Hammer Creek Headwaters Alternate Restoration Plan

Lebanon County, Pennsylvania

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Executive Summary

An Alternative Restoration Plan (ARP) for sediment pollution was developed for a subwatershed of Hammer Creek (Figure 1) to address the siltation impairments noted in the 2018 Final Pennsylvania Integrated Water Quality Monitoring and Assessment Report (Integrated Report), including the Clean Water Act Section 303(d) List. Agriculture was identified as the cause of these impairments. Because Pennsylvania does not have numeric water quality criteria for sediment, the loading rate from a similar unimpaired watershed was used to calculate allowable loading.

Existing sediment loading in the Hammer Creek Headwaters Subwatershed was estimated to be 7,199,913 pounds per year. To meet water quality objectives, sediment loading should be reduced by 51% to 3,492,676 pounds per year. Allocation of sediment loading among the ARP variables is summarized in Table 1. To achieve this reduction while maintaining a 10% margin of safety, loading from croplands should be reduced by 62% whereas loading from hay/pasture lands and streambanks should each be reduced by 24%.

Table 1. Summary of ARP Variables for the Hammer Creek Headwaters Subwatershed. All values are annual averages in lbs/yr.

Pollutant	AL	UF	SL	LNR	ASL
Sediment	3,492,676	349,268	3,143,409	24,547	3,118,862

AL=Allowable Load; UF = Uncertainty Factor; SL=Source Load; The SL is further divided into LNR = Loads Not Reduced and ASL=Adjusted Source Load.

An analysis of realistic BMPs opportunities suggests that, if fully implemented as prescribed, sediment loading in the subwatershed could be reduced by about 83%, or 5,945,377 pounds per year. The most effective BMP opportunities were determined to be the use of precision grass filter strips along concentrated overland flowpaths, implementation of agricultural erosion and sedimentation plans, increasing the use of conservation tillage, the use of forested buffers along streams, and streambank stabilization.

This plan proposes a joint effort between the Doc Fritchey Chapter of Trout Unlimited and the Pennsylvania Department of Environmental Protection (PA DEP), in cooperation with landowners and other organizations, to implement a suite of BMPs over a nine-year period that are estimated to achieve the prescribed reductions. A proposed monitoring plan is also included to evaluate the benefits to aquatic communities. The ultimate goal is the reversal of aquatic life impairments and the establishment of healthy trout populations.

Introduction

Hammer Creek is a tributary of Cocalico Creek, with the confluence at the village of Millway in Lancaster County. This alternative restoration plan has been prepared to address siltation from agriculture impairments occurring in Hammer Creek's headwaters, the area upstream of the Furnace Hills region (Figure 1), per the 2018 Final Integrated Report (see Appendix A for a description of assessment methodology). The "Hammer Creek Headwaters Subwatershed" was approximately 13 square miles and occurred entirely within Lebanon County. It contained approximately 19 stream miles, most of which were designated for Cold-Water Fishes (CWF). However, a small portion of the watershed, including tributaries originating in the Furnace Hills near the former Lebanon Reservoir, plus a short reach below their confluence, were designated for High Quality-Cold Water Fishes (HQ-CWF). All stream segments were designated for migratory fishes.

Hammer Creek is of particular interest for stream restoration because it is believed to have high potential as a trout fishery if the impairments noted in its headwaters were corrected. As is the case with some of Pennsylvania's greatest trout streams, such as Penns Creek, the Little Juniata River, Fishing Creek (Clinton County), the Kishacoquillas etc, Hammer Creek is fed by limestone/dolomite springs in its headwaters, and then flows through a higher gradient mountainous/hilly region (Figure 2 and 3). Karst springs moderate stream temperatures throughout the year, allowing for the survival of cold-water fishes such as trout, especially during Pennsylvania's hot summers. On the other hand, the mountainous/hilly regions (in this case, the Furnace Hills) provide good trout habitat, as they are generally forested, higher-gradient, and rocky. DEP has confirmed the presence of substantial cold-water fish populations, including wild trout and sculpins, in Hammer Creek within the Furnace Hills region, which is somewhat rare for Lebanon and Lancaster Counties. However, no portion of Hammer Creek is currently classified as a Class A Wild Trout Stream, perhaps due to the intensive agriculture (Figure 1) and associated pollution impairments noted in the headwaters region (Table 2). In addition to improving aquatic community health locally, restoration of the Hammer Creek Headwaters Subwatershed would likely address a major sedimentation problem within Speedwell Forge lake, which is formed by a dam several miles downstream of our study area. This lake and dam were deemed unsafe in 2011 in part because so much sediment had accumulated in the lakebed (Milt Lauch, personal communication). The lake was drained and then restored at a cost of over 4 million dollars, but only a small amount of the accumulated sediment load was removed (Milt Lauch). According to Milt Lauch of "Friends of Speedwell" and former PA DEP employee, "the eventual destruction of the lake will take place if the sediment from the 26 square mile drainage of Hammer Creek is not better managed".

According to the NLCD 2016 GIS raster layer, land use in the study subwatershed was estimated to be 60% agriculture, 27% forest/naturally vegetated lands, and 13% mixed development (Appendix B, Table B1). Of the agricultural lands, approximately three quarters were classified as croplands. There were no NPDES permitted point source discharges in the subwatershed with limits relevant to sedimentation (Table 3).

The removal of natural vegetation and soil disturbance associated with agriculture increases soil erosion leading to sediment deposition in streams. Excessive fine sediment deposition may destroy the coarse-substrate habitats required by many stream organisms. While Pennsylvania does not have numeric water quality criteria for sediment, it does have applicable narrative criteria:

> *Water may not contain substances attributable to point or nonpoint source discharges in concentration or amounts sufficient to be inimical or harmful to the water uses to be protected or to human, animal, plant or aquatic life. (25 PA Code Chapter 93.6 (a)); and,*
>
> *In addition to other substances listed within or addressed by this chapter, specific substances to be controlled include, but are not limited to, floating materials, oil, grease, scum and substances which produce color, tastes, odors, turbidity or settle to form deposits. (25 PA Code, Chapter 93.6 (b)).*

While agriculture has been identified as the source of the impairments, this restoration plan document is applicable to all significant sources of solids that may settle to form deposits.

Table 2. Aquatic-Life Impaired Stream Segments in the Hammer Creek Headwaters Subwatershed per the 2018 Final Pennsylvania Integrated Report

HUC: 02050306 – Lower Susquehanna				
Source	EPA 305(b) Cause Code	Miles	Designated Use	Use Designation
Agriculture	Siltation	15.8	CWF or HQ-CWF, MF	Aquatic Life

HUC= Hydrologic Unit Code; CWF= Cold Water Fishes; HQ-CWF=High Quality-Cold Water Fishes; MF= Migratory Fishes
The use designations for the stream segments in this TMDL can be found in PA Title 25 Chapter 93.
See Appendix A for more information on the listings and listing process, and Appendix C for a listing of each stream segment.

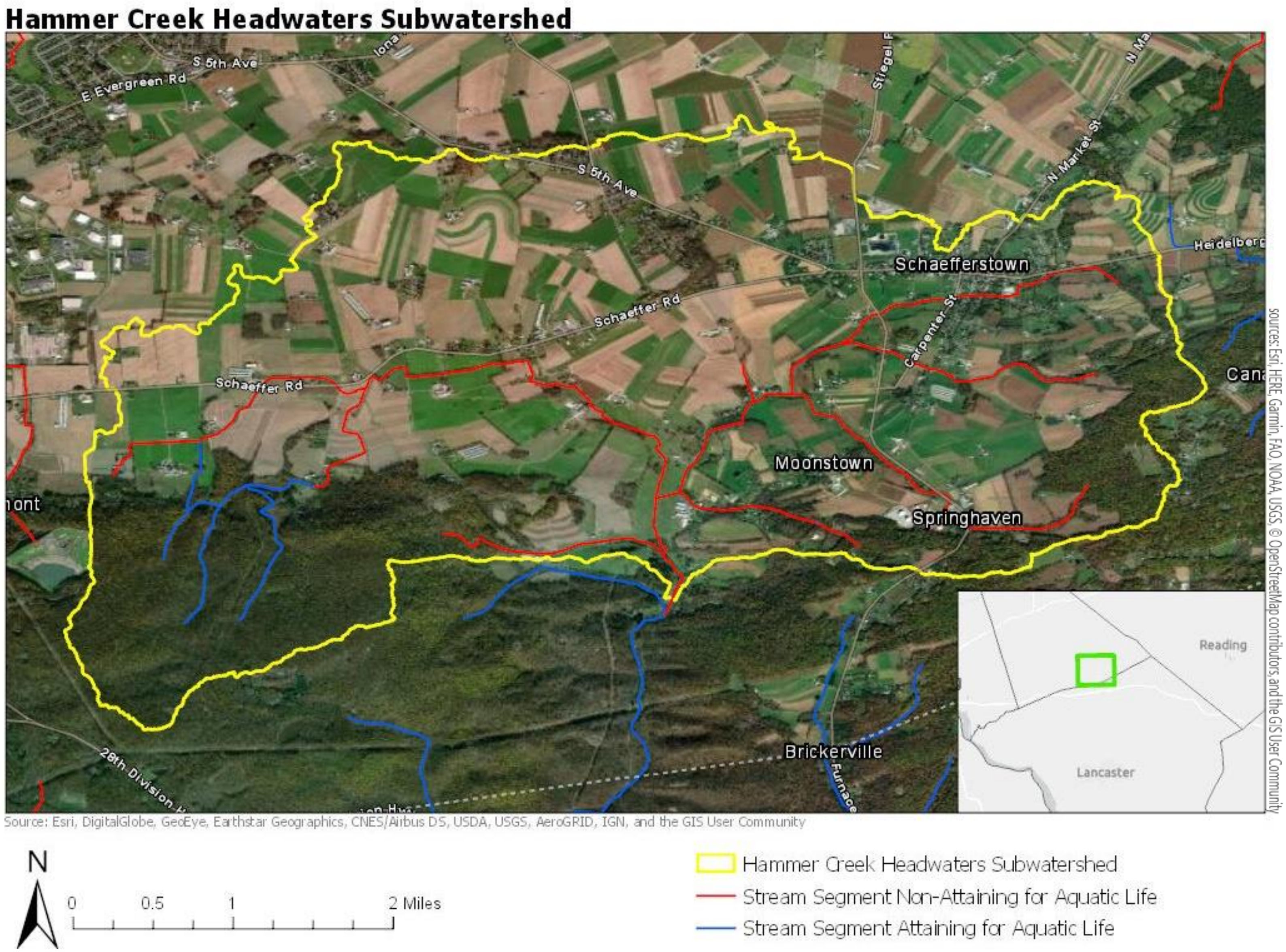


Figure 1. Hammer Creek Headwaters Subwatershed. Stream segments within the subwatershed were listed as either attaining or non-attaining for aquatic life per the 2018 Final Pennsylvania Integrated Report. Note, one stream segment was truncated based on site observations because it was a dry drainageway that emerged as a limestone spring.

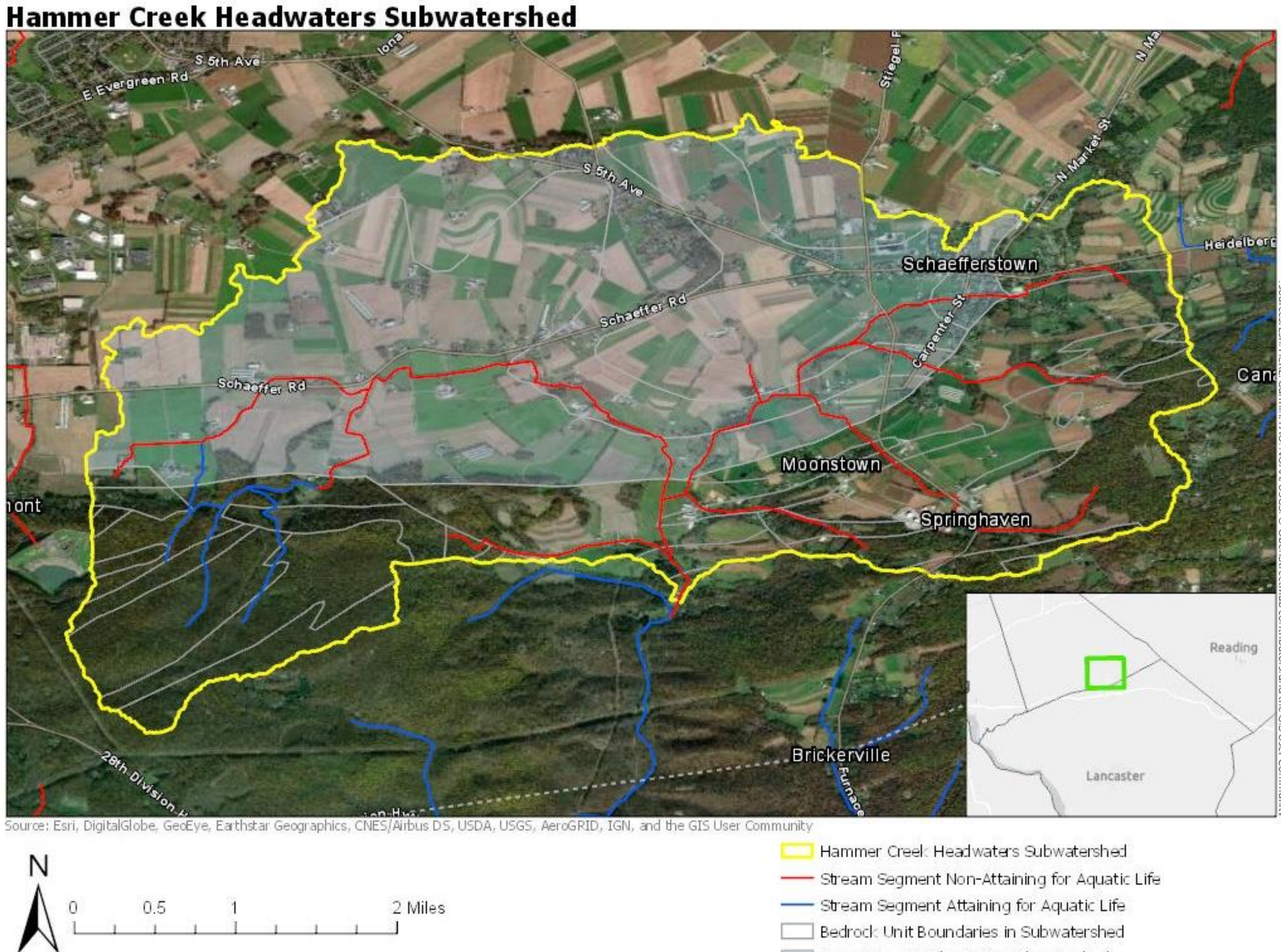


Figure 2. Limestone and dolomite bedrocks in the Hammer Creek Headwaters Subwatershed. Note, that a limestone fanglomerate unit was not included with the other carbonate bedrocks due to its heterogenous nature. Geology information were derived from the pagpoly GIS layer provided by Pennsylvania Bureau of Topographic and Geological Survey, Dept. of Conservation and Natural Resources.

Figure 3. Example stream segments illustrating upper Hammer Creek's potential as a trout fishery. The upper photograph shows a segment just below a high-volume karst spring, which provides a consistent flow of cold water. The lower photograph was taken in the Furnace Hills region downstream of the study watershed. The hilly topography and forested landscape of this area create favorable habitat conditions for trout.

Table 3. Existing NPDES-Permitted Discharges in Hammer Creek Headwaters Subwatershed.		
Permit No.	Facility Name	Load, lbs/yr
PAG123774	Furnace Hill Holsteins[1]	NA
PA0259802	Wen Crest Farms[1]	NA
PA0260657	Hammer Creek Dairy Farm[1]	NA
PA0260185	Barry Farms[1]	NA
PAG123724	Ken Haller Farms[1]	NA
PA0260843	Ken Haller Farms[1]	NA
PAG133745	Heidelberg Twp MS4[2]	NA

Permits within the watershed were based on DEP's eMapPA available at http://www.depgis.state.pa.us/emappa/ and EPA's Watershed Resources Registry available at https://watershedresourcesregistry.org/map/?config=stateConfigs/pennsylvania.json

Note that given their transient nature, any stormwater construction permits were not included above.

[1]In Pennsylvania, routine, dry-weather discharges from concentrated animal feeding operations (CAFOs) are not allowed. Wet weather discharges are controlled through best management practices, which result in infrequent discharges from production areas and reduced sediment loadings from lands under the control of CAFOs owner or operators, such as croplands where manure is applied. Although not quantified in this table, sediment loadings from CAFOs is accounted for in the modeling of land uses within the watershed, with the assumption of no additional CAFO-related BMPs.

[2]A very small area (approximately 100 acres, or about 1% of the subwatershed) occurs within the Heidelberg Twp's MS4 urbanized area, and they received an MS4 permit waiver. Note that Model My Watershed accounts for development when calculating loading rates.

ARP Approach

Per the Federal Clean Water Act, waters with pollutant impairments require the establishment of "Total Maximum Daily Loads" (TMDLs) that set allowable pollutant loading limits. The TMDL is then allocated among point source dischargers, nonpoint sources, natural and anthropogenic background sources not considered responsible for the impairments as well as a margin of safety factor. TMDLs can then be used to set appropriate loading limits for NPDES permitted dischargers. However, where the pollution problem is due primarily to unpermitted nonpoint sources there may be no effective mechanism to force pollution reduction. Thus, historically there have been many nonpoint source TMDLs developed that have led to little actual stream improvements.

In recognition of this, EPA has allowed an alternative approach, which is essentially a short-term restoration plan that is to be implemented to address the pollution impairments. If it can be shown that the plan can be implemented and could result in the reversal of the impairments, the development of a TMDL may be postponed. If, however, the ARP fails to reverse impairments then a TMDL would be required.

The same basic TMDL process is also relevant to ARPs. These steps include:

1. Collection and summarization of pre-existing data (watershed characterization, inventory contaminant sources, determination of pollutant loads, etc.);
2. Calculation of a TMDL, or in the case of the ARP, an allowable loading value that appropriately accounts for critical conditions and seasonal variations;
3. Allocation of pollutant loads to various sources;
4. Submission of draft reports for public review and comments; and
5. EPA approval of the TMDL, or recognition of the ARP.

Because Pennsylvania does not have numeric water quality criteria for sediment, the "Reference Watershed Approach" was used. This method estimates sediment loading rates in both the impaired watershed as well as a similar watershed that is not listed as impaired for sediment. Then, the loading rate in the unimpaired watershed is scaled to the area of the impaired watershed so that necessary load reductions may be calculated. It is assumed that reducing loading rates in the impaired watershed to the levels found in the attaining watershed will result in the impaired stream segments attaining their designated uses.

Selection of the Reference Watershed

In addition to anthropogenic influences, there are many other natural factors affecting sediment loading rates and accumulation. Thus, selection of a reference watershed with similar natural characteristics to the impaired watershed is crucial. Failure to use an appropriate reference watershed could result in problems such as the setting of sediment reduction goals that are unattainable, or nonsensical TMDL calculations that suggest that sediment loading in the impaired watershed should be increased.

To determine the suitability of the reference site, the Department's Integrated Report GIS-based website was used to search for watersheds that were similar to the Hammer Creek Headwaters Subwatershed, but lacked stream segments impaired for sediment.

Since the study subwatershed was approximately 54% limestone/dolomite geology, an effort was made to find a reference watershed with similar karst geology. However, for a variety of reasons, no such reference could be found. For one, stream impairments were common in karst regions, likely due to intensive agricultural uses being common in these areas. Attaining watersheds in karst areas could be found in the more mountainous regions of the Ridge and Valley Physiographic Province, however they often had much greater landscape slope than in the Hammer Creek Headwaters Subwatershed, which was only 6% (Table 4). There was concern that higher gradient reference streams may be less vulnerable to sediment deposition, which may ultimately cause prescribed sediment reductions in the impaired subwatershed to be too low.

A subwatershed of Ontelaunee Creek (Figure 4) was chosen as a potential reference because all of its stream segments were listed as attaining for aquatic life use and it was similar to the impaired subwatershed, though it lacked karst geology. Key watershed characteristics are summarized in (Table 4).

Ontelaunee Creek Subwatershed

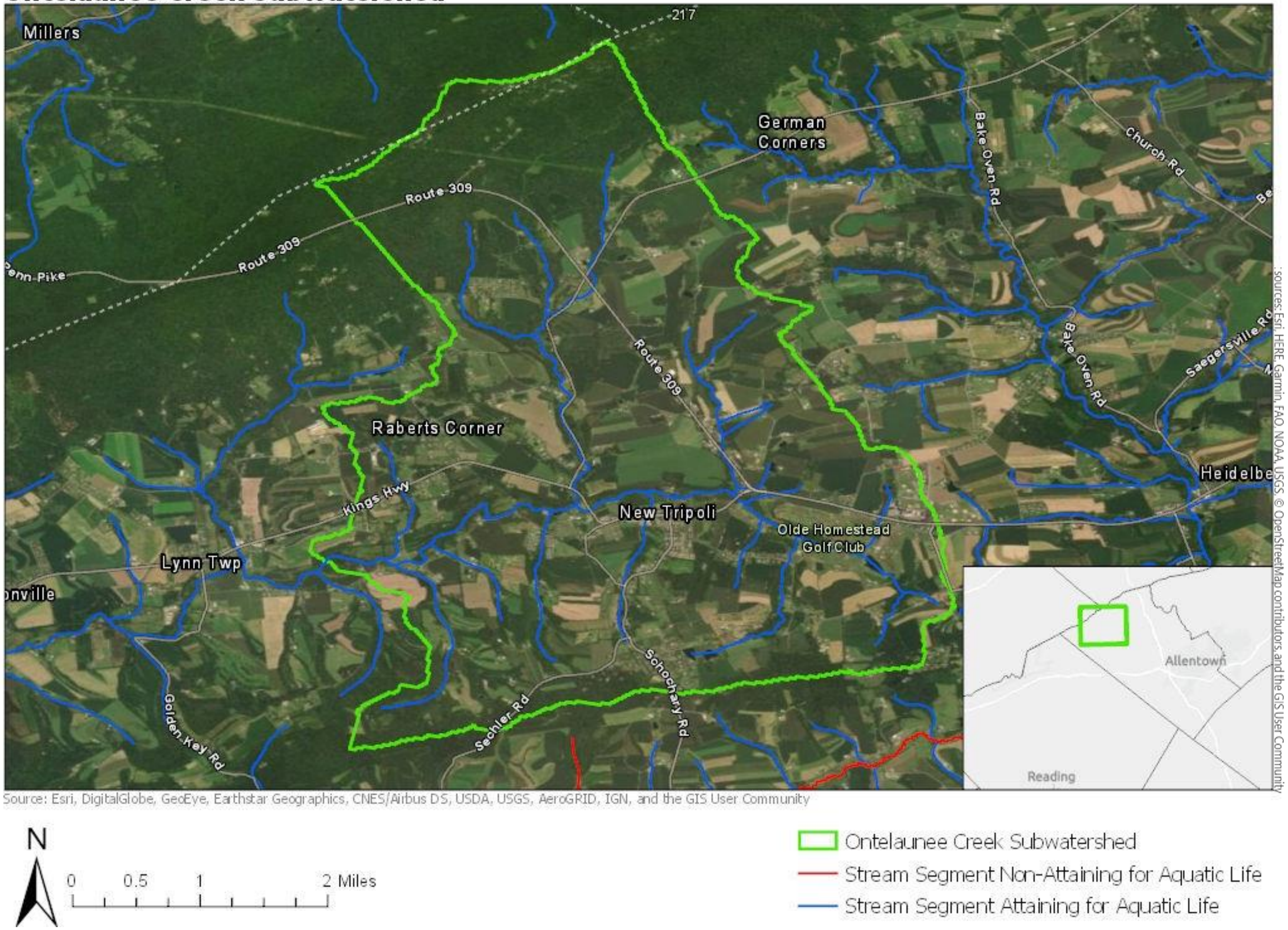


Figure 4. Ontelaunee Creek Subwatershed. Stream segments are shown as attaining or non-attaining for aquatic life per the 2018 Final Pennsylvania Integrated Report.

Table 4. Comparison of the Impaired (Hammer Creek Headwaters) and Reference (Ontelaunee Creek) Subwatersheds.

	Hammer Creek	Ontelaunee Creek
Phys. Province[1]	58% Great Valley Section of Ridge and Valley 42% Gettysburg Newark Lowland Section of Piedmont	88% Great Valley Section of Ridge and Valley 12% Blue Mountain Section of Ridge and Valley
Land Area[2], ac	8,001	8,046
Land Use[2]	60% Agriculture 27% Forest/Natural Vegetation 13% Developed	52% Agriculture 37% Forest/Natural Vegetation 11% Developed
Soil Infiltration[3]	0% Group A 77% Group B 2% Group B/D 15% Group C 5% Group C/D 0.5% Group D	14% Group A 62% Group B 5% Group B/D 8% Group C 0% Group C/D 11% Group D
Dominant Bedrock[4]	39% Limestone 24% Sandstone 16% Dolomite 10% Quartz Conglomerate 6% Limestone Conglomerate 3% Shale 2% Diabase	61%shale 38% Graywacke 2% Sandstone
Average Precipitation[5], in/yr	40.7	39.9
Average Surface Runoff[5], in/yr	2.1	2.0
Average Elevation[5] (ft)	617	712

Average Slope[5]	6%	9%
Stream Channel Slope[5]	1st Order:1.7% 2nd Order: 0.8 3rd Order: 0.42	1st Order: 1.8 2nd Order: 0.6

[1]Per PA_Physio_Sections GIS layer provided by Pennsylvania Bureau of Topographic and Geological Survey, Dept. of Conservation and Natural Resources
[2]MMW output corrected for NLCD 2016
[3]As reported by Model My Watershed's analysis of USDA gSSURGO 2016
[4]Per pagpoly GIS layer provided by Pennsylvania Bureau of Topographic and Geological Survey, Dept. of Conservation and Natural Resources
[5]As reported by Model My Watershed

More than half of the land area of both subwatersheds was in the Great Valley Section of the Ridge and Valley physiographic province, and upland regions occurred on their margins. Land cover/use distributions in these two subwatersheds were similar (Table 4). More than half the land cover in both subwatersheds was in agricultural use while naturally vegetated lands were of secondary importance. Both subwatersheds were dominated by soils with moderate infiltration rates (group B), and on average, their terrain was of relatively low slope.

A concern in using a reference without karst geology was that the hydrology of the two subwatersheds would differ greatly. However, the average surface runoff rate in both subwatersheds was estimated to be about the same (2.1 in/yr versus 2.0 in/yr-see Table 4), and no better karst references were found.

As was the case for most of the stream segments in the impaired subwatershed, stream segments within the Ontelaunee Creek Subwatershed were designated for cold-water fishes. The Ontelaunee Creek Subwatershed had one, relatively minor, NPDES permitted point source discharge with numeric limits relevant to sediment (Table 5).

Table 5. Existing NPDES-Permitted Discharges in the Ontelaunee Creek Subwatershed and their Potential Contribution to Sediment Loading.

Permit No.	Facility Name	Load, lbs/yr
PA0070254	Lynn Twp WWTP	7,306

Permits within the watershed were based on DEP's eMapPA available at http://www.depgis.state.pa.us/emappa/ and EPA's Watershed Resources Registry available at https://watershedresourcesregistry.org/map/?config=stateConfigs/pennsylvania.json

Note that given their transient nature, any stormwater construction permits were not included above.

*Loading rates based on their permit issued January 8, 2019. Their average annual load was calculated assuming they discharged at their effluent concentration limit of 30 mg/L (monthly average) for total suspended solids and a flow rate equal to their hydraulic design capacity of 0.08 MGD.

After selecting the potential reference, the two subwatersheds were visited during the summer of 2019 to confirm the suitability of the reference as well as to explore whether there were any obvious land use differences that may help explain why one watershed was impaired for sediment while the other was attaining. In the Hammer Creek Headwaters Subwatershed, fine sediment deposition problems were obvious at many sites (Figure 5). These problems were consistent with the high coverage of agricultural lands (60% of land area) and lack of agricultural best management practices (BMPs). For instance, crop fields were observed in close proximity to streams with little to no riparian buffering, and pasture sites were observed where cattle had direct access to streams (Figure 6). Sites were also observed with significant bank erosion that was likely attributable to the lack of riparian buffers and possible "legacy sediment" deposits (Figure 7).

In contrast, expansive forested riparian buffers were the norm in the Ontelaunee Creek Study Subwatershed (Figure 8). In only a few cases were agricultural activities observed in close proximity to waterways without significant forested buffers (Figure 9). And, while some localized problems were observed, the Ontelaunee Creek Subwatershed largely lacked the bank erosion and major siltation deposits observed in the Hammer Creek Headwaters Subwatershed. Thus, conditions appeared to be much better in the Ontelaunnee Creek Subwatershed, even though its total agricultural landcover was similar to that of the Hammer Creek Headwaters Subwatershed (Table 4).

Figure 5. Example stream segments in the Hammer Creek Headwaters Subwatershed with heavy sediment deposition.

Figure 6. Example agricultural practices in the Hammer Creek Headwaters Subwatershed that may result in excessive sediment loading. In photograph A and B, croplands extend nearly to the streambanks with minimal riparian buffering. Photograph C shows a stream segment flowing between an active pasture and sloping croplands. Photograph D shows a large area of pasture where cattle directly accessed the stream.

Figure 7. Example stream segments in the Hammer Creek Headwaters Subwatershed with obvious bank erosion and potential legacy sediment accumulations.

Figure 8. Example buffered headwater and mainchannel stream segments in the Ontelaunee Creek reference subwatershed. Forested buffers were exceptionally common in this watershed, comprising an estimated 74% of the land area within 100 feet of the stream segments. In contrast, the buffering rate was only 28% in the agricultural area of the Hammer Creek Headwaters Subwatershed.

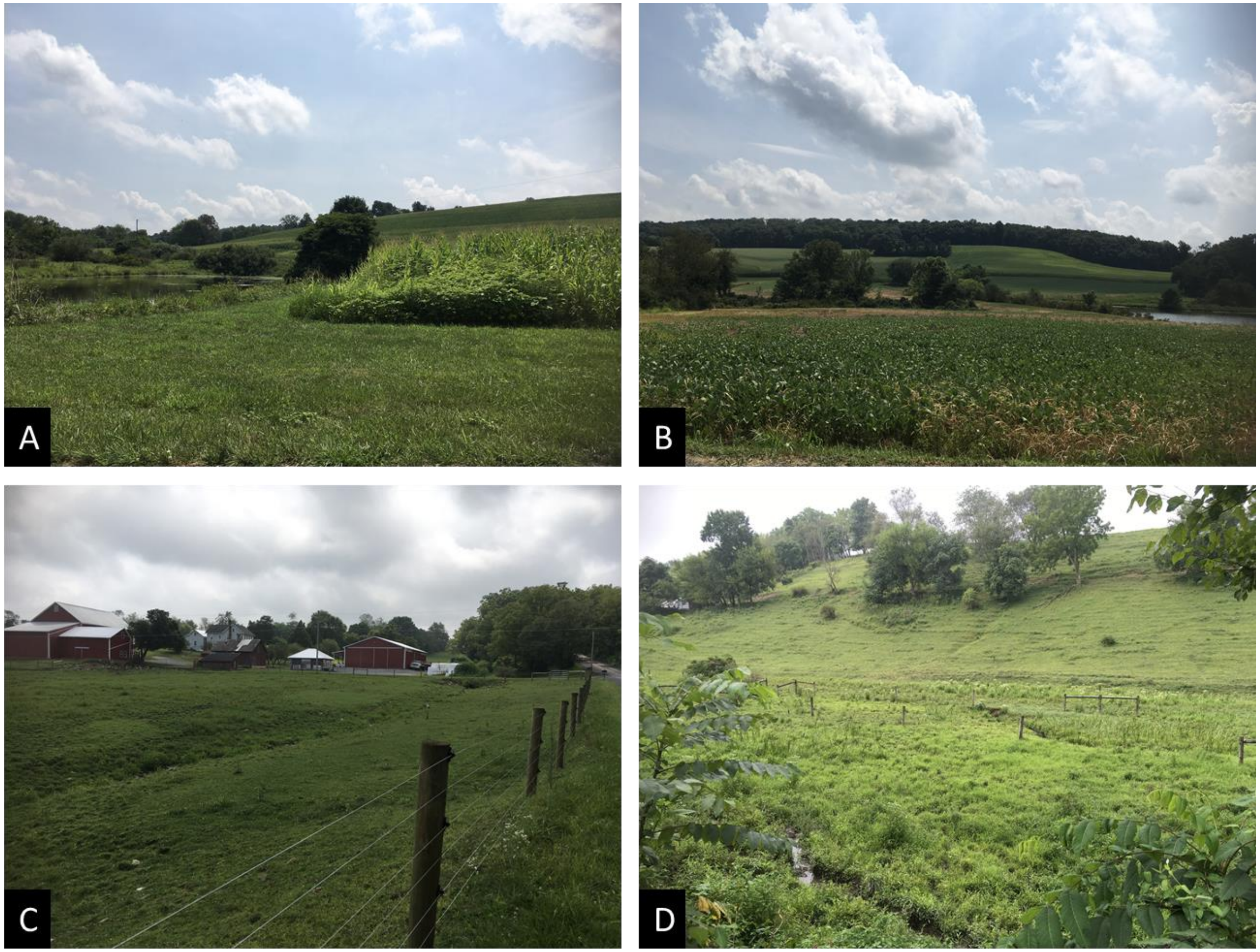


Figure 9. Example agricultural practices in the Ontelaunee Creek Subwatershed that may lead to excessive sediment loading. Photographs A and B show rare cases where croplands were located near waterways without substantial forested buffers. In the case of photograph, A, the waterway was a pond, which may help settle out sediment and prevent it from being transported downstream. Photograph C shows pastureland where cattle have access to the stream. Photograph D shows steeply sloping pasture lands along a stream segment, though it appears that the cattle had been fenced out of the stream.

Comparison of Fine Sediment Deposits in the Impaired and Reference Watersheds

Sediment deposits were measured in both the Hammer Creek Impaired Subwatershed and the Ontelaunee Creek Reference Subwatershed in order to confirm that the reference subwatershed did indeed have less fine sediments and also to collect baseline data to allow for comparisons before and after restoration in Hammer Creek.

Study reaches were established near the downstream-most extent of the mainstems of both subwatersheds (Figures 10 and 11). These sites were within valley topography and the stream segments were low gradient. The placement of these study reaches avoided bridges or culverts. The study reach in Ontelaunee Creek was placed upstream of a large island, which would have made defining the mainchannel difficult. Within each reach, fine sediments were measured in five consecutive obvious mainchannel riffles, as well as five consecutive obvious mainchannel large scour pools. Riffles were chosen because they were the most common habitat for benthic macroinvertebrate collection in assessment surveys, and excessive fine sediments are known to embed, or even smother this habitat. Pools were chosen because they are natural areas of fine sediment deposition, and thus may be habitats where excessive fine sediments may be most readily detected. In order to qualify for measurement, pools had to cover at least one half of the wetted width of the stream, be formed by the shape of the bed substrate rather than debris jamming, and be at least twice as deep at their deepest point than the water depth at the apex of the tailout.

Perpendicular transects were established at approximately 25, 50 and 75% of the pool or riffle length. Within each pool, fine sediment deposits (small gravels and smaller) were measured by probing with a metal-tipped broom handle that had cm graduations. The probe was pushed into the substrate until penetration was impeded, typically by the presence of coarser materials (large gravels and cobbles). These measurements were taken along each transect at approximately 10, 20, 30, 40, 50, 60, 70, 80 and 90% of the stream's wetted width. For riffles, fine sediment deposits (<2mm sieve size) were measured using a modified version of the pebble count procedure. Along each perpendicular riffle transect, the observer reached down with an extended index finger at 17 approximately evenly spaced points across the streams wetted width. The presence or absence of a deposit dominated by <2mm sieve size particles was recorded. Where a deposit of fines was felt that had particles that were both greater than and less than 2mm sieve size, the observer took a pinch and considered whether the volume of the pinch was dominated by the larger or smaller particles.

For analysis, data from all three transects within a riffle or pool was averaged to make one value for each riffle and pool. Thus, within each subwatershed, there were five replicate riffles and five replicate pools. Statistical analyses were conducted using the Wilcoxon Rank Sum Test in "R version 3.6.1" (R Core Team 2019).

It should be noted that the methodology used herein, though highly customized for our purposes, drew heavily from existing methodologies used in other jurisdictions, particularly methods used by the Montana Department of Environmental Quality as well as the US Forest Service. See especially Kusneirz et al. (2013) and Hilton and Lisle (1993).

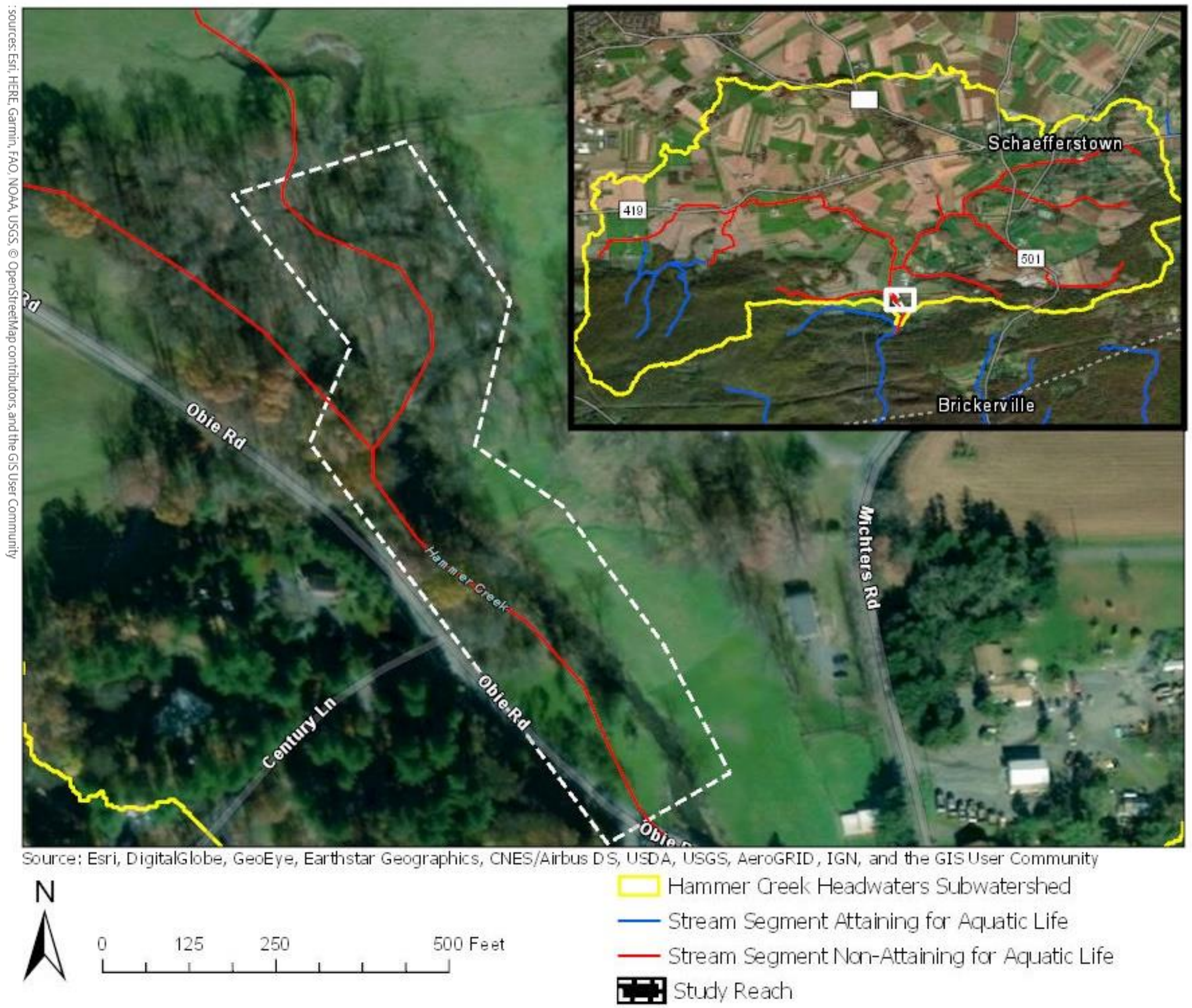


Figure 10. Sediment sampling reach within Hammer Creek Headwaters Subwatershed

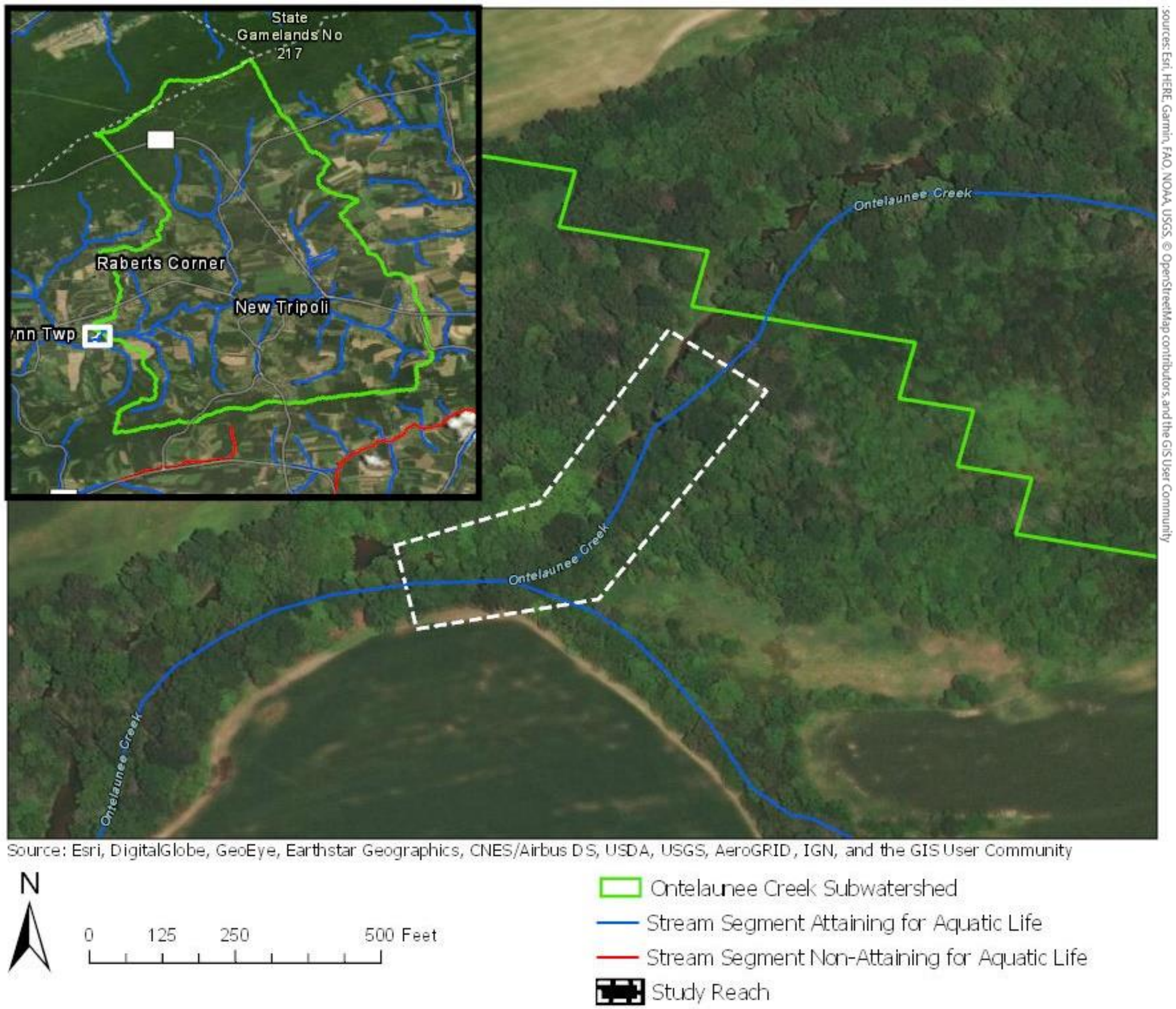


Figure 11. Sediment sampling reach within the Ontelaunee Creek Subwatershed.

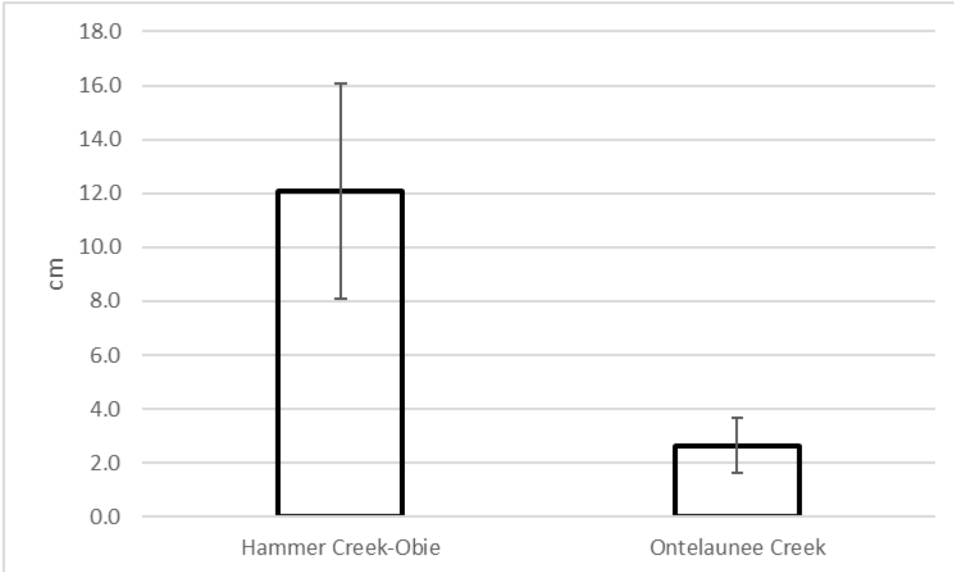


Figure 12. Mean (+/- sd) depth of fine sediment deposits in pools of the Hammer Creek (impaired) and Ontelaunee Creek (reference) subwatersheds. Measurements were made in five consecutive, large mainchannel scour pools within each subwatershed. According to the Wilcoxon Rank Sum Test, pool sediment depth was significantly different between the two groups (p=0.0079).

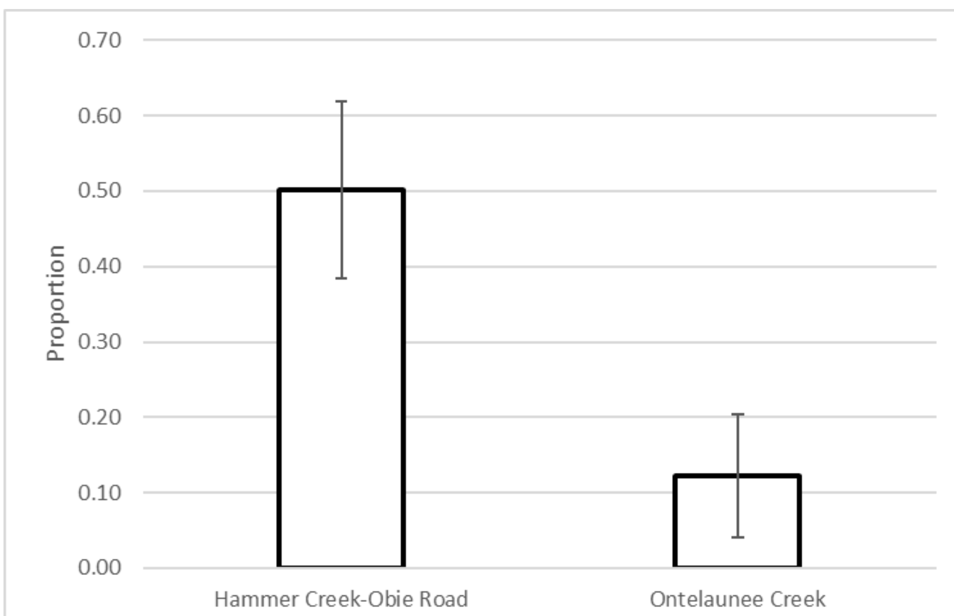


Figure 13. Mean (+/- sd) proportion of sampling points dominated by <2mm (sieve size) deposits within riffles of the Hammer Creek (impaired) and Ontelaunee Creek (reference) subwatersheds. Measurements were made in five consecutive mainchannel riffles within each watershed. According to the Wilcoxon Rank Sum Test, the amount of fine sediment in riffles was significantly different between the two groups (p=0.0079)

Both the depth of fine sediments in pools, as well as the proportion of riffle sampling points dominated by fine particles were far greater in the Hammer Creek sampling reach than in the Ontelaunee Creek sampling reach, and these differences were statistically significant. On average, the pools of the Hammer Creek sampling reach had nearly 12 cm thick fine sediment deposits versus only about 3cm thick fine sediment deposits in the Ontelaunee Creek sampling reach (Figure 12). Within riffles, the mean percentage of sampling points with <2mm sieve size deposits was nearly 50% in the Hammer Creek sampling reach versus only about 12% in the Ontelaunee Creek sampling reach (Figure 13). These results support the use of Ontelaunee Creek Subwatershed as a reference for Hammer Creek.

Hydrologic / Water Quality Modeling

Estimates of sediment loading for the impaired and reference watersheds were calculated using the "Model My Watershed" application (MMW), which is part of the WikiWatershed web toolkit developed through an initiative of the Stroud Water Research Center. MMW is a replacement for the MapShed desktop modelling application. Both programs calculate sediment and nutrient fluxes using the "Generalized Watershed Loading Function Enhanced" (GWLF-E) model. However, MapShed was built using a MapWindow GIS package that is no longer supported, whereas MMW operates with GeoTrellis, an open-source geographic data processing engine and framework. The MMW application is freely available for use at https://wikiwatershed.org/model/. In addition to the changes to the GIS framework, the MMW application continues to be updated and improved relative to its predecessor.

In the present study, the watershed area for the Ontelaunee Creek Subwatershed was defined using MMW's Watershed Delineation tool (see https://wikiwatershed.org/documentation/mmw-tech/#delineate-watershed). The watershed area for Hammer Creek was determined primarily using ArcGISPro and TauDEM tools (see the later "Precision Grass Filter Strips Section"). Then, the mathematical model used in MMW, GWLF-E, was used to simulate 30-years of daily water, nitrogen, phosphorus and sediment fluxes. To provide a general understanding of how the model functions, the following excerpts are quoted from Model My Watershed's technical documentation.

> The GWLF model provides the ability to simulate runoff, sediment, and nutrient (nitrogen and phosphorus) loads from a watershed given variable-size source areas (e.g., agricultural, forested, and developed land). It also has algorithms for calculating septic system loads, and allows for the inclusion of point source discharge data. It is a continuous simulation model that uses daily time steps for weather data and water balance calculations. Monthly calculations are made for sediment and nutrient loads based on the daily water balance accumulated to monthly values.
>
> GWLF is considered to be a combined distributed/lumped parameter watershed model. For surface loading, it is distributed in the sense that it allows multiple land use/cover scenarios, but each area is assumed to be homogenous in regard to various "landscape" attributes considered by the model. Additionally, the model does not spatially distribute the source areas, but simply aggregates the loads from each source area into a watershed total; in other words there is no spatial routing. For subsurface loading, the model acts as a lumped parameter model using a water balance approach. No distinctly separate areas are considered for sub-surface

flow contributions. Daily water balances are computed for an unsaturated zone as well as a saturated subsurface zone, where infiltration is simply computed as the difference between precipitation and snowmelt minus surface runoff plus evapotranspiration.

With respect to major processes, GWLF simulates surface runoff using the SCS-CN approach with daily weather (temperature and precipitation) inputs from the EPA Center for Exposure Assessment Modeling (CEAM) meteorological data distribution. Erosion and sediment yield are estimated using monthly erosion calculations based on the USLE algorithm (with monthly rainfall-runoff coefficients) and a monthly KLSCP values for each source area (i.e., land cover/soil type combination). A sediment delivery ratio based on watershed size and transport capacity, which is based on average daily runoff, is then applied to the calculated erosion to determine sediment yield for each source sector. Surface nutrient losses are determined by applying dissolved N and P coefficients to surface runoff and a sediment coefficient to the yield portion for each agricultural source area.

Evapotranspiration is determined using daily weather data and a cover factor dependent upon land use/cover type. Finally, a water balance is performed daily using supplied or computed precipitation, snowmelt, initial unsaturated zone storage, maximum available zone storage, and evapotranspiration values.

Streambank erosion was calculated as a function of factors such as the length of streams, the monthly stream flow, the percent developed land in the watershed, animal density in the watershed, the watersheds curve number and soil k factor, and mean topographic slope.

For a detailed discussion of this modelling program, including a description of the data input sources, see Evans and Corradini (2016) and Stroud Research Center (2020).

Model My Watershed allows the user to adjust model parameters, such as the area of land coverage types, the use of conservation practices and the efficiencies of those conservation practices, the watershed's sediment delivery ratio, etc. Default values were used for the modelling run, with the exception that: the flow value associated with point source discharge listed in Table 5 was added and landcover types were adjusted to reflect newer NLCD 2016 landcover data. A raster dataset of NLCD 2016 landcover was opened in ArcGISPro or ArcMap and clipped to the shapefile of each subwatershed to determine the proportion of non-open water pixels accounted for by each landcover class. These proportions were then multiplied by the total area reported in Model My Watershed's landcover adjustment feature to readjust the inputs. Presumably due to rounding, the inputs sometimes added up to 0.1 hectares greater or lesser than the exact landcover area needed by the program. Where this occurred, whichever landcover class was closest to having been rounded in the other direction needed was changed by a negligible +/- 0.1 hectare to get the exact number needed.

A correction for the presence of existing riparian buffers was made in the BMP Spreadsheet Tool provided by Model My Watershed following the model run. The following paragraphs describe the riparian buffer correction methodology.

Riparian buffer coverage was estimated via a GIS analysis in ArcMap or ArcGISPro. Briefly, landcover per a high resolution landcover dataset (University of Vermont Spatial Analysis Laboratory 2016) was examined within 100 feet of NHD flowlines. To determine riparian buffering within the "agricultural area," a polygon tool was used to clip riparian areas that, based on cursory visible inspection, appeared to be in an agricultural-dominated valley or have significant, obvious agricultural land on at least one side. This was necessary to exclude the Furnace Hills areas of the Hammer Creek Headwaters Subwatershed (Figure 14), but this was unnecessary in the Ontelaunee Creek Subwatershed because no stream segments were mapped outside of an "agricultural area" (Figure 15). Then the sum of raster pixels that were classified as either "Emergent Wetlands", "Tree Canopy" or "Shrub/Scrub" was divided by the total number of non-water pixels to determine percent riparian buffer. Using this methodology, percent riparian buffer was determined to be 28% in the agricultural area of the impaired subwatershed versus 74% in the reference subwatershed.

An additional reduction credit was given to the reference subwatershed to account for the fact it had more riparian buffers than the impaired subwatershed. Applying a reduction credit solely to the reference watershed to account for its extra buffering was chosen as more appropriate than taking a reduction from both watersheds because the model has been calibrated at a number of actual sites (see https://wikiwatershed.org/help/model-help/mmw-tech/) with varying amounts of existing riparian buffers. If a reduction were taken from all sites to account for existing buffers, the datapoints would likely have a poorer fit to the calibration curve versus simply providing an additional credit to a reference site.

When accounting for the buffering of croplands using the BMP Spreadsheet Tool, the user enters the length of buffer on both sides of the stream. To estimate the extra length of buffers in the agricultural area of the reference subwatershed over the amount found in the impaired subwatershed, the approximate length of NHD flowlines within the reference subwatershed was multiplied by the difference in the proportion of buffering between the agricultural area of the reference subwatershed versus that of the impaired subwatershed, and then by two since both sides of the stream are considered. The BMP spreadsheet tool then calculates sediment reduction using a similar methodology as the Chesapeake Assessment Scenario Tool (CAST). The length of riparian buffers is converted to acres, assuming that the buffers are 100 feet wide. For sediment loading the spreadsheet tool assumes that 2 acres of croplands are treated per acre of buffer. Thus, twice the acreage of buffer was multiplied by the sediment loading rate calculated for croplands and then by a reduction coefficient of 0.54. The BMP spreadsheet tool is designed to account for the area of lost cropland and gained forest when riparian buffers are created. However, this part of the reduction equation was deleted for the present study since historic rather than proposed buffers were being accounted for.

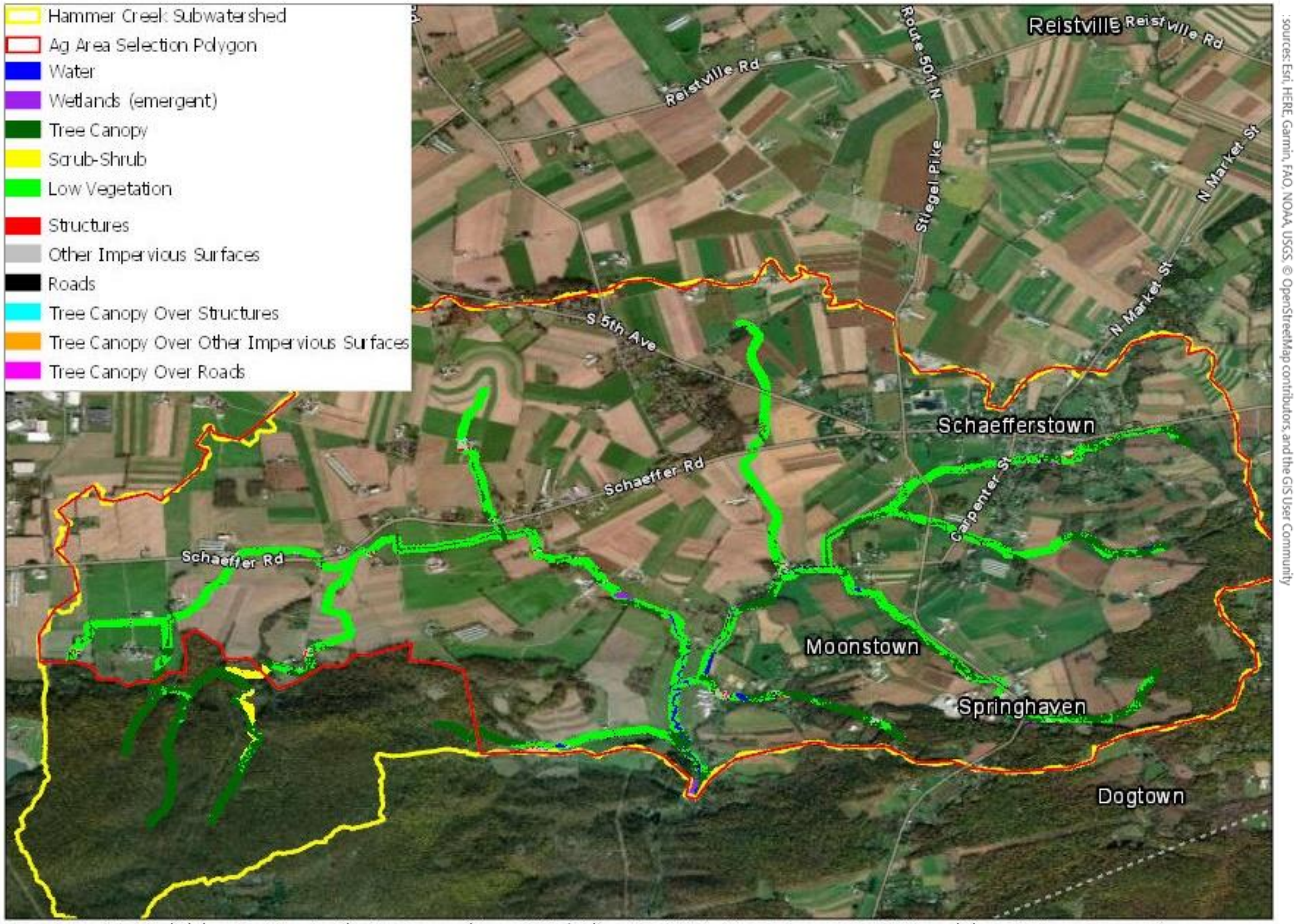


Figure 14. Riparian buffer analysis in the Hammer Creek Headwaters Subwatershed. A raster dataset of high-resolution land cover (University of Vermont Spatial Analysis Laboratory 2016) is shown within 100 feet (geodesic) of either side of NHD flowlines. The agricultural area selection polygon is shown in red. It was estimated that approximately 28% of land within 100 feet of NHD flowlines in the agricultural area was comprised of tree canopy, shrub/scrub or wetlands.

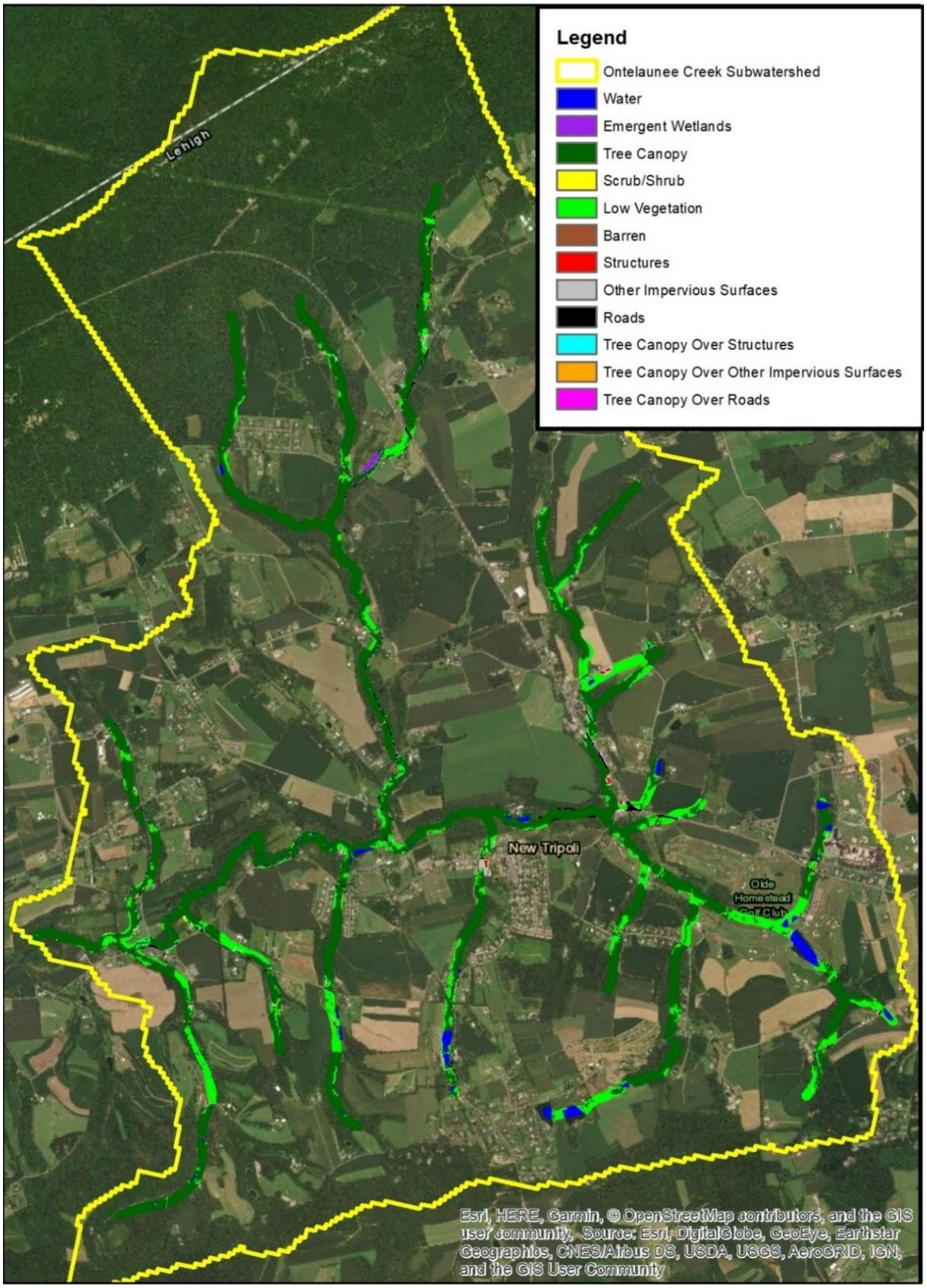


Figure 15. Riparian buffer analysis in the Ontelaunee Creek reference subwatershed. A raster dataset of high-resolution land cover (University of Vermont Spatial Analysis Laboratory 2016) is shown within 100 feet (geodesic) of either side of NHD flowlines. All stream segments were determined to be within an agricultural area, so no selection polygon is shown. It was estimated that approximately 74% of land within 100 feet of NHD flowlines was comprised of tree canopy, shrub/scrub or wetlands.

Calculation of the Allowable Loading Rate

The mean watershed-wide sediment loading rate for the unimpaired reference subwatershed (Ontelaunee Creek Subwatershed) was estimated to be 437 pounds per acre per year (Table 6). This was substantially lower than the estimated loading rate in the impaired Hammer Creek Headwaters Subwatershed (900 pounds per acre per year, Table 7). Thus, to achieve the loading rate of the unimpaired subwatershed, sediment loading in the Hammer Creek Headwaters Subwatershed should be reduced to 3,492,676 pounds per year (Table 8).

Table 6. Existing Annual Average Loading Values for Ontelaunee Creek Subwatershed, reference

Source	Area, ac	Sediment, lbs/yr	Unit Area Load, lb/ac/yr
Hay/Pasture	1,065	285,895	268
Cropland	3,112	3,008,190	967
Forest and Shrub/Scrub	2,909	4,039	1
Wetland	49	104	2
Herbaceous/Grassland	1	32	49
Bare Rock	1	0	0
Low Intensity Mixed Development	851	10,190	12
Medium Intensity Mixed Development	51	3,593	70
High Intensity Mixed Development	7	486	71
Streambank[1]		456,741	
Point Sources		7,306	
Riparian Buffer Discount[2]		-264,177	
total	8,046	3,512,402	437

[1]"Streambank" sediment loads were calculated using Model My Watershed's streambank routine which uses length rather than area.

[2]Accounts for the extra amount of riparian buffering of the reference subwatershed versus the impaired subwatershed

Table 7. Existing Annual Average Loading Values for the Hammer Creek Headwaters Subwatershed, impaired			
Source	Area ac	Sediment, lbs/yr	Unit Area Load, lbs/ac/yr
Hay/Pasture	1,239	216,036	174
Cropland	3,602	6,164,580	1,712
Forest and Shrub/Scrub	2,106	6,243	3
Wetland	13	35	3
Herbaceous/Grassland	6	0	0
Low Intensity Mixed Development	910	10,382	11
Medium Intensity Mixed Development	95	5,946	63
High Intensity Mixed Development	31	1,941	63
Streambank		794,750	
Point Sources		0	
total	8,001	7,199,913	900

"Streambank" sediment loads were calculated using Model My Watershed's streambank routine which uses length rather than area.

Table 8. Annual Average Allowable Loading for the Hammer Creek Headwaters Subwatershed			
Pollutant	Loading Rate in Reference, lbs/ac/yr	Total Land Area in Impaired Watershed, ac	Target AL Value, lbs/yr
Sediment	437	8,001	3,492,676

Calculation of the Source Load Allocations

Calculation of the Uncertainty Factor and Source Load

In the ARP equation, the Allowable Load (AL) is comprised of the Source Load (SL) which accounts for all significant natural and anthropogenic sources of the pollutant plus an Uncertainty Factor (UF). Thus:

AL = SL + UF

Reserving a portion of the load as an uncertainty factor requires further load reductions from targeted sectors to achieve the allowable load. For this analysis, the UF was explicitly designated as ten-percent of the AL based on professional judgment. Thus:

3,492,676 lbs/yr AL * 0.1 = 349,268 lbs/yr UF

Then, the SL is calculated as:

3,492,676 lbs/yr AL – 349,268 lbs/yr UF = 3,143,409 lbs/yr SL

Calculation of the Adjusted Source Load

In the ARP equation the Source Load is further divided into the Adjusted Source Load (ASL), which is comprised of the sources causing the impairment and targeted for reduction, as well as the loads not reduced (LNR), which is comprised of the natural and anthropogenic sources that are not considered responsible for the impairment nor targeted for reduction. Thus:

SL =ASL + LNR

Therefore, before calculating the allowable loading from the targeted sectors, the loads not reduced must also be defined.

Since the impairment addressed by this TMDL is for sedimentation due to agriculture, sediment contributions from forests, wetlands, developed lands and any non-agricultural point source discharges within the Hammer Creek Headwaters Subwatershed were considered loads not reduced (LNR). LNR was calculated to be 24,547 lbs/yr (Table 9).

Then, the ASL is calculated as:

3,143,409 lbs/yr SL – 24,547 lbs/yr LNR = 3,118,862 lbs/yr ASL

Table 9. Source Load, Loads Not Reduced and Adjusted Source Load as Annual Averages

	Sediment, lbs/yr
Source Load (SL)	**3,143,409**
Loads Not Reduced (LNR):	**24,547**
Forest	6,243

Wetlands	35
Non-Agricultural Herbaceous/Grasslands	0
Low Intensity Mixed Development	10,382
Medium Intensity Mixed Development	5,946
High Density Mixed Development	1,941
Adjusted Source Load (ASL)	**3,118,862**

Calculation of Sediment Load Reductions by Source Sector

To calculate prescribed load reductions by source, the ADL was further analyzed using the Equal Marginal Percent Reduction (EMPR) allocation method described in Appendix D. Although the Hammer Creek Headwaters ARP was developed to address impairments caused by agricultural activities, streambanks were also significant contributors to the sediment load in the subwatershed, and streambank erosion rates are influenced by agricultural activities. Thus, streambanks were included in the ASL and targeted for reduction.

In this evaluation, croplands exceeded the adjusted source load by itself. Thus, croplands received a greater percent reduction (62%) than hay/pasture lands and streambanks (24% each) (Tables 10 and 11). Note however, the prescribed reductions by source sectors are simply suggested targets and not rigid goals that must be met. During implementation, greater or lesser reductions can be made for each source sector so long as the overall adjusted source load is achieved.

Table 10. Sediment Load Allocations for Source Sectors in the Hammer Creek Headwaters Subwatershed, Annual Average Values

		Load Allocation	Current Load	Reduction Goal
Land Use	Acres	lbs/yr	lbs/yr	
CROPLAND	3,602	2,355,479	6,164,580	62%
HAY/PASTURE	1,239	163,158	216,036	24%
STREAMBANK		600,225	794,750	24%
AGGREGATE		3,118,862	7,175,366	57%

Consideration of Critical Conditions and Seasonal Variations

"Model My Watershed" uses a continuous simulation model with daily time steps for weather data and water balance calculations. The source of the weather data (precipitation and temperature) was a dataset compiled by USEPA ranging from 1961-1990 (Stroud Water Research Center 2019). The evapotranspiration calculations also take into account the length of the growing season and changing day length. Monthly calculations are made for sediment loads based on daily water balance accumulated in monthly values. Therefore, variable flow conditions and seasonal changes are inherently accounted for in the loading calculations.

An Analysis of Possible BMPs

The following proposes a hypothetical set of Best Management Practices (BMPs) that are calculated to exceed the prescribed sediment loading reductions and address the specific problems observed in the Hammer Creek Headwaters Subwatershed. Table 11 presents the proposed BMPs and their calculated sediment reductions. Key locations for the proposed physical BMPs are shown in Figure 16. Note that other BMP opportunities may exist in other areas and it is not intended to limit physical BMPs to only those opportunities shown in Figure 16.

Where relevant, BMP implementation should follow USDA-NRCS standards from the Field Office Technical Guide for Pennsylvania, unless there is a good reason to deviate from these standards. In cases where there are deviations from these standards a review should be made of the BMP to determine whether the changes would likely result in substantially diminished sediment pollution prevention. If so, a decision could be made to not credit the BMP. It should be noted that there are likely be other BMP opportunities beyond what is envisioned here, and what is ultimately implemented will largely be dependent on the landowner's preferences.
In any case, it will be important to keep careful track what is implemented so that progress may be documented.

Table 11. BMP opportunities and their calculated sediment loading reductions.

Proposed BMPs	Sediment reduction *lbs/yr*
14,067 feet streambank stabilization	385,443
7,674 feet comprehensive stream restoration	210,260
95% ag. erosion and sedimentation plan implementation	1,480,506
10% more cropland with cover crops (360 acres)	61,646
30% more conservation tillage (1,081 acres)	758,243
300 acres grazing land management	15,699
162 acres forested riparian buffers	260,636
62 acres croplands retired for establishing the riparian buffers	105,933
99 acres hay/pasture lands retired for establishing the riparian buffers	16,975
102 acres precision grass filter strips[1]	2,522,996
83 acres of cropland retired for establishing filter strips[2]	127,040
subtotal	*5,945,377*
	lbs/yr
current loading for targeted sectors[3]	7,175,366
current loading for targeted sectors - all reductions	1,229,989
adjusted source load	3,118,862

[1]Must be installed along main drainagelines shown in Figure 16 for crediting to be applicable; deviation from proposed design (location, length, width) will require new modelling of reductions.
[2]Conservatively assumed filter strips would load at the rate of hay.
[3]Targeted sectors include croplands, hay/pasture lands, and streambanks.

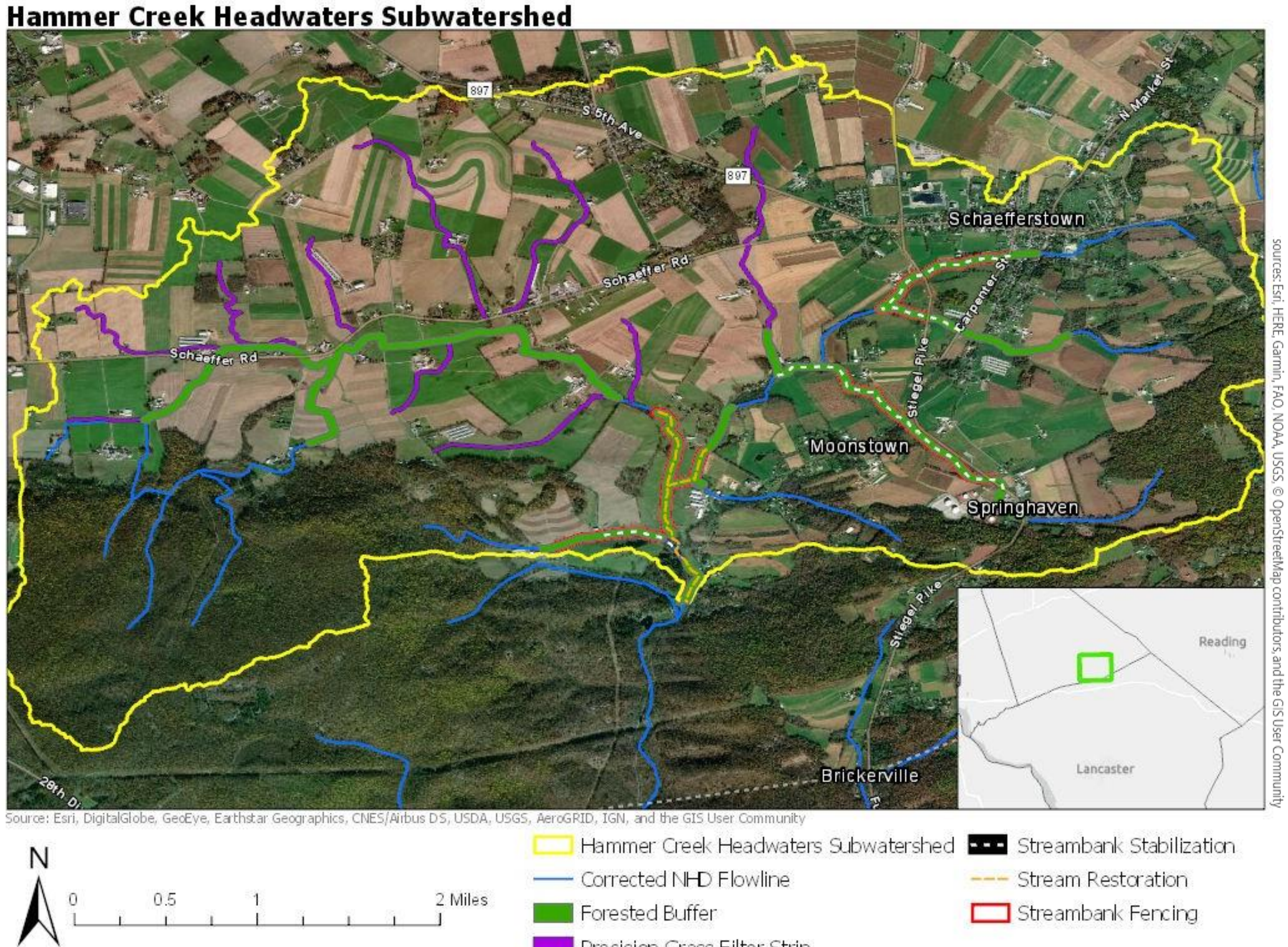


Figure 16. Proposed physical BMPs in the Hammer Creek Headwaters Subwatershed. Note that other BMP opportunities may exist in other areas and it is not intended to limit physical BMPs to only those opportunities shown on this map.

Table 12. Cost analysis of BMP opportunities. All costs are reported as dollars.

BMP	Unit	Lifespan in years	Capital Cost per unit	Annual O&M Cost per unit	One Time Opportunity Cost per unit (land cost)	Total Annualized Cost per unit	Units Proposed	Total Capital Cost	Total Capital + Land Cost	Total Annualized Cost	Total Annualized Cost per pound of sediment per year
Streambank Stabilization[1]	ft	20	74.75	0.00	0.00	6.00	14,067	1,051,460	1,051,460	84,368	0.219
Stream Restoration[2]	ft	20	350.00	0.00	0.00	28.08	7,674	2,685,900	2,685,900	215,524	1.025
Erosion and Sedimentation Plans[3]	ac	10	15.00	0.00	0.00	1.94	4,598	68,974	68,974	8,921	0.006
Cover Crops[4]	ac	1	0.00	75.50	0.00	75.50	360	0	0	27,195	0.441
Conservation Tillage[4]	ac	1	0.00	0.00	0.00	0.00	1,081	0	0	0	0.000
Grazing Land Management[4]	ac	1	81.27	0.00	0.00	85.33	300	24,381	24,381	25,599	1.631
Forested Riparian Buffer w/o Fence[4]	ac	40	4,062.42	81.25	1,770.23	406.51	83	337,181	484,110	33,740	0.139
Forested Buffer w/Fence[4]	ac	30	7,216.47	238.95	971.31	756.96	79	570,101	646,835	59,800	0.425
Grass Filter Strips[4]	ac	10	899.15	35.97	1,770.23	240.93	102	91,713	272,277	24,575	0.009
							sum	***4,829,710***	***5,233,936***	***479,722***	

Where necessary, costs were annualized using CAST methodology. See https://cast.chesapeakebay.net/Documentation/CostProfiles

[1] Current CAST methodology reports a much higher cost for "Non Urban Stream Restoration Protocol". However, per personal communication with Shaun McAdams of Trout Unlimited, smaller projects using general permit type structures and restoration designs provided by government agencies tend to be much cheaper, approximately $50 per foot. To be conservative, $63.56 per foot was used in accordance to the second most recent CAST methodology for Pennsylvania. This value however was multiplied by 1.176 to adjust for inflation from April 2010 to April 2020 per the CPI inflation calculator provided at https://data.bls.gov/cgi-bin/cpicalc.pl.

[2]This cost estimate for more comprehensive stream restoration was provided by Shaun McAdams of Trout Unlimited.

[3]Based in internal discussions at DEP, the most current CAST estimate of $24.91 per year for "Soil Conservation and Water Quality Plans" does not seem to reflect typical costs and longevity for agricultural erosion and sedimentation plans in Pennsylvania. Thus the prior CAST cost estimate was used.

[4]Based on most recent CAST methodology

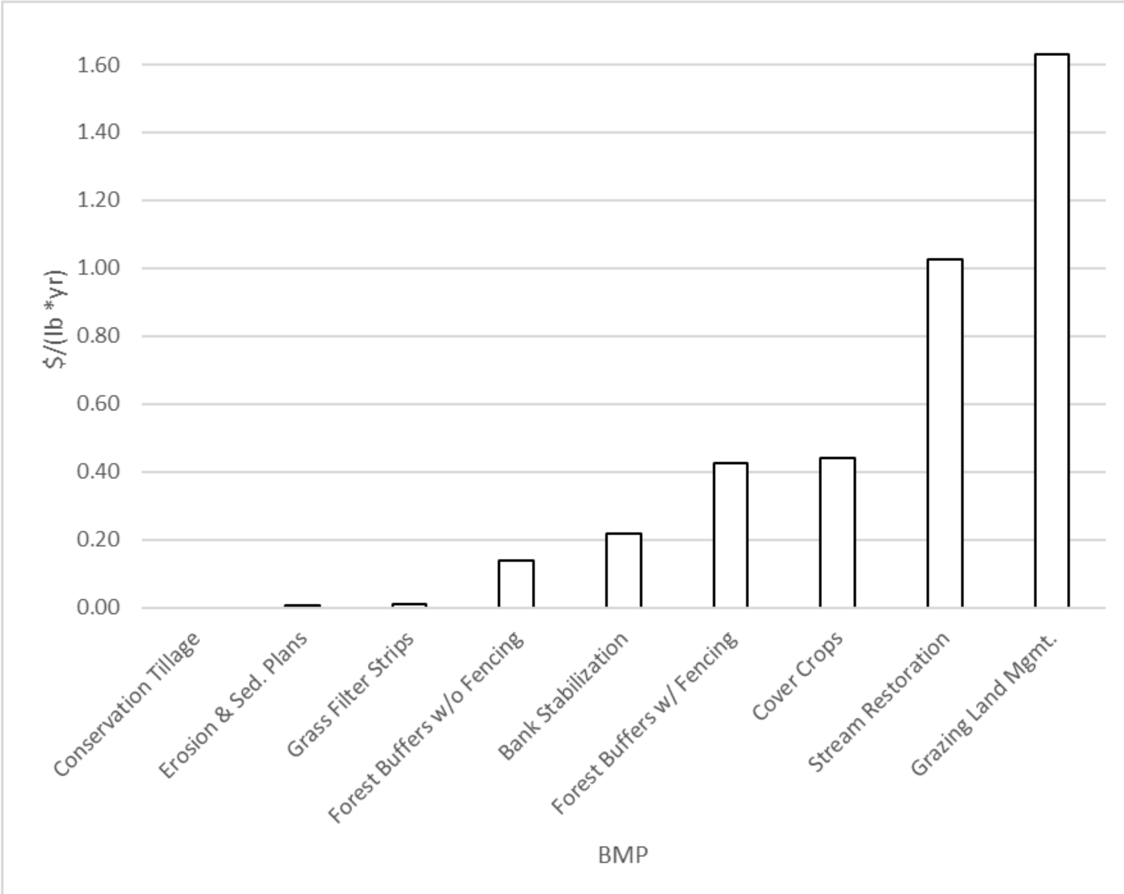


Figure 17. Estimated total annualized cost per pound of sediment removed per year for BMPs. See footnotes in Table 12 for a description of how costs were derived.

Agricultural Erosion and Sedimentation Control Plans

PA DEP and County Conservation Districts are currently working towards ensuring that agricultural operations are implementing required erosion and sedimentation control plans, and a 95% implementation rate was assumed. Note that this is not to be interpreted as an acceptable 5% rate of noncompliance. Rather such conservative assumption may help account for factors such as temporary noncompliance, implementation lag time during transitions, potential error in NLCD classifications, acreage comprised of by BMPs, etc. This would result in an estimated 3,422 acres of cropland and 1,177 acres of hay/pasture lands covered by plans. Based on Chesapeake Bay Program (2018) methodology, it was assumed that these plans would reduce sediment loading on croplands by 25% and loading on hay/pasture lands by 8% (See Appendix F). Therefore, an annual sediment reduction of 1,480,506 lbs/yr is predicted (Table 11).

Based on internal discussions at DEP and prior CAST methodology, these plans were estimated to have a capital cost of about $15 per acre, so, if applied to 95% of the acreage of croplands and hay/pasture lands in the subwatershed, the total capital cost of these plans would be about $68,974 (Table 12). The total annualized cost per pound of sediment removed per year was only $0.006, which suggests that this BMP is very cost effective (Figure 17).

For tracking purposes, load reductions associated with agricultural erosion and sedimentation plan implementation may be calculated as:

lb/yr reduction = acres of agricultural lands with implemented plan * agricultural land loading rate * reduction coefficient

where: cropland loading rate = 1,712 lbs/(ac*yr)

hay/pasture land loading rate = 174 lbs/(ac*yr)

reduction coefficient for croplands = 0.25

reduction coefficient for hay/pasture lands = 0.08

Note that the loading rates for croplands and hay/pasture lands given above should not be confused with erosion rates reported in agricultural erosion and sediment plans, as the above values reflect loading rates transported to the watershed outlet.

Conservation Tillage

The current rate of conservation tillage use is currently unknown, but it was conservatively assumed that its use could increase by an acreage equivalent to 30% of the current cropland acreage, or about 1,081 acres. Based on Chesapeake Bay Program (2018) methodology, a sediment reduction efficiency of 41% was assumed (See Appendix F). Therefore, implementation of this BMP as proposed would be estimated to reduce the sediment load by about 758,243 lbs/yr.

According to CAST documentation, use of conservation tillage is considered to be cost neutral; thus with a cost estimate of $0 per pound of sediment removed per year this is considered the most cost effective BMP (Table 12, Figure 17).

For tracking purposes, load reductions associated with conservation tillage implementation may be calculated as:

lb/yr reduction = acres croplands with new/recent conservation tillage * cropland loading rate * reduction coefficient

where: cropland loading rate = 1,712 lbs/(ac*yr)

reduction coefficient = 0.41

If an additional 1,081 acres are not available for implementation of this BMP relative to current conditions, increased use of this BMP since 2004 could be credited, if implementation since then can be clearly demonstrated. An argument can be made for using 2004 as the baseline year because it was the last time that physical habitat assessment scores, which included a sedimentation component, were taken for the Hammer Creek Headwaters Subwatershed. Since 2004 much progress may have already been made in implementing this BMP, because on a statewide level, no-till use went from a little over 20% in 2004 to close to 70% by 2014 (USDA-NRCS 2019).

Cover Crops

According to Chesapeake Bay Program (2018) methodology, no additional credit is given for the use of cover crops on croplands that are already managed with low tillage. And, on lands with higher tillage, use of cover crops would provide much less sediment reductions versus converting to conservation tillage. Thus, only a small amount of cover crops, 360 acres or 10% of the cropland land area, were presently proposed, to account for areas where landowners are unwilling to implement conservation tillage.

Based on Chesapeake Bay Program (2018) methodology, this BMP was given a 10% sediment reduction efficiency (See Appendix F). It should be noted however that crediting is only applicable when this BMP is used on high tillage lands and when the cover crop is not a commodity crop. It is estimated that this would reduce sediment loading by a meager 61,646 lbs/yr.

According to CAST's cost estimates for Pennsylvania, use of cover crops is estimated to have an annual operation and maintenance cost of $75.50 per acre. Thus, if applied to 10% of the acreage of cropland in the subwatershed, the total annual cost of the proposed cover crops would be about $27,195 (Table 12). The total annualized cost per pound of sediment removed per year is $0.441, which indicates that this BMP is fairly expensive (Figure 17).

For tracking purposes, load reductions associated with cover crop implementation may be calculated as:

lb/yr reduction = acres croplands on high tillage lands with new/recent cover crop use * cropland loading rate * reduction coefficient where: cropland loading rate = 1,712 lbs/(ac*yr) reduction coefficient = 0.1

If an additional 360 acres are not available for implementation of this BMP relative to current conditions, increased use of this BMP since 2004 could be credited, if implementation since then can be clearly demonstrated. An argument can be made for using 2004 as the baseline year because it was the last time that physical habitat assessment scores, which included a sedimentation component, were taken for the Hammer Creek Headwaters Subwatershed. Since then, much progress may have already been made in implementing this BMP; in Berks, Lancaster, Lebanon and York Counties, use of cover crops after growing corn went from about 40% in 2009 to about 65% in 2012 (USDA-NRCS 2019).

Conventional Riparian Buffers

It is widely recognized that riparian buffers are highly beneficial to stream communities for many reasons. Not only do they filter out pollutants, such as sediment and nutrients, but they also provide habitat and nutrition for aquatic, semi-aquatic and terrestrial organisms; protect streambanks; and moderate stream temperature. Thus, riparian buffers should be encouraged *wherever* possible. Therefore, Figure 16 essentially shows proposed 100-foot wide forested buffers for all streamside areas where they are substantially lacking and are feasible (not within a significantly developed area). The acreages of buffer opportunities reported in Table 11 were reduced relative to the full area shown in Figure 16 to reflect only the area with croplands or hay/pasture coverage per NLCD 2016, as some areas may already have some natural vegetative cover and it is unlikely that significant buffers would be established on many developed lands.

While many experimental studies suggest riparian buffers can be very effective at removing upland pollutant loads, recent research suggests that buffer filtration performance may be limited by real-world environmental conditions, especially due to the existence of concentrated flowpaths (Dosskey et al. 2002, Sweeney and Newbold 2014). Furthermore, for any given buffer there may not be much uplands contributing pollutants to it. Or, if there are too much uplands communicating to a unit area of buffer it is thought that its filtration capacity may become less effective. For such reasons, the CAST expert panel report chose to very conservatively assume that the sediment load from only two acres of uplands are filtered by about half (though variable by region) per acre of buffer created. Credit is also given for the land conversion associated with the creation of the buffer. For more information, see Belt et al. (2014) and Appendix F. Similarly, to Belt et al. (2014) and Chesapeake Bay Program (2018), reductions associated with conventional buffers may be calculated as:

lb/yr reduction = (acres of new streamside buffers created * 2 * cropland loading rate * filtration reduction coefficient) + [acres of new streamside buffers created * (current land use loading rate – forest land use loading rate]

where: cropland loading rate = 1,712 lbs/(ac*yr)

filtration reduction coefficient = 0.47

current land use loading rate for hay/pasture lands (if needed) = 174 lbs/(ac*yr)

forest land use loading rate = 2.96 lbs/(ac*yr)

One advantage to crediting buffers by the acre rather than by length of stream buffered is that buffer width and configuration will likely vary depending on the landowner’s degree of commitment to this BMP. While ≥ 100 foot buffers are preferable, the above formula allows for crediting buffers of varying widths.

Using the above methodology, it is estimated that the proposed buffers shown in Figure 16 would remove 383,544 pounds of sediment per year (Table 11).

Note that while forested buffers are preferable for wildlife habitat, grass buffers are thought to provide a similar sediment filtration benefit (see Belt et al. 2014). Reductions associated with streamside grass buffers could be modelled using the above formula, in which case the loading for hay/pasture could be used for the loading rate of the grass buffers when calculating the reductions associated with the change of land use.

According to CAST’s cost estimates for Pennsylvania, the cost of forested riparian buffer is substantially higher if livestock exclusion fencing is necessary. If implemented as proposed in Figure 16, exclusion fencing would be necessary about half of the time. Without fencing, riparian buffers are expected to have a capital cost of $4,062.42 per acre, so, for the 83 acres of forested buffers proposed, the capital cost is expected to be $337,181 (Table 12). For forested buffers with exclusion fencing, the capital cost is expected to be $7,216.47 per acre, so for the 79 acres proposed the total capital cost is expected to be $570,101

If the cost of the land is included, the total estimated capital + land cost for all the proposed buffers is $1,130,945. With a total annualized cost of $0.14 per pound of sediment removed per year, conventional forested buffers without fencing appear to be moderately cost effective (Figure 17), even with very conservative assumptions of sediment removal. In contrast, buffers where fencing is needed are moderately expensive, at around $0.43 per pound of sediment removed per year.

Precision Grass Filter Strips

As mentioned previously, CAST derived methodology for calculating the effectiveness of riparian buffers was purposely very conservative to account for: lack of knowledge of how much sediment communicates to any given buffer and the possibilities of concentrated flowpaths and saturation of filtration effectiveness. Rather than using very conservative crediting to account for these uncertainties, it was sought to directly address these concerns by strategically placing buffers where they would intercept the most runoff and design them so they would be effective at sediment removal (see Dosskey et al. 2005, Allenby and Burke 2012, Holden et al. 2013).

To determine the locations where buffers may intercept the most storm runoff/sediment loads, USGS QL2 LiDAR data (USGS 2017) was analyzed using the TauDEM Version 5 toolkit in ArcGISPro. Briefly, the bare earth digital elevation model (DEM) was clipped to the general area of the Hammer Creek Headwaters Subwatershed, and then the “Pit Remove”, “D8 Flow Direction”, “D8 Contributing Area”, “Grid Network” and “Stream Definition by Threshold” tools were used to create drainage networks based on an accumulated stream source grid cell threshold value of 10,000. Different thresholds were explored, but this value was chosen as sufficient for displaying the major drainageways without overwhelming their visualization with too much detail. The “D8 Contributing Area” tool was used to delineate the Hammer Creek Headwaters Subwatershed at a delineation point placed near the desired outlet. Then the “Stream Definition by Threshold” tool, again with a threshold value of 10,000, was used to define drainageways just within the delineated watershed. Then the “Stream Reach and Watershed” tool was used to create a shapefile of the watershed’s drainage networks. See Figure 18. The “Watershed Grid to Shapefile” tool was used to help create a shapefile of the DEM delineated watershed, though some subsequent editing of the shapefile was necessary as there was some disconnectedness in the center due apparently to poor resolution of flow in the very flat central portion of the watershed (Figure 18).

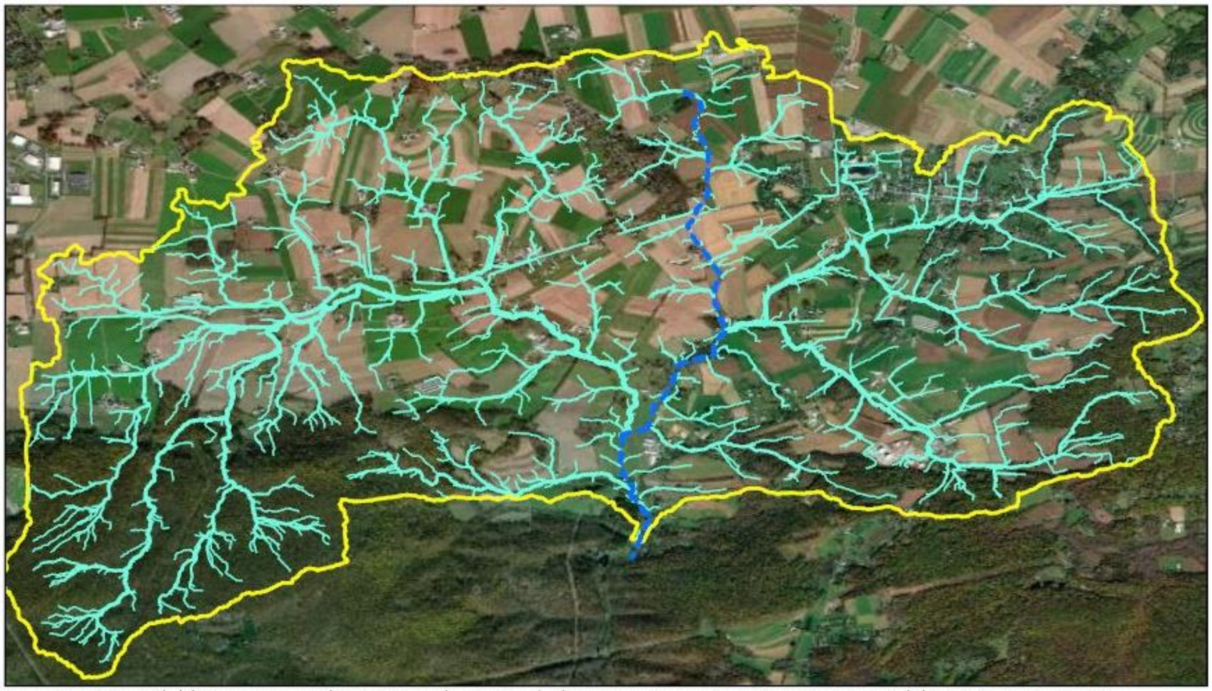


Figure 18. Drainage networks within the Hammer Creek Headwaters Subwatershed. Drainage networks were mapped using USGS bare earth digital elevation model and the TauDEM toolkit in ArcGISPro. The drainage networks are shown in light blue. Note, they were disconnected in the central portion, apparently due to this area being very flat. The flow in this area, shown as a dashed dark blue line, was reconstructed using flowlines from Pennsylvania's 2016 integrated report.

As is obvious when comparing the drainageways to the assessed stream segments in Figure 19, these results confirm the presence of concentrated overland flowpaths. Therefore, riparian buffers in certain areas would intercept larger amounts of overland flow, whereas buffers established in other areas would filter virtually no upland runoff. To choose the areas that would be most important for buffering, it was sought to define the key overland drainagesheds that drained the greatest amount of croplands. This was accomplished by visually inspecting the drainage network along with the NLCD 2016 landcover and stream network layers (Figure 19). Key drainagesheds were then delineated primarily using the aforementioned TauDEM tools at outlet points near where main drainagelines entered the stream (Figure 20). Additional shapefile editing was done where necessary in ArcGISPro. For areas that were poorly resolved with TauDEM tools, final delineations were also in part based on watershed delineation using Model My Watershed's "Watershed Delineation Tool" (see https://wikiwatershed.org/documentation/mmw-tech/#delineate-watershed). Some potential area was excluded because proposed buffering would have interfered with existing roadway.

To determine the sediment load associated with these drainagesheds, the proportion of each NLCD 2016 landcover class within each drainageshed was multiplied by the overall area of the drainageshed per Model My Watershed to solve for the area of each NLCD 2016 landcover class. These areas were then multiplied by the landcover loading rates in the BMP spreadsheet tool provided by Model My Watershed. Estimated sediment loads for each key drainageshed labeled in Figure 20 are reported in Table 13. It should be noted that approximately half of the Hammer Creek Headwaters Subwatershed's total sediment load appears to derive from these key drainagesheds, and thus pass through the outlets (delineation points) shown in Figure 20.

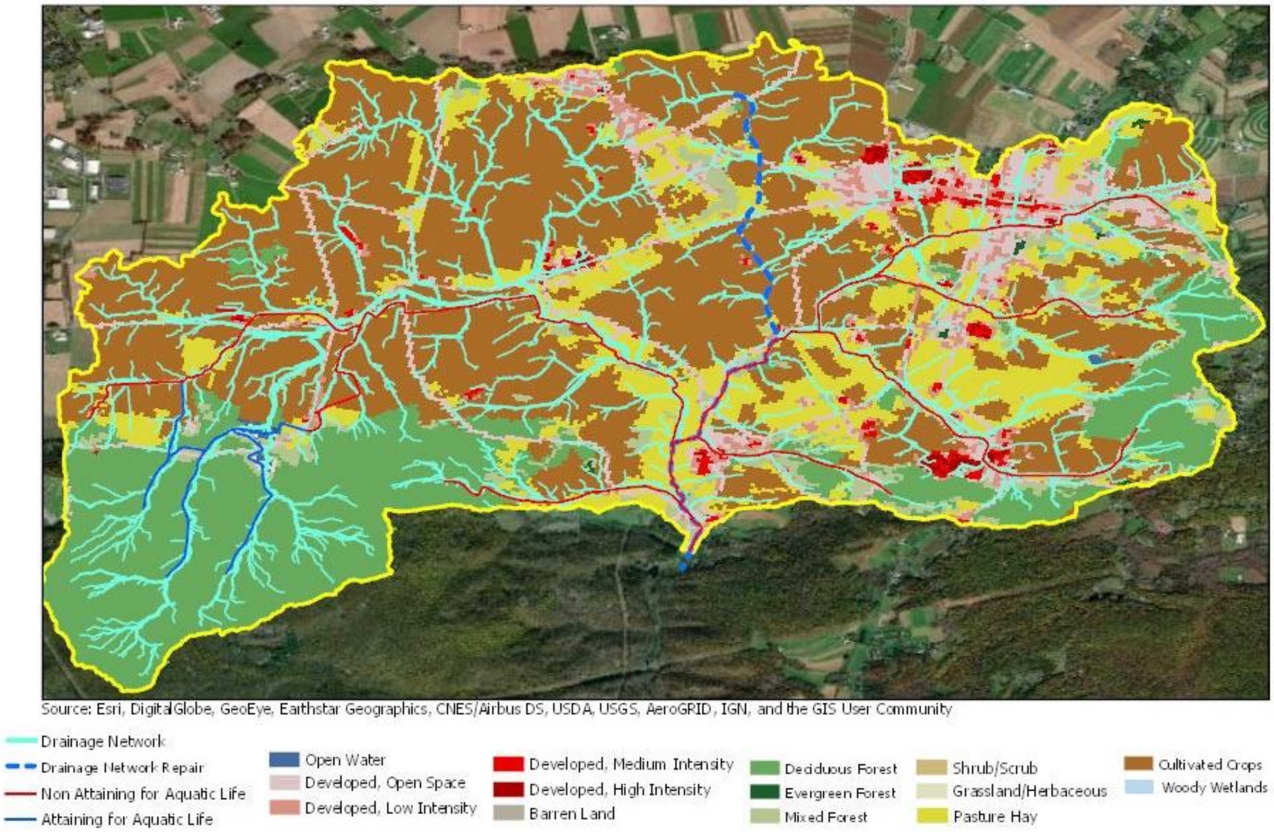
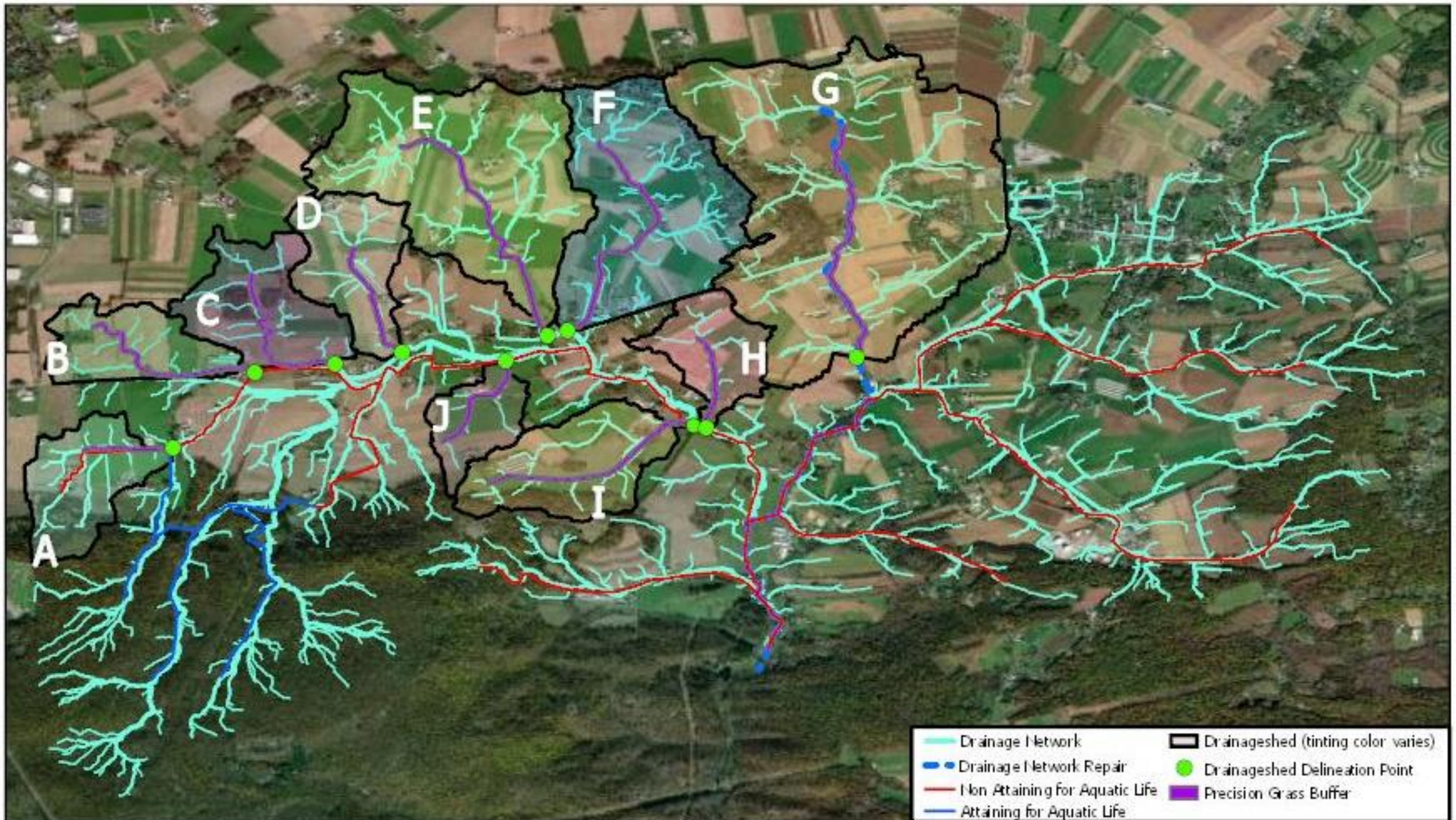


Figure 19. Drainage networks with flowlines and land use. Flowlines are shown as either attaining or non-attaining for aquatic life and largely correspond to permanently flowing channels. Land use is from the NLCD 2016 landcover layer. See Figure 18 for a description of the drainage network. Drainage networks that drained large amounts of croplands (brown) were chosen as the most crucial for buffering. Note that “Drainage Network Repair” refers to correction of the flowline image rather than a proposed BMP.

Simply establishing riparian buffers along the flowing stream at the outlet of the drainagesheds may be ineffective because large amounts of sediment and flow could overwhelm very small areas of buffers (Dosskey et al. 2002 and personal observations). Thus, to provide adequate area to buffer these drainagesheds, it was proposed to extend buffers up the main flowline of each key drainageway (Figure 20).

Because these drainagelines pass through agricultural fields, establishing forested buffers, though preferable for wildlife habitat, would likely be unacceptable to farmers. Thus, it was proposed to use tall grass buffers instead. Such grass lined waterways are a commonly used BMP, and the CAST Expert Panel Report (See Belt et al. 2014) indicates that grass buffers may be as effective as forested buffers for sediment removal.



Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

Figure 20. Key drainagesheds with proposed precision grass buffers. The green dots show the outlet of the drainageshed near where it empties into a regularly flowing channel. Because key drainagesheds were chosen to be areas that drained a large amount of croplands, it is estimated that approximately half of the subwatershed's sediment load gets into the stream through these 10 outlets. Each precision buffer would be comprised of a dense, tall grass mixture on 50 feet on either side of the main drainage flowline. The letter labels correspond to the labels in Table 13.

Table 13. Contribution of sediment from each drainageshed to the subwatershed total and predicted % sediment removal by the precision buffers for the 1-yr and 5-yr storms. Note: drainageshed labels correspond to labels in Figure 20.

		contribution to watershed total	Reductions for 1yr storm		Reductions for 5yr storm	
Drainageshed	acres	mean, lbs/yr	%	lbs/yr	%	lbs/yr
A	152	147,731	64	94,696	29	42,842
B	137	212,220	100	211,159	98	206,914
C	183	276,224	99	274,014	95	262,689
D	159	238,353	98	233,824	84	200,455
E	489	706,178	95	670,870	66	466,078
F	407	493,276	96	475,025	73	358,612
G	897	1,082,609	89	963,522	50	540,222
H	115	141,112	99	140,266	95	134,339
I	201	241,267	99	238,131	76	183,363
J	90	140,399	99	139,136	91	127,483
			Total:	**3,440,641**	**Total:**	**2,522,996**

Note: % reduction corresponds to % sediment reduction due to retention in the buffer during the 1-yr or 5-yr storm. The lbs/yr reductions were calculated by simply multiplying the % reduction for the 1 or 5yr storm by the average annual sediment contribution of each drainageshed to the subwatershed total per Model My Watershed and its BMP spreadsheet tool. Note that these reductions are for upslope filtration only and do not account for land conversion when creating the buffers.

In order to design and credit these buffers for sediment removal, a rigorous, scientifically-justifiable approach was sought. Ultimately the VFSMOD program was chosen because it was a freely-available mechanistic model designed to estimate sediment and other pollutant removal from grass buffers based on site specific conditions. Further, this model has been the subject of numerous peer-reviewed scientific publications and it has been validated under experimental conditions.

Using user defined parameters, VFSMOD simulates storm events, generates landscape runoff and sediment loads, and estimates sediment retention versus export in grass filter strips. Since the model cannot accommodate complex site geometry, the total non-buffer land area of the drainageshed was assumed to be a uniform rectangle that drained to a rectangular 15m (or 50 ft) wide grass buffer that was twice as long (to account for two sides) as the purple strips shown in Figure 20. Simulations were conducted using two storm events corresponding to the one and five year storms for this region of Pennsylvania: 66.9 mm and 99.4 mm in 24 hours (PENNDOT 2010). The buffer was assumed to have uniform slope and be comprised of a dense grass mixture. See Appendix G for VFSMOD parameter inputs and further details on how site geometry was simplified.

According to the VFSMOD output, the proposed vegetated filter strips (Figure 20) were typically predicted to remove nearly all of the sediment from upland runnoff during the 1-year storm and most of the sediment during the 5-year storm. For crediting these buffers however, it is proposed to be very conservative and base claimed reductions on performance during the 5-years storm. Thus, % reductions during the 5-year storm were multiplied by the drainageshed's contribution to the overall annual average sediment load (Table 13), even though these buffers would perform far better during more typical storms. Another reason to believe these results are conservative is that estimated amount of sediment getting through these buffers is really just sediment reaching the center-line of the drainageway. To actually get to the stream this sediment would have to flow down through the buffer and reach the drainageshed outlet. Filtration in this flow direction was not even accounted for. This likely compensates for one reason the buffers might not perform as well as expected: the fact that additional concentrated flowpaths feed into the main drainageline and perhaps overwhelm the buffers at certain points. Note that if this is the case, the buffer would be underwhelmed at other points.

Using strategically placed buffers and crediting them with realistic methodology suggests they may be the most effective BMP opportunity in terms of the amount of sediment removed (Table 11). It is estimated that if implemented as proposed, these filter strips would occupy only 102 acres of land, which would be equivalent to about 2% of current agricultural lands. Yet these buffers would be conservatively estimated to remove more than 2.5 million pounds of sediment per year (Table 11), which is about a third of subwatershed's annual sediment load.

According to CAST's cost estimates for Pennsylvania, grass buffers/filter strips are expected to have a capital cost of $899.15 per acre, so, for the 102 acres proposed, the total capital cost is expected to be $91,713 (Table 12). If the cost of the land is included, the total capital + land cost is $272,277. There was also an annual operation and maintenance cost of $35.97 per acre. Given the high amount of predicted sediment removal, these filter strips are predicted to be the most cost effective physical (as opposed to practice) BMP, with a total annualized cost of less than 1 cent per pound of sediment removed per year (Table 12, Figure 17).

For tracking purposes, the following credit can be claimed for fully implementing the 50-foot wide (each side) precision grass filter strips as shown in Figure 20:

Table 14. Sediment reduction credit for installing 50-foot wide (or 15m) tall grass buffers on each side of the drainagelines as shown in Figure 16.

Total lbs/yr reduction = filtration component + land conversion component

Filtration Component:

Buffer	Length (ft)	lbs/yr
A	1,850	42,842
B	4,334	206,914
C	4,321	262,689
D	3,159	200,455
E	6,850	466,078
F	6,309	358,612
G	6,759	540,222
H	2,602	134,339
I	4,770	183,363
J	2,825	127,483

Note that deviations from the configurations proposed herein will require additional modelling to calculate appropriate reductions.

Land Conversion Component:

lbs/yr = acres croplands retired in creating filter strips * (cropland loading rate – hay/pasture loading rate)

Where: cropland loading rate = 1,712 lbs/(ac*yr)
hay pasture loading rate = 174 lbs/(ac*yr)

Streambank Stabilization/Stream Restoration

Substantial streambank erosion was common in the Hammer Creek Headwaters Subwatershed (Figure 7), and it was conservatively assumed that streambanks in these areas loaded sediment at ten-times the rate as other areas. Therefore, to calculate crediting, the total length of NHD flowlines (corrected for underground streams) in the subwatershed shown in Figure 1 was estimated via a GIS analysis. Then based on site observations and examination of satellite imagery, the length of the NHD flowlines with obvious bank erosion problems was estimated to be 21,741 feet.

This being the case, the normal erosion rate (X) was then calculated as follows:

(ft of flowlines with normal banks)(X) + (ft of flowlines with degraded banks)(10)(X) = total streambank erosion

Therefore, for the Hammer Creek Headwaters Subwatershed:

(72,278 ft)(X) + (21,741 ft)(10X) = 794,750 lbs/yr

Thus, the normal streambank sediment loading rate was calculated to be 2.74 lbs/(ft*yr), in which case the credit given for stabilizing the eroding reaches was calculated to be 10X or 27.4 lbs/(ft*yr). In reality, site to site differences in streambank erosion rates are highly variable (see Figures 6 and 7) and actual site measurements could be used to justify higher or lower credit claims.

Using this new methodology, stabilization of the proposed 21,741 feet of streams with suspected degrading banks would reduce sediment loading by 595,703 lbs/yr (Table 11). Most of the proposed stabilization sites were observed from a distance during site visits, so further detailed inspection should be done to choose the most important sites for streambank stabilization.

For the purposes of calculating the costs associated with streambank stabilization, this larger category was subdivided into cheaper bank stabilization focused projects (shown in white in Figure 12) versus a more comprehensive stream restoration site (shown in orange in Figure 12). The simpler bank stabilization sites were small streams, generally in the non-karst region of the subwatershed, where bank stabilization for the sake of pollution prevention was needed, but there was less interest in the far more expensive comprehensive stream restoration. In contrast, the proposed stream restoration site (Figure 21) tended to have far more severe channel instability that would benefit from a more comprehensive natural channel design approach. Furthermore, since it is a larger reach downstream of a major karst area, there is also interest in improving trout/fish habitat at this site. The simpler sites would utilize general permit approved structures and only light equipment (S. McAdams, Trout Unlimited personal communication) and thus are expected to be far cheaper, approximately $75 per foot. In contrast, the comprehensive stream restoration site will require greater design work, more time and heavier equipment, and thus is estimated to cost $350/ft (S. McAdams, personal communication).

Based on visual estimations of severity of bank erosion and suspected presence of legacy sediments, it is thought that improvements at the more comprehensive restoration site will result in far more sediment removal per foot versus stabilization at the simpler sites. However, given the current lack of actual measurements, a BMP effectiveness rate of 27.4 pounds per foot removal was used at all sites. Thus, at about $1.03 per pound of sediment removed per year (Table 12), the total annualized cost per pound of sediment removed at the comprehensive restoration site is very expensive (Figure 17) but might be greatly overestimated. In contrast, basic stabilization projects appear to be moderately cost effective, at about $0.22 per pound of sediment removed per year.

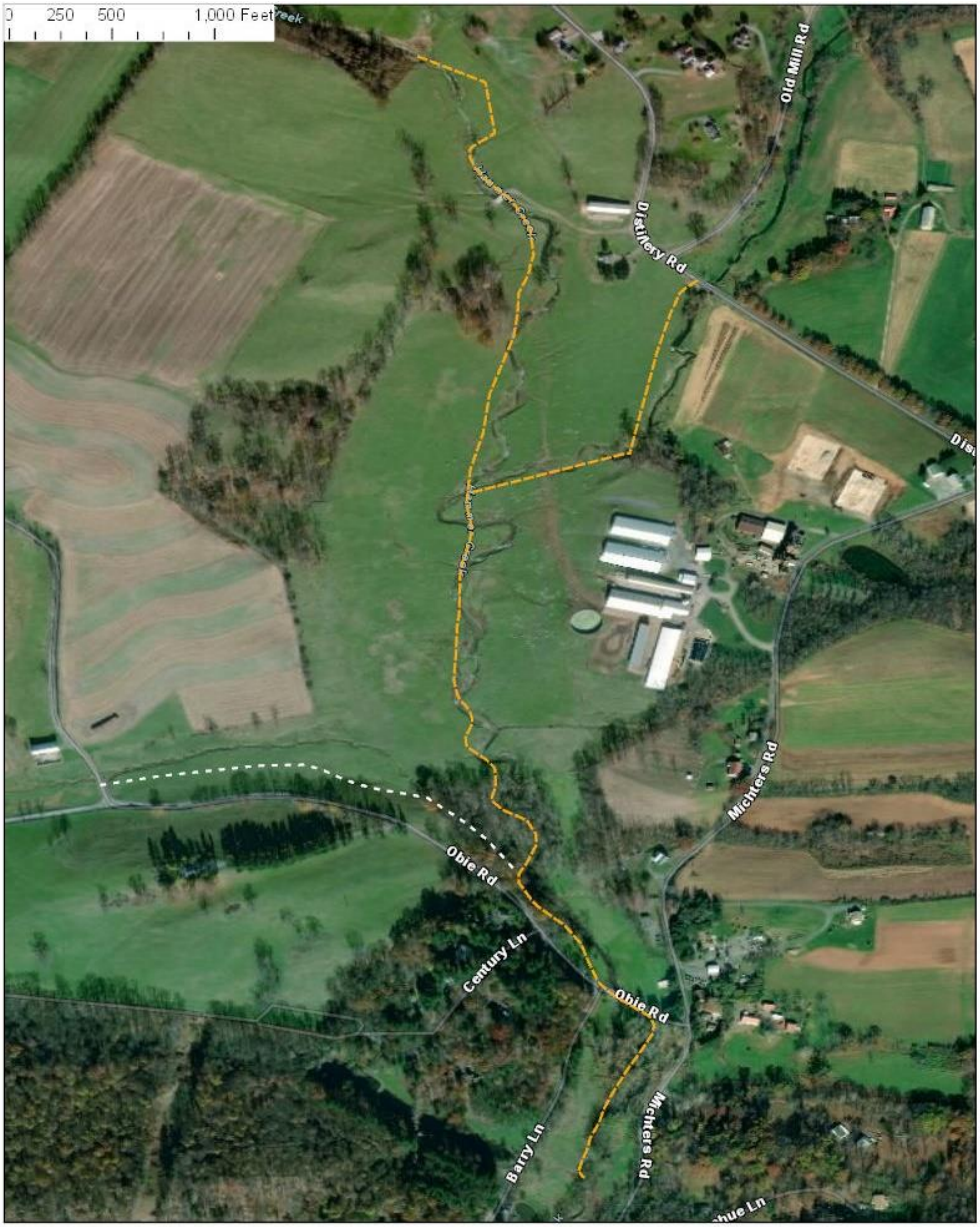
For tracking purposes, reductions associated with streambank stabilization/stream restoration may be calculated as:

Feet of streambank stabilized * estimated annual erosion rate per foot

Where estimated annual erosion rate per foot is either:

the modeled value of 27.4 lbs/ft*yr

or, an empirically derived value based on site specific measurements



Sources: Esri, HERE, Garmin, FAO, NOAA, USGS, © OpenStreetMap contributors, and the GIS User Community

Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

Figure 21. Proposed comprehensive stream restoration site (NHD flowline shown as orange dates) in the Hammer Creek Headwaters Subwatershed.

Grazing Land Management

A target of 300 acres was set for grazing land management programs. According to Chesapeake Bay Program (2018), such programs are predicted to reduce sediment loading by 30% per acre in cattle pastures (See Appendix F). If implemented as proposed, it is estimated that these programs would reduce sediment loading by a very modest 15,699 lbs/yr (Table 11). The estimated total annual cost of $1.63 per pound of sediment removed per year suggests that this BMP is very expensive, thus it may be sensical to choose more cost effective BMPs, except perhaps where this BMP is necessary to address severely degraded pasturelands or a localized water quality problem.

For tracking purposes, reductions associated with grazing land management may be calculated as:

lb/yr reduction = acres with implemented grazing land management plan * hay/pasture land loading rate * reduction coefficient

where: hay/pasture land loading rate = 174 lbs/(ac*yr)

reduction coefficient = 0.3

Considerations of Cost Effectiveness in Implementation and Funding Sources

While the 4.8 million dollar capital and 5.2 million dollar capital plus land costs for the feasible BMP opportunities identified in Table 12 may seem high, it should be considered that 1) the actual implementation costs to meet the prescribed reductions may be lower, as not all proposed BMPs are necessary, and 2) these BMPs may prevent other very expensive costs associated with downstream sedimentation in Speedwell Forge Lake.

If fully implemented, these BMP opportunities, as shown in Table 11, would far exceed the prescribed reductions for this subwatershed (5,945,377 lbs/yr versus 4,056,504 lbs/yr). Showing more BMP opportunities than necessary is important, however, because implementation of most requires the voluntary cooperation of landowners. This also allows for the selection of the most cost effective BMPs. Given the very small costs per unit sediment reduction associated with conservation tillage, erosion and sediment plans, and precision grass filter strips, these BMPs should be implemented to the maximum extent possible (Table 12, Figure 17). While riparian buffers may be moderately cost effective or expensive, depending on whether fencing is necessary, it is suggested that they also be implemented as much as possible because of all their other positive effects, particularly regarding wildlife habitat. By comparison, stream restoration is expensive per pound of sediment removed, yet these projects may also be desirable for aquatic habitat improvement, protection of property.

Approximately four and a half miles downstream of our study subwatershed Hammer Creek flows into Speedwell Forge Lake, which is created by a dam on Hammer Creek. Considering that most of the area between our subwatershed outlet and the lake is forested, our study subwatershed appears to be the major source of sediment to the lake. This is especially concerning because the dam on this lake was deemed unsafe in 2011 and subsequently rebuilt at a cost of 4 million dollars (M. Lauch, personal communication). Part of the reason that the lake was deemed unsafe was that accumulated sediment had decreased the hydraulic buffering capacity of the lake (M. Lauch, personal communication). In addition to the cost of dam repair, another $436,000 was spent to remove 38,000 cubic yards of sediment from the lakebed, though, this was only a small fraction of the estimated 255,000 cubic yards of sediment that has accumulated behind the dam (M. Lauch, personal communication). Thus, it would likely have cost millions of dollars to remove it all. According to Milt Lauch of "Friends of Speedwell" and former DEP employee, "the eventual destruction of the lake will take place if the sediment from the 26 square mile drainage of Hammer Creek is not better managed". Thus, in addition to improving water quality locally and potentially creating a great trout fishery, the prevention of millions of dollars of damage to Speedwell Forge Lake helps justify the projected costs of this project.

This project seeks funding under Section 319 of the Clean Water Act which is specifically allocated for addressing nonpoint source pollution. In addition to use of 319 funds to implement this restoration plan, BMPs may also be paid for as described in the following.

Since agricultural erosion and sedimentation plans are the responsibility of the individual agricultural operator/landowner, they would be responsible for expenses associated with them. In some cases farmers may be able to write their own plans. Where a consultant is utilized, funding assistance may be available from USDA-NRCS, the Resource Enhancement and Protection (REAP) Tax Credit, and DEP's Agricultural Planning Reimbursement Program for Pennsylvania's Chesapeake Bay watershed.

There are many ways to fund the establishment of streamside buffers. In fact, there is an entire document describing funding opportunities. See "A Landowner's Guide to Conservation Buffer Incentive Programs in Pennsylvania" (Talbert 2009). In short, there are various programs that range from loan programs that provide funding assistance for designing and implementing buffers, all the way to programs that pay landowners more than the county's average agricultural land rental rate for the land use associated with the buffers. Specific sources of such funding include the USDA Conservation Reserve Program (CRP), USDA-NRCS's Wetlands Reserve Program, Pennsylvania's Conservation Reserve Enhancement Program (CREP), USDA Environmental Quality Incentives Program (EQIP), USDA's Wildlife Habitat Incentives Program (WHIP), PA DEP's Chesapeake Bay Financial Assistance Funding Program (FAFP), Chesapeake Bay Foundation/Ducks Unlimited Habitat Stewardship Program, PA DEP's Stream Bank Fencing Program, US Fish and Wildlife Service's Partners for Fish and Wildlife Program, the State Treasury's AgriLink loan program, Pennsylvania's Growing Greener program, USEPA's 319 program, and the State Conservation Commission's Nutrient Management Plan Implementation Grant Program (NMPIGP). PA DCNR also gives grants for the establishment of riparian buffers. Given the complexities of potential funding sources, coordination with the Lebanon County Conservation District should occur on a case by case basis to help choose the most appropriate funding options.

With regard to agriculture specific BMPs such as, cover crops, conservation tillage, grazing land management, grass filter strips and streambank fencing there may be numerous ways to fund such projects, especially through various programs administered through USDA's Natural Resources Conservation service. See https://www.nrcs.usda.gov/wps/portal/nrcs/main/pa/programs/financial/. Thus it is recommended to contact the Lebanon County Conservation District as well as the Lebanon Service Center NRCS office on a case by case basis to help choose the most appropriate funding options.

Pennsylvania's Growing Greener program may also fund agricultural BMPs and farmers and businesses who install BMPs may be eligible for REAP tax credits.

Stream restoration specific BMPs may be paid for through various funding sources, such as Pennsylvania's Growing Greener program and the National Fish and Wildlife Foundation. In the past, organizations such as the Pennsylvania Fish and Boat Commission and the US Fish and Wildlife service has supported stream restoration projects, for instance by providing restoration design work. Also, Trout Unlimited invests volunteer hours working on stream restoration projects.

The above paragraphs only list some of the major funding opportunities for BMP implementation as part of this project. Again, consultation with groups such as the Lebanon County Conservation District, USDA-NRCS, and DEP grant administrators should be done on a case by case basis for choosing the best way to fund specific BMPs.

Stakeholder Roles

Trienniel Update Report

It is proposed that DEP, in coordination Trout Unlimited (Figure 22), prepare a brief triennial (every 3 year) report over the nine-year project period that, among other things, reports progress towards prescribed pollutant reduction goals, improvements in water quality, and any other updates on key activities. Furthermore, a public meeting is planned after the first two triennial reports to review the report, update the public, and encourage additional participation (Figure 23). It is proposed that the triennial reports be shared with EPA's TMDL and 319 sections.

Education

With the exception of the Triennial Report, which would be a joint effort with DEP, The Doc Fritchey Chapter of Trout Unlimited would be responsible for education. Significant progress has already been made towards educating landowners and stakeholders. Past activities have included: mailings, phone calls, and door-to door visits with landowners in the subwatershed, a meeting in February 2019 to encourage farmers in the subwatershed to adopt conservation practices, and a watershed restoration tour during June of 2020. Trout Unlimited will typically continue to cover necessary expenses associated with the aforementioned activities with their own funding.

For the future, it is planned at a minimum to have mailings to landowners, a public report, and a public meeting on a triennial basis to keep the public informed and involved in the project. The nearby Middle Creek Wildlife Sanctuary Visitor Center owned by the Pennsylvania Game Commission has been used as a very convenient and free location to host meetings.

In addition to these activities, it is proposed to construct signs informing the public of significant restoration sites in the watershed as well as more general educational signs. These signs would be paid for with grant money, with an estimated cost perhaps of $5,000 total over the life of the project. Educational signs could be placed at park lands in Schaefferstown, within State Game Lands along Pumping Station Road, and at Speedwell Forge Lake.

Implementing BMPs

The Doc Fritchey Chapter of Trout Unlimited, with help from the Donegal Chapter of Trout Unlimited, would ultimately be responsible for implementation of most of the BMPs called for in this plan (Figure 22). These chapters have a history of successful stream restoration work which includes projects on Fishing Creek, Lititz Run and Conowingo Creeks in Lancaster County, as well as projects on Clarks Creek and Manada Creek in Lebanon County. The comprehensive watershed restoration project currently underway on Fishing Creek in Lancaster county may serve as a model for Hammer Creek. The Trout Unlimited chapters would be responsible for day to day stream restoration logistics, such as applying for funds, landowner outreach, acquiring site designs, hiring contractors, and assuring that work is done according to schedule. As was done for prior projects, Trout Unlimited may partner with US Fish and Wildlife Service and the Pennsylvania Fish and Boat Commission for the development of stream restoration designs.

While Trout Unlimited would advocate for all of the BMPs proposed in Table 11 generally, some agriculture specific BMPs would be beyond their area of expertise. It is therefore expected that they would rely heavily on organizations such as the County Conservation District and the USDA's Natural Resources Conservation Service (NRCS) for assistance in encouraging the use of these BMPs (Figure 23). On the other hand, the DEP and the Lebanon County Conservation District would be responsible for ensuring that agricultural operations were operating in accordance with legally-required erosion and sedimentation plans.

Prescription and Tracking of Pollutant Reductions

The present document, largely drafted by the DEP, establishes a quantitative sediment reduction goal and includes an analysis of hypothetical BMPs that are estimated to achieve the prescribed reduction. Furthermore, this document provides simple ways to calculate the credit received for implementing most BMPs. DEP's TMDL section plans on being involved over the life of the project to aid in additional modelling and the calculation of BMP reductions. It is proposed that the Department, in coordination with other stakeholders, prepare a brief triennial update report over the nine-year project period that, among other things, reports progress towards prescribed pollutant reduction goals (Figure 23). It will be important therefore for stakeholders and cooperating organizations to keep accurate records of all BMPs and report them to DEP when possible for tracking in the triennial report. It is understood however that careful consideration must be given to landowner confidentiality agreements.

Assessment

DEP is responsible for assessing and monitoring The Commonwealth's waterways. Thus, even before the inception of this project, DEP had already assessed the Hammer Creek Watershed using benthic macroinvertebrates and physical habitat screening to determine locations of impairment. And, The Department would continue to assess the watershed even if this project did not go forward. However, given the interest in this project, it is expected that Hammer Creek will be the focus of additional assessment by The Department. These proposed measures will be detailed in the “Effectiveness Monitoring and Evaluation of Progress Section”. Furthermore, the Susquehanna River Basin Commission has established a remote water quality monitoring station that continuously collects temperature, pH, conductance, dissolved oxygen and turbidity data about two and a half miles downstream of our study subwatershed. Since most of the area between our subwatershed and their monitoring site is forested, it is expected that improvements at their monitoring site could be directly attributable to pollution reductions associated with BMPs proposed in this study. Since SRBC’s data is made readily available on their website (See https://mdw.srbc.net/remotewaterquality/data_viewer.aspx), it could be downloaded and summarized for the triennial monitoring reports, so long as data collections continue over the life of the project.

Disclaimer

It must be stated up front that the administrative and BMP implementation goals in this document cannot be firm commitments because among other things: 1) Trout Unlimited is primarily a volunteer organization 2) DEPs ability to commit to the project may change with changing personnel, resources, funding and management goals and 3) most of the proposed BMPs require the voluntary consent of land owners. Since the bulk of the grant monies are allocated on a project by project basis, the funding organizations may choose to stop funding projects proposed in this document if satisfactory progress is not made. It should also be noted that even if implemented BMPs do not allow for the full amelioration of all impairments in the Hammer Creek Headwaters Subwatershed, water quality will almost assuredly improve both in this subwatershed and in downstream areas. If it becomes clear that the impairments will not be reversed as a result of this project, then TMDLs will be required.

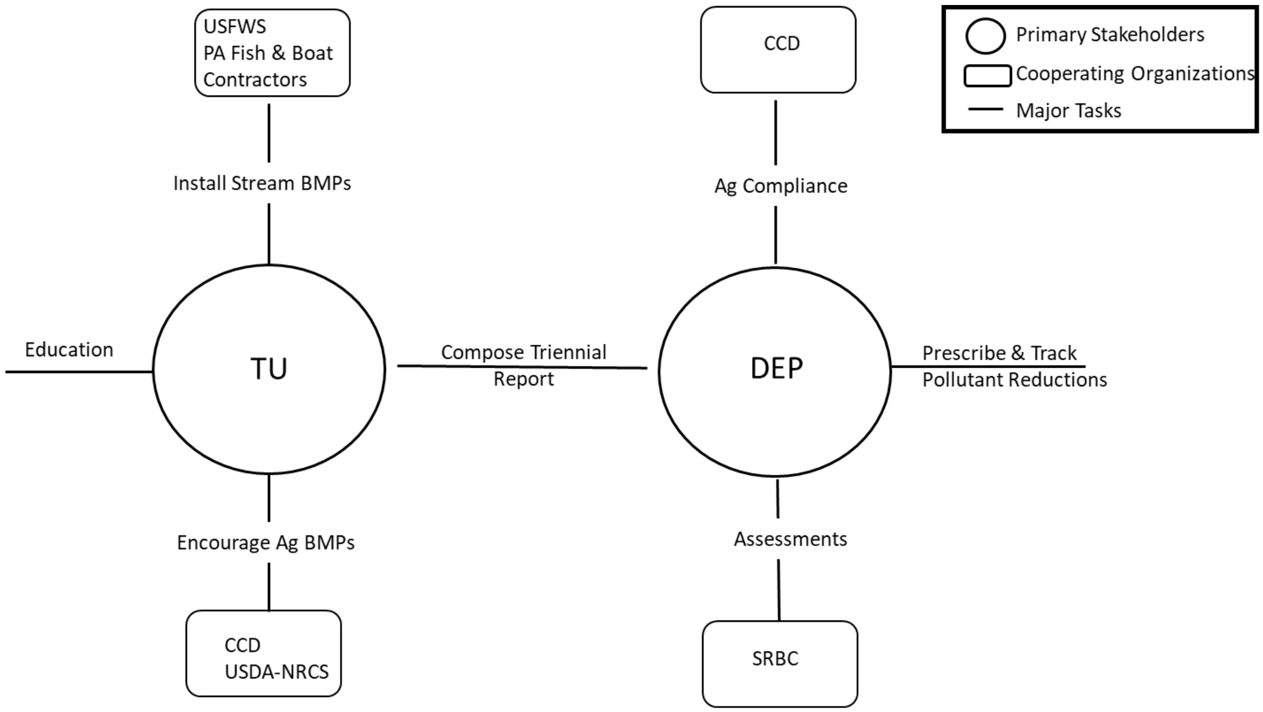


Figure 22. Proposed organizational structure for the Hammer Creek Alternate Restoration Plan. TU = Trout Unlimited, DEP = Pennsylvania Department of Environmental Protection, CCD = the Lebanon County Conservation District, USDA-NRCS = United States Department of Agriculture Natural Resources Conservation Service, SRBC = Susquehanna River Basin Commission, USFWS = United States Fish and Wildlife Service. Trout Unlimited and PA DEP would be the primary stakeholders but would require cooperation from landowners and assistance from cooperating organizations for completion of each of the major tasks shown above.

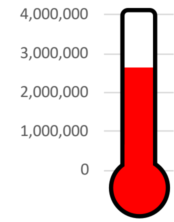
Schedule and Milestones

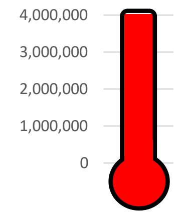
Figure 23 details a schedule of the major goals and milestones in the implementation project. The basic organizational unit of the schedule is a 3-year period after which there is proposed to be a "Triennial Report" that summarizes: progress made to date, updated assessment information, and makes needed adjustments to future goals. After preparation of the first two triennial reports a corresponding public meeting is proposed to review the reports as well as solicit more stakeholder involvement. A public mailing would likely be used in advance of the meetings to also solicit public involvement. The total active length of the project is anticipated to be nine years, plus additional assessment samplings around year twelve.

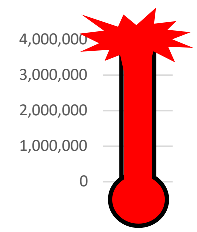
Proposed BMPs to satisfy the prescribed sediment reductions are approximately evenly divided among the three triennial periods, with a few exceptions. For one, 95% implementation of agricultural erosion and sedimentation plans are projected for the first three years, as these are a current legal requirement and there is an effort underway to evaluate for compliance as part of the Chesapeake Bay Watershed Implementation Plans. It is expected that such compliance evaluation will involve site visits to farms and will be a joint effort between DEP and the Lebanon County Conservation District. Furthermore, Trout Unlimited is currently in talks with a major landowner in the subwatershed to conduct a comprehensive stream restoration and fencing project (Figure 21), so this project was scheduled for the first three years. Otherwise, the major BMPs of precision grass filter strips, streambank stabilization, and forested buffers were distributed approximately evenly across either two or three triennial periods. It is proposed to evaluate the need for additional cover crops and conservation tillage after the push for compliance with erosion and sedimentation plans, as these BMPs might be adopted as a result of the plans.

It must be clearly stated, however, that there will likely be substantial deviations from the schedule. Specific BMPs would be implemented as opportunity allows and there are other more minor BMPs that are not even on the schedule. Also, from prior experience, landowner involvement may ramp up over time as they see examples of successful projects on neighboring properties. But, in any case, the BMP implementation goals as well as the schedule presented herein cannot be firm commitments, as explained in the previous section.

Timeline	Administrative Goal	BMP Target Goal	Responsible Party	Sediment reductions (lbs/yr)
2021	*Approval of Restoration Plan*		PA DEP and US EPA	
	Macroinvertebrate Sampling		PA DEP	
		7,674 feet stream restoration project	Trout Unlimited	210,260
		95% Implement Ag. Erosion & Sediment. Plans	PA DEP and Lebanon CCD	1,480,506
		34 acres precision grass filter strips	Trout Unlimited and USDA-NRCS	883,345
		30 acres forested buffers	Trout Unlimited and USDA-NRCS	71,027
2024	*First Triennial Report and Meeting*		PA DEP and Trout Unlimited	
	Macroinvertebrate, Fish and Sediment Sampling		PA DEP	
		5,000 feet sreambank stabilization	Trout Unlimited	137,000
		34 acres precision grass filter strips	Trout Unlimited and USDA-NRCS	883,345
		30 acres forested buffers	Trout Unlimited and USDA-NRCS	71,027
		180 more acres cover crops	Trout Unlimited and USDA-NRCS	30,823
		541 acres more conservation tillage	Trout Unlimited and USDA-NRCS	379,122
2027	*Second Triennial Report and Meeting*		PA DEP and Trout Unlimited	
	Macroinvertebrate, Fish and Sediment Sampling		PA DEP	
		5,000 feet streambank stabilization	Trout Unlimited	137,000
		34 acres precision grass filter strips	Trout Unlimited and USDA-NRCS	883,345
		30 acres forested buffers	Trout Unlimited and USDA-NRCS	71,027
		541 acres more conservation tillage	Trout Unlimited and USDA-NRCS	379,122
2030	*Third Triennial Report*		PA DEP and Trout Unlimited	
	Macroinvertebrate, Fish and Sediment Sampling		PA DEP	
2033	Macroinvertebrate, Fish and Sediment Sampling		PA DEP	







Note-because most of these BMPs require the voluntary cooperation of the landowner; Trout Unlimited is primarily a volunteer organization; DEP priorities, personell and resources may change; and grant funds are allocated on a case by case basis, the above are "target goals" rather than firm commitments. Furthermore, other BMPs may be substituted in as opportunities arise. And, because potential reductions overshoot the target, failure to fully implement any of the BMPs listed above may still allow for the the pollutant reduction goal to be reached.

Figure 23. Proposed timeline of major goals. The thermometer graphs indicate progress towards the overall sediment reduction goal (lbs/yr) during the three main triennial periods. Note that only a subset of BMP opportunities were chosen as goals.

Effectiveness Monitoring and Evaluation of Progress

Evaluation of "progress" will include indicators of landowner commitment, BMP implementation, and assessments of: water quality, physical habitat and biotic communities. It is proposed to summarize such progress for each triennial report.

Sediment loading reductions associated with BMP implementation can be estimated using the methodology described in the "An Analysis of Possible BMPs" section. If at the time if the second triennial report it becomes clear that there are major irreparable problems such as: lack of progress towards the sediment reduction goals or failure in stakeholder involvement to the point that it is clear that there will be insufficient BMP implementation, the restoration plan approach should be abandoned in favor of TMDL development.

It is proposed to conduct quantitative assessments of streambed sediment in accordance with the methodology discussed in the "Comparison of Fine Sediment Deposits in the Impaired and Reference Watersheds" section. Such data can be used to confirm that fine sediment deposits are decreasing as a result of BMP implementation. Pre-implementation data has already been collected (see Figures 12 and 13) and it is proposed to continue collect data at the same Hammer Creek assessment site (Figure 10 and 24) approximately every three years during the expected duration of the project, and then again three years after the projected has ended. Furthermore, to explore for localized effects, it is proposed to use this methodology before and after BMP implementation at several other yet to be determined restoration sites within the subwatershed, and/or at sites within the proposed study reaches on the two main headwater branches shown in Figure 24. Considering that there may be a lag time for benthic macroinvertebrate recolonization following restoration, or that other factors could continue to inhibit benthic communities once fine sediment loading has been reduced to an appropriate level, directly measuring fine sediment reductions will be important in demonstrating restoration progress. One criterion for BMP implementation success could be when Hammer Creek's fine sediment values were comparable to those observed in the reference subwatershed (see Figures 12 and 13).

The present aquatic life use impairments listed for the Hammer Creek Headwaters Subwatershed were based on macroinvertebrate sampling and descriptive physical habitat screening. Thus, the Hammer Creek Subwatershed should continue to be evaluated for these attributes in accordance with DEP's most current protocols. Due to the interest in the wild trout population, it is also proposed to add fish population sampling. The most current versions of these protocols, along with criteria for making assessments and delistings, are described in PA DEP's "Assessment Methodology for Rivers and Streams" (2018). It is suggested that macroinvertebrate sampling, physical habitat screening and fish population surveys be conducted on Hammer Creek's mainstem within the sediment evaluation study reach shown in Figure 10, as well within the proposed study reaches on the two main headwater branches shown in Figure 24. In addition to these major sites, such sampling may also occur at localized restoration sites. Since the most recent assessment samples were from 2007, it is suggested that new sampling should be conducted at the major sites around the time of project initiation in 2021. These major sites should continue to be sampled approximately every three years during the expected duration of the project, and then again three years after the project has ended to evaluate for impairment delistings (Figure 23). In the unlikely scenario that sampling indicates that the aquatic life use criteria improve to the point that the entire subwatershed is no longer impaired prior to the estimated completion date in 2030, a decision can be made to either: 1) end the project or 2) continue the project to overshoot prescribed reductions as a layer of protection and for the benefit of downstream aquatic resources.

The Susquehanna River Basin Commission also has a long-term monitoring site approximately two miles downstream of the study subwatershed on Hammer Creek's mainstem. The instrumentation installed at this site continuously monitors several variables, including turbidity, and thus may be used to look for improvements resulting from watershed restoration. Depending on time and resource availability, additional sediment, macroinvertebrate and fish sampling may occur in this area.

It is expected that the earliest improvements will be noticed in physical habitat screening, sediment sampling and fish populations at the local sites of restoration projects. In contrast, there is expected to be a lag time in the perception of improvements in sediment metrics at the downstream sampling reach (Figure 10) as well as at SRBC's downstream monitoring site until substantial progress is made throughout the study subwatershed. Based on prior experience, it is expected that benthic macroinvertebrate communities will take the longest time to improve. Since the sampling design includes both the two major headwater branches, as well as the lower mainstem (Figure 24), partial regions of the watershed could be delisted as impaired should this occur before the entire watershed is delisted. If however at least localized improvements in physical habitat screening, sediment sampling or fish populations are not apparent at restoration sites at the time of the second triennial report, it should be considered whether the restoration plan needs to be overhauled or abandoned in favor of a TMDL.

Hammer Creek Headwaters Subwatershed

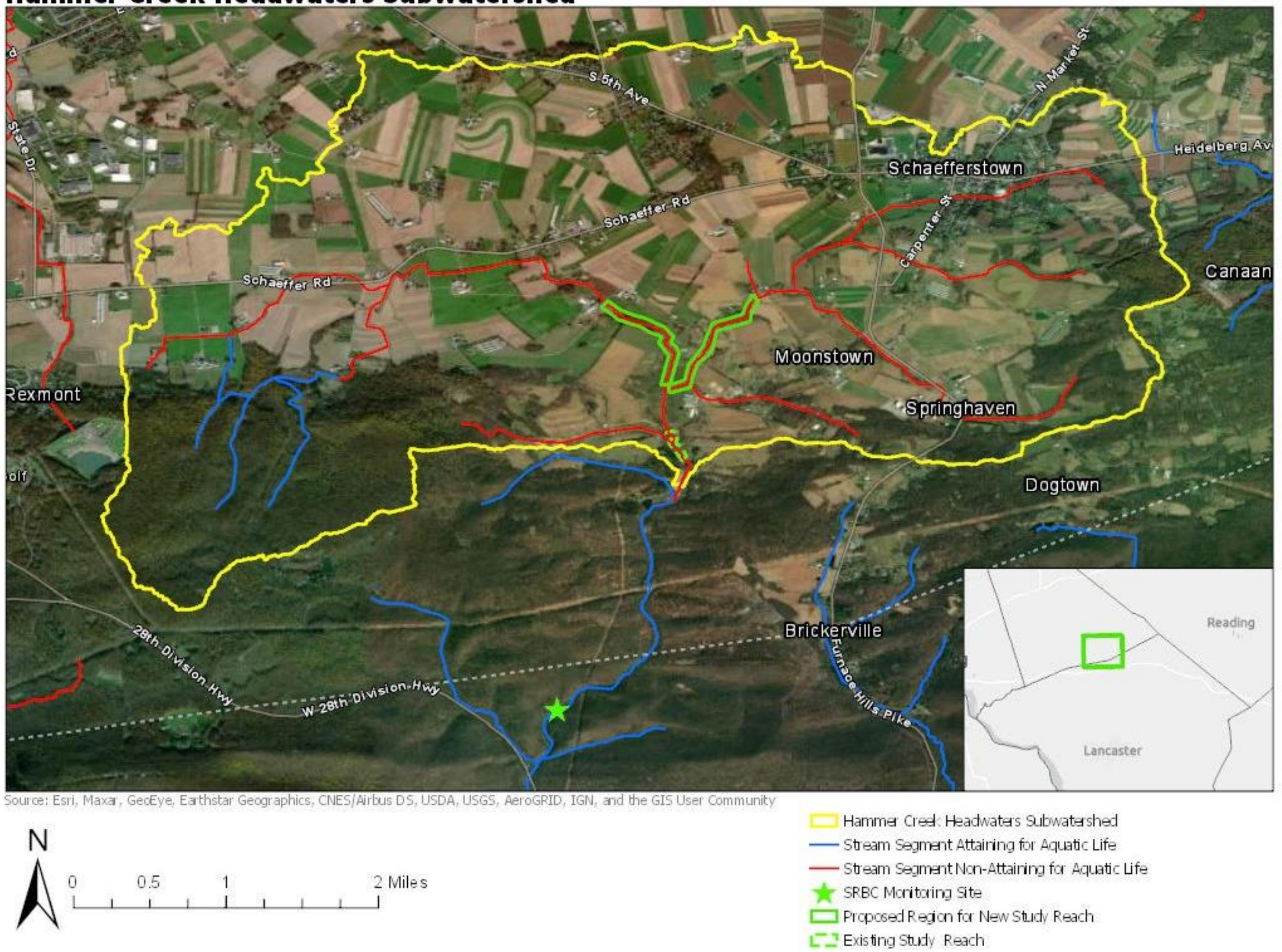


Figure 24. Existing and proposed sampling reaches in the Hammer Creek Headwaters Subwatershed. The proposed regions on the two main branches are longer than necessary; ultimate site selection will depend on willingness of landowners to grant access and sites may need to be placed even further upstream. Depending on resources, it is proposed sample sediment, benthic macroinvertebrates and fish within each of these two study reaches as well within the downstream existing study reach. Additional sampling may also occur at the SRBC monitoring site, and limited additional sampling focusing on streambed sediment may also take place at major BMP installation locations.

Summary

This document proposes a 51% reduction in sediment loading for the Hammer Creek Headwaters Subwatershed. To achieve this goal while maintaining a margin of safety and minor allowance for point sources, sediment loading from croplands should be reduced by 62% while loading from hay/pasture lands and streambanks should be reduced by 24% each. The present document proposes a nine-year restoration project to be administered jointly between Trout Unlimited and the PA DEP, along with cooperation from landowners, and agencies such as the Lebanon County Conservation District, the United States Department of Agriculture's Natural Resources Conservation Service, the Pennsylvania Fish and Boat Commission, the Susquehanna River Basin Commission and the US Fish and Wildlife Service. Critical BMPs proposed herein include agricultural erosion and sedimentation plan implementation, use of cover crops, conservation tillage, forested riparian buffers, precision grass filter strips and streambank stabilization.

Public Participation

Public notice of a draft of the Alternative Restoration Plant was published in the February 20th, 2021 issue of the Pennsylvania Bulletin to foster public comment. A 30-day period was provided for the submittal of comments. Public comments with responses are available in Appendix H.

Citations

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Appendix A: Background on Stream Assessment Methodology

Integrated Water Quality Monitoring and Assessment Report, List 5, 303(d), Listing Process

Assessment Methods:

Prior to developing TMDLs for specific waterbodies, there must be sufficient data available to assess which streams are impaired and should be listed in the Integrated Water Quality Monitoring and Assessment Report. Prior to 2004 the impaired waters were found on the 303(d) List; from 2004 to present, the 303(d) List was incorporated into the Integrated Water Quality Monitoring and Assessment Report and found on List 5. Table A1. summarizes the changes to listing documents and assessment methods over time.

With guidance from EPA, the states have developed methods for assessing the waters within their respective jurisdictions. From 1996-2006, the primary method adopted by the Pennsylvania Department of Environmental Protection for evaluating waters found on the 303(d) lists (1998-2002) or in the Integrated Water Quality Monitoring and Assessment Report (2004-2006) was the Statewide Surface Waters Assessment Protocol (SSWAP). SSWAP was a modification of the EPA Rapid Bioassessment Protocol II (RPB-II) and provided a more consistent approach to assessing Pennsylvania's streams.

The assessment method called for selecting representative stream segments based on factors such as surrounding land uses, stream characteristics, surface geology, and point source discharge locations. The biologist was to select as many sites as necessary to establish an accurate assessment for a stream segment; the length of the stream segment could vary between sites. The biological surveys were to include kick-screen sampling of benthic macroinvertebrates, habitat surveys, and measurements of pH, temperature, conductivity, dissolved oxygen, and alkalinity. Benthic macroinvertebrates were identified to the family level in the field.

The listings found in the Integrated Water Quality Monitoring and Assessment Reports from 2008 to present were derived based on the Instream Comprehensive Evaluation protocol (ICE). Like the superseded SSWAP protocol, the ICE protocol called for selecting representative segments based on factors such as surrounding land uses, stream characteristics, surface geology, and point source discharge locations. The biologist was to select as many sites as necessary to establish an accurate assessment for a stream segment; the length of the stream segment could vary between sites. The biological surveys were to include D-frame kicknet sampling of benthic macroinvertebrates, habitat surveys, and measurements of pH, temperature, conductivity, dissolved oxygen, and alkalinity. Collected samples were returned to the laboratory where the samples were to be subsampled for a target benthic macroinvertebrate sample of 200 ± 20% (N = 160-240). The benthic macroinvertebrates in this subsample were typically identified to the generic level. The ICE protocol is a modification of the EPA

Rapid Bioassessment Protocol III (RPB-III) and provides a more rigorous and consistent approach to assessing Pennsylvania's streams than the SSWAP.

After these surveys (SSWAP, 1998-2006 lists or ICE, 2008-present lists) were completed, the biologist determined the status of the stream segments. The decision was based on the performance of the segment using a series of biological metrics. If the stream segment was classified as impaired, it was then listed on the state's 303(d) List or presently the Integrated Water Quality Monitoring and Assessment Report with the source and cause documented.

Once a stream segment is listed as impaired, a TMDL typically must be developed for it. A TMDL addresses only one pollutant. If a stream segment is impaired by multiple pollutants, each pollutant receives a separate and specific TMDL within that stream segment. Adjoining stream segments with the same source and cause listings are addressed collectively on a watershed basis.

Table A1. Impairment Documentation and Assessment Chronology

Listing Date:	Listing Document:	Assessment Method:
1998	303(d) List	SSWAP
2002	303(d) List	SSWAP
2004	Integrated List	SSWAP
2006	Integrated List	SSWAP
2008-Present	Integrated List	ICE

Integrated List= Integrated Water Quality Monitoring and Assessment Report
SSWAP= Statewide Surface Waters Assessment Protocol
ICE= Instream Comprehensive Evaluation Protocol

Justification of Mapping Changes to 303(d) Lists 1998 to Present

The following are excerpts from the Pennsylvania DEP Section 303(d) narratives that justify changes in listings between the 1996-2002 303(d) Lists and the 2004 to present Integrated Water Quality Monitoring and Assessment Reports. The Section 303(d) listing process has undergone an evolution in Pennsylvania since the development of the 1996 list.

In the 1996 Section 303(d) narrative, strategies were outlined for changes to the listing process. Suggestions included, but were not limited to, a migration to a Global Information System (GIS), improved monitoring and assessment, and greater public input.

The migration to a GIS was implemented prior to the development of the 1998 Section 303(d) list. Because of additional sampling and the migration to the GIS, some of the information appearing on the 1996 list differed from the 1998 list. Most common changes included:

1. mileage differences due to recalculation of segment length by the GIS;
2. slight changes in source(s)/cause(s) due to new EPA codes;
3. changes to source(s)/cause(s), and/or miles due to revised assessments;
4. corrections of misnamed streams or streams placed in inappropriate SWP subbasins; and
5. unnamed tributaries no longer identified as such and placed under the named watershed listing.

Prior to 1998, segment lengths were computed using a map wheel and calculator. The segment lengths listed on the 1998 Section 303(d) list were calculated automatically by the GIS (ArcInfo) using a constant projection and map units (meters) for each watershed. Segment lengths originally calculated by using a map wheel and those calculated by the GIS did not always match closely. This was the case even when physical identifiers (e.g., tributary confluence and road crossings) matching the original segment descriptions were used to define segments on digital quad maps. This occurred to some extent with all segments, but was most noticeable in segments with the greatest potential for human errors using a map wheel for calculating the original segment lengths (e.g., long stream segments or entire basins).

Migration to National Hydrography Data (NHD)

New to the 2006 report is use of the 1/24,000 National Hydrography Data (NHD) streams GIS layer. Up until 2006 the Department relied upon its own internally developed stream layer. Subsequently, the United States Geologic Survey (USGS) developed 1/24,000 NHD streams layer for the Commonwealth based upon national geodatabase standards. In 2005, DEP contracted with USGS to add missing streams and correct any errors in the NHD. A GIS contractor transferred the old DEP stream assessment information to the improved NHD and the old DEP streams layer was archived. Overall, this marked an improvement in the quality of the streams layer and made the stream assessment data compatible with national standards but it necessitated a change in the Integrated Listing format. The NHD is not attributed with the old DEP five-digit stream codes so segments can no longer be listed by stream code but rather only by stream name or a fixed combination of NHD fields known as reachcode and ComID. The NHD is aggregated by Hydrologic Unit Code (HUC) watersheds so HUCs rather than the old State

Water Plan (SWP) watersheds are now used to group streams together. A more basic change was the shift in data management philosophy from one of “dynamic segmentation” to “fixed segments”. The dynamic segmentation records were proving too difficult to manage from an historical tracking perspective. The fixed segment methods will remedy that problem. The stream assessment data management has gone through many changes over the years as system requirements and software changed. It is hoped that with the shift to the NHD and OIT’s (Office of Information Technology) fulltime staff to manage and maintain SLIMS the systems and formats will now remain stable over many Integrated Listing cycles.

Appendix B: Model My Watershed Generated Data Tables

Land Cover Type	Area (Ha)	%
Hay/Pasture	501.6	15
Cropland	1458.7	45
Wooded Areas	852.9	26
Wetlands	5.1	0
Open Land	2.6	0
Barrren Areas	0	0
Low-Density Mixed	130.2	4
Medium Density Mixed	38.3	1
High Density Mixed	12.5	0
Low Density Open Space	238.4	7
sum	*3240.3*	

Table B1. "Model My Watershed" Land Cover Inputs for the Hammer Creek Headwaters Subwatershed based on Correction for NLCD 2016

Land Cover Type	Area (Ha)	%
Hay/Pasture	431.3	13
Cropland	1260.5	39
Wooded Areas	1178.2	36
Wetlands	19.8	1
Open Land	0.3	0
Barren Areas	0.5	0
Low-Density Mixed	90.9	3
Medium-Density Mixed	20.7	1
High-Density Mixed	2.8	0
Low-Density Open Space	253.7	8
Sum	*3258.7*	

Table B2. "Model My Watershed" Land Cover Inputs for the Ontelaunee Creek reference subwatershed based on Correction for NLCD 2016

Month	Stream Flow (cm)	Surface Runoff (cm)	Subsurface Flow (cm)	Point Src Flow (cm)	ET (cm)	Precip (cm)
Jan	4.83	0.86	3.97	0	0.4	7.46
Feb	5.58	0.81	4.77	0	0.6	7.42
Mar	6.68	0.57	6.11	0	1.85	8.53
Apr	6.05	0.09	5.96	0	4.49	8.42
May	4.94	0.19	4.75	0	8.76	10.28
Jun	3.74	0.62	3.12	0	12.69	9.4
Jul	2.14	0.34	1.8	0	11.78	9.94
Aug	1.1	0.22	0.88	0	9.2	8.52
Sep	0.85	0.44	0.41	0	5.79	8.81
Oct	0.73	0.27	0.46	0	3.67	7.37
Nov	1.26	0.41	0.86	0	1.83	8.63
Dec	3.24	0.61	2.63	0	0.8	8.53
Total	41.14	5.43	35.72	0	61.86	103.31

Table B3. "Model My Watershed" Hydrology Outputs for the Hammer Creek Headwaters Subwatershed.

Month	Stream Flow (cm)	Surface Runoff (cm)	Subsurface Flow (cm)	Point Src Flow (cm)	ET (cm)	Precip (cm)
Jan	5.17	0.74	4.4	0.03	0.26	6.69
Feb	5.87	0.97	4.87	0.03	0.39	6.47
Mar	6.69	0.41	6.25	0.03	1.46	7.4
Apr	6.39	0.41	5.95	0.03	3.17	8.25
May	5.07	0.16	4.88	0.03	7.24	9.96
Jun	3.53	0.27	3.23	0.03	10.86	9.81
Jul	1.86	0.24	1.59	0.03	11.54	10.08
Aug	0.89	0.17	0.69	0.03	9.5	9.66
Sep	1	0.47	0.51	0.03	6.02	9.19
Oct	1.34	0.23	1.08	0.03	3.36	7.27
Nov	2.75	0.38	2.35	0.03	1.54	8.82
Dec	4.84	0.53	4.28	0.03	0.56	7.62
Total	45.4	4.98	40.08	0.36	55.9	101.22

Table B4. "Model My Watershed" Hydrology Outputs for the Ontelaunee Creek reference subwatershed

Sources	Sediment (kg)
Hay/Pasture	97,975.50
Cropland	2,795,727.80
Wooded Areas	2,831.40
Wetlands	15.8
Open Land	0
Barren Areas	0
Low-Density Mixed	1,663.20
Medium-Density Mixed	2,696.50
High-Density Mixed	880.1
Low-Density Open Space	3,045.30
Farm Animals	0
Stream Bank Erosion	360,432.00
Subsurface Flow	0
Point Sources	0
Septic Systems	0

Table B5. Model My Watershed outputs for Sediment in the Hammer Creek Headwaters Subwatershed. Note that where relevant, sediment contributions from point sources were added after the modelling run.

Sources	Sediment (kg)
Hay/Pasture	129,657.80
Cropland	1,364,258.70
Wooded Areas	1,831.60
Wetlands	47.3
Open Land	14.6
Barren Areas	0
Low-Density Mixed	1,219.10
Medium-Density Mixed	1,629.60
High-Density Mixed	220.4
Low-Density Open Space	3,402.40
Farm Animals	0
Stream Bank Erosion	207,139.00
Subsurface Flow	0
Point Sources	0
Septic Systems	0

Table B6. Model My Watershed outputs for Sediment in the Ontelaunee Creek reference subwatershed. Note that where relevant, sediment contributions from point sources were added after the modelling run.

Appendix C: Stream Segments in the Hammer Creek Headwaters Subwatershed with Siltation Impairments per the 2018 Integrated Report

Stream Name:	Assessed Use:	Impairment Source:	Impairment Cause:	COMID:	Miles:
Hammer Creek	Aquatic Life	Agriculture	Siltation	57461245	0.36
Hammer Creek	Aquatic Life	Agriculture	Siltation	57461347	0.38
Hammer Creek	Aquatic Life	Agriculture	Siltation	57461331	0.04
Unnamed Tributary to Hammer Creek	Aquatic Life	Agriculture	Siltation	57461233	0.03
Unnamed Tributary to Hammer Creek	Aquatic Life	Agriculture	Siltation	57461197	1.54
Unnamed Tributary to Hammer Creek	Aquatic Life	Agriculture	Siltation	57461291	0.12
Unnamed Tributary to Hammer Creek	Aquatic Life	Agriculture	Siltation	57461299	0.48
Unnamed Tributary to Hammer Creek	Aquatic Life	Agriculture	Siltation	57461199	1.38
Hammer Creek	Aquatic Life	Agriculture	Siltation	57461395	0.43
Unnamed Tributary to Hammer Creek	Aquatic Life	Agriculture	Siltation	57461311	0.24
Unnamed Tributary to Hammer Creek	Aquatic Life	Agriculture	Siltation	57461351	0.57
Unnamed Tributary to Hammer Creek	Aquatic Life	Agriculture	Siltation	57461305	0.04
Unnamed Tributary to Hammer Creek	Aquatic Life	Agriculture	Siltation	57461287	0.73
Hammer Creek	Aquatic Life	Agriculture	Siltation	57461267	0.80
Unnamed Tributary to Hammer Creek	Aquatic Life	Agriculture	Siltation	57461303	0.05
Unnamed Tributary to Hammer Creek	Aquatic Life	Agriculture	Siltation	57461229	0.21
Unnamed Tributary to Hammer Creek	Aquatic Life	Agriculture	Siltation	57461235	0.19
Unnamed Tributary to Hammer Creek	Aquatic Life	Agriculture	Siltation	57461219	0.46
Hammer Creek	Aquatic Life	Agriculture	Siltation	57461327	0.83
Hammer Creek	Aquatic Life	Agriculture	Siltation	57461293	1.08
Unnamed Tributary to Hammer Creek	Aquatic Life	Agriculture	Siltation	57461363	1.18
Unnamed Tributary to Hammer Creek	Aquatic Life	Agriculture	Siltation	57461283	1.83
Unnamed Tributary to Hammer Creek	Aquatic Life	Agriculture	Siltation	57461309	1.05
Hammer Creek	Aquatic Life	Agriculture	Siltation	57461243	0.03
Unnamed Tributary to Hammer Creek	Aquatic Life	Agriculture	Siltation	57461295	0.11
Unnamed Tributary to Hammer Creek	Aquatic Life	Agriculture	Siltation	57461301	0.04
Unnamed Tributary to Hammer Creek	Aquatic Life	Agriculture	Siltation	57461231	1.57

Table C1. Stream segments with siltation impairments per the 2018 Integrated Report. To convert from the COMID to the Attains ID, simply put PA-SCR- in front of each COMID. All stream segments were in hydrologic unit code (HUC) 020503060903.

Appendix D: Equal Marginal Percent Reduction Method

Equal Marginal Percent Reduction (EMPR) (An Allocation Strategy)

The Equal Marginal Percent Reduction (EMPR) allocation method was used to distribute the Adjusted Load Allocation (ALA) between the appropriate contributing nonpoint sources. The load allocation and EMPR procedures were performed using a MS Excel spreadsheet. The 5 major steps identified in the spreadsheet are summarized below:

Step 1: Calculation of the TMDL based on impaired watershed size and unit area loading rate of reference watershed.

Step 2: Calculation of Adjusted Load Allocation based on TMDL, MOS, WLA and existing loads not reduced.

Step 3: Actual EMPR Process:

a. Each land use/source load is compared with the total ALA to determine if any contributor would exceed the ALA by itself. The evaluation is carried out as if each source is the only contributor to the pollutant load of the receiving waterbody. If the contributor exceeds the ALA, that contributor would be reduced to the ALA. If a contributor is less than the ALA, it is set at the existing load. This is the baseline portion of EMPR.

b. After any necessary reductions have been made in the baseline, the multiple analyses are run. The multiple analyses will sum all the baseline loads and compare them to the ALA. If the ALA is exceeded, an equal percent reduction will be made to all contributors' baseline values. After any necessary reductions in the multiple analyses, the final reduction percentage for each contributor can be computed.

Step 4: Calculation of total loading rate of all sources receiving reductions.

Step 5: Summary of existing loads, final load allocations, and percent reduction for each pollutant source

	Current Load, lbs/yr	Any > ASL?	If > ASL, reduce to ASL	How much does sum exceed ASL?	Proportions of total after initial adjust	Assign reductions still needed per proportions after intial adjust	ALA: subtract reductions still needed from initial adjust	proportion Reduction
Cropland	6,164,580	yes	3,118,862		0.76	763,383	2,355,479	0.62
Hay/Pasture	216,036	no	216,036	1,010,786	0.05	52,878	163,158	0.24
Streambank	794,750	no	794,750		0.19	194,526	600,225	0.24
sum	**7,175,366**		**4,129,648**		**1.00**	**1,010,786**	**3,118,862**	**0.57**

Table D1. Equal Marginal Percent Reduction calculations for the Hammer Creek Headwaters Subwatershed

Appendix E: Legal Basis for the TMDL and Water Quality Regulations for Agricultural Operations

Clean Water Act Requirements

Section 303(d) of the 1972 Clean Water Act requires states, territories, and authorized tribes to establish water quality standards. The water quality standards identify the uses for each waterbody and the scientific criteria needed to support that use. Uses can include designations for drinking water supply, contact recreation (swimming), and aquatic life support. Minimum goals set by the Clean Water Act require that all waters be "fishable" and "swimmable."

Additionally, the federal Clean Water Act and the United States Environmental Protection Agency's (EPA) implementing regulations (40 CFR 130) require:

- States to develop lists of impaired waters for which current pollution controls are not stringent enough to meet water quality standards (the list is used to determine which streams need TMDLs);
- States to establish priority rankings for waters on the lists based on severity of pollution and the designated use of the waterbody; states must also identify those waters for which TMDLs will be developed and a schedule for development;
- States to submit the list of waters to EPA every two years (April 1 of the even numbered years);
- States to develop TMDLs, specifying a pollutant budget that meets state water quality standards and allocate pollutant loads among pollution sources in a watershed, e.g., point and nonpoint sources; and
- EPA to approve or disapprove state lists and TMDLs within 30 days of final submission.

Despite these requirements, states, territories, authorized tribes, and EPA have not developed many TMDLs since 1972. Beginning in 1986, organizations in many states filed lawsuits against EPA for failing to meet the TMDL requirements contained in the federal Clean Water Act and its implementing regulations. While EPA has entered into consent agreements with the plaintiffs in several states, many lawsuits still are pending across the country.

In the cases that have been settled to date, the consent agreements require EPA to backstop TMDL development, track TMDL development, review state monitoring programs, and fund studies on issues of concern (e.g., Abandoned Mine Drainage (AMD), implementation of nonpoint source BMPs, etc.).

Pennsylvania Clean Streams Law Requirements, Agricultural Operations

Pennsylvania farmers are required by law to operate within regulatory compliance by implementing the applicable requirements outlined in the Pennsylvania Clean Streams Law, Title 25 Environmental Protection, Part I Department of Environmental Protection, Subpart C Protection of Natural Resources, Article II Water Resources, Chapters: § 91.36 Pollution control and prevention at agricultural operations, § 92a.29 CAFO and § 102.4 Erosion and sediment control requirements. Water quality regulations can be found at following website: http://www.pacode.com/secure/data/025/025toc.html

Agricultural regulations are designed to reduce the amount of sediment and nutrients reaching the streams and ground water in a watershed.

Appendix F: Information on Use of the Chesapeake Bay Program's BMP Crediting

For many of the Best Management Practices (BMPs) proposed in this study, the calculated sediment reductions were based on the logic used by the Chesapeake Bay Program's Chesapeake Assessment Scenario Tool (CAST). See:

Chesapeake Bay Program. 2018. Chesapeake Bay Program Quick Reference Guide for Best Management Practices (BMPs): Nonpoint Source BMPs to Reduce Nitrogen, Phosphorus and Sediment Loads to the Chesapeake Bay and its Local Waters. CBP DOC ID. Downloaded at: https://www.chesapeakebay.net/documents/BMP-Guide_Full.pdf

The following explains how this study used some of the Chesapeake Bay Program's information. Please note that some BMP crediting in this study did not follow the Chesapeake Bay Program's methods, as described in the "An Analysis of Possible BMPs" section.

Agricultural Erosion and Sedimentation Plans

Chesapeake Bay Program:

"Soil Conservation and Water Quality Plans" (A-24): considers many types of agricultural lands. All croplands received a sediment reduction efficiency of 25%. Pasture lands received an 14% reduction efficiency and hay lands typically received an 8% efficiency.

This Study:

The 25% sediment reduction efficiency was used for croplands. Because land use classifications didn't distinguish between hay and pasture lands, the 8% efficiency was used to be conservative.

Cover Crops

Chesapeake Bay Program:

CAST "Cover Crops-Traditional" A-4*:* has numerous different cover crop types and breaks them into low and high till land uses. When used in combination with low till, there is no additional sediment reduction. Sediment reductions range from 0-20% on high till lands.

CAST "Cover Crops-Commodity" A-5: when grown as a commodity, there are no sediment reductions.

This Study:

For simplicity, this study settled on a 10% reduction in all cases to account for the fact that sometimes it will be 0 and sometimes it will be 20%, depending on the cover crop type. It was also specified that the reductions are only to be applied to non-commodity cover crops used on high till lands.

Conservation Tillage

Chesapeake Bay Program:

"Conservation Tillage" A-3: % reductions vary based on "low residue" (15-29% crop residue immediately after planting) "conservation tillage" (30-59% crop residue) or "high residue" (at least 60% crop residue) categories. For sediment, low residue tillage gets an 18% reduction, conservation tillage gets a 41% reduction and high residue tillage gets a 79% reduction.

This Study

For simplicity, the middle "conservation tillage" reduction value of 41% was assumed in all cases.

Riparian buffers

Chesapeake Bay Program:

"Forest Buffers and Grass Buffers" A12: Forest Buffers and Grass Buffers with Stream Exclusion Fencing A13: Riparian buffers are credited two ways: the land conversion effect and the upland filtration effect. For the upland sediment filtration effect, it is assumed that the loading from two acres of upland is reduced by an efficiency value of 40-60% depending on hydrogeomorphic region. Note that for buffers less than 35 feet wide average width, only the land conversion, and not the upslope filtration effect is credited. Buffers less than 10 feet wide get no credit.

This Study:

For simplicity, rather than using a different upland efficiency by region, the average efficiency value for the geomorphic regions that occur in Pennsylvania, 47%, was used. Also, it was assumed that loading from two acres of *cropland* are filtered per acre of buffer created. Note that CAST assumes two acres of *uplands*, not necessarily croplands, are filtered per acre of buffer created. However, there was an abundance of croplands in the Hammer Creek Headwaters Subwatershed, and logic would suggest that if there is something else upslope that loads at a lower rate, the buffer may be capable of filtering more of it. The land conversion factor from croplands and hay/pasture lands to forests was also taken into account. The present study doesn't specify a minimum buffer width. If buffers are very narrow then they will be of low acreage and thus will not get much filtration credit.

Grazing Land Management

Chesapeake Bay Program:

"Pasture and Grazing Management Practices" A8: for sediment there is a 30% reduction efficiency, except in the case of horse pasture management where there is a 40% efficiency.

This Study:

Given that horse pastures are far less common and the difference is not that great, the 30% efficiency was assumed for all cases.

Appendix G: Information on VFSMOD inputs

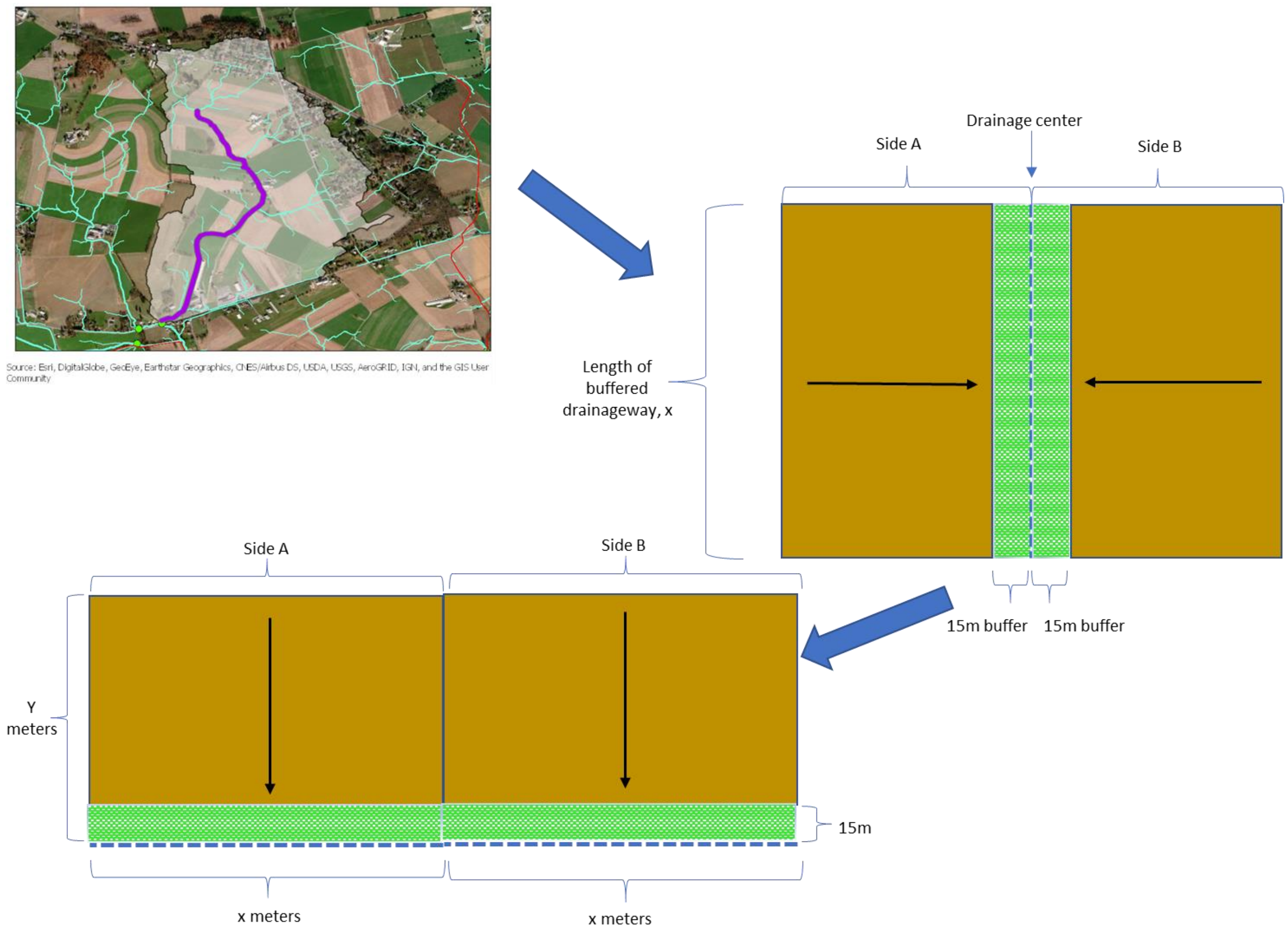

Figure F1. Conceptualization showing how site geometry was simplified for input into VFSMOD. Complex buffersheds were first assumed to be a uniform rectangle with a central buffered drainageway. The length of the rectangle (X) was assumed to be the length of the buffered drainageway. However, since VFSMOD only accepts inputs in one direction, from the source area to the buffer, the rectangle was split down the middle along the central drainageline and the two sides of the rectangle were laid end to end. Thus Y was solved by assuming that 2X * Y = total watershed area. The source area length along the slope was calculated as Y-15m. The upland area was calculated as the total watershed area minus the area of the buffer.

	Drainageshed A	Drainageshed B	Drainageshed C	Drainageshed D	Drainageshed E	Drainageshed F	Drainageshed G	Drainageshed H	Drainageshed I	Drainageshed J
Source Area Inputs										
rainfall (mm) for the one year storm[1]	66.9	66.9	66.9	66.9	66.9	66.9	66.9	66.9	66.9	66.9
rainfall (mm) for the five year storm[1]	99.4	99.4	99.4	99.4	99.4	99.4	99.4	99.4	99.4	99.4
storm duration (hrs)	24	24	24	24	24	24	24	24	24	24
curve no[2]	77	75	74	75	74	75	72	72	70	75
storm type[3]	II	II	II	II	II	II	II	II	II	II
length along slope (m)[4]	530	194.9	266.4	318.5	459	413	866.1	279.2	264.2	197.6
watershed slope fraction[2]	0.067	0.017	0.022	0.03	0.033	0.029	0.027	0.023	0.06	0.036
upland area (ha)[4]	59.8	51.5	70.2	61.4	192	158.8	357	44.3	76.8	34
soil erodibility (metric ton*hectare*hour)/(hectare*megajoule*millimeter)[5]	0.0380	0.0440	0.0434	0.0432	0.0437	0.0429	0.0426	0.0439	0.0430	0.0445
soil type[6]	Silt Loam	Silt Loam	Silt Loam	Silt Loam	Silt Loam	Silt Loam	Silt Loam	Silt Loam	Silt Loam	Silt Loam
percent OM[6]	2.2	2.6	2.7	2.7	2.7	2.8	2.9	2.7	2.3	2.5
dp particle class diam[3]	default	default	default	default	default	default	default	default	default	default
crop factor[2]	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
practice factor[2]	0.85	0.85	0.85	0.85	0.85	0.85	0.85	0.85	0.85	0.85
rainfall factor[3]	Williams	Williams	Williams	Williams	Williams	Williams	Williams	Williams	Williams	Williams
Overland Flow Inputs										
buffer length from input to output (m)	15	15	15	15	15	15	15	15	15	15
Manning's n roughness for dense grass[3]	0.24	0.24	0.24	0.24	0.24	0.24	0.24	0.24	0.24	0.24
buffer slope, proportion[7]	0.04	0.036	0.023	0.04	0.05	0.4	0.02	0.035	0.075	0.0555
double filter strip width in longest direction (m)[8]	1128	2642	2634	1926	4176	3846	4120	1586	2908	1722
kinematic wave parameters	default	default	default	default	default	default	default	default	default	default
Filter Strip Infiltration Inputs										
shallow water table[9]	No	No	No	No	No	No	No	No	No	No
number soil layers[9]	1	1	1	1	1	1	1	1	1	1
saturated conductivity, surface layer (m/s)[6]	9.1630E-06	9.1700E-06	9.6501E-06	9.1841E-06	1.0324E-05	9.2124E-06	9.1700E-06	9.1700E-06	9.5512E-06	9.1700E-06
bottom depth (cm)	default 15	default 15	default 15	default 15	default 15	default 15	default 15	default 15	default 15	default 15
average suction at the wetting front, Sav, (m)[3]	0.1668	0.1668	0.1668	0.1668	0.1668	0.1668	0.1668	0.1668	0.1668	0.1668
surf. layer initial water content (assume field capacity, or proportion at 1/3 Barr)[6]	0.28619	0.266178218	0.280828	0.269437	0.258779874	0.280093	0.293277419	0.263502	0.275083	0.261911765
saturated water content, proportion[3]	0.48	0.48	0.48	0.48	0.48	0.48	0.48	0.48	0.48	0.48
surface storage[9]	0	0	0	0	0	0	0	0	0	0
fraction ponding checked[9]	0	0	0	0	0	0	0	0	0	0
Buffer Vegetation Properties										
spacing for grass stems (cm)[3]	2.15	2.15	2.15	2.15	2.15	2.15	2.15	2.15	2.15	2.15
roughness, Manning's n[3]	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012
height of grass[3]	18	18	18	18	18	18	18	18	18	18
roughness, bare surface Manning's n (default)[3]	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04
feedback[3]	0	0	0	0	0	0	0	0	0	0
Outputs										
one year storm sediment delivery ratio	0.359	0.005	0.008	0.019	0.05	0.037	0.11	0.006	0.013	0.009
five year storm sediment delivery ratio	0.71	0.025	0.049	0.159	0.34	0.273	0.501	0.048	0.24	0.092

[1]PENNDOT 2010

[2]estimated from Model My Watershed or Mapshed

[3]per suggestions in VFSMOD help or Manual

[4]calculated assuming the subwatershed was a rectangle draining unidirectionally and uniformly to a rectangular buffer strip

[5]USDA WSS english units value multiplied by 0.1317 to convert to the metric value per VFSMOD manual and Foster et al. 1981

[6]USDA WSS

[7]estimated from USGS QL2 Lidar Data and TAUDEM tools in ArcGISPro

[8]longest direction length of the filter strip estimated using measuring tool (geodesic) in ArcGISPro; multiplied by two because two sides to the centerline of the buffer

[9]assumed for simplicity and likely to have minor effections on modelling results and/or be conservative

Table G1. VFSMOD inputs.

Appendix H: Comment and Response

Comment

Received via an email dated Monday March 22, 2021 from Russell Collins (russthepres@dftu.org):

Mr. Morris:

I and my Trout Unlimited Chapter (Doc Fritchey) feel that the proposed ARP be accepted. Our efforts to assess and restore this valuable asset started over 2 years ago and we are anxious to partner with PA DEP in the continuing effort to restore the watershed. We have established a good relationship with many property owners who are also anxious to support the effort.

We believe one of the major sources of runoff appears to come from the Borough of Schaffertown in the upper reaches of the watershed. There appears to be little consideration for stormwater runoff management in housing developments in this area. In the advent of heavy rains, the tributaries appear to carry significant runoff and siltation.

I also feel that a good deal of siltation also comes from the direction of the Rexmont area.

Thank you,

Russ

Russ Collins, Immediate Past President--Doc Fritchey Chapter of Trout Unlimited

S. Central Regional V.P.--PA Council of Trout Unlimited

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TROUT UNLIMITED DOC FRITCHEY CHAPTER

DEP First Response to runoff from the Schaefferstown Area.

Addressing development directly was not considered a priority for this ARP. Per Table 2, the impairments were attributed to agriculture. While this does not prevent us from addressing development as well, our model results indicate that the direct sediment contribution from developed lands was only about 20,000 lbs/yr versus about 6,400,000 lbs/yr from agricultural sources (Table 7). In addition to this however, development also increases sediment loadings indirectly via enhanced streambank erosion. This ARP does address this by proposing streambank stabilization for the tributaries draining the Schaefferstown Area (See Figure 16). In a subsequent conversation, Mr. Collins expressed concern that a proposed housing development may further exacerbate stormwater runoff problems. Cursory model runs in Model My Watershed were used to explore the effect of a modest (100 acre) low-density residential development. These results suggest that If built on hay/pasture lands, sediment loading would likely increase, but only by a very small amount of the watershed total (<1%). However, if this development replaced croplands, sediment loading would likely decrease. In short, addressing low density residential development directly via enhanced stormwater infrastructure would likely result in modest but expensive sediment reductions and therefore such projects will not be included as part of this ARP.

DEP First Response to sediment contributions from the Rexmont Area.

Per a subsequent conversation with Mr. Collins, the concern in the Rexmont area is two abandoned reservoirs on State Game Lands (Figure H1). The upstream reservoir is labelled "Lebanon Res" and the downstream reservoir, which is connected via a channel, is just to the north. The reservoirs appear to have been on the order of eight acres each. According to various sources on the internet, the reservoirs were a water supply for the City of Lebanon. They were originally been built in the late 1800's and then rebuilt around 1925. The dams were then drained in the early 2000's because they were determined to be a safety hazard and would have been expensive to repair.

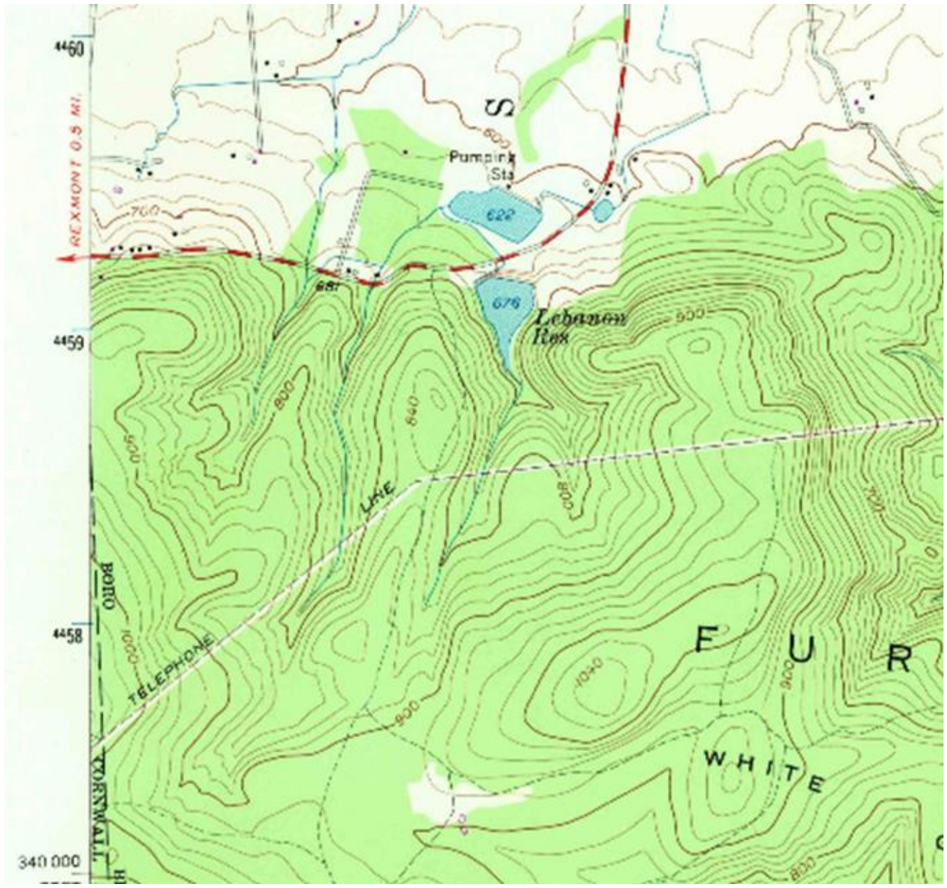

Figure H1. USGS Topographic Map excerpt showing the former Rexmont Reservoirs (Richland Quadrangle PA N4015-W7615/7.5 from 1955, photo revised 1969).

In consideration of this comment, a site visit was made on April 1st, 2021. While former reservoirs can be a persistent source of excessive sediment loads if not remediated, observations suggest that the former Rexmont Reservoirs should not be a restoration priority in this ARP. Our reasoning is as follows.

Firstly, aerial photographs dating back to 1940 indicate that, like today, the watershed feeding these reservoirs has been primarily forested for a long time. With the exception of minor bank erosion near the inlet of the former reservoir, stream conditions upstream of the first reservoir appear to be healthy (Figure H2). Thus, rather than accumulating huge quantities of agriculturally-derived sediments, as occurred in the downstream Speedwell Forge Lake, it is expected that the Rexmont Reservoirs had been accumulating much more modest loads typical of a forested landscape. If so, the former dams may have historically functioned to remove much of the natural sediment load from this tributary. Now that these dams have been breached, this natural load is being reexported to the stream, albeit perhaps at a temporarily higher rate.

Figure H2. Stream segments upstream of the upper Rexmont Reservoir. Note the healthy appearing stream conditions within a forested landscape. However, some modest bank erosion occurred along a short reach just above the inlet to the former reservoir (right).

Figure H3 shows conditions within the upper former reservoir. The bed was dominated by very dense growth of *Phragmites*. The outlet channel was rocky and clear while the channel(s) within the former reservoir were rocky in some areas but exhibited fines deposition in others, as may be expected for wetland conditions. Either way, severe channel downcutting, highly erosive banks or other symptoms of major sediment export were not observed. In fact, it appeared that the *Phragmit*es stand may be regularly flooded, in which case they could actually serve to filter out sediment.

Figure H3. Photographs within the upper former Rexmont Reservoir. The reservoir bed was dominated by thick growth of *Phragmites.* The outlet channel (upper right) was rocky and clear. Within the basin, channel reaches could be rocky and sandy, or exhibit fine sediment deposition, as may be expected for a wetland. Either way, severe downcutting and steep erosive banks were not observed.

Observations were also made of the short (approximately ¼ mile) channel that connected the upper and lower reservoirs (Figure H4). Some sections of this channel were rocky, while other lower gradient areas exhibited substantial fines deposition. While this fines deposition was likely at least in part due to export from the upper reservoir, it should also be noted that the hydrology of this reach has been highly modified via channelization.

Figure H4. Photographs of the channel connecting the upper and lower reservoirs.

Like the upper reservoir, the lower reservoir was dominated by dense *Phragmites* growth. Much of the channel through it was rocky, though fines deposits occurred in other areas. Either way, severe bank erosion or downcutting were not observed. And, like the upper reservoir, the wetland conditions in this former reservoir might serve to remove sediment.

Figure H5. Photographs of the channels within the lower reservoir.

Finally, observations of the stream reach leaving the second reservoir indicate that it was primarily rocky, clear, and apparently healthy.

Figure H6. Photographs of the stream channel below the two reservoirs.

In conclusion, these observations do not support reclamation of the former Rexmont Reservoirs as part of this ARP. Sediment export from these areas did not appear to be severe nor derived from agriculture. Such a project would likely be costly and may only result in modest sediment reductions. Plus, the wetland conditions that have developed in this area may have benefits to the stream. It is possible that these cursory observations underestimate the role of these former reservoirs as a sediment source. Thus, it is suggested that they be reconsidered in the future if the lower reaches of this tributary fail to improve sufficiently in response to downstream agricultural BMPs. If determined to be a problem in the future, reclamation of these areas could be considered in an update to this ARP.

Finally, these two comments point out that other physical BMP opportunities will likely be discovered in areas besides just those shown in Figure 16. Thus, language has been added to indicate that we did not intend to limit implementation to only the physical BMPs shown in Figure 16.