Beaver Run Sediment TMDL

Montour County, Pennsylvania

Prepared by:

pennsylvania
DEPARTMENT OF ENVIRONMENTAL PROTECTION

Final Draft

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Executive Summary

"Total Maximum Daily Loads" (TMDLs) for sediment were developed for the Beaver Run Watershed (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 rates from a similar unimpaired watershed were used to calculate the TMDLs.

"TMDLs" were calculated using both a long-term annual average value ($TMDL_{Avg}$) which would be protective under most conditions, as well as a 99th percentile daily value ($TMDL_{Max}$) which would be relevant to extreme flow events. Current annual average sediment loading in the Beaver Run Watershed was estimated to be 6,623,887 pounds per year. To meet water quality objectives, annual average sediment loading should be reduced by 68% to 2,121,441 pounds per year. Allocation of annual average sediment loading among the TMDL variables is summarized in Table 1. To achieve this reduction while maintaining a 10% margin of safety and minor allowance for point sources, annual average loading from croplands should be reduced by 80% whereas loading from hay/pasture lands and streambanks should be reduced by 50% each.

Table 1. Summary of Annual Average TMDL ($TMDL_{Avg}$) Variables for the Beaver Run Watershed

lbs/yr:						
Pollutant	$TMDL_{Avg}$	MOS_{Avg}	WLA_{Avg}	LA_{Avg}	LNR_{Avg}	ALA_{Avg}
Sediment	2,121,441	212,144	21,640	1,887,656	20,409	1,867,247

TMDL=Total Maximum Daily Load; MOS = Margin of Safety; WLA=Wasteload Allocation (point sources); LA = Load Allocation (nonpoint sources). The LA is further divided into LNR = Loads Not Reduced and ALA=Adjusted Load Allocation. Subscript "Avg" indicates that these values are expressed as annual averages.

Current 99thpercentile daily loading in the Beaver Run Watershed was estimated to be 291,593 pounds per day. To meet water quality objectives, 99th percentile daily sediment loading should be reduced by 75% to 72,499 pounds per day. Allocation of 99th percentile daily sediment loading among the TMDL variables is summarized in Table 2.

Table 2. Summary of 99th Percentile Daily Loading TMDL ($TMDL_{Max}$) Variables for the Beaver Run Watershed

lbs/d:						
Pollutant	$TMDL_{Max}$	MOS_{Max}	WLA_{Max}	LA_{Max}	LNR_{Max}	ALA_{Max}
Sediment	72,499	7,250	727	64,522	698	63,824

TMDL=Total Maximum Daily Load; MOS = Margin of Safety; WLA=Wasteload Allocation (point sources); LA = Load Allocation (nonpoint sources). The LA is further divided into LNR = Loads Not Reduced and ALA=Adjusted Load Allocation. Subscript "Max" indicates that these values are expressed as 99th percentile for daily loading.

Introduction

Beaver Run is a tributary of Chillisquaque Creek, with the confluence approximately one-half mile southeast of the Village of Potts Grove (Figure 1). This Total Maximum Daily Load (TMDL) document has been prepared to address the siltation from agriculture impairments listed for the entire watershed (Figure 1), per the 2018 Final Integrated Report (see Appendix A for a description of assessment methodology). The Beaver Run Watershed was approximately 12 square miles and occurred almost entirely within Montour County, just north and east of the border with Northumberland County. It contained approximately 25 stream miles, all of which were designated for warm water fishes (WWF) and Migratory Fishes (MF).

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)*
>
> *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 TMDL document is applicable to all significant sources of solids that may settle to form deposits.

According to an analysis of NLCD 2011 landcover data, as reported by Model My Watershed, land use in the study watershed was estimated to be 39% forest/naturally vegetated lands, 51% agriculture, and 10% mixed development (Table 5). The agricultural lands were nearly evenly split between croplands and hay/pasture lands (Appendix B, Table B1). There were four NPDES permitted point source discharges in the watershed with concentration limits relevant to sedimentation, but all were estimated to be very minor sediment sources (Table 4).

Table 3. Aquatic-Life Impaired Stream Segments in the Beaver Run Watershed per the 2018 Final Pennsylvania Integrated Report

HUC: 020506 – Lower West Branch Susquehanna				
Source	EPA 305(b) Cause Code	Miles	Designated Use	Use Designation
Agriculture	Siltation	10.4	WWF, MF	Aquatic Life

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

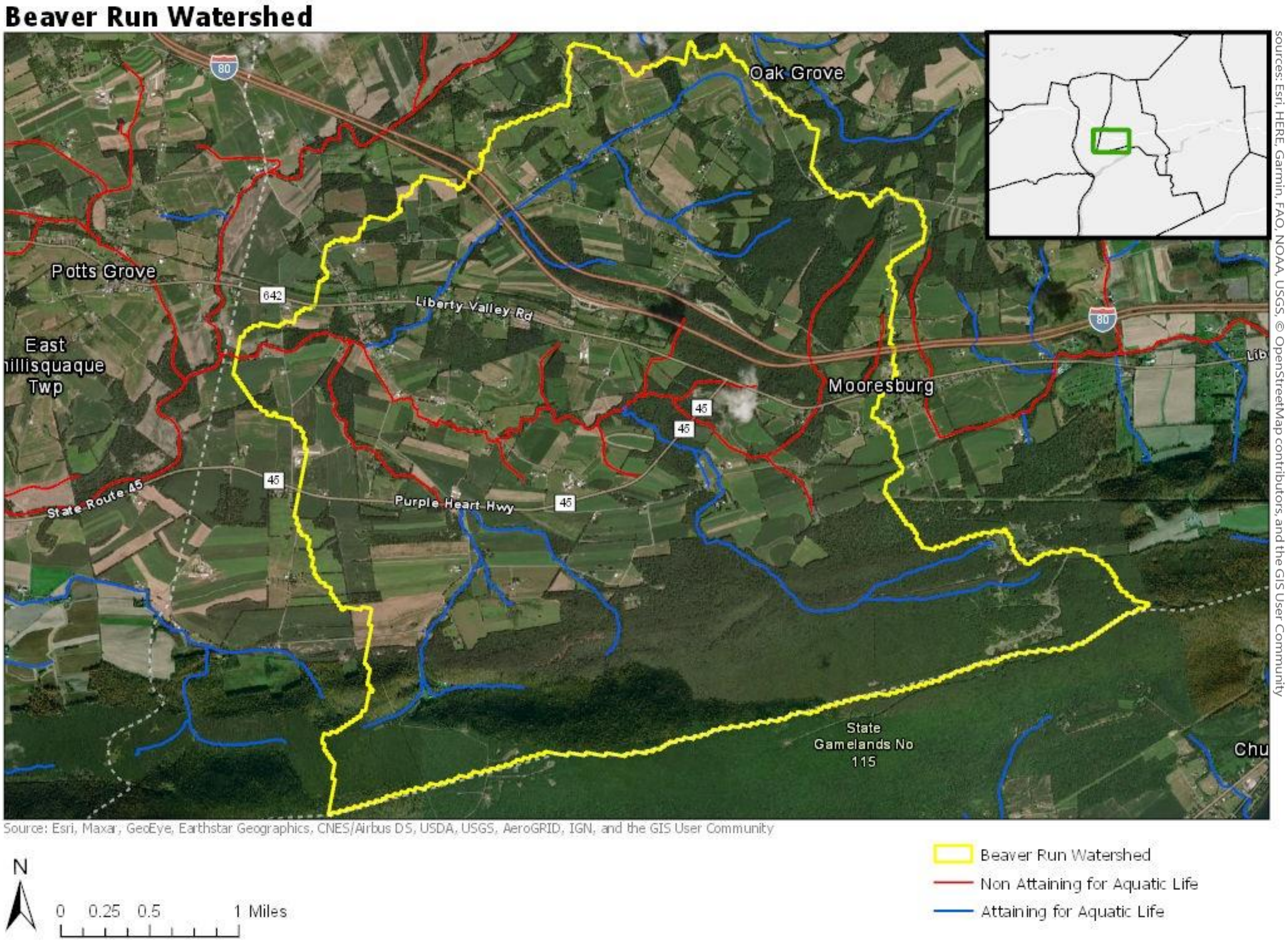

Figure 1. Beaver Run Watershed. Per the approved 2018 Integrated Report, all aquatic life use impairments within the watershed were attributed to siltation from agriculture.

Table 4. Existing NPDES-Permitted Discharges in the Beaver Run Watershed and their Potential Contribution to Sediment Loading.					
		Permit Based Limits		DMR Based Loading	
Permit No.	Facility Name	Load, mean lbs/yr	Load, max lbs/d	Load, mean lbs/yr	Load, max lbs/d
PAG045007	Martin & Vicki Ruk SFTF	8	0.07	NA	NA
PAG045157	Anthony & Jenny Beaver Conmy Residence	8	0.07	NA	NA
PA0035599	PA DOT Bur of Proj Delivery	213	1.2	10	0.4
PA0035602	PA DOT Bur of Proj Delivery	213	1.2	11	0.4

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.

Martin & Vicki Ruk
Small flow wastewater treatment facility for a single-family residence. Average daily flows of 262.5 gpd and a daily maximum flows of 400 gpd were assumed. The average flow along with an average monthly total suspended solids (TSS) concentration of 10 mg/L was used to calculate the annual average loadings. A 20 mg/L TSS concentration along with the assumed peak daily flow were used to calculate the daily max load. No eDMR data were available.

Anthony & Jenny Beaver Conmy
Small flow wastewater treatment facility for a single-family residence. Average daily flows of 262.5 gpd and a daily maximum flows of 400 gpd were assumed. The average flow along with an average monthly TSS concentration of 10 mg/L was used to calculate the annual average loadings. A 20 mg/L TSS concentration along with the assumed peak daily flow were used to calculate the daily max load. No eDMR data were available.

PA DOT Bur of Proj Delivery. Wastewater treatment plants serving rest areas along Interstate 80. Both permits had concentration limits for total suspended solids of 10 mg/L average monthly 20 mg/L daily max. Permit limits were based on effluent flow rates of 0.007 MGD. This flow along with the average monthly concentration limit was used to calculate mean lbs/yr; this flow along with the daily maximum concentration limit was used to calculate maximum lbs/d.

For mean annual load based on electronic discharge monitoring report (eDMR) data, both sites had three full years (2017-2019) of monthly reported average flow (in MGD) as well as average monthly TSS concentration (in mg/L). Each month's flow and concentration were used to calculate an average daily load for each month. This was multiplied by the number of days in the month, and all months were added in each year to make an annual load. All three annual loads were averaged to generate the mean lbs/yr values reported above. To calculate the maximum daily load, daily maximum flows and daily maximum total suspended solids concentrations reported monthly from January 2017 to October 2020 were used to calculate the daily maximum load for each month. The values reported above were the maximum of those values for each site.

TMDL Approach

Although watersheds must be handled on a case-by-case basis when developing TMDLs, there are basic processes that apply to all cases. They include:

1. Collection and summarization of pre-existing data (watershed characterization, inventory contaminant sources, determination of pollutant loads, etc.);
2. Calculation of a TMDL that appropriately accounts for any 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.

Because Pennsylvania does not have numeric water quality criteria for sediment, the "Reference Watershed Approach" was used. This method estimates pollutant loading rates in both the impaired watershed as well as a similar watershed that is not listed as impaired for the same use. 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 and accumulation rates in a watershed. 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 find a reference, the Department's Integrated Report GIS-based website (available at https://www.depgis.state.pa.us/integrated_report_viewer/index.html), or GIS data layers consistent with the Integrated Report, was used to search for nearby watersheds that were of similar size as the Beaver Run Watershed, but lacked stream segments listed as impaired for sediment. Once potential references were identified, they were screened to determine which ones were most like the impaired watershed with regard to factors such as landscape position, topography, bedrock geology, hydrology, soil drainage types, land use etc. Furthermore, benthic macroinvertebrate and physical habitat assessment scores were reviewed to confirm that a reference was acceptable. Preliminary modelling was conducted to make sure that use of a particular reference would result in a reasonable pollution reduction.

Considering that: it was nearby (only about fourteen miles to the northwest), partially within the same physiographic province, had similar topography and hydrologic characteristics, and there was good evidence that it was attaining its aquatic life use, a subwatershed of the Black Hole Creek in Lycoming County was considered for use as a reference (Figures 2 and 3, Table 5).

Table 5. Comparison of the Impaired Beaver Run Watershed and the Black Hole Creek Subwatershed.

	Beaver Run	Black Hole Creek
Phys. Province[1]	Susquehanna Lowland Section of the Ridge and Valley Province	68% Susquehanna Lowland Section of the Ridge and Valley Province 32% Appalachian Mountain Section of the Ridge and Valley Province
Land Area[2], ac	7,753	7,618
Land Use[2]	51% Agriculture 39% Forest/Natural Vegetation 10% Developed	23% Agriculture 63% Forest/Natural Vegetation 14% Developed
Soil Infiltration[3]	16% Group A 24% Group B 3% Group B/D 5% Group C 14% Group C/D 38% Group D	30% Group A 32% Group B 1% Group B/D 3% Group C 19% Group C/D 15% Group D
Dominant Bedrock[4]	65% Shale 14% Quartzite 8% Calcareous Shale 7% Limestone 5% Siltstone	48% Shale 16% Quartzite 11% Calcareous Shale 11% Siltstone 7% Sandstone 6% Limestone
Average Precipitation[5], in/yr	41.5	41.5
Average Surface Runoff[5], in/yr	3.1	2.7

Average Elevation[5] (ft)	686	905
Average Slope[5]	9%	9%
Stream Channel Slope[5]	1st order: 1.86% 2nd order: 0.44% 3rd order: 0.05	1st order: 4.38% 2nd order: 1.18% 3rd order: 0.59%

[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 based on NLCD 2011 for Beaver Run, but based on NLCD 2016 for Black Hole Creek Subwatershed.
[3]As reported by Model My Watershed's analysis of USDA gSSURGO 2016
[4]Per Bedrock Geology GIS layer provided by Pennsylvania Bureau of Topographic and Geological Survey, Dept. of Conservation and Natural Resources
[5]As reported by Model My Watershed

Both watersheds were either primarily or entirely within the Susquehanna Lowlands Section of the Ridge and Valley Physiographic Province and had significant agricultural coverage, though the percentage of agricultural land area was more than twice as much in the Beaver Run Watershed versus the Black Hole Creek Subwatershed (51 versus 23%-Table 5). This being the case, there was substantially more natural lands cover in the Black Hole Creek Subwatershed (63% versus 39%). The amount of developed lands were nearly the same (10 and 14%) in both watersheds.

Both watersheds were dominated by non-karst sedimentary bedrocks, though both had small amounts of limestone (7 and 6%) (Table 5). The average topographic slope in both watersheds was virtually the same (9%), though stream channel slopes were higher on average in the Black Hole Creek Subwatershed (Table 5). Estimated surface runoff rates were similar, though somewhat higher in the Beaver Run Watershed (3.1 versus 2.7 inches per year).

While stream segments within the Beaver Run Watershed were designated for warm water fishes (WWF), stream segments within the Black Hole Creek Subwatershed were designated for trout stocking. Neither watershed contained stream segments designated for special protection (high quality or exceptional value). Like the Beaver Run Watershed, there were several NPDES permitted point source discharges with concentration limits relevant to sediment in the Black Hole Creek Subwatershed, but none were major sediment sources (Table 6).

Table 6. Existing NPDES-Permitted Discharges in the Black Hole Creek Subwatershed and their Potential Contribution to Sediment Loading.

Permit No.	Facility Name	Load, mean lbs/yr	Load, max lbs/d
PAR604816	Robert Twigg B&C Auto Wreckers	NA	NA

PA0010421	Moran Ind. Inc. West Pharm Svc Montgomery Plt[2] (rescinded)	274	2.5
PAR234808	West Pharmaceutical Service	NA	NA
PA0228311	Brady Township	207	10
PAG045256	White Deer Hole Golf Course[5]	46	0.3
PA0041327	PA College of Technology WWTP[6]	24	2.8

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.

In Pennsylvania, routine, dry-weather discharges from concentrated animal feeding operations (CAFOs) are not allowed. Wet weather discharges are controlled through best management practices, resulting in infrequent discharges from production areas and reduced sediment loadings associated with lands under the control of CAFOs owner or operators, such as croplands where manure is applied. Although not quantified in this table, sediment loading from CAFOs is accounted for since the modelling program estimates loadings from croplands and hay/pasturelands.

Robert Twigg B&C Auto Wreckers
Industrial stormwater permit without sediment loading limits. Note that Model My Watershed accounts for loading from developed lands.

Moran Ind. West Pharm Svc Montgomery Plt.
This discharge has ceased and the permit has been rescinded. However, since the discharge recent and was apparently active before and during the watershed's assessment, its pollutant loading was included in the watershed total. Their NPDES permit issued in 2010 indicated that there were two outfalls, but only one had limits relevant to sedimentation. Total suspended solids limits were 10 mg/l monthly average and 20 mg/l instantaneous maximum. A bulletin notice and Water Quality Management permit indicated that this outfall had an average annual flow listing of 0.009 MGD and a design hydraulic capacity of 0.015 MGD. The average annual flow listing and the monthly average concentration limit was used to calculate mean lbs/yr. The instantaneous maximum concentration limit along with design hydraulic capacity was used to calculated max lbs/d. The other outfall without sediment limits had a design flow of 0.041 MGD.

West Pharmaceutical Service
Industrial stormwater permit without sediment loading limits. Note that Model My Watershed accounts for loading from developed lands.

Brady Township
Permit for a wastewater treatment plant. Mean lbs/yr was based on two full years of eDMR data where average monthly pounds per day of TSS were reported. The monthly value was multiplied by the number of days in the month and then all months were summed to give an annual value. The two annual values were then averaged. The daily max sediment load was based on the 20 mg/l instantaneous maximum concentration limit for total suspended solids and a 0.06 MGD hydraulic design capacity for the wastewater treatment plant per their permit issued July 31, 2017

White Deer Hole Golf Course
Permit for wastewater treatment plant expired 2013. According to EPA's Enforcement and Compliance History Online website and internal documentation, the facility had a design flow of 0.0015 MGD. A TSS concentration limit of 10 mg/l monthly average was assumed when calculating the mean annual load and concentration limit of 20 mg/l instantaneous maximum was assumed when calculating the maximum daily load.

PA College of Technology WWTP
Permit for this WWTP has been terminated, but it was recent and active during assessment sampling. Mean lbs/yr was based on five full years of eDMR data where average monthly flows and TSS concentrations were reported. These

values were used to derive an average daily load in lbs/d for each month, and these values were then multiplied by the number of days in the month and then all months were summed to calculate lbs/yr. The five years were then averaged to calculate mean lbs/yr. From their eDMR data ranging from November 2011 through June 2017 the highest instantaneous maximum TSS concentration reported was 56 mg/L This value along with a flow rate of 0.006 MGD per their permit issued in 2016 was used to generate the daily maximum load.

After selecting the potential reference, the two watersheds were visited 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. The impaired watershed was visited during October 2020, whereas the Black Hole Creek Subwatershed was visited during November 2020. However, since the Black Hole Creek Subwatershed was used as a reference in prior projects, recent observations from September and April 2020 were also used to evaluate this watershed.

Site observations in the Beaver Run Watershed suggested there were some areas of substantial impairment, though conditions were highly variable (Figure 4). For instance, steeper tributaries originating near the mountainous or hilly margins of the watershed tended to have rocky substrate. In contrast mainstem reaches within the valley appeared to have substantial fines deposition and high turbidity in some, though not all, cases.

It is hypothesized that these impairments may be attributable to a moderately high amount of agriculture in a watershed that may be especially susceptible to sedimentation deposition. At 51% of its total land area, the amount of agriculture in this watershed was high, though not as extreme as some of the most intensively farmed regions of the state. However, at 0.44% slope on average, its second order channel segments were low gradient, and at 0.05% slope its third order segments were exceptionally low gradient (Table 5). Such low gradient reaches may promote sediment deposition rather than export, and thus portions of this watershed may not be able to tolerate even moderate agricultural land cover without exhibiting sedimentation problems, unless perhaps if exceptional best management practices (BMPs) are implemented.

While site observations indicated there were areas where agricultural practices clearly could have been improved, conditions typically did not seem that bad in this watershed. While areas of ploughed fields, pastures with cattle access to the stream, and bad bank erosion were all observed (Figure 6), there were also areas with riparian buffers, cattle exclusion fencing, and stream restoration projects (Figure 7). It should be noted however that many crop fields had not been harvested yet during the site visit so it was difficult to evaluate BMPs such as the use of conservation tillage or cover crops.

Part of the reason that the Black Hole Creek Subwatershed was selected as a potential reference was that like the Beaver Run Watershed it also had some stream segments with very low gradient, yet it was listed as attaining its aquatic life use. In fact, the mainchannel reach through the White Deer Golf Course had comparable slope to the 3rd order reach in Beaver Run (0.08 vs 0.05, see Figure 8). It was hypothesized that the far lesser agricultural cover in the Black Hole Creek Subwatershed (23% vs 51% of land area) allowed it to largely maintain aquatic life health despite these low stream slopes, and thus serve as a model for restoration in the Beaver Run Watershed.

In general, site observations within the Black Hole Creek Subwatershed indicated healthier stream substrate conditions (see Figures 9 through 12). In addition to having lesser overall agricultural landcover, expansive forested riparian buffers were somewhat more common in the Black Hole Creek Subwatershed (Figures 13 and 14). According to a GIS analysis, approximately 76% of the land area within 100 feet of NHD flowlines was comprised of tree canopy vegetation, shrub/scrub lands or emergent wetlands in the agricultural valley area of the Black Hole Creek Subwatershed versus about 61% in the Beaver Run Watershed (see the “Hydrologic / Water Quality Modelling” section). While conditions were generally better in the Black Hole Creek Subwatershed, there were instances where agricultural/land use practices could have been improved (Figure 15).

One area of the Black Hole creek Subwatershed was observed to have heavy sediment deposition, the mainstem reach within and around the White Deer Hole Golf Course (Figure 10). However, it is thought that this may be in large part attributable to the very low gradient of the stream in this area, the abundance of wetlands and beaver activity (Figures 11). Given this potential natural explanation in addition to the fact that stream substrate conditions appeared to be excellent further downstream (Figure 12), the Black Hole Creek Subwatersed was not disqualified for use as a reference on this basis.

The far lesser amount and intensity of agricultural land uses within the Black Hole Creek Subwatershed may be in large part due to the presence of the restricted Susquehanna Ordnance Depot military site, which along with the neighboring White Deer Golf Course and Pennsylvania College of Technology Earth Science Center campus, comprised a large fraction of the land area within the subwatershed that would have been suitable for agriculture (Figure 16). In fact, the land that is now the Susquehanna Ordnance Depot previously contained numerous farms until the Federal Government acquired these lands in the early 1940s for the purpose of manufacturing and stockpiling munitions for World War II (Beauge 2019). At present, the site is fenced and posted against trespassing. And, according to satellite imagery, GIS land use classification, and observations from its perimeter, it appears to be mostly comprised of patches of forest, wetland, and areas of hay/mowed grass (Figure 17). Such grasslands and even developed lands associated with golf courses would be expected to be a far lesser sources of sediment than crop fields.

It should be noted that the Beaver Run and the Black Hole Creek watersheds had somewhat different topographic characteristics (see Table 5 and Figure 8). In particular, valley mainchannel stream reaches were generally steeper upstream and flatter downstream in the Beaver Run Watershed whereas the opposite was true in the Black Hole Creek Subwatershed. This could at least in part explain the apparently healthier conditions in the downstream area of the Black Hole Creek Subwatershed. While the uncertainties resulting from such factors are not ideal, the Black Hole Creek Subwatershed was chosen as the most suitable reference candidate identified following a diligent search for potential references. And, as detailed in the “Calculation of the Load Allocations” section, the prescribed pollution reductions include a safety factor that helps account for such uncertainty.

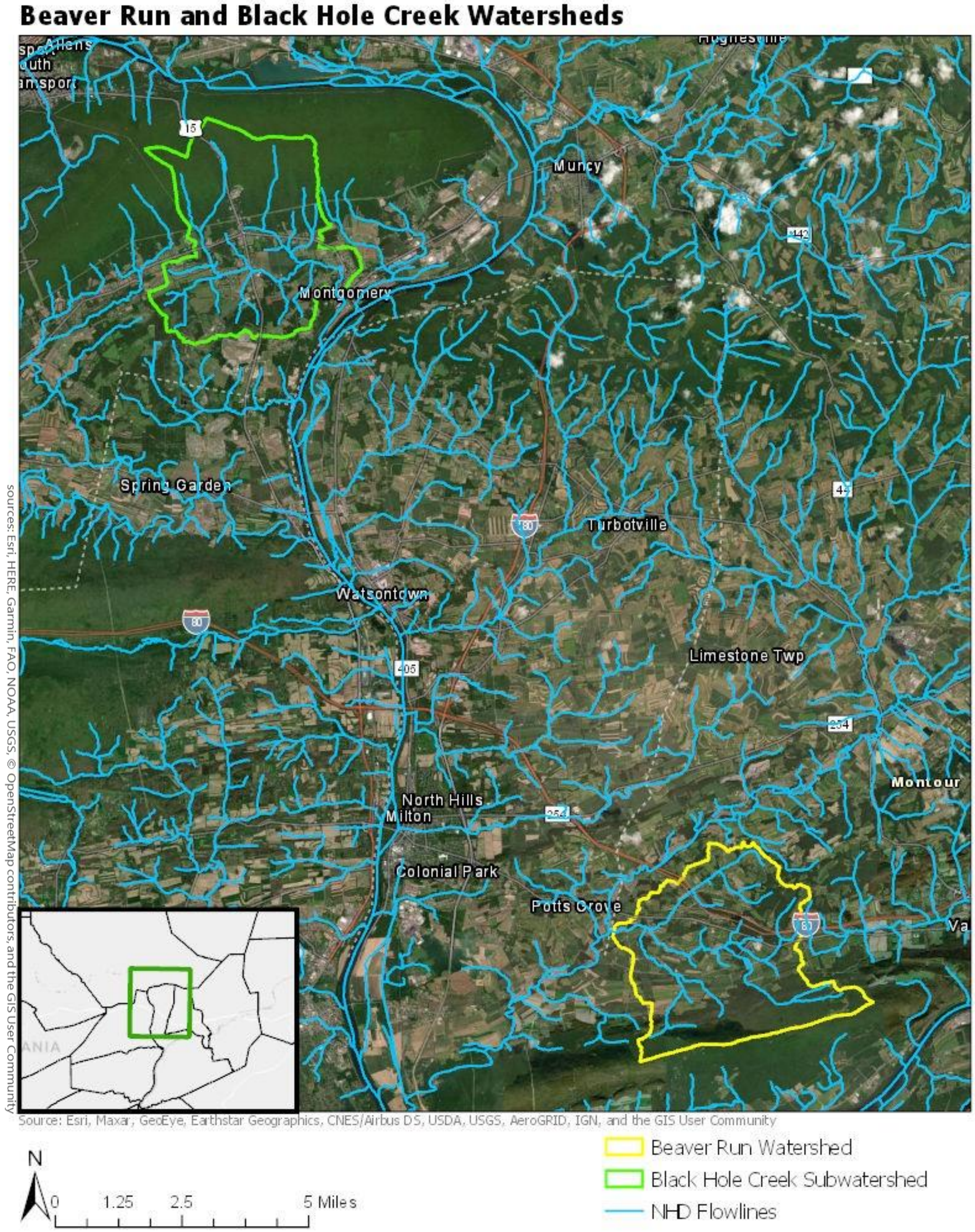

Figure 2. Beaver Run and Black Hole Creek Watersheds.

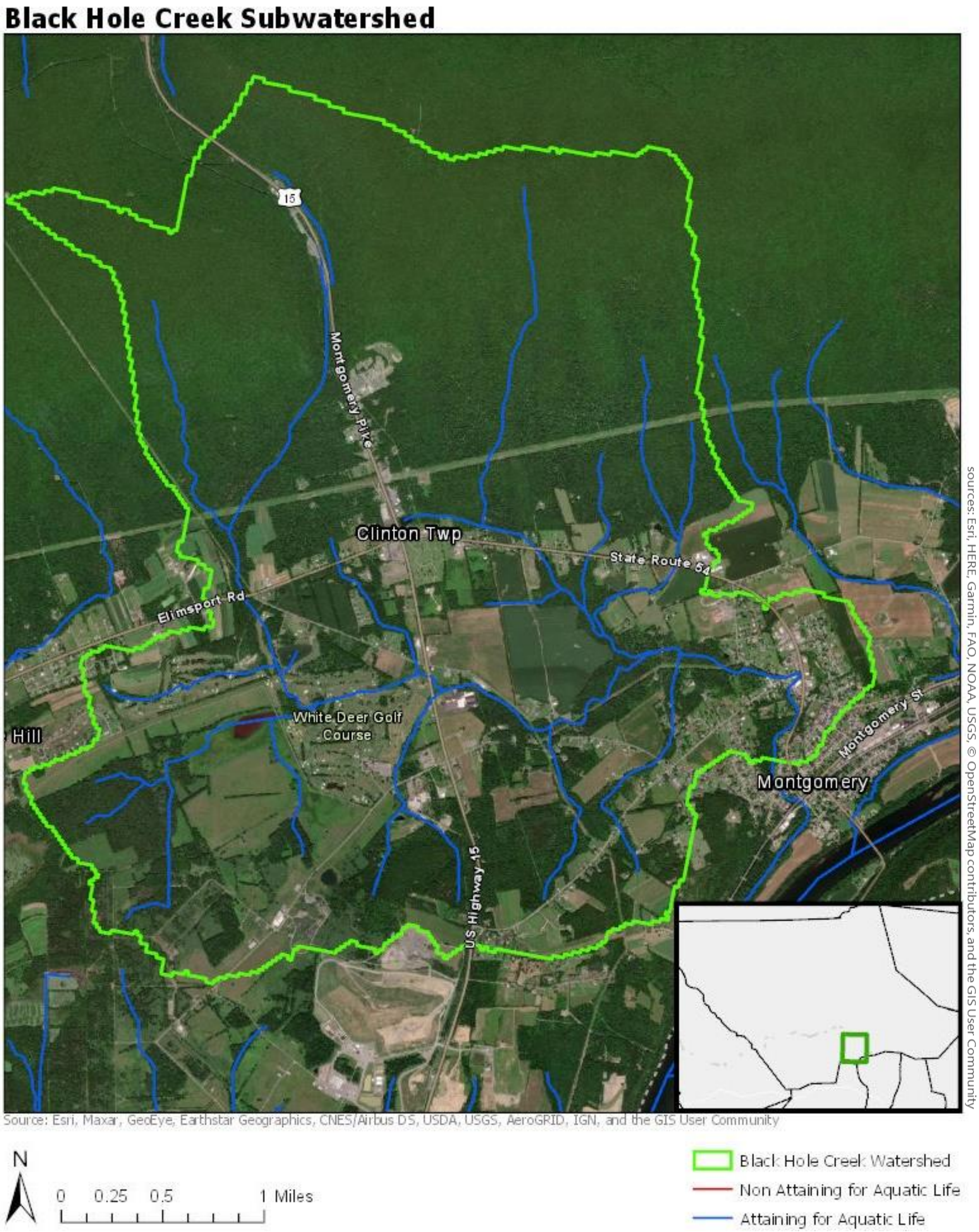

Figure 3. Black Hole Creek Subwatershed.

Figure 4. Example stream substrate and turbidity conditions within the Beaver Run Watershed. The lower mainstem exhibited diverse conditions, including areas that were slow and turbid (A), areas with heavy fines deposition (B), areas that were primarily rocky (C) and areas that were gravelly with fines deposition. Tributaries were often primarily rocky as in E and F.

Figure 5. Example landscapes within the Beaver Run Watershed. Note the existence of large expanses of agricultural fields in the valley. Oftentimes however, these fields were intermixed with patches of forest, particularly along the stream segments.

Figure 6. Examples of conditions within the Beaver Run Watershed that may exacerbate sediment loading. Note the presence of vast expanses of croplands, including sites that were tilled (A) as well as pasture lands where cattle had direct access to the stream (B). Photographs C and D show sites with excessive bank erosion. In the case of D, this was likely in part due to intentional riparian vegetation removal and the presence of lawn and agricultural fields along the banks.

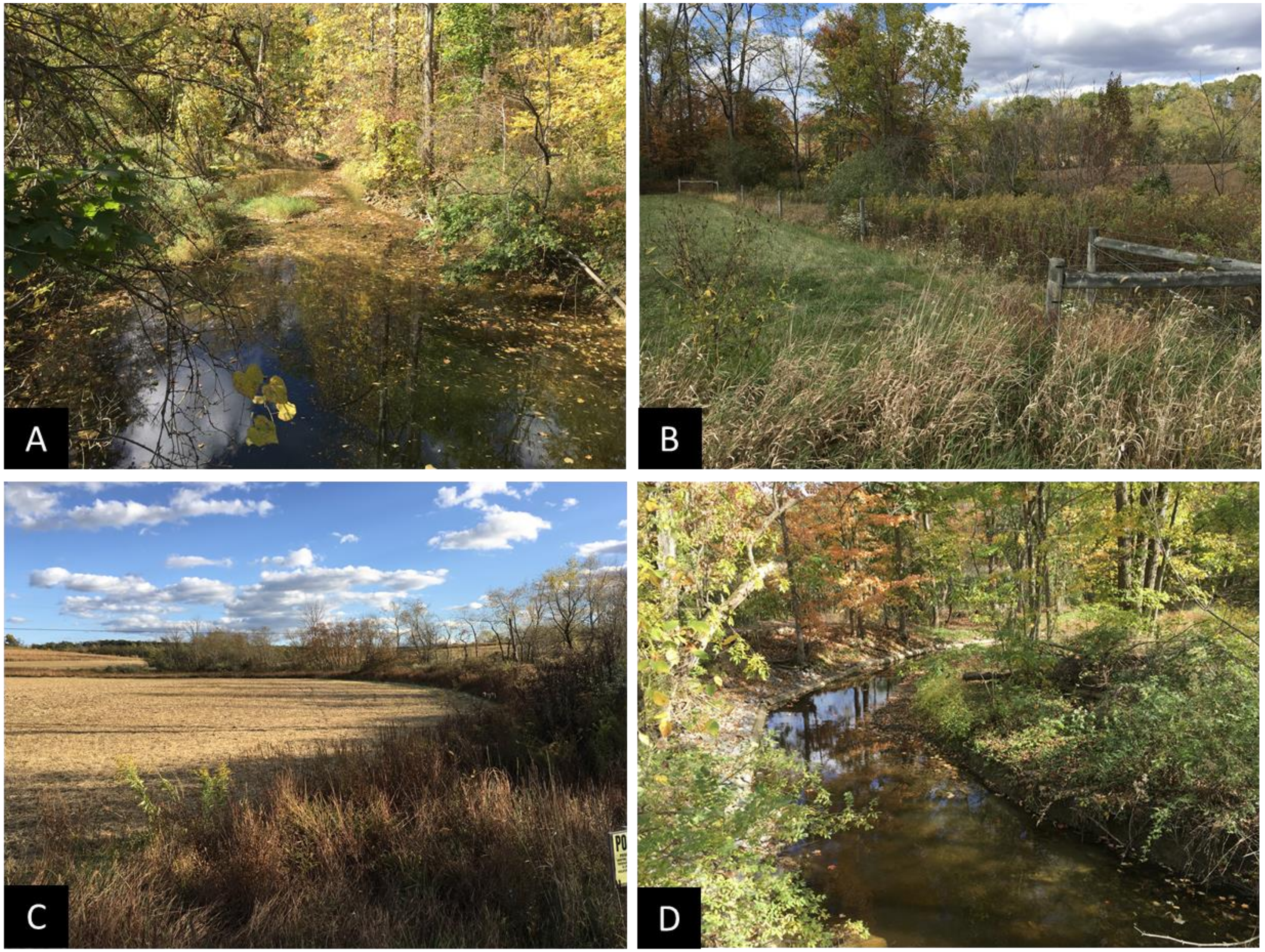

Figure 7. Example conditions and agricultural practices in the Beaver Run Watershed that may help prevent sediment loading. Photograph A shows an expansive forested riparian buffer. Photograph B shows cattle exclusion fencing and an herbaceous buffer. Photograph C shows stream/drainageway protection among agricultural fields and photograph D shows a streambank stabilization project.

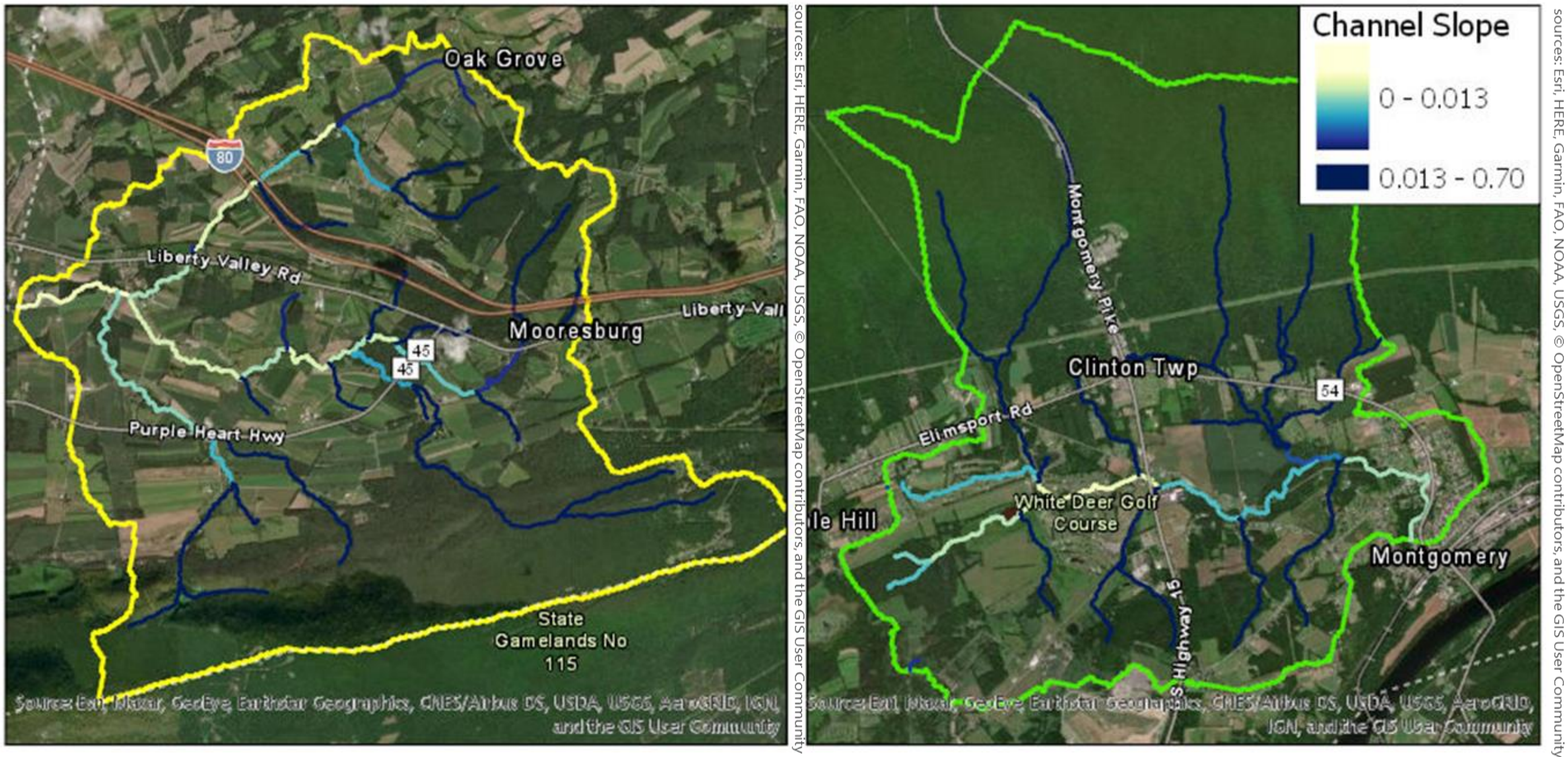

Figure 8. Map of channel slopes in the Beaver Run (left) and Black Hole Creek (right) watersheds. Slopes were reported as drop:length per USGS FACET output (see Hopkins et al. 2020)

Figure 9. Example substrate conditions of stream segments originating in the mountainous/hilly areas of the Black Hole Creek Subwatershed. These streams were primarily rocky, though some fines deposition could be observed in photograph D. This photograph was taken where the tributary entered an agriculturally dominated valley. Note that due to dry conditions during the Summer of 2020, many first order tributaries were dry during site visits.

Figure 10. Example substrate conditions within the White Deer Golf Course region of the Black Hole Creek Subwatershed. While some reaches were substantially rocky, as in A and B, other reaches exhibited heavy fines deposition (C and D). While this could indicate sedimentation pollution, it is expected that natural factors including exceptionally low stream gradient, natural wetland conditions and beaver activity could also explain the observed deposition in this approximately half-mile reach.

Figure 11. Examples of beaver activity in the Black Hole Creek Subwatershed. Signs of beaver activity (right) were obvious in the golf course area. The upper left photo shows a beaver dam. While the area below the dam was somewhat rocky (upper left), heavy fine sediment deposition occurred above the dam (lower left).

Figure 12. Examples of stream substrate conditions within the lower mainstem of the Black Hole Creek. Sites occurring below the golf course reach tended to have rocky substrates and clear conditions, even in pools.

Figure 13. Example landscapes within in the Black Hole Creek Subwatershed. Some stream segments originated in a forested mountainous area, while others flowed through a low relief valley dominated by agricultural lands, a golf course, and a restricted military site.

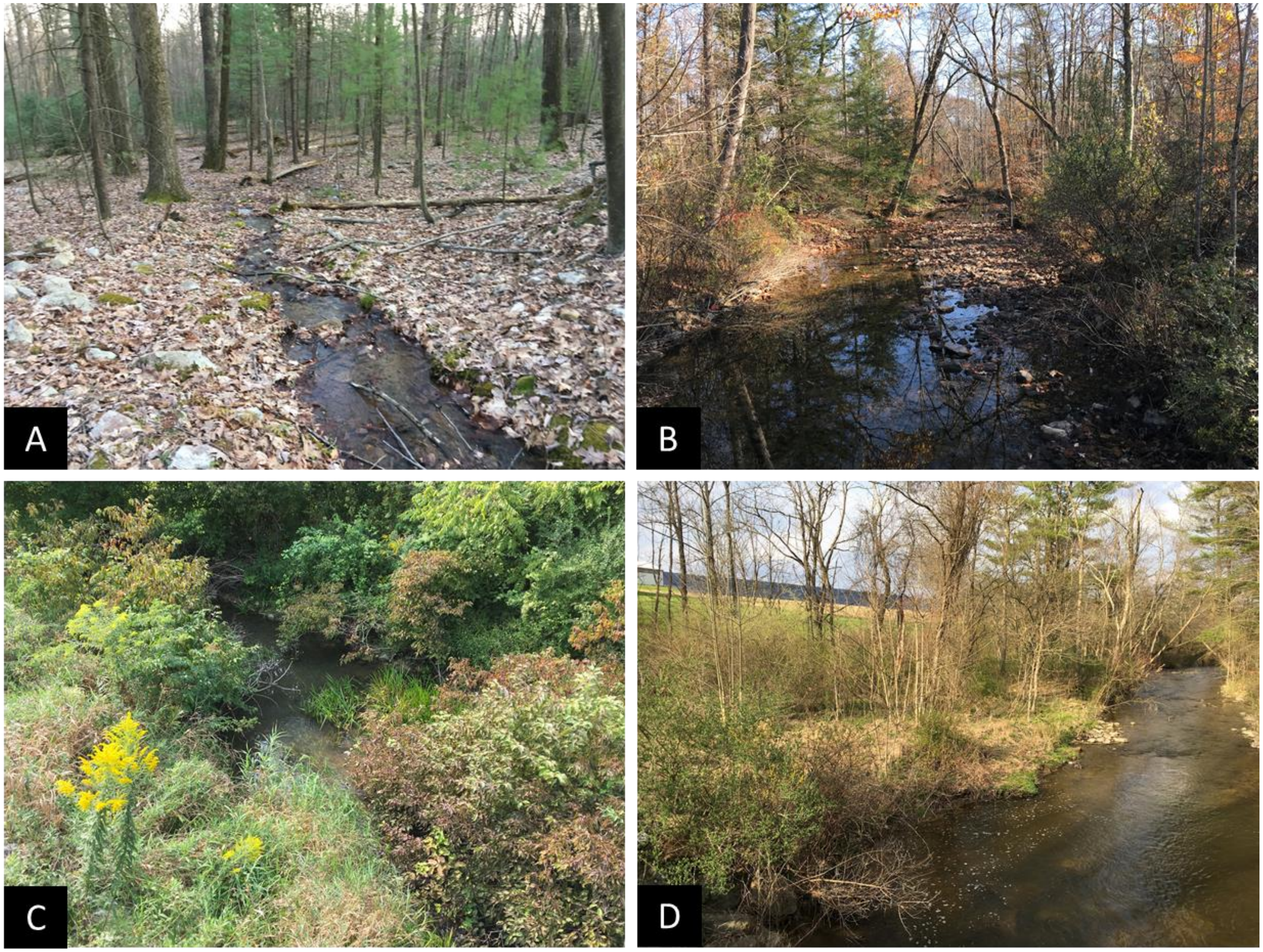

Figure 14. Examples of conditions within the Black Hole Creek Subwatershed that may help prevent sediment pollution. Photograph A shows a forested mountainous area within the northern part of the watershed. Photographs B through D show forested and wetland buffers along the lower mainstem.

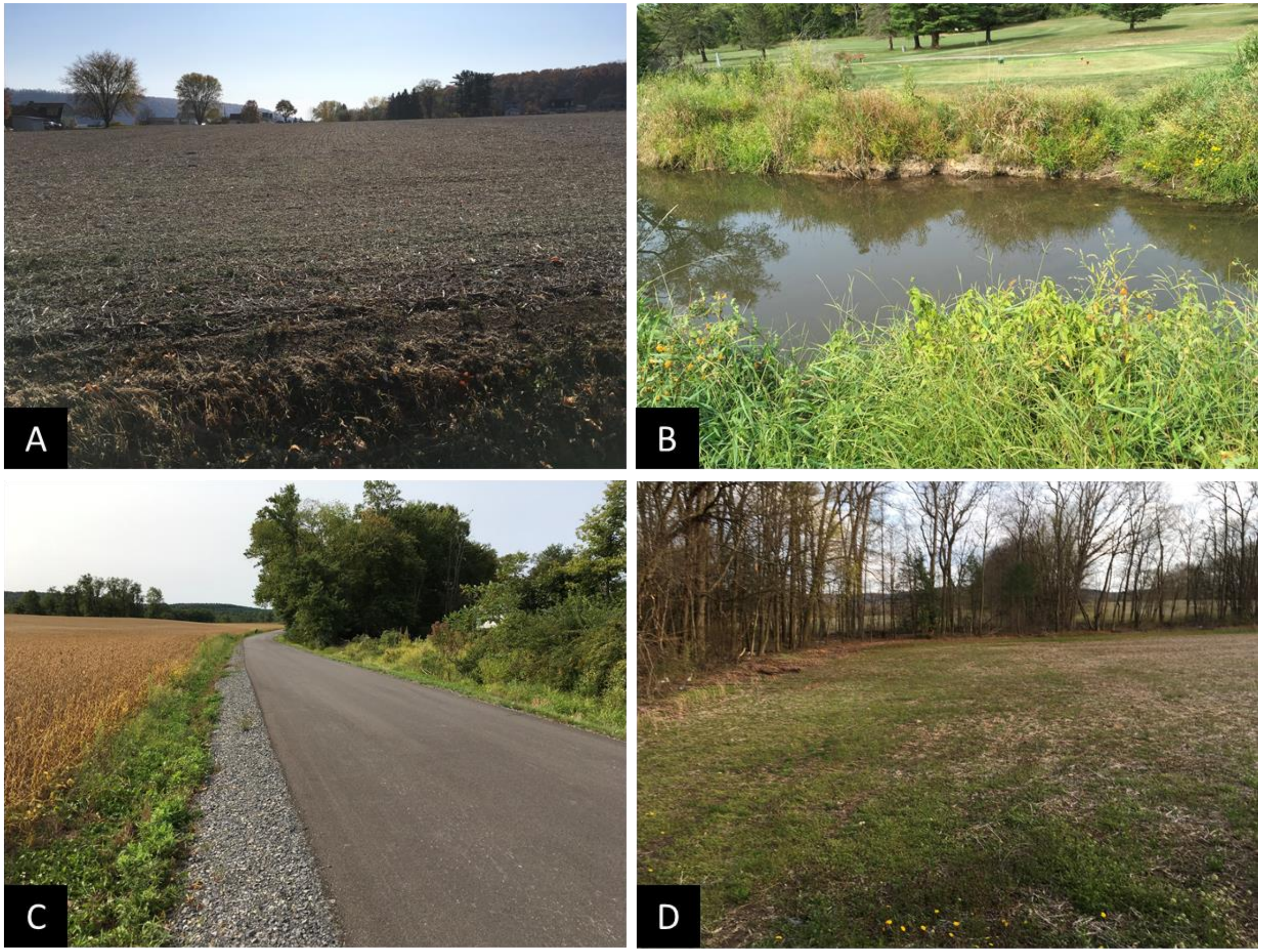

Figure 15. Examples of conditions within the Black Hole Creek Subwatershed that may exacerbate sediment loading. Photograph A shows a large expanse of croplands, and photographs B through D show riparian buffers that were either nearly absent or likely too narrow to be highly protective of the stream. Note that in Photograph C the stream ran right along the road shoulder on the right side of the photo. Overall, however, riparian buffering tended to be good in this watershed.

Black Hole Creek Subwatershed

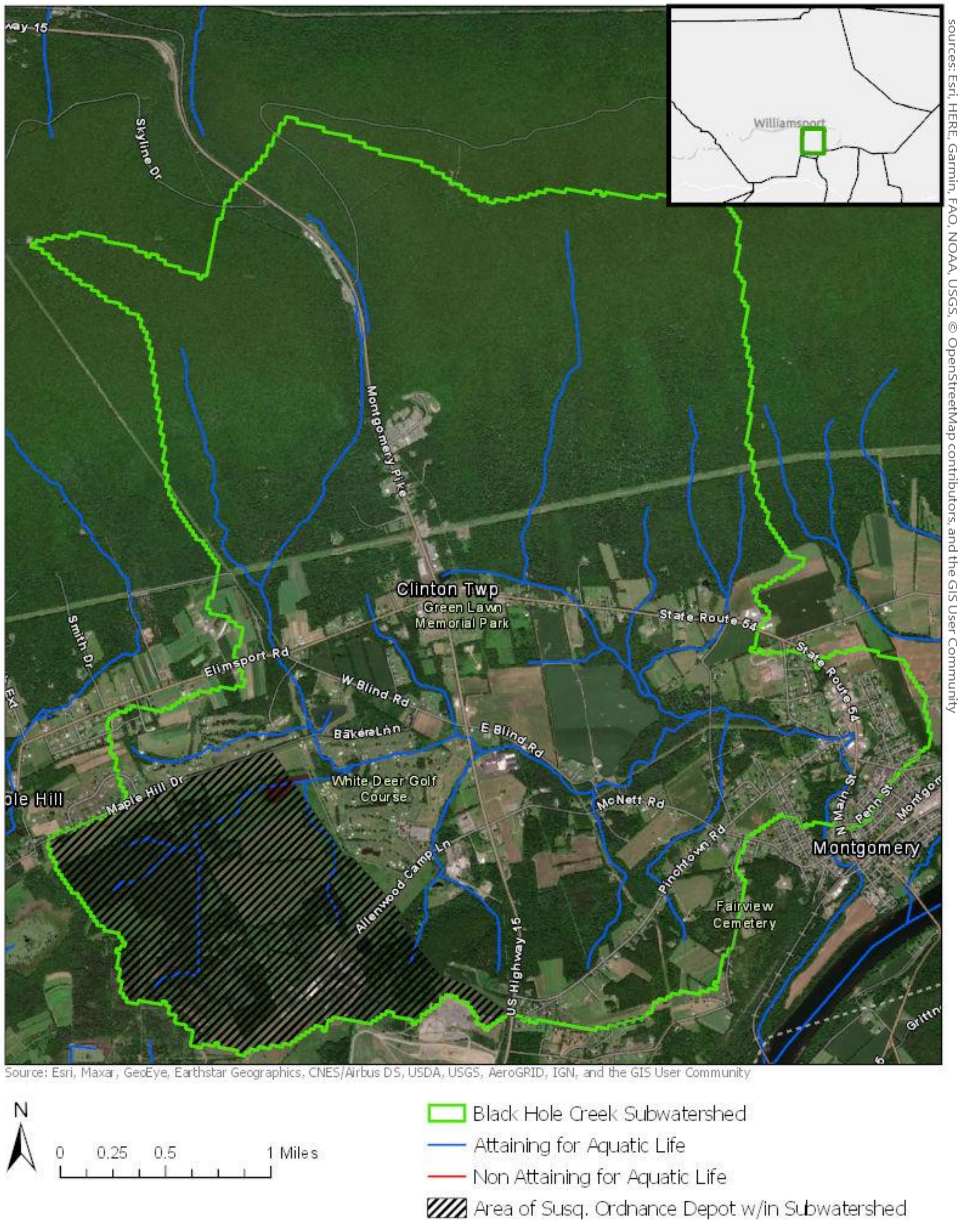

Figure 16. Approximate area of the Susquehanna Ordnance Depot within the Black Hole Creek Subwatershed. The location of the Depot's lands as shown in this figure is approximate and based on visual inspection of the Lycoming County Parcel Viewer. Also, be aware that only Depot lands within the watershed are shown; their lands actually extend well beyond the watershed boundary.

Figure 17. Photograph looking into the Susquehanna Ordnance Depot from the fenced periphery along Maple Hill Drive. Note the presence of mowed grass fields/hay and forested area down in the valley.

Hydrologic / Water Quality Modeling

This section deals primarily with the $TMDL_{Avg}$ calculation, as use of annual average values was determined to be the most relevant way to express the "TMDL" variables. For information about the $TMDL_{Max}$ calculations, see the later "Calculation of a Daily Maximum '$TMDL_{Max}$'" section.

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, watershed areas were defined using MMW's Watershed Delineation tool (see https://wikiwatershed.org/documentation/mmw-tech/#delineate-watershed). 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 is 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 (2019).

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 landcover within the Black Hole Creek Subwatershed was adjusted to reflect newer NLCD 2016 landcover data, and average annual wastewater (but not stormwater) flows associated with the relevant facilities in Tables 4 and 6 were added as inputs. Landcover was adjusted in the Black Hole Creek Subwatershed because the older NLCD 2011 data used by Model My Watershed indicated the presence of substantial croplands in the Susquehanna Depot restricted military site. Not only did this seem unlikely, but newer NLCD 2016 data indicated that there were no croplands in this area. Furthermore, the amount of croplands reported by NLCD 2016 were more consistent with USDA's Cropland Data Layer's 2019 classifications. To make the landcover corrections, a raster dataset of NLCD 2016 landcover was opened in ArcGISPro and clipped to the shapefile of the Black Hole Creek 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 total hectares calculated for the 2016 adjustment differed from the value required by Model My Watershed by 0.1 ha. Thus, the amount of wooded areas was reduced by a negligible 0.1 ha to produce the exact value required by the program. Landcover corrections were deemed unnecessary for the Beaver Run Watershed because the older NLCD 2011 classifications of croplands and hay pasture lands appeared to more consistent with the USDA's Cropland Data Layer's 2019 classifications.

Based on an analysis of eDMR Data and permit limits, it was estimated that the point sources in the Beaver Run Watershed discharged a total of approximately 10.3 cubic meters per day on average, whereas the facilities in the Black Hole Creek Subwatershed contributed approximately 284.8 cubic meters per day.

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

Riparian buffer coverage was estimated via a GIS analysis. 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. The selection polygons are shown in Figures 18 and 19. 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 61% in the agricultural area of the impaired watershed versus 76% in the reference watershed.

An additional reduction credit was given to the reference watershed to account for the fact it had more riparian buffers than the impaired watershed. 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 watershed over the amount found in the impaired watershed, the length of NHD flowlines within the reference watershed was multiplied by the proportion of riparian pixels that were within the agricultural area selection polygon (see Figure 19) and then by the difference in the proportion of buffering between the agricultural area of the reference watershed versus that of the impaired watershed, 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 is 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.

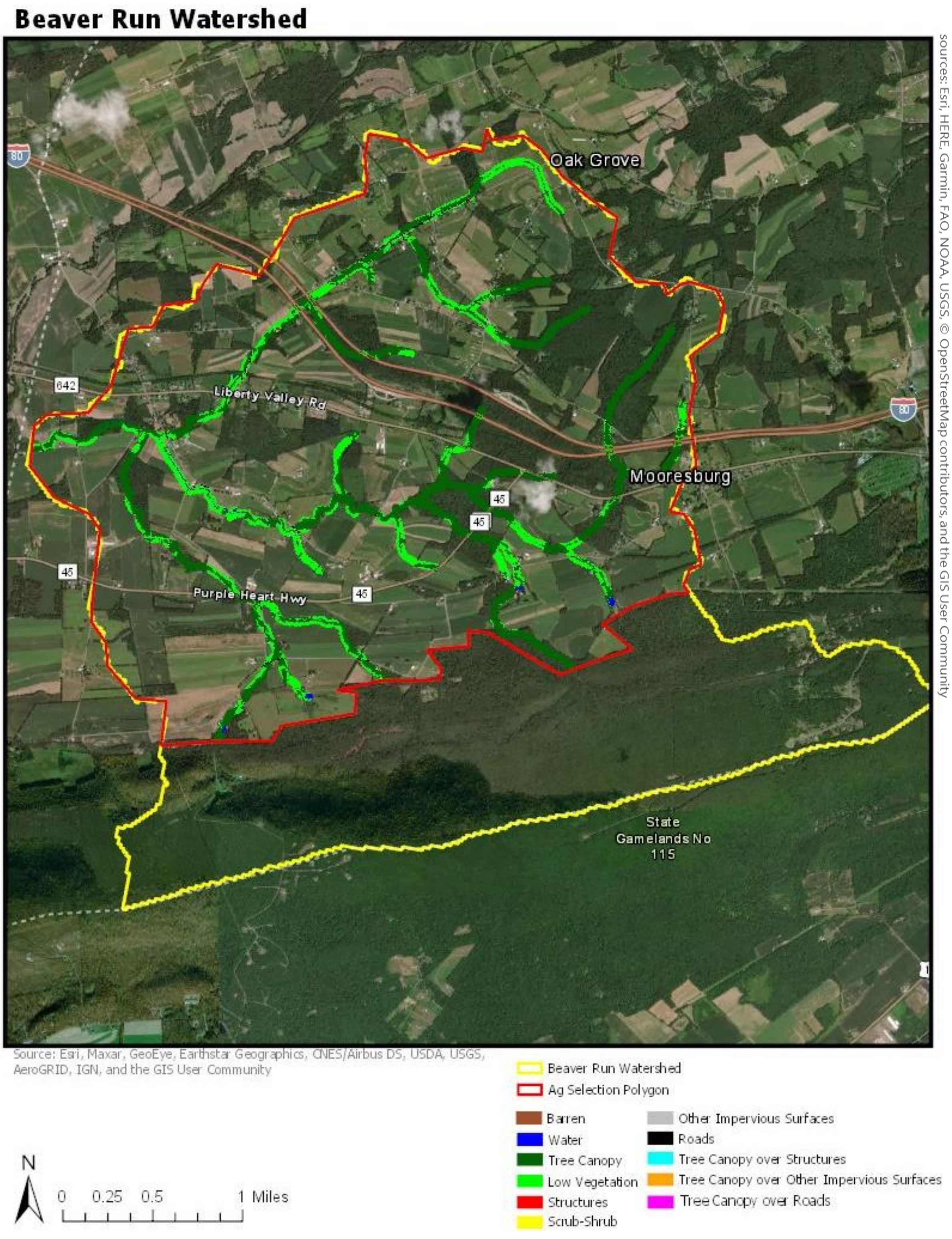

Figure 18. Riparian buffer analysis in the Beaver Run Watershed. A raster dataset of high-resolution land cover (University of Vermont Spatial Analysis Laboratory 2016) is shown within 100 feet (geodesic) of either side of NHD flowlines. The rate of riparian buffering within the agricultural selection polygons was estimated to be about 61%.

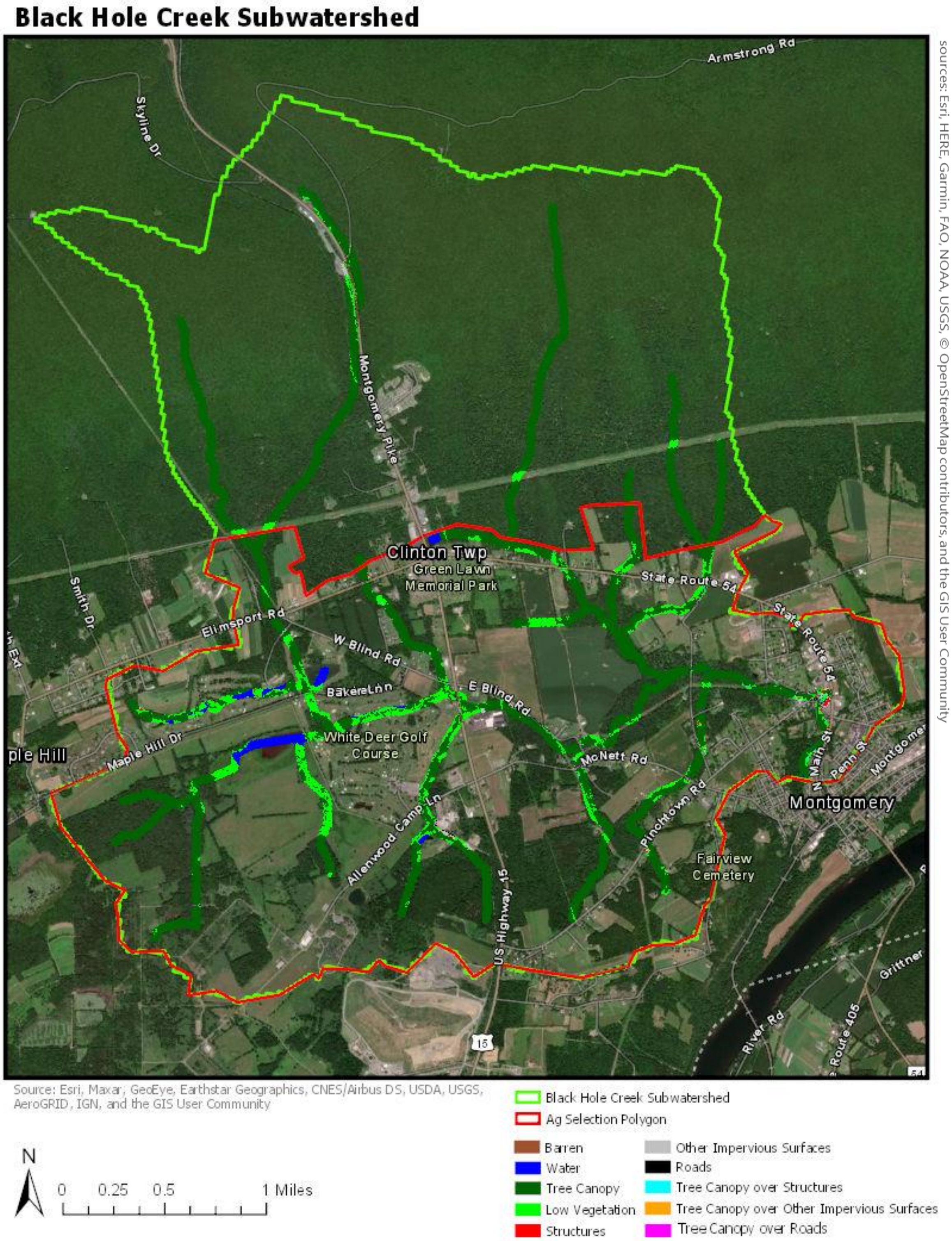

Figure 19. Riparian buffer analysis in the Black Hole Creek Subwatershed. A raster dataset of high-resolution land cover (University of Vermont Spatial Analysis Laboratory 2016) is shown within 100 feet (geodesic) of either side of NHD flowlines. The rate of riparian buffering within the agricultural selection polygons was estimated to be about 76%.

Calculation of the $TMDL_{Avg}$

The mean annual sediment loading rate for the unimpaired reference subwatershed (Black Hole Creek) was estimated to be 274 pounds per acre per year (Table 7). This was substantially lower than the estimated mean annual loading rate in the impaired Beaver Run Watershed (854 pounds per acre per year, Table 8). Thus, to achieve the loading rate of the unimpaired watershed, sediment loading in the Beaver Run Watershed should be reduced to 2,121,441 pounds per year or less (Table 9).

Table 7. Existing Annual Average Loading Values for the Black Hole Creek Subwatershed, Reference

Source	Area ac	Sediment lbs/yr	Unit Area Load, lbs/ac/yr
Hay/Pasture	1,238	654,267	528
Cropland	501	679,224	1,355
Forest and Shrub/Scrub	4,731	9,383	2
Wetlands	77	0	0
Grassland/Herbaceous (Open Land)	4	161	38
Bare Rock	26	0	0
Low Intensity Mixed Development	949	10,190	11
Medium Intensity Mixed Development	74	4,947	67
High Density Mixed Development	18	1,224	67
Streambank[1]		815,358	
Point Sources		551	
Additional Buffer Discount[2]		-90,753	
total	7,618	2,084,552	274

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

[2]Accounts for the amount of extra riparian buffering in the agricultural area of reference watershed versus the impaired watershed. For details on this calculation, see the "Hydrologic / Water Quality Modelling" section.

Table 8. Existing Annual Average Loading Values for the Beaver Run Watershed, Impaired			
Source	Area, ac	Sediment, lbs/yr	Unit Area Load, lb/ac/yr
Hay/Pasture	2,032	1,130,841	556
Cropland	1,946	4,717,253	2,424
Forest and Shrub/Scrub	2,988	7,368	2
Wetland	35	77	2
Grassland/Herbaceous (Open Land)	10	619	63
Bare Rock	2	1	1
Low Intensity Mixed Development	679	8,092	12
Medium Intensity Mixed Development	59	4,131	70
High Density Mixed Development	2	121	49
Streambank		755,347	
Point Sources		37	
total	7,753	6,623,887	854

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

Table 9. Calculation of an Annual Average TMDL Value for the Beaver Run Watershed			
Pollutant	Mean Loading Rate in Reference, lbs/ac/yr	Total Land Area in Impaired Watershed, ac	Target $TMDL_{Avg}$ Value, lbs/yr
Sediment	274	7,753	2,121,441

Calculation of Load Allocations

In the TMDL equation, the load allocation (LA) is the load derived from nonpoint sources. The LA is further divided into the adjusted loads allocation (ALA), which is comprised of the nonpoint 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:

LA = ALA + LNR

Considering that the total maximum daily load (TMDL) is the sum of the margin of safety (MOS), the wasteload allocation (WLA), and the load allocation (LA):

TMDL = MOS + WLA + LA,

then the load allocation is calculated as follows:

LA = TMDL - MOS - WLA

Thus, before calculating the load allocation, the margin of safety and wasteload allocation must be defined.

Margin of Safety

The margin of safety (MOS) is a portion of pollutant loading that is reserved to account for uncertainties. Reserving a portion of the load as a safety factor requires further load reductions from the ALA to achieve the TMDL. For this analysis, the MOS_{Avg} was explicitly designated as ten-percent of the $TMDL_{Avg}$ based on professional judgment. Thus:

2,121,441 lbs/yr $TMDL_{Avg}$ * 0.1 = 212,144 lbs/yr MOS_{Avg}

Wasteload Allocation

The wasteload allocation (WLA) is the pollutant loading assigned to existing permitted point sources as well as future point sources. The wasteload includes a bulk reserve, which is a minor allowance for insignificant dischargers and new sources. The bulk reserve was defined as one percent of the targeted

TMDL. There were four very minor National Pollutant Discharge Elimination System (NPDES) point source discharges with numeric limits for sediment (Table 4). Two of them were for wastewater treatment plants serving single family residences, and since these were negligible sediment sources in the watershed, they will simply be covered under the bulk reserve. The wastewater treatment plants serving the two highway rest stops will be given individual wasteload allocations based on their current effluent concentration limits in their permits and their design flows (213 lbs/yr each, see Table 4).

Thus, the WLA was calculated as:

2,121,441 lbs/yr $TMDL_{Avg}$ * 0.01 = 21,214 lbs/yr bulk $reserve_{Avg}$ + 426 lb/yr permitted loads = 21,640 lbs/yr WLA_{Avg}

Load Allocation

Now that the margin of safety and wasteload allocation have been defined, the load allocation (LA) is calculated as:

2,121,441 lbs/yr $TMDL_{Avg}$ – (212,144 lbs/yr MOS_{Avg} + 21,640 lbs/yr WLA_{Avg}) = 1,887,656 lbs/yr LA_{Avg}

Loads Not Reduced and Adjusted Load Allocation

Since the impairments addressed by this TMDL were for sedimentation due to agriculture, sediment contributions from forests, wetlands, non-agricultural herbaceous/grasslands, bare rock and developed lands within the Beaver Run Watershed were considered loads not reduced (LNR). LNR_{Avg} was calculated to be 20,409 lbs/yr (Table 10).

The LNR is subtracted from the LA to determine the ALA:

1,887,656 lbs/yr LA_{Avg} – 20,409 lbs/yr LNR_{Avg} = 1,867,247 lbs/yr ALA_{Avg}

Table 10. Average Annual Load Allocation, Loads Not Reduced and Adjusted Load Allocation

	Sediment, lbs/yr
Load Allocation (LA_{Avg})	**1,887,656**
Loads Not Reduced (LNR_{Avg}):	**20,409**
Forest	7,368
Wetlands	77
Open Land	619

Bare Rock	1
Low Intensity Mixed Development	8,092
Medium Intensity Mixed Development	4,131
High Density Mixed Development	121
Adjusted Load Allocation (ALA_{Avg})	**1,867,247**

Note, the ALA is comprised of the anthropogenic sediment sources targeted for reduction: croplands, hay/pasturelands and streambanks (assuming an elevated erosion rate). The LNR is comprised of both natural and anthropogenic sediment sources. While anthropogenic, developed lands were considered a negligible sediment source in this watershed and thus not targeted for reduction. Forests, wetlands, open lands (non-developed, non-agricultural grass/herbaceous lands) were considered natural sediment sources. Bare rock may or may not be of natural origin, but either way it was considered a negligible sediment source in the watershed.

Calculation of Sediment Load Reductions

To calculate load reductions by source, the ALA was further analyzed using the Equal Marginal Percent Reduction (EMPR) allocation method described in Appendix D. Although this Beaver Run TMDL was developed to address impairments caused by agricultural activities, streambanks were also significant contributors to the sediment load in the watershed, and streambank erosion rates are influenced by agricultural activities. Thus, streambanks were included in the ALA and targeted for reduction.

In this evaluation croplands exceeded the allocable load by itself. Thus, it received an 80% reduction whereas hay/pasture lands and streambanks each received a 50% reduction (Table 11).

Table 11. Average Annual Sediment Load Allocations for Source Sectors in the Beaver Run Watershed

		Load Allocation	Current Load	Reduction Goal
Land Use	Acres	lbs/yr	lbs/yr	
CROPLAND	1,946	928,912	4,717,253	80%
HAY/PASTURE	2,032	562,567	1,130,841	50%
STREAMBANK		375,768	755,347	50%
AGGREGATE		1,867,247	6,603,441	72%

Calculation of a Daily Maximum "$TMDL_{Max}$" Value

When choosing the best timescale for expressing pollutant loading limits for siltation, two major factors must be considered:

1) Sediment loading is driven by storm events, and loads vary greatly even under natural conditions.
2) Siltation pollution typically harms aquatic communities through habitat degradation as a result of chronically excessive loading.

Considering then that siltation pollution has more to do with chronic degradation rather than acutely toxic loads/concentrations, pollution reduction goals based on average annual conditions are much more relevant than daily maximum values. Nevertheless, a truer "Total Maximum Daily Load" ($TMDL_{Max}$) is also calculated in the following.

Model My Watershed currently does not report daily loading rates, but its predecessor program, "MapShed" does. Thus, for the calculation of a $TMDL_{Max}$ value, modelling was initially conducted in Model My Watershed, and the "Export GMS" feature was used to provide an input data file that was run in MapShed. The daily output was opened in Microsoft Excel (Version 2002), and current "maximum" daily loads were calculated as the 99th percentiles (using the percentile.exc function) of estimated daily sediment loads in both the Beaver Run (impaired) and Black hole Creek (reference) Watersheds. The first year of data was excluded to account for the time it takes for the model calculations to become reliable. The 99th percentile was chosen because 1) sediment loading increases with the size of storm events, so, as long as there could be an even larger flood, a true upper limit to sediment loading cannot be defined and 2) 99% of the time attainment of water quality criteria is prescribed for other types of pollutants per PA regulations (see PA Code Title 25, Chapter 96, Section 96.3(e)).

As with the average loading values reported previously (see the Hydrologic / Water Quality Modelling section), a correction was made for the additional amount of existing riparian buffers in the reference watershed versus the impaired watershed. This was calculated simply by reducing the 99th percentile loading rate for the reference watershed by the same reduction proportion that was calculated previously for the average loading rate.

Then, similarly to the $TMDL_{Avg}$ value reported in Table 9, $TMDL_{Max}$ was calculated as the 99th percentile daily load of the reference watershed, divided by the acres of the reference watershed, and then multiplied by the acres of the impaired watershed. Thus, the $TMDL_{Max}$ loading rate was calculated as 72,499 pounds per day (Table 12), which would be a 75% reduction from Beaver Run's current 99th percentile daily loading rate of 291,593 pounds per day.

Table 12. Calculation of $TMDL_{Max}$ for the Beaver Run Watershed

Pollutant	99th Percentile Loading Rate in Reference, lbs/ac/d	Total Land Area in Impaired Watershed, ac	Target $TMDL_{Max}$ Value, lbs/d
Sediment	9.4	7,753	72,499

Also, in accordance with the previous "Calculation of Load Allocations" section, the WLA_{Max} would consist of a bulk reserve defined as 1% of the $TMDL_{Max}$ plus the wasteload allocations for the two wastewater treatment plants serving the highway rest areas (1.2 lbs/d each, see Table 4). Note that the wastewater treatment plants serving the single-family residences will be covered under the bulk reserve. The MOS_{Max} was defined as 10% of the $TMDL_{Max}$. The LA_{Max} was then calculated as the amount remaining after subtracting the WLA_{Max} and the MOS_{Max} from the $TMDL_{Max}$. See Table 13 for a summary of these $TMDL_{Max}$ variables.

Table 13. 99th Percentile of Daily Loading TMDL ($TMDL_{Max}$) Variables for the Beaver Run Watershed

lbs/d:				
Pollutant	$TMDL_{Max}$	MOS_{Max}	WLA_{Max}	LA_{Max}
Sediment	72,499	7,250	727	64,522

Mapshed did not break down daily loads by land use type. Thus, the daily maximum load allocation variables were calculated assuming the same distribution as occurred for the annual average load allocation variables. For instance, if the streambanks allocation was 20% of LA_{Avg} it was assumed that it was also 20% of LA_{Max}. While the distribution of sources likely changes with varying flow levels, this might be an acceptable assumption considering that the largest flow events may control the bulk of annual sediment loading (see Sloto et al. 2012). See Table 14 for a summary of the LA_{Max} variables.

Table 14. Allocation of the 99th Percentile Daily Load Allocation (LA_{Max}) for the Beaver Run Watershed

	Annual Average (lbs/yr)	Proportion of Load Allocation	Max Daily (lbs/d)
Load Allocation	1,887,656		64,522
Loads Not Reduced	20,409	0.01	698
Adjusted Loads Allocation	1,867,247	0.99	63,824
Croplands	928,912	0.49	31,751
Hay/Pasturelands	562,567	0.30	19,229
Streambanks	375,768	0.20	12,844

Because the modelling program did not break down daily loadings by land use types, the load allocations for $TMDL_{Max}$ were calculated by assuming the same distribution as occurred for the LA_{Avg} variables. For instance, if the streambanks allocation was 20% of LA_{Avg} it was assumed that it was also 20% of LA_{Max}.

Because sediment loading varies so greatly with discharge, the $TMDL_{Max}$ value would probably only be relevant on a handful of days each year with the highest flow conditions. And, while these times are especially important to overall annual sediment loading (see-Sloto and Olson 2011, Sloto et al. 2012), it is cautioned that reliance solely on a $TMDL_{Max}$ value may not be protective of the Beaver Run Watershed because chronic excessive sediment inputs occurring at lower discharge levels may be ignored. Take for instance an extreme scenario where the $TMDL_{Max}$ was met every day but never exceeded. In this case, the annual sediment loading in the Beaver Run Watershed would skyrocket to 26,462,123 lbs/yr, which is approximately four-times the current annual average. The $TMDL_{Avg}$ value on the other hand is sensitive to typical conditions, extreme events, and long-term effects, and thus is the most relevant of the two TMDL targets for achieving restoration in the Beaver Run Watershed. Therefore, BMP implementation would ultimately be deemed adequate if the prescribed annual average reductions were satisfied.

Consideration of Critical Conditions and Seasonal Variations

According to Model My Watershed's technical documentation (see Stroud Water Research Center 2019), Model My Watershed uses a "continuous simulation model that uses daily time steps for weather data and water balance. Monthly calculations are made for sediment and nutrient loads based on the daily water balance accumulated to monthly values." The source of the weather data (precipitation and temperature) was a dataset compiled by USEPA ranging from 1961-1990. Therefore, variable flow conditions and seasonal changes are inherently accounted for in the loading calculations. Furthermore, this document calculates both annual average and 99th percentile daily TMDL values. See the discussion of the relevance of these values in the previous section. Seeking to attain both of these values will be protective under both long-term average and extreme flow event conditions.

Recommendations

This document proposes a 68% reduction in annual average sediment loading for the Beaver Run Watershed. To achieve this goal while maintaining a margin of safety and minor allowance for point sources, annual average sediment loading should be reduced by 80% from croplands, and 50% each from hay/pasture lands and streambanks. Similarly, the 99th percentile daily sediment loading should be reduced by 75%. Reductions in stream sediment loading due to agricultural activities can be made through the implementation of required Erosion and Sediment Control Plans (Pennsylvania Clean Streams Law, Title 25 Environmental Protection, Chapter 102.4, see also Appendix E) and through the use of BMPs such as conservation tillage, cover crops, vegetated filter strips, rotational grazing, livestock exclusion fencing, riparian buffers, etc.

It was obvious during the site visit that there has been recent BMP implementation (Figure 7), and thus progress towards the sizeable reductions prescribed herein has already being made. Since the impairment decision for the Beaver Run Watershed dates back to 1997, the landcover GIS layer used for determining "current" sediment loading dates back to 2011, and that most of these recent BMPs have not been explicitly accounted for in the modelling, it would be reasonable to credit recent (within the last decade) BMPs if a watershed implementation plan is to be developed in response to this TMDL.

Use of forested riparian buffers is widely recognized as one of the best ways to promote stream health. Riparian buffers protect streams from sedimentation and nutrient impairments by filtering these pollutants from runoff and floodwaters and by protecting streambanks from erosion. Furthermore, riparian buffers are also beneficial for many other reasons beyond just protecting from sedimentation and nutrients. For instance, riparian buffers may: filter out other pollutants such as pesticides; provide habitat and nutrition for aquatic, semi-aquatic and terrestrial organisms; and moderate stream temperature. Thus, use of forested riparian buffers should be encouraged wherever possible.

Development of a more detailed watershed implementation plan is recommended. Further ground truthing should be performed to assess both the extent of existing BMPs and to determine the most cost effective and environmentally protective combination of BMPs required for meeting the prescribed sediment reductions. Key personnel from the regional DEP office, the County Conservation District, Susquehanna River Basin Commission (SRBC) and other state and local agencies and/or watershed groups should be involved in developing a restoration strategy. There are a number of possible funding sources for agricultural BMPs and stream restoration projects, including: The Federal Nonpoint Source Management Program (§ 319 of the Clean Water Act), PA DEP's Growing Greener Grant Program, United States Department of Agriculture's Natural Resource Conservation Service funding, and National Fish and Wildlife Foundation Grants.

Public Participation

Public notice of a draft of this TMDL was published in the January 30th, 2021 issue of the Pennsylvania Bulletin to foster public comment. A 30-day period was provided for the submittal of comments. No public comments were received.

Citations

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Evans, B.M. and K.J. Corradini. 2016. Mapshed Version 1.5 Users Guide. Penn State Institutes of Energy and the Environment. The Pennsylvania State University. University Park, PA 16802

Hopkins, K.G., Ahmed, L., Metes, M.J., Claggett, P.R., Lamont, S., and Noe, G.B, 2020, Geomorphometry for Streams and Floodplains in the Chesapeake and Delaware Watersheds: U.S. Geological Survey data release, https://doi.org/10.5066/P9RQJPT1. GIS dataset downloaded at: https://www.sciencebase.gov/catalog/item/5cae39c3e4b0c3b00654cf57

Mapshed Version 1.5.1. Penn State Institutes of Energy and the Environment. The Pennsylvania State University. University Park, PA 16802

Multi-Resolution Land Characteristics Consortium. National Land Cover Database (NLCD 2016 and 2011). See https://www.mrlc.gov/data

Sloto, R. A. and L.E. Olson. 2011. Estimated Suspended -Sediment Loads and Yields in the French and Brandywine Creek Basins, Chester County, Pennsylvania, Water Years 2008-09. USGS Scientific Investigations Report 2011-5109. Available at https://pubs.usgs.gov/sir/2011/5109/support/sir2011-5109.pdf

Sloto, R.A., A.C. Gellis, and D.G. Galeone. 2012 Total Nitrogen and Suspended-Sediment Loads and Identification of Suspended-Sediment Sources in the Laurel Hill Creek Watershed, Somerset County, Pennsylvania, Water Years 2010-11. USGS Scientific Investigations Report 2012-5250. Available at https://pubs.usgs.gov/sir/2012/5250/support/sir2012-5250.pdf

Stroud Water Research Center (2020). Model My Watershed [Software]. Version 1.31.0 Available from https://wikiwatershed.org/ Technical Documentation available at: https://wikiwatershed.org/documentation/mmw-tech/

University of Vermont Spatial Analysis Laboratory. (2016). High-Resolution Land Cover, Commonwealth of Pennsylvania, Chesapeake Bay Watershed and Delaware River Basin, 2013. Available at: http://www.pasda.psu.edu/uci/DataSummary.aspx?dataset=3193

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 typically 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 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) are completed, the biologist are to determine the status of the stream segment. Decisions are to be based on the performance of the segment using a series of biological metrics. If the stream segment is classified as impaired, it was to be 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 Classification	NLCD Code	Hectares	%
Perennial Ice/Snow	12	0.0	0
Developed, Open Space	21	168.0	5
Developed, Low Intensity	22	107.0	3
Developed, Medium Intensity	23	24.0	1
Developed, High Intensity	24	1.0	0
Barren Land (Rock/Sand/Clay)	31	1.0	0
Deciduous Forest	41	685.0	22
Evergreen Forest	42	100.0	3
Mixed Forest	43	406.0	13
Shrub/Scrub	52	19.0	1
Grassland/Herbaceous	71	4.0	0
Pasture/Hay	81	823.0	26
Cultivated Crops	82	788.0	25
Woody Wetlands	90	12.0	0
Emergent Herbaceous Wetlands	95	2.0	0
Total		*3140.0*	*100*

Table B1. Land Cover based on NLCD 2011 for the Beaver Run Watershed. "Open Water" pixels were excluded from the analysis.

Land Classification	NLCD Code	Hectares	%
Developed, Open Space	21	312.5	10
Developed, Low Intensity	22	71.8	2
Developed, Medium Intensity	23	29.9	1
Developed, High Intensity	24	7.4	0
Barren Land	31	10.4	0
Deciduous Forest	41	1656.7	54
Evergreen Forest	42	18.8	1
Mixed Forest	43	239.9	8
Shrub/Scrub	52	0.7	0
Herbaceuous	71	1.7	0
Hay/Pasture	81	501.6	16
Cultivated Crops	82	203.1	7
Woody Wetlands	90	13.4	0
Emergent Herbaceuous Wetlands	95	17.7	1
Sum		*3085.4*	*100*

Table B2. Land Cover based on NLCD 2016 for the for the Black Hole Creek Subwatershed. "Open Water" pixels were excluded from the analysis.

Month	Stream Flow (cm)	Surface Runoff (cm)	Subsurface Flow (cm)	Point Src Flow (cm)	ET (cm)	Precip (cm)
Jan	5.86	1.1	4.77	0	0.33	7.15
Feb	6.51	1.36	5.15	0	0.5	7.31
Mar	7.36	0.72	6.64	0	1.81	8.36
Apr	6.04	0.21	5.83	0	4.58	8.41
May	4.09	0.19	3.9	0	8.9	10.51
Jun	3.22	0.98	2.24	0	12.02	10.58
Jul	1.14	0.23	0.91	0	11.3	9.86
Aug	0.41	0.18	0.23	0	8.97	8.64
Sep	1	0.89	0.11	0	5.81	9.04
Oct	1.39	0.7	0.68	0	3.64	8.06
Nov	2.52	0.58	1.94	0	1.76	9.38
Dec	5.36	0.81	4.55	0	0.7	8.11
Total	44.9	7.95	36.95	0	60.32	105.41

Table B3. "Model My Watershed" Hydrology Outputs for the Beaver Run Watershed.

Month	Stream Flow (cm)	Surface Runoff (cm)	Subsurface Flow (cm)	Point Src Flow (cm)	ET (cm)	Precip (cm)
Jan	5.89	0.96	4.91	0.01	0.34	7.15
Feb	6.56	1.19	5.36	0.01	0.52	7.31
Mar	7.45	0.6	6.84	0.01	1.85	8.36
Apr	6.03	0.16	5.85	0.01	4.56	8.41
May	3.99	0.14	3.84	0.01	8.71	10.51
Jun	3.15	0.92	2.22	0.01	12.04	10.58
Jul	1.07	0.19	0.87	0.01	11.34	9.86
Aug	0.33	0.13	0.18	0.01	9.11	8.64
Sep	0.91	0.8	0.1	0.01	5.93	9.04
Oct	1.39	0.62	0.76	0.01	3.6	8.06
Nov	2.63	0.47	2.14	0.01	1.76	9.38
Dec	5.51	0.7	4.8	0.01	0.69	8.11
Total	44.91	6.88	37.87	0.12	60.45	105.41

Table B4. "Model My Watershed" Hydrology Outputs for the Black Hole Creek Subwatershed.

Sources	Sediment (kg)
Hay/Pasture	512,852.90
Cropland	2,139,343.70
Wooded Areas	3,341.70
Wetlands	35
Open Land	280.5
Barren Areas	0.6
Low-Density Mixed	1,428.50
Medium-Density Mixed	1,873.50
High-Density Mixed	54.9
Low-Density Open Space	2,241.30
Farm Animals	0
Stream Bank Erosion	342,561.00
Subsurface Flow	0
Point Sources	0
Septic Systems	0

Table B5. Model My Watershed outputs for sediment in the Beaver Run Watershed.

Sources	Sediment (kg)
Hay/Pasture	296,719.90
Cropland	308,037.90
Wooded Areas	4,255.20
Wetlands	0
Open Land	72.9
Barren Areas	0
Low-Density Mixed	863.4
Medium-Density Mixed	2,243.50
High-Density Mixed	555.3
Low-Density Open Space	3,757.80
Farm Animals	0
Stream Bank Erosion	369,777.00
Subsurface Flow	0
Point Sources	0
Septic Systems	0

Table B6. Model My Watershed Outputs for Sediment in the Black Hole Creek Subwatershed.

Appendix C: Stream Segments in the Beaver Run Watershed with Siltation Impairments for Aquatic Life Use

Stream Name:	Impairment Source:	Impairment Cause:	COMID:	Miles:
Unnamed Tributary to Beaver Run	Agriculture	Siltation	66919993	0.26
Unnamed Tributary to Beaver Run	Agriculture	Siltation	66919997	0.02
Beaver Run	Agriculture	Siltation	66919963	0.46
Unnamed Tributary to Beaver Run	Agriculture	Siltation	66919891	0.12
Unnamed Tributary to Beaver Run	Agriculture	Siltation	66919971	0.40
Unnamed Tributary to Beaver Run	Agriculture	Siltation	66919811	0.64
Unnamed Tributary to Beaver Run	Agriculture	Siltation	66920017	1.48
Unnamed Tributary to Beaver Run	Agriculture	Siltation	66919867	0.56
Unnamed Tributary to Beaver Run	Agriculture	Siltation	66919909	0.56
Beaver Run	Agriculture	Siltation	66919919	0.02
Beaver Run	Agriculture	Siltation	66919913	0.83
Unnamed Tributary to Beaver Run	Agriculture	Siltation	66919903	0.42
Beaver Run	Agriculture	Siltation	66919925	0.40
Beaver Run	Agriculture	Siltation	66919965	1.16
Unnamed Tributary to Beaver Run	Agriculture	Siltation	66919973	0.43
Unnamed Tributary to Beaver Run	Agriculture	Siltation	66919923	0.67
Unnamed Tributary to Beaver Run	Agriculture	Siltation	66919975	0.02
Beaver Run	Agriculture	Siltation	66919881	0.10
Beaver Run	Agriculture	Siltation	66919911	0.20
Unnamed Tributary to Beaver Run	Agriculture	Siltation	66919865	0.52
Unnamed Tributary to Beaver Run	Agriculture	Siltation	66919805	0.95
Unnamed Tributary to Beaver Run	Agriculture	Siltation	66919869	0.22

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 > ALA?	If > ALA, reduce to ALA	How much does sum exceed ALA?	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	4,717,253	yes	1,867,247		0.50	938,335	928,912	0.80
Hay/Pasture	1,130,841	no	1,130,841	1,886,188	0.30	568,274	562,567	0.50
Streambank	755,347	no	755,347		0.20	379,579	375,768	0.50
sum	**6,603,441**		**3,753,435**		**1.00**	**1,886,188**	**1,867,247**	**0.72**

Table D1. Equal Marginal Percent Reduction calculations for the Beaver Run Watershed.

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.

Pennsylvania Clean Streams Law Requirements, Agricultural Operations

Pennsylvania farms 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: Comment and Response

This section is reserved for public comments and responses. No public comments were received.