South Fork Tenmile Creek Watershed Assessment

Prepared By

Greene County Conservation District

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Contents

Executive Summary

This assessment has described the South Fork Tenmile Creek Watershed, identified primary causes of water quality degradation, described activities likely to improve water quality and developed novel tools to implement these improvements. Stormwater runoff, NPS pollution from agriculture and other development, and discharges from energy development and other industry are the principle contributors to water quality degradation within the watershed.

Challenges in overcoming these causes of water quality degradation include funding, public interest and landowner investment. Funding sources for watershed restoration and protection projects are limited and competitive. The watershed suffers from a lack of committed watershed-based organizations to undertake projects. Individual Landowners are often unable or unwilling to alter traditional practices to include BMP.

In light of these challenges, the following should be considered priority activities within the South Fork Tenmile Creek Watershed:

- Using the precision conservation approach in developing and implementing projects to reduce NPS pollution
- Promoting improved practices and BMP adoption among landowners, particularly in areas where agriculture is a dominant land use
- Developing projects that stabilize existing eroded streambanks and protect at-risk streambanks by promoting intact streamside vegetation
- Building closer relationships with existing watershed-based organizations and undertaking outreach to foster interest in formation of additional watershed-based organizations
- Working with landowners, municipalities and other stakeholder groups to improve stormwater management practices, particularly in areas where development has led to a preponderance of impervious surface
- Monitoring areas where industrial impairments are probable, such as areas of industrial or energy extraction activities, and where necessary developing projects to treat polluted discharges
- Seeking funding to implement projects and overcome challenges to landowner adoption of BMP through cost-share programs. Whether they be sought through government programs, private foundations and other sources, these funds are imperative to improving water quality in the South Fork Tenmile Creek Watershed

1. Introduction

1.1 Watershed Description

Hydrology

The South Fork Tenmile Creek Watershed (HUC 0502000503) is located in North-Central Greene County, and drains a land area of 514.6 square miles (mi^2). It is the largest watershed in Greene County and includes 489 miles of stream. The South Fork Tenmile Creek is formed by the convergence of Gray's Fork and Claylick Run (-80.34106, 39.89521) near the community of Rutan. It is a fifth order, low gradient stream with seven major- and numerous minor-tributaries. The South Fork meanders nearly 32 miles northeast through Rogersville, Waynesburg, Mather, and Jefferson until it reaches Clarksville where it empties into the main stem of Tenmile Creek (-80.04004, 39.97402) and ultimately to the Lower Monongahela River.

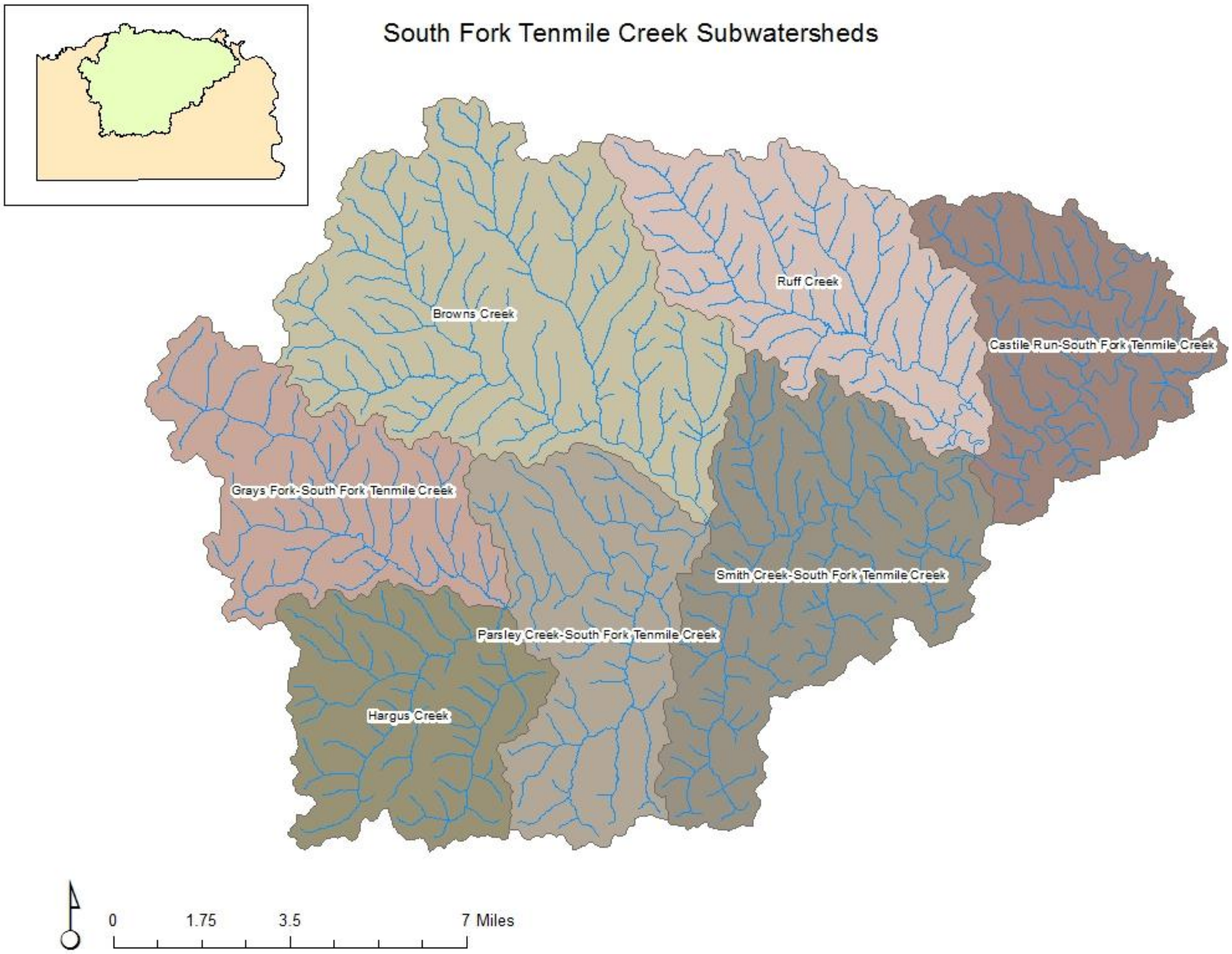
The United States Geological Survey maintains a gaging station on the South Fork near the town of Jefferson that has been operational since 1931 (Station # 03073000; -80.08944, 39.92305). This station has collected discharge and temperature data for nearly this entire period. In addition to this, the USGS has sporadically collected water quality data for this station as early as 1953 and has more systematically collected data since 2011. Based on this long-term dataset, monthly mean discharge ranges from a low of 50 ft^3/s to a high of 450 ft^3/s with distinct seasonal variation. Mean discharge rates begin to rise in the autumn and winter, peak in the spring and then decrease during the late spring and summer (USGS 2015).

Average annual precipitation for the watershed varies along a Latitudinal gradient and ranges from 40 inches per year (in/yr) in the southern portion of the watershed to 43 in/yr in the northern portions of the watershed. Mean monthly precipitation measured in Waynesburg from 1981 through 2012 shows seasonal variation. Precipitation means rise through the autumn and winter, peak in May and then decrease through the spring and summer months reaching its lowest in October (NOAA, 2015).

Table 1.1: South Fork Subwatersheds

Subwatershed Name	***Hydrologic Unit Code (HUC)***
Hargus Creek	50200050301
Grays Fork – South Fork Tenmile Creek	50200050302
Pursley Creek– South Fork Tenmile Creek	50200050303
Browns Creek	50200050304
Smith Creek– South Fork Tenmile Creek	50200050305
Ruff Creek	50200050306
Castile Run– South Fork Tenmile Creek	50200050307

The South Fork Tenmile Creek Watershed is divided into seven sub-watersheds defined by its major tributaries (See Table 1.1). Although similar to one another, subtle differences in geography and land use make each subwatershed distinct. Likewise, distinct are the sources of water quality impairment affecting each subwatershed and for this reason, each will be treated independently in subsequent sections of this assessment.



Geology and soils

The South Fork Tenmile Creek Watershed is situated within the Central Allegheny Plateau (Major Land Resource Area 126) and exhibits the hilly physiography that is characteristic of this region (USDA, NRCS, 2006). Narrow valleys with steep side slopes and rounded ridge tops predominate within the watershed and result in a dendritic drainage pattern. Elevations within the watershed range from 285 meters (m) – 438 m and slopes over 25% are not uncommon.

Dormont-Culleoka and Dormont silt loams are the dominant soil associations within the South Fork; together comprising 75% of the watershed. These associations are known for rapid runoff and high susceptibility to erosion. Hills with benches and slips are common landforms with these associations. Slope, a seasonal high-water table, and the depth to bedrock limit the suitability of these associations for development. These soil associations are most suitable for woodland although less sloping areas are suitable for use as pasture and crop cultivation so long as best management practices are employed to reduce erosion (Seibert et. al, 1979).

Land Cover

Land cover within a watershed is known to have major implications for water quality within that watershed. A large body of research has been completed defining both the relationship between land cover and stream health, as well as attempting to identify thresholds of land cover conversion that result in stream impairment. Much of this research focusses on stormwater runoff and its relation to land cover alteration and increases in impervious surfaces. Impervious surfaces are those that either do not allow infiltration of stormwater or that have dramatically reduced capacity for infiltration and include paved roads or parking areas, rooftops of structures and areas where land use has resulted in highly compacted soils.

Like most of Greene County, this watershed is largely forested. Deciduous forest makes up 68% of the watershed's land cover. Forested land covers offer the greatest reductions in stormwater runoff. Well-developed tree canopy and understory vegetation reduce overall volumes of stormwater runoff and delay its effect on streams through a number of processes including interception, root uptake and evaporation/transpiration. These land covers also provide some natural filtration of pollutants that might be carried by stormwater runoff. What portions of the watershed that have been converted to other land covers are predominantly agricultural. Much of the watershed is made up of smaller rural communities. Urban development is extremely limited and concentrated near the town of Waynesburg and interstate highway access.

Agriculture is a major land use in the South Fork and accounts for 20.7% of the watershed's land cover. Developed land covers account for only 9.5% of the overall watershed area and are located in the easternmost sub-watersheds. Land use conversion from forested land covers to agricultural and developed land covers reduces perviousness, or the ability of a surface to allow water to pass through it, and eliminates the beneficial effects of forest vegetation. In addition to this, agricultural activities compact soils and reduce the capacity for stormwater infiltration. Urban and industrial development bring structures and pavement that eliminates stormwater infiltration altogether. The results of these land use changes are higher volumes of stormwater runoff that affect streams very quickly during precipitation events. These higher peak flows increase flood risk and provide greater sheer strength that accelerates streambank erosion. In addition to this, these activities increase the risk of Thermal and Non-Point Source Pollutants, including sediment, agricultural waste and urban pollutants entering streams.

Equally important to the amounts of land cover alteration taking place in a watershed is the location of that alteration in relation to streams. Well-developed riparian vegetation mitigates the effects of stormwater runoff on streams through several processes. Strong plant roots stabilize banks and hold soil in place. Above-ground vegetation reduces peak and overall discharge by slowing stormwater flow and allowing for more infiltration. Additionally, these areas provide nutrients, thermal protection, and habitat diversity to streams that benefit aquatic life.

Much of the development in the South Fork Tenmile Creek Watershed is situated adjacent to streams. Roads within this watershed range from simple dirt and gravel roads to large paved roads and interstate highways. Whatever their construction, the majority of these roads are directly adjacent to and follow the course of streams. Farms, homesteads and other development are likewise inordinately situated directly adjacent to streams. These alterations to naturally occurring land covers are perhaps more important because the Riparian vegetation they replaced represented the first line of defense of the streams they neighbor. Wholesale elimination of riparian vegetation related to land use change increases susceptibility of stream channels to erosion and sedimentation through reduced channel stability and increased peak discharges. It also eliminates the additional benefits for aquatic life.

Demography

The South Fork Tenmile Creek Watershed includes portions of 14 townships and boroughs (See Table 1.2). United States Census tracts 9702 – 9707 contain the South Fork Tenmile Creek Watershed. The 2005 – 2009 American Community Survey estimated the population of these tracts to be 28,049 people who are predominantly Caucasian. Approximately 75% of sampled residents in this area reside in rural housing. This underscores the limited spatial extent of urban development within the watershed.

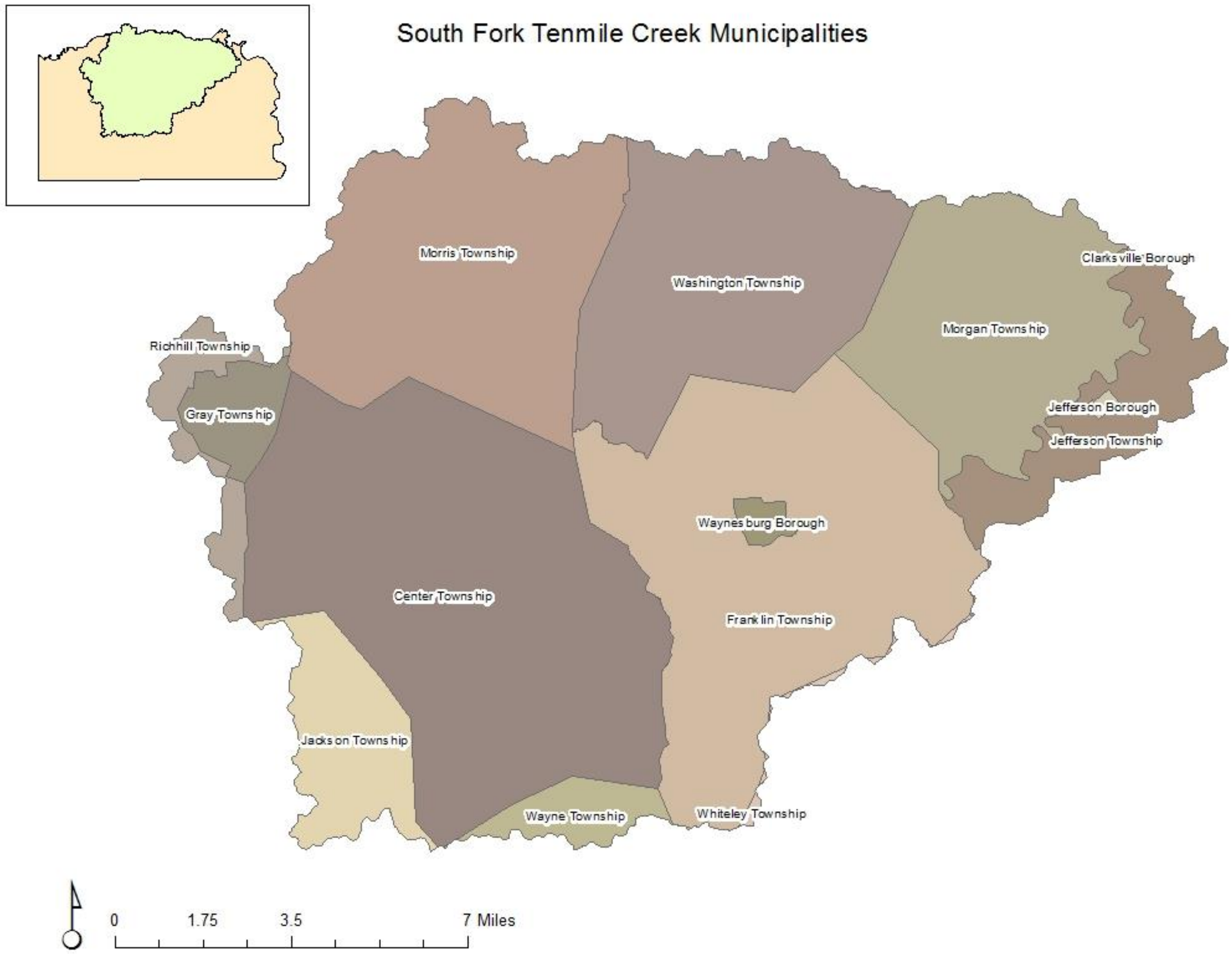
Table 1.2: Municipalities making up the South Fork Tenmile Creek Watershed

Municipality	***Area of watershed (km^2)***
Morgan Township	22
Jefferson Township	9
Whiteley Township	<1
Clarksville Borough	<1
Morris Township	31
Richhill Township	4
Wayne Township	3
Washington Township	27
Gray Township	3
Jackson Township	8
Center Township	49
Jefferson Borough	<1
Franklin Township	40
Waynesburg Borough	<1

Approximately 84% of the population 25 years and over have attained high school graduation. This is comparable to the state rate of high school graduation attainment of 88.7%. There is greater disparity, however, when higher education rates are considered. Approximately 15% of the population 25 years and over have attained a bachelor's degree or higher. This is much lower than the state average of 27.5%.

Median household income across these areas is $39,578, which is well below the state average of $52,548. The average percentage of people living below poverty level for this area is 16% with some areas being as high as 22.5%. The state average for Pennsylvania is 13.3%. Additionally, approximately 1,100 households across this area receive government assistance in the form of food stamps.

Approximately 40% of the South Fork is classified as an Environmental Justice (EJ) area. EJ areas are census tracts where are large proportion of the population (>20%) live in poverty and/or a large proportion of the population (>30%) are identified as minority. These areas are identified so that the people living here receive fair and equal involvement in the process of environmental conservation and protection. There are two areas of the South Fork that are EJ areas. The first are the western areas in the headwaters of the watershed. The second are the areas surrounding Waynesburg and urban areas in the eastern portion of the watershed.



1.2 Water Quality

Regulation

The South Fork Tenmile Creek Watershed is divided into two sections to facilitate management under Title 25; Chapter 93 of the Pennsylvania Code. Streams in the lower section, which is defined as the area downstream of the mouth of Brown's Creek to the mouth of the South Fork itself, are designated as a Warm Water Fishery. This designation means that these water bodies are suitable for the "…(M)aintenance and propagation of fish species and additional flora and fauna which are indigenous to a warm water habitat." These include game species like smallmouth bass, rock bass, walleye, sauger, bluegill, green sunfish, yellow bullhead, and common carp.

Streams in the upper section of the watershed, defined as the headwaters of the South Fork to the mouth of Browns Creek (-80.20555, 39.89745), are designated as a High Quality Warm Water Fishery. The High Quality designation means that these water bodies have been shown to exceed the water quality requirements necessary for classification as a warm water fishery and/or these water bodies support a high quality aquatic community.

Additionally, several small, unnamed tributaries in the Hargus Creek sub-watershed have been designated as Exceptional Value waters. This means that these streams have been given special protection because they are, "…(O)f exceptional ecological importance." In addition to this, local advocacy groups are currently petitioning the Pennsylvania Department of Environmental Protection (DEP) to change the status of certain streams in the Browns Creek Watershed to Exceptional Value as well.

Despite these pockets of exceptional water quality, much of the South Fork Tenmile Creek Watershed is not so pristine. Fish and macroinvertebrate communities in the South Fork are dominated by species which are intermediate in stress tolerance, while in certain areas, pollution intolerant species are completely absent. (Kimmel and Argent, 2012). As part of their ongoing assessment of the Commonwealth's waters, Pennsylvania DEP has identified several streams in the South Fork that are not attaining their designated use of supporting aquatic life as described above (See Table 1.3).

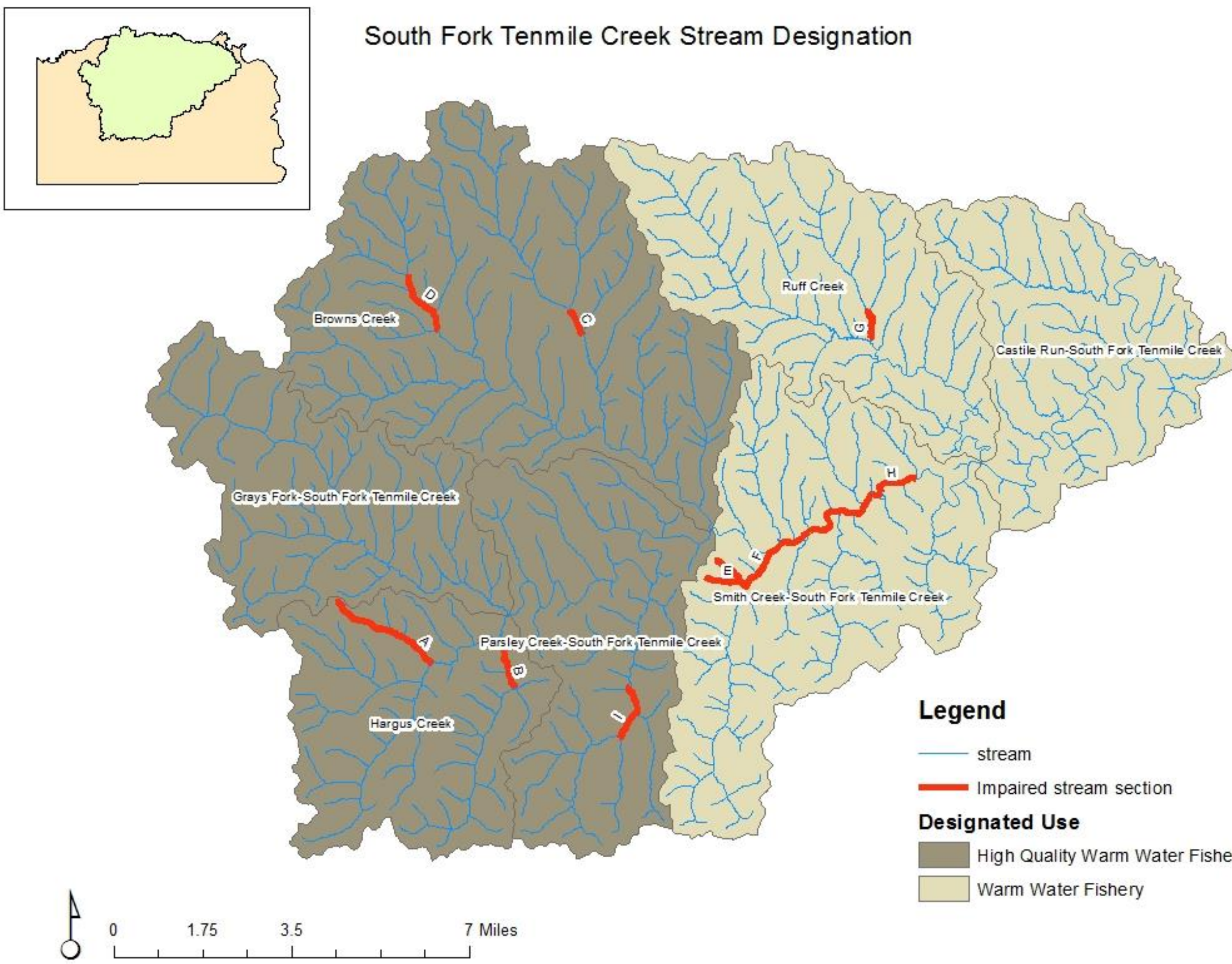


Table 1.3: Non-attaining Stream segment	
Impaired Stream segment	***Source/Cause of impairment***
Hoge Run (A) – Entire Length	Agriculture – Siltation
Hargus Creek (B) – Upstream of McCourtey, extending approximately 1.6 Km	Agriculture – Siltation
Bates Fork (C) – Upstream of Dille Run, extending to the Mouth of Fonner Run	Agriculture – Siltation
Browns Creek (D) – Upstream of Unnamed Tributary near Nineveh, extending upstream approximately 2 Km	Bank Modifications - Siltation; Road Runoff - Siltation; Removal of Vegetation - Cause Unknown; Channelization - Flow Alterations
Unnamed Tributaries to Smith Creek below Emerald Mine Complex (E) – Entire Length	Subsurface Mining - Metals; Subsurface Mining - Oil and Grease; Abandoned Mine Drainage - Metals; Abandoned Mine Drainage - Oil and Grease; Land Disposal - Metals; Land Disposal - Oil and Grease
Smith Creek (F) – Upstream of the mouth of Smith Creek to Unnamed Tributary below Emerald Mine complex	Abandoned Mine Drainage - Metals; Abandoned Mine Drainage - Oil and Grease; Land Disposal - Oil and Grease; Land Disposal - Metals; Subsurface Mining - Metals
Craynes Run (G) – Upstream of the mouth of Craynes Run extending up to Craigs Run	Agriculture – Siltation
South Fork Tenmile Creek (H) – Downstream of Smith Creek, extending approximately 6 Km	Source Unknown - Cause Unknown
Pursley Creek (I) – At the Mouth of Stewart Run	Source Unknown – Cause Unknown

The principle water quality impairments of the South Fork Tenmile Creek Watershed are high rates of erosion and sedimentation, nutrient enrichment, elevated conductivity and high concentrations of metals. These impairments are attributable to a variety of sources, including outdated and inadequate stormwater management infrastructure, mismanagement of household sewage, improper agricultural practices and industrial pollution related to both legacy and current energy extraction.

Stormwater Management

Although developed land cover classes represent only a small portion of the South Fork Tenmile Creek Watershed; stormwater management is a concern throughout. Greene County entered into an agreement with DEP to develop a stormwater management plan under Act 167 in 2009. Efforts associated with plan development have since stalled due to a lack of funding. Greene County does not currently have an Act 167 plan. Although there is a set of county-wide subdivision and land development ordinances (SALDO), these only address stormwater management for new land developments and subdivisions. There are no consistent ordinances that address existing or failed stormwater management systems.

Roadways are the most common impervious surface to be found in the watershed and in many instances, follow the course of streams through narrow valleys. The proximity of these roadways to streams makes non-point source pollutants in stormwater runoff a concern. Typically, these include sediment, vehicle fluids and roadway deicing agents but can also be related to cargos being transported themselves. Additionally, there are many unpaved roads in the watershed. These gravel or dirt roads are themselves a source of sediment to adjacent streams.

Structures, another source of impervious surface, are generally single residence homes, sheds, and barns that are more spread out than in more urban areas. The exception to this loose spatial arrangement would be several small communities where clusters of structures exist. Stormwater management infrastructure in these communities is minimal if it is present at all.

Increased levels of development have occurred in the eastern portions of the watershed resulting in larger proportions of impervious surface. Small, country roads give way to larger highways and densely packed city streets. Similarly, structures are more numerous and more densely arranged. Parking lots, commercial and industrial buildings are more common. This accumulation of impervious surface brings greater concern for stormwater management to deal with increased surface runoff and non-point source pollution.

While stormwater catch basins, pipes and culverts are present in the few more urban municipalities, these structures are rarer in rural areas. Open ditches and swales are the most common stormwater conveyance to be found in the watershed. Regardless of the type and sophistication of the system, responsibility for maintaining these rests with the individual municipalities which vary in their resources and ability to keep these systems operational.

Even in communities that have more developed stormwater management systems in place, there can still be problems. Combined systems are common throughout Southwestern Pennsylvania. These systems use a single sewer network to transport both stormwater and sanitary waste to a central sewage treatment plant. During intense storm events, the influx of stormwater increases flow through this system to levels that would overwhelm the treatment plant and cause a catastrophic pollution event. To ensure that this does not happen, the combined sewer systems include combined sewer overflows (CSO). CSO are structures that allow volumes of liquid waste beyond the capacity of sewage treatment plants to be directed into adjacent water bodies. The resulting water pollution from a CSO is dramatically less severe than if the treatment plant is overwhelmed but is still a problem.

Municipalities are required to permit CSO through DEP. As part of this permitting process, the municipality must develop and implement a long-term control plan designed to eliminate the CSO as a source of water quality impairment.

Mismanagement of household sewage

For the majority of homeowners in the South Fork Tenmile Creek Watershed, municipal sewage treatment is unavailable due to a lack of infrastructure in rural areas. In these areas landowners must develop an on-lot septic system which is costly, may not be practical based on soil types, requires regular maintenance and can fail unexpectedly. On-lot sewage treatment is regulated both by Chapter 73, Title 25 of the Pennsylvania Code and by various local municipalities zoning.

Of even greater concern are so called, “wildcat sewers” which are homes that lack an on-lot system and instead pipe sewage directly into streams. There is no estimate on the number of wildcat sewers in the South Fork; however, the lack of municipal system availability combined with limited economic development and lack of municipal oversight suggests that there may be numerous such systems in the watershed. Whether from a failing on-lot system or a wildcat sewer, nutrient and bacteriological pollution of groundwater and surface water are a very real concern in the South Fork Tenmile Creek Watershed.

Agriculture

Although not nearly as financially substantial as energy development, agriculture is a large part of both the economy and culture of Greene County. The importance of livestock farming in the South Fork Tenmile Creek Watershed is evident in that nearly 20% of the watershed is classified as hay and pasture land. Livestock sales accounted for 61% of the 2012 market value of agriculture in Greene County. Many of those farms are located in the South Fork Tenmile Creek Watershed.

Improper management of livestock heavy use areas, including barnyards, feeding and watering areas, animal walkways, stream crossings and any other areas where livestock congregate is a major driver of non-point source pollution. Mismanagement of these areas eliminates vegetation; increasing the susceptibility of exposed soils to erosion while at the same time reducing the ability of the landscape to filter polluted runoff. In addition to this, animal wastes in these areas become a concentrated source of nutrients. When these factors are combined with surface runoff, the result is sediment- and nutrient-polluted runoff to nearby streams. The effects of this improper management are exacerbated in the South Fork Tenmile Creek Watershed by the fact that these areas are often located directly adjacent to streams or within their immediate floodplain. Anecdotal information suggests these areas appear to be preferentially selected for this type of development based on the fact that they are relatively level when compared with adjacent areas. An additional consequence of situating these areas adjacent to streams is the effect on riparian vegetation. In many cases, riparian vegetation is reduced or in some cases, eliminated altogether. It is not uncommon to see cattle standing in streams. Lack of adequate riparian vegetation combined with the mechanical destabilization of streambanks by livestock result in streambank erosion and further increase sediment and nutrient loads to streams.

Abandoned Mining

Underground mining has been taking place in the South Fork and surrounding watersheds for over a century. Bituminous coal mining provides Greene County’s economic backbone. Approximately 180 km^2 of the South Fork have been mined and additional areas are actively permitted by DEP for current and future underground mining.

The oldest mines in the South Fork are located in the easternmost sub-watersheds, almost all of which are long since closed. These include the Dillworth Mine, the Gateway Mine, the Clyde Mine, the Marianna 58 Mine, the Pitt Gas Mine, the Mather Mine and the Emerald mine.

Communication between mines and groundwater aquifers is a costly nuisance for mines while active. Underground mines require extensive pumping systems to keep their operations from filling with water. Once these mines close, however, the pumps are shut off or removed and groundwater seeps into these abandoned underground mine complexes forming vast mine pools.

The formations through which these underground mines have been carved are rich in sulfide minerals containing metals, including iron, pyrite, aluminum, and manganese. Oxidation of these minerals is sped up with the addition of water, oxygen, and various bacteria. This oxidation frees hydrogen ions resulting in highly acidic waters in mine pools that are also heavily laden with sulfate and metals.

Water levels in mine pools are related to groundwater recharge. This means that when storm events or seasonal snow melt increase infiltration, it not only recharges groundwater aquifers it also increases water levels in mine pools. When mine pool levels rise far enough to reach discharge points, discharge to surface water occurs. This abandoned mine drainage upsets the delicate acid-base balance of aquatic ecosystems and introduces many toxic metals to the system. Pollution intolerant species will be the first to succumb leaving only those species which can survive in the altered conditions.

The above-ground remnants of these immense operations are also a concern. Waste coal piles, or gob piles as they are commonly known, are mountainous stockpiles of both low-quality coal and overburden, or non-coal debris extracted from underground mines and stored above ground. These piles are comprised of similar materials as those found in underground mine pools. Introduction of water to these piles through precipitation results in similar chemical reactions as those described above. This results in similarly polluted runoff during and after precipitation events. Also, fine coal dust and other particles in these piles contribute to sedimentation of streams.

Active Mining

There are three active underground bituminous coal mines operating as longwall mines in the South Fork Tenmile Creek Watershed. These include the Harvey Mine (formally known as the Bailey Mine and the Bailey Mine Extension (BMX)), the Cumberland Mine and the Enlow Mine. Mine operators like these are required to obtain permits for their various activities, including permits for underground mine operations, above-ground preparation plants and point source discharges. Coal mines in Pennsylvania are regulated by DEP under various chapters of title 25 of the Pennsylvania Code. These regulations are designed to ensure that mining activities are undertaken in ways that do not result in environmental degradation.

These active mines excavate through similar formations as the abandoned mines discussed above. Also, like abandoned mines, water enters active coal mines through infiltration and other pathways and is similarly polluted. Before mine operations can discharge this water into surface water bodies like streams, they are required to obtain permits under the National Pollutant Discharge Elimination System (NPDES). These permits require that water be treated to meet strict guidelines for pollutant loads and place limits on discharged volumes. Despite treatment efforts, this discharge is generally alkaline and has high conductivity.

Above-ground mining facilities such as preparation plants that clean, sort and otherwise make the product ready to market are also required to be permitted. These permits require that the operator takes appropriate measures to ensure that erosion and sedimentation are controlled. This ensures that these sites don’t become sources of non-point source pollution like the waste coal piles discussed above. Slurry impoundments must be permitted and are required to meet certain design criteria to protect surface waters from pollution of potential breaches. Other mine wastes are carefully regulated and controlled to ensure that they don’t become pollutants. Mines are required to reclaim sites once they are no longer needed. In fact, other laws require that they set funds aside in the form of bonds. These funds are designed as a safeguard to complete remediation of their site should the mining company refuse to do so or be unable to do so.

In addition to concerns about how our energy extraction activities affect water quality, we must also consider how they affect water availability. Dewatering of streams and groundwater resources is a major concern for landowners residing in Greene County and other areas where coal mining takes place. Note that this review omits concerns for structures or other property damage from this consideration of mining subsidence and focuses strictly on water resources. Mining subsidence affects streams and groundwater resources through a number of processes.

The first is through formation of subsidence basins. These basins form where longwall panels remove coal from seams and allow overburden to drop into this void once the panel is removed. Subsidence basin formation alters hydrological regimes of surface water by promoting pooling within subsidence basins. The second process that affects hydrological resources is bedrock fracturing. As overburden shifts it can crack bedrock materials that underlay streams. These bedrock fissures reduce surface stream flow as the water begins flowing below ground. Shifting and fracturing of overburden materials increases permeability of soils layers, and modifies groundwater hydrology. This results in a lowering of the water table and fundamental changes in how water moves through groundwater flow pathways.

The Bituminous Mine Subsidence and Land Conservation Act (BMSLCA) passed in 1966 specifically required mining operations to prevent subsidence-related damage to structures and water resources. Amendments to this law passed in 1994 and known collectively as Act 54, changed the wording of the law to allow subsidence-related damage to occur with restoration, replacement or compensation by the mine operator. This allowed a shift from traditional room and pillar mining to more modern longwall mining methods. These latter methods are more efficient and profitable but are far less discriminant in preventing subsidence-related damage. Part of Act 54 requires DEP to conduct assessments of subsidence-related issues, every five years.

Four such assessments have been completed with the latest being released in 2015. This latest assessment noted that approximately 40% of the undermined acreage in Pennsylvania occurred within Greene County. Previous Act 54 assessments have listed subsidence-related stream dewatering of Greene County streams and loss of hydrological resources for Greene County landowners.

The Harvey Mine (formerly Bailey Mine Extension, or BMX) is currently extending beneath the western-most portions of the South Fork Tenmile Creek Watershed. The third and fourth Act 54 assessments identify numerous streams previously undermined as part of this operation that have experienced loss of flow and/or pooling as well as fractures and other changes in streambeds. One of these, an unnamed tributary to the North Fork Dunkard Fork is listed above us unrecoverable and requiring compensatory mitigation. Within these same assessments, 140 water supply effects were reported of which the mine operator was found liable for 40. Fifty-seven effects were not resolved by the end of the assessment's respective reporting periods.

The Cumberland Mine, which extends beneath the Southern portions of the South Fork Tenmile Creek Watershed is also associated with multiple stream dewatering issues in the third and fourth Act 54 assessments. Flow loss, pooling and bed heaving are listed as problems associated with undermining. There were 96 water supply effects reported between these assessments. Of these, the Cumberland mine operator was found liable for 48 while 25 remained unresolved.

The Enlow Mine is set to extend beneath the North-western portions of the South Fork Tenmile Creek Watershed. In the third and fourth Act 54 assessments, multiple stream dewatering issues were associated with this mining operation. Flow loss, pooling, flooding and bed fractures were listed results of subsidence. 265 water supply effects were reported in the third and fourth assessments of which, the mine operator was found liable for 127. A total of 96 water supply effects remained unresolved by the end of the assessment's respective reporting periods.

The now closed Emerald Mine extends beneath much of the central portion of the South Fork Tenmile Creek Watershed. In the latest two Act 54 assessments, four streams are listed as experiencing flow loss from subsidence related to the Emerald Mine. Three of these streams occur within the South Fork Tenmile Creek Watershed and include, Coal Lick Run, an unnamed tributary (UNT) of Frosty Run and Muddy Creek. The issues affecting Coal Lick Run were listed as resolved by DEP in the third assessment while the UNT to Frosty run did not. As of the end of the fourth reporting period, DEP is reviewing a stream recovery report for Muddy Creek. There were 94 water supply effects reported between these assessments. Of these, the mine operator was found liable for 52 while 21 remained unresolved.

As three of these mines actively undermine various portions of the South Fork Tenmile Creek Watershed, many landowner express concerns over water resource loss. Landowners that have dewatered wells and springs must secure an additional source of water in areas where public utilities are often not available. In many cases, landowners must pay to have water hauled to on-property storage tanks. Resolution of these impacts, when possible at all, is a complicated and protracted process. The Fourth Act 54 assessment addressed resolution time for landowners experiencing loss of a water resource with the longest resolution time being over three years.

Oil & Gas Development

Oil and gas development also has a long history in Greene County; going on nearly as long as mining. This historic oil and gas development used conventional means, which included drilling a vertical well into an underground reservoir of oil or gas. Either by naturally occurring pressure or by pumping, the oil or gas in this reservoir is brought to the surface where it can be processed and used. There have been 6,036 conventional wells drilled in the South Fork Tenmile Creek Watershed and 5,449 are classified as active.

In recent years, this industry has boomed due to technological and market developments that have made it profitable for companies to begin developing the various shale formations that underlie parts of Pennsylvania. Tapping these resources has required industry to utilize unconventional means including horizontal drilling and hydraulic fracturing processes. There have been 3,760 unconventional wells drilled in the South Fork Tenmile Creek Watershed and 3,606 of these are classified as active.

Many of the wells recently drilled in Greene County have utilized hydraulic fracturing. Hydraulic fracturing is a process to stimulate oil and gas production from rock formations where conventional methods would be ineffective. The process generally begins with the application of high explosives which are delivered into a well and detonated many thousands of feet below the surface. This forms fissures in the geological formations of interest. A mixture of water, sand and salts are then pumped into the well at extremely high pressures to further open these fissures and free the trapped oil and gas resources. The water is then pumped out of the well and the oil and gas resources may be collected. There are a number of water quality related concerns associated with these practices.

During the actual process of hydraulic fracturing, there are two possible pathways for water quality impairment; communication through the well casing and/or communication between the intermediary formations between the water resource and the production zone being fractured. Of these two possibilities, the former is far more likely as the vertical distance between drinking water resources and production zones are unlikely to allow communication. Casing design and quality varies by company and by well. Poorly constructed, faulty or aging casings can allow communication of fluids into groundwater and ultimately surface water resources.

Perhaps the greatest possibility of water resource contamination is related to the wastewater produced by the hydraulic fracturing process. This produced water contains part of the fluid mixture that was initially injected into the well and water from the formation being fractured. The nature and chemical composition of produced water varies based on the initial fracturing fluid used and the nature of the formation being fractured but typically contain very high levels of total dissolved solids, metals and other compounds. Water quality concerns regarding wastewater include spills, leaking storage impoundments and improper treatment and disposal.

Water withdrawals have become a major concern in Pennsylvania as the state experiences this boom in oil and gas development. Unlocking these resources using the hydraulic fracturing process requires extremely large volumes of water. These unconventional wells are very deep and often extend beneath the surface horizontally to access resources. To fracture such a well can take as much as 10 million gallons of water. The sheer number of wells being drilled in Pennsylvania, coupled with the fact that a well may need to be re-fractured in as little as five years to maintain production, result in an unprecedented demand on our state's resources. This demand is of particular concern as hydraulic fracturing is considered a consumptive use of water resources. This means that the water used for hydraulic fracturing cannot be returned to our streams and water bodies as it is heavily polluted through the process. As such, special regulations have been developed specifically to address water withdrawals by these industries.

Within the Susquehanna River and Delaware River basins, there are multi-state basin commissions that have authority to regulate water withdrawals within their basins. For example, the Susquehanna River Basin Commission requires companies to obtain prior approval for withdrawing any amount of water for consumptive use in developing shale formations. The Delaware River Basin Commission requires approval for any ground or surface water withdrawal that meets a certain threshold. Additionally, they have since required prior approval for any natural gas extraction projects within the regions underlain by shale formations.

The Ohio River Basin, in which the South Fork Tenmile Creek is located, has no basin commission with legal authority to regulate water withdrawals. As such, the only agency providing any oversight for water withdrawals in the Ohio River Basin is DEP. In Pennsylvania, any water withdrawal that exceeds 10,000 gallons per day for a 30-day period must be registered under the Water Resources Planning Act, or Act 220 and under Chapter 110 of Title 25 of the Pennsylvania Code. Registration does not need to occur prior to water withdrawal but must occur within thirty days of the beginning of water withdrawal. Without controls on water withdrawals, stream flows can be reduced to levels that are incapable of supporting aquatic life or meeting other designated uses under Chapter 93 (as discussed above).

To safeguard against this, DEP requires a water management plan be submitted with all permits issued under the Oil and Gas Act. DEP has adopted the “Passby flow guidelines” developed by the Susquehanna River Basin Commission to control withdrawals. Passby guidelines involve a specified amount of flow that must be allowed to continue downstream of a withdrawal point. These guidelines are centered on an estimate of the minimum flow that occurs for a period of seven consecutive days just one time in a ten-year period, called Q7-10. The general rule is that if either a single withdrawal or number cumulative withdrawals is/are greater than 10% of Q7-10, then passby conditions exist and the withdrawal should be halted. Site-specific conditions may impose passby conditions on withdrawals that do not exceed 10%Q7-10 as well. Compliance with these guidelines ensures compliance in with Pennsylvania’s Clean Streams Law by maintaining adequate instream flow to achieve a stream’s designated use.

Brownfields

Brownfields are sites or properties that previous industrial or commercial activities have rendered unlikely to be reused or redeveloped because of existing or potential sources of pollution. These fallow sites are an impediment to local and regional development and oftentimes a source of water quality degradation. Brownfield sites directly contribute to contamination of surface and groundwater resources. Contaminated soils and faulty underground storage facilities represent a contaminant vector into groundwater resources that often communicate with surface waters. Hazardous materials on the surface and contaminated soils become NPS pollutants when runoff and soil erosion carry these contaminants into streams and other surface waters.

Examples include former automotive service and repair stations, abandoned industrial or commercial properties with above- and/or below-ground storage tanks, manufacturing and machining facilities and any other site where hazardous materials remain on the site after activity has concluded. Many abandoned mine sites could easily be included in this section but are discussed individually within this plan. Hazardous materials at Brownfield sites may include petroleum hydrocarbons, diesel and other fuels, lead and other metals, arsenic and other industrial chemicals and treated construction materials such as items containing asbestos or creosote.

While brownfield sites may be found anywhere human activity takes place; they are generally concentrated in more developed areas.

2. Subwatershed Descriptions

2.1 Hargus Creek Watershed

Watershed Description

The Hargus Creek Watershed is located in the Southwestern corner of the South Fork Tenmile Creek Watershed. Hargus Creek and its tributaries make up 81.4 km of stream that drains a land area of 56.1 km^2. The major tributary to Hargus Creek is McCourtney Run, which is formed at the convergence of Grinnage Run and Garner Run. McCourtney Run flows northeast through the community of Holbrook where it receives water from House Run then continues until it empties into Hargus Creek. Hargus Creek itself is formed of the convergence of several unnamed tributaries and flow in a northerly direction before and empties into the South Fork Tenmile Creek upstream of Rogersville, Pa.

The overall impression of the Hargus Creek Watershed is that it is an agriculturally focused watershed that has retained much of its forest. Forested land covers dominate the Hargus Creek Watershed, comprising approximately 78% of the watershed area. This is most evident in the headwater areas which are best described as forest interspersed with the occasional farm or homestead. Additionally, Pennsylvania State Game Lands #179 is located near the headwaters of House Run.

Lower in the watershed, along the main stems of larger streams, land use is more intense and forested land gives way to larger farms and higher densities of homesteads. Agricultural land, predominantly focused on livestock propagation, make up 15% of this watershed. Pasture land for cattle, horses and other livestock are the most common agricultural sites with some areas used for hay production.

Higher levels of development in the form of more homes and farms are evident along Golden Oaks Road which follows the course of McCourtney Run and Garner Run. Urban and industrial development in this watershed is minimal, accounting for only 7% of the watershed area. What development there it is to be found is located along larger roadways. For example, the communities of Holbrook and Woodruff are located along Golden Oaks Road. Development becomes more concentrated in the lower segments of the watershed.

Mining operations within the Hargus Creek Watershed are minimal so there is less concern for mining-related impairments than in other parts of the South Fork Tenmile Creek Watershed. The Cumberland mine has an above-ground storage tank near an unnamed tributary of Hargus Creek and there has recently extended underground mining into this watershed. There are also moderate levels of oil and gas development interspersed throughout the watershed. As of 2015, permits have been issued for 460 conventional wells and 286 unconventional wells within the watershed.

Water Quality Regulation

The bulk of streams within this watershed are designated as High Quality Warm Water Fishery under Title 25; Chapter 93 of the Pennsylvania Code. The exceptions to this are five unnamed streams that are designated as Exceptional Value waters. In 2008, Foundation Coal petitioned the Environmental Quality Board to downgrade the status of two unnamed tributaries to House Run (40637 & 40638), two unnamed tributaries of Hoge Run (40633 & 40634) and an unnamed tributary to McCourtney Run (40629) from HQ Warm Water Fishery to simply Warmwater Fishery. Various citizens groups and researchers conducted investigations of conditions within these streams, ultimately finding evidence supporting an eventual upgrade in their Chapter 93 status to Exceptional Value. Permits for this underground mining operation as well as two NPDES discharges into Hoge Creek have been applied for but, in light of these upgraded statuses, it is not currently known when or even if these activities will take place.

Two segments have been identified by DEP as not attaining their designated use of supporting aquatic life as described in chapter one. A segment of Hargus Creek that extends approximately 1.6 Km upstream from the mouth of McCourtney Run as well as the entire length of Hoge Run are designated as not attaining due to agricultural pollution and siltation.

It is also important to note that virtually the entire Hargus Creek Watershed is situated within census tract 9704, which is designated as an environmental justice area due to a large percentage of the population living in poverty.

Water Quality Impairment

Agricultural pollution, widespread stream erosion and sedimentation are major issues affecting the Hargus Creek Watershed. Lack of stormwater management is a major driver of these problems. Impairments are most severe in downstream segments where development is more intense and flow accumulation is greatest. As is common throughout the larger South Fork Tenmile Creek Watershed, much of the development in the Hargus Creek Watershed is situated adjacent to streams. Roads within this watershed range from simple dirt and gravel roads to large paved roads. Whatever their construction, the majority of these roads are directly adjacent to and follow the course of streams. Farms, homesteads and other development are likewise, generally situated directly adjacent to streams.

Land use conversion from forested land covers to agricultural and developed land covers alter or remove vegetation, compact soils and reduce the overall capacity for stormwater infiltration. The results of these land use changes are higher volumes of stormwater runoff that affect streams very quickly during precipitation events. These higher peak flows increase flood risk, provide greater sheer strength that accelerates streambank erosion and allow for transport of increased volumes of non-point source pollutants, including sediment and animal waste. Wholesale elimination of riparian vegetation related to land use change increases susceptibility of stream channels to erosion and sedimentation through reduced channel stability and increased peak discharges. It also eliminates thermal protection for aquatic life.

Municipal sewage services are not available to landowners within the Hargus Creek Watershed, meaning that landowners must develop their own on-lot systems. Although likely not as widespread as the problems arising from stormwater runoff, contamination of surface and groundwater resources from faulty or damaged on-lot systems is a concern for this watershed.

At the present time, underground mining is just moving into the Hargus Creek Watershed. The Cumberland mine is extending into the South-east corner of the watershed. Current activities include an underground mine and a single above ground storage facility. The mine has permits to extend beneath much of the watershed area. This mining activity will extend beneath large portions of Hargus Creek, McCourtney Run, Garner Run, Grinnage Run and all of House Run. It is likely that some or all of these streams will experience dewatering. Of greater concern for many landowners within this watershed are the loss of wells and springs that longwall mining threatens. At the present time, Municipal water services are unavailable to landowners within this watershed. Also proposed as part of this expanded activity are two NPDES discharges on Hoge Run, a stream reach already listed as impaired.

Development for oil and gas extraction contributes to stormwater management issues within the watershed. Even though these sites are required to implement erosion and sediment controls, they involve landscape conversion to impervious surfaces. Beyond this, there are no indications of industrial water pollution resulting from these activities.

2.2 Grays Fork – South Fork Tenmile Creek Watershed

Watershed Description

The Grays Fork – South Fork Tenmile Creek Watershed (hereafter, Grays Fork Watershed) is located on the Western-most side of the larger South Fork Tenmile Creek Watershed. This watershed includes 91.6 km of stream that drains a land area of 60.3 km^2. This watershed represents the headwaters of the South Fork Tenmile Creek. Grays Fork begins in the Northwestern corner of the watershed near Graysville, PA and flows southeast until it converges with Claylick Run near Rutan, PA to form the South Fork Tenmile Creek. The South Fork then continues its easterly course to the mouth of the Grays Fork Watershed.

Like most of the South Fork's western sub-watersheds, forested land covers make up the bulk of the Grays Fork Watershed, making up nearly 68% of the watershed area. Forest lands are dispersed throughout the watershed. The largest pockets of forest land covers are typically located at higher elevations. These areas are generally steep and access for development is limited. Much more development occurs within the valleys of the watershed. Here, farms, homes and forested areas are interspersed with one another. Although the watershed retains much of its forested land cover, there is an emphasis on agricultural development throughout the watershed. Agricultural land covers make up approximately 24% of the watershed area. Pasture land for cattle, horses and other livestock are the most common agricultural sites with some areas used for hay production.

More land has been cleared of tree cover in lower sections of the watershed. This is particularly evident along the Roy Furman Highway, which follows the course of Grays Fork and eventually the South Fork Tenmile Creek. Much of the developed land cover that occurs in the watershed can be found along this stretch of road and amounts to nearly 7% of the watershed area. This includes homes and businesses that make up the communities of Rutan and Graysville.

The westernmost portions of this watershed have and continue to experience underground mining from the Harvey mine. The Cumberland mine plans to mine under a very small portion of the watershed but this is not likely to occur in the near future. The watershed also has substantial oil and gas development with permits being issued for 1035 conventional wells and 415 unconventional wells.

Water Quality Regulation

All streams within this watershed are designated as High Quality Warm Water Fishery under Title 25; Chapter 93 of the Pennsylvania Code. DEP has not identified any stream segments within this watershed as impaired.

It is also important to note that the entirety of the Grays Fork Watershed is situated within census tract 9704, which is designated as an environmental justice area due to a large percentage of the population living in poverty.

Water Quality Impairment

Like the Hargus Creek Watershed, the major issues affecting the Grays Fork Watershed are agricultural pollution, widespread stream erosion and sedimentation. This is largely due to a lack of stormwater management. Impairments are most severe in downstream segments where development is more intense and flow accumulation is greatest. Much of the development in the Grays Fork Watershed is situated adjacent to streams. Roads within this watershed range from simple dirt and gravel roads to large paved roads. Whatever their construction, the majority of these roads are directly adjacent to and follow the course of streams. Farms, homesteads and other development are likewise situated directly adjacent to streams.

As in the Hargus Creek Watershed, land use conversion is a contributor to increased runoff volume resulting in higher incidence of NPS pollutions and, hydrograph alteration and greater flood risk. Likewise, elimination of riparian vegetation related to land use change increases susceptibility of stream channels to erosion and sedimentation through reduced channel stability and increased peak discharges. It also eliminates thermal protection for aquatic life.

None of the communities within the Grays Fork Watershed maintain sewage treatment plants, meaning that landowners must develop their own on-lot systems. Although likely not as widespread as the problems arising from stormwater runoff, contamination of surface and groundwater resources from faulty or damaged on-lot systems is a concern for this watershed.

Existing underground mining associated with the Harvey mine is minimal within this watershed and at the present time has a low likelihood of impairing water quality or negatively affecting water availability. Planned underground mining associated with the Cumberland mine is similarly unlikely to adversely affect water resources.

Increased levels of development for oil and gas extraction likely contribute to stormwater management issues within the watershed as these activities involve landscape conversion to impervious surfaces despite the fact that erosion and sediment controls are required at these sites. Beyond this, there are no indications of industrial water pollution resulting from these activities.

2.3 Browns Creek Watershed

Watershed Description

The Browns Creek Watershed is located in North-central Greene County and is the largest of all of the South Fork Tenmile Creek's sub-watersheds. Brown's Creek begins near Greene County's northern border and flows southwest. The Creek passes through the communities of Nineveh and Sycamore before emptying into the South Fork Tenmile Creek near Waynesburg. It receives water from several large and numerous small tributaries, including Patterson Creek, Bates Fork, Garners Run and Wisecarver Run. Browns Creek and its tributaries make up 180.3 Km of stream and drain a land area of 118.5 Km^2.

Another aquatic resource of note is the Wisecarver reservoir, an 18-acre impoundment constructed on Wisecarver Run in 1931. This area had served as a potential drinking water source owned and operated by the Southwestern Pennsylvania Water Authority as well as a recreational site for anglers. Concerns regarding the structural integrity of the earthen dam arose in the mid 1990's leading to partial draw downs and ultimately a complete drainage of the reservoir by 2010. Repairs have since been made to the dam and plans made to use the reservoir and the 380 acres of land surrounding as a park.

The Browns Creek Watershed retains much of its forested land cover. Deciduous forest is the dominant land cover in the Browns Creek Watershed, comprising approximately 73% of the watershed area. This is most evident in the headwater areas which are best described as forest interspersed with farms and homesteads. Lower in the watershed, along the main stems of larger streams, land use is more intense and forested land gives way to larger farms and higher densities of development. Agricultural land covers, predominantly focused on livestock propagation, make up 19% of this watershed. Pasture land for cattle, horses and other livestock are the most common agricultural sites with some areas used for hay production. Crop farming is much less common in the watershed.

Higher levels of development, including smaller communities like Nineveh and Sycamore, are particularly evident along Brown's Creek Road (SR18) which follows the course of the stream from which its name is derived. Urban and industrial development in this watershed is minimal, accounting for only 6% of the watershed area. Several small communities exist within the Browns Creek Watershed, including Swartz, Nineveh, Sycamore, West Union, Deer Lick and Rees Mill. The larger of these occur lower in the watershed. In general terms, development intensity grows higher nearer to Waynesburg.

Like much of Greene County, the Browns Creek Watershed has a history of extractive energy development. The now-closed Emerald Mine extends into the watershed from the Southeast while the still operational Harvey mine extends into the watershed from the Northwest. The Harvey mine operates an NPDES permitted discharge into Patterson Creek. There are also high levels of oil and gas development interspersed throughout the watershed. As of 2015, permits have been issued for 1270 conventional wells and 1450 unconventional wells within the watershed.

Water Quality Regulation

Streams within the Browns Creek Watershed are designated as a High Quality Warm Water Fishery under Title 25; Chapter 93 of the Pennsylvania Code. As part of their ongoing assessment of the Commonwealth's waters, Pennsylvania DEP has identified multiple stream segments in the Browns Creek Watershed that are not attaining their designated use of supporting aquatic life as described above. The first impaired segment is located on the main stem of Browns Creek upstream of Nineveh. The second is a segment of Bates Fork near Swartz. Sources of impairment include siltation from agriculture and other land uses, runoff from roads, bank modification and removal of vegetation, channelization and flow modifications.

It is also important to note that the easternmost portions of the Browns Creek Watershed are situated within census tract 9704, which is designated as an environmental justice area due to a large percentage of the population living in poverty.

Water Quality Impairment

The Browns Creek Watershed begins a departure from the conditions in the Hargus Creek and Grays Fork Watershed. Like these watersheds, agricultural pollution, widespread stream erosion and sedimentation are major issues affecting the Browns Creek Watershed. At the same time, land use change becomes more pronounced and development becomes more intense. As such, other sources of water quality concern emerge in this watershed.

As in the Hargus Creek and Grays Fork Watersheds, much of the development in the Browns Creek Watershed, including roads, farms, homesteads and other development, is situated adjacent to streams. Stormwater Management remains a serious concern, particularly in downstream segments where development is more intense and flow accumulation is greatest.

Land use conversion affects runoff, water pollution and flood risk. These effects have been discussed in previous sections and are therefore not discussed here. They do remain an issue affecting the Brown's Creek Watershed.

Municipal sewage services are available in the community of Nineveh but are lacking throughout the rest of the Browns Creek Watershed. Landowners outside of Nineveh must develop their own on-lot systems. As in other rural watersheds, contamination of surface and groundwater resources from faulty or damaged on-lot systems is a concern for this watershed.

The Harvey mine extends beneath Browns Creek from the Northwest. At the present time areas of Patterson Creek have been undermined and future plans involve further mining that will extend beneath Browns Creek itself and other tributaries. It is likely that some or all of these streams will experience dewatering to some extent. Of greater concern for many landowners within this watershed are the loss of wells and springs that longwall mining threatens. At the present time, Municipal water services are unavailable to landowners within this watershed. Discharge from the Harvey Mine is permitted under the NPDES. This permit requires that discharged water be treated and meet specific criteria for pollutants. Despite treatment, discharges can have deleterious effects on receiving streams. Treated mine wastewater may still have high conductivity and may alter natural instream flow regimes.

Increased levels of development for oil and gas extraction likely contribute to stormwater management issues within the watershed as these activities involve landscape conversion to impervious surfaces despite the fact that erosion and sediment controls are required at these sites. Beyond this, there are no indications of industrial water pollution resulting from these activities.

2.4 Pursley Creek – South Fork Tenmile Creek Watershed

Watershed Description

The Pursley Creek – South Fork Tenmile Creek Watershed (hereafter, Pursley Creek Watershed) is located in the South-central portion of the South Fork Tenmile Creek Watershed. This is one of four sub-watersheds in the South Fork Tenmile Creek Watershed that actually contain a segment of the South Fork itself. The South Fork flows eastward from the mouth of Hargus Creek to through the communities of Rogersville and Eastview before leaving the watershed near the mouth of Browns Creek. During this time, it receives water from several tributaries including Lightner Run, Rush Run, Throckmorton Run and the eponymous Pursley Creek.

Pursley Creek itself begins in the southernmost part of the watershed, flows through the community of Oak Forest and continues northeast until it empties into the South Fork Tenmile Creek upstream of Eastview. Along the way, it receives water from several tributaries including, Maple Run, Stewart Run and Woods Run. Taken together, this watershed contains 85.4 Km of stream and drains and area 63.5 Km^2.

The Pursley Creek Watershed, like other western sub-watersheds, retains a great deal of its forested land covers. Forested land covers make up approximately 70% of the watershed's surface area. The largest areas of forested land cover tend to be those that are farthest from major roads and other infrastructure that would encourage development. Areas where access is more developed exhibit greater interspersion of agricultural and developed land covers.

The majority of the development that has taken place in this watershed is situated in areas of lower elevation and occurs along roadways that follow the course of streams; such as route 21, which follows the course of the South Fork Tenmile Creek, and Oak Forest Road, which follows the course of Pursley Creek. Land covers related to agriculture account for 21 % of the watershed's surface area. Pasture land for cattle, horses and other livestock are the most common agricultural sites with some areas used for hay production.

Development within the watershed is limited to two or three small communities and makes up approximately 7 % of the watershed's area. Rogersville and Eastview, both located along route 21 represent the largest amounts of developed land covers within the watershed. Oak Forest, located along Oak Forest Road is another small community within the Pursley Creek Watershed and accounts for a small amount of developed land covers.

The majority of the Pursley Creek Watershed has been mined as part of the Cumberland and Emerald mines. The Cumberland mine operates an NPDES permitted discharge into an unnamed tributary near the headwaters of Pursley Creek. There are also moderate levels of oil and gas development interspersed throughout the watershed. As of 2015, permits have been issued for 521 conventional wells and 481 unconventional wells within the watershed.

Water Quality Regulation

All streams within this watershed are designated as High Quality Warm Water Fishery under Title 25; Chapter 93 of the Pennsylvania Code. DEP has not identified any stream segments within this watershed as impaired.

It is also important to note that a large proportion of the Pursley Creek Watershed is situated within census tract 9704, which is designated as an environmental justice area due to a large percentage of the population living in poverty.

Water Quality Impairment

Like the Browns Creek Watershed, the Pursley Creek Watershed exhibits a transition from the rural to the urban and industrial. The watershed retains the rural aesthetic and emphasis on agriculture, but also has a greater industrial presence. The major issues affecting this watershed remain related to stormwater in that agricultural pollution, widespread stream erosion and sedimentation are common. Once again, much of the development in the Pursley Creek Watershed is situated adjacent to streams. Roads often follow the course of streams; while farms, homesteads and other development are disproportionately situated directly adjacent to streams.

As in previous sub-watershed descriptions, land use conversion is an issue affecting this subwatershed. The results of this conversion are higher incidents of NPS pollution, increased flood risk, degraded water quality and unhealthy aquatic communities.

Municipal sewage services are nonexistent, meaning that landowners must develop their own on-lot systems. For this reason, contamination of surface and groundwater resources from faulty or damaged on-lot systems is a concern for this watershed.

Underground mining has an extensive footprint within the Pursley Creek Watershed. Both the Cumberland mine and the Emerald mine extend beneath the watershed. Although the Emerald mine is now closed, the Cumberland mine plans further mining activities within this watershed. Loss of water resources has and will likely continue to be a problem for landowners within this watershed as underground mining continues. Municipal water supplies are available along the Route 21 corridor and in a very limited area near the community of Oak Forest. As in Browns Creek, an NPDES permitted discharge is present within the Pursley Creek Watershed near an unnamed tributary to Pursley Creek. This discharge, operated by the Cumberland mine is surrounded by similar concerns of elevated conductivity and flow regime alteration.

Moderate levels of development for oil and gas extraction contribute to stormwater management issues within the watershed as these activities involve landscape conversion to impervious surfaces despite the fact that erosion and sediment controls are required at these sites. Beyond this, there are no indications of industrial water pollution resulting from these activities.

2.5 Smith Creek – South Fork Tenmile Creek Watershed

Watershed Description

The Smith Creek – South Fork Tenmile Creek Watershed (hereafter, Smith Creek watershed) is located in the South-central portion of the South Fork Tenmile Creek Watershed. Like Pursley Creek, a segment of the South Fork Tenmile Creek flows through this watershed. The South Fork flows eastward from the mouth of Browns Creek, through the city of Waynesburg and to the mouth of Ruff Creek. Within this watershed, The South Fork receives water numerous tributaries including; Toll Gate Run, Purman Run, Jackson Run, Grimes Run, Sugar Run and obviously Smith Creek. Smith Creek is the largest of these tributaries, hence the watershed is named for it. Taken together, this watershed includes 135 Km of stream and drains a land area of almost 89 Km^2.

While upstream watersheds have been predominantly forested and agricultural, Smith Creek exhibits a marked increase in developed land covers which for the first time eclipse agriculture as a dominant land use. While portions of this watershed retain their forested land covers, much of it has been converted to other land uses. Forested land covers account for only 61% of the watershed's surface area. These pockets of forest land covers are generally situated in upstream areas where development for agriculture or urbanization has been impractical due to steeper slopes, and lack of access.

Development, as in most of the South Fork Tenmile Creek Watershed, is tied to roadways that follow the courses of streams through valleys. The Smith Creek Watershed has the highest percentage of developed land cover of any of the South Fork's sub-watersheds. Developed land cover makes up approximately 18% of the watershed's area. The borough of Waynesburg is the county seat of Greene County and its largest urban area. Together with smaller adjacent communities of Blairtown and Morrisville, this area accounts for much of the development in this watershed. Access to Interstate 79 and the establishment of Waynesburg University has likely driven some of this development.

Agricultural land covers are interspersed among these forested and developed land covers and make up approximately 17% of the watershed's area. Pasture land for cattle, horses and other livestock are the most common agricultural sites with some areas used for hay production.

Extractive energy development has a large footprint in this watershed. Multiple underground mines, including the currently active Cumberland mine and the now closed Emerald, Gateway and Mather mines extend beneath the majority of the Smith Creek watershed. The now closed Emerald Mine maintained a mineral preparation plant, refuse disposal facilities and NPDES permitted discharge points on unnamed tributaries of Smith Creek. In addition to mining, there are also moderate levels of oil and gas development interspersed throughout the watershed. As of 2015, permits have been issued for 1088 conventional wells and 218 unconventional wells within the watershed.

Water Quality Regulation

All streams within this watershed are designated as Warm Water Fishery under Title 25; Chapter 93 of the Pennsylvania Code. As part of their ongoing assessment of the Commonwealth's waters, Pennsylvania DEP has identified multiple stream Segments in the Smith Creek Watershed that are not attaining their designated use of supporting aquatic life as described above. The first impaired Segments are the unnamed tributaries to Smith Creek that are adjacent to NPDES discharges associated with the Emerald Mine. Sources of impairment of these Segments include metals, oil and grease associated with subsurface mining, land disposal and abandoned mining. The next impaired segment identified is a section of Smith Creek beginning at the mouth of these tributaries and extending downstream to the mouth of Smith Creek. Impairments identified for this segment are the same as the unnamed tributaries described above. A third impaired segment has been identified on the South Fork Tenmile Creek itself. This segment extends from the mouth of Smith Creek downstream approximately 6 Km. DEP has not identified sources of this impairment.

The Smith Creek Watershed includes census tract 9705.01 and the majority census tract 9706. Each of these is designated as an environmental justice area due to either a large percentage of the population living in poverty or a large percentage of the population identifying as a minority.

Water Quality Impairment

The Smith Creek sub-watershed is the first watershed in the South Fork that exhibits water quality concerns indicative of urban and industrial land uses. In sub-watersheds located upstream, the major factors affecting water quality are agriculture and siltation. While the effects of these are still present in the Smith Creek sub-watershed and those downstream, there are additional factors present in these sub-watersheds. Active and legacy mining, treatment of wastewater associate with oil and gas development, industrial sites and municipal stormwater all play an increased role in determining water quality.

State Route 21 follows the course of The South Fork Tenmile Creek. It is also the major corridor for development within this watershed. Comparatively intense urban development around the city of Waynesburg drives the proliferation of impervious surface and the increases in stream erosion, flood risk and water pollution that are attendant to it. Wholesale elimination of riparian vegetation related to land use change increases susceptibility of stream channels to erosion and sedimentation through reduced channel stability and increased peak discharges. It also eliminates thermal protection for aquatic life.

The Borough of Waynesburg maintains municipal sewage service while outlying areas must develop their own on-lot systems. Contamination of surface and groundwater resources from faulty or damaged on-lot systems is a concern for this watershed. In addition to the concerns of faulty or damaged on-lot systems, the Borough of Waynesburg maintains a combined sewer system. There are two CSO in the Waynesburg Borough. The Purman Run By-pass and the Morgan Street By-pass both contribute polluted effluent to the South Fork Tenmile Creek during intense storm events. The borough must maintain a permit with DEP for these discharges and is required to monitor them. Additionally, the Borough's permit requires that a long-term control plan be developed to eliminate these CSO. Activities associated with this long-term control plan include increasing capacity at the Borough's sewage treatment plant, separating stormwater and sanitary waste by constructing parallel infrastructure or a combination of the two.

The Smith Creek Watershed has been extensively mined through both surface and underground mining. The Greene Coal Company operated a surface mine near Waynesburg, which has since been reclaimed. NPDES permitted discharges associated with this mine are still present on unnamed tributaries of the South Fork Tenmile Creek. The Mather and Gateway mines extended beneath the watershed from the north.

The Emerald Mine, operated by Alpha Natural Resources, had the largest footprint within the watershed and operated until September of 2015. Emerald maintained a preparation plant and a refuse disposal site adjacent to Sugar Run, and two NPDES permitted discharges to an unnamed tributary of Smith Creek. Pennsylvania DEP identified three sites below these discharges, two on the main stem and one on an unnamed tributary that exhibited impairment. These sites had very high conductivity readings and macroinvertebrate communities exhibited low diversity and abundance. What species were present were pollution tolerant species. (Kenderes, 2001).

Kimmel and Argent described a longitudinal gradient of increasing conductivity between the mouth of the South Fork and the mouth of Smith Creek with values ranging from 440 µS/cm at an established reference site upstream of the South Fork to 4,500 µS/cm at their site downstream of Smith Creek and the, then active, Emerald Mine treated effluent discharge. Values upstream of Smith Creek were similar to their reference site. The authors found that fish community metrics were related to conductivity levels. Marked decreases in species richness and abundance were observed at sites below the Emerald Mine discharge and below the Mather legacy mine site (Kimmel and Argent, 2010).

Water resource loss has been an issue within this watershed as well. Coal Lick Run was dewatered as a result of undermining by the Emerald mine. Landowners have also experienced water resource loss. A larger proportion of this watershed has municipal water supplies available. This is due in part to mining companies being compelled to pay for development of this infrastructure.

In addition to mining, Oil and Gas development have affected water quality in the Smith Creek Watershed. Amid growing concerns about the treatment of oil and gas wastewater in municipal treatment plants, Pennsylvania DEP conducted a Cause and Effect Stream Survey on the South Fork in 2008. This study examined water chemistry and aquatic community dynamics both upstream and downstream of a wastewater treatment plant that received drilling wastewater.

Their findings showed that downstream Segments had demonstrably higher levels of Total Dissolved Solids (TDS) and elevated levels of chlorine and metals associated with oil and gas activity. They found that the aquatic community was dramatically altered in downstream Segments. A macroinvertebrate-based Index of Biotic Integrity developed by DEP showed that the downstream Segments were impaired. Additionally, analysis of plankton communities showed a taxonomical shift from freshwater species to species more commonly associated with a brackish environment. They attributed these changes to the sewage treatment plant effluent

(Spear and Kenderes, 2009). Steps have since been taken to eliminate drilling wastes from municipal treatment plants based on this and other research.

It is important to remember that Mining and Oil and gas development are not the only causes of concern for water quality. The developed areas surrounding Waynesburg Borough host a number of other industrial sites, include scrap yards and automotive salvage yards, which contribute to water quality impairment. Taken together; agriculture, siltation, industry and inadequate stormwater management in the Smith Creek Watershed result in some of the most impaired Segments within the South Fork Tenmile Creek Watershed.

2.6 Ruff Creek Watershed

Watershed Description

The Ruff Creek Watershed is located in the North-central portion of the South Fork Tenmile Creek Watershed. Ruff Creek begins near Greene County's northern border and flows southeast through the community of Ruff Creek and ultimately to the South Fork Tenmile Creek. Several large tributaries drain to Ruff Creek including Walkers Run, Boyd Run, Jersey Run, Craynes Run, Poverty Run and Grimes Run. Ruff Creek and its tributaries comprise 112.3 Km of stream and drain a land area of 69.3 Km^2.

The Ruff Creek Watershed is less forested than western sub-watersheds, maintaining nearly 64% of its forested land covers. These pockets of forest land covers are generally situated in areas where development for agriculture or urbanization has been impractical. These areas include steeper slopes, higher elevations and limited infrastructure. Similarly, to western sub-watersheds, agricultural land uses are emphasized within the Ruff Creek watershed. Narrow valleys adjacent to streams are the centers for agricultural development and make up approximately 25% of the watershed land area. Pasture land for cattle, horses and other livestock are the most common agricultural sites with some areas used for hay production.

Development, as in most of the South Fork Tenmile Creek Watershed, is tied to roadways that follow the courses of streams and accounts for nearly 10% of the watershed area. Higher levels of development in the form of more homes and farms as well as the community of Lippincott are found along route 221, a major road that follows the course of Ruff Creek. The community of Ruff Creek has grown at the crossroads of route 221 and interstate 79.

Extractive energy development has a large footprint in this watershed. Multiple inactive underground mines, including the Clyde, Gateway, Marianna58 and Mather Mines all extend below the Ruff Creek watershed. As of 2015, permits have been issued for 983 conventional wells and 350 unconventional wells within the watershed.

Water Quality Regulation

All streams within this watershed are designated as Warm Water Fishery under Title 25; Chapter 93 of the Pennsylvania Code. As part of their ongoing assessment of the Commonwealth's waters, Pennsylvania DEP has identified a segment of Craynes Run as not attaining its designated use of supporting aquatic life as described above, due to agricultural pollution and siltation.

Water Quality Impairment

The Ruff Creek Watershed is much like more western watersheds like the Hargus Creek and Grays Fork Watersheds. Much of the development, including roads, farms, homesteads and other development, is situated adjacent to streams. Stormwater Management remains a serious concern, particularly in downstream segments where development is more intense and flow accumulation is greatest. The area of the watershed surrounding Interstate 79 at the Ruff Creek exit is one of the most developed areas of the watershed. Businesses and industrial sites in this area are constructed directly adjacent to streams and likely contribute to stormwater management issues within the watershed.

As in previous sub-watershed descriptions, land use conversion is an issue affecting this subwatershed. The results of this conversion are higher incidents of NPS pollution, increased flood risk, degraded water quality and unhealthy aquatic communities.

Although not currently active, large portions of this watershed have been undermined by various operators listed above. As such, issues of water loss and stream dewatering are a historical and current concern for landowners as municipal water supplies are unavailable in most areas of this watershed.

Likewise, municipal sewage services are lacking, meaning that landowners must develop their own on-lot systems. For this reason, contamination of surface and groundwater resources from faulty or damaged on-lot systems is a concern for this watershed.

Moderate levels of development for oil and gas extraction contribute to stormwater management issues within the watershed as these activities involve landscape conversion to impervious surfaces despite the fact that erosion and sediment controls are required at these sites. Beyond this, there are no indications of industrial water pollution resulting from these activities.

2.7 Castile Run – South Fork Tenmile Creek Watershed

Watershed Description

The Castile Run – South Fork Tenmile Creek Watershed (hereafter, Castile Run Watershed) is the easternmost subwatershed in the South Fork Tenmile Creek Watershed. A segment of the South Fork Tenmile Creek flows through this watershed. Beginning at the mouth of Ruff Creek and continuing through the communities of Mather, Jefferson and Chartiers before converging with the main stem of Tenmile Creek near the community of Clarksville. Along the way it receives water from Browns Run and Castile Run, as well as several unnamed tributaries.

Castile run itself begins near Greene County’s northern border and flows southeast until it meets the South Fork Tenmile Creek near Chartiers. It receives water from several smaller tributaries including Bacon Run. The Castile Run Watershed includes 96 Km of stream and drain a land area of 573.9 Km^2.

Like the Smith Creek Watershed, the Castile Run Watershed exhibits more intense urban and industrial development interspersed with large amounts of agricultural development and pockets of retained forest. Forested land covers account for 60% of the watershed’s surface area. Pockets of forest land covers are generally situated in areas where development for agriculture or other land use has been impractical due to factors like steeper slopes, higher elevations and limited infrastructure. Narrow valleys adjacent to streams are the centers for agricultural development and make up approximately 26% of the watershed land area. Pasture land for cattle, horses and other livestock are the most common agricultural sites with some areas used for hay production.

Developed land covers, including communities and industrial sites comprise roughly 12% of the watershed area. Development, as in most of the South Fork Tenmile Creek Watershed, is associated with roadways that follow the courses of streams. Route 188 is a corridor for development within this watershed. Additionally, community development within this watershed is tied to the industries that have operated within the watershed. Historically, communities grew adjacent to mining operations as the need for laborer housing grew. This watershed includes moderate sized communities like Mather, Jefferson and Clarksville as well as smaller communities like Stony Point, Burson Plan, Braden Plan and Teagarden Homes. These communities are generally situated along major roads, such as Route 188 which follows the course of the South Fork Tenmile Creek.

Virtually all of the Castile Run Watershed has experienced underground mining. The now closed Mather, PittGas, Dilworth, Gateway, Clyde, Freeport and Marianna58 mines all extend beneath this watershed. The Mather waste coal site has long been a concern of residents and community leaders. The waste coal pile at Mather is a remnant of the Mather Mine, operated by the Picklands Mather Company from 1917 through 1964. It covers 70 acres and is up to 170 feet thick. There is approximately 6.2 million cubic yards of material that make up the mountainous pile, and portions are known to still be burning. In addition to a history long associated with coal, oil and gas development is a major land use within the Castile Run Watershed. As of 2015, permits have been issued for 679 conventional wells and 560 unconventional wells within the watershed.

Water Quality Regulation

All streams within this watershed are designated as Warm Water Fishery under Title 25; Chapter 93 of the Pennsylvania Code.

Water Quality Impairment

The Castile Run Watershed can largely be described as an amalgamation of the conditions of the Ruff Creek and the Smith Creek Watersheds that it borders. Portions of the watershed retain their rural aesthetic, while pockets of development follow major roadways. Most of these roadways and the development attendant to them are situated adjacent to streams. Stormwater Management remains a serious concern, particularly in downstream segments where development is more intense and flow accumulation is greatest.

Moderate levels of development for oil and gas extraction contribute to stormwater management issues within the watershed as these activities involve landscape conversion to impervious surfaces despite the fact that erosion and sediment controls are required at these sites. Beyond this, there are no indications of industrial water pollution resulting from these activities.

Likewise, municipal sewage services are lacking outside of the borough of Clarksville. This means that landowners must develop their own on-lot systems. For this reason, contamination of surface and groundwater resources from faulty or damaged on-lot systems is a concern for this watershed.

As in previous sub-watershed descriptions, land use conversion is an issue affecting this subwatershed. The results of this conversion are higher incidents of NPS pollution, increased flood risk, degraded water quality and unhealthy aquatic communities.

The communities of Clarksville and Chartiers are worth mentioning as both have developments that extend right to the banks of the South Fork. Landowners typically adhere to societal standards of neatness where lawn maintenance is concerned; maintaining short, manicured lawns over most if not all of their property. When a landowner lives directly adjacent to a stream, this becomes problematic as the vegetation they remove in their pursuit of tidiness is often the vegetation that provides stability for the streambank. The resulting destabilized bank creates a frustrating and dangerous situation for landowners and a source of sediment pollution for streams. The area, colloquially known as Chartiers Bottom (39.960725, -80.046937) and the portions of Clarksville downstream of the Kayak launch (39.971833, -80.043496) are indicative of sites throughout the watershed where streambanks are in need of stabilization

Although not currently active, virtually this entire watershed has been undermined. As such, issues of water loss and stream dewatering are a historical and current concern for landowners as municipal water supplies are unavailable in most areas of this watershed. Municipal water supplies are available in the southern portions of the watershed which are more developed, however these resources are not available in the more rural northern areas.

The Castile Run Watershed continues along the same gradient of water quality that was observed in the Smith Creek sub-watershed by Kimmel and Argent. These authors described a longitudinal gradient of increasing conductivity between the mouth of the South Fork and the mouth of Smith Creek with values ranging from 440 µS/cm at an established reference site upstream of the South Fork to 4,500 µS/cm at their site downstream of Smith Creek and the, then active, Emerald Mine treated effluent discharge. Values upstream of Smith Creek were similar to their reference site. The authors found that fish community metrics were related to conductivity levels. In addition to this, these authors noted marked decreases in species richness and abundance were observed at sites below the Emerald Mine discharge and below the Mather legacy mine site (Kimmel and Argent, 2010).

Mather is a community that has lived in the shadow of past industry for many years. The Mather site and adjacent parcels are considered brownfields and legacy mining sites. They represent major concerns for water quality in this area. The Mather site was mined by the Picklands Mather Company as early as 1917, with adjacent parcels being used for coal preparation and processing. Coal mining refuse was stored on all three sites but most notably on the Mather site itself which features a waste coal pile of approximately 6.2 million cubic yards. Mining operations ended in 1964, but industrial activity continued. Throughout the late 1970's and early 1980's, Gateway Forest Products operated a railroad tie creosote treatment operation on one of the parcels adjacent to the Mather site. Stockpiles of treated railroad ties and other construction materials remain on the site.

Work has been done to improve water quality at the Mather site. In 2001, a collaborative group of county agencies made efforts to stabilize the steep slopes of the Mather pile and reduce its impact on water quality in the South Fork Tenmile Creek. This project involved grading the pile, stabilizing the streambanks of the South

Fork, and vegetating portions of the pile. In 2016, a joint project undertaken by DEP and Pennsylvania Department of Conservation and Natural Resources (DCNR) undertook further grading and used sediment dredged from the bed of the now dry Duke Lake to complete reclamation of the Mather site. This work has the potential to improve water quality downstream of this site but until it is complete, any improvement is speculative at this point. In addition to work completed on the Mather site itself, Greene County's Industrial Development Authority is working assess and ultimately reclaim the adjacent Gateway Forest Products parcel.

Like the Smith Creek subwatershed, the Castile Run subwatershed is affected by water quality impairments associated with a number of sources, including; historical mining, stormwater management, agriculture and sporadic industrial development.

3. Water Quality Data

3.1 Sampling Sites

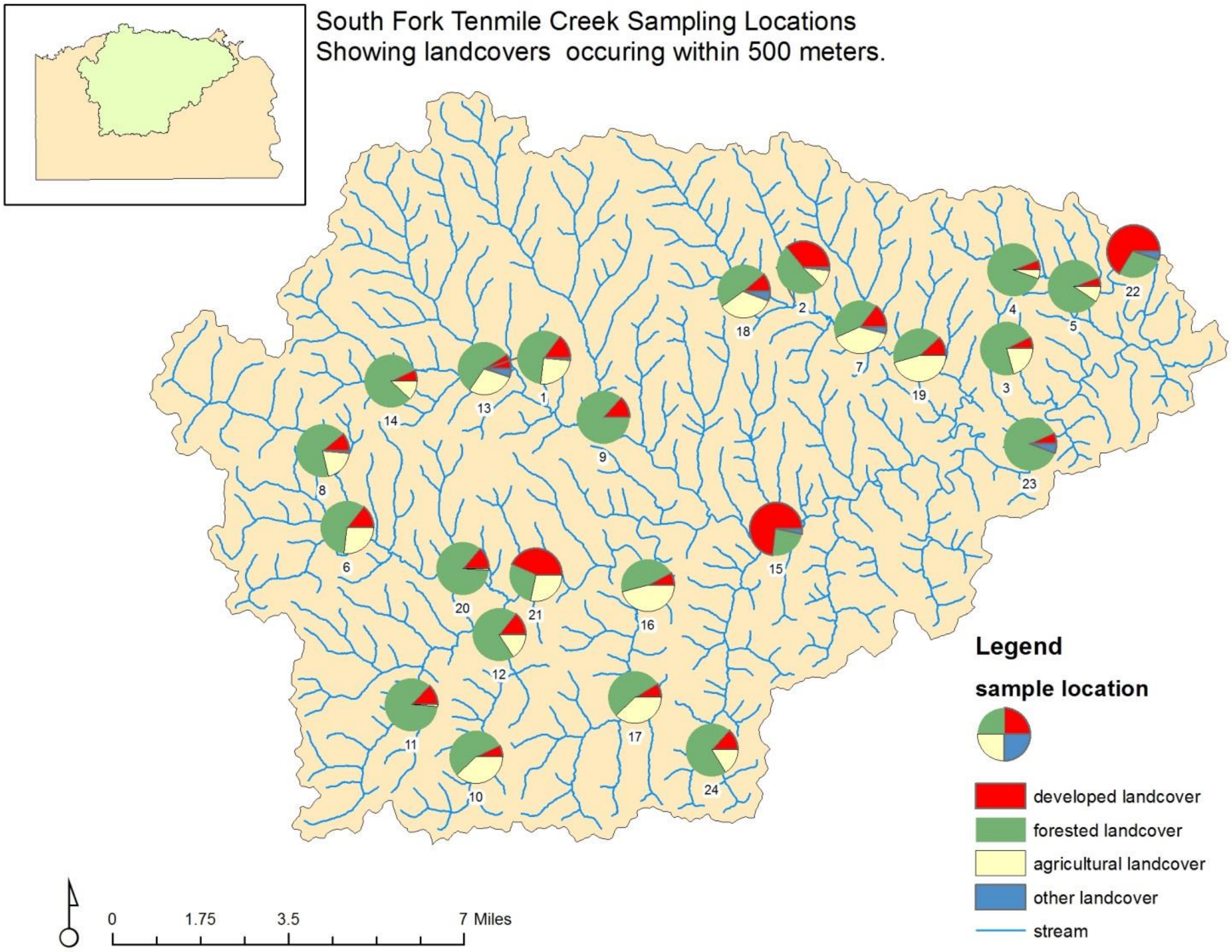
As part of this assessment, 24 stream sites were selected within the South Fork Tenmile Creek Watershed (See map and descriptions below). These sites were selected to be representative of water quality across their individual subwatersheds. Field measurements of conductivity and pH were taken at each site and water samples were collected for laboratory analysis. Aquatic habitat was also assessed at each site using the habitat assessment methodology developed by DEP and used in their instream comprehensive evaluation (ICE).

Upper Brown's Creek site (1)

The Upper Brown's Creek site is situated downstream of the mouth of Patterson Creek. Adjacent land use is predominantly agricultural. Other development near the sample site includes railways, oil and gas infrastructure and a municipal storage yard.

Boyd Run site (2)

Boyd Run is a tributary of Ruff Creek. The sample site on this stream is situated amongst various industrial developments that include, communication towers, a fueling station, a municipal storage yard, an industrial storage yard and various other businesses. The site is very near interstate 79 and other roadways.



Brown's Run site (3)

The Brown's Run site is situated within a mixture of agricultural land use and rural homesteads. There is limited industrial development around the sample sites, including oil and gas well pads and associated infrastructure.

Upper & Lower Castile Run sites (4 & 5)

Both sites on Castile Run are predominantly forested. The upper site tends to be mixed more with agricultural land uses while the lower site tends to be mixed more with residential land uses. Development for utility lines and oil and gas infrastructure are present around the sites.

Claylick Run (6)

The Claylick Run site is centered in an area largely made up of agricultural land uses. Oil and gas infrastructure is present in the area.

Craig Run (7)

The Craig run site is situated among agricultural land uses and rural homesteads.

Gray's Fork (8)

The area around the Gray's Fork site is largely agricultural and residential with large pockets of forest. Oil and gas infrastructure are present as well.

Bates Fork (9)

The Bates Fork site is located in the community of Sycamore. Residential land use is interspersed between forest and agriculture. Industrial development is not a major land use although a railway and some development are present.

Hargus Creek (10)

The Hargus Creek site includes rural homesteads, a church and oil and gas development that are interspersed among this largely agricultural landscape.

Upper and Lower McCourtney Run (11 & 12)

The Upper McCourtney Run site is largely forested with some agriculture, a railway and several rural homesteads nearby. The lower site is more developed. Agriculture is more prevalent. Additionally, the site is situated near a school, railway, various industrial yards and residences.

Upper and Lower Patterson Creek (14 & 13)

The Upper Patterson Creek site is in a largely forested area interspersed with agriculture and various industrial activities. Oil and gas infrastructure and above-ground facilities associated with underground mining are located near this site. The lower site has a larger emphasis on agriculture than the upper. Other development near the lower site includes a railway, oil and gas infrastructure and a municipal storage yard.

Purman Run (15)

The Purman Run site is located within Waynesburg Borough. Residential land use is dominant with industrial land uses being interspersed throughout the area.

Upper and Lower Pursley Run (16 &17)

The Upper Pursley Run site is situated amongst a diverse landscape. While predominantly agricultural, this area includes Oak Forest, a small rural community, and various industrial sites associated with energy distribution and resource extraction. The lower site is less diverse. This area is heavily influenced by agriculture and interspersed with rural homesteads. Industrial development is minimal and related to roadways.

Upper and Lower Ruff Creek (18 &19)

The upper Ruff Creek site is surrounded by agricultural land use and rural homesteads. Industry is present but not a dominant land use. The lower site has a greater emphasis on industrial development. Agriculture is still present but other land uses are more prevalent. The density of homes is greater as you approach the community of Lippincott. Industrial sites include oil and gas well pads and equipment storage and maintenance yards.

South Fork Tenmile Creek sites (20, 21, 22 & 23)

Two sites were selected on the upper South Fork Tenmile Creek. The first upstream site (20) is generally surrounded by forested lands intermixed with rural homesteads and agriculture. Some industrial developments in the form of oil and gas well pads are present. The second upstream site (21) is situated in a more urban setting. Residential land use is much more prevalent as is agriculture. Industrial sites include a municipal storage yard, a water treatment plant and various businesses.

Two sites were selected on the lower South Fork Tenmile Creek. The first downstream site (22) I located in forested patch surrounded by various land uses. Agriculture remains an important land use as do rural homesteads. Residential areas are nearby as well. Industrial development is common and includes oil and gas well pads, legacy mining, wood product manufacturing and others. The second downstream site (24) is situated within the community of Clarksville. Residential land use is dominant here and agricultural land uses are less common. Industrial land uses including oil and gas infrastructure, legacy mining and an automotive salvage yard are in the area.

3.2 Water Quality Parameters

Various guidelines exist to interpret water chemistry results. The United States Environmental Protection Agency EPA develops maximum contaminant levels (MCL) for various contaminants found in drinking water. These MCL are broken down into two categories. Contaminants that are known to pose a human health risk are given a primary MCL, which municipal water suppliers are required to meet. Secondary MCL are given to contaminants that are not known to pose a human health risk and instead affect the taste, smell or aesthetic of water. Secondary MCL are non-enforceable guidelines. In addition to the EPA MCL, Pennsylvania DEP has developed specific criteria for water quality in surface water bodies. These guidelines are found in Title 25; Chapter 93 of the Pennsylvania Code and are based on the specific designated use of a water body. A table, summarizing these various guidelines is included in this section (Table 3.1)

pH

The pH parameter measures the alkalinity or acidity of a water sample by quantifying the presence of Hydrogen ions in solution. This measure is generally reported without units, although technically pH is measured as moles of hydrogen ions per liter of solution. A value of seven is considered to be neutral, neither acidic nor alkaline. Values below seven are considered acidic, while values above seven are considered alkaline. Optimally, streams should be near neutral with bias toward alkaline values. Values very far from neutral indicate some pollutant, such as abandoned mine drainage. Many species of fish and macroinvertebrates are intolerant of pH ranges outside of this neutral zone. For this reason, DEP developed guidelines for surface waters under Chapter 93. Additionally, because alkalinity and acidity affect the taste and feel or water, a similar secondary MCL has been developed by EPA.

Dissolved and suspended solids

In terms of water quality, solids include many organic and inorganic materials that are either dissolved or suspended within water. Examples of inorganic solids include metals, minerals and salts; while organic solids include things like decaying plant and animal matter. We measure solids in two ways. Total dissolved solids (TDS) is a measure of solid materials that are incorporated into a solution along with water. These solids are very small and cannot be separated from the solution by filtration. Total suspended solids (TSS) is a measure of solid materials that are not in solution with water. Rather, they are suspended or floating within the water column. These solids are larger and can be separated through filtration. Both of these measures are reported as mg/L, or milligrams of solid per liter of water.

These measures inform researchers about the amount of organic and inorganic materials contained within a sample but it is important to note that these measures do not identify specific materials or sources. Neither USEPA or DEP have developed a primary maximum contaminant level (MCL) for TDS/TSS; however, a secondary MCL has been established for TDS. Chapter 93 guidelines for surface waters also establish a TDS criterion.

Conductivity

Conductivity is simply a measure of the ability of water to pass an electrical current. Conductivity of water is related to TDS because the number of dissolved solids affects how water passes electrical current. When very little dissolved solids are present, a water sample will only weakly pass an electrical current. When higher amounts of solids are present, current will pass much more readily. Conductivity is measured in micro-Siemens per centimeter, or µS/cm.

There are no MCL of Chapter 93 guidelines for conductivity. EPA has developed an aquatic life benchmark for conductivity of 300 µS/cm for streams in the Central Appalachian region. This benchmark was established using field data from West Virginia and may not be completely applicable the South Fork Tenmile Creek as Kimmel and Argent documented diverse aquatic communities in stream segments where conductivity far exceeded this threshold (Kimmel & Argent, 2012).

Metals & other compounds

The presence of various metals and compounds contribute to TDS/TSS and may be associated with one or more types of industrial pollution. For example, polluted effluents from abandoned coal mining operations often contain metals like iron, manganese, sulfate and aluminum. Another example includes contaminants associated with oil and gas drilling activities such as chloride and bromide. Contaminants of the type described here negatively affect aquatic communities and threaten to pollute drinking water supplies.

Secondary MCL have been developed for iron, manganese, aluminum, sulfate and chloride. No MCL has been developed for bromide; however, bromide in nature reacts with ozone to become bromate which has a primary MCL established as 0.010 mg/L. Chapter 93 guidelines for surface waters establish water quality criteria for Iron, manganese, sulfate and chloride.

Nitrate and phosphate

Nitrate is a naturally occurring ion of nitrogen that forms when various bacteria break down soil organic matter. Phosphate is the naturally occurring ion of phosphorous in soil and rocks. As both of these are naturally occurring ions, it is expected that low, background levels of each will be present in streams and other water bodies. Anthropogenic activities, such as agriculture, lawn and grounds maintenance, sewage treatment and various industrial processes result in much greater volumes of nitrate and phosphate entering streams. Nitrate and phosphate are both reported as mg/L.

Excessive amounts of nitrate and phosphate in streams and other water bodies drive a process called eutrophication. With dramatically more nutrients to take advantage of, plankton and algae begin unprecedented population growth. This process unbalances aquatic ecosystems and dramatically alters both aquatic habitat and water chemistry. Principle among the deleterious consequences of eutrophication is a reduction in dissolved oxygen (DO). Fish and other aquatic organisms rely on DO for survival. As DO levels drop, these individuals become stressed and will die if levels fall low enough. This process can lead to devastating fish kills.

EPA has established a primary MCL for nitrate as it can be dangerous for infants less than six months old to drink water containing larger volumes of nitrate. EPA and DEP have developed no regulatory criteria for phosphate.

Fecal Coliform Bacteria

Fecal coliform bacteria are a group of bacteria that occurs exclusively within the digestive tracts of animals and ultimately within their wastes. Their presence in water indicates that a source of animal waste, such as agricultural runoff from feedlots and pastures and failing on-lot sewage systems.

Although most coliform bacteria are harmless to humans, there are some, such as *Escherichia coli*, that do represent a human health concern. Presence of these bacteria may also indicate the presence of associated waterborne pathogens. Effects of inputs of coliform bacteria on streams and aquatic communities are similar to those of nitrate and phosphate. The organic waste that contains coliform bacteria will break down in streams promoting aerobic bacteria and driving DO down.

Turbidity and sediment

Turbidity describes the clarity of water by measuring how freely light penetrates a water sample. This measure is related to TDS/TSS as more turbid (or cloudy) samples will typically have a higher concentration of solids. Turbidity is useful to measure the amount of inorganic minerals, or sediment, within a water sample. Sediment in streams is largely attributable to erosion. Surface runoff picks up soil particles as moves through the landscape, depositing them into streams. Additionally, as runoff increases and streambanks become less stable, these areas become a source for even more sediment.

The role of sediment in degrading water quality, altering aquatic habitat and ultimately impacting aquatic communities cannot be overstated. It is the most widespread pollutant throughout Greene County, Pennsylvania and the United States. Pennsylvania DEP has not developed numeric statewide criteria for sediment. Instead they have developed narrative criteria that prohibit pollutant concentrations high enough to be harmful to a stream’s designated uses or to human and other life.

Table 3.1: Collected water chemistry variables with federal and state guidelines				
Measured variable	Reported units	EPA Drinking Water Standard		Surface Water Standard
		Primary MCL	Secondary MCL	Chapter 93 criteria by critical use Cold Water Fishery (CWF), Warm Water Fishery (WWF), Trout Stocked Fishery (TSF), Migratory Fishes (MF), Potable Water Supply (PWS) and Water Contact Sports (WC)
Conductivity	µS/cm	N/A	N/A	N/A
pH	N/A	N/A	6.5-8.5	CWF, WWF, TSF, MF - From 6.0 to 9.0 inclusive.
Alkalinity	mgCACO3	N/A	N/A	CWF, WWF, TSF, MF - Minimum 20 mg/l as CaCO3, except where natural conditions are less. Where discharges are to waters with 20 mg/l or less alkalinity, the discharge should not further reduce the alkalinity of the receiving waters.
Acidity (Hot)	mgCACO3	N/A	N/A	N/A
Total Suspended Solids	mg/L	N/A	N/A	N/A
Total Dissolved Solids	mg/L	N/A	500 mg/L	PWS - 500 mg/l as a monthly average value; maximum 750 mg/l
Turbidity	ntu	N/A	N/A	
Sulfate	mg/L	N/A	250 mg/L	PWS - Maximum 250 mg/l.
Iron	mg/L	N/A	0.3 mg/L	CWF, WWF, TSF, MF - 30-day average 1.5 mg/l as total recoverable.
				PWS - Maximum 0.3 mg/l as dissolved.
Manganese	mg/L	N/A	0.05 mg/L	PWS - Maximum 1.0 mg/l, as total recoverable.
Aluminum	mg/L	N/A	0.2 mg/L	N/A
Chloride	mg Cl-/l	N/A	250 mg/L	PWS - Maximum 250 mg/l.
Bromide	mg/L	As Bromate 0.01 mg/L	N/A	N/A
Nitrate	mg/L	10 mg/L	N/A	N/A
Fecal Coliform Bacteria	#/100mL	No more than 5.0% samples total coliform-positive (TC-positive) in a month	N/A	WC - (Fecal coliforms/ 100 ml)—During the swimming season (May 1 through September 30), the maximum fecal coliform level shall be a geometric mean of 200 per 100 milliliters (ml) based on a minimum of five consecutive samples each sample collected on different days during a 30-day period. No more than 10% of the total samples taken during a 30-day period may exceed 400 per 100 ml. For the remainder of the year, the maximum fecal coliform level shall be a geometric mean of 2,000 per 100 milliliters (ml) based on a minimum of five consecutive samples collected on different days during a 30-day period.
				PWS - (Coliforms/100 ml)—Maximum of 5,000/100 ml as a monthly average value, no more than this number in more than 20 of the samples collected during a month, nor more than 20,000/100 ml in more than 5% of the samples.
Phosphate	mg/L	N/A	N/A	N/A

3.3 Results

Laboratory testing

Values of pH ranged from 7.41 to 8.44 indicating neutral to basic conditions. Conductivity ranged from 292 µS/cm to 743 µS/cm and Total Dissolved Solids ranged from 164 mg/L to 492 mg/L. Metals commonly associated with mining activities such as iron, manganese and aluminum were present in samples but were not found in high concentrations. Bromide, which has received increased awareness as a pollutant associated with oil and gas development was detected in only one sample and even then, in a low amount (Table 3.2). These are all reasonable results that do not indicate pollution from industrial sources. In comparison with the above discussed pollutant load standards, these stream segments are meeting the appropriate surface water standards as a warm water fishery (WWF).

Nitrate and phosphate were present in most samples as were fecal coliform bacteria (Table 3.2). Some difficulty detection occurred with these parameters due to sample hold times. The presence of these pollutants suggests that non-point sources of nutrients are influencing water chemistry. Additionally, failing on-lot septic or wildcat septic systems may play a role.

Habitat Assessment

Instream comprehensive evaluation (ICE) scores ranged from marginal to optimal with most sites falling into the sub-optimal range (Table 3.3). Sediment deposition and embeddedness were widespread issues. Lack of habitat diversity was another. Riffle habitats were found to be particularly infrequent at sample sites. Riparian vegetation zone width was a problem at virtually every site visited.

Table 3.2: Laboratory water chemistry results

Map Reference	Site Name	Temperature	Conductivity	pH	Alkalinity	Acidity (Hot)	Total Suspended Solids	Total Dissolved Solids	Turbidity	Sulfate	Iron	Manganese	Aluminum	Chloride	Bromide	Nitrate	Fecal Coliform Bacteria	Phosphate
		°(C)	µS/cm		mgCACO3	mgCACO3	mg/L	mg/L	ntu	mg/L	mg/L	mg/L	mg/L	mg/l	mg/L	mg/L	#/100ml	mg/L
10	Hargus Creek	21.70	292	7.55	pH4.5=110	pH8.3=-106	12.0	164.0	N/A	12.4	0.6	0.2	0.4	9.0	ND	N/A	N/A	N/A
18	Upper Ruff Creek	8.55	306	7.48	pH4.5=105	pH8.3=-99	7.0	186.0	2.3	22.1	0.3	0.04	0.1	14.0	ND	<0.1	172	0.04
12	Lower McCourtney Run	15.90	438	7.51	pH4.5=111	pH8.3=-106	10.0	187.0	N/A	16.7	0.4	0.1	0.1	17.5	ND	N/A	N/A	N/A
6	Claylick Run	15.15	368	7.67	pH4.5=129	pH8.3=-125	24.0	205.0	11.0	10.7	1.7	0.7	0.7	12.5	ND	<0.1	N/A	N/A
9	Bates Fork	19.25	357	7.76	pH4.5=132	pH8.3=-128	21.0	210.0	4.8	11.5	0.6	0.2	0.3	12.0	ND	<0.1	N/A	N/A
21	Upper South Fork Tenmile Creek 2	16.50	422	7.98	pH4.5=128	pH8.3=-124	23.0	243.0	8.3	30.1	0.9	0.4	0.4	30.0	ND	<0.1	390	N/A
3	Brown's Run	8.95	418	7.70	pH4.5=172	pH8.3=-166	<5.0	254.0	0.4	40.8	0.1	<0.01	0.1	10.0	ND	<0.1	19.0	<0.03
11	Upper McCourtney Run	20.50	318	7.97	pH4.5=122	pH8.3=-117	11.0	256.0	N/A	15.8	1.0	0.2	0.4	51.5	ND	N/A	N/A	N/A
19	Lower Ruff Creek	10.15	451	7.41	pH4.5=138	pH8.3=-133	16.0	261.0	3.1	39.9	0.4	0.1	0.1	24.0	ND	<0.1	51	0.03
23	Mouth of South Fork Tenmile Creek	9.20	465	8.18	pH4.5=114	pH8.3=-108	6.0	278.0	1.5	51.4	0.4	0.02	0.1	32.0	ND	<0.1	13	0.09
13	Lower Patterson Creek	18.25	483	8.00	pH4.5=151	pH8.3=-147	11.0	279.0	3.2	24.5	0.3	0.1	0.2	23.5	ND	0.158	N/A	N/A
1	Upper Brown's Creek	19.60	447	8.05	pH4.5=166	pH8.3=-162	18.0	282.0	3.4	18.0	0.4	0.05	0.2	17.0	ND	<0.1	N/A	N/A
14	Upper Patterson Creek	18.35	476	8.21	pH4.5=199	pH8.3=-194	23.0	283.0	5.2	23.9	0.3	0.1	0.2	10.5	ND	<0.1	N/A	N/A
7	Craig Run	8.25	468	7.67	pH4.5=189	pH8.3=-183	8.0	288.0	1.3	40.0	0.2	0.1	0.1	7.5	ND	<0.1	44	0.03
20	Upper South Fork Tenmile Creek 1	15.90	522	7.82	pH4.5=131	pH8.3=-127	19.0	296.0	10.0	35.4	1.2	0.3	0.6	44.0	ND	<0.1	N/A	N/A
15	Purman Run	10.95	535	8.21	pH4.5=132	pH8.3=-125	<5.0	307.0	0.45	53.0	1.3	0.1	0.7	52.5	ND	<0.1	237	<0.03
4	Upper Castile Run	10.60	514	7.60	pH4.5=171	pH8.3=-166	9.0	309.0	0.55	65.3	0.1	0.03	0.1	8.0	ND	<0.1	40	<0.03
24	Smith Creek	12.40	570	8.03	pH4.5=188	pH8.3=-182	6.0	341.0	0.95	75.1	0.2	0.2	0.1	23.5	ND	<0.1	58	<0.03
22	Lower South Fork Tenmile Creek	11.55	522	8.44	pH4.5=114	pH8.3=-108	35.0	344.0	3.6	81.0	1.7	0.1	1.1	36.5	ND	<0.1	120.0	0.06
16	Lower Pursley Run	14.35	601	8.00	pH4.5=219	pH8.3=-215	18.0	349.0	8.2	46.0	1.0	0.2	0.4	23.0	ND	<0.1	140	N/A
2	Boyd Run	8.95	686	8.14	pH4.5=166	pH8.3=-160	5.0	385.0	0.9	41.5	0.3	0.1	0.1	76.0	ND	<0.1	62	<0.03
17	Upper Pursley Run	13.95	634	8.20	pH4.5=222	pH8.3=-218	<5.0	410.0	2.1	48.5	0.2	0.04	0.1	30.5	ND	<0.1	168	N/A
8	Gray's Fork	13.75	743	8.11	pH4.5=154	pH8.3=-149	11.0	427.0	3.2	67.1	0.4	0.1	0.2	76.0	0.34	<0.1	N/A	N/A
5	Lower Castile Run	9.80	719	8.07	pH4.5=174	pH8.3=-167	9.0	492.0	1.5	155.5	0.2	<0.01	0.1	7.5	ND	<0.1	14	<0.03

Table 3.3: ICE habitat assessment results

Map Reference	Site Name	Instream Cover (Fish)	Epifaunal Substrate	Embeddedness	Velocity/Depth Regimes	Channel Alteration	Sediment Deposition	Frequency of Riffles	Channel Flow Status	Condition of Banks	Bank Vegetation Protection	Grazing or Other Disruptive Pressure	Riparian Vegetative Zone Width	Total	Score
10	Hargus Creek	9	6	8	5	13	10	5	14	11	10	10	10	111	Suboptimal
18	Upper Ruff Creek	7	5	5	5	6	1	5	6	10	10	10	1	71	Marginal
12	Lower McCoutrney Run	16	11	11	10	14	13	15	15	15	15	15	5	155	Optimal
6	Claylick Run	14	9	10	10	20	5	10	10	5	10	12	6	121	Suboptimal
9	Bates Fork	16	12	11	10	15	13	11	15	15	14	13	10	155	Optimal
21	Upper South Fork Tenmile Creek 2	5	5	5	5	10	13	3	6	9	11	10	2	84	Marginal
3	Brown's Run	5	6	5	8	11	5	11	9	5	10	11	5	91	Marginal
11	Upper McCourtney Run	11	7	7	11	13	13	15	11	10	10	12	3	123	Suboptimal
19	Lower Ruff Creek	10	11	10	10	12	13	11	14	5	7	10	5	118	Suboptimal
23	Mouth of South Fork Tenmile Creek	8	8	8	7	15	13	11	10	13	14	11	5	123	Suboptimal
13	Lower Patterson Creek	13	10	12	13	13	12	15	14	12	16	20	10	160	Optimal
1	Upper Brown's Creek	9	7	6	6	11	8	8	10	11	15	17	6	114	Suboptimal
14	Upper Patterson Creek	10	8	5	10	11	1	3	9	13	11	2	2	85	Marginal
7	Craig Run	15	3	5	5	13	5	5	10	11	7	11	5	95	Suboptimal
20	Upper South Fork Tenmile Creek 1	10	13	11	14	11	10	13	17	13	10	10	5	137	Suboptimal
15	Purman Run	16	5	6	1	13	11	2	12	11	11	8	1	97	Suboptimal
4	Upper Castile Run	14	10	13	14	14	15	11	13	10	7	10	5	136	Suboptimal
24	Smith Creek	10	8	10	10	13	10	6	7	3	9	8	5	99	Suboptimal
22	Lower South Fork Tenmile Creek	20	11	13	10	13	14	8	15	14	13	13	5	149	Optimal
16	Lower Pursley Run	20	14	9	12	19	9	10	15	10	11	13	5	147	Optimal
2	Boyd Run	10	8	5	10	10	10	9	13	11	6	8	4	104	Suboptimal
17	Upper Pursley Run	12	8	10	10	8	11	11	16	14	9	7	1	117	Suboptimal
8	Gray's Fork	15	13	9	11	13	13	10	15	15	15	13	6	148	Optimal
5	Lower Castile Run	10	10	11	8	10	5	7	13	11	13	10	2	110	Suboptimal

Taken together, these results are indicative of a watershed plagued more by NPS pollutants such as sediment and nutrients while other sources of pollution from industrial sources play a much smaller and less widespread role in degrading water quality.

4. Water Quality Protection and Restoration

4.1 Addressing Non-Point Source Pollution

In reviewing water quality conditions across all seven sub-watersheds, it is apparent that NPS pollution and sediment deposition are the most ubiquitous sources of water quality impairment. Therefore, any strategy for restoring and conserving water resources within the South Fork Tenmile Creek Watershed must include measures to reduce and manage surface runoff, isolate sources of NPS pollutants and reduce susceptibility of streambanks to erosion. Critical among these measures are reestablishment of streamside forests, implementation of agricultural best management practices and development of stormwater management.

Stabilization of streambanks and protection of at-risk streambanks

Steep, eroded streambanks are not only a risk to the communities that they occur within. These banks also represent a source of sediment and other NPS pollutants. Streambank stabilization projects tend to face fewer challenges in obtaining landowner approval than some of the practices discussed below. Landowners are often aware of problems with encroachment of streams and are anxious to avoid property loss. As noted throughout this assessment, a large proportion of the development in the South Fork occurs in the more-level valley bottoms. This creates a challenge for stabilization as structures and activities occurring directly adjacent to the stream must, in some cases, be relocated. Funding is another challenge for projects of this type. Many state grants are interested in water quality improvement rather than flood control or protection of personal property. Establishing a need for water quality improvement based solely on sediment can be challenging and time consuming. Overcoming these challenges should involve good data collection to document water quality impairment from sediment and other NPS pollutants to leverage available grant funding. It should also include concerted outreach promoting protection or establishment of vegetation on streambanks. Furthermore, education on minimizing activities that damage streamside vegetation should be developed. Where practical, projects should be pursued to reshape steep, eroded banks and reestablish non-intact streamside vegetation.

Reestablishment of streamside forests

The role of streamside forests in determining stream health is well documented within the scientific literature. These areas host diverse ecosystems that protect water quality, promote biodiversity, increase soil health and reduce flood risks. At the same time, they provide recreational, economic and aesthetic opportunities to landowners. Healthy streamside forests control erosion by stabilizing soils and reducing the volume and velocity of surface runoff. They promote healthy channel development and habitat structure. They provide thermal regulation by shielding streams from solar radiation. Additionally, these areas trap sediment, nutrients and other non-point source pollutants originating in upland areas. Streamside forests provide nutrient storage and conversion through natural biological cycles and are a critical source of nutrients for aquatic communities (Welsch, 1991; Bentrup, 2008).

Protection of streamside forests should be a priority throughout those portions of the watershed where they remain intact. In areas where agricultural and other development has eliminated streamside forests, reestablishment through implementation of riparian buffers is equally important. It is important to note that the bulk of lands where implementation of riparian buffers would be most beneficial are privately owned. Private land ownership complicates reestablishment of streamside forests as adoption of riparian buffers by landowners faces many challenges.

Research has shown that landowners typically value streams and natural areas for both for their ecological and aesthetic values. When asked about a landowner's responsibility to conserve these resources, most respondents assent to that such a responsibility exists (Drutcher et al., 2004). Further, when asked to make a photographic choice between streams with well-forested buffers and deforested riparian areas, most respondents selected the more forested images (Shandas, 2007). Given that landowners generally believe that they have a responsibility to conserve natural resources and they generally believe that natural forested streams are preferable, it would seem that adoption of riparian buffers would be near universal. Unfortunately, this is not the case. The dissonance between a landowner's expressed environmental values and his or her decisions regarding adoption of riparian buffers stems from economic and societal concerns.

Riparian buffer adoption requires commitment of resources on the part of the landowner and a sacrifice of previous land use, such as pasture land, lawn or other use. They will sacrifice the alternative cost derived from that previous land use while the benefits of the riparian buffer are more abstract and therefore difficult to quantify (Shandas, 2007). After adoption, landowners must undertake management and maintenance of these areas. Research has shown the landowners perception of this maintenance burden to vary by the land use background of the individual landowner. Traditional farmers accepted the additional maintenance, while hobby farmers and non-farmers felt the additional maintenance to be an imposition (Armstrong, 2010).

Economic concerns are not the only challenges to adoption of riparian buffers by landowners. Societal standards of neatness and a landowner's perception of their obligation to maintain these standards affect adoption of riparian buffers. Landowners have expressed a view of riparian buffers as not meeting these societal standards of neatness. Also at play is the difficulty in overcoming traditional management strategies. Many landowners are reluctant to adopt new management strategies simply because this means abandoning what they know and are familiar with. Like any new practice there is uncertainty associated with riparian buffers. Many landowners are concerned that riparian buffers will exacerbate flooding or reduce property values. Others question their effectiveness or their ability to improve water quality (Drutcher et al., 2004).

Additionally, many landowners are unaware of, or are unwilling to accept, their own role in determining water quality throughout a larger watershed. Landowners tend to downplay their own contribution to water pollution and often blame others for water quality impairment (Drutcher et al., 2004). Many landowners simply do not believe that their activities are significant to water quality and view pressure to adopt riparian buffers as an intrusion on their right to determine how their land is managed. This is particularly evident with smaller streams that may flow intermittently Many landowners are mistrustful of government agencies and environmental advocacy groups. At the heart of this discussion is a fear of losing control of their land and future (Drutcher et al., 2004; Shandas, 2007; Armstrong, 2010).

Long-term success of riparian buffer adoption requires commitment on the part of the landowner that can only be achieved when they choose to adopt riparian buffers. Regulatory or programmatic pressure to adopt riparian buffers results in negative views of the buffers themselves. Consider financial incentive programs that include riparian buffers as a requirement for some other benefit; say for example, that an agricultural landowner is interested in adopting some BMP and is required to adopt riparian buffers as a condition of funding. Landowners in these situations feel that they did not choose to adopt but were forced into it. Such programmatic pressure results in a negative perception of riparian buffers, less personal ownership of the practice and oftentimes abandonment of the practice over time (Shandas, 2007; Armstrong, 2010). Instead, efforts should be focused on appeals to landowner's expressed values of environmental stewardship that overcome the economic and societal concerns associated with adoption and dispel the uncertainty surrounding riparian buffers (Drutcher et al., 2004; Armstrong, 2010).

In order to encourage landowners to adopt riparian buffers, we need to first overcome the perception that an individual landowner's riparian management activities do not have a tangible effect on water quality (Drutcher et al., 2004). Many landowners seem to recognize that they, along with all the other land owners within a watershed, collectively determine water quality. Unfortunately, this recognition does not usually translate to a feeling of empowerment in determining improvement in water quality. This is especially true among landowners who have small parcels, agricultural landowners who have small or hobby farms and landowners who live in more developed areas. These landowners in often feel that any contribution they make to improved water quality will be negated by other landowners that they perceive to have more impact, such as those who have larger farms or more intense development (Armstrong, 2010). Outreach should be community focused and promote empowerment of individual landowners, particularly those that may feel marginalized (Drutcher et al., 2004).

Once landowners are convinced that their riparian management activities have the potential to increase or decrease water quality in their community, we need to convince them that riparian buffers are an effective management practice that will improve water quality. Challenges include overcoming the mistrust noted above and avoiding perceptions of regulatory and programmatic pressure. Overcoming this challenge involves outreach to various types of landowner that typically obtain their information from a diverse range of sources (Shandas, 2007; Armstrong, 2010). To effectively reach various landowner types, we need to develop a consistent, concise and palatable message that taps farm and conservation organizations as well as traditional media and existing social networks.

This message needs to do several things in order to be successful. First it must recognize the concerns that landowners have about adopting riparian buffers, including flood risk concerns, questions of neatness and impacts on property values. It must recognize and justify the sacrifices that a landowner will make through adoption by showing through credible and accessible evidence that riparian buffers are an effective and necessary best management practice. It should make good use of financial incentives, including tax breaks, cost sharing programs and easements to offset those sacrifices. Finally, it needs to work past the perception that buffers are a governmental intrusion on private land management and create a sense of ownership on the part of the landowner that leads to satisfaction from choosing to make a difference in water quality (Drutcher et al., 2004; Shandas, 2007; Armstrong, 2010).

Agricultural Best Management Practices

Agricultural best management practices conserve soil health and protect water quality. They do this by reducing erosion and isolating pollutants associated with livestock propagation or crop cultivation. Reduced erosion results in lower sediment loads to streams. Isolating sources of phosphorous, nitrogen and other agriculturally-associated pollutants from runoff protects aquatic streams from degradation. Examples of agricultural best management practices include manure storage facilities, animal heavy use areas, streambank fencing, woodlot exclusions, winter feeding areas and watering systems, as well as grazing systems and manure and nutrient management plans (Chaubey et al., 2010). These practices have been shown to be effective by government studies, university research laboratories and on working farms across the nation and world.

Agriculture is a dominant land use in virtually every subwatershed of the South Fork Tenmile Creek Watershed. Multiple stream segments within the South Fork are listed as impaired by DEP due to agriculture and siltation. Beyond this, sediment and other NPS pollution are the primary water quality impairments throughout the South Fork. Installation and implementation of agricultural best management practices that isolate sources of NPS pollutants and reduce sediment loads to streams are a major need and should be a priority for restoration. As with the restoration of streamside forests, the bulk of lands where implementation of agricultural BMP would be advantageous are privately owned. Likewise, landowner implementation of agricultural BMP meets with some of the same socioeconomic challenges.

As in the discussion of streamside forests above, farmer landowners generally value natural resources and hold to an ideal of environmental stewardship. At the same time, they often do no perceive their land management activities as contributing to water quality degradation. Overcoming this widely held perception that farming practices are not important in protecting and restoring water quality is a critical first step in implementing this assessment. At the same time, it is not simply a matter of confronting farmer landowners with evidence to the contrary of their perception. Instead a well-planned and -executed outreach program that, like above, delivers a consistent, concise and palatable message through farm and conservation organizations as well as traditional media and existing social networks is necessary.

While most if not all agricultural practices provide a benefit to the landowner, all require a sacrifice on the part of the landowner. This may involve taking on additional maintenance responsibility, sacrificing an alternative use of some resource or simply the cost of implementing the practice. Farmer landowner attitudes towards conservation practices can be affected by farm size. Research indicates that while farmers of small farms and rural non-farmers typically have a more positive attitude toward the environment, these landowners are less likely to adopt BMP than farmers of large farms. This is attributed by some authors to a disconnect between these landowners and the outreach programs promoting BMP implementation, which are generally directed to farmers of larger farms (Perry-Hill & Prokopy, 2014).

It should also be recognized that farmers of small farms, or hobby farms as they are sometimes called make up the majority of agriculture in the South Fork Tenmile Creek Watershed. Large farms, operated as a primary means employment are not common within the watershed. Much more common are small farms where the primary farmer works a full-time job and still maintains necessary work on the farm. Farms like these are often less able to absorb the costs associated with BMP implementation. This is true of the financial costs as well as more indirect costs such as loss of pasture area. When your farm is small to begin with, the message that you need to sacrifice part of it for the good of the environment is a difficult sell.

Outreach should recognize the sacrifice being asked of farmer landowners and justify implementation through credible and accessible evidence that individual practices are both necessary and effective. Proper application of existing financial incentives, including tax breaks, cost sharing programs and easements may offset some sacrifices of the landowner. Special care should be taken to include resources for small farms. All of these things work in concert to encourage farmer landowners to adopt these practices willingly rather than through regulatory or programmatic pressure which often leads to poor perceptions of the practice and eventual practice abandonment.

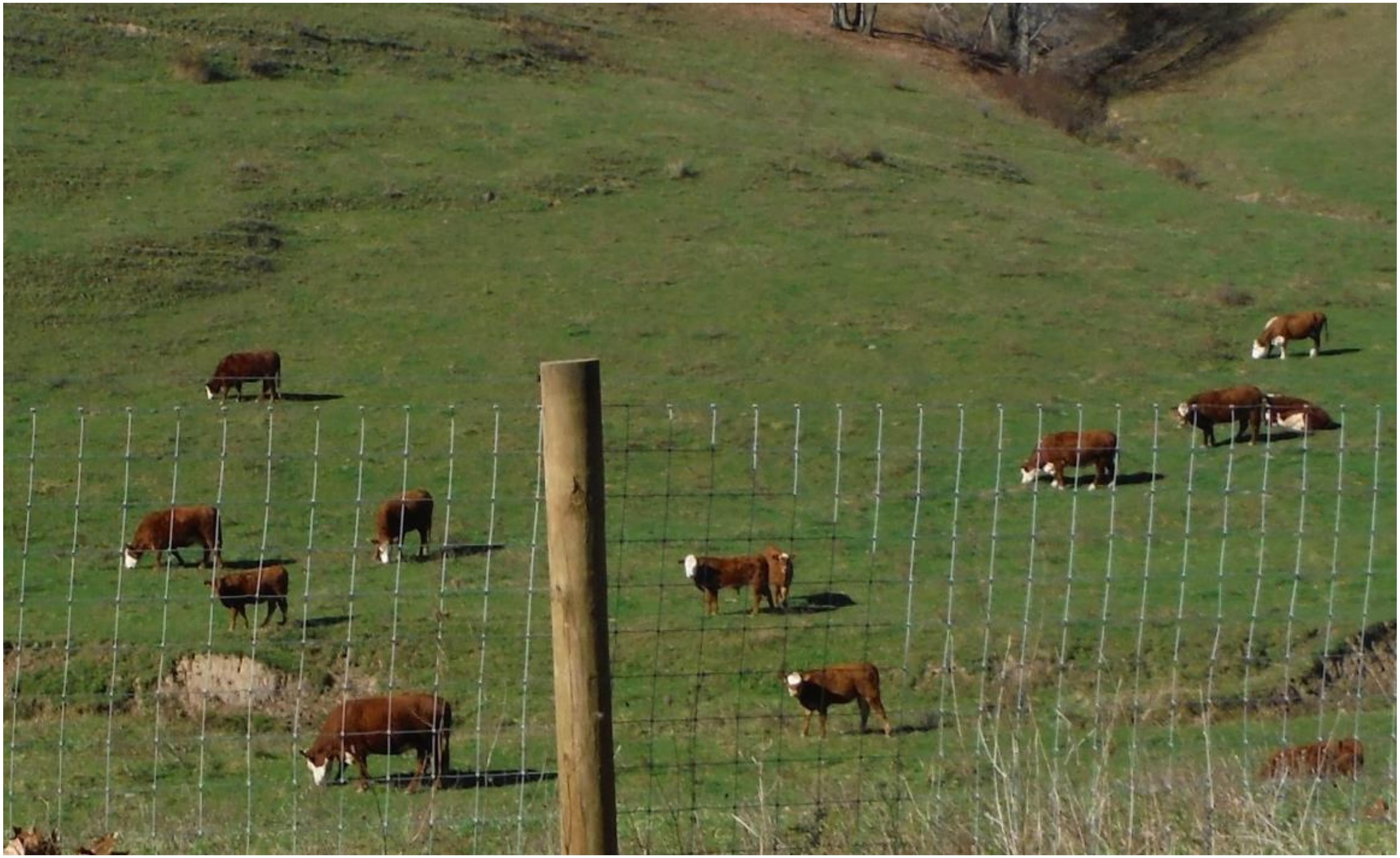
As part of the assessment process, we noted numerous sites where implementation of agricultural BMP would benefit water quality. The following are by no means an exhaustive list and are merely meant to serve as examples of potential sites and conditions where improvement can be made

In this example, what appears to be an uncovered manure pile is stored directly adjacent to the stream. Water quality would benefit from construction of an appropriately situated manure storage facility to isolate this source of pollution. This stream also lacks any protection by a riparian buffer. Implementing a buffer would protect the stream from further pollution.

This site is a pasture with no streambank fencing to exclude livestock and no riparian buffers to protect the stream. Livestock are seen crossing the stream, causing mechanical destabilization of the banks and risking injury to themselves. Implementing riparian buffers, streambank fencing and an agricultural stream crossing would better protect water quality in this stream. Off-stream watering systems could also be developed as part of any potential project.

Erosion action is evidenced in this photograph by steep banks, fallen trees and step formation on the hillside. Aside from a few trees, the streambanks lack riparian vegetation. Additionally, livestock congregate at this feeding site which is located directly adjacent to the stream. Relocating this feeding site and providing heavy use protection would be a good start towards isolating this source of pollution. Fencing the streambanks and developing riparian buffers would provide additional protection.

This site lacks exclusionary fencing and cattle are seen near and even in the stream. The banks are steep and eroded. The stream has even undercut the fencing now extends beyond it by several feet. Exclusionary fencing and riparian buffer development in conjunction with bank shaping would likely restore this site and improve water quality.



This site exhibits steep, eroded stream banks and step formation upslope. Water quality at this site would benefit from streambank exclusionary fencing and woodlot exclusionary fencing as this would isolate pollutants from areas of concentrated flow and ultimately from the stream. Development of riparian buffers would further protect the stream from pollutants. An agricultural crossing placed on the smaller stream would facilitate livestock movement with minimal impact on the stream.

The barnyard shown in this site has a small stream flowing through it that lacks all protection. It is directly adjacent to a roadway and therefore has little to no vegetation on either bank. Establishing full riparian buffers for this stream is likely not an option at this site given available space. Implementing heavy use protection and working with the operator to establish some riparian protection for this stream are likely the best options for improving water quality at this site.

The stream at this site is located immediately adjacent to the feeding troughs pictured near the center of the picture. Nearly all vegetation in this area is gone to high livestock traffic. On the far side of the stream is an additional feeding site that is also extensively devoid of vegetation. Relocating these troughs, livestock exclusionary fencing and development of a riparian buffer in this area would improve water quality in this stream. Implementing heavy use protection on the relocated feeding area would further isolate these sources of pollution.

This site has two small streams converging in area where livestock congregate. Clearly the stream has no protection from sediment and nutrient pollution. Viewing the top, left hand corner of the photograph indicates that livestock are being fed directly upslope of this stream. Relocating this feeding site and implementing heavy use protection would isolate this source of pollution. Livestock exclusionary fencing and development of a riparian buffer would further protect the stream from sediment and nutrient pollution.

Stormwater Management

The problems of stormwater management are intrinsically tied to any discussion of erosion, sedimentation and other forms of NPS pollution because it is the stormwater runoff that drives these processes. Anthropogenic landscape conversion is responsible for increased surface runoff in the South Fork Tenmile Creek Watershed and throughout Greene County. This is largely due to insufficient stormwater management to offset increases in impervious surfaces from development. This is especially true for the South Fork Tenmile Creek Watershed as it contains the majority of the county's urbanized areas. Whether due to aging infrastructure, inadequate infrastructure, or lack of infrastructure; virtually every municipality is overwhelmed by peak surface runoff. Functionally, this increases flood frequency and magnitude, reduces groundwater recharge, accelerates soil erosion, drives nonpoint source (NPS) water pollution, and alters the structure and function of surface water bodies.

As economic development comes to the South Fork, stormwater management problems will only get worse. At the present time, the entire county is experiencing the latest in a series of drilling booms for oil and gas resources. It is important to note that this development represents a surge in impervious surface across the county. Well pads and other infrastructure have sprung up in the portions of the county that are historically least likely to see dramatic increases in impervious surfaces and therefore least prepared to manage these increased stormwater loads. Landowners and municipalities are struggling to manage increased stormwater volumes and velocities.

As discussed above, the county does not yet have an approved Storm Water Management Plan under Pennsylvania Act 167. Having a Storm Water Management Plan under Pennsylvania Act 167 would benefit many of the communities in the South Fork by aiding municipalities in developing consistent ordinances and standards for managing runoff from new development.

While that would help with future development, it would do little to ameliorate stormwater management problems from existing or historical development. Abandoned industrial sites, or brownfields, mentioned in the first part of this assessment, are often a source of NPS pollution and therefore a concern for stormwater management. The Greene County Brownfield Redevelopment Advisory Committee is currently undertaking an inventory of brownfield sites. Projects should be developed to address pollution from these site-specific stormwater management problems.

In broader terms, however most stormwater management problems are not site-specific and require cooperation of entire communities. Some of the things already discussed will help with stormwater management. Reestablishment of streamside forests will provide some protection to streams from runoff. Implementation of BMP on agricultural sites would isolate vast sources of NPS pollutants. Beyond these, general stormwater BMP designed to increase infiltration and slow runoff are effective strategies that should be installed and implemented across the watershed.

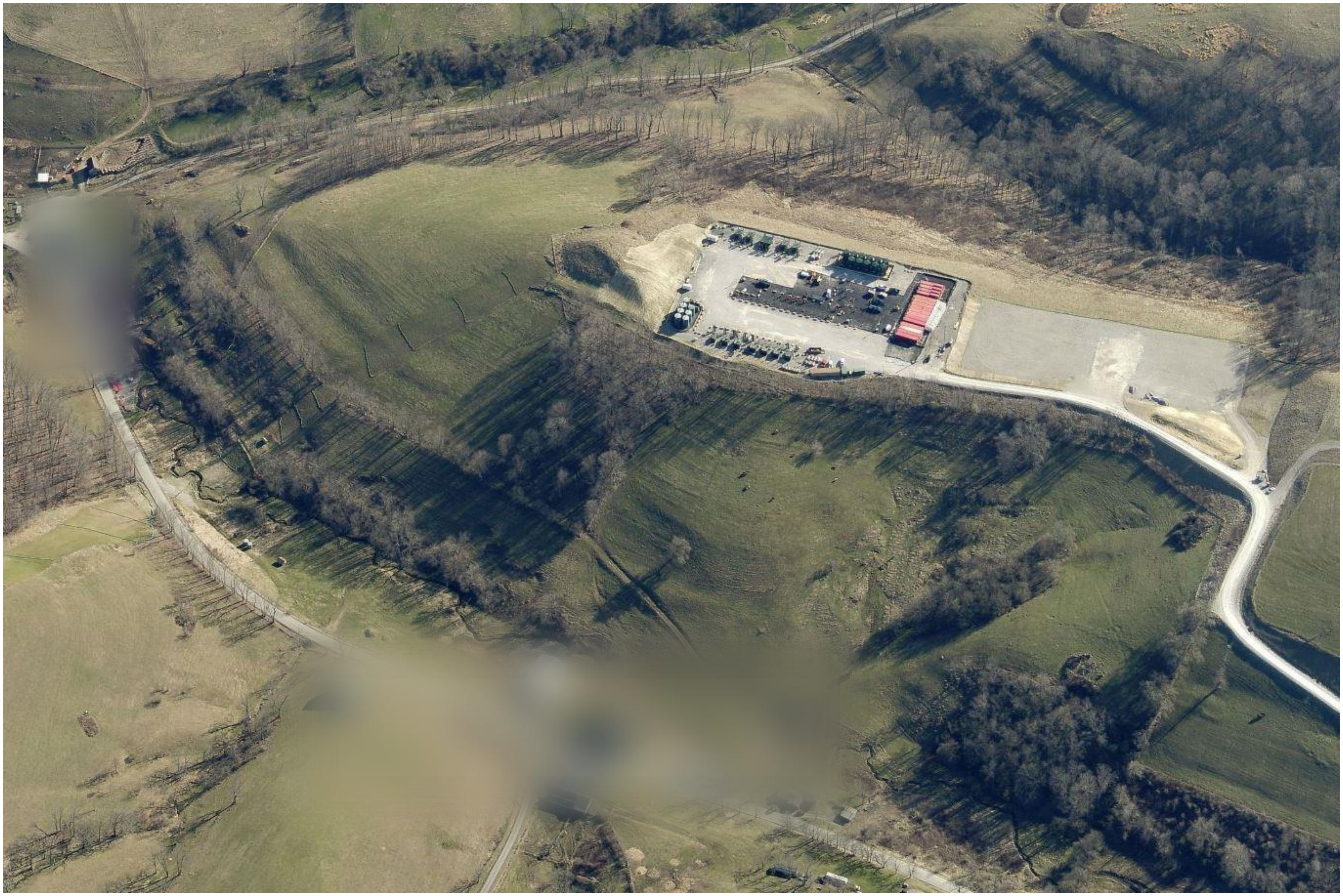
While our discussion of riparian buffers and agricultural BMP involved predominantly private lands, the bulk of stormwater management projects will likely be done in cooperation with municipalities. It is important to recognize the challenges faced by municipalities. Many of the municipalities in the South Fork have large surface areas and small tax bases. These municipalities often struggle with limited budgets and manpower. Both are often stretched simply to maintain roads, facilities and other municipal responsibilities. From the perspective of many municipalities, stormwater concerns center around flooding and property damage rather than the effects of NPS pollution on stream water quality. Programs that would add to their workload or require large funding amounts are likely to be shunned by these municipalities.

Instead, programs need to be designed in ways that help municipalities complete their necessary functions while improving either their practices or facilities. A great example is the Dirt, Gravel and Low-volume Roads program, administered by the Conservation District. This program helps municipalities to make improvements to their roads that result in water quality protection. Building close relationships with municipal leaders is a critical step in developing projects that will improve existing stormwater management and implementing stormwater BMP into future development.

One of the critical pathways to improve stormwater management in the South Fork is education targeting both municipal leaders and the general public. Historic misconceptions about stormwater management persist today and affect water quality throughout the South Fork. Many people still believe that the best way to manage stormwater is to direct it to a stream as quickly as possible. The idea that an ideal stream channel is deep, wide and straight is unfortunately still with us as well.

We have discussed education programs above and many of the same ideas hold true here. Information needs to be presented in a way that recognizes the challenges and concerns of both municipal leaders and the public. It needs to be processed through existing social networks. Finally, it must be credible and based on sound logic.

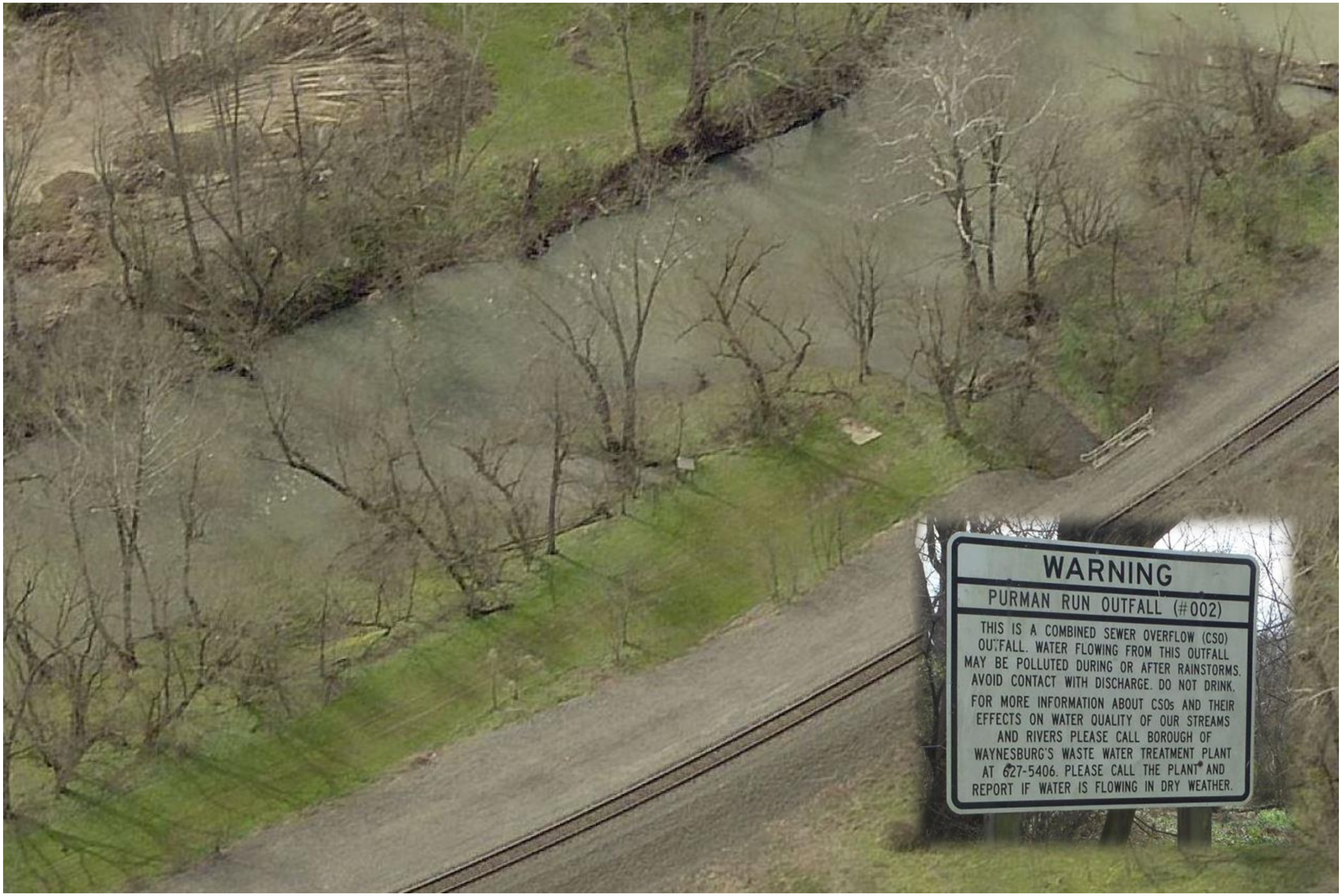
As with our discussion of agricultural BMP, we are including some examples of sites where stormwater practices may be improved as examples. The difficulty with stormwater management is that the problem shown at one site may not be a direct result of stormwater management problems at that site but at multiple upslope or upstream sites. The first photograph below is an example of this as the downslope landowners must contend with runoff from upslope land uses. The second two photographs show sites where it is in fact the on-site land management in the form of aggressive lawn maintenance that is contributing to the problem.



This photograph shows multiple land uses. Homes, farms and businesses are interspersed with energy extraction infrastructure. While this infrastructure is required to include erosion and sediment controls, it translates to increased impervious surface and increased surface runoff that downslope landowners must manage. Parts of this image have been obscured to preserve landowner's privacy.

This site features two streams, both of which exhibit highly eroded banks. Neither stream is protected by riparian vegetation as the currently land management includes mowing to the edge of the streambank. Water quality at this site would benefit from bank shaping and development of riparian buffers. Parts of this image have been obscured to preserve landowner's privacy.

Again, the banks at this site are highly eroded due to lack of riparian vegetation. Water quality at this site would benefit from bank shaping and development of riparian buffers. Parts of this image have been obscured to preserve landowner's privacy.



Near the center of this photograph is the discharge point of one of Waynesburg Borough's combined sewer overflows (CSO) and an associated warning sign. The inset photograph shows detail of the warning sign. Water quality in the South Fork Tenmile Creek would benefit from the elimination of this and other CSO.

This photograph shows a section of the South Fork Tenmile Creek near Waynesburg. On the southern bank, are situated railroad tracks and coal mining infrastructure. On the northern bank are a scrap metal dealer, roadways and other businesses. Note that riparian vegetation is thin throughout most of this reach and therefore affords little protection to the stream. It should also be noted that the section of the South Fork directly downstream is listed as impaired. Implementing stormwater management BMP to manage runoff and isolate sources of pollution would improve water quality in this section of the stream.

4.2 Monitoring and Elimination of Mining Discharges

Pennsylvania's bituminous coal region has long been a center of discussion regarding the remediation of abandoned mine sites. There are a number of organizations that exist to provide financial and technical assistance in these efforts, such as the DEP's Bureau of Abandoned Mine Reclamation (BAMR) and the Western Pennsylvania Coalition for Abandoned Mine Reclamation (WPCAMR).

The role of the Conservation District in mine reclamation has been limited in recent years, largely due to the dearth of active watershed associations within the county. Such organizations typically spearhead mine reclamation activities with assistance from organizations like the Conservation District and those listed above.

That is not to say that there are not opportunities for reclamation projects. Work is currently being conducted by DEP to eliminate the Mather site as a source of pollution. Other legacy sites exist within these eastern portions of the watershed where the footprint of underground mining is most heavily felt. Additionally, actively permitted mines discharge into streams throughout the watershed.

Monitoring

Monitoring water quality below both legacy and active mine discharge sites should be undertaken throughout the watershed. The potential for polluted discharges is closely related to water depths in mine pools which are driven by runoff and infiltration. Therefore, this potential is only exacerbated by increased stormwater volumes. This underscores the need for comprehensive stormwater management as described below.

Challenges in establishing long-term monitoring projects include equipment costs and manpower. The initial cost of equipment and ongoing costs of maintenance can often be offset by grant funds. Identifying a reliable source of manpower can prove problematic. Partnering with existing groups, such as watershed associations, civic organizations, sportsmen's clubs and universities offer a solution. The principle difficulty here is creating and maintaining interest in the project.

Establishment of long-term monitoring sites either independently or in concert with other conservation groups is a need to identify further and future issues related to mining

Watershed Associations

Monitoring projects and potentially restoration projects would become more feasible with increased cooperation between the Conservation District and existing watershed-based groups, such as the Harry Enstrom chapter of the Izaak Walton League, Greene County Watershed Alliance and the Tenmile Creek Watershed Association. While these groups do some monitoring, advocacy and outreach; none are actively engaged in the work of restoration.

Existing watershed associations are declining across the state from several causes. Principle among these is lack of membership. Memberships in watershed groups are down overall and mean ages of membership are trending upward. This means that young people are not taking an active role within these groups. Outreach to promote awareness and encourage involvement on the part of the general public could possibly reverse these trends. Education should focus in younger demographics and be based on sound science.

Restoration Projects

Developing Restoration projects for AMR sites faces some of the same challenges as other types of projects as they often take place on private land. Treatment system construction occupies land; meaning that the landowner sacrifices alternative land uses. In addition to this cost, regular maintenance, upkeep and repairs are necessary to keep the system functioning. It is important to determine who is responsible for these services and where funding will come from.

Finally, there are the legal ramifications of installing a treatment system. All treatment systems discharge treated water into a nearby waterbody. There is concern over whether this discharge is treated as a pollutant, necessitation a National Pollution Discharge Elimination System permit and the associated mandatory testing and reporting. While Pennsylvania has enacted a Good Samaritan Law that shields landowners and watershed groups from liability, there is currently no such law at the federal level.

Encouraging landowners to engage in restoration of AMR sites is perhaps easier than encouraging BMP installation as AMD is a more visible problem. Still, it is important to overcome the challenges faced by landowners. Key among these are assuaging landowner concerns by ensuring long-term operation, maintenance and repair costs and ensuring available good Samaritan protection.

Funding opportunities currently exist for AMR projects at the state and federal levels. Increasingly there is a desire that AMR restoration projects also include some economic recovery component as well. Developing projects that create or maintain jobs is priority among funding agencies at this time.

As stated in the discussion of the Smith Creek-South Fork Tenmile Creek Watershed, Kimmel and Argent noted high conductivity values in the South Fork below the mouth of Smith Creek. DEP has listed the unnamed tributaries of Smith Creek, Smith Creek itself and the section of the South Fork Tenmile Creek as impaired by sources related to mining. Developing a project or projects to identify and address these sources of impairment should be a priority moving forward.

This site shows the Emerald Complex. Two unnamed tributaries of Smith Creek flow through this area and enter Smith Creek in the lower right-hand portion of this picture. Smith Creek then flows northeast to the South Fork Tenmile Creek Watershed. Both unnamed tributaries, the section of Smith Creek below their mouth and the section of the South Fork Tenmile Creek below Smith Creek's mouth are listed as impaired.

This site shows the site of the NPDES permitted Harvey Mine discharge into Patterson Creek. Monitoring flow and water quality above and below this discharge would provide a better picture of how active mining affects water quality

5. Precision Conservation

5.1 Introduction

Background

Precision conservation involves the use of spatial mapping technologies to integrate variability across the landscape and through time into planning and evaluating conservation management practices. The concept of precision conservation goes back to 2003 and has only grown with the advent of increased awareness from the academic community and, increasingly available spatial data and more powerful computational systems (Berry et. al., 2005; Delgado et. al., 2005). While various groups define precision conservation in different terms, the overall idea is utilizing spatial technologies to better understand the variability occurring across a landscape and allowing this greater understanding to direct conservation management decisions.

Precision conservation operates at multiple scales within the conservation planning process. At the watershed scale, they allow managers to identify areas of conservation concern that have a greater effect on water quality than their small surface area would indicate. At the parcel scale, they allow for more precise placement of BMP where their effectiveness will be maximized.

There is a growing expectation, particularly within the public sector, that some sort of decision support be employed to provide defensibility for management prescriptions. Precision conservation is one way to ensure that conservation efforts and funding resources are allocated to the areas where they will provide the greatest benefit. Additionally, parcel-level conservation planning using these technologies reduce the burden placed on landowners by allowing BMP to be appropriately sized and placed.

The Chesapeake Conservancy developed a report on critical technologies underpinning precision conservation within the Chesapeake Bay (Allenby and Burke, 2012). These included the need for high-resolution land use data and concentrated flow path analysis, both of which have broad applicability beyond the bay watershed. These technologies formed the basis for this consideration of precision conservation within the South Fork Tenmile Creek Watershed.

Land Use Analysis

Human land use has the greatest potential to impact water quality. Every challenge facing conservation managers within the South Fork Tenmile Creek Watershed is directly associated with land use. Increased surface runoff and attendant flooding are driven by land use changes. The availability of sediment, nutrients and other NPS pollutants are all associated with one land use or another. It is imperative that we have a clear understanding of land use processes and an accurate knowledge of land use patterns.

The work by the Chesapeake Conservancy demonstrated the need for high-resolution land use data which prior to this assessment did not exist for Greene County (Allenby and Phelan, 2013). The most recent National Land Cover Dataset (NLCD) is from 2011 and has a resolution of 30 meters. Much has changed in Greene County since 2011 so this dataset is temporally inappropriate to drive conservation planning in 2017 and beyond. Additionally, the 30 meter resolution of this dataset lends itself to large-scale analysis and planning at the level of the state and nation. It is unfortunately not detailed enough for analysis and planning at the watershed or parcel level.

Flow Path Analysis

Our understanding of hydrology is growing each year as our ability to understand how water moves over and through the landscape. Over the past decade, it has become known that the very small, sometimes ephemeral, headwater streams that are often considered to be of little consequence by landowners and managers are in fact some of the most important waters of a watershed. These areas host a broad diversity of life that cannot exist in downstream reaches. Furthermore these areas are often the most at-risk of being destroyed along with the communities they support (Kaplan et. al. 2008; Hunter 2017).

As incredibly important as these areas are they are the stream sections most often left off the maps and out of the planning process. Hydrological modeling process typically begin with water in a stream channel with an underlying assumption that runoff moves uniformly prior to reaching that channel. One of the central concepts of precision conservation is that variation exists within a landscape. In the Chesapeake Conservancy report referenced above, Allenby and Phelan analyzed concentrated flow paths using digital elevation models. The resulting map identified areas of convergent flow, gave a much clearer picture of how water moves towards streams and highlighted those headwater areas whose management are so critical.

Normalized Difference Flow Index

This assessment has already discussed the role of land use in stormwater management and its influence on runoff volume and velocity. The normalized difference flow index (NDFI) was developed by Allenby and Phelan (2013) to account for the effect of land use on overland flow. By using the high resolution land use data they developed to weight their concentrated flow path analysis, they were able to graphically represent areas where flow and ultimately pollutant loads would be either augmented or diminished by land use.

This tool has great utility to identify areas in need of conservation, such as areas where weighted flows are less than expected, as well as areas in need of restoration, such as where weighted flows are greater than expected.

Variable Width Riparian Buffer Modeling

Effective buffer width has been the subject of numerous studies, with general guidelines ranging from 4.6 m (15 ft.) to 30 m (100 ft.) to effectively reduce runoff and sedimentation and 15 m (50 ft.) to 30 m (100 ft.) to effectively reduce nitrogen levels. (Wenger 1999; Fischer et al. 2000).

Fixed-width riparian buffers grew out of a need to provide consistent guidelines for stream protection and regulatory administration (Richardson et al., 2012). Such buffers do not account for variability across the landscape such as changes in slope or flow concentration. The precision conservation approach allows for variable width buffers that account for variability across the landscape (Delgado, 2015).

Berry et al. (2005) describe a procedure for developing erosion potential data and ultimately a variable width buffer guideline based on slope and flow accumulation. The authors note that this model is simple and does not include other variables that could influence erosion potential (Berry et al. 2005). Following the logic of Allenby and Phelan (2013) we feel that while more complex models may be developed, parsimonious models may be of more use in directing conservation in the South Fork Tenmile Creek Watershed. Incorporating the concentrated flow data that we weighted for land use allowed us to create guidelines for variable riparian buffers based on topography and land use-weighted flow accumulation.

5.2 Methods

Land Use Analysis

To develop high-resolution land use data, we first obtained imagery collected as part of the USDA National Agriculture Imagery Program (NAIP). The NAIP imagery we used was collected in 2015 and is four-band imagery (RGB+NIR) with a one meter resolution. This imagery came packaged as digital ortho, quarter quad tiles and was accessed through the National Map. For our purposes, we focused on bands 4, 1, and 2 to emphasize the near-infrared band.

All image processing and classification processes were performed in ArcGIS 10.3 (Environmental Systems Research Institute, Redlands, California) using an object-based classification approach. Our first step in processing the imagery was to create a mask for the South Fork Tenmile Creek Watershed. A shapefile of the watershed was extracted from the Watershed Boundary Dataset developed by USGS and USDA-NRCS; which we accessed through the USDA Geospatial Data Gateway. To ensure that edge effects were not an issue in any subsequent analysis, a 1 Km buffer was applied to the watershed boundary. We mosaicked the imagery and applied our 1 Km buffered mask.

We then segmented the imagery using the Segment Mean Shift tool found in ArcMap's Spatial Analyst extension (ESRI). Segmenting an image groups pixels into segments based on spatial and spectral details.

Once the image was segmented, we identified training samples for use in classification of land use. While the NLCD uses 20 individual land cover classes, some of these are regional in nature. For example, "Perennial Ice/Snow" is found nowhere in Greene County. The Chesapeake Conservancy reduced this number to 7 in their classification work. In viewing the South Fork Tenmile Creek Watershed, we selected four land use classes that describe the bulk of land uses present within the watershed.

These were water, forest, low vegetation and developed. While it is possible to tease these apart into sub-categories, such as deciduous versus evergreen forest or low intensity versus high intensity development; it was not felt that these additional classes would any better describe the land uses for our purposes.

Once a suitable number of training samples were identified, we created a definition file using the Train Support Vector Machine Classifier in conjunction with the Classify Raster tool. We used the support vector machine classifier as it is one of the more modern supervised classifiers and is able to process large segmented rasters that may have correlation in bands. It is also known to be robust when sample sizes among training data are not equal.

One obstacle to classification was shadow. This was particularly prevalent in the western portions of the county where the topography is more diverse. To overcome this, we included shadow as a land cover type by identifying shadows in training samples. Once the classifier has been run, we used the Reclassify tool to reclassify as NoData, any cells identified as shadow. We then used the Nibble tool to fill in these NoData cells by extrapolating from the land use of adjacent cells. The final step in producing the land cover was to filter the classified image using the Majority Filter tool. This tends to smooth the overall image by cleaning up boundaries and eliminate noise.

We assessed the accuracy of the land use data by verifying land use at 200 random points. These points were generated using the Create Random Points tool in conjunction with the Extract by Points tool. Each point was then manually verified against the original NAIP imagery for accuracy. 184 of 200, or 92% of points were accurately classified.

Flow Path Analysis

Do develop a flow path analysis for the South Fork Tenmile Creek Watershed we needed an accurate digital elevation model (DEM). We chose the National Elevation Dataset developed by the USGS, EROS Data Center and distributed through the USDA Geospatial Data Gateway. This dataset has a three meter cell size and is the best available dataset covering Greene County.

We processed this elevation data using ArcMap 10.3 (ESRI) and the TAUDEM 5.3 extension (Dr. David Tarboton; http://hydrology.usu.edu/taudem/taudem5/). The TauDEM toolbox includes, among others, tools to process DEM, calculate flow direction, slope and flow accumulation using a D-infinity algorithm. The D-infinity approach provides a more accurate representation of flow movement across a landscape (Tarboton, 1997). Following the methodology described by Allenby and Phelan (2013) we used TauDEM's Basic Grid Analysis Tools to develop both a weighted and unweighted concentrated flow path map for the South Fork Tenmile Creek Watershed. We ranked water, forest, low vegetation and developed land uses classes zero, one, five and ten respectively. Finally we calculated the NDFI as Allenby and Phelan (2013).

Riparian Buffer Width Analysis

The process described by Berry et al. (2005) began by reclassifying slope and flow accumulation data into three classes. These were then combined and reclassified to indicate erosion potential (Berry et al. 2005). We began with the slope and land use-weighted flow concentration data produced during the flow path analysis.

The TAUDEM 5.3 flow direction calculation produces slope data as an output. This data is reported as drop over distance. We used the Raster Calculator function in ArcGIS (ESRI) to convert this to percentage slope. We then reclassified the resulting raster into three slope classes; low slope (0-8%), moderate slope (8-16%) and high slope (>16%).

The land use-weighted concentrated flow map calculates flow accumulation as a linear unit representing how many map units drain to each cell. In our concentrated flow analysis, we used 250 meters as a guide to determining concentrated flow paths. We used this same value as a guide to create three flow accumulation classes; Low flow (0-100 m), moderate flow (100 m – 250 m) and high flow (>250 m).

These were then combined using the Raster Calculator function ArcGIS (ESRI) to form erosion potential data. There were nine classes of erosion potential based on possible combinations of slope and flow accumulation (i.e. low slope & high flow or high slope and moderate flow).

Using the erosion potential data to generate a variable width buffer layer involved the use cost distance analysis. The Cost Distance Tool in ArcGIS's Spatial Analyst Extension (ESRI) calculates the least costly path from each cell in one raster to a selected "source" cell in another based on user supplied data about the cost of moving through each cell.

We began by creating a binary raster from the stream layer where cells identified as stream were given a value of one and all other cells were classed as NoData. This would become the source raster. Next we reclassified our erosion potential raster so that the classes (1-9) correlated to costs (9-1). Higher costs being associated with low erosion potential meant that the cost of traveling would increase quickly the farther from a source (stream) the cell is. Conversely, lower costs being associated with higher erosion potential meant that the cost of traveling would increase more slowly.

Setting a cost threshold on the resulting raster would create a buffer surrounding streams that would be wider where costs were low (high erosion potential) and more narrow where costs were high (low erosion potential). Selecting an appropriate cost threshold that would provide suitable buffer widths was very important. In doing so, we referred to the research cited above regarding effective buffer widths. We ultimately used cost threshold of 50 as this provided a mean buffer width of approximately 10 m.

5.3 Bringing Precision Conservation to the South Fork Tenmile Creek Watershed

There is a greater emphasis being placed on modeling of pollutant loads by DEP in recent years. Defensible spatial decision support is playing a much larger role in determining funding allocations. The spatial data produced as part of this assessment is the foundation of that type of decision support.

We developed accurate high resolution land use data for the watershed (Figure 5.1). This dataset is much finer scaled and more temporally relevant than previously available land use datasets. As such, it provides a much clearer picture of the land use and more detailed models of runoff and NPS pollution.

We derived elevation, slope, flow direction and flow accumulation data for the South Fork Tenmile Creek Watershed. From these, we now have a greater understanding of the pathways where runoff concentrates within this watershed. Figure 5.2 shows two visualizations of hydrology overlain on aerial imagery. In blue, is the commonly available stream data layer developed by DEP. In yellow is the concentrated flow path analysis that we have developed. Note how much greater detail this data provides in tracing the movement of runoff from upland areas to streams.

We incorporated Land use and concentrated flow path data into the NDFI which uses the relationship between land use and runoff flow to illustrate areas where land use either augments or diminishes flow concentration and attendant pollutant loads. This tool has practical applicability at multiple spatial scales.

At the level of the entire South Fork Tenmile Creek Watershed, these tools assist in mapping pollutants, planning outreach and targeting project sites. Viewing NDFI data for the entire watershed highlights areas where land use has augmented flow and where NPS pollution projects are most necessary (Figure 5.3). Areas in yellow and red indicate runoff flows and pollutant loads that are higher than what we would expect from topographic data alone. These areas are where projects incorporating BMP to reduce stormwater and isolate pollutants are predicted to provide the greatest water quality improvement.

The same data when viewed at the parcel level show areas of where concentrated flows carry pollutants into streams. This data may be used to design individual projects to provide the maximum benefit to water quality while minimizing the impact on landowners. Figure 5.3 shows an example of how this data is to be used at the parcel scale. This image show multiple land uses, including forest, agriculture and development. Note that near the top, right hand side of the image, flows are lower than expected as the stream is buffered by forest land use. Low vegetation, in this case either hay or pasture, is the predominant land use near the center of the image. The model predicts higher than expected flows here. Where development occurs and impervious surfaces are found, the model predicts much higher flows. Highlighting these excessive flows indicates where the greatest projected benefit of BMP implementation would occur. In many cases, this knowledge will help us implement appropriately sized BMP at the most efficient locations.

A practical application of this data is in determining appropriate riparian buffer width. Using the land use-weighted flow data from the NDFI analysis allowed us to determine a variable width buffer guideline for every stream in the watershed that takes topography, flow accumulation and land use into account. Figure 5.5 shows an example of how these factors interact to control the width of the buffer. This is another valuable tool in balancing the needs of a landowner with the interests of conserving water quality. By allowing for variable width buffers, we ensure that the areas in critical need of maximum protection, such as areas of high flow concentration, receive it while allowing the landowner to retain maximum use of their resources.

Figure 5.1: Land Use Classification of the South Fork Tenmile Creek Watershed

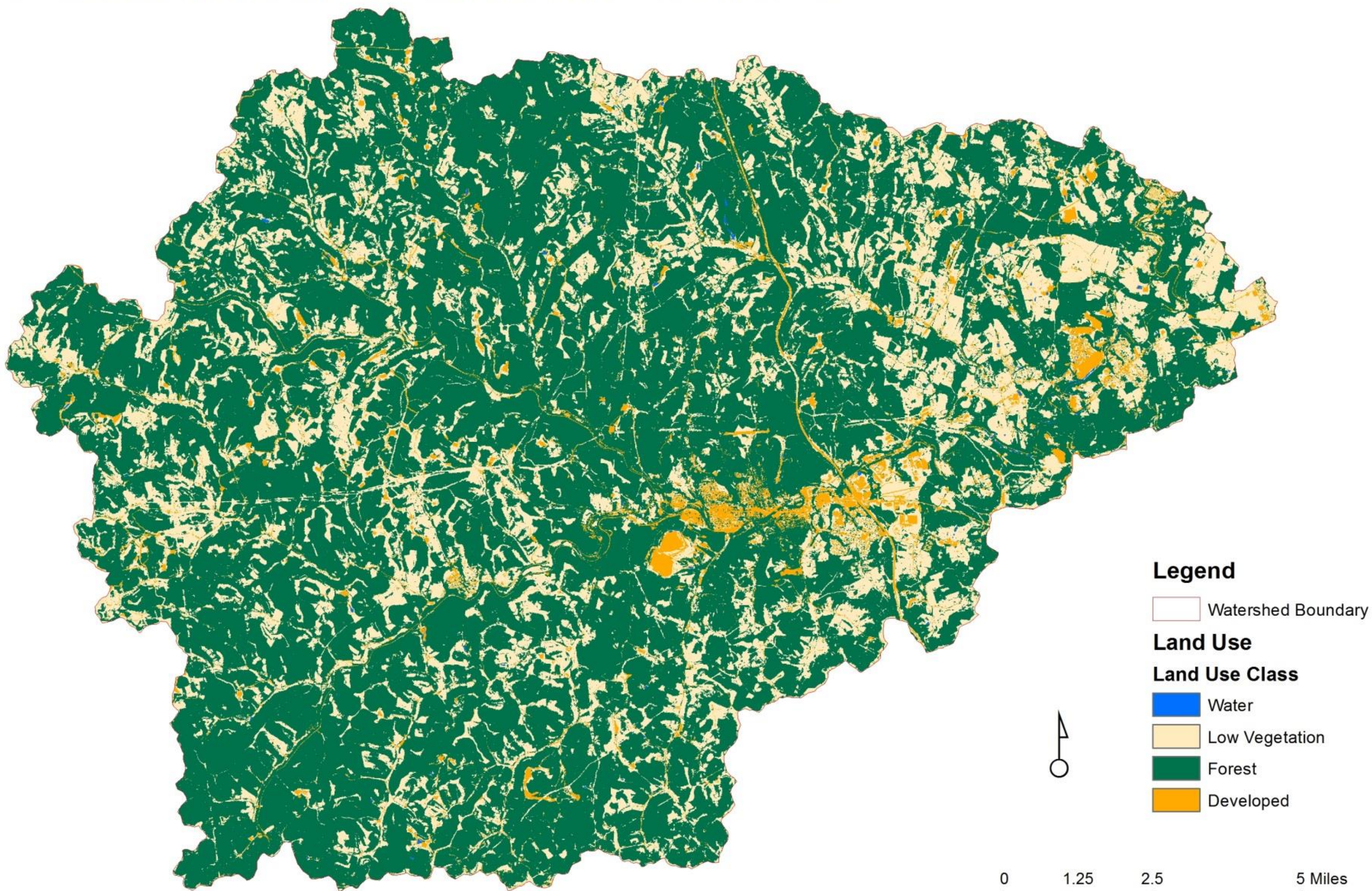


Figure 5.2: Concentrated Flow Pathways

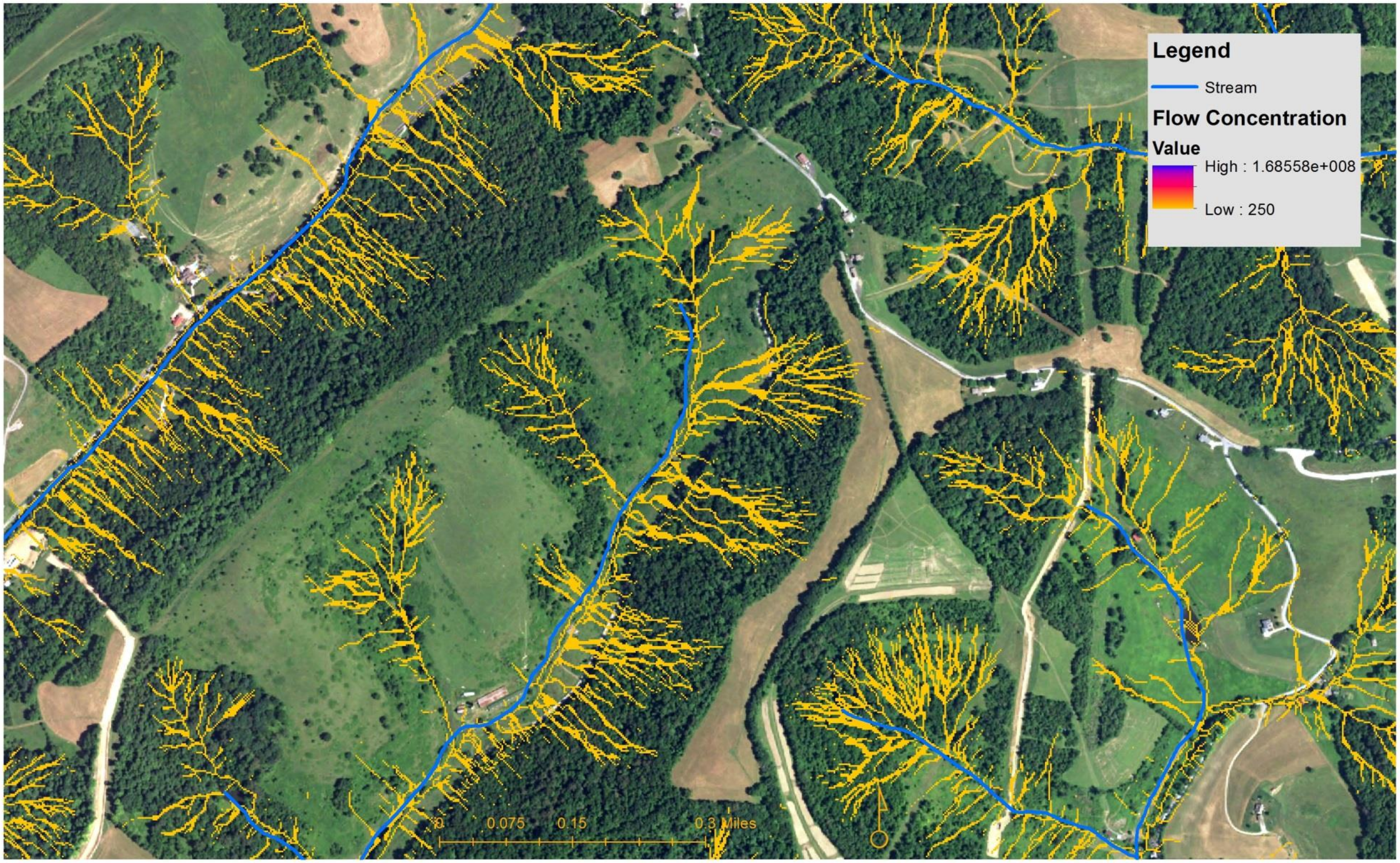


Figure 5.3: Normalized Difference Flow Index (NDFI) for the South Fork Tenmile Creek Watershed

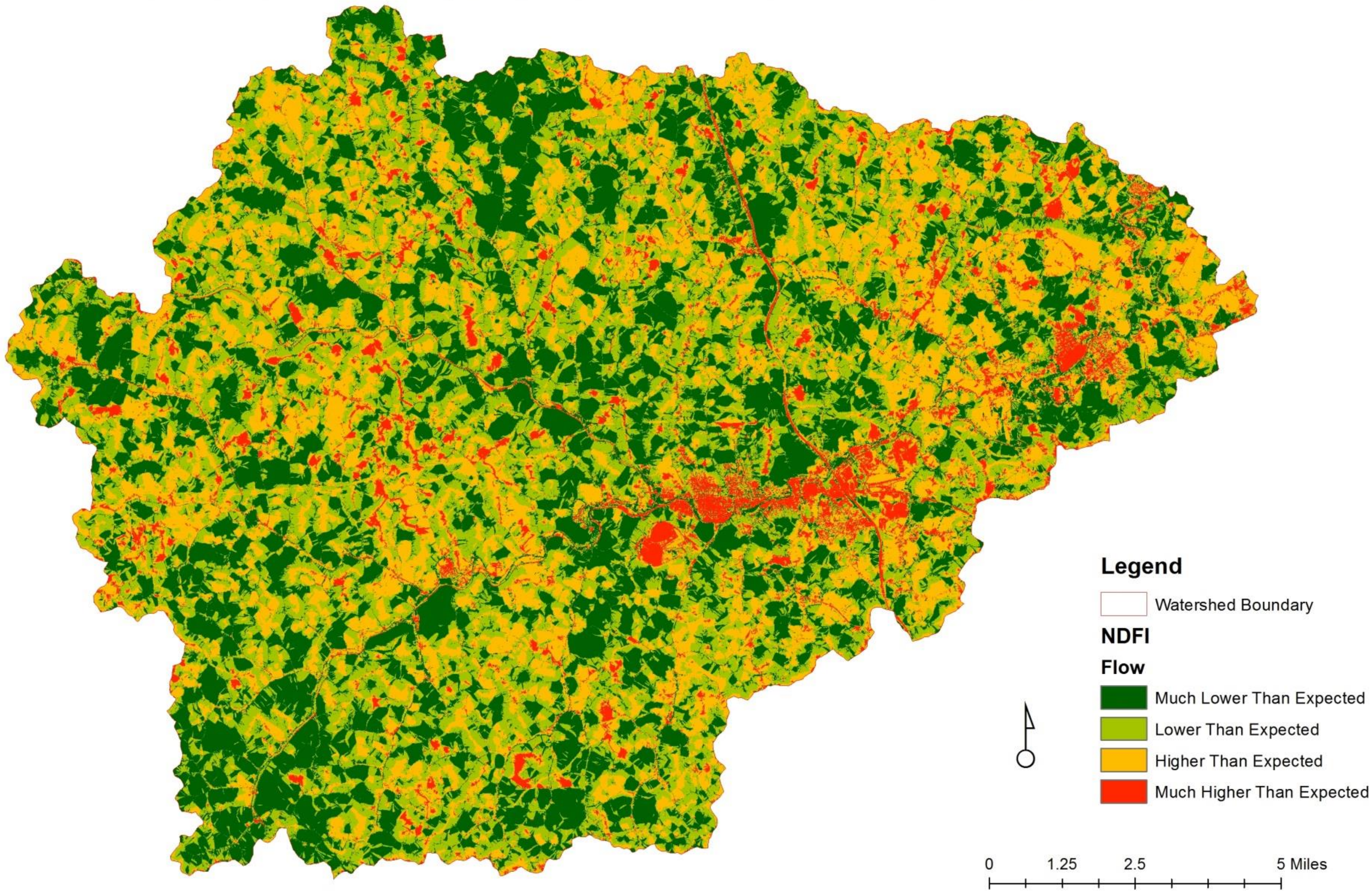


Figure 5.4: Normalized Difference Flow Index (NDFI) Weighted Flow Path

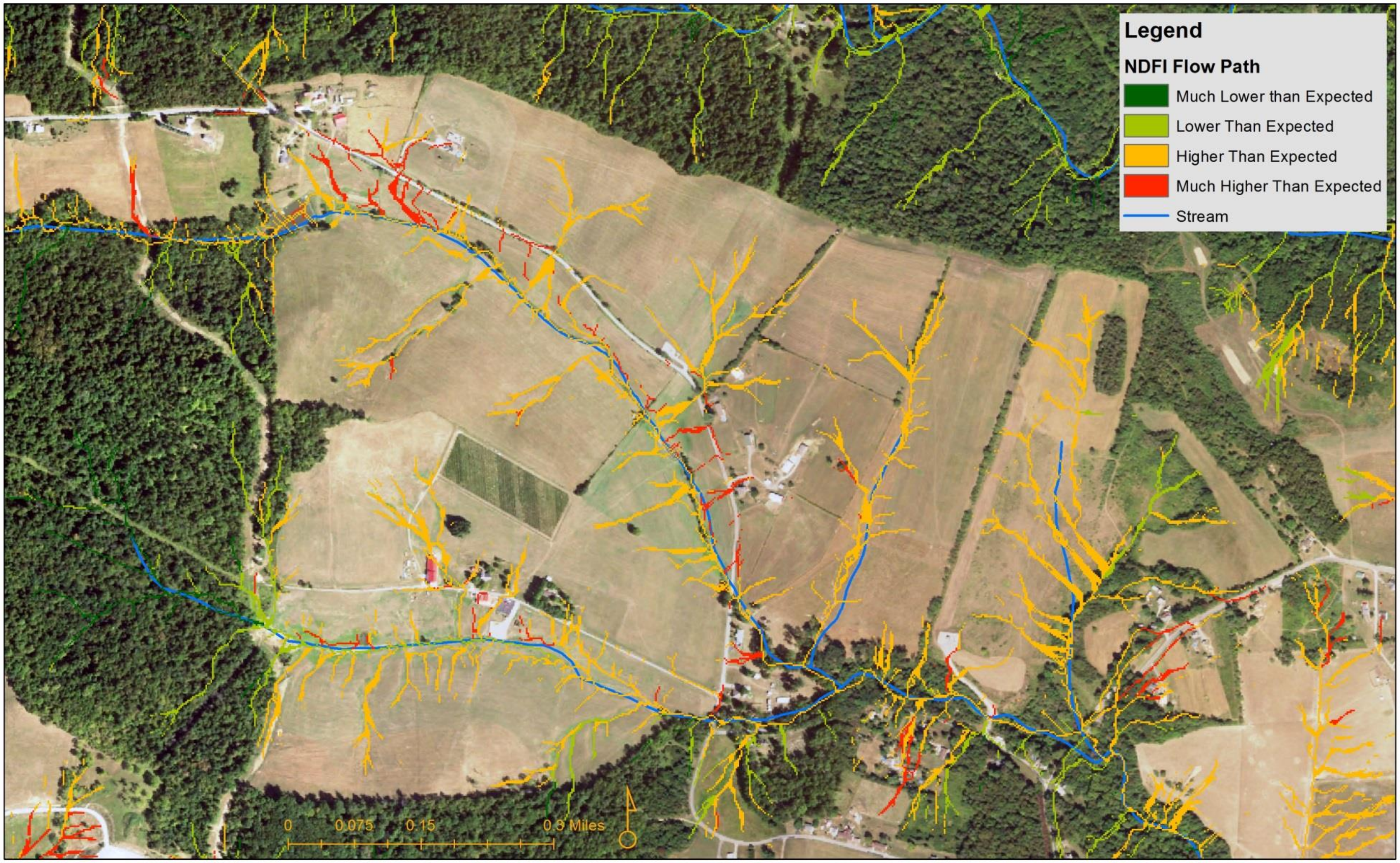
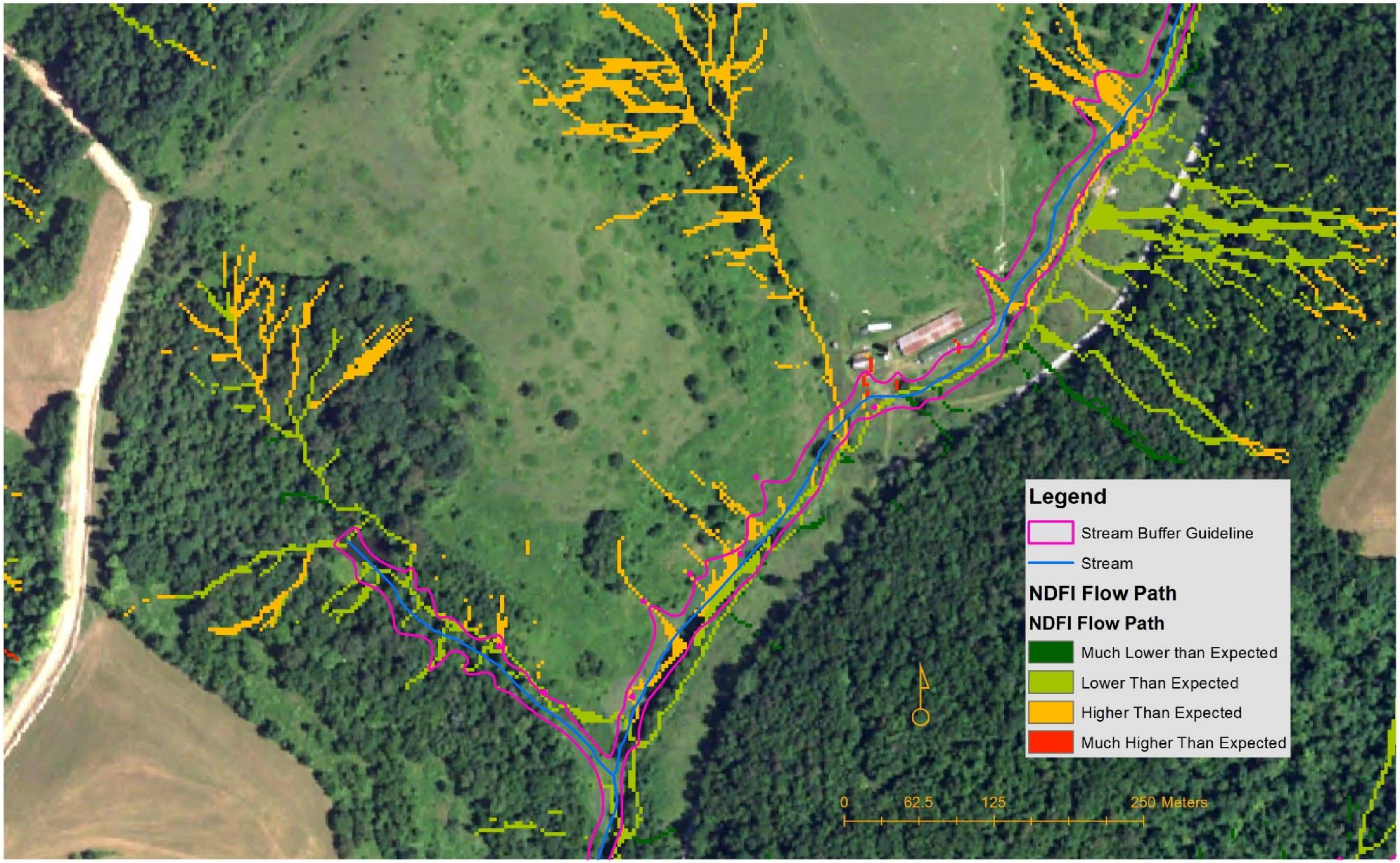


Figure 5.5: Variable Width Stream Buffer Model



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