground knowledge to ground-truth the results. Within each upland drainage area of the monitoring sites, the five landscape variables described below were identified and attributed back to the monitoring site. For monitoring sites directly downstream of others, the cumulative sums of the five landscape variables across all upstream monitoring sites were also calculated. As an example, the most upstream monitoring site's cumulative sums would be equal to its own landscape variable sums. The second-most upstream monitoring site's cumulative sums would consist of its own landscape variable sums plus those of the upstream monitoring point.

4.6.1 Intact Forest Buffer

Intact buffer areas are defined as areas within the 35' buffer zone of the water network that were classified as land cover of tree canopy or shrubland. The total acreage of intact buffer was calculated by summing the acreage of all intact buffer areas within the upland drainage area of each monitoring site.

4.6.2 Restoration Opportunity Area

Restoration opportunity areas (ROAs) are defined as areas within the 35' buffer zone of the water network that were classified as land cover of barren, low vegetation, or wetlands. The total acreage of ROAs was calculated by summing the acreage of all ROAs within the upland drainage area of each monitoring site.

4.6.3 Total Drainage Areas

The total acreage of untreated upland area—the drainage areas (DAs) to ROAs—was calculated by summing the acreage of all DAs to ROAs, within the upland drainage area of each monitoring site.

4.6.4 High Pollutant Runoff Risk Areas

The total acreage of untreated upland area with high pollutant runoff risk was calculated by summing the acres of land within the untreated upland areas classified as land use of agriculture, impervious, or turf.

4.6.5 Return on Restoration Investment

The potential return on restoration investment metric was defined as the acreage of high pollutant runoff risk upland that could be treated per acre of buffer restoration opportunity. This represents the potential return on investment for implementing buffer restoration within the upland drainage area of each monitoring site. The return on investment metric was calculated as the ratio of untreated upland area with high pollutant runoff risk (agriculture, impervious, and turf in DAs) to the ROA area.

5. Field Monitoring Timeline

Monitoring data were collected between Spring 2017 and Summer 2019. Specific timing of monitoring by parameter is included for each sampling location by quarter in Table 1 for agriculturally impacted sites and in Table 2 for reference locations.

Table 1. Agriculturally impacted monitoring location data collection timeline for fish and macroinvertebrates, sediment, water chemistry, and ecosystem function. Highlighted fields indicate that these data were included in the landscape analysis as "pre-restoration" data.

Timeframe	Elk Creek Sites				Spring Creek Sites			Pine Creek Sites	
	Miller	Brown	Sheats	Neff	Upper Dreibellbis	Middle Dreibelbis	Mountain View	Upstream Bzdil	Downstream Bzdil
Spring 2017	W	W			W	W	W	W	W
Summer 2017	F S W E	F S W E	F S W	F S	F S W	F S W	F S W	F S W E	F S W E
Fall 2017	W	W	W						
Winter 2017/2018	W	W	W						
Spring 2018	W	W	W						
Summer 2018	F S W E	F S W E	F S W E	F S	F S W	F S W	F S	F S W E	F S W E
Fall 2018	W	W	W						
Winter 2018/2019	W	W	W						
Spring 2019	W	W	W						
Summer 2019	F S W E	F S W E	F S W E	F S	F S		F S	F S W E	F S W E

F—Fish and Macroinvertebrates

S—Sediment

W—Water Chemistry

E—Ecosystem Function

Table 2. Forested reference monitoring location data collection timeline for fish and macroinvertebrates, sediment, water chemistry, and ecosystem function. Highlighted fields indicate these data were included in the landscape analysis as "pre-restoration" data.

Timeframe	Pine Creek Sites		White Deer Creek Site	Buffalo Creek Site
	Pine Creek	Voneida Run	Tributary to White Deer Creek	Yankee Run
Spring 2017				
Summer 2017	S W E	S W E	F S	F
Fall 2017				
Winter 2017/2018				
Spring 2018				
Summer 2018	F S W E	F S W	F S	F S
Fall 2018				
Winter 2018/2019				
Spring 2019				
Summer 2019	F S W E	F S	F S	F S

F—Fish and Macroinvertebrates

S—Sediment

W—Water Chemistry

E—Ecosystem Function

6. Precision Conservation Mapping Results

For each monitoring site a landscape analysis was completed, examining five main landscape variables: 1) intact forest buffer areas, 2) restoration opportunity areas (ROAs), 3) total untreated upland areas, 4) composition of untreated upland areas, and 5) potential return on restoration investment. The results of the landscape analysis for each monitoring site are found in Table 3.

Table 3. Results of the landscape analysis for each monitoring site.

	Intact upstream forest buffer (acres)	**Restoration opportunity area (area that can be converted to forest buffer) [in acres]**	**Total unfiltered drainage area (acres)**	**Upstream agriculture, turf, and impervious surfaces that drains unfiltered into waterway (acres)**	**Unfiltered agriculture, impervious, and turf drainage area: restoration opportunity area (acres)**
Forest Reference Streams					
Pine Creek	219.029	6.410	279.656	133.941	20.896
Trib – White Deer	19.371	0.149	0.866	0.010	0.067
Voneida Run	36.332	0.559	59.728	9.843	17.608
Yankee Run	15.485	0.056	0.826	0.079	1.411
Agriculturally-impacted sites					
Spring Creek					
Dreibelbis	8.963	19.366	676.741	466.937	24.111
Middle Dreibelbis	10.658	25.430	991.317	674.641	26.529
Mountain View	17.073	35.134	1358.227	903.923	25.728
Elk Creek					
Miller	192.931	64.260	1928.326	1139.026	17.725
Brown	193.603	65.022	1966.780	1143.757	17.590
Sheats	194.964	66.124	2028.946	1170.319	17.699
Neff	196.742	68.221	2131.647	1266.110	18.559
Pine Creek					
Bzdil Upstream	2.570	17.317	796.530	632.532	36.527
Bzdil Downstream	2.789	19.812	853.344	682.851	34.467

7. Field Monitoring Results and Discussion: Landscape Analysis

7.1 Fish and Benthic Macroinvertebrates

To identify patterns in community composition between fish or macroinvertebrate communities and precision conservation landscape analyses, scientists used redundancy analyses (RDA) with precision conservation as predictor variables for community composition. The following plots are a representation of how similar or different the samples (single points) of sampled watersheds (color-coded) are in terms of the species of fish or macroinvertebrates. Points closer to each other in space represent more similarities in the species found, and their relative abundance. The blue arrows indicate the direction of the assessed landscape variables. Points closer to a given blue vector arrow and farther away from the center of the plot are better explained by the given landscape variable. Therefore, this tool can be useful in segregating samples from various creeks and determining how they differ from each other, based on what specific landscape variables predict the samples with high efficiency. In addition to looking at these general trends, scientists also tested for significant relationships between communities and precision conservation variables with a multivariate analysis of variance (ANOVA-like permutations). All RDAs and significance tests were performed in RStudio with the vegan package (Oksanen et al., 2019; R Core Team, 2016).

Macroinvertebrate communities from Elk Creek appear to be well-predicted by precision conservation variables (Figure 9) along with the most downstream site on Spring Creek (Mountain View). This relationship indicates that landscape variables have the potential to act as a proxy for macroinvertebrates in identifying impairment in streams, and these three variables explained 42% of the variability in macroinvertebrate communities, a high explanatory ability for landscape variables. However, this relationship was not significant ($P = 0.20$). The lack of significance may be a result of the heavily altered hydrology in Spring Creek where habitat was more similar to lentic (ponds or lakes) rather than lotic (streams and rivers) ecosystems in the middle Spring Creek site. This hydrologic alteration, which was not clearly apparent from landscape variables, completely changed the macroinvertebrate community and lowered the scientists' ability to explain community composition. While these data did not show a significant relationship, the scientists believe the explanatory ability for Elk Creek and lack of explanatory power for Spring Creek are a positive result and indicate clearly where current landscape variables might not represent aquatic communities such that other metrics (such as slope) should be incorporated into site selection.

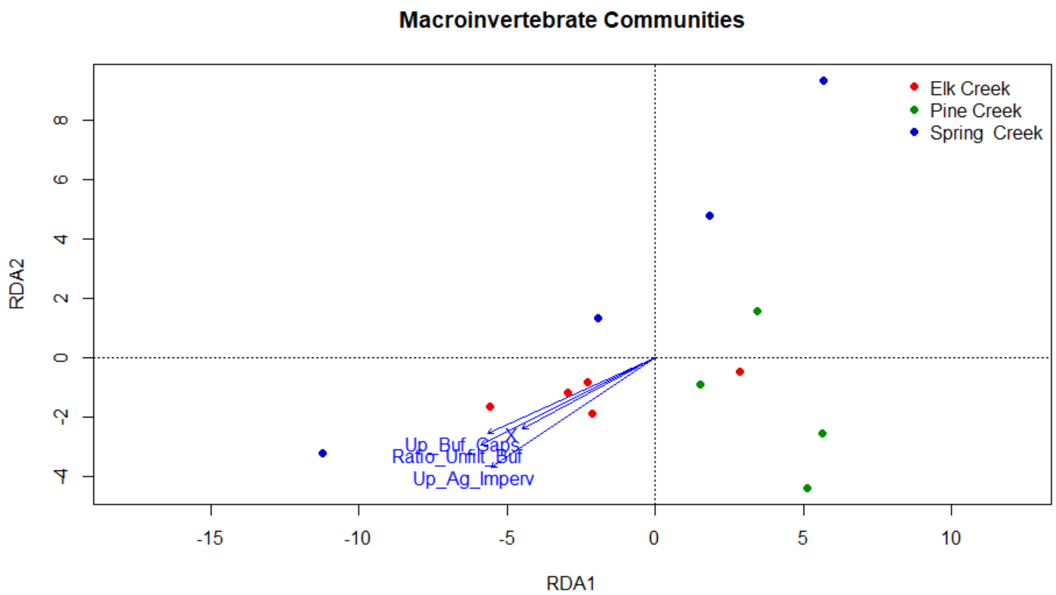

Figure 9. Redundancy analysis of macroinvertebrate communities as related to precision conservation variables. Samples are grouped by watershed.

Fish communities were much less well-explained by landscape conservation variables, with only 6.6% of variance explained with highly significant results, $P = 0.001$. As in the case of macroinvertebrates, Elk Creek samples were most closely associated with precision conservation variables (Figure 10). While it might be counterintuitive, this lower predictive ability with a significant relationship provides support to the patterns in macroinvertebrate communities between Elk and Spring Creek. Only the most upstream site on Spring Creek contained fish communities, leading to exclusion of the site with strongly altered hydrology from analysis in the fish community data. Because samples from lower Spring Creek were not included in the fish community RDA the data were less variable, and thus significant. From these data the scientists can conclude that precision conservation variables have the potential to act as effective proxies for fish and macroinvertebrate samples in quantifying impairment. However, the suite of precision conservation variables might require more spatial data related to elevation and intensity of use to be effective in prioritization for highly impacted streams.

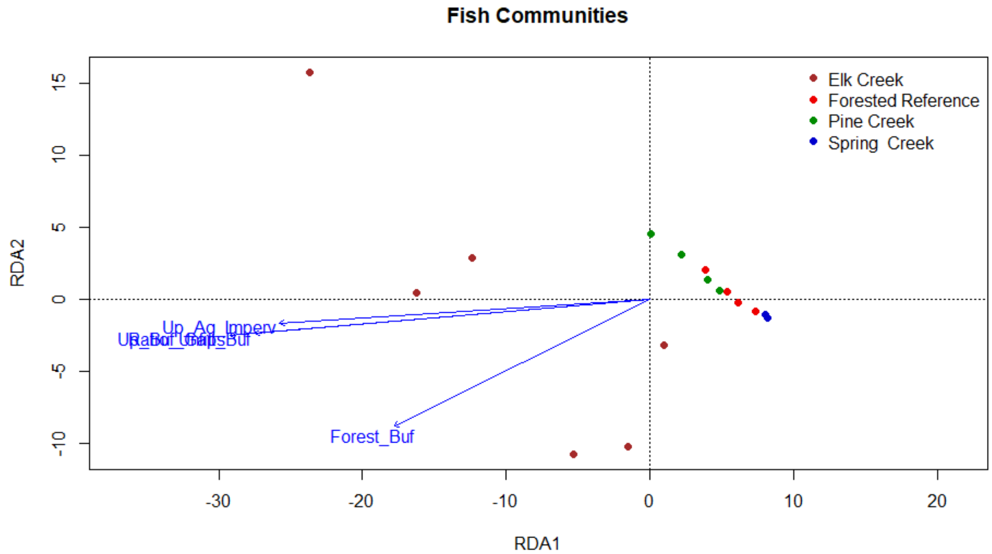

Figure 10. Redundancy analysis of fish communities as related to precision conservation variables. Samples are grouped by watershed.

7.2 Sediment

The C:N ratio was measured to provide a relative index of nitrogen available to a stream compared to other components of plant matter decay, recognizing that even forests release nutrients to streams consistent with leaf and detritus decomposition. The hypothesis is that C:N ratio will be small in agricultural systems, because agricultural sources of nitrogen, like animal waste and crop residues, will provide significant nitrogen contributions, but only modest carbon contributions. Alternatively, the scientists suspect that forest runoff will provide high ratios, in keeping with abundant carbon from leaf litter decomposition from nitrogen starved settings.

Figure 11 shows the C:N ratios measured in the sediments at forested reference streams. Across sites and years, the ratio appeared to be relatively stable with an average of 9.3. By rough comparison, the collection of bacteria and fungi responsible for the decomposition of plant material in soil have a C:N ratio of about 11, and the forest topsoil layer has a C:N ratio of about 20. The forest reference C:N ratio seems to be consistent with long-decomposed soil organic matter and would correspond to rainwater in equilibrium with the drainage of stable forest soils (C:N values used for comparison are from Brady and Weil, 2002).

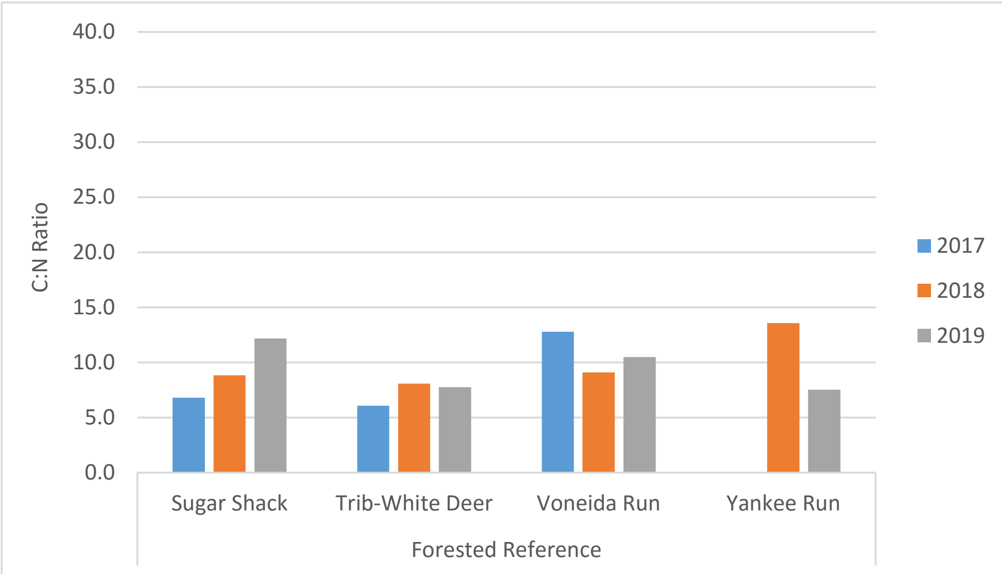

Figure 11. Carbon:Nitrogen ratios for forested reference sites.

Both carbon and nitrogen are natural byproducts of plant decomposition, and their ratio can signal the relative contributions of forest decomposition (carbon rich sources) or agricultural additions (nitrogen rich sources). The monitoring team has shown that the pre-restoration C:N ratio was correlated with the landscape variables indicating degraded ecosystems (Figure 12, plots B, C, D) measured for each monitoring site.

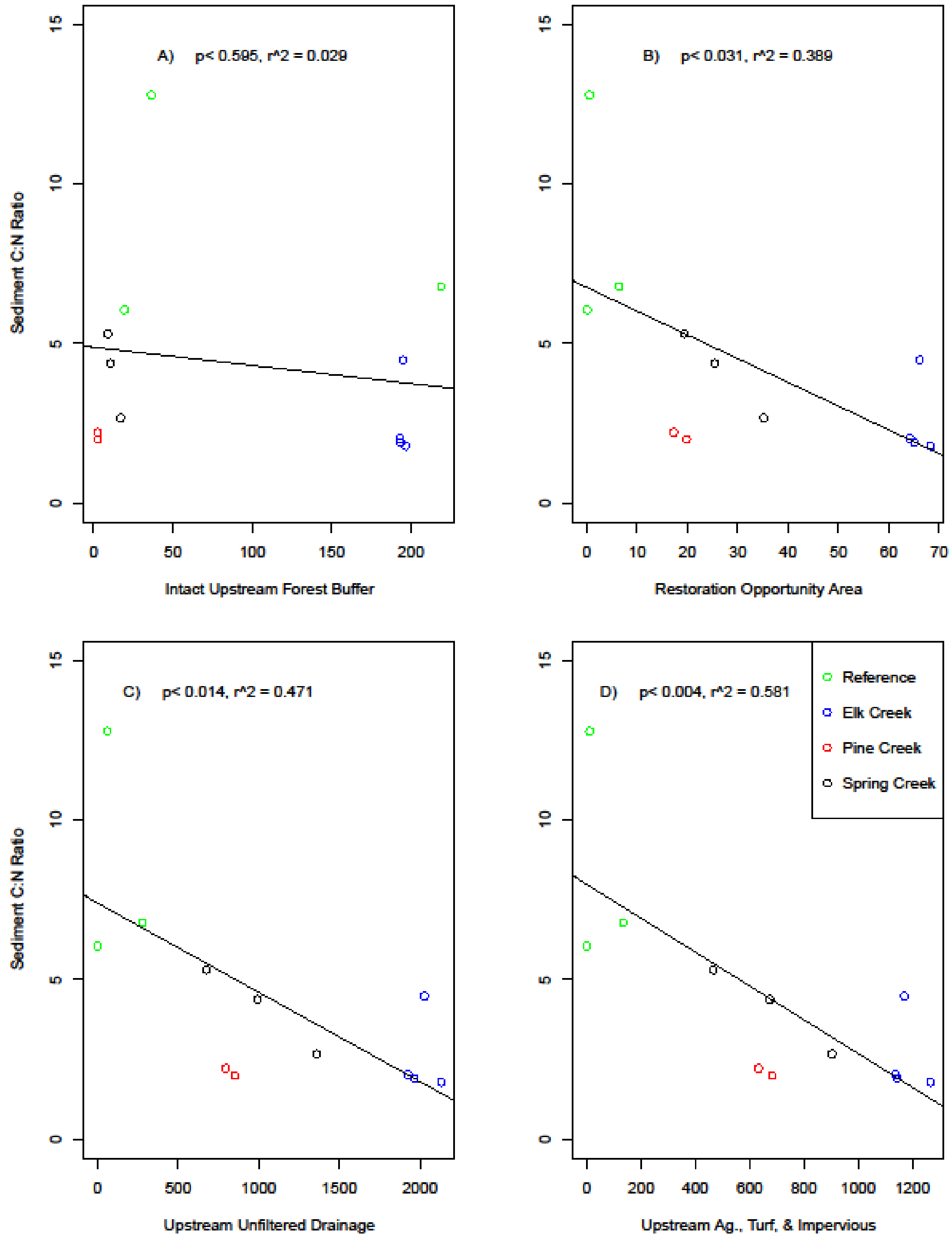

Figure 12. Landscape variables impacting C:N ratio of sediment. Intact Upstream Forest Buffer (A) has a non-significant trend with C:N. Restoration Opportunity Area (B), Upstream Unfiltered Drainage (C), and Upstream Ag and Turf (D) have significant relationships with C:N. As degradation increases, either in the form of more unforested area (B), or in upstream unfiltered drainage area (C and D), C:N decreases. The variance explained (R2) is shown in the plot. Landscape measures in plots B, C, and D appear to be reliable variables that can be used to prioritize parcels for restoration according to impairment that can be documented in the field.

7.3 In-situ Water Quality and Ecosystem Function

7.3.1 Nitrogen

Several chemical parameters of water were examined as they relate to landscape properties. When the sites from all creeks were aggregated, it was determined that total nitrogen in water is reduced by intact upstream forest buffer strongly and significantly ($P = 0.001$, $R^2 = 0.59$, Figure 13A). This offers an ecological explanation for reduction of nitrogen in water because more buffer takes up more nitrogen flowing in water. Therefore, this not only provides evidence for reduction of total nitrogen in water with more buffer, but also gives a general strategy for improving water quality by increasing buffer.

When the area of unfiltered drainage is scaled by restoration opportunity, this strongly and significantly explains total nitrogen in water with a positive relationship ($P = 0.003$, $R^2 = 0.64$, Figure 13B). This shows that for the same amount of unfiltered drainage, if there is a smaller unbuffered area (area of restoration opportunity), that gives a higher ratio of the two which corresponds to higher N concentration in water. If the unbuffered area is bigger for the same amount of unfiltered drainage, the ratio is smaller and corresponds to smaller N concentration. Conservation efforts should be focused on the first type of drainage with smaller restoration opportunity, because filtering water from the same area of unfiltered drainage can be done with conservation effort in a smaller amount of buffer gap. This will take advantage of rapid reduction of high level of nitrogen in water as observed in Figure 13B.

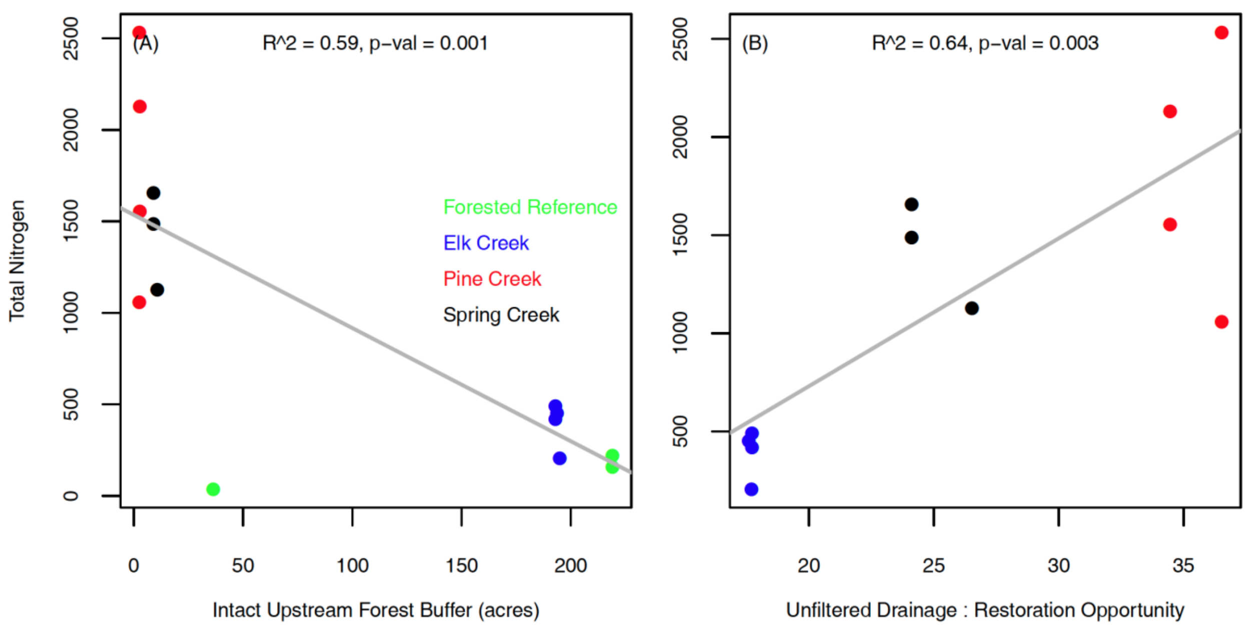

Figure 13. Total nitrogen in water as predicted by landscape characteristics. (A) Intact upstream forest buffer explains total nitrogen significantly and strongly with a negative relationship ($P = 0.001$, $R^2 = 0.59$). (B) Total nitrogen has a strong and significant positive relationship with the ratio of area of unfiltered drainage to that of restoration opportunity ($P = 0.003$, $R^2 = 0.64$).

7.3.2 Phosphorus

In the case of total phosphorus in water, relationships with landscape variables were observed in the same direction. However, the relationships were not statistically significant because of an influential point in the small dataset (Figure 14). When the single influential point (one site from Spring Creek) was removed, the relationship became significant for intact forest buffer (Figure 15A), offering the same explanation as in the case of total nitrogen: more buffer absorbs more phosphorus from water, leaving a smaller quantity in water, and performing more nutrient reduction for the water flowing toward Chesapeake Bay. The ratio of area of unfiltered drainage to that of restoration opportunity is, however, still non-significant, but it shows a clear positive trend, suggesting a similar explanation as in the case of nitrogen.

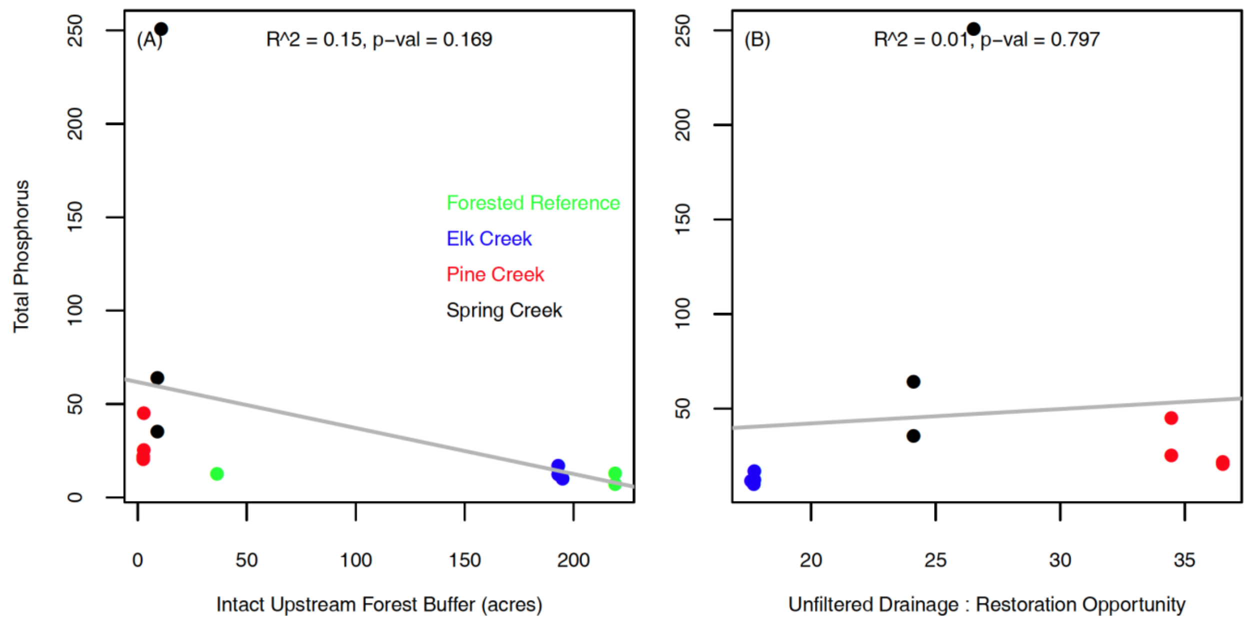

Figure 14. Total phosphorus in water as predicted by landscape characteristics. The explaining variables are as in Figure 1 but the relationships are not statistically significant (*P* = 0.169 and 0.797).

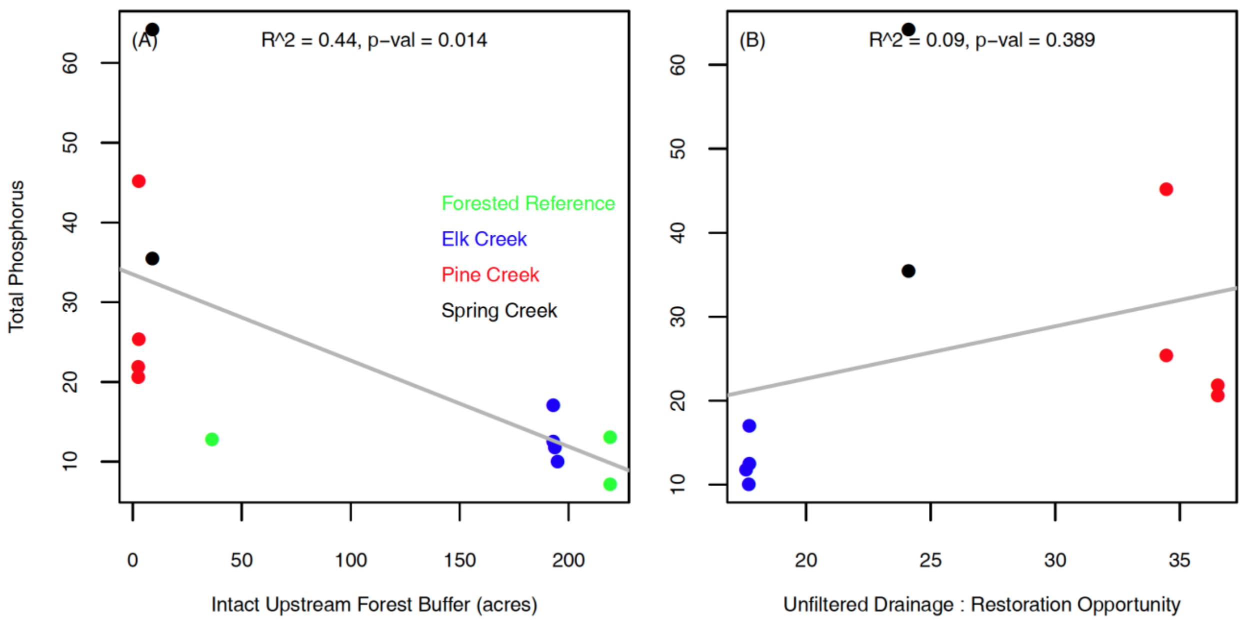

Figure 15. Total phosphorus in water as predicted by landscape characteristics when a single influential point from Figure 14 was removed. (A) Intact upstream forest buffer explains total phosphorus significantly and strongly with a negative relationship ($P = 0.014$, $R^2 = 0.44$). (B) Total nitrogen has a non-significant positive trend with the ratio of area of unfiltered drainage to that of restoration opportunity ($P = 0.389$).

7.3.3 Ecosystem Productivity and Respiration

Gross primary productivity (photosynthesis), ecosystem respiration and net primary productivity all have statistically non-significant and weak relationships with landscape variables (Figure 16). It is not wise to draw any inference out of these weak and non-significant relationships; however, these measures of productivity and respiration show a similar trend as in the case of total nitrogen. A general conclusion that arises from these analyses is that sites with higher amount of intact buffer have both high ecosystem respiration and net primary productivity, which could result from more organic matter flowing from the buffer itself into water and supporting more biological community.

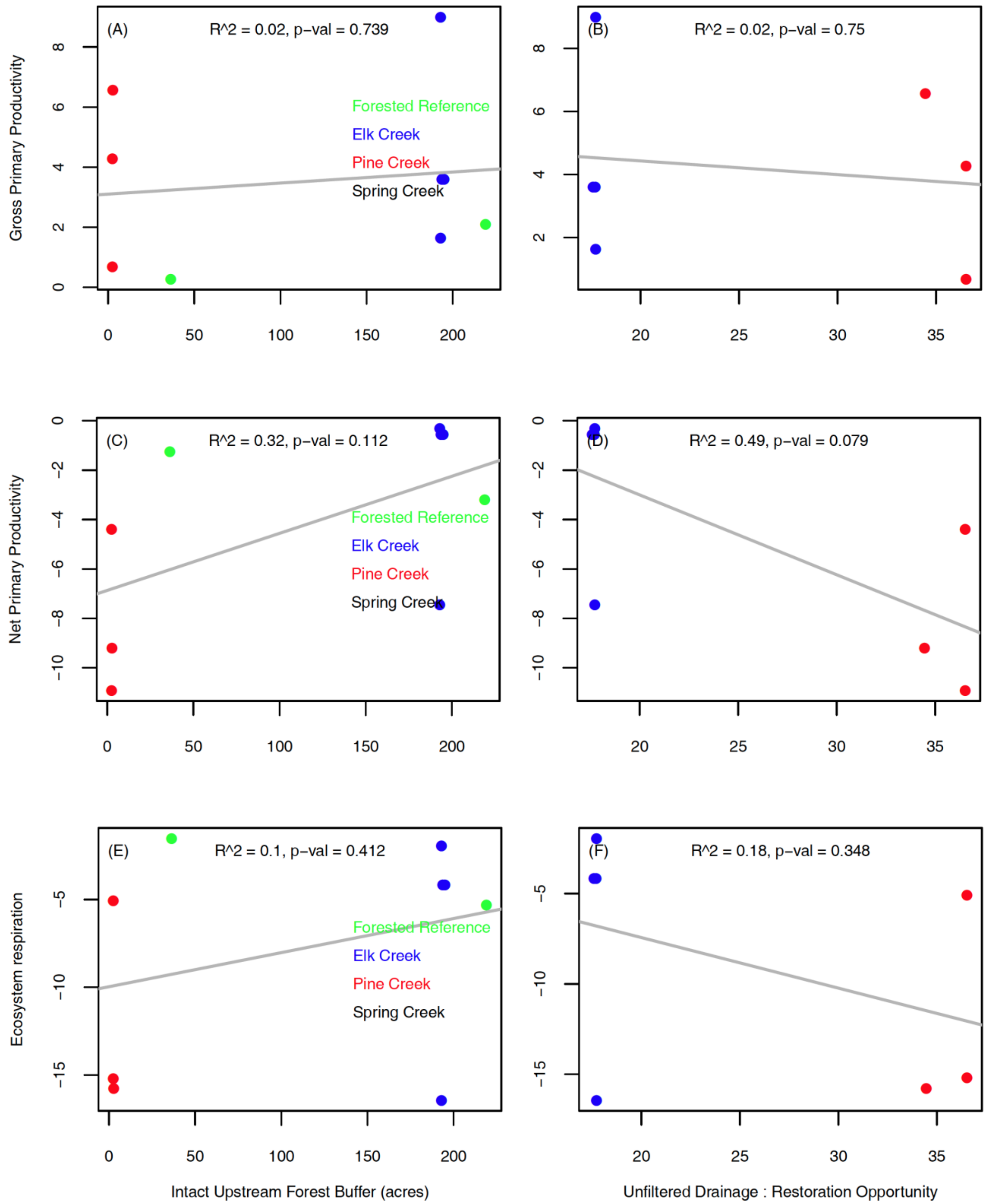

Figure 16. Landscape characteristics have weak and non-significant trends with gross primary productivity (A,B), net primary productivity (C,D), and ecosystem respiration (E,F).

7.4 Model Validation and Research Conclusions

1. Nitrogen and phosphorus in streams not only directly pollute water for humans and other living creatures, but also provide nutrients for a number of undesirable consequences including algal blooms. This study found strong and highly significant evidence for reduction of nitrogen and phosphorus by intact upstream riparian forest buffers.
2. Based on this ecological explanation and statistical evidence, a general strategy for management can be implemented to improve water quality. Sites with restoration opportunity areas should be given high priority for forest buffer installation. The data support prioritizing sites with smaller forest buffer planting areas as compared to sites with larger forest buffer planting areas when unfiltered drainage area is held constant. This is expected as these sites correspond to higher nitrogen in water and lower cost relative to conservation and water quality returns.
3. Chemical composition of sediment is less affected than that of water by short term phenomena like storms. Therefore, sediment analyses provide a more robust proxy of longer term environmental characteristics. The study shows that C:N ratios are stable across three years of sampling at stream sites that have received no modifications. There is significant evidence that larger upstream unfiltered drainage areas correlate to lower C:N ratio in stream sediment. This means that for the same amount of carbon, a larger upstream unfiltered drainage results in higher amount of nitrogen than does a smaller upstream unfiltered drainage. This indicates such sites should be high conservation priorities, since a restoration solution has higher impact on water quality and downstream environment if improvements are made on such sites with higher C:N.
4. Precision conservation landscape variables have the potential to act as a proxy for the community composition of macroinvertebrates. Collectively, these variables explained 42% of the variance in macroinvertebrate communities, although results were not statistically significant. However, among fish communities, the landscape variables show little predictive capability for community composition (7% variance explained).
5. Additional research findings examining the before and after restoration monitoring results are presented in Appendix B.

7.5 Data Limitations

There are some important caveats in this study. The site-level landscape analysis includes a total of 12 data points. With such a small sample size, it is hard to detect a statistically significant signal. Therefore, the signals detected with very small p-value represent strong evidence of true signals. On the contrary, trends that are not significant are common. Such trends might have been significant with a larger sample size. Additionally, sites used in the analysis on each stream segment were autocorrelated with one another because of their position downstream of one another. Ideally, sites would have been on different stream segments and the landscape factors would have varied widely.

8. Applications of High-Resolution Data

8.1 Overview

The Chesapeake Conservancy and partners worked across four counties in central Pennsylvania to translate high-resolution data and on-the-ground restoration knowledge into a targeted approach to forest buffer restoration. This section presents methods used for mapping and consensus building, results of the forest buffer prioritization, and applications across the four-county region.

8.2 Focal Area

Within the four-county area, there are 170,747 parcels. Of those, 6,286 parcels were identified as containing at least 0.4 acres of forest buffer restoration opportunity areas (locations to install forest riparian buffers) and prioritized based on opportunity for restoration and potential to improve water quality. A summary of the number of parcels prioritized by county is found in Table 4.

Table 4. Number of prioritized parcels by county.

County	Parcels Prioritized
Centre	2,024
Clinton	772
Huntingdon	1,573
Lycoming	1,917
Four-county region	**6,286**

8.3 Data-Driven Consensus Building Background

8.3.1 Stakeholder Meetings and Engagement

The basis of the forest buffer prioritization was a verbal exercise at a workshop in January 2017 where it was identified that partners wanted to work in "places where water quality was degraded by agriculture, but trout populations were nearby and restoration was perceived as attainable." The Conservancy team took that verbal statement and worked with partners over several workshops and webinars to relate the verbal activity back to spatial datasets that would provide a roadmap to key locations for restoration to improve water quality.

8.3.2 Scale

A key component in translating mapping prioritization into a workable restoration strategy was identifying the correct scale. Initially, an individual buffer gap prioritization was created, but was later changed to the parcel level for two reasons. First, the parcel is the scale at which partners were doing landowner outreach and implementing restoration projects. Second, the team identified that forest buffers are the last chance to intercept pollutant-laden runoff before it enters a stream. Although forest buffer restoration was recommended at these locations, other best management practices may be needed, which will ultimately be determined by an implementation partner organization.

8.3.3 Prioritizing Water Quality Improvements on Agricultural Lands

The goal of the resulting forest buffer prioritization was to identify at the parcel scale where runoff from agriculture, impervious surfaces, and turf is entering waterways, unfiltered from the landscape upstream, or along agriculturally impaired stream segments. These land use categories were used to represent where high loads of sediment and nutrients are likely originating on the landscape. Agriculturally impaired streams were used to identify where pollutants entering the stream unfiltered are causing degradation of in-stream communities and water quality. By identifying parcels upstream of these impairments, prioritization can inform where restoration should be completed to achieve the greatest water quality improvements.

Initially, a forest buffer restoration prioritization was designed that included priorities for both wildlife and water quality weighted almost equally. It was the consensus of the partnership after delivery of a draft prioritization in March 2018 that the prioritization should be reworked to include only priorities for water quality improvements, the main goal of the project, and use wildlife datasets as overlays.

8.3.4 Weighting and Calibration of the Model

During a precision conservation workshop in June 2018, attendees individually identified importance of priority datasets by ranking all datasets as low priority to high priority (1-5). The Chesapeake Conservancy translated these priority rankings into a model examining how the ranked parcels compared to one another. Previously completed projects on partner parcels were also used to calibrate the model to ensure on-the-ground priorities were reflected in the prioritization weighting.

8.4 Data-Driven Prioritization methodology

8.4.1 Attributes

All attributes calculated for ROAs and DAs were aggregated, as described above, to the parcel scale. Each parcel was scored on the attributes listed in Table 5.

Table 5. Attributes included in the precision conservation parcel-scale prioritization.

Attribute	Rationale
Total area of restoration opportunity areas on parcel (acres)	Indicates potential project area
Total area of drainage areas to restoration opportunity areas on parcel (acres)	Land area draining to unbuffered area
Sum of land areas classified as agriculture, impervious surfaces, or turf in drainage areas to restoration opportunity areas on parcel (acres)	Unbuffered runoff (nitrogen, phosphorus, sediment, chemicals) to water network
Ratio of agriculture, impervious, and turf in the drainage area to ROAs // total ROA area	Indication of cost effectiveness
Parcel contains ROAs that are located: 0 - not on an impaired stretch (ag or non-ag) 1 - on a non-agriculturally impaired stretch 2 - on an agriculturally impaired stretch	Need for water quality improvement
Parcel contains ROAs that are located: 0 - not on an EVHQ stretch 1 - on an EVHQ stretch	Need for preservation of high quality streams
Parcel contains ROAs that are located: 0 - not upstream of ag or non-ag impaired stretches 1 - upstream of only non-ag impaired stretches 2 - upstream of ag-impaired stretches	Potential upstream impact on downstream impairments

8.4.2 Scoring

8.4.2.1 Gap Score

Gap score was the determination for how valuable restoration of an individual gap in forest buffer coverage would be. Each parcel's gap score was calculated by applying Equation 1 using values of three attribute values:

- Drainage Areas to ROAs on parcel [Drain_Area]
- Area of agriculture, impervious, and turf in drainage areas [AIT_DA]
- Ratio of (AIT in drainage areas): (area of ROAs) [AIT_DA_ROA]

Equation 1.

(1.0 * AIT_DA) + (0.09 * Drain_Area) + (1.1 * AIT_DO_ROA)

Range of gap scores across the four county region: [0 – 1359]

8.4.2.2 Designation Score

Each parcels' designation score was calculated to identify how valuable restoration on this individual property would be to the overall landscape. Designation score was assigned based on values of three attribute values found in Table 6:

- Impaired Stretch
- EVHQ Stretch
- Impaired Proximity

Table 6. Range of designation scores across the four county region: [0 - 540]. In the table, 0 - not impaired, 1 - ag impaired, 2 - non-ag impaired.

Parcel Description	Impaired Stretch	EVHQ Stretch	Impaired Proximity	Designation Score
No designations	0	0	0	0
Non-ag impaired proximity only	0	0	1	30
Non-ag impaired stretch and proximity	1	0	1	40
Ag-impaired proximity only	0	0	2	180
Non-ag impaired stretch, ag-impaired proximity	1	0	2	180
Ag-impaired stretch and proximity	2	0	2	240
EVHQ only	0	1	0	60
Non-ag impaired proximity + EVHQ	0	1	1	90
Non-ag impaired stretch, non-ag impaired proximity + EVHQ	1	1	1	100
Ag impaired proximity + EVHQ	0	1	2	280
Non-ag impaired stretch, ag-impaired proximity + EVHQ	1	1	2	280
Ag-impaired stretch, Ag-impaired proximity + EVHQ	2	1	2	540

8.4.2.3 Total Score

Each parcel's total score was calculated by adding the gap score and designation score.

8.4.3 Precision Conservation Prioritization Results

8.4.3.1 Ranking and Tiers for Prioritization

Based on each parcel's total score, it was assigned a rank and tier (1-5) for the four-county region (a parcel was ranked against all other parcels in the four counties) and a rank and tier (1-5) for the individual county (a parcel ranked against only other parcels in the same county). Ranges for the four-county ranking and individual county ranking are found in Table 7.

Table 7. Possible ranges of ranks by four-county region and by individual county. Total number of parcels ranked was 6,286 across the four-county region.

County	Rank Range
Four-county region	[1 - 6,286]
Centre	[1 - 2,024]
Clinton	[1 - 772]
Huntingdon	[1 - 1,573]
Lycoming	[1 - 1,917]

Tiers were generated in R, using natural breaks (Jenks method) based on the distribution of final scores for both the four-county region and for each county (Table 8). See Appendix C for specific breaks and graphs of data distributions.

Table 8. Summary of parcel tier distributions by four-county region and by individual county. All four counties included 812 tier 1 and tier 2 parcels. Centre County had most tier 1 and tier 2 parcels of any individual county.

Tier	All 4 Counties	Lycoming	Huntingdon	Clinton	Centre
1	278	36	71	28	169
2	534	161	142	72	253
3	1044	346	262	142	419
4	1904	676	559	238	532
5	2526	698	539	292	651
Sum	6286	1917	1573	772	2024
Tier 1 and 2	812	197	213	100	422

8.4.3.2 Restoration Opportunity Area Results and Impact

The analysis resulted in identification of 10,992 restoration opportunity area acres on ranked parcels. These ROAs would filter 410,715 upslope acres, 216,080 of which are agriculture, impervious surface and turf acres.

Tier 1 and tier 2 parcels include 2,684 restoration opportunity area acres. These ROAs would filter 106,732 upslope acres, of which 64,270 are agriculture, impervious surface, and turf acres.

8.4.4 Distribution of Information to Partners

Results of the precision conservation prioritization for the four-county region were delivered to restoration partners through an online web viewer. The online web viewer for the forest buffer restoration opportunity area analysis can be found at this web link: http://www.arcgis.com/home/webmap/viewer.html?webmap=6e69bc81727d490d85742842e6a88426&extent=-79.6172,39.8445,-75.2831,41.7898. A screenshot of the web viewer is included in Figure 17.

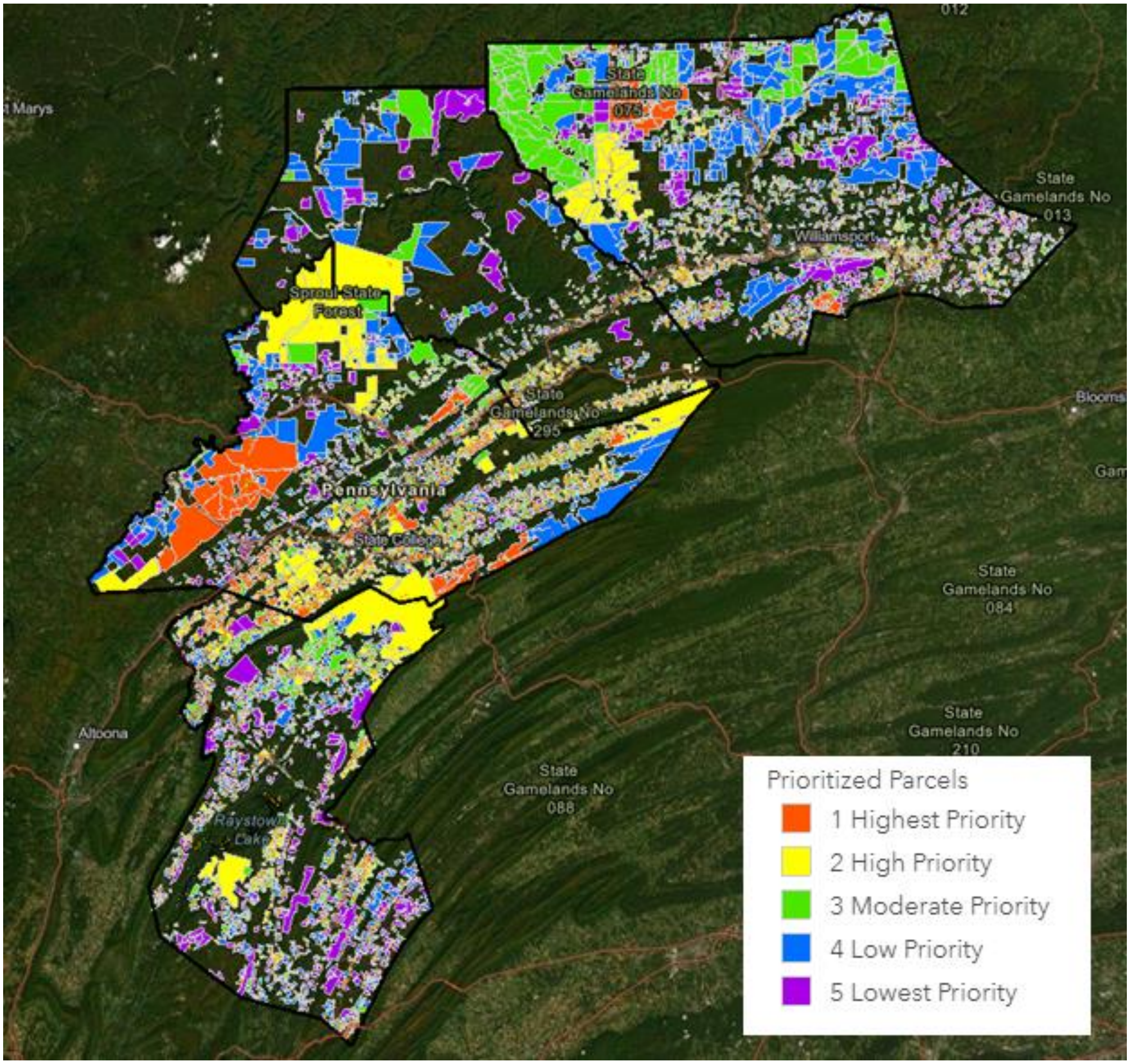

Figure 17. A screenshot from the precision conservation forest buffer prioritization web viewer displaying ranked parcels in five tiers across Centre, Clinton, Huntingdon, and Lycoming counties in central Pennsylvania.

8.5 Data-Driven Applications

8.5.1 Restoration Projects

From the precision conservation analysis through August 2019, 8 high-priority restoration projects were implemented across the four-county study area. These projects resulted in the installation of 70.35 acres of forest riparian buffer, filtering 1,390 total upslope acres, 895 of which contained agriculture, impervious surface, and turf land covers. The average treatment area to forest buffer ratio is 4 upslope acres treated to 1 acre of forest buffer installed. These 11 high-priority projects treat almost 20 upslope acres for every single acre of buffer.

8.5.2 Forest Buffer Conservation Opportunity Area Analysis

Conservation and restoration professionals across Pennsylvania are unified in their common goals to protect and improve water quality of local streams and rivers. Conserving existing riparian forest buffers is a highly effective option to intercept and treat runoff from upslope farmland, protecting water quality in the receiving waters. As Pennsylvania focuses on major riparian forest buffer restoration goals, it is necessary to couple that approach with buffer conservation to reduce losses *and* achieve gains in forest buffer coverage. Farmers who are currently enrolled in, or applying for, preservation programs are good prospects for buffer protection and restoration. New high-resolution data can inform farmland preservation decision makers on where forested buffers have the largest impact on protecting water quality and should be high priorities for conservation.

The Chesapeake Conservancy is working in partnership with the ClearWater Conservancy, Western Pennsylvania Conservancy, and Centre County Ag Land Preservation to create a web tool for prioritizing parcels for conservation in Centre County. As of August 2019, a draft conservation prioritization web viewer has been created that prioritizes 464 high-value parcels as excellent candidates for forest buffer conservation. Over the next several months the tool will be calibrated to ensure it meets the needs of local conservation organizations and we will explore the number of parcels that align as high priorities for restoration and conservation activities.

8.5.3 Rapid Stream Delisting Strategy

In 2019, Pennsylvania had 3,084 miles of stream listed as impaired due to agricultural activities, the most impaired stream miles attributed to any specific land use in the state. The Chesapeake Conservancy and partners in central Pennsylvania have developed a strategy to examine each of the ten agricultural impairments in Centre County and evaluate each to assess which ones could potentially be removed from the impaired list most quickly by reducing sediment and nutrient inputs from the landscape. The segments were evaluated for how many parcels upstream and along the impaired stream stretch are likely contributing pollutants to the impairment. The rapid stream delisting strategy looks at agriculturally impaired stream segments where there are less than ten likely parcels contributing. This strategy is coupled with a project to track as many restoration projects completed by partner organizations as possible to link places where progress can be made fastest, with locations where partners have built strong landowner relationships. The next step for rapid delisting catchments will be to focus partners' landowner outreach and build out full budgets to delist these streams by completing full farm restoration projects on all priority parcels in each. To date, eight partner organizations have committed to exploring the rapid delisting strategy in their geography.

8.5.4 Outreach

The Halfmoon Valley Farm Tour was an event led by Chesapeake Conservancy in partnership with eleven conservation organizations to engage landowners of parcels critical to water quality improvements in conversations about restoration projects. The theme of the workshop was minimizing impacts of heavy rains on farmland, which has hurt on-farm economy over the past several years and can be improved through installation of best management practices. The Chesapeake Conservancy and partners designed this workshop around engaging the right landowners with the right practices, and moving forward with project implementation. The Chesapeake Conservancy created an outreach plan by looking at priority parcels in relation to where organizations had existing relationships and wanted to reach out to landowners. Each partner organization selected priority landowners to reach out to personally, either via door knocking, a phone call, or a planned visit—the first time several organizations have made a concerted effort to engage many landowners in key locations. Forty-eight priority landowners were invited to the workshop.

At the workshop, 4 local priority landowners discussed their on-farm practices and how those practices have led to economic and water quality benefits on their property. Attendance at the workshop included eight priority farmers, 12 total farmers, and 32 total participants. Two priority restoration projects are moving forward as a result of the workshop.

8.5.5 Pennsylvania Forest Buffer Analysis Handout

Chesapeake Conservancy has created a handout that summarizes opportunities for forest buffer restoration and conservation across counties within the Chesapeake Bay Watershed in Pennsylvania. The handout can be found in Appendix D.

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Appendices

Appendix A. Monitoring Quality Assurance Project Protocol

Click image to access PDF version of document.

Implementing precision conservation in the Susquehanna River watershed

QUALITY ASSURANCE PROJECT PLAN

COMPLETED PLAN PREPARED BY:

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5-1-17

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Appendix B. Elk Creek Case Study

B1. Overview

As a part of the monitoring project, the scientists also took measurements to understand how in-stream and riparian best management practices affect in-stream measurements. In this section, a case study is presented for a single restoration project on Elk Creek, in eastern Centre County, Pennsylvania. The results, discussion, and conclusions discuss pre-and post-restoration data findings.

B2. Elk Creek Monitoring Sites

Elk Creek monitoring sites are described in Section 2.1.1 of this technical report. Locations of the Elk Creek monitoring sites are shown in Figure 2 and relative locations of individual monitoring sites to one another are found in Figure 5.

B3. Methods

In-stream data collection methods can be found in Section 3 of the technical report. A timeline for data collection at Elk Creek sites can be found in Section 5.

B3.1 Restoration Techniques

Restoration practices installed at the Brown site on Elk Creek include a total of 35 in-stream habitat and streambank stabilization structures, 1,500 linear feet of streambank exclusion fencing, an in-stream watering access for livestock, and a 1.5 acre forest riparian buffer planting. In-stream restoration structures are shown in Figure 18. The footprint of the forest riparian buffer planting and watering access are shown in Figure 19.

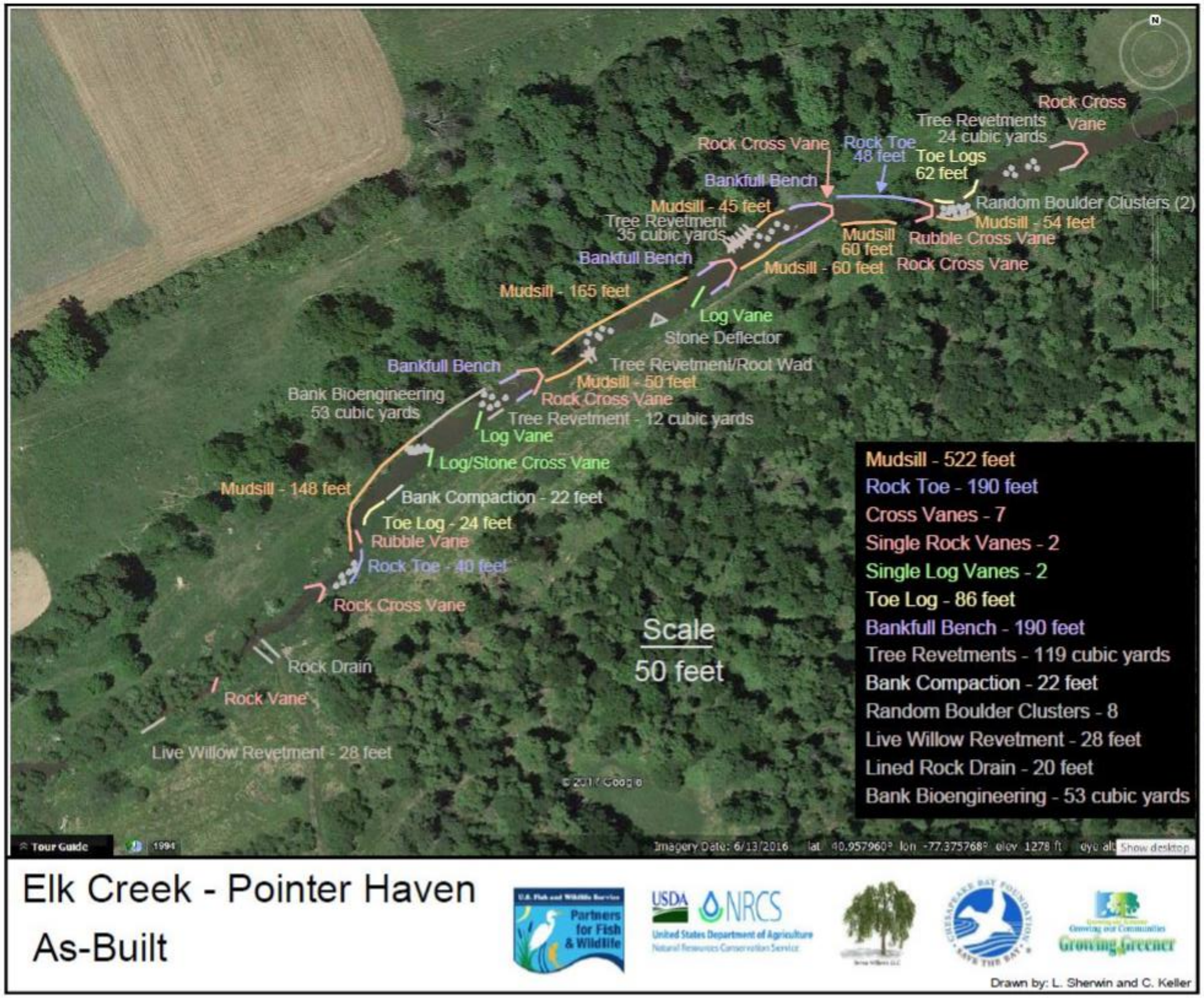


Figure 18. In-stream restoration and streambank stabilization structures installed on the Brown property, Elk Creek, Centre County, Pennsylvania.

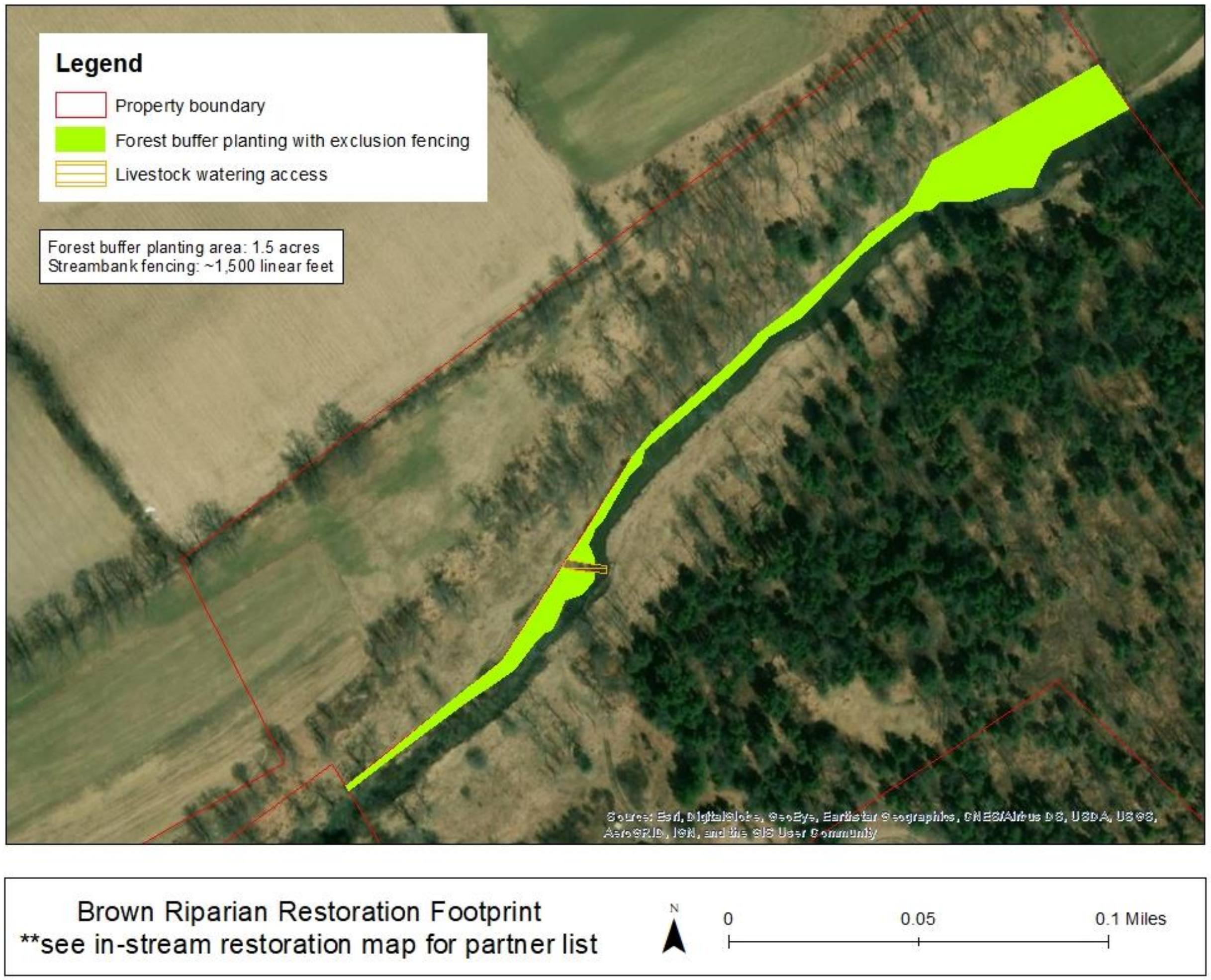


Figure 19. Brown property riparian restoration footprint. Riparian restoration included 1.5 acres of forest riparian buffer planting, installation of 1,500 linear feet of streambank fencing, and a livestock watering access.

B4. Results

B4.1 Fish and Benthic Macroinvertebrates

There is a clear visual separation between macroinvertebrate communities sampled from Elk Creek pre-restoration, shown with green points, and post-restoration, shown with brown points in Figure 20. This separation also explains 23% of the variability in communities throughout the study; however, the relationship is highly variable and not significant (*P* = 0.21). Similarly, for fish communities there is a visual difference in community similarity pre- and post-restoration (Figure 21). However, this is not a significant effect of restoration (*P* = 0.272) and only explains 7.5% of the variability in fish communities sampled.

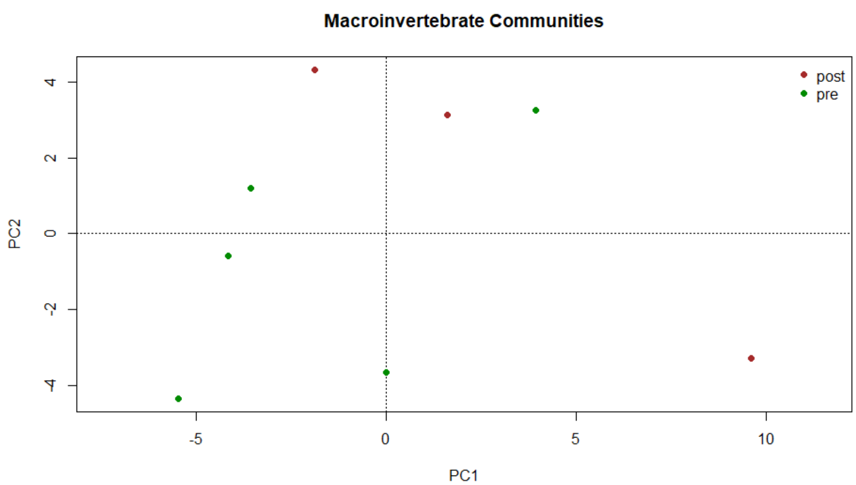


Figure 20. Redundancy analysis of macroinvertebrate communities as related to restoration actions. Samples are grouped by pre- and post-restoration.

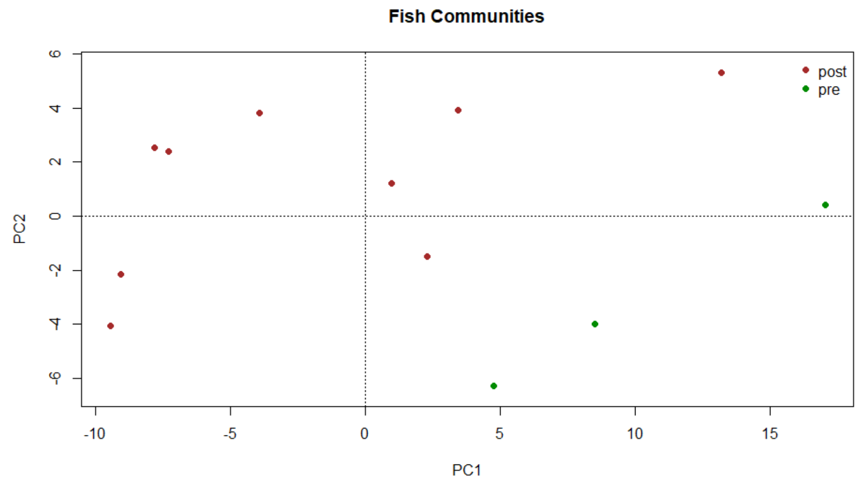


Figure 21. Redundancy analysis of fish communities as related to restoration actions. Samples are grouped by pre- and post-restoration.

B4.3 Sediment

Grain size is measured using the Wentworth ψ scale, which is $-\log_2$ (diameter in millimeters) of grain size (Table 9). By convention, large particles have a negative value, while fine particles are a large positive number. The largest clay particle at 0.002 mm is 8.96 ψ, and the largest silt particle is 0.05 mm or 4.32 ψ.

Table 9. Size ranges and classification of the Wentworth (1922) Scale.

Millimeters (mm)		Micrometers (μm)	Phi (ϕ)	Wentworth size class		Rock type
	4096		-12.0			
				Boulder	Gravel	Conglomerate/ Breccia
	256		-8.0			
				Cobble		
	64		-6.0			
				Pebble		
	4		-2.0			
				Granule		
	2.00		-1.0			
				Very coarse sand	Sand	Sandstone
	1.00		0.0			
				Coarse sand		
1/2	0.50	500	1.0			
				Medium sand		
1/4	0.25	250	2.0			
				Fine sand		
1/8	0.125	125	3.0			
				Very fine sand		
1/16	0.0625	63	4.0			
				Coarse silt	Silt	Siltstone
1/32	0.031	31	5.0			
				Medium silt		
1/64	0.0156	15.6	6.0			
				Fine silt		
1/128	0.0078	7.8	7.0			
				Very fine silt		
1/256	0.0039	3.9	8.0			
				Clay	Mud	Claystone
	0.00006	0.06	14.0			

Sediment characterization is not typically a part of stream restoration monitoring but it can yield clues about the overall effectiveness of a stream restoration project. The scientists hypothesize that streams in balance with the local hydrology will receive little surface overland flow, and fine particles from adjacent terrain will winnow out during periods of high stream flow. In restored streams, the overall mean grain size should be small (on the Wentworth ψ scale, Wentworth, 1922) and particles should span a narrow range of grain sizes (low sorting values). On degraded steams, it is thought the stream bed has abundant fine sediment (larger values on the Wentworth ψ scale) and a broad mix of particles across a wide range of sizes (high sorting values). The grain size characterization in the forest reference streams demonstrated three of the hypotheses:

1. Both mean grain size and sorting values were relatively consistent for each site across three years of monitoring. Because these sites did not receive modification, this result confirms that grainsize in stream bed sediments can be stable across annual weather fluctuations.
2. Mean Grain Size in the forest references sites averaged to -0.03ψ, or Very Coarse Sand. Coarse sand is considered to be particles between 1 and 2 millimeters. These particles are known to be suitable habitat for macroinvertebrate burrows and trout redds.
3. The calculated sorting of sediments in the forest reference sites were an average of 2.4 mm (± 5 mm). This value is considerable smaller than sites that are known to be agriculturally impaired.

The Brown restoration site along Elk Creek received installation of in-stream habitat structures and forest riparian buffer plantings between 2017 and 2018. This site comprises an effective pre-restoration, post-restoration comparison with one upstream site as a local control (Miller site). Sediment characteristics for Elk Creek are shown in Figure 22. Before site restoration was completed, the three downstream sites (Brown, Sheats, and Neff) had an average grain size of 1.04 ψ, or Medium sand. Following restoration, these sites were found to have -0.8ψ or Very coarse sand, which is similar to the forest reference sites. Sorting for this group of three downstream sites was 2.81 mm prior to restoration and 2.48 mm following restoration. Consistent with the hypotheses, Elk Creek sites downstream of the restoration area contained sediments that became coarser and the sorting range became narrower. The reason for the notable change in the upstream local reference site grain size is not clear to the scientists. The Miller farm is upstream of all restoration activities and the grain size changed from 2.19 ψ in 2017 to -0.37 ψ (average of 2018 and 2019). This corresponds to classifications of Fine sand and Very Coarse Sand, respectively. It is unclear if this change was due to weather and spring freshets during 2018 or other land use changes from upstream or adjoining properties.

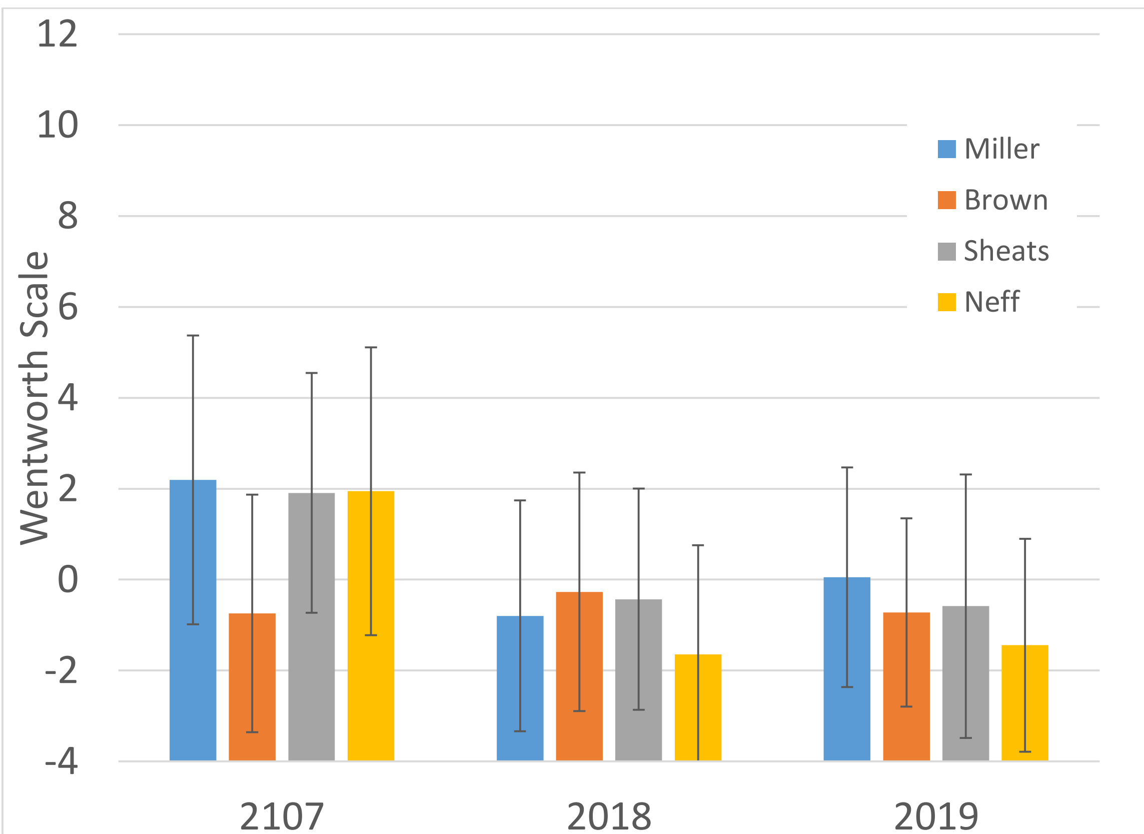


Figure 22. Grain size characteristics in Elk Creek show considerable change from 2017 (prior to restoration) and 2018-2019 (post-restoration). Grain sizes for downstream sites after restoration are smaller after restoration than before, and sorting ranges became narrower.

The change in mean grain size from 2017 to 2019 was used in a regression with the landscape variables presented in Section 4.6 to assess a relationship between the agricultural land use impacts and the scale of grain size change observed during the study (Figure 23). There has been dramatic shift to coarser particles at some of the monitoring sites as stream restoration progresses—the samples taken from the forested reference sites show little change in particle size through time. While these correlations between sediment size shift and landscape variables (Figure 23) are not statistically significant at this time, sites seem to be showing a response to restoration. There appears to be an emerging trend that the scale of improvement may be related to the landscape variables that indicate the level of agricultural impairment. The relationship between sediment size change and intact upstream forest buffer appears to be confounded by upstream watershed size, which is not normalized in the calculation of forest acres.

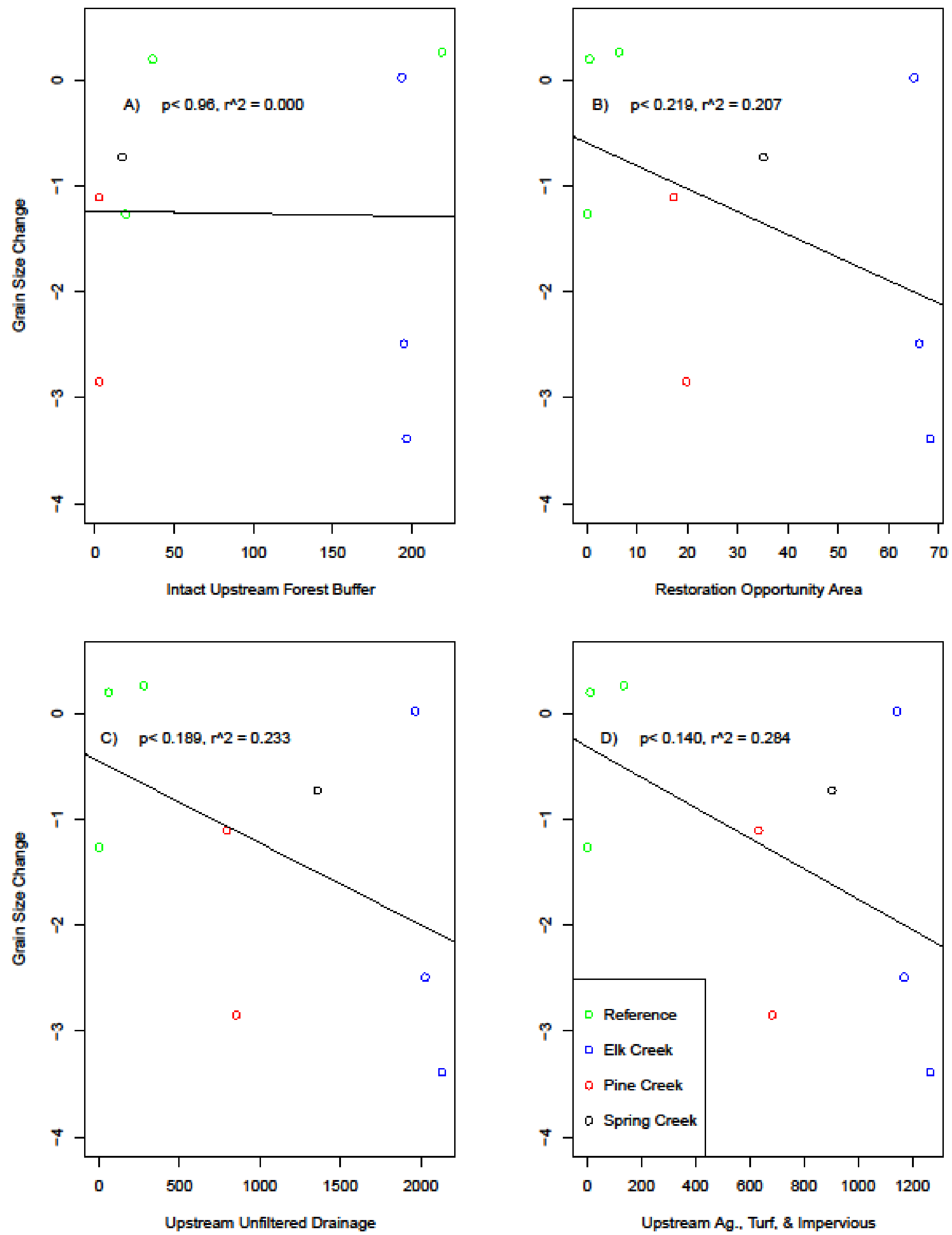


Figure 23. Change in mean grain size from pre-restoration samples to post restoration samples (2017 to 2019). Upstream samples that were not restored were removed from the analysis, as were sites that did not have complete records. All areas are measured in acres, the grain size change is $-\log_{(2)}$ (Diameter in millimeters): a -3 grain size shift is a particle size 8 times (2^3) larger than at the beginning of the experiment.

B4.2 In-situ Water Quality and Ecosystem Function

This analysis is very preliminary in that only the effects of in-stream habitat work were monitoring. More dramatic changes are expected after the newly planted riparian forest becomes established. Because there were considerable between-year differences in precipitation (e.g., 2018 had record rainfall), the unaltered upstream station was included in all subsequent analyses (two-way analysis of variance with before/after and upstream/downstream as factors) to account for this variability.

Although we did not expect habit restoration to have a substantial effect on stream nutrients, total phosphorus was highest at the bottom of the Brown property post-construction (Figure 24) after accounting for the between-year differences (significant site x restoration interaction, $P < 0.028$). This indicates that the downstream site had a higher phosphorus concentrations after restoration than before, when upstream sites measurements were taken into account. Although statistically different, it is unlikely that a median difference of only 3 µg P/L is biologically important in the long-term. Total phosphorus concentrations at the Brown station post-construction were within the interquartile range of agriculturally-impacted streams in central Pennsylvania (Figure 24, red lines). Total nitrogen, soluble reactive phosphorus, and nitrate-nitrogen did not exhibit a statistically significant interaction of sites and restoration and the measurements were within or near the interquartile range for forested streams in central Pennsylvania (Figure 24, green lines). It is possible that the construction activity associated with the restoration work might have exposed or temporarily dislodged phosphorus-rich sediment that was then mobilized into the water column during rain events. This observation is supported by lower alkaline phosphatase activity by algae and other microorganisms growing on cobbles at the Brown site compared to the upstream reference (Figure 25) Alkaline phosphatase is an enzyme produced by microorganisms when phosphorus stressed. Lower alkaline phosphates activity indicates less phosphorus stress and, therefore, more phosphorus availability.

Ecosystem metabolism parameters also differed considerably between the pre- and post-construction periods (Figure 26, significant interaction between sites and restoration for all three plots, $P < 0.001$). Gross primary productivity (i.e., all photosynthesis occurring immediately upstream of the monitoring location) and ecosystem respiration were higher for both sites in the post-construction period with a more substantial increase occurring in the upstream reference site (note that a more negative value in ecosystem respiration plot means higher rate of respiration). Although we were unable to detect the impact of restoration on algal biomass (chlorophyll a) or maximum electron transport rate (photosynthetic capacity) (Figure 25), differences between the pre- and post-construction periods might be partially due to greater short-term nutrient runoff driven by increased precipitation during the 2018 season. It is also possible that less tree canopy covering the upstream site, allowed for a greater photosynthetic response to increased runoff during 2018 contributing to the observed statistical interaction. We observed a significant impact of restoration on net ecosystem productivity as well (significant site x restoration interactions, $P = 0.017$), although the effect of restoration was in opposite direction compared to GPP, showing NEP increases with restoration. This would make sense because, although GPP decreased with restoration, respiration also decreased with restoration. The relative difference in these two variables can result in increase or decrease in NEP which indicates the relative balance between carbon production (gross primary productivity) and consumption (ecosystem respiration). The more negative the value for net ecosystem production, the more the microbial community depends on sources of energy entering the stream from the terrestrial landscape (e.g., leaf litter and dissolved organic matter). Generally, more forested streams have a more negative net ecosystem productivity. It is possible that high rains encountered during the post-construction period washed in additional terrestrial organic matter that fueled additional microbial productivity in both reaches. Greater rates of metabolism also likely resulted in higher 24-hour oxygen fluctuations (Figure 27, significant post-restoration effects for all sites, $P < 0.001$). However, these effects did not differ between the upstream control and the restored site (non-significant restoration x sites interaction, $P > 0.05$).

Nitrogen uptake within the Brown restoration site varied between the pre-construction and the post-construction periods (Table 10). Uptake length, the distance a nitrogen atom travels before being taken up by microorganisms on the stream bottom, was nearly twice as far post-construction. Likewise, uptake velocity, an indicator of nitrogen demand, during the post-construction period, was half that of pre-construction. Higher nitrate concentrations on the day the post-construction measurements were made is the most likely explanation of this apparently lower nitrogen assimilation capacity during the post-construction period (pre-construction NO_3-N=120 μg/L, post-construction NO_3-N=286 μg/L). When nitrate concentration is taken into account in the calculation of ambient areal uptake rate, the difference between the periods is indistinguishable (Table 10).

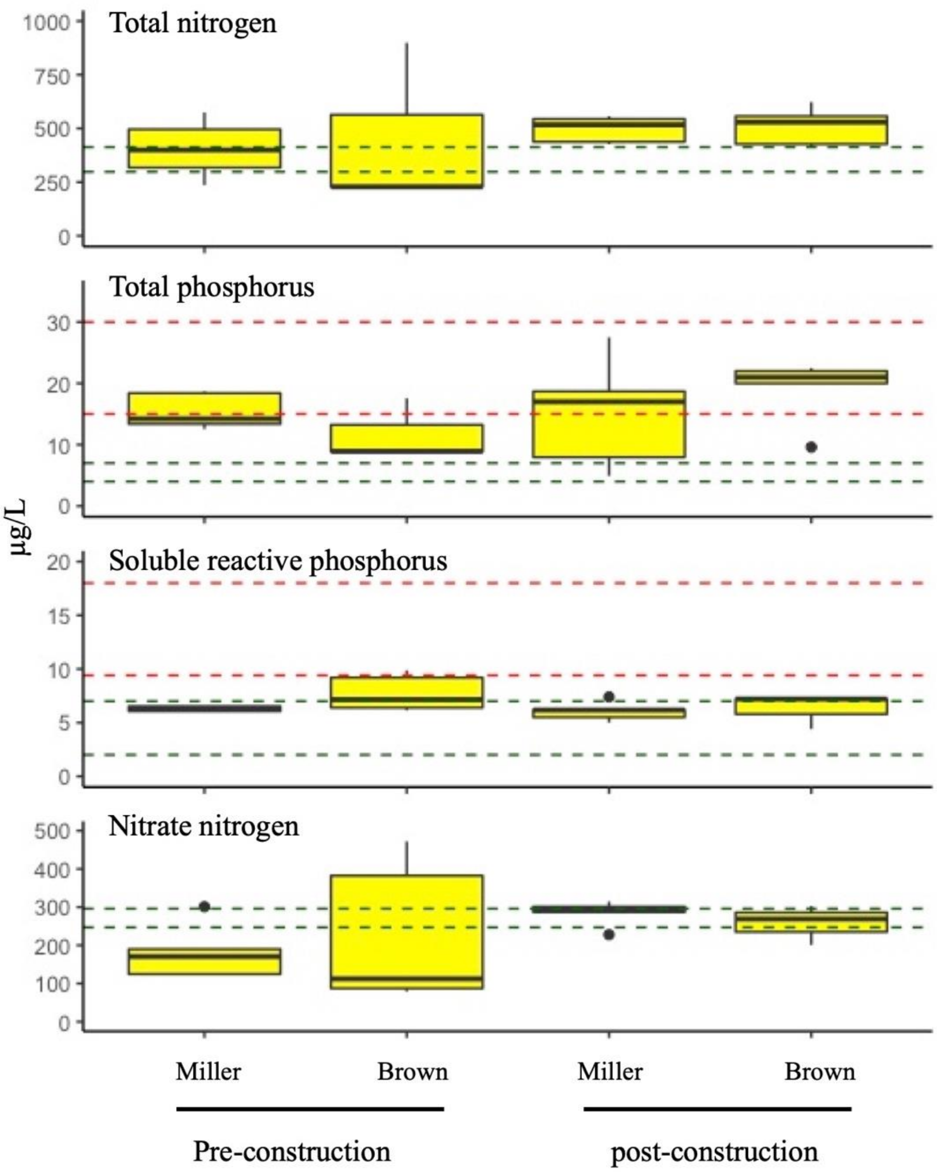


Figure 24. Boxplots showing the interquartile range (25% to 75%, yellow boxes) and total ranges for measurements of nitrogen and phosphorus concentrations both upstream (Miller) and downstream (Brown);pre-construction and post-construction restoration in Elk Creek. Dashed green lines depict the interquartile range for five additional minimally-impacted forested streams in this region and red lines depict the interquartile range for five additional agriculturally-impacted streams in this region (S.T. Rier, unpublished data). A two way ANOVA full model was performed at an alpha of 0.05. Since there are factors other than restoration that can potentially impact the measurements between upper (Miller) vs lower (Brown) sites**,** the scientists are interested in the interaction between sites and restoration such than a significant interaction indicates a significant effect of restoration. The same approach was used for Figures 25-26.

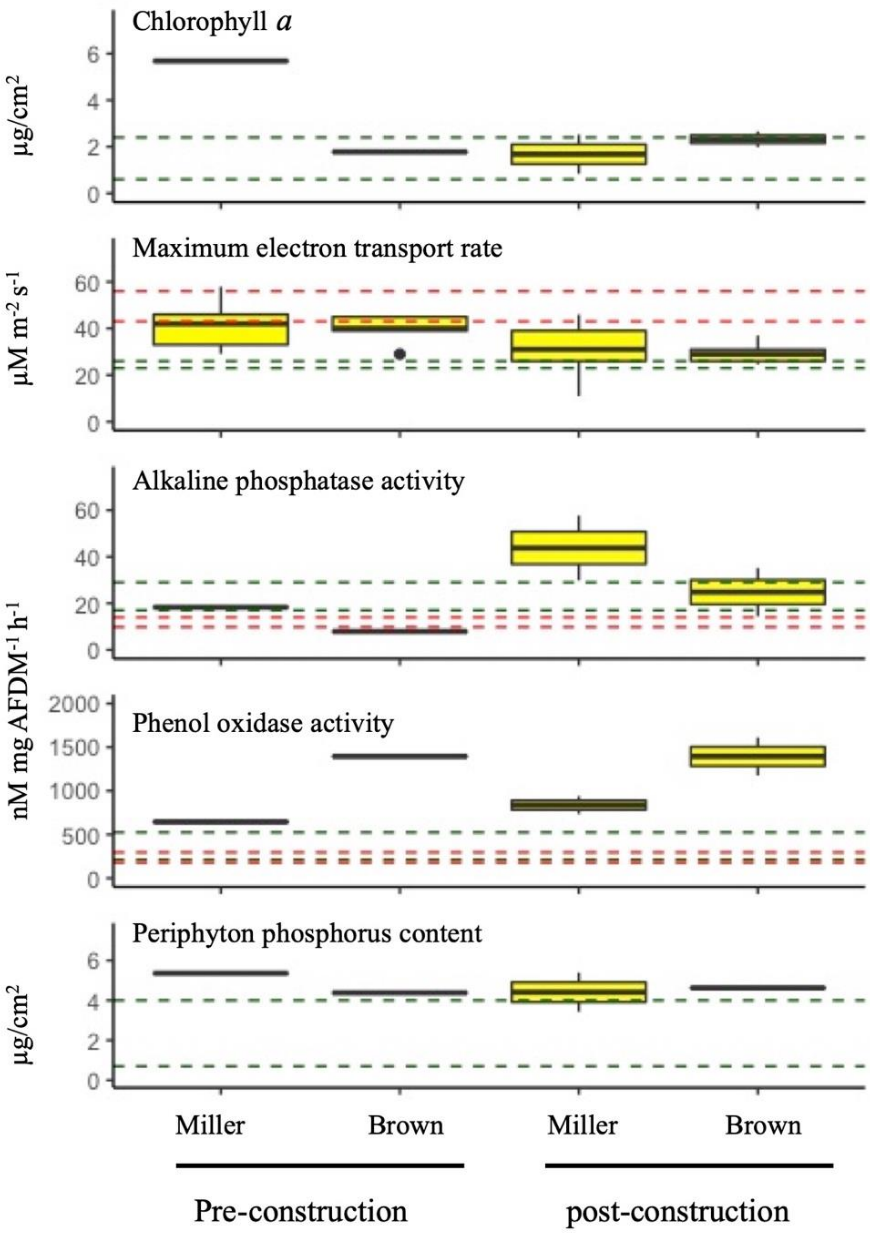


Figure 25. Boxplots showing the interquartile range (25% to 75%, yellow boxes) and total ranges for measurements of periphyton (algae and other microorganisms colonizing cobbles) biomass and physiological condition both upstream (Miller) and downstream (Brown) and pre- and post-construction restoration in Elk Creek. Dashed green lines depict the interquartile range for five additional minimally-impacted forested streams in this region and red lines depict the interquartile range for five additional agriculturally-impacted streams in this region (S.T. Rier, unpublished data). Analysis as in Figure 24.

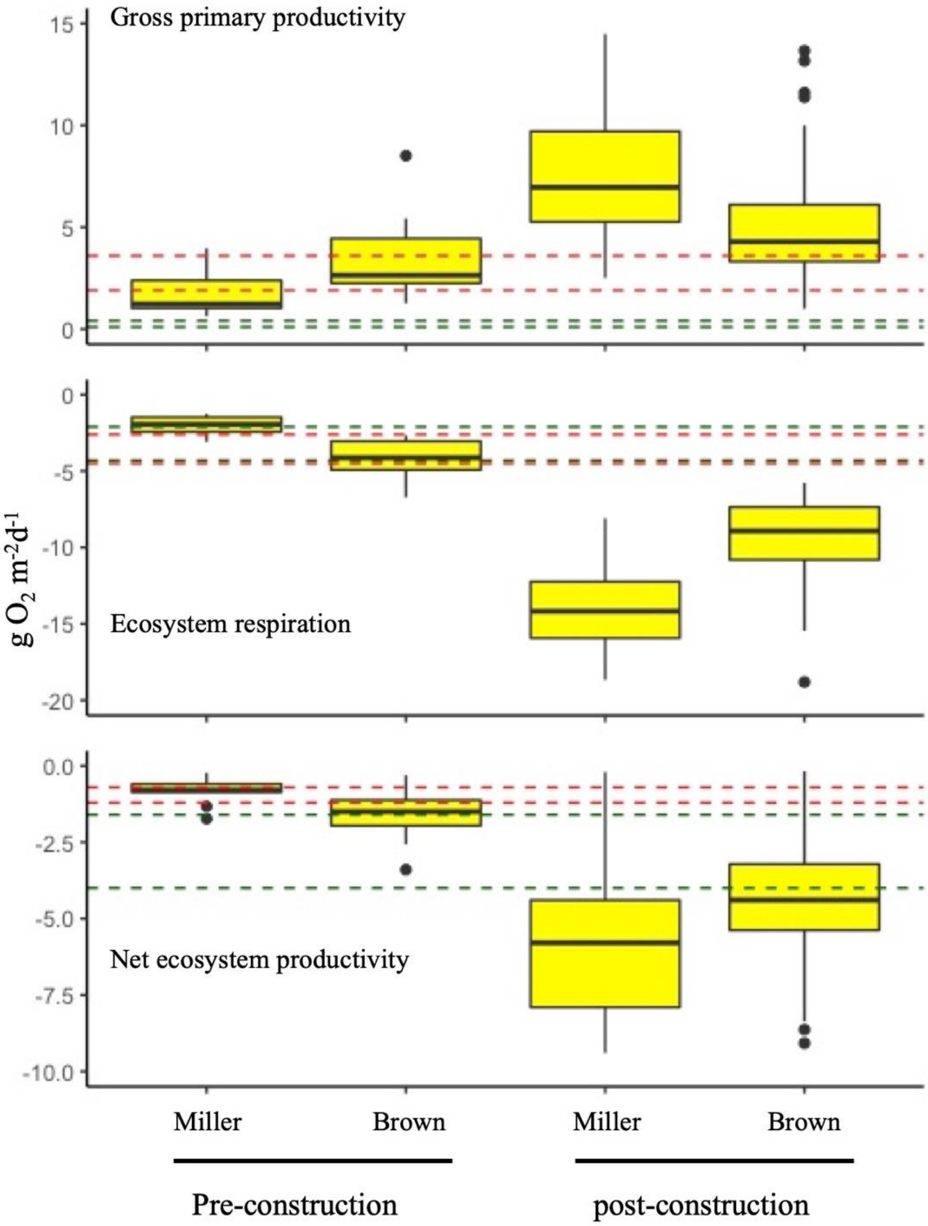


Figure 26. Boxplots showing the interquartile range (25% to 75%, yellow boxes) and total ranges for measurements of ecosystem metabolism both upstream (Miller) and downstream (Brown) and pre- and post-construction restoration in Elk Creek. Dashed green lines depict the interquartile range for five additional minimally-impacted forested streams in this region and red lines depict the interquartile range for five additional agriculturally-impacted streams in this region (S.T. Rier, unpublished data). Analysis as in Figure 24. Note: the more negative numbers in ecosystem respiration mean more rapid respiration.

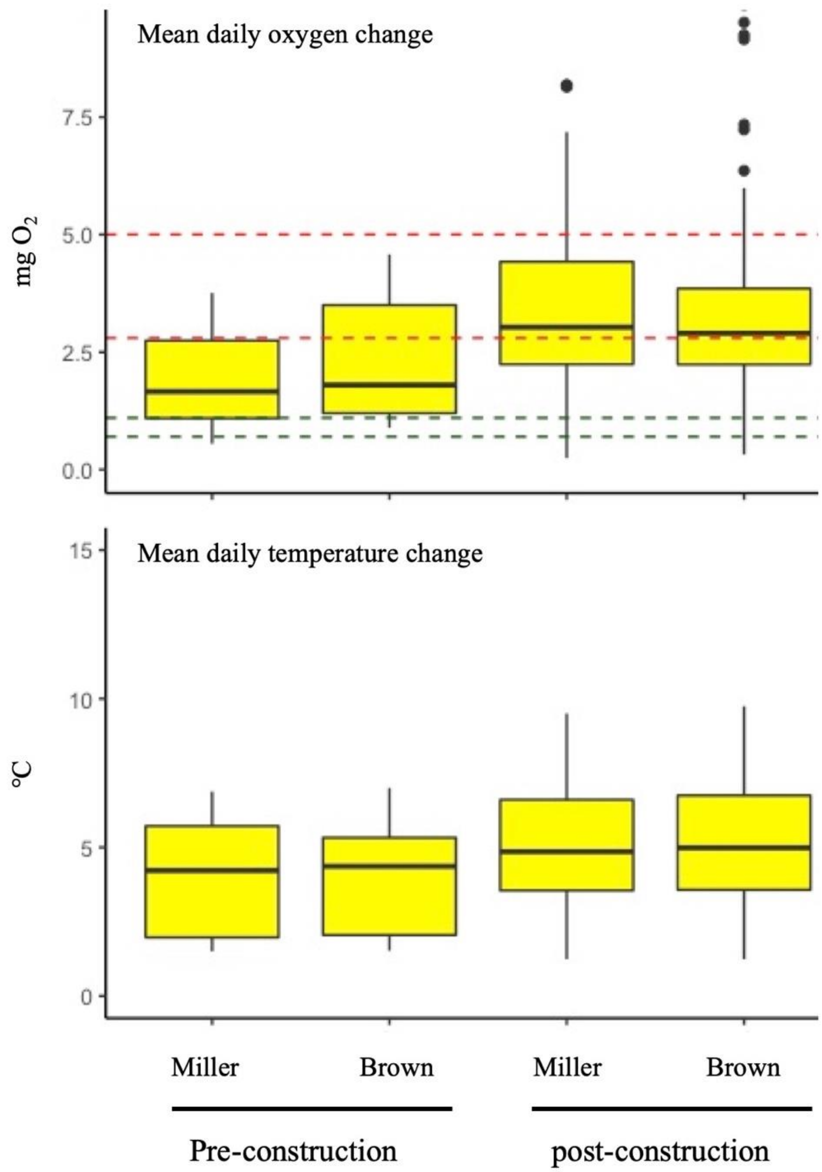


Figure 27. Boxplots showing the interquartile range (25% to 75%, yellow boxes) and total ranges for measurements of mean daily oxygen and temperature change both upstream (Miller) and downstream (Brown) and before (pre-construction) and after (post-construction) restoration in Elk Creek. Dashed green lines depict the interquartile range for five additional minimally-impacted forested streams in this region and red lines depict the interquartile range for five additional agriculturally-impacted streams in this region (S.T. Rier, unpublished data). Analysis as in Fig 24.

Table 10. Nitrogen uptake parameters measured using the Tracer Additions for Spiraling Curve Characterization (TASCC) method (Covino et al. 2010) at the Brown site both pre- and post-construction.

	Brown pre-construction	Brown post-construction
Ambient uptake length ($S_{w\text{-}amb}$, meters)	262	436
Ambient uptake velocity ($V_{f\text{-}amb}$, m/s)	0.0134	0.0057
Ambient N uptake rate ($\mu g\ m^{-2}\ s^{-1}$)	1.6270	1.6320

B5. Conclusions of pre- and post- Elk Creek Restoration Study

1. When looking at macroinvertebrate and fish communities from Elk Creek pre- and post-restoration, there is a clear visual separation between communities sampled prior to restoration taking place and samples taken after restoration, however these results are not significant with such a small sample size.
2. At restoration sites and sites downstream, sediment generally became coarser in the years following in-stream restoration. Coarser stream bottom sediments are better suited to macroinvertebrate and fish habitat than silty sediments that can smother insect and fish eggs. There is a weak trend suggesting the larger the size of the area being restored, the larger the potential for grain size change after stream restoration. However, because of the variability of the measurements at a limited number of sites, this is not a statistically significant trend.
3. There is very little evidence that restoration at this site is having an impact on water chemistry or ecosystem function in the short time period that has elapsed since construction. We did observe a small but statistically significant effect of restoration on total phosphorus. However, the difference in concentrations were unlikely high enough to be biologically important in the long-term and may have been a lingering artifact of the disturbance caused by construction. Gross primary productivity and respiration were higher during the post-construction period, which may have been driven by runoff generated from rain events in 2018. The magnitude of this difference was greatest at the upstream site, producing a significant site x restoration interaction. This difference is best explained by a lack of canopy at the upstream site, which may have allowed for a higher photosynthetic response to 2018 runoff because of greater light availability.

Appendix C. Precision Conservation Tiering and Ranking System

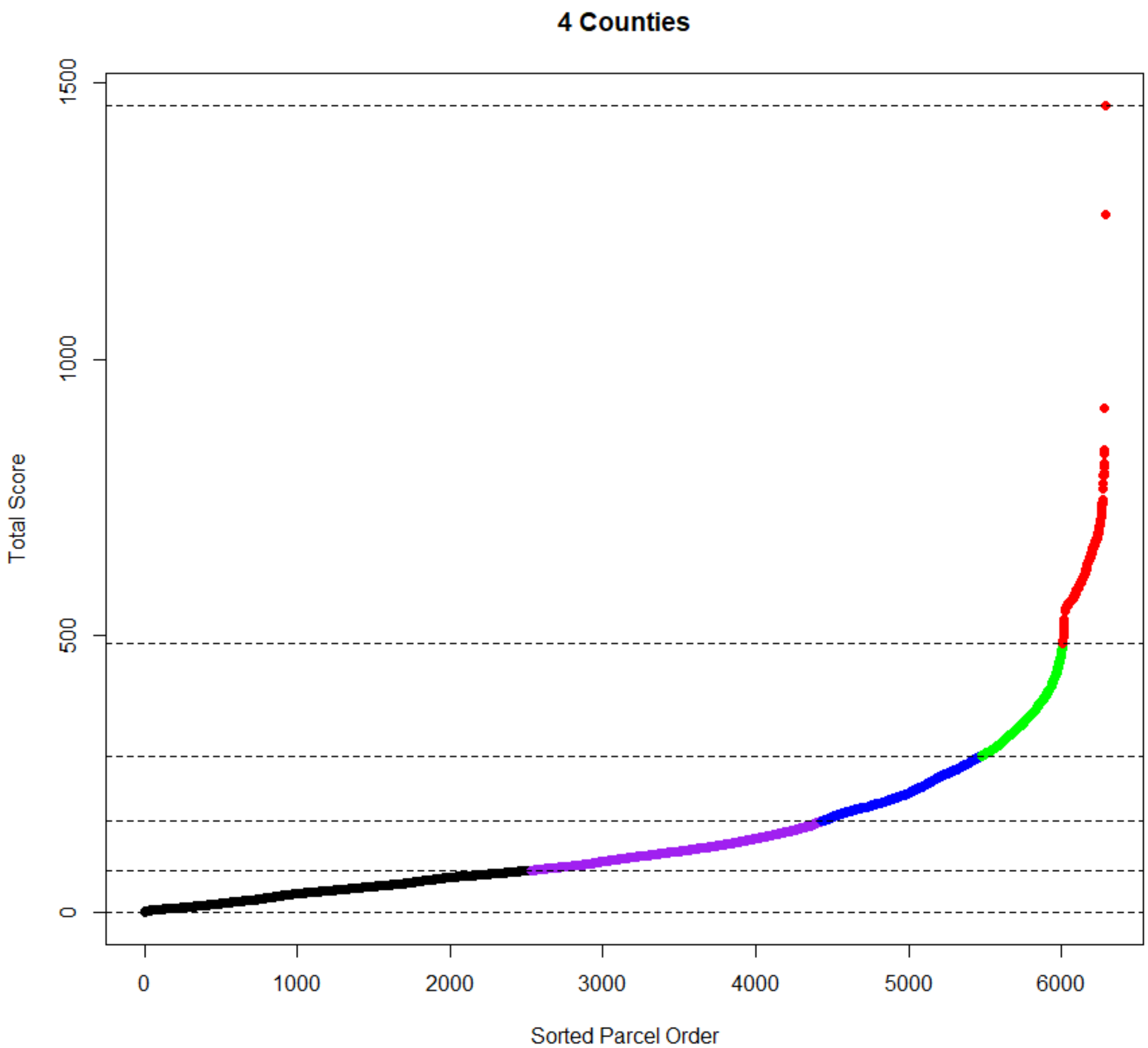


Figure 28. The distribution of prioritized parcel scores across all four counties. Highest scores fall in Tier 1, lowest scores fall in Tier 5. Tier 1 - red; Tier 2 - green; Tier 3 - blue; Tier 4 - purple; Tier 5 - black. The score thresholds (see below) that define the tiers are based on the Jenks natural breaks classification method and the total distribution of scores in all four counties. This method reduces the variance within classes and maximizes the variance between classes.

<u>All 4 Counties</u>
Tier 1: 486-1459
Tier 2: 282-486
Tier 3: 164-282
Tier 4: 75-164
Tier 5: 0-75

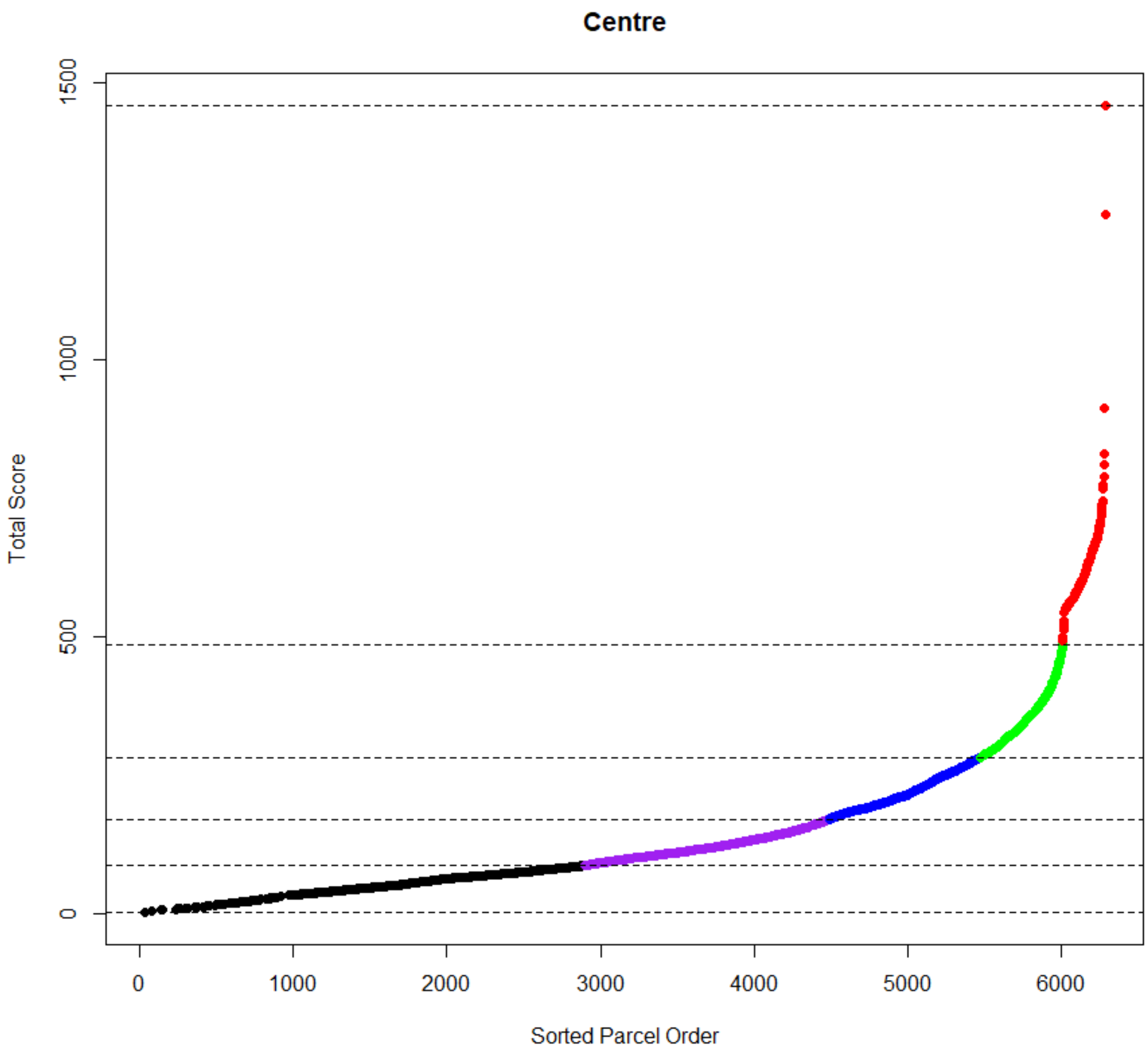


Figure 29. The distribution of prioritized parcel scores in Centre county. Highest scores fall in Tier 1, lowest scores fall in Tier 5. Tier 1 - red; Tier 2 - green; Tier 3 - blue; Tier 4 - purple; Tier 5 - black. The score thresholds (see below) that define the tiers are based on the Jenks natural breaks classification method and the total distribution of scores in Centre county. This method reduces the variance within classes and maximizes the variance between classes.

<u>Centre</u>
Tier 1: 485-1459
Tier 2: 281-485
Tier 3: 169-281
Tier 4: 86-169
Tier 5: 0-86

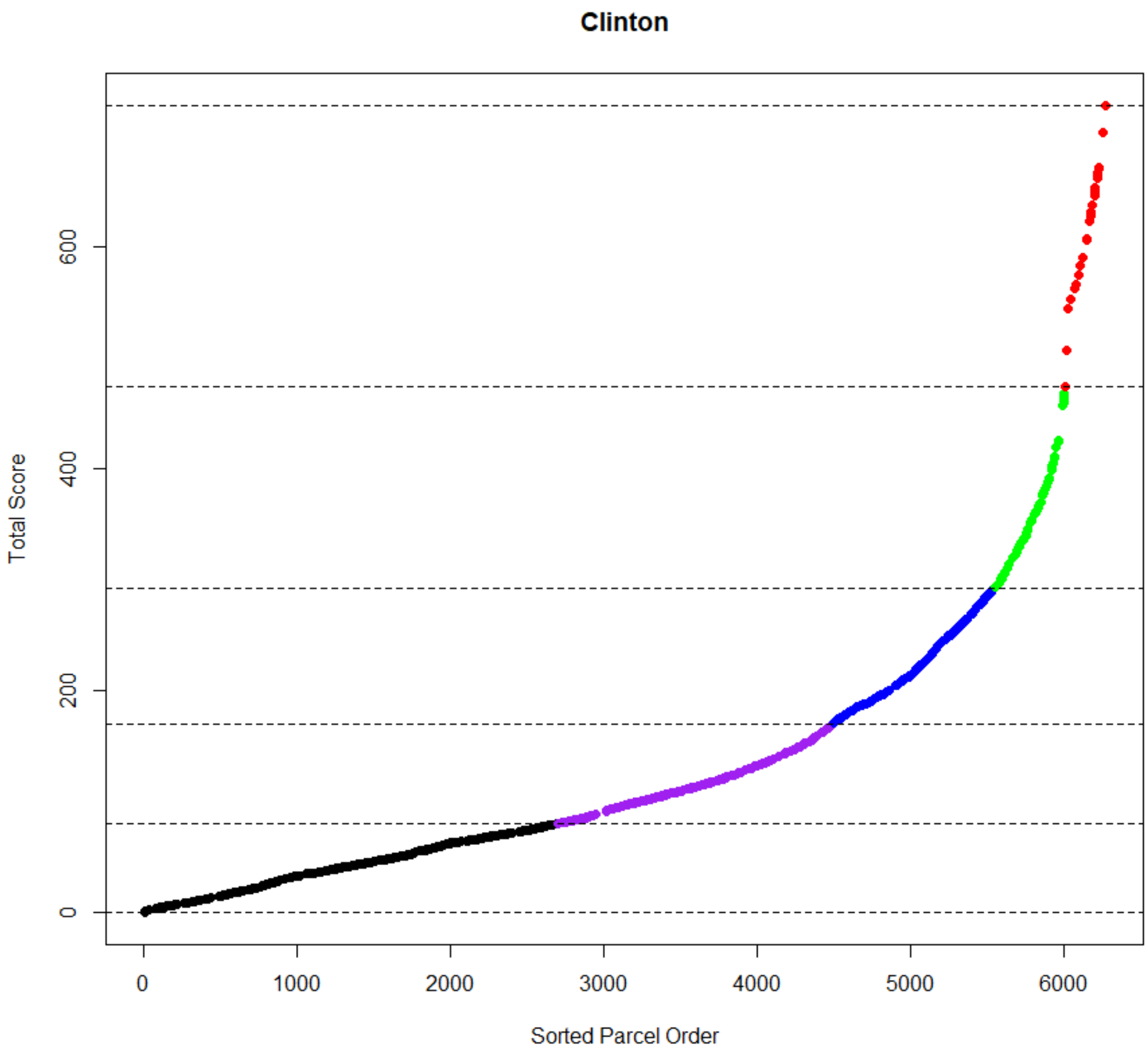


Figure 30. The distribution of prioritized parcel scores in Clinton county. Highest scores fall in Tier 1, lowest scores fall in Tier 5. Tier 1 - red; Tier 2 - green; Tier 3 - blue; Tier 4 - purple; Tier 5 - black. The score thresholds (see below) that define the tiers are based on the Jenks natural breaks classification method and the total distribution of scores in Clinton county. This method reduces the variance within classes and maximizes the variance between classes.

<u>Clinton</u>
Tier 1: 474-728
Tier 2: 293-474
Tier 3: 170-293
Tier 4: 80-170
Tier 5: 0-80

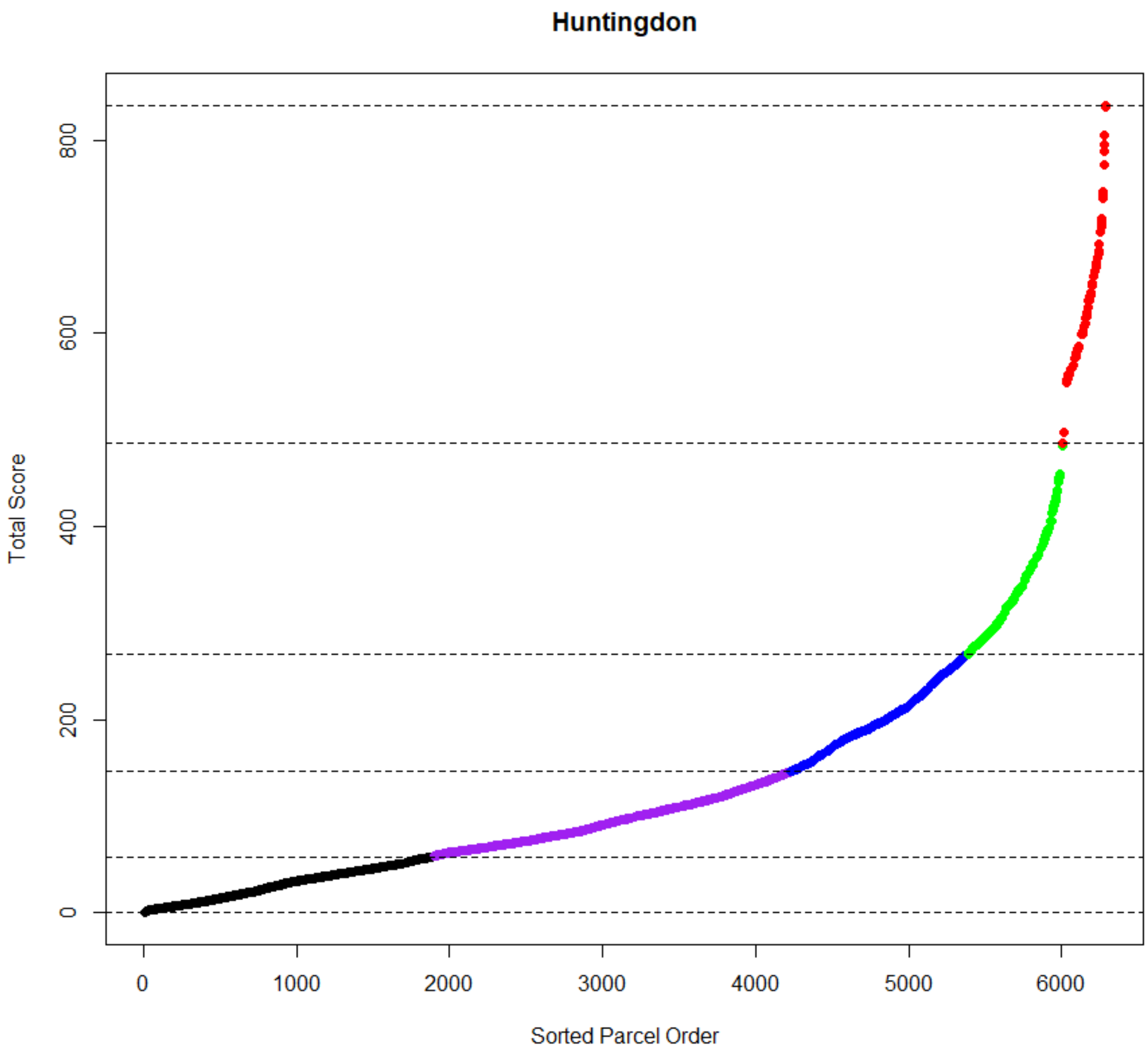


Figure 31. The distribution of prioritized parcel scores in Huntingdon county. Highest scores fall in Tier 1, lowest scores fall in Tier 5. Tier 1 - red; Tier 2 - green; Tier 3 - blue; Tier 4 - purple; Tier 5 - black. The score thresholds (see below) that define the tiers are based on the Jenks natural breaks classification method and the total distribution of scores in Huntingdon county. This method reduces the variance within classes and maximizes the variance between classes.

<u>Huntingdon</u>
Tier 1: 486-835
Tier 2: 268-486
Tier 3: 146-268
Tier 4: 58-146
Tier 5: 0-58

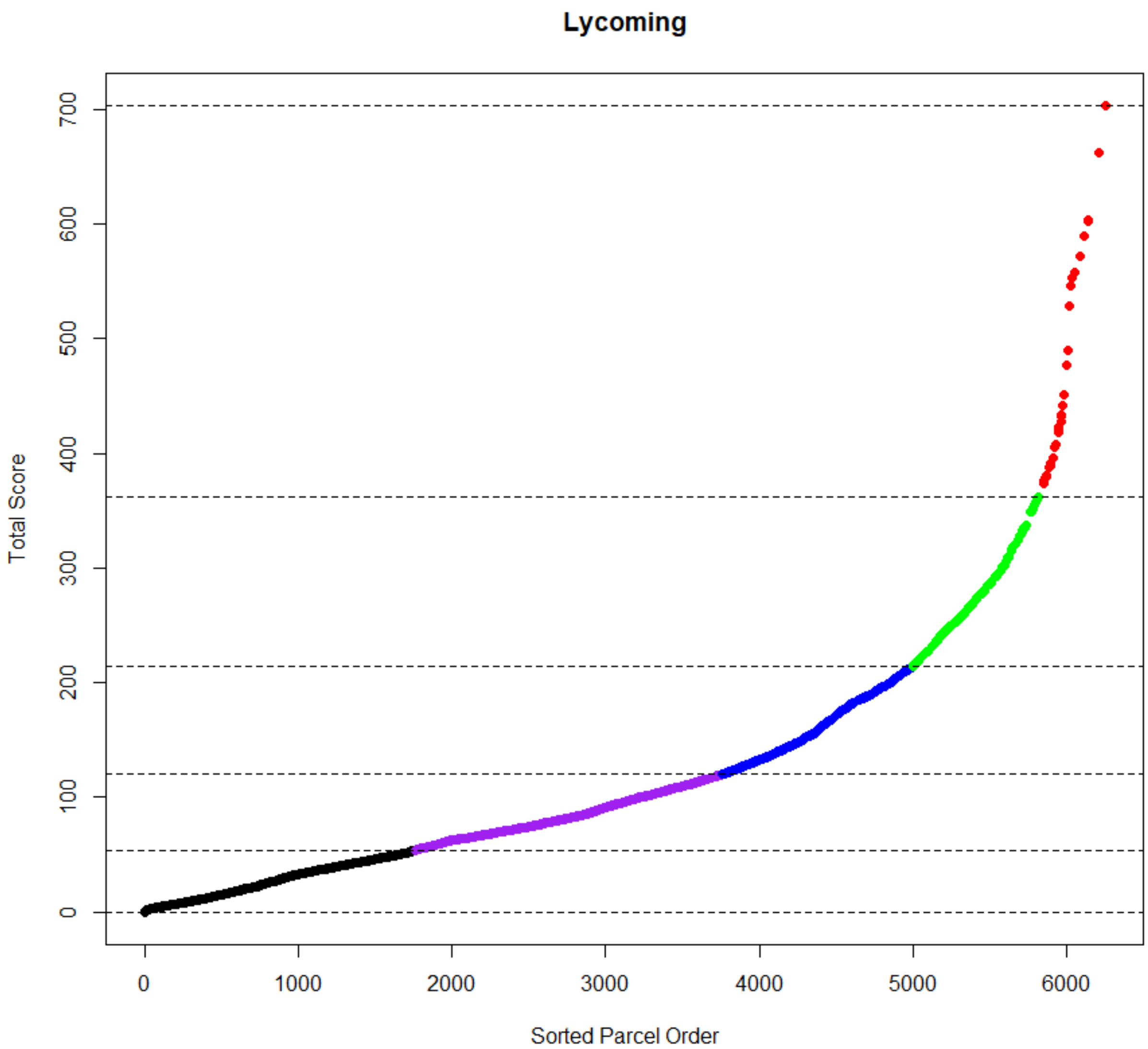


Figure 32. The distribution of prioritized parcel scores in Lycoming county. Highest scores fall in Tier 1, lowest scores fall in Tier 5. Tier 1 - red; Tier 2 - green; Tier 3 - blue; Tier 4 - purple; Tier 5 - black. The score thresholds (see below) that define the tiers are based on the Jenks natural breaks classification method and the total distribution of scores in Lycoming county. This method reduces the variance within classes and maximizes the variance between classes.

Lycoming
Tier 1: 362-703
Tier 2: 214-362
Tier 3: 120-214
Tier 4: 54-120
Tier 5: 0-54

Appendix D. Pennsylvania Forest Buffer Analysis Handout

Click image to access PDF version of document.

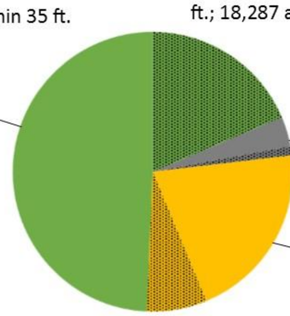
Forest Buffer Mapping for Pennsylvania's Chesapeake Bay Watershed

Supporting data-driven decision-making for collective impact

February 2019

Summary

The Chesapeake Conservancy recently completed an analysis to quantify forested buffer coverage across the entire 22,610 square miles of the Chesapeake Bay watershed within Pennsylvania. Of the total land area within a 35 ft. and 100 ft. buffer of the water network, approximately 70% and 67% of buffers are considered forested, respectively. The Chesapeake Conservancy is working with partners across Pennsylvania to use this data to make smarter decisions about restoration; and to set achievable, collective goals to maximize impact and accelerate water quality improvements.



100 ft. buffer restoration opportunity areas by sector

Protected & public land: 21,059 ac. of 100 ft. buffer restoration opportunity areas are on properties with conservation easements,[1] and 13,310 ac. are on state property.[2]

Urbanized areas[3]: 13,751 ac. of 100 ft. buffer restoration opportunity areas are within urbanized areas of Municipal Separate Storm Sewer System (MS4) regulated municipalities.

Farmland[4]: 209,349 ac. of 100 ft. buffer restoration opportunity areas are on farmland.

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