The *WEST BRANCH SUSQUEHANNA RECOVERY BENCHMARK* Project

A Technical Report
by

TROUT UNLIMITED

And Contributing Authors

pennsylvania DEPARTMENT OF ENVIRONMENTAL PROTECTION

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Trout Unlimited's West Branch Susquehanna Restoration Initiative and the Need for a Benchmark of Recovery

In 1998, Trout Unlimited (TU), an organization committed to the conservation, protection, and restoration of North America's coldwater fisheries, embraced the significance of abandoned mine drainage (AMD) problems in the Kettle Creek Watershed in Clinton County, Pennsylvania as a component of its nationally renowned Home Rivers Initiative. Since then, TU has taken the role as the lead catalyst, working in close partnership with the local Kettle Creek Watershed Association to address severe AMD problems that plague the lower Kettle Creek Watershed. TU and its partners have conducted numerous assessments and developed restoration plans, completed construction of multiple reclamation and remediation projects, and are currently in the planning and construction phases for two more treatment and land reclamation projects.

While remaining actively involved with AMD cleanup in the Kettle Creek Watershed, TU took its AMD remediation work to the next level and established the West Branch Susquehanna Restoration Initiative in 2004, which is aimed at the restoration of coldwater streams and the ultimate recovery of the West Branch Susquehanna River. As the lead non-profit organization for this initiative, TU is working with numerous local, state, and federal government and non-government organizations on a coordinated, strategic, and cost-effective AMD cleanup approach for the entire river basin. TU is also providing organizational support to the West Branch Susquehanna Restoration Coalition, a group that represents the collective efforts of watershed groups, TU chapters, county conservation districts, businesses, and others that are working to address AMD problems throughout the West Branch Susquehanna River watershed.

As a result of all the individual and collaborative efforts over the past couple decades to restore the West Branch Susquehanna River watershed from the effects of AMD, numerous AMD remediation projects have been implemented throughout the watershed to improve water quality and biological conditions. However, despite the vast amount of resources spent by government agencies, non-government organizations, the private industry, and philanthropy, there had never been a concerted effort to quantify the resulting improvements on a watershed-scale. Recognizing this need, TU developed the West Branch Susquehanna Recovery Benchmark Project to quantify the effects of these remediation projects.

TU led this collaborative Project in 2009 in partnership with the DEP, PFBC, SRBC, and members of the WBSRC. The goals of this ambitious evaluation were to compare the current water quality and biological conditions in the West Branch Susquehanna River watershed to historical conditions, provide sufficient water quality data for the integrated database and model created as part of the West Branch Susquehanna Remediation Strategy (SRBC 2008), and provide a benchmark to compare future assessments of remediation efforts. To accomplish these goals, TU and its partners targeted 90 sites throughout the watershed and collected water quality and benthic macroinvertebrate samples, measured stream flows, conducted habitat surveys, and assessed fish populations over a five-month period.

Copies of this report may be obtained from:

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Photo: L. Kester

Abbreviations

AMD	abandoned mine drainage
BAMR	Bureau of Abandoned Mine Reclamation
BMP	best management practice
DEP	Department of Environmental Protection
EPA	Environmental Protection Agencey
EPT	Ephemeroptera, Plecoptera, Trichoptera
GIS	geographic information system
GPM	gallons per minute
IBI	Index of Biological Integrity
ICE	Instream Comprehensive Evaluation
PFBC	Pennsylvania Fish & Boat Commission
SMCRA	Surface Mining Control & Reclamation Act
SRBC	Susquehanna River Basin Commission
TU	Trout Unlimited
UNT	unnamed tributary
USGS	United States Geological Survey
WBSRC	West Branch Susquehanna Restoration Coalition

Note: All references to metal concentrations in the report refer to total metal concentrations.

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Acknowledgements

A project of such magnitude could have only been successful with generous support and strong partnerships. Accordingly, TU would like to thank the DEP and the Richard King Mellon Foundation for their financial support of our efforts. A listing of individuals who participated in the Project follows. TU is especially grateful for the efforts of these individuals and their respective organizations.

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Thank you!

Rebecca Dunlap (Project Lead), Amy Wolfe, Rachel Kester, Dr. Shawn Rummel, and Rebecca Holler.

Introduction

AMD, the number one source of pollution to Pennsylvania's waterways (DEP 2010) is the consequence of the historical unregulated coal mining that occurred before the establishment of the federal Surface Mining Control and Reclamation Act (SMCRA) of 1977. Mine drainage is formed when pyrite, a naturally occurring mineral often found in tandem with coal, reacts with oxygen and water to produce iron hydroxide and sulfuric acid. The acidic water associated with most mine drainage may also leach metals such as aluminum and manganese from the surrounding bedrock into the water. These toxic metals can negatively influence the growth rate, development, behavior, and metabolic processes of fishes. Additionally, mine drainage can cause a reduction in the abundance and diversity of benthic macroinvertebrate populations and the metal precipitates can armor the stream substrate, thereby reducing habitat and diminishing the food supply for other aquatic organisms. All but the most pollution tolerant fish and macroinvertebrate species are usually eliminated from AMD-impaired streams.

Unfortunately, just over 20% (approximately 1,200 miles) of Pennsylvania's AMD pollution plagues streams within the West Branch Susquehanna watershed (Figure 1), hindering the realization of the region's full ecological and economic potential. The costs required to remediate the watershed from AMD are at first overwhelming. The most recent estimates range between $110 and $453 million in capital costs and up to $16 million in annual operation and maintenance costs (Downstream Strategies 2008). In addition, it has been determined that the Commonwealth has spent $11 million in the watershed to correct problems caused by AMD for drinking water supplies.

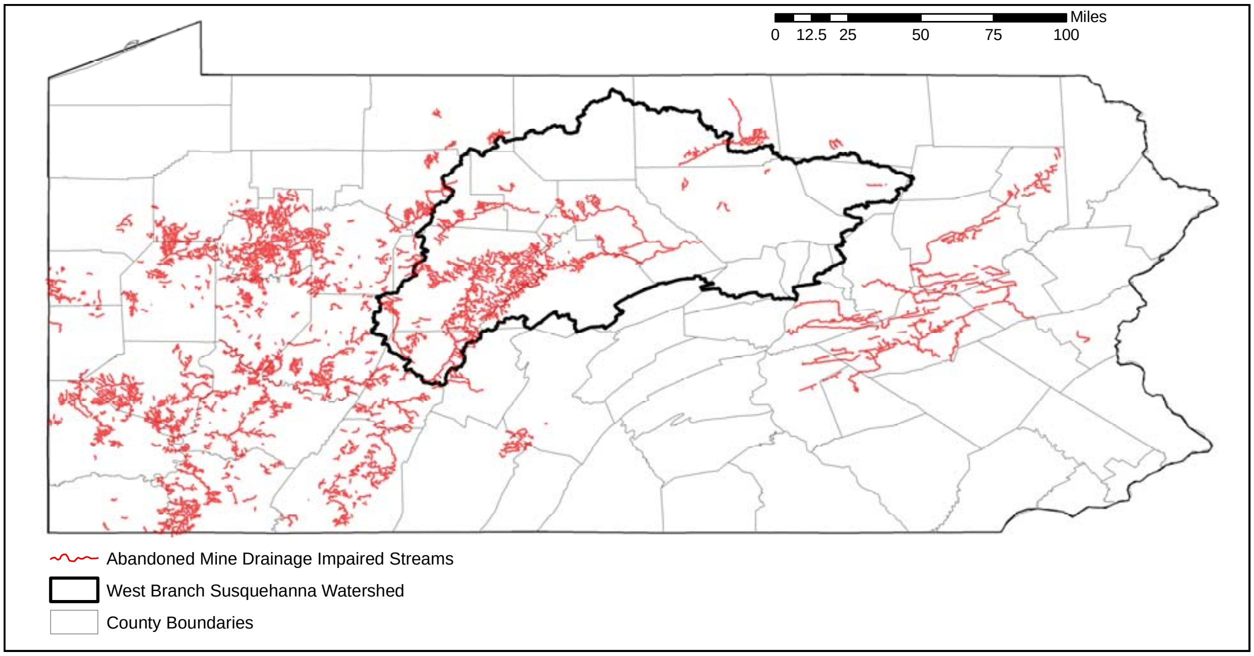


Figure 1*—Abandoned mine drainage impaired streams in Pennsylvania.*

However, when the long-term economic benefits that can be realized from a restored watershed are taken into consideration, the cost to remediate AMD becomes more palatable. For instance, in 2006 it was estimated that the West Branch Susquehanna watershed lost approximately $22.3 million in annual sport fishing revenue dollars due to the AMD that renders more than a thousand stream miles fishless (Downstream Strategies 2008). Furthermore, it was estimated that owners of single family residences in Clearfield County, the most heavily AMD impacted county in the watershed, have lost approximately $4 million in property values as a result of AMD pollution (Downstream Strategies 2008).

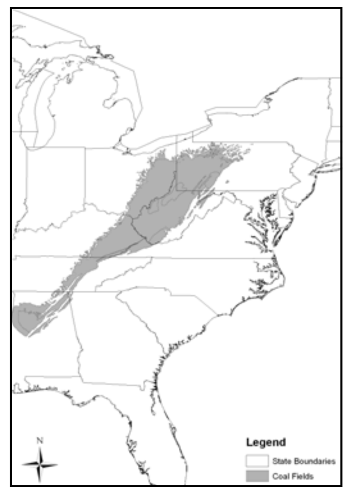
In 2003, Governor Rendell launched the PA Wilds Initiative to promote the growth of tourism and related businesses in north-central Pennsylvania based on the significant amount of outdoor experiences that are available on public land within the area. Since water quality impairment from AMD is a major limiting factor to the tourism and development opportunities as well as the economic potential of the region, cleanup of the West Branch Susquehanna's AMD became a priority for the Commonwealth.

To that end, more than $70 million in Growing Greener grants have been awarded for AMD projects in the watershed. These funds, combined with funds from sources such as the Office of Surface Mining's Watershed Cooperative Agreement Program, EPA's 319 Nonpoint Source Grant Program, the National Fish and Wildlife Foundation, the Foundation for Pennsylvania Watersheds, and other philanthropic organizations, have resulted in many abandoned mine treatment systems and a multitude of reclamation projects by watershed groups, county conservation districts, and other groups including TU. In addition, as of 2010 the Commonwealth had completed 210 remining projects and reclaimed 5,100 acres of abandoned mine lands in the watershed.

However, despite the millions of dollars spent to restore the West Branch Susquehanna watershed and the number of groups vested in the region's recovery, there had never been a concerted effort to measure the improvements on a watershed-scale. TU recognized that such documentation was necessary to sustain the tremendous amount of effort already realized and to also provide a "return on investment" for the funding agencies and the countless entities contributing to the recovery of the watershed. As a result, TU developed the West Branch Susquehanna Recovery Benchmark Project (hereinafter referred to as the "Project") for the purpose of documenting improvements in water quality and biological conditions, as well as to establish a benchmark of current conditions so that future remediation efforts may be evaluated.

Photo: R. Dunlap

Cooks Run, Clinton County.



Appalachian coal fields.

Photo: R. Dunlap

White Oak AMD discharge near Madera, Clearfield County.

Scope of Work / Methodology

The Project was organized to provide documentation of water quality conditions on a watershed-scale, substantiate anecdotal fishery improvements in the river, and provide baseline documentation of benthic macroinvertebrate populations and habitat conditions in AMD impacted tributaries.

Water Quality and Flow

The only water quality evaluation of a similar magnitude occurred in 1984 by the USGS. As part of this evaluation, streamflow and water quality were measured in May and July 1984 at four sites on the West Branch Susquehanna River and near the mouths of 94 tributaries between Curwensville and Renovo. All data were collected during high baseflow conditions in May 1984 and during low baseflow conditions in July 1984, with the exception of the river site at Renovo in which a rain event resulted in conditions not representative of baseflow (Hainly & Barker 1993).

As part of the Project, stream flow and water quality data (Table 1) were collected in May and July 2009 at 48 of the sites sampled in 1984. While the 1984 survey sampled every tributary along the river, the Project only resampled those tributaries deemed AMD impaired according to DEP's Integrated List. The Project also included collections at an additional 9 river sites and 23 tributaries so as to include every AMD impacted tributary entering the river from its headwaters to Lock Haven, as well as selected sites within larger subwatersheds (Table 2, Figure 2).

Table 1*—Water quality parameters measured.*

Parameter	Method
Acidity	SM 2310B
Alkalinity	SM 2320B
Aluminum	200.7
Aluminum (Dissolved)	200.7
Calcium	200.7
Calcium (Dissolved)	200.7
Chloride	SM 44110B
Copper	200.7
Copper (Dissolved)	200.7
Iron	200.7
Iron (Dissolved)	200.7
Magnesium	200.7
Magnesium (Dissolved)	200.7
Manganese	200.7
Manganese (Dissolved)	200.7
Nickel	200.7
Nickel (Dissolved)	200.7
pH	SM 4500B
Specific Conductance	SM 2510B
Sulfate	SM 4110B
Total Dissolved Solids	USGS I-1750-85
Total Suspended Solids	USGS I-3765-85
Zinc	200.7
Zinc (Dissolved)	200.7

In order to accurately compare data collected between the sites included in the Project and also to the data collected in 1984, all sites were sampled within a 3-day spring and summer period and during the recession portion of the hydrograph when there was no appreciable surface runoff flow component. The only exception was 15 samples collected in August as denoted in Table 2. Precipitation events required a lag time between sampling from these sites and the other 65 sites sampled during summer conditions to ensure that stream levels reflected the recession portion of the hydrograph.

Photo: R. Kester

Alysha Trexler and Mark Killar measure flow rate.

Photo: M. Carello

Shirley Sholtis and Pam Milavec prepare to sample the river.

Photo: R. Dunlap

Study participants are trained how to properly take flow measurements.

Flow measurements were made perpendicular to the direction of mid-channel flow and in areas where backwater and as many obstacles as possible could be avoided. Cross-sectional measurements of depth, velocity at 6/10th of the stream depth, and distance from the bank were taken at approximately 20 locations or at intervals that comprised no more than 10% of the entire flow of the site. Where flows were too large to measure using conventional wading techniques, the existing USGS stream gage network was used.

Water quality samples were taken from the vertical profile of the main current usually in the center of the stream. In the case of larger tributaries or main stem river sample locations, 3 to 6 samples from across the sample site were composited. A 500-ml raw sample, a 250-ml sample fixed with 15 to 20 drops of HNO_3, and a 250-ml sample filtered through a 0.45-micron filter and then fixed with 15 to 20 drops of HNO_3 were obtained from each site. Samples were placed on ice and transferred to a DEP-accredited laboratory for analysis of 24 parameters (Table 1). In addition, field measurements of pH, temperature, and conductivity were taken at each site.

For quality assurance purposes, an orientation and training session was held during which project participants were trained in proper water quality and flow data collection techniques. Each sampling team consisted of a "leader" from TU or the DEP and all persons collecting data were TU personnel, DEP personnel, County Conservation District personnel, or other relevant professionals.

Fish

The last comprehensive evaluation of the fishery of the river from its headwaters to Lock Haven by the PFBC was in 1998 and 1999 (Hollender and Kristine, 1998 & 1999). For the purposes of this Project, PFBC re-surveyed 9 (Table 2) and the SRBC re-surveyed 8 of 12 historic sampling locations (Table 3). Sampling occurred at sites along a stretch that encompassed approximately 144 miles of the upper and middle West Branch Susquehanna River during the period of June through August 2009. Data collection protocols followed those of Hollender and Kristine (1998 and 1999) using backpack and mini-boom boat electrofishing gear.

Backpack electrofishing samples consisted of two 100-meter single-pass runs along the shoreline. When possible, a 100-meter site was conducted on each side of the river. The fish catch reported for each backpack site is the sum of the two 100-meter samples combined. Mini-boom boat electrofishing samples consisted of two > 20 minute single-pass runs along the shoreline. One run was conducted on each side of the river. The fish catch reported for each mini-boom site is the sum of the two > 20 minute runs combined. An attempt to capture all fish observed was made and all fish captured that could be identified at the site were tallied by species and released. Juvenile cyprinids and other unidentifiable fish were preserved and returned to the laboratory for identification.

Photo provided by PFBC

Jason Detar, Dave Kristine, and Andrew Leakey prepare to sample the river at Hyner.

Photo provided by PFBC

Dave Kristine, and Andrew Leakey sample the river at Hyner.

For quality assurance purposes, a training session was held to familiarize the SRBC with PFBC sampling protocols prior to the reinventory. However, due to high river flows, the training was limited to a "dry run" on land. In addition, PFBC personnel utilized a Coffelt-type generator-powered AC backpack electrofisher to maintain consistency with the Hollender and Kristine (1998 and 1999) surveys while SRBC staff used a battery-powered AC backpack electrofisher. Significant differences in number of species collected and overall catch rates were documented between PFBC and SRBC sampling. It is unclear as to why these differences occurred, but they may have been a result of differences in backpack electrofishing gear, inability to conduct an actual electrofishing run during the training session to ensure that both groups were using similar effort, and higher river flows during SRBC evaluations. For these reasons, the SRBC data were not used in subsequent analyses.

Benthic Macroinvertebrate and Habitat

In order to provide a baseline of biological and habitat conditions in the AMD impacted tributaries entering the river and in the river itself, benthic macroinvertebrate and habitat data were collected at 66 locations. All benthic collections were carried out according to DEP's ICE protocols (Chalfant, 2007) and were conducted by TU personnel who were previously trained by DEP Bureau of Water Standards and Facility Regulation staff in such protocols. Benthic macroinvertebrate samples consisted of a combination of six kick efforts in a 100-meter stream section. These efforts were spread out so as to select the best riffle habitat areas with varying depths. Each effort consisted of an area of 1-m^2 to a depth of at least 4 inches as substrate allowed and was conducted with a 500 micron mesh 12-inch diameter D-frame kick net. Samples were composited and then identified.

Photo: R. Dunlap

Rachel Kester collects benthic macroinvertebrates from Wolf Run.

Although the ICE protocol only requires individuals to be identified to genus or the next highest possible taxonomic level in order for evaluation according to the six standardized metrics comprising the DEP's IBI, individuals were identified to species or the next highest possible taxonomic level by North American Benthological Society certified taxonomists for the Project. This was done assuming that a change in community structure over time would be first documented at the species-level. This level of precision paired with DEP collection techniques will allow future studies to detect recovery more quickly by assessing species-shift as water quality improves, and will also allow the DEP to use the genera-level identifications for its purposes.

Photo: R. Dunlap

Lori Smith and Carl Undercoffler assess habitat of an unnamed tributary.

A qualitative habitat assessment was also conducted on a 100-meter reach of stream at each site according to DEP's ICE protocols. The habitat assessment included rating twelve parameters (instream fish cover, epifaunal substrate, embeddedness, velocity/depth regime, channel alteration, sediment deposition, riffle frequency, channel flow status, conditions of banks, bank vegetative protection, grazing or other disruptive pressures, and riparian vegetative zone widths) as optimal, suboptimal, marginal, or poor by using a numeric value ranging from 0-20. In order to reduce the amount of variation due to subjectivity by different investigators between sites, habitat evaluations were conducted by the same person at each site when possible.

Table 2a*—Data collection sites.* † *Indicates lag summer water quality, and flow collections. * Indicates control site.*

Site Number	Site Name	Water Quality (80)	Flow (71)	Benthic Macroinvertebrates & Habitat (66)	Fish (7)	Included in 1984 Study (48)
1	Lesle Run†	X	X	X		
2	Fox Run†	X	X	X		
3	Walnut Run†	X	X	X		
4	Moss Creek†	X	X	X		
5	Cush Cushion Creek†	X	X	X		
6	Bear Run†	X	X	X		
7	Chest Creek at Mahaffey†	X	X	X		
R1	West Branch Susquehanna at Cherry Tree†	X	X	X		
F1	West Branch at Shyrock Run				X	
R2	West Branch Susquehanna at Burnside†	X	X	X		
R3 / F2	West Branch Susquehanna at McGees Mills†	X				
R4 / F3	West Branch Susquehanna at Bower†	X	X			
8	Anderson Creek	X	X			X
F4	West Branch Susquehanna River at Hogback Run				X	
9	Hartshorn Run	X	X	X		X
10	Tributary 26641	X	X	X		X
11	Montgomery Creek	X	X	X		X
R5	West Branch Susquehanna at Lumber City	X				
R6	West Branch Susquehanna at Curwensville	X	X			
F5	West Branch Susquehanna at Clearfield				X	
12	Moose Creek	X	X	X		X
13	Tributary 26608	X	X	X		X
R7	West Branch Susquehanna at 879 Bridge	X				
14	Wolf Run	X	X	X		X
15	Clearfield Creek	X	X	X		X
16	Abes Run	X	X	X		X
17	Tributary 26104	X	X	X		X
18	Lick Run	X	X	X		X
19	Devils Run	X	X	X		X
R8	West Branch Susquehanna at Shawville	X		X		
20	Trout Run	X	X	X		X
F6	West Branch Susquehanna at Egypt				X	
21	Millstone Run	X	X	X		X
22	Surveyor Run	X	X	X		X
23	Bald Hill Run	X	X	X		X
24	Moravian Run	X	X	X		X
25	Deer Creek	X	X	X		X
F7	West Branch Susquehanna at Deer Creek				X	
26	Tributary 25976	X	X	X		X
27	Big Run	X	X	X		X
28	Sandy Creek	X	X	X		X
29	Alder Run	X	X	X		X
30	Rollingstone Run	X	X	X		X

Table 2b*—Data collection sites.* † *Indicates lag summer water quality, and flow collections. * Indicates control site.*

Site Number	Site Name	Water Quality	Flow	Benthic Macroinvertebrates & Habitat	Fish	Included in 1984 Study
31	Mowry Run	X	X	X		X
32	Basin Run	X	X	X		X
33	Rock Run	X	X	X		X
34	Potter Run*	X	X	X		X
35	Tributary 25913*	X	X	X		X
36	Rupley Run*	X	X	X		X
37	Moshannon Creek	X	X	X		X
38	Redlick Run	X	X	X		X
39	Tributary 25693*	X	X	X		X
40	Mosquito Creek	X	X	X		X
R9	West Branch Susquehanna at Karthus	X				X
41	Laurel Run*	X	X	X		X
42	Tributary 25622	X	X	X		X
43	Saltlick Run	X	X	X		X
44	Tributary 25611*	X	X	X		X
45	Sterling Run	X	X	X		X
45	Loop Run	X	X	X		X
47	Birch Island Run	X	X	X		X
48	Black Stump Run	X	X	X		X
F8	West Branch Susquehanna at Burns Run				X	
49	Sinnemahoning Creek†	X	X	X		X
50	Cooks Run	X	X	X		X
51	Milligan Run	X	X	X		X
52	Kettle Creek	X	X	X		X
53	Drury Run	X	X	X		X
R10	West Branch Susquehanna at Westport	X				
R11	West Branch Susquehanna at Renovo	X				X
F9	West Branch Susquehanna at Hyner				X	
54	Tangascootak Creek	X	X	X		
R12	West Branch Susquehanna at Lock Haven	X				
55	Clearfield Creek at SR 1021	X	X			
56	Muddy Run	X	X			
57	Clearfield Creek at Dimeling	X				
58	Chest Creek at Westover†	X	X	X		
59	Moshannon Creek at Osceola Mills	X	X	X		
60	Moshannon Creek at Philipsburg	X	X			
61	Little Anderson Creek	X	X	X		
62	Kratzer Run†	X	X	X		
63	Twomile Run	X	X	X		
64	Babb Creek	X	X	X		
65	Sterling Run (Sinnemahoning)†	X	X	X		
66	Bennett Branch†	X	X	X		
67	Beech Creek	X	X	X		
68	Dents Run†	X	X	X		

Water Quality of the West Branch Susquehanna Watershed

Historical Water Quality

Photo: R. Dunlap

AMD in Clearfield County.

The first qualitative assessment of the pollutant load in and delivered to the West Branch Susquehanna River occurred as part of Operation Scarlift in the early 1970s. As part of this assessment, a thorough investigation of the stream water quality data was compiled for the 40-mile reach of the West Branch from its headwaters to Bower and cursory data were also collected between Bower and Renovo. The river, according to this report, was either predominantly acidic or intermittently acidic along its entire length (Commonwealth of Pennsylvania 1972). The river at Germantown, between Bakerton and Bower was documented to have a pH of 4.1, an acidity of 17,820 lbs/day, and an iron loading of more than 1,000 lbs/day (Commonwealth of Pennsylvania 1972). What's more is that the conditions of the headwaters were so deteriorated that one conclusion of this study stated "The overall acid loading conditions to the West Branch are such that no significant length of stream above Bower Station can be permanently recovered for recreational use even with abatement expenditures of the order of $20 to $30 million" (Commonwealth of Pennsylvania 1972).

The next assessment that quantified a large portion of the river was in 1984 when the USGS completed an evaluation of water quality and flow in the West Branch Susquehanna River and all its tributaries between Curwensville and Renovo. This investigation documented that the river was still polluted throughout much of its length. In fact, the pH of the river at Renovo was measured to be 4.6 in the spring and 3.8 in the summer and concentrations of acidity were measured to be 9.9 mg/L as $CaCO_3$ in the spring and 15 mg/L as $CaCO_3$ in the summer. Additionally, this study identified Moshannon Creek, Sinnemahoning Creek, Clearfield Creek, and Kettle Creek as the major sources of acidity and iron to the river. Moshannon Creek, Sinnemahoning Creek, and Clearfield Creek accounted for 63% (231 tons/day) of acidity measured in the river in spring conditions while Moshannon Creek, Kettle Creek, and Clearfield Creek accounted for 60% (78 tons/day) of the acidity measured in the river during summer conditions (Hainley and Baker 1993). With respect to iron, Clearfield Creek and Moshannon Creek alone accounted for 76% (34 tons/day) of the total iron measured in the river in spring conditions and Kettle Creek and Moshannon Creek accounted for 51% (3 tons/day) of the total iron measured in the river in summer conditions (Hainley and Baker 1993).

Present Day Water Quality

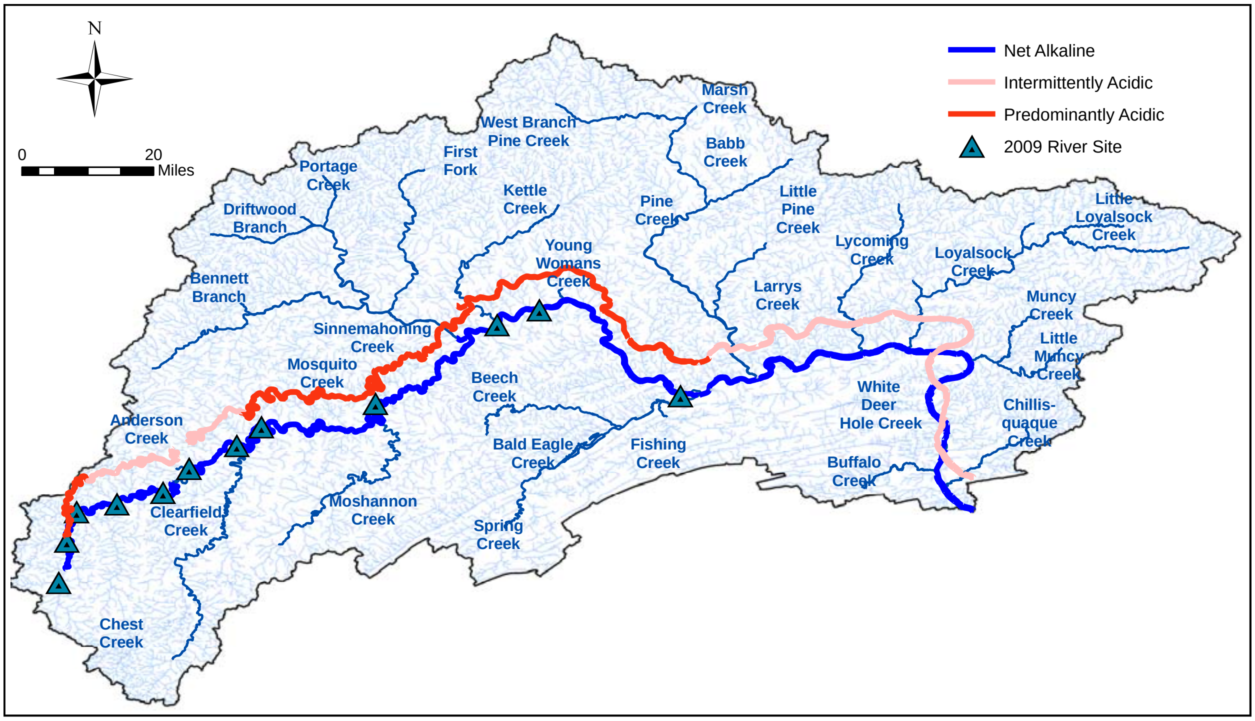


__Figure 2__— Acidity of the West Branch Susquehanna River as documented in the 1972 Scarlift report and net acidity (as calculated by pH, metals, and alkalinity) (mg/L) as documented by the twelve river sites included in the Project.

Data collected in 2009 as part of the Project indicate markedly improved conditions in the river compared to conditions reported in both of the aforementioned studies. As an example, instead of predominantly or intermittently acidic conditions along the entire length of the river as was found in the early 1970s, data collected in 2009 reveal that the river is now in a net alkaline state according to its calculated net acidity based on pH, metals, and acidity (Figure 2). Even though there was a notable decreasing trend in alkalinity concentrations from the headwaters downstream from the addition of AMD impacted tributaries, the river remained in a net alkaline state (Figure 3). Additionally, the pH of the river at Renovo was measured to be 6.6 and 6.3, 2.0 and 2.5 units higher in spring and summer 2009 conditions respectively compared to measurements in 1984. Lastly, concentrations of acidity, iron, and aluminum in 2009 were each reduced compared to concentrations found in 1984 (Figure 4).

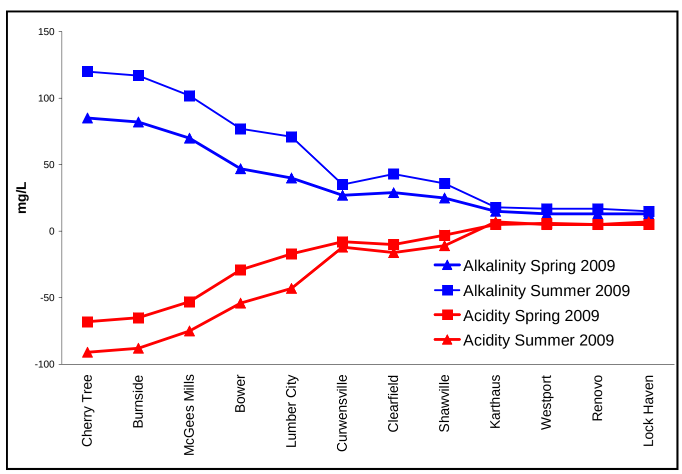


__Figure 3__— Alkalinity (mg/L) and acidity (represented as hot peroxide acidity) (mg/L) of the West Branch Susquehanna River as documented by the twelve river sites included in the Project.

Water quality conditions in the tributaries were also markedly improved. At those sites sampled in both 1984 and 2009, 85% percent of the tributary pH measurements in 2009 were higher than what was measured in 1984, 79% of the acidity concentrations were lower, 68% of the iron concentrations were lower, and 92% of the aluminum concentrations were lower. In addition, while a considerable amount of the acidity measured in the river can still be attributed to three tributaries, the total amount of acidity measured and those tributaries delivering the load has changed (Figures 4 & 5). For instance, Clearfield Creek, a once net acidic tributary delivering 45 tons/day of acidity in the spring and 15.5 tons/day of acidity in the summer was measured to be net alkaline (according to acidities reported by the lab and also by calculating net acidity with pH, metals, and alkalinity) at its mouth in 2009.

Although Moshannon Creek in both 1984 and 2009 and in both spring and summer conditions delivered the most acidity loading to the river, 2009 data indicate that this tributary had 109 tons/day less acidity in the spring and 26.5 tons/day less acidity in the summer compared to 25 years ago. Additionally, although Sinnemahoning Creek and Kettle Creek still contributed marked loadings to the river in 2009, those loadings were much less and the season during which their impact was most noted changed when compared to 1984 (Figures 4 & 5). Finally, although Alder Run did not contribute significantly to the acid load delivered to the river in 1984 it was found to be responsible for 10% and 11% of the acidity entering the river in spring and summer conditions respectively as measured in 2009.

Despite the overwhelming improvements in water quality over the last quarter century, many of the tributaries entering the river are still degraded with AMD. Fifty-five percent of the tributaries sampled as part of the Project in the spring and 63% sampled in the summer had concentrations of aluminum higher than DEP Chapter 93 water quality criteria of 0.75 mg/L, while 41% and 50% in the spring and summer respectively had concentrations of iron higher than the Chapter 93 water quality criteria of 1.5 mg/L. Furthermore, 61% of the tributaries sampled as part of the Project in the

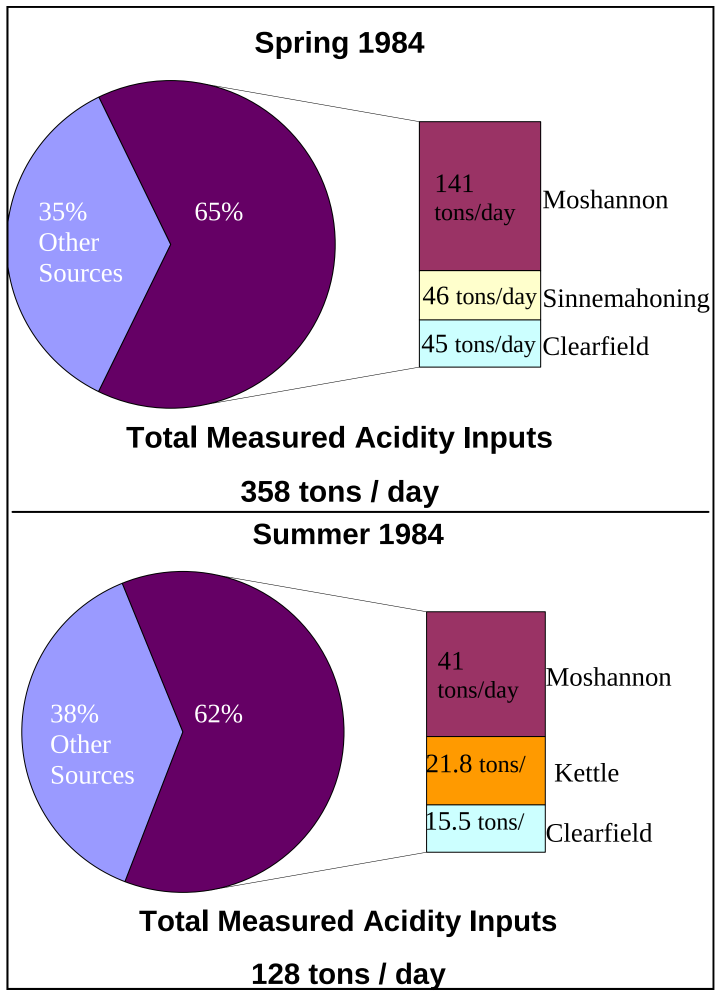


***Figure 4** — Total acidity loading (tons/day) and major sources of acidity to the West Branch Susquehanna River in 1984 as measured by the tributaries included in both the Project and 1984 USGS study (Hainley and Barker 1993).*

spring and 60% of the tributaries in the summer had a pH of less than 6. Figures 6 and 7 depict how many Chapter 93 water quality criteria concentrations (considering the criteria for aluminum, iron, pH, manganese, sulfate, and total dissolved solids) were exceeded at each sampling location. Only 10 of the 68 tributaries sampled were found to have water quality that met all Chapter 93 water quality criteria concentrations in the spring and only 11 were found to meet all criteria in the summer (see Appendix).

Additionally, the water quality of a few tributaries to the West Branch Susquehanna showed little change or was worse in 2009 than was documented in 1984. For example, while Sandy Creek, a tributary that enters the river in Clearfield County, exhibited slight improvements in pH, acidity, and aluminum, concentrations of iron in 2009 were 1.5 mg/L and 2.2 mg/L higher than what were found in the spring and summer of 1984. Also, Alder Run, another tributary that enters the river in Clearfield County had 15 mg/L more of iron in the spring of 2009 than it did in the spring of 1984 and 26 mg/L more in the summer and has shown no improvement in pH since 1984.

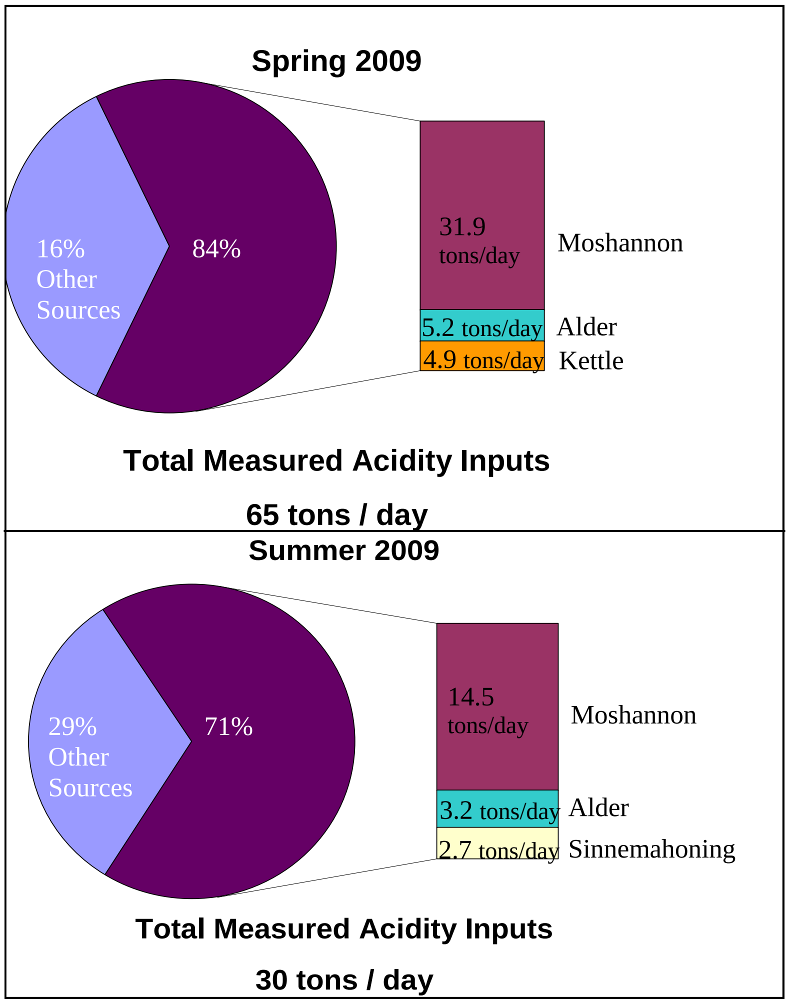


Figure 5— *Total acidity loading (tons/day) and major sources of acidity to the West Branch Susquehanna River in 2009 as measured by the tributaries included in both the Project and 1984 USGS study (Hainley and Barker 1993). Acidity represented as hot peroxide acidity (mg/L). Sites with a negative hot acidity value were not included.*

In addition to reductions in acidity, the West Branch Susquehanna River has experienced significant, albeit less dramatic, reductions in sulfate and total dissolved solids concentrations and specific conductance. At Karthaus, for example, sulfate concentrations have declined by 12% to 29% from 1984 to 2009. Total dissolved solids and specific conductance levels have similarly declined between 16% and 26%.

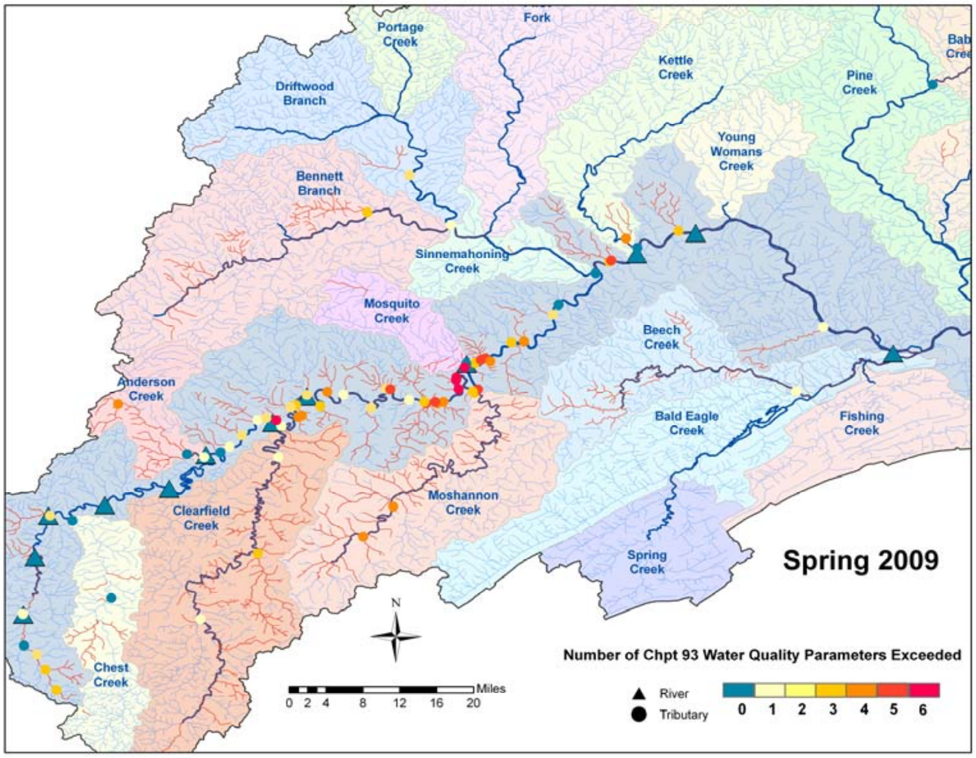


Figure 6 — *Number of chapter 93 water quality criteria (aluminum, iron, pH, manganese, sulfates, and total dissolved solids) exceeded in the spring of 2009.*

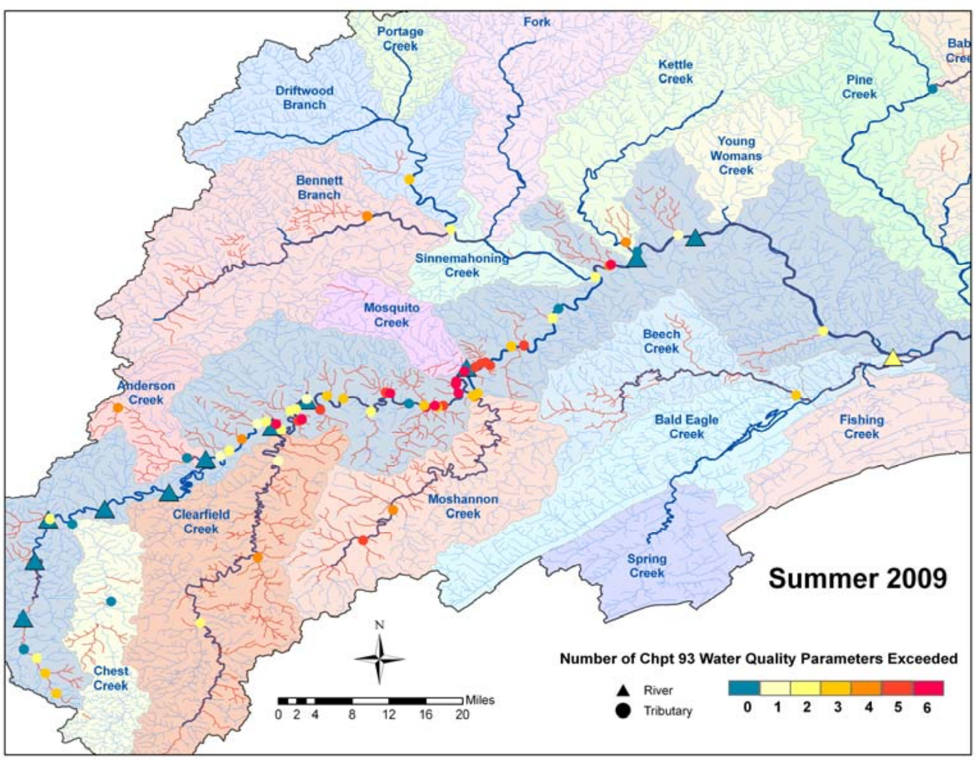


Figure 7 — *Number of chapter 93 water quality criteria (aluminum, iron, pH, manganese, sulfates, and total dissolved solids) exceeded in the summer of 2009.*

The Fishery of West Branch Susquehanna River

Historical Fishery

This historical degraded water quality of the West Branch Susquehanna River had a predictable effect on its fishery. For many years, much of the river was thought to be devoid of any biological life. The 1972 Scarlift report for the West Branch Susquehanna River denotes that the water quality in the river was so detrimental that the costs for complete abatement of the pollution could not be economically justified (Commonwealth of Pennsylvania 1972). The report states that "conditions in the study area are such that no more than 30 miles of stream between Barnesboro and Bower could possibly be restored to fishing and recreational use under the most ideal abatement treatment costs for which could easily range from $20 to $30 million. This is completely unrealistic in terms of the Federal Water Pollution Control Act benefit values for this reach" (Commonwealth of Pennsylvania 1972). In fact, the Scarlift report identifies that the essential abatement benefit was not for the recovery of the biota in the river itself but for the protection of the recreational waters of the Curwensville reservoir. In addition the report indicates that since "recreation, aesthetics, and fishing are the main benefits desired in the West Branch headwater area, these benefits might be made available within the watershed at a justifiable cost by converting one of the tributaries into an improved fishing stream" (Commonwealth of Pennsylvania 1972).

Despite the inhospitable conditions of the river in the 1970s as well as the expected longevity of those conditions, anecdotal reports of an improving fishery became commonplace in the late 1990s. The last comprehensive evaluation of the fishery of the river from its headwaters to Lock Haven by the PFBC was in 1998 and 1999 (Hollender and Kristine 1998). This evaluation resulted in 30 fish species in the river and indicated that the reach of the river between the headwaters and Clearfield supported only low to moderate densities of fish. The limiting factors were identified to be acid mine drainage and siltation (Hollender and Kristine 1998). Additionally, the section of the river between Clearfield to Bald Eagle Creek in Lock Haven was deemed essentially sterile due to acid mine drainage and heated water discharge from the power plant near Shawville with only sparse concentrations of fish found near the base of dams and mouths of unpolluted tributaries (Hollender and Kristine 1998).

Photo provided by PFBC

Andrew Leakey and Dave Kristine survey the West Branch Susquehanna near Hyner.

Present Day Fishery

A total of 35 fish species were collected in the river during the 2009 survey including two species of hatchery trout. In addition, five species were collected which were not detected during the previous surveys including mimic shiner, central stoneroller, shorthead redhorse, green sunfish, and greenside darter. In general, fish diversity increased or was similar during 2009 compared to previous surveys in the sections of the river from the headwaters to Clearfield. Surveys of the sections from Clearfield downstream to Hyner showed a two-fold to five-fold increase with the largest improvement at the Hyner site (Figure 8, Table 3). In addition to the stable or increased diversity of the fishery, multiple age classes were collected for most species including many juveniles suggesting that successful reproduction is occurring.

Besides an increase in fish species diversity in the upper and middle portions of the river, there has also been a change in the distribution of some species. Bluntnose minnow, a pollution tolerant species, was only found at three sites in the headwaters during the 1999 survey but was collected at nine sites in 2009. Similarly, other tolerant species including white sucker and green sunfish as well as the pollution intolerant species northern hog sucker, river chub, and longnose dace were found to occur at a greater number of sites in 2009, especially those between Clearfield and Hyner (Figures 9 & 10).

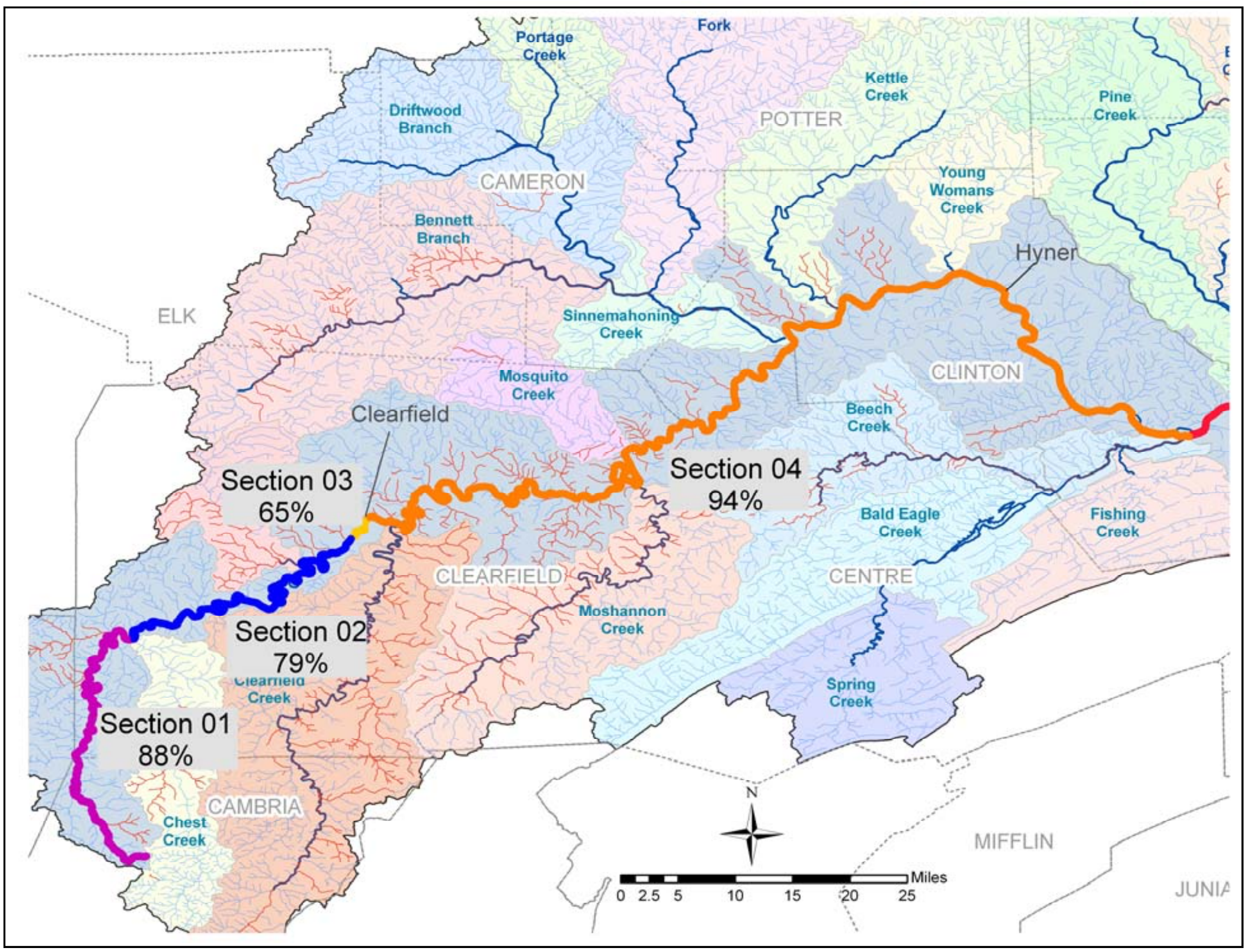


Figure 8 — *Total catch increases in the four PFBC river management sections evaluated as part of the Project.*

These data provide further evidence of improved and sustained water quality which has allowed more species to occur in reaches of river once considered "dead" and even intolerant species to occur in some abundance.

Total fish catches followed a pattern similar to species occurrence and indicated a substantial increase in relative abundance at all sites. However, when compared to other area waters or in downstream sections of the West Branch Susquehanna River, fish catches are relatively low (Hollender and Kristine 1999) and while current abundances reflect an improved condition they have still not reached their full potential.

In summary, results from this evaluation indicate an improving and sustaining fishery. Especially significant are the presence and abundance of fish in the section of river between Clearfield and Hyner, which has long been considered mostly inhospitable to fish. However, while results indicate that substantial improvements have been made, the river is still being impacted by AMD, siltation, thermal impacts from the power plant near Shawville, and fish passage barriers at Lock Haven, Shawville, and Clearfield, and is not yet functioning at its full potential.

Photo provided by PFBC

Bluegill from the West Branch Susquehanna River near Hogback Run.

Photo provided by PFBC

Smallmouth bass from the West Branch Susquehanna River at Hyner.

Table 3 *— Total catch and species captured at PFBC sampling locations in 1998/1999 and 2009.*

	Total Catch			Species	
Site	1998	1999	% Increase	1998	1999
Shyrock Run	57	150	163%	6	10
McGees Mills	113	143	26%	14	14
Bower	141	167	18%	11	13
Hogback	234	504	115%	19	20
Clearfield	40	113	182%	6	10
Egypt	8	115	134%	5	11
Deer Creek	12	135	1025%	6	14
Burns Run	9	45	400%	5	12
Hyner	13	420	3130%	3	16

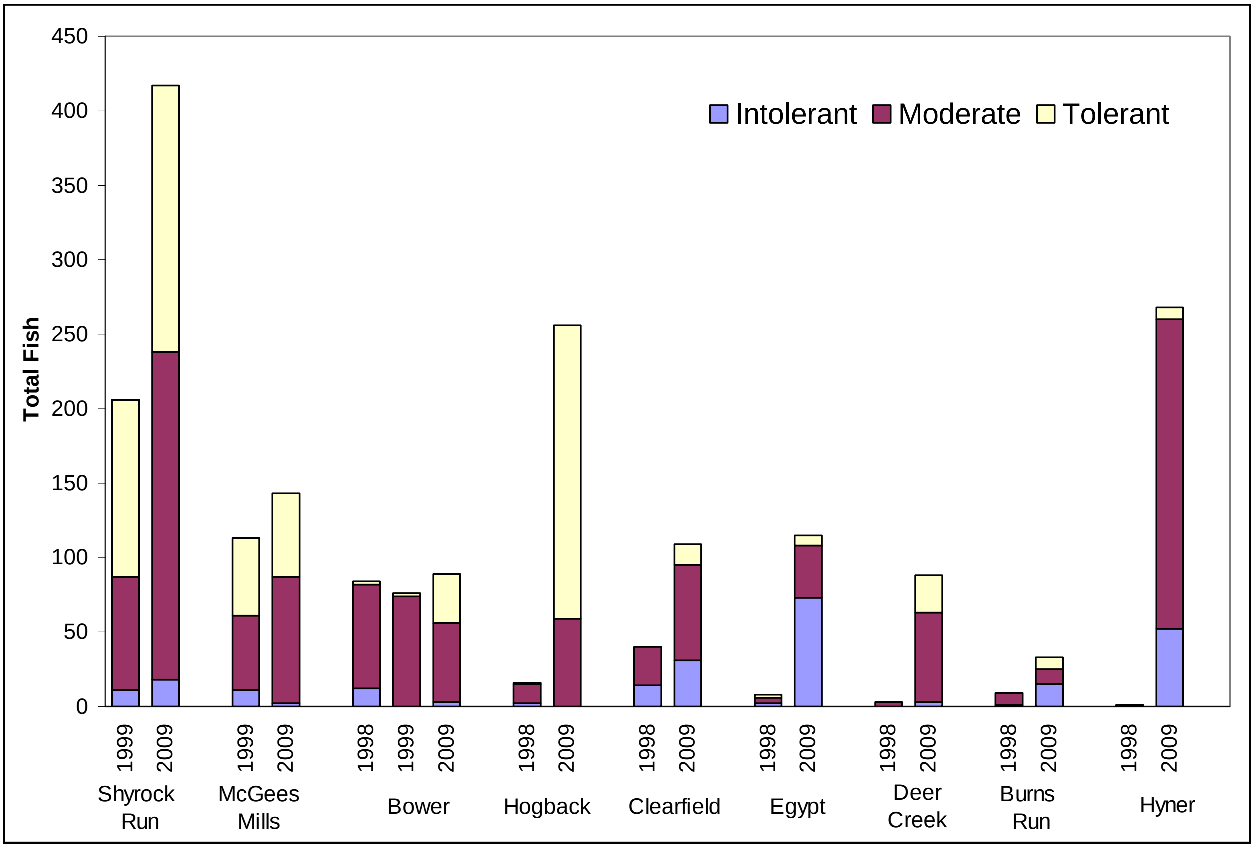


Figure 9 *— Total fish captured and fish tolerance at backpack electrofishing sites in 1998 / 1999 and 2009.*

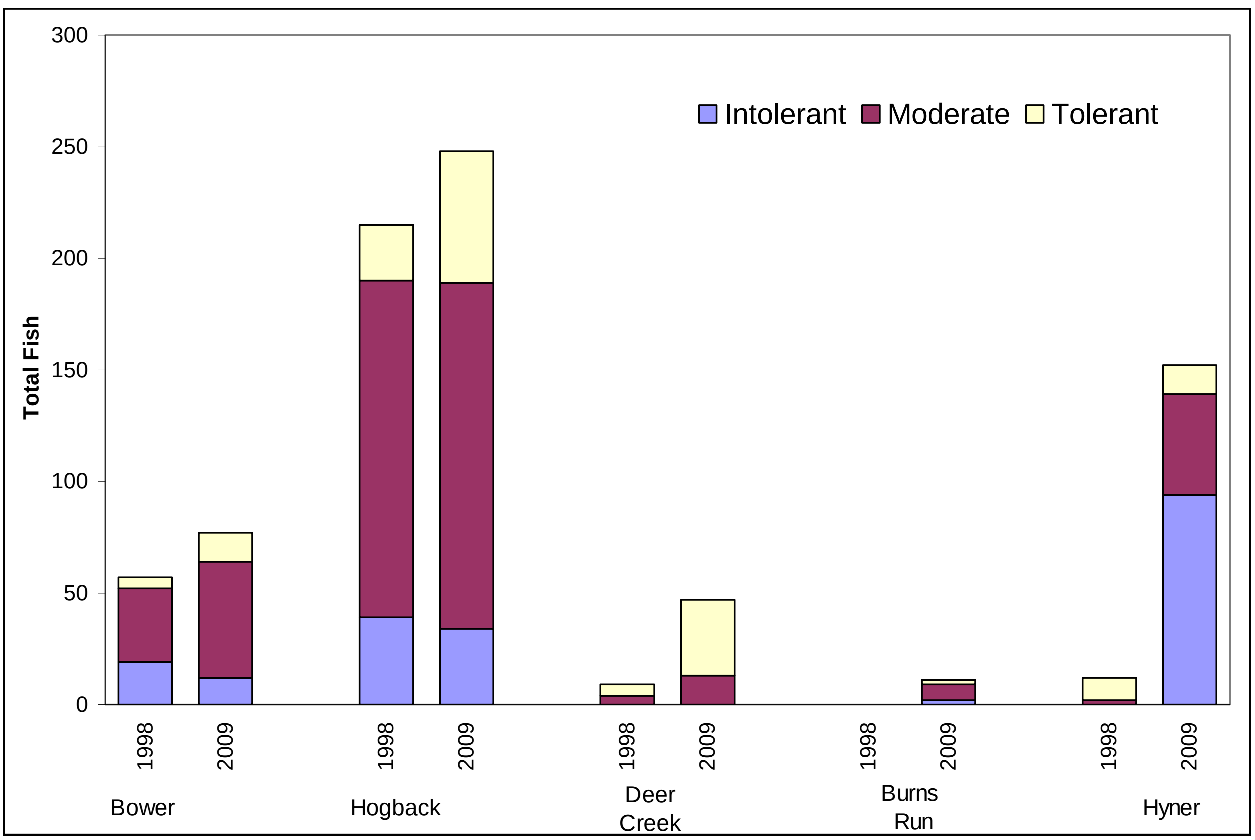


Figure 10 *— Total fish captured and fish tolerance at mini-boom electrofishing sites in 1998 / 1999 and 2009.*

The Fishery of Selected AMD Impaired Tributaries

In addition to the improved fishery in the river, numerous tributaries have also experienced enhanced fisheries as a result of improved water quality. For instance, the Babb Creek Watershed Association and its partners have been treating AMD in Tioga County's Babb Creek watershed since 1991 and have been successful in removing 14 miles of Babb Creek and 5 miles of Pine Creek from the Commonwealth's list of impaired waters. The PFBC conducted evaluations of Babb Creek in 1999 and again in 2005 and determined that the number of brook trout, brown trout, and smallmouth bass captured during survey efforts increased by 83%, 35%, and 69% respectively at ten sites in the creek (Detar and Hollender 2005).

Similar fishery improvements have been noted in Centre County's Sterling Run watershed. Remediation of the Boake Run headwaters via passive treatment resulted in the delisting of just over 12 stream miles from the DEP's impaired streams list. Accordingly, the number of brook trout collected at the mouth of Boake Run substantially increased subsequent to treatment (Spotts 2009). Fishery surveys in both 2006 and 2008 in Sterling Run approximately one mile downstream of its confluence with Boake Run, a section of stream containing very few or no brook trout previously, produced several year classes of brook trout as well as pumpkinseed sunfish (Spotts 2009).

The aforementioned projects are just a few of examples of fishery improvements that are becoming more commonplace across the West Branch Susquehanna in tributary watersheds where water quality conditions are improving and fish are returning to historically degraded or lifeless sections of streams.

Photo provided by DEP

Brook trout from below the Pine Glen East passive treatment system.

Photo provided by DEP

Pine Glen East passive treatment system in the Boake Run watershed.

Photo provided by W. Beacom

Josh McCormick, Jason Detar, and Bruce Hollendar survey Babb Creek post AMD-remediation efforts.

Baseline Benthic Macroinvertebrate and Habitat Data

Sixty-six sites were sampled for benthic macroinvertebrates and evaluated for habitat (Table 2). Those 14 sites that did not have these analyses completed, but were sampled for water quality were too deep for ICE protocols or conditions were too unsafe for data collection. Of the sites sampled for benthic macroinvertebrates, five samples had no taxa present and 69% of the samples were dominated by the pollution tolerant family chironomidae (Table 7).

While the ICE protocol is appropriately used to identify when a stream is impaired, its application to determine degree of impairment is limited especially in mine drainage impacted waters. For example, in order to calculate an IBI a sample must consist of 200 ± 40 individuals, a condition which rarely occurs in mine drainage impacted waters. Furthermore, in mine drainage impacted streams that do have 200 ± 40 individuals, a large percentage of taxa are often comprised of the Plectopteran (stonefly) genera *Leuctra* and *Amphinemura*. Although Plecopteran are largely considered pollution sensitive, these taxa are considered acid tolerant and their presence can erroneously inflate IBI scores.

Of those project sites that had individuals present, only four had individual counts of 200 ± 40 and one of these streams, Rupley Run, was dominated by the acid-tolerant genera *Leuctra* and *Amphinemura*. Therefore IBI scores were only calculated for three streams and those scores indicated impaired conditions. However, although not attaining the required number of taxa for a calculated IBI score, several streams did contain notably high numbers of pollution sensitive taxa suggesting that if their total numbers were slightly higher they might be potential candidates for an unimpaired classification and should be further investigated. These streams include Birch Island Run, Chest Creek at Mahaffey, Babb Creek, Tangascootack Creek,

Photo: R. Dunlap

Sampling for benthic macroinvertebrates.

Photo: R. Dunlap

Orange Trichoptera found in an unnamed AMD-impacted tributary in Clearfield Creek during the Project.

Photo: R. Kester

Plecoptera found in an unimpaired stream in the West Branch Susquehanna watershed.

Black Stump Run, Devils Run, Big Run, and Sterling Run. Since the time of data collection for this Project, Babb Creek and Sterling Run were removed from the Commonwealth's list of impaired waters further corroborating this assumption.

Habitat evaluations indicate that habitat is generally not the limiting factor throughout the study area. Fifty-six percent of all the sites had total scores above 180 indicating optimal habitat and 44% had scores indicating suboptimal conditions (Figure 11). The "embeddedness" parameter consistently scored lower than other habitat parameters as a result of the metal precipitation associated with AMD (Figure 12).

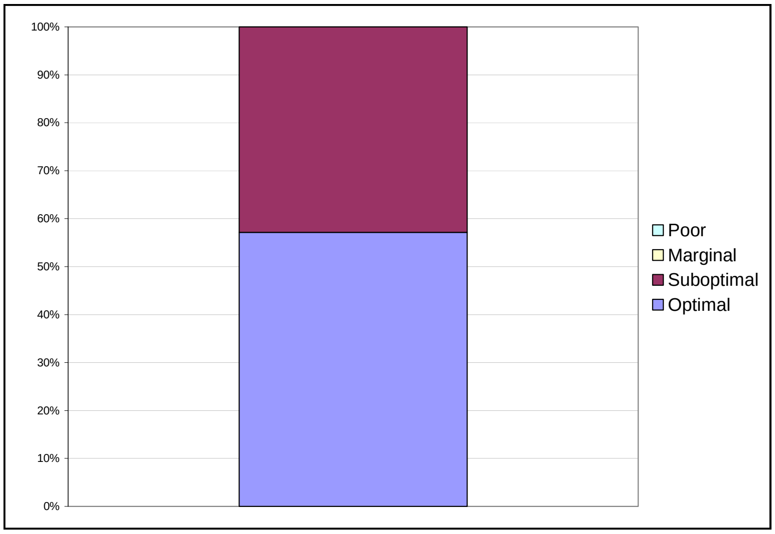


Figure 11— *Percentage of habitat sites considered optimal (total score >180, suboptimal (total score between 181 an 120), and marginal (total score between 121 and 60).*

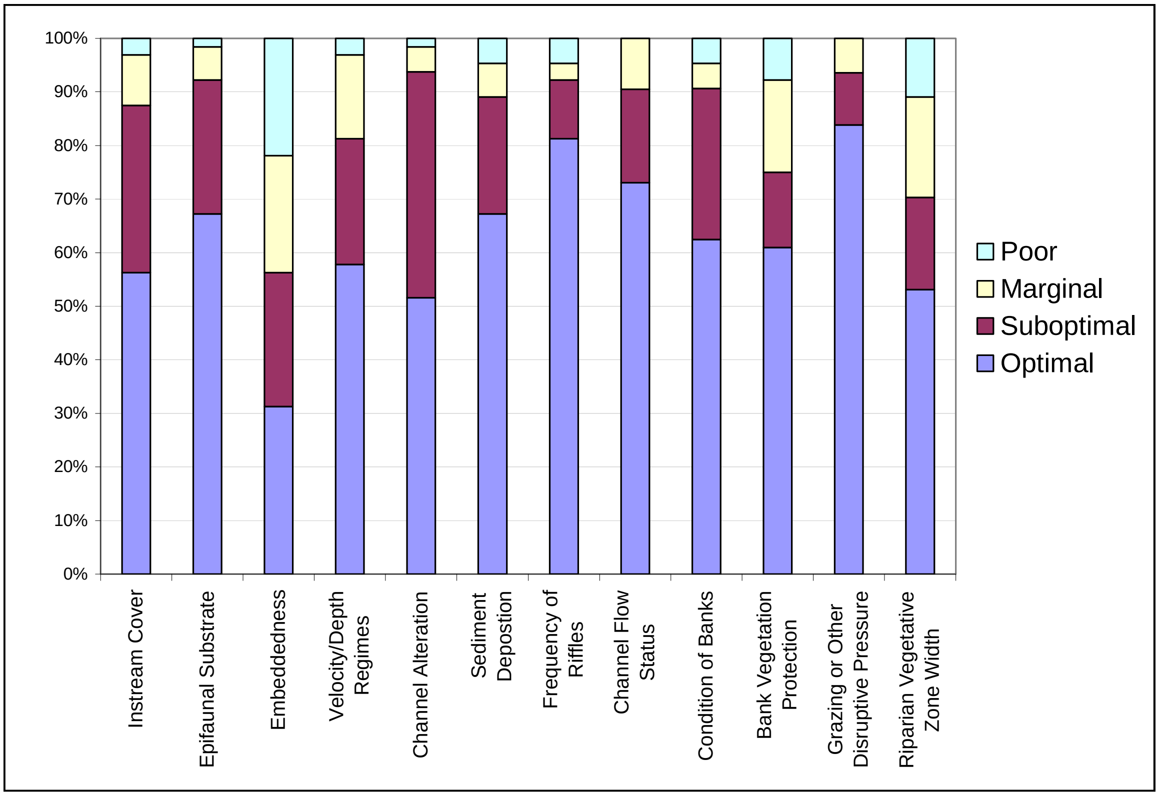


Figure 12 *— Percentage of habitat parameter evaluated at each site as either poor, marginal, suboptimal, and optimal.*

Water Quality Changes

The tremendous improvements documented in the West Branch Susquehanna River and its tributaries are a result of a combination of factors that primarily include a gradually diminishing amount of pyrite available for oxidation, remining and reclamation activities, better permitting for mining projects, and passive and active treatment projects. In the subsequent sections improvement is allocated to contributing factors where supporting data exist and several specific watershed changes are discussed.

Geochemical Weathering of Pyrite and Remining

Photo: R. Dunlap

KC2O4 mine pool in the Kettle Creek Watershed.

A majority of the large-scale improvements observed in the West Branch Susquehanna River and some of its major tributaries can be allocated to the geochemical weathering of pyrite and remining activities over the last 25 years. Pyrite, a mineral found in coal seams and the surrounding rock strata, oxidizes when in the presence of water and oxygen to produce acidity, dissolved iron, and dissolved sulfate. This reaction, the basis for acid mine drainage production, is limited by the amount of and exposure of reactive pyrite on fragment surfaces. Over time it is expected that the geochemical weathering of pyrite will naturally decrease or demonstrate a natural attenuative-like effect, thereby reducing the amount of acidity produced from abandoned mine sites. However, the exact amount of time required for natural attenuation to substantially reduce the amount of acid mine drainage produced depends on geologic and environmental factors including coal seam, overburden thickness and geochemistry, mine location relative to the regional water table, and initial acidity. While these influencing factors make it such that not all mines will attenuate pyrite and improve over time in homogenous increments, general long-term pyrite attenuation trends have been characterized for both below and above drainage mines (Donovan et a 2003, Mack and Skousen 2008). Of particular significance to the West Branch Susquehanna is research completed by Mack and Skousen (2008) characterizing 44 above-drainage mines, the typical mine-type found in the West Branch Susquehanna watershed, in the Pittsburgh and Upper Freeport coal seams. Despite varying initial concentrations of acidity, the average annual decrease in acidity in these mines over a 38-year period was determined to be a result of natural attenuation at an average rate of 2.1% per year (Mack and Skousen 2008).

Six control tributaries, AMD polluted tributaries located in subwatersheds that are known to have experienced no known treatment and have had no mining activity over the last 25 years (DEP, personal communication) were selected to estimate natural attenuation or the rate of pyrite oxidation typical for AMD in the West Branch Susquehanna watershed. These tributaries all enter the West Branch in Clearfield and Centre Counties near the mouth of Moshannon Creek (Figure 2). Initial acidity concentrations as measured by the USGS in 1984 in these tributaries ranged from 40 to 397 mg/L as $CaCO_3$. All six tributaries showed marked decreases (12.5% to 81.3%) in acidity concentrations in 2009 (Figure 13). Rupley Run and UNT 25611 were measured to have the highest initial acidity in 1984. These streams demonstrated the most improvement with reductions in acidity of 81.3 % and 47.4% respectively while Laurel Run, the tributary with the least amount of acidity in 1984 (40 mg/L as $CaCO_3$) demonstrated the lowest percentage (12.5%) of acidity reduction over the 25-year period.

This control data set confirms that the variation of total percent attenuated per stream is dependent both on season and initial concentration. However, the amount attenuated on a per year basis is less influenced by these variables. Evaluation of the acidity attenuated per year by the exponential decay equation $N = N_o e^{kt}$ where N represents the 2009 acidity concentration, N_o the 1984 acidity concentration at 2009 flows based on the slope of the inverse log-linear relationship of decreasing acidity and increasing discharge rate, and t the 25 years spanning the data collections, produced results that ranged from 0.5% to 6.7% per year and an average annual percent attenuation of 3.8% per year. Sulfate, another proxy for pyrite oxidation that is less affected by neutralization processes, demonstrated similar attenuation rates. The range of sulfate attenuated per year ranged from 2.6% to 11.1% and averaged 4.7% per year in the control tribu-

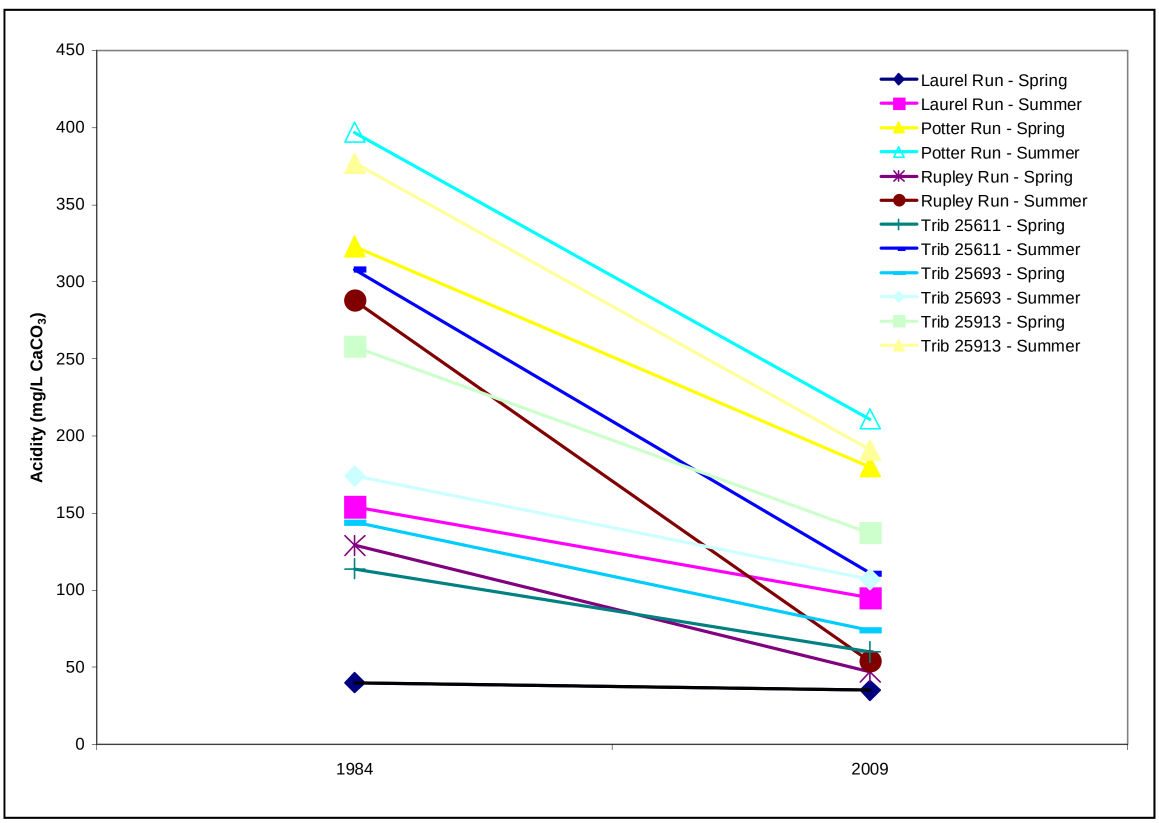


***Figure 13** — Acidity reduction in six control tributaries between 1984 and 2009.*

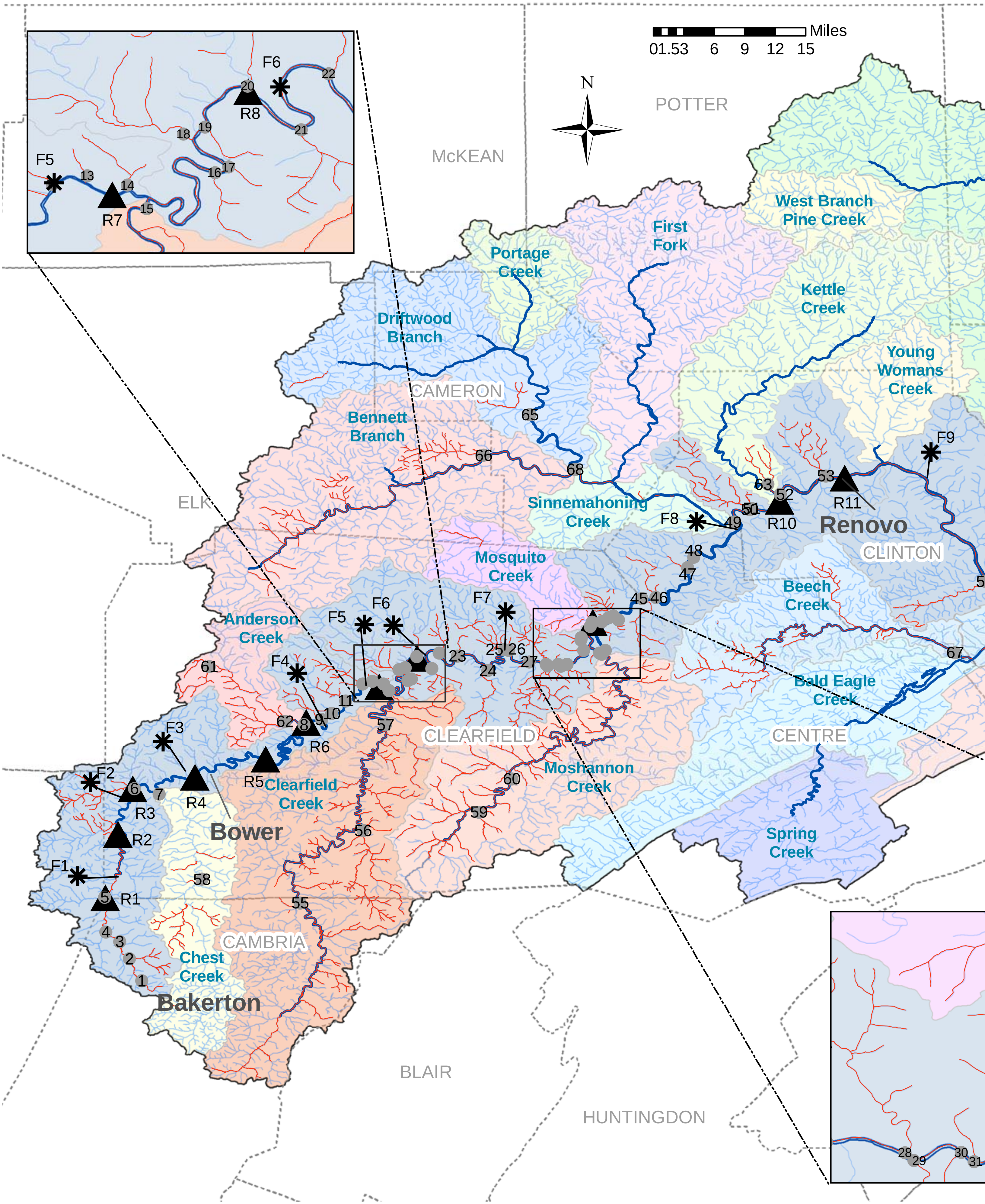
taries using the aforementioned decay equation. These average annual percent attenuation rates are slightly higher than the 2.1% per year reduction observed in other studies (Mack and Skousen 2008). However, because the 1984 concentrations of acidity and sulfate utilized in these calculations were presumed based on the 2009 flows and only 2 data points, effort was made to avoid over-estimating the effects of natural attenuation. Therefore, a conservative 2.0% exponential reduction rate based on Mack and Skousen (2008) was used to predict attenuation at other sites within the watershed in subsequent analyses.

The Commonwealth has identified remining as a potential reclamation practice since the early 1980s (Office of Resources Management 1983). In fact, according to Pennsylvania's 1983 Abandoned Mine Reclamation Plan, "It shall be the environmental policy of the Commonwealth to strongly encourage additional federal, state, and private activities directed to the abatement of the environment in any areas degraded by previous coal mining activities" and that possible related activities include "tax incentives for remining and restoring previously degraded areas" (Office of Resources Management 1983).

Remining typically involves the surface mining of the remaining economically minable coal reserves found in abandoned surface and underground mines (Smith et al. 2002) and has become routine practice in eastern states (Zipper et al. 2002). In remining operations, the mining operator assumes the liability for reclaiming the mine to current standards. In order to encourage the remining of abandoned mine lands, the operator may obtain a limitation of liability for pre-existing pollutional discharges. That waiver limits liability to increased pollution loading, but requires the implementation of BMPs designed to abate mine drainage pollution. The principal BMPs utilized in remining that affect water quality are surface reclamation and revegetation of abandoned surface mines, alkaline addition, encountering or redistribution of alkaline overburden, daylighting of abandoned underground mines, coal refuse removal, special handling of acid-forming overburden, and special water handling (EPA 2001).

Photo provided by DEP

Remining project near Mill Run in the Bennett Branch watershed.


Miles
0 1.5 3 6 9 12 15
N
POTTER
McKEAN
CAMERON
ELK
CLINTON
CLEARFIELD
CENTRE
CAMBRIA
BLAIR
HUNTINGDON
West Branch Pine Creek
First Fork
Portage Creek
Kettle Creek
Driftwood Branch
Young Womans Creek
Bennett Branch
Sinnemahoning Creek
Mosquito Creek
Beech Creek
Anderson Creek
Bald Eagle Creek
Clearfield Creek
Moshannon Creek
Spring Creek
Chest Creek
Renovo
Bower
Bakerton
F1
F2
F3
F4
F5
F6
F7
F8
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R1
R2
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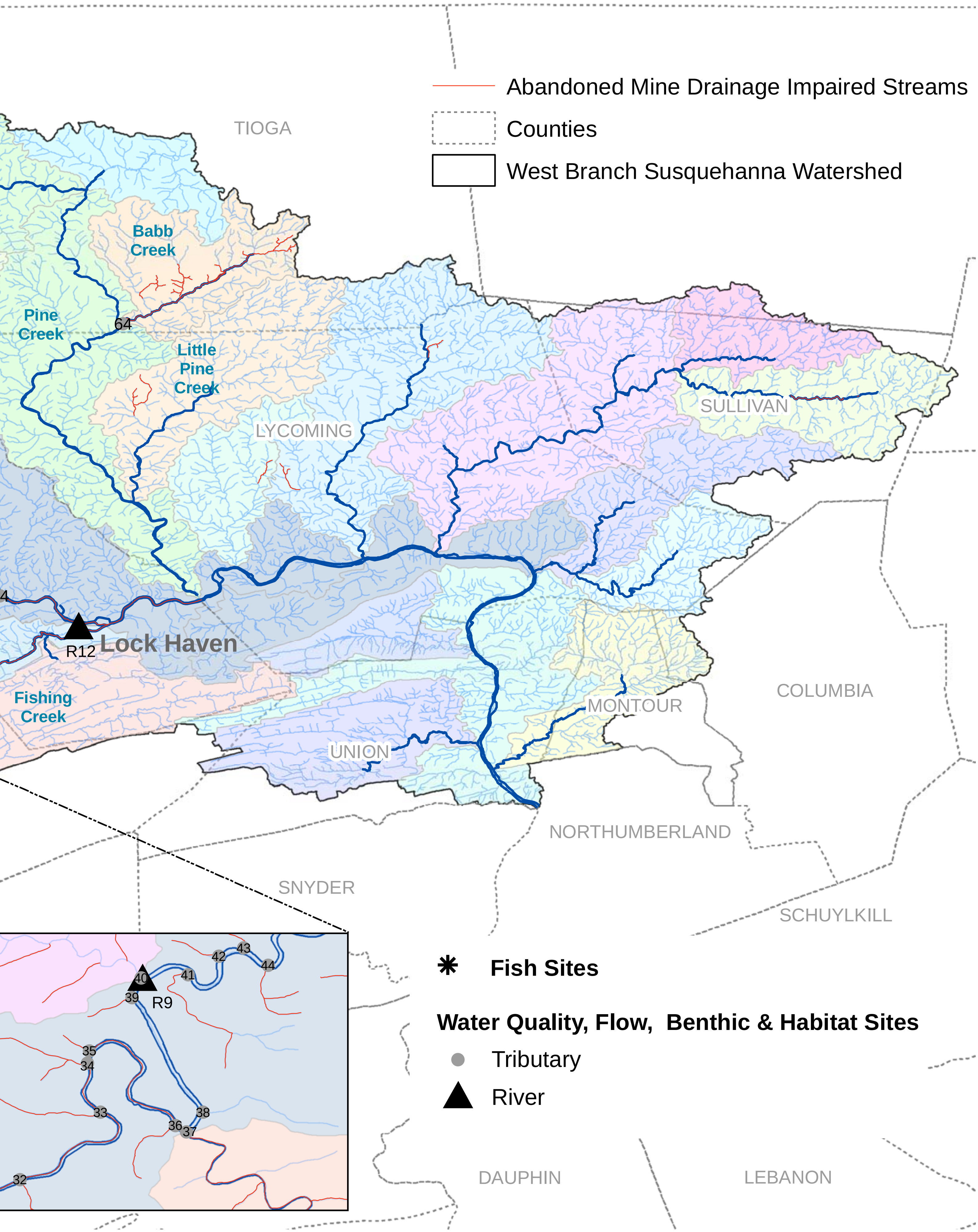
Abandoned Mine Drainage Impaired Streams
Counties
West Branch Susquehanna Watershed
TIOGA
Babb Creek
Pine Creek
64
Little Pine Creek
LYCOMING
SULLIVAN
Lock Haven
R12
Fishing Creek
COLUMBIA
MONTOUR
UNION
NORTHUMBERLAND
SNYDER
SCHUYLKILL
DAUPHIN
LEBANON
42
43
44
40
41
39
R9
35
34
33
38
36
37
32
Fish Sites
Water Quality, Flow, Benthic & Habitat Sites
Tributary
River

Photo: R. Dunlap

Unreclaimed abandoned mine area.

Photo: M. Smith

Reclaimed remining site.

Typically, the water quality of acidic and/or metal-laden discharges is improved after remining because the discharge rate and/or the concentration of the mine drainage is reduced, erosion and sedimentation control problems are abated, and reclamation sites are revegetated (Smith et al. 2002). Frequently, the addition of alkalinity via $CaCO_3$ containing overburden or imported alkaline material causes post-remining water quality to be alkaline rather than acidic.

The DEP has been issuing surface mining permits that authorize remining in areas contributing to pre-existing AMD discharges since 1984. The beneficial effects of remining in abating acid mine drainage are widely documented. Smith, et al. (2002) provide quantitative estimates on load reductions from remining based on a study of 112 completed remining operations in Pennsylvania. That study documented an average acid load reduction of 61% when post-remining water quality was compared to the pre-remining baseline. Approximately 38% of the observed reduction was due to reduced flow rates. The other 62% was due to actual changes in chemistry. Those results, combined with the remining acreage in the West Branch Susquehanna watershed and major subbasins, can be used to approximate the amount of pollution load reduction which is expected to have occurred due to remining.

For example, in the 12-year period from 1998 through 2010, permits authorizing the remining of 4,353 total acres of abandoned mine lands with pre-existing AMD discharges (averaging 335 acres/year) were issued by the DEP in the West Branch Susquehanna watershed above Karthaus (Figure 14) (DEP unpublished data). Records detailing acres remined prior to 1998 were not kept. Thus, assuming that the rate of remining has been relatively constant on a yearly basis, there were an estimated 8,375 acres of remining authorized in DEP permits over the 25-year period from 1984 through 2009. In actual practice, not all of what is permitted actually gets mined and reclaimed. A rate of 85% is a close approximation of what ultimately gets reclaimed under a remining permit. As such, the best approximation of the acreage remined in the West Branch watershed upstream of Karthaus during the period from 1984 through 2009 based on current data is 7,119 acres.

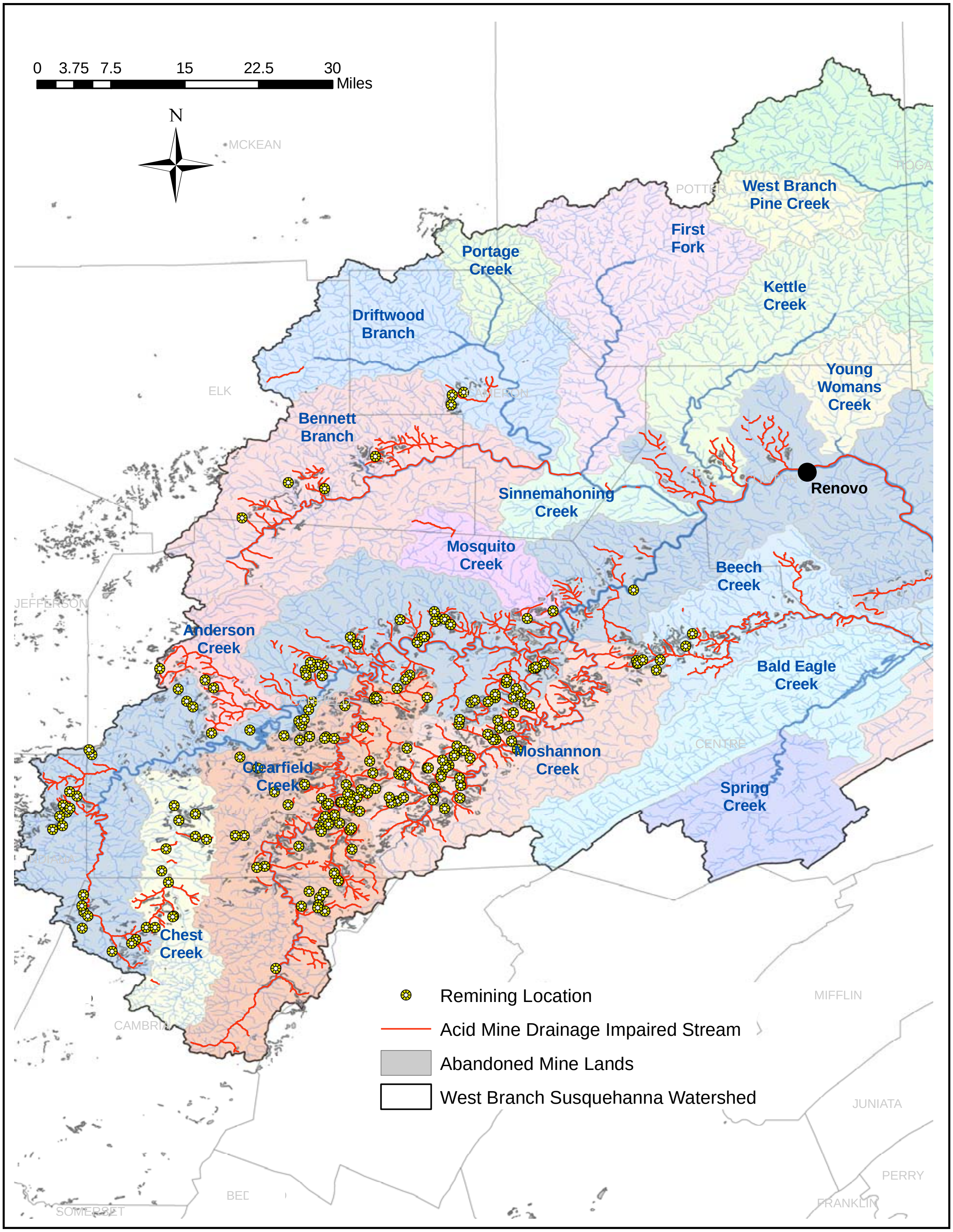

***Figure 14** — Remining locations in the West Branch Susquehanna river watershed between 1998 and 2009.*

The approximate remining acreage, combined with an acid load reduction of 61%, can be used to estimate the portion of the water quality improvement which can be expected to have resulted from remining. The average annual groundwater recharge within the West Branch Susquehanna River basin is 15 inches per year (Taylor, et al. 1983). This equates to an average groundwater recharge rate of 0.775 gallons per minute per acre. Lastly, the Smith et al. (2002) remining study identified an average pre-remining acidity concentration of 500 mg/l. Thus the average pre-remining acidity load from the remined acres is approximated to be 33,000 lbs/day. Using the average 61% load reduction in Smith et al. (2002), remining would be expected to reduce acidity loads by approximately 20,000 lbs/day.

By utilizing the above equations paired with the data collected in 1984 and 2009, it is estimated that between 43% and 44% of the acidity load reduction in the river at Karthaus can be allocated to natural attenuation and another 22% and 9% of the reduction to remining activities (Figure 15). Similar allocations were found in the Moshannon Creek watershed where natural attenuation explained between 53% and 56% of the improvements and remining another 4% to 8% .

The reduction residual, or the observed reduction that is not accounted for by natural attenuation or remining, serves as both a check on the reasonableness of the estimated attenuation and remining figures as well as an estimation of other load-influencing factors. These factors include reductions from passive and active treatment of AMD, surface reclamation, coal refuse pile removal, and other alkalinity-generating activities such mining in alkaline rock. Additionally, these factors include potential increasing variables such as the post-1984 production of new sources of acid mine drainage as well as acid precipitation. The residual noted in the West Branch Susquehanna at Karthaus is between 36% and 47% (Figure 15).

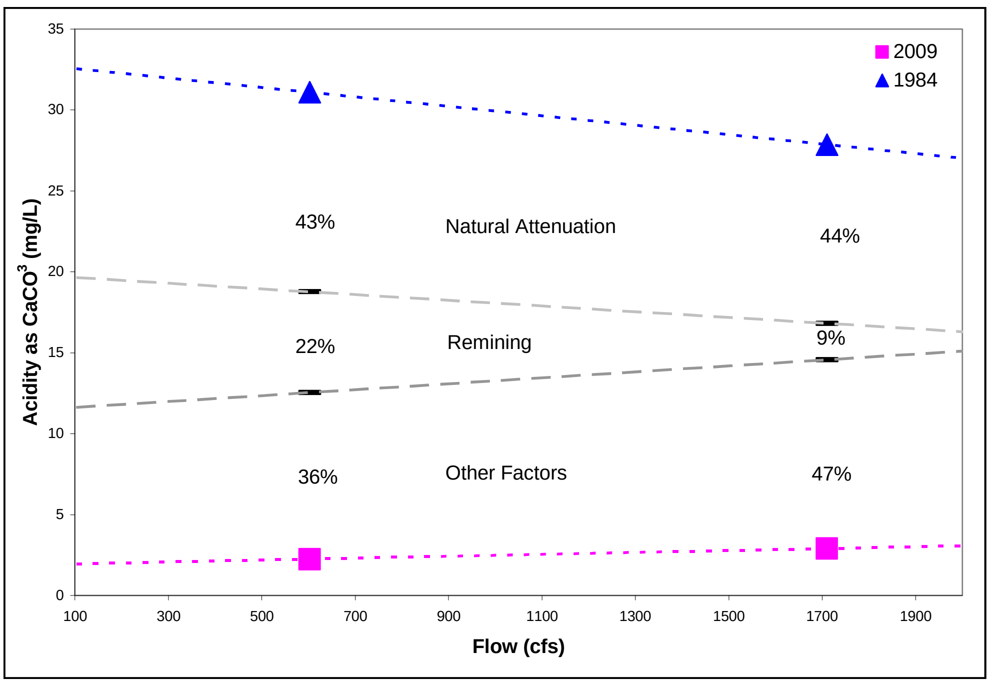

Figure 15 *— Acidity change in the West Branch Susquehanna at Karthaus and allocation of change to natural attenuation, remining, and other factors.*

By applying the expected reductions from natural attenuation and remining to various subwatershed scales the relative importance of the activities responsible for the load reduction residual is highlighted. For instance, residual values of 69% and 74% in the Clearfield Creek watershed suggest that other factors beyond attenuation and remining have provided important contributions to the improved water quality in that area. It is theorized that in this watershed the large amount of active surface mining on previously unmined lands and on unreclaimed lands that did not have pre-existing AMD problems has had a prominent effect on water quality. Mining in this watershed between 1984 and 2009 predominately occurred in the Middle Kittanning to Upper Freeport coal seams which tend to have increased alkalinity over background conditions and characteristically produce alkaline drainage. As a result, this mining appears to have liberated additional alkalinity which subsequently neutralized some of the acidity in the Clearfield Creek watershed.

Confluence of Little Clearfield Creek and Clearfield Creek.

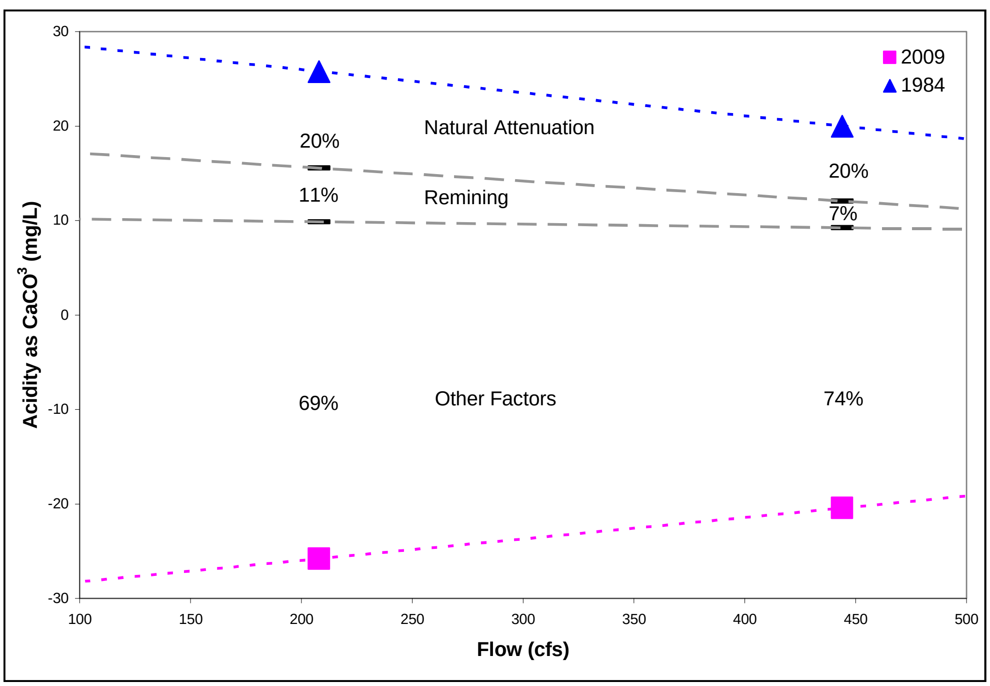

Figure 16 *— Acidity change at the mouth of Clearfield Creek and allocation of change to natural attenuation, remining, and other factors.*

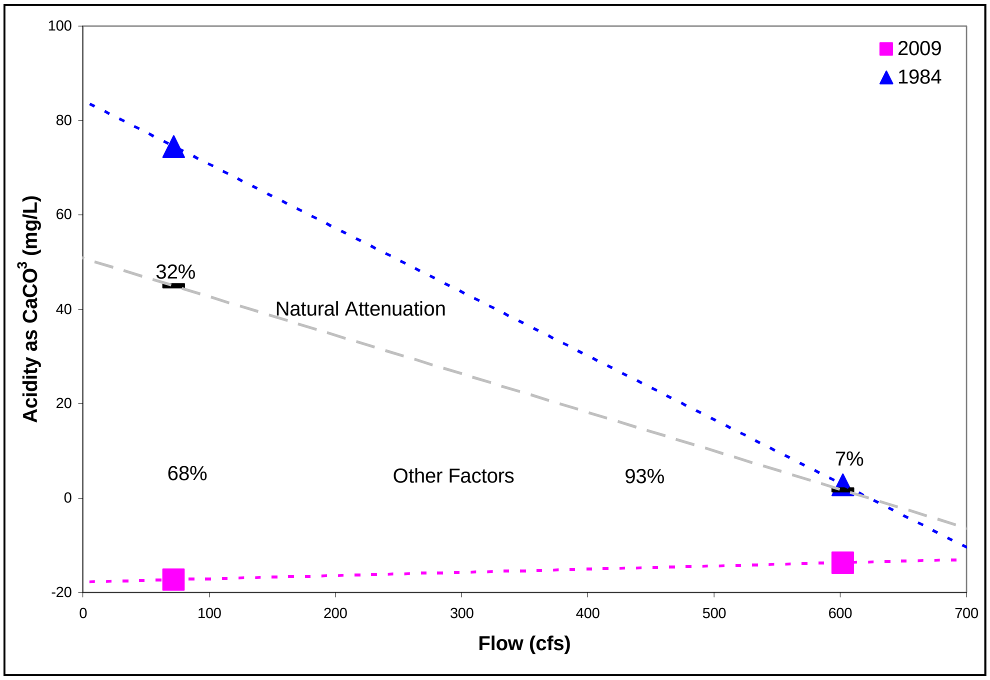

Figure 17 *— Acidity change at the mouth of Kettle Creek and allocation of change to natural attenuation and other factors.*

Deep mine complex in the Kettle Creek watershed.

The application of the expected reductions in watersheds where no remining or active mining activities occurred over the last 25 years can be used to support other known acid-changing events. For example, in the Kettle Creek watershed, large scale surface and deep mining of coal ended before 1984 yet a very high percentage of improvement (68% and 93%) cannot be allocated to natural attenuation. Here it is thought that a mine subsidence event at a deep mine complex on the west side of Kettle Creek played a key role in the acidity reduction noted at the mouth of the watershed. Until at least 1978 the deep mine complex discharged significant amounts of AMD to Kettle Creek. At some point between 1978 and 2002, but likely after 1984, the mine drain became blocked from the subsidence and the discharge flow ceased causing a mine pool to form. As a result, when the mine pool would fill, it would spill out another drain to Kettle Creek, as well as flow out of entries to Milligan Run. The portion of flow discharging to Milligan Run represents a decrease in loading to Kettle Creek. In addition, the formation of the mine pool post-subsidence allowed the mine to store large inputs of water and release them more slowly. This decrease in loading combined with the change in the discharge hydrograph of the mine would have produced a net reduction in pollution loading to Kettle Creek and caused positive changes in water quality.

In other subwatersheds water quality did not improve as much as is predicted from natural attenuation and remining. In these areas the predicted amount of acidity loading reduced from natural attenuation and remining exceeds what was observed, indicating that a load-increasing variable had an effect on overall water quality. Such was the case believed to have also occurred in the Alder Run watershed. While the concentration of acidity in Alder Run did improve based on the data collected in 1984 and 2009, this improvement was less than what was expected to be improved by natural attenuation alone. This lack of improvement is a result of mine drainage creation in the early 1980s.

Photo: A.Brison

Alder Run.

In 1977, SMCRA regulations were put in place so that pollution would no longer be created by coal mining operations. In addition, Pennsylvania assumed primacy of SMCRA in 1983 and required the prediction of the probable hydrologic consequences of new mining permits and also required a demonstration of no potential pollution (25 Pa. code section 86.37(a)(3)) thereby requiring the mining permit applicant to do the analysis necessary to show that coal could be extracted without resulting in post-mining discharges of acidity or metals. Although these regulations were in place in 1983, it took science nearly a decade to catch up with the law as industry and state regulators learned to use tools such as overburden geochemical analysis to make this determination. Subsequently, in the late 70s and early 80s, approximately 20% of mining permits issued resulted in post-mining AMD, oftentimes very severe in quality and difficult or impossible to treat. By 1996, fewer than 1% of new permits resulted in AMD, and those that did were generally mild forms that were readily amenable to passive treatment (Smith et al, 1999).

* *Note: So as to appropriately compare the 1984 and 2009 data at the same flows, acidity values were estimated in 1984 at the flow rates measured in 2009 by using the slope of the inverse log-linear relationship of decreasing acidity and increasing discharge rate based on the 1984 data. In addition, because the applicability of the hot-peroxide method of measuring acidity can be erroneous in waters with near-neutral pH and low metal concentrations, calculated net acidity based on metals (Hedin 2004) and reported alkalinity was utilized instead of the reported hot-peroxide acidity in 2009 for Clearfield Creek, Kettle Creek, and the West Branch Susquehanna at Karthaus. Since Alder Run was still severely polluted with AMD in 2009, the reported hot-peroxide acidities were utilized when evaluating why conditions changed in the aforementioned calculations.*

Passive Treatment

Passive treatment abates acid mine drainage via naturally occurring chemical and biological processes that require minimal operation and maintenance. Passive treatment typically utilizes a combination of components such as wetlands, limestone-filled channels or ponds, and ponds containing both limestone and organic compost. This is the most common form of remediation used by watershed groups throughout the Commonwealth, as well as across the West Branch Susquehanna watershed.

According to Datashed, a fully-featured, GIS enabled, Internet database designed to assist in the operation and maintenance of passive treatment systems, there are approximately 300 passive treatment systems in Pennsylvania treating AMD (Datashed 2011). Of these, 167 are characterized by Datashed to remove approximately 3.5 million lbs/year of iron, 200,000 lbs/year of aluminum and manganese, and 23 million lbs/year of acidity from the Commonwealth's waterways (Datashed 2011). In addition, 46 passive treatment systems have been built in the West Branch Susquehanna since the mid-1990s (Figure 18). Data characterizing these systems were not readily available to quantify their effect on the West Branch Susquehanna watershed. However, the many success stories of improved water quality conditions and recovering fisheries that are direct results from passive treatment projects point to the importance of passive treatment in the overall effort to restore the West Branch Susquehanna River and tributary watersheds from AMD pollution.

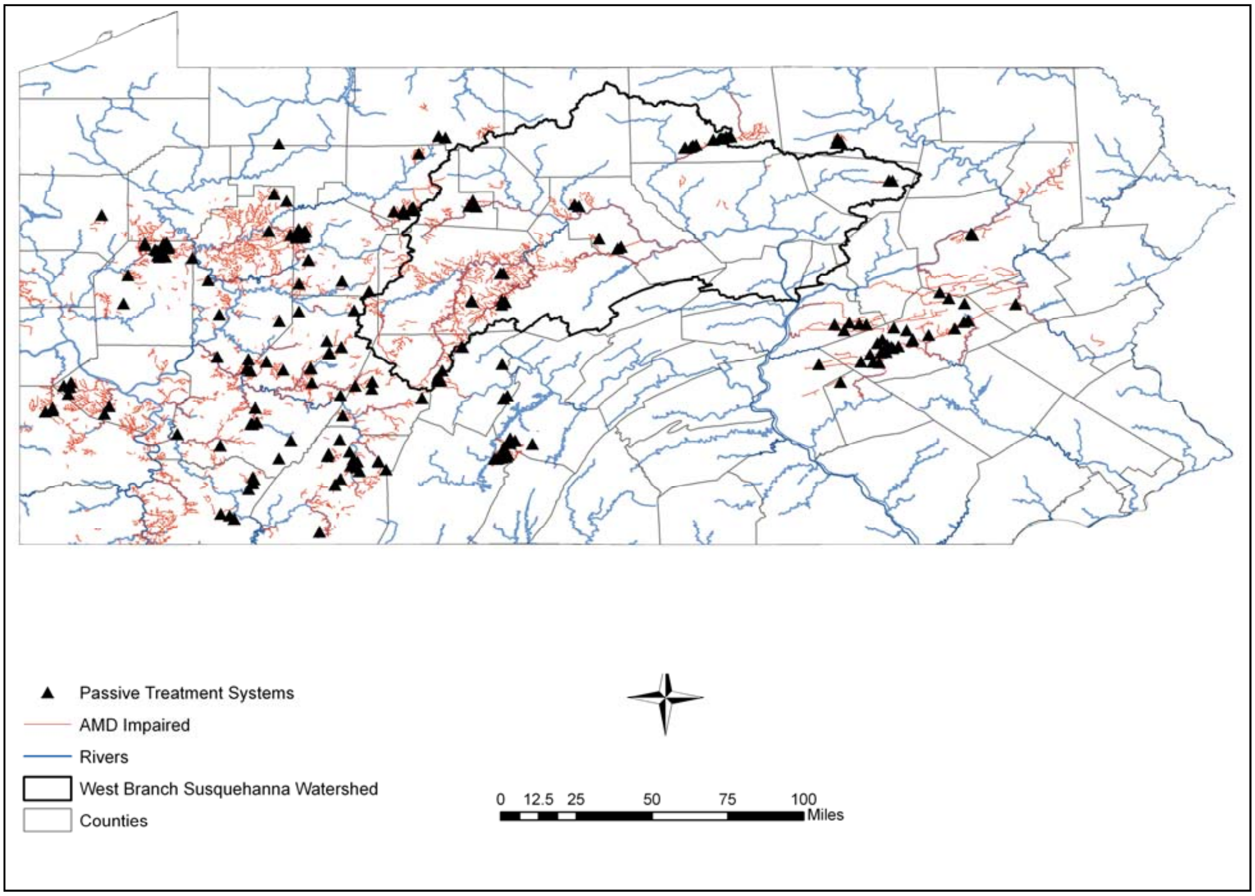

Figure 18— *Passive treatment systems in Pennsylvania.*

One such example is Middle Branch, a tributary to Twomile Run in the lower Kettle Creek watershed. In 1995 the average acidity at the mouth of Middle Branch was 48 mg/L as $CaCO_3$. Following a rehabilitation to the Middle Branch Passive Treatment System that addressed these AMD discharges to Middle Branch, the average acidity at the mouth was observed to be 4 mg/L (as measured via hot peroxide methods) – a difference of 92% when compared to acidity measured prior to successful passive treatment of the AMD (TU 2010 unpublished data). Without passive treatment this stream would have predictably taken until the year 2111, or 116 years, to achieve the low levels of acidity currently present considering the natural attenuation rate of 2.0% per year discussed in previous sections of the report (Figure 19).

Several existing passive treatment systems in the West Branch Susquehanna watershed have been used Commonwealth-wide as examples of how the science related to the design and construction of this type of treatment is both effective and evolving. In addition to the effectiveness of passive treatment technologies, the Middle Branch Passive Treatment System in the Kettle Creek watershed also serves as a an example of the need for adequate mine drainage characterization for treatment design. This system was initially constructed in 2000 to treat two highly acidic discharges characterized by high metal concentrations. TU in partnership with the Kettle Creek Watershed Association established a monitoring program to evaluate the system's efficacy and documented that the system was declining in treatment performance within one year post-construction. Subsequently, a system "autopsy" was performed and it was determined that during peak flows, the system was being severely overloaded (Hedin Environmental 2007).

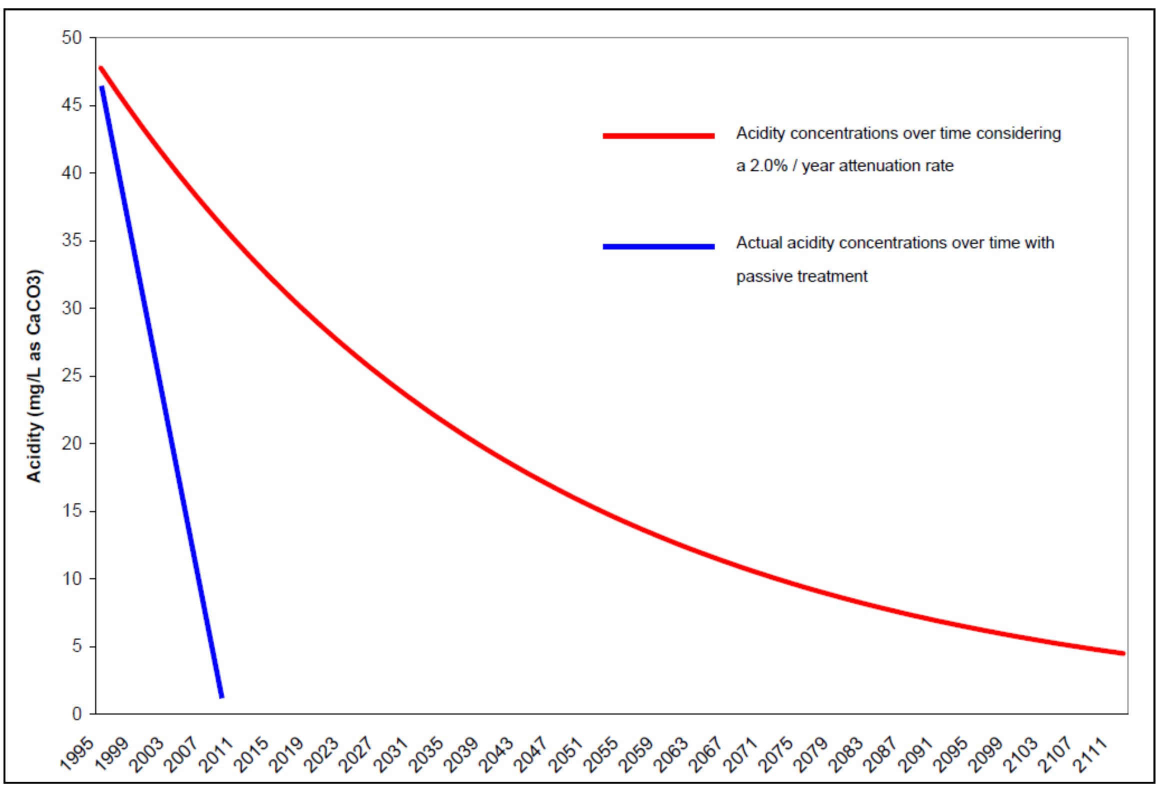

***Figure 19** — Observed acidity concentration reduction in Middle Branch post-passive treatment and expected acidity concentration reduction from natural attenuation.*

Therefore the system was rehabilitated in 2007 and presently, the Middle Branch Passive Treatment System utilizes four vertical flow ponds, an oxidation / settling pond, and an aerobic wetland to treat AMD with a pH of 3.2 to a pH of 7.1 and effectively remove metals. Within one year of the system rehabilitation, mayflies were discovered downstream of the treatment system and within 3 years, brook trout were documented in a stream segment considered lifeless for more than 100 years.


Photo: A. Wolfe

Middle Branch passive treatment system.

The Pine Glenn East Passive Treatment System in the Sterling Run subwatershed in Centre County is another testament to the efficacy of passive treatment in the West Branch Susquehanna watershed. Constructed in 2005, this treatment system consists of a vertical flow limestone bed and a settling pond (Milavec 2010) and treats water consisting of pH between 4.0 and 4.7 (Spotts 2009). The Pine Glenn East Passive Treatment System improved Sterling Run to a point so that just over 12 stream miles were removed from the DEP's impaired streams list and a reproducing brook trout fishery was naturally re-established downstream (Milavec 2010).

While most passive treatment systems are utilized to treat moderate AMD pollution, the breadth of conditions suitable for this type of treatment are becoming clearer as technologies advance. As an example, the Anna S Mine Passive Treatment Complex in the Babb Creek Watershed in Tioga County is the largest passive treatment system in the Commonwealth spanning over 20


Photo: S. Koser


Photo: R. Dunlap

Brook trout found downstream of the Middle Branch Passive Treatment System.

acres and treating an average of 520 gpm (Hedin et al. 2010). The Anna S mine encompasses an abandoned 840-acre mine with mine drainage characterized by a pH of 2.8 to 3.6 and high metal concentrations. The Babb Creek Watershed Association constructed the Anna S Mine Passive Treatment Complex to treat three discharges from the mine. The passive treatment complex consists of two systems, each containing four parallel vertical flow ponds followed by aerobic wetlands (Hedin et al. 2010). Despite the voluminous flow and severe chemistry discharged into the system, the passive treatment complex has treated the AMD to a neutral pH, effectively removed metals, and discharged measurable alkalinity for six years (Hedin et al, 2010). While this passive treatment complex is only one component to Babb Creek Watershed Association's stream restoration program, it is one of the major factors in the removal of 14 miles of Babb Creek from the Commonwealth's list of impaired waters in 2010.

Anna S passive treatment complex in the Babb Creek watershed.

Babb Creek Watershed Association celebrates removal of Babb Creek from the impaired streams list.

Active Treatment


Photo provided by DEP

Lime dosers in the Dents Run watershed.

Acid mine drainage abatement via active treatment generally refers to the continuous application of alkaline material to raise the pH of the water, accelerate the rate of chemical oxidation of ferrous iron, and precipitate many of the metals present in solution as hydroxides and carbonates (Johnson and Hallberg 2005). A variety of substances including limestone, hydrated lime, pebble quicklime, soda ash, caustic soda and ammonia are typically used to treat acid mine drainage in this manner.

Pennsylvania oversees the treatment of 34 active treatment facilities to treat AMD that was created by previous mining operations, but where the mining operator is no longer in existence and 117 facilities on permitted mining sites (DEP personal communication). In addition, several high-priority but pre-SMCRA active treatment operations are maintained by BAMR using abandoned mine restoration funds, also known as the Title IV Acid Mine Drainage Set-Aside Funds, provided through a per-ton fee on coal.

Compared to passive treatment technologies, fewer active treatment systems have been utilized by watershed groups in the West Branch Susquehanna watershed to treat AMD owing to the high cost of alkaline material and continuous operation and maintenance needs. However, there are examples of active treatment system presently in operation in the West Branch Susquehanna watershed in which watershed groups play an active role. In addition, the DEP has several additional active treatment systems either in the planning or construction phase.

The Babb Creek Watershed Association has successfully operated the Antrim Number One Mine Treatment Plant in the Babb Creek watershed for more than 15 years under an agreement with the DEP. This system is cited to be responsible for abating 50% of the pollution in Wilson Creek, a tributary to Babb Creek in the Pine Creek drainage in Tioga County (Barr 2004). The treatment system treats two abandoned mine discharges: one characterized by an average flow of 2,000 gpm and a pH of 3.14 and the other characterized by an average flow of 119 gpm and a pH of 2.99. The polluted water is treated with lime kiln byproduct slurry and the precipitated metals and limestone grit are settled in a clarifier before the resulting effluent ranging in pH from 8.0 to 10.0 is discharged into the receiving stream (Bill Beacom & Mike Smith, personal communication). This treatment system was put into operation in late 1991 and is managed by the Antrim Treatment Trust, primarily with funds established under an agreement with the PA DEP when Antrim Mining Company went out of business. As corroboratory proof of the importance of this active treatment system, within two years after the plant became operational, mayfly hatches were noted in Pine Creek, downstream of the confluence with Babb Creek, where none existed previously (Barr, 2004).

Another example of active treatment of AMD in the West Branch Susquehanna watershed is the "Swedish Tipping Buckets" in the Dents Run and Bear Run watersheds in Elk and Cambria Counties. In contrast to the Antrim Number One Mine Treatment Plant, which utilizes electricity, these automatic tipping bucket-type lime dosers add pulverized limestone using the inertia of the water being treated and subsequently require no external power (Cavazza and Smoyer 2008). The dosers in the Dents Run watershed are located on a discharge known to contribute 40% of the total acid load in the Dents Run watershed and were installed in 2008 by BAMR and the Bennett Branch Watershed Association.

Photo provided by DEP

"Swedish Tipping Bucket" in the Dents Run watershed.

The first Bear Run lime doser was placed online in April 2011 to treat the discharge originating from the Banks #2 Mine, a high acidity and aluminum concentrated discharge. Success was immediate as effluent water quality to the South Branch of Bear Run was documented at pH greater than 7.0 with low metal concentrations. This success was also realized without the current use of a sedimentation pond. However, a future sedimentation pond may be built for sludge disposal. The two other lime dosers that will be placed on mine discharges are scheduled for fall 2011 installation. Those dosers will restore the final AMD impacted tributary to the South Branch of Bear Run and may be the final project needed for a near restored Bear Run watershed.

Three additional active treatment systems are in the process of being constructed to treat AMD in the West Branch Susquehanna watershed. The Hollywood plant will be located in Clearfield County near the villages of Hollywood and Tyler and is expected to reduce approximately 41% of the acid load to 33 miles of impacted waters in the Bennett Branch of the Sinnemahoning Creek watershed. Currently, AMD emanates from over 20 individual mine openings from four different underground mine complexes near the plant's proposed location. BAMR intends to collect these discharges via more than 18,000 feet of gravity sewer and numerous wet mine seals and convey them to a centralized location in Hollywood where they will be collectively treated with two ferrous oxidation reactors, a clarifier, two sludge conditioning reactors, and a 4.5 acre polishing pond (Milavec 2010).

Photo: T. Clark

Active treatment in the Bear Run watershed.

In addition, BAMR has entered into an agreement with the SRBC to provide 15.7 million gallons per day of treated AMD to the West Branch Susquehanna River via two active treatment systems to mitigate for agricultural consumptive use under low-flow stream conditions. The Lancashire No. 15 plant will treat a discharge that emanates from a 7,100 acre mine complex which naturally drains to the West Branch Susquehanna River watershed (DEP 2009). Despite the geographic origin of the waters in the mine complex, the discharge has been received into Blacklick Creek in the Ohio River Basin since approximately 1970 (SRBC 2009). BAMR has relocated the discharge back to its original receiving water and will be treating it at the Lancashire No. 15 active treatment plant (Milavec 2010). The active treatment facility consists of an equalization basin, lime storage and supply system, clarifiers, and settling ponds and has the ability to treat up to 10 millions gallons per day of AMD and is expected to improve the water quality in at least 35 miles of the West Branch Susquehanna River.

Photo: R. Dunlap

Future Hollywood treatment facility location.

A second AMD treatment facility, currently in the pre-design phase, is being proposed for Clearfield Creek to provide 5.7 million gallons per day of treated AMD water for low-flow stream conditions. Construction and operation of the treatment plant in the headwaters of Clearfield Creek, near Cresson Borough, is expected to restore water quality in the main stem of Clearfield Creek to a level that will support a viable fishery from the headwaters downstream to the confluence with Brubaker Run. This facility will also collect and treat the most significant source of mine drainage to Sugar Run, a tributary of the Juniata River, thereby allowing for biological restoration with the completion of other priority projects within the Sugar Run restoration plan.

Photo: R. Dunlap

Photo: R. Dunlap

Abandoned mine reclamation project in the Bennett Branch watershed.

Coal Refuse Pile Removal and Surface Reclamation

Other methods commonly used to abate acid and metal loading resulting from AMD include surface reclamation and coal refuse pile removal. Coal refuse, or coal with high ash content and minimal heating value, was historically separated from the usable extractions and left in piles commonly referred to as "boney" or "gob"(garbage of bituminous) piles in the bituminous region of Pennsylvania (EPA 2008). When exposed to the elements, these coal refuse piles have the ability to generate enormous amounts of acid loading as documented in the 1972 Scarlift report for the West Branch Susquehanna River. As such, removal of these piles is a long-term, permanent solution to the generation of AMD. In the early 1970s there were 12 coal refuse piles each containing more than 100,000 cubic yards of refuse between the West Branch Susquehanna headwaters in Barnesboro and Cherry Tree. At that time, it was thought that these refuse piles accounted for 70% of the acid in the uppermost reaches of the West Branch (Commonwealth of Pennsylvania 1972).

The Barnes-Watkins coal refuse pile project is an example of the successes that can be realized by removing these refuse piles. The Barnes-Watkins coal refuse pile contained 1.3 million tons of refuse coal and covered an area of approximately 18 acres (Cambria County Conservation and Recreation Authority 2011). This refuse pile, located on the river, not only degraded water quality but also degraded local air quality as it burned for decades (Cambria County Conservation and Recreation Authority 2011).

Photo provided by DEP

Former Barnes Watkins coal pile.

Photo: R. Dunlap

Present-day site of former Barnes Watkins coal pile.

The Cambria County Conservation and Recreation Authority removed this coal refuse pile with a $4.4 million pass-through grant from BAMR. The coal was reprocessed and either utilized at a local co-generation power plant or deposited in a permitted disposal site (Milavec 2010). Surveys of benthic macroinvertebrates in the West Branch Susquehanna within one year of post-pile removal indicated an increased aquatic life population and young-of-the-year brown trout were found within two years in a section of the river assumed dead for decades (Milavec 2010; Commonwealth of Pennsylvania 1972).

Photo: A. Wolfe

Twomile Run surface reclamation site before reclamation.

Photo: A. Wolfe

Twomile Run surface reclamation area after reclamation.

Another simple and effective method to reduce mine drainage pollution is through reclamation of abandoned mine lands. Lands with unregraded mine spoil and/or sparse vegetation promote infiltration of precipitation and reduced evapotranspiration. In mine land environments these characteristics are associated with mine drainage production. Abatement, in many cases, includes recontouring of the surface to promote positive drainage, augmentation of the surface with alkaline material and topsoil substitutes to encourage vegetation growth, and planting of vegetation.
TU's Twomile Run surface reclamation project in the Kettle Creek watershed is a good example of this type of remediation. This project included the recontouring of 57-acres of abandoned surface mine to promote surface runoff of clean water from precipitation and addition of an alkaline byproduct to promote the growth of an elk food seed mix. The resulting new vegetation also allowed precipitation to more readily leave the site through evaportranspiration and inhibited the precipitation from infiltrating into the coal spoil and creating acidity. The Twomile Run surface reclamation project successfully reduced flow, acidity, and metal loadings to Twomile Run by 30-50% (TU 2010).

Prevention of Future Discharges

As discussed previously, Pennsylvania assumed primacy for the federal SMCRA in 1983. Despite the fact that it took several years for mining operations to consistently result in suitable post-mining water quality, the results of SMCRA have been remarkable. In the late 1970s and early 1980s, approximately 20% of mining permits issued resulted in post-mining acid mine drainage, oftentimes very severe in quality and difficult or impossible to treat. By 1996, fewer than 1% of new permits resulted in acid mine drainage, and those that did generally produced very mild mine drainage that is readily amenable to passive treatment (DEP 1999). This had the important effect, since around 1990, of largely preventing additional inputs of mine drainage into the West Branch, setting the stage for its future recovery.

Comparable to the rest of the state, surface coal mining has experienced a slow but steady downward trend within the West Branch Susquehanna watershed but continues to be a significant activity. By the early 1980s underground mining within the West Branch was far less extensive than surface mining. Total annual coal production in 1984 was approximately 14.5 million tons. It slowly declined over the next 25 years to an annual production of approximately 5 million tons (DEP personal communication). Notably, even though more than 190 million tons of coal had been extracted (an average of 7.5 million tons per year) (Figure 20) from within the West Branch watershed by the time of this study, water quality continued to improve rather than further deteriorate.

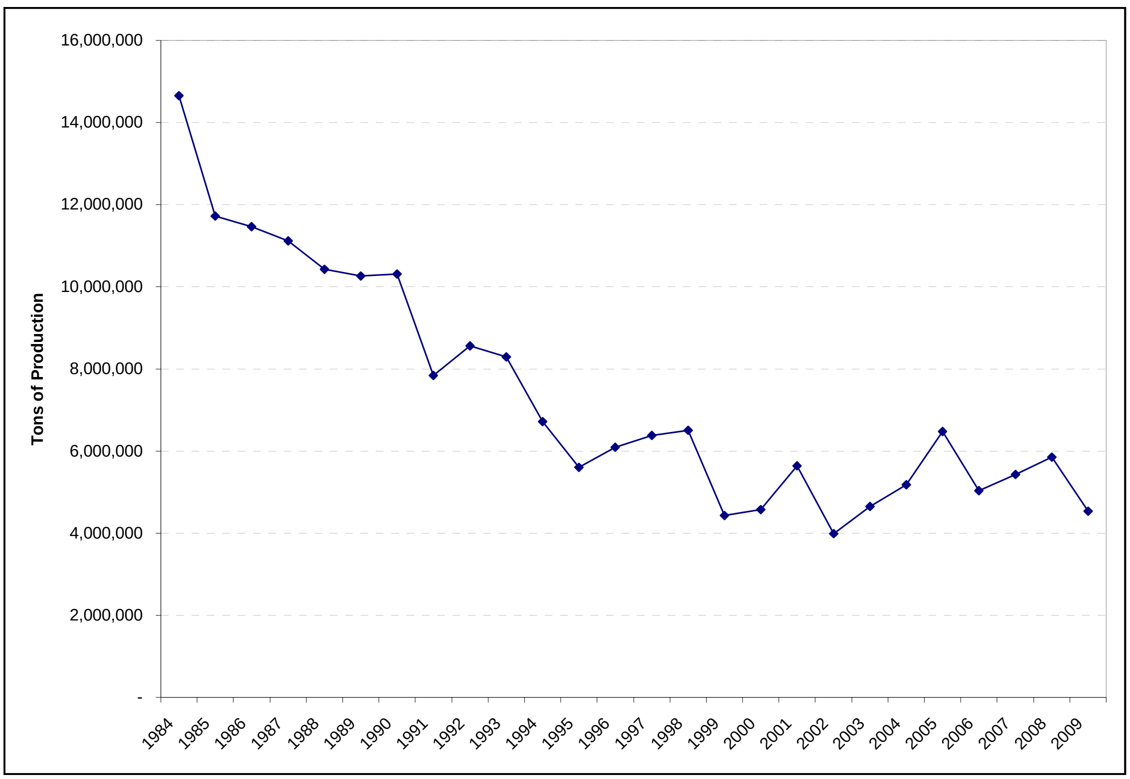

Figure 20 *— Estimated coal production in the West Branch Susquehanna watershed.*

Conclusions

Results from this West Branch Susquehanna Recovery Benchmark Project indicate significantly better water quality and biological conditions compared to historical conditions. For example, in contrast to the acidic conditions documented along the entire length of the river in the early 1970s, the Project revealed that the river is now in a near net alkaline state and that concentrations of acidity, iron, and aluminum have all decreased over the last 25 years. Additionally 85% of the tributaries had a higher pH than they did in 1984, and 79%, 68% and 92% of the tributaries were lower in acidity, iron, and aluminum concentrations respectively compared to 25 years ago.

West Branch Susquehanna River as seen from Hyner View State Park.

The fishery of the West Branch Susquehanna River also responded to the improved water quality conditions. Surveys of the sections from Clearfield downstream to Hyner, a section that has been considered mostly inhospitable to fish, showed a two-fold to five-fold increase in fish species diversity with the largest improvement at the Hyner site. Additionally, habitat evaluations indicate that habitat is generally not the limiting factor throughout the study area. Fifty-five percent of the 66 sites surveyed had scores that indicated optimal habitat.

These improvements can be attributed to a combination of factors that primarily include a gradually diminishing amount of pyrite available for oxidation, remining and reclamation activities, better permitting for mining projects, and passive and active treatment projects. However, despite these significant improvements only 10 of the 68 tributaries sampled were found to have water quality that met all Chapter 93 water quality criteria concentrations in the spring and only 11 were found to meet all criteria in the summer. Also, although the fishery on the river is showing obvious signs of recovery, fish species diversity and total abundance are still relatively low when compared to other non-AMD impacted streams and more downstream sections of the river.

While the improvements documented in this Project indicate remarkable achievements toward the recovery of the West Branch Susquehanna watershed, the sheer number of tributary sites that do not meet water quality criteria and the relatively low numbers for fish species diversity and abundance indicate that there is much to achieve before the watershed makes a full recovery.

The water quality and biological improvements accomplished to date deserve to be cautiously celebrated as the watershed ecosystem is only in its beginning stages of recovery. Maintaining the trajectory of improvement toward complete recovery will require the continued diligence and collaboration of government agencies, non-government organizations, private industry, and all other partners to continue implementing new AMD remediation, reclamation, and remining projects; maintaining the existing passive and active treatment systems; and protecting the resulting water quality and biological improvements from new sources of potential impairment.

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Appendix Table 1a—DEP Chapter 93 water quality parameter exceeded in the spring of 2009 as documented by the Project. All parameters are reported as total.

Site Number	Site Name	Aluminum >.75 mg/L	Iron > 1.5 mg/L	Manganese >1. mg/L	pH < 6	Sulfate >25 mg/L	Dissolved Solids > 75 mg/L
1	Lesle Run	X			X	X	
2	Fox Run	X	X			X	
3	Walnut Run	X				X	
4	Moss Creek						
5	Cush Cushion Creek	X					
6	Bear Run			X	X		
7	Chest Creek at Mahaffey						
8	Anderson Creek				X		
9	Hartshorn Run						
1	Tributary 26641			X			
11	Montgomery Creek			X	X		
12	Moose Creek			X			
13	Tributary 2668					X	X
14	Wolf Run	X	X	X	X	X	X
15	Clearfield Creek			X			
16	Abes Run	X		X	X	X	
17	Tributary 2614	X		X	X	X	
18	Lick Run		X		X		
19	Devils Run	X		X	X		
2	Trout Run		X		X		
21	Millstone Run	X		X	X		
22	Surveyor Run	X		X	X	X	
23	Bald Hill Run					X	
24	Moravian Run		X		X		
25	Deer Creek			X	X		
26	Tributary 25976	X	X	X	X	X	
27	Big Run	X					
28	Sandy Creek		X	X	X		
29	Alder Run	X	X	X	X	X	
3	Rollingstone Run	X	X	X	X	X	
31	Mowry Run	X	X	X	X		
32	Basin Run	X	X	X	X		
33	Rock Run	X	X	X	X	X	X
34	Potter Run	X	X	X	X	X	X
35	Tributary 25913	X	X	X	X	X	X
36	Rupley Run	X		X	X		
37	Moshannon Creek	X		X	X		
38	Redlick Run	X	X	X		X	X
39	Tributary 25693	X	X	X	X	X	X
4	Mosquito Creek						
41	Laurel Run	X		X	X		
42	Tributary 25622	X	X	X		X	X
43	Saltlick Run	X	X	X		X	X

Appendix Table 1b *—DEP Chapter 93 water quality parameter exceeded in the spring of 2009 as documented by the Project. All parameters are reported as total.*

Site Number	Site Name	Aluminum >.75 mg/L	Iron > X.5 mg/L	Manganese >X. mg/L	pH < 6	Sulfate >25 mg/L	Dissolved Solids > 75 mg/L
44	Tributary 25611	X	X	X	X		
45	Sterling Run	X	X		X		
46	Loop Run	X		X	X	X	
47	Birch Island Run		X		X		
48	Black Stump Run						
49	Sinnemahoning Creek						
5	Cooks Run	X	X		X		
51	Milligan Run	X	X	X	X	X	
52	Kettle Creek						
53	Drury Run	X		X	X		
54	Tangascootak Creek		X				
55	Clearfield Creek at SR 121			X			
56	Muddy Run		X	X		X	
57	Clearfield Creek at Dimeling			X			
58	Chest Creek at Westover						
59	Moshannon Creek at Osceola Mills	X		X	X	X	
6	Moshannon Creek at Philipsburg	X	X	X	X		
61	Little Anderson Creek	X	X	X	X		
62	Kratzer Run						
63	Twomile Run	X	X	X	X		
64	Babb Creek						
65	Sterling Run (Sinnemahoning)	X	X				
66	Bennett Branch	X		X	X		
67	Beech Creek				X		
68	Dents Run				X		
R1	WB at Cherry Tree						
R2	WB at Burnside						
R3	WB at McGees Mills						
R4	WB at Bower						
R5	WB at Lumber City						
R6	WB at Curwensville						
R7	WB at 879 Bridge						
R8	WB at Karthaus						
R9	WB at Shawville						
R1	WB at Westport						
R11	WB at Renovo						
R12	WB at Lock Haven						

Appendix Table 2a*—DEP Chapter 93 water quality parameter exceeded in the summer of 2009 as documented by the Project. All parameters are reported as total.*

Site Number	Site Name	Aluminum >0.75 mg/L	Iron > 1.5 mg/L	Manganese >1.0 mg/L	pH < 6	Sulfate >250 mg/L	Dissolved Solids > 750 mg/L
1	Lesle Run	X			X	X	
2	Fox Run	X	X			X	
3	Walnut Run	X				X	
4	Moss Creek						
5	Cush Cushion Creek						
6	Bear Run			X	X		
7	Chest Creek at Mahaffey						
8	Anderson Creek						
9	Hartshorn Run				X		
10	Tributary 26641	X				X	
11	Montgomery Creek	X		X	X	X	
12	Moose Creek			X			
13	Tributary 26608					X	X
14	Wolf Run	X	X	X	X	X	X
15	Clearfield Creek			X		X	
16	Abes Run	X		X	X	X	X
17	Tributary 26104	X	X	X	X	X	X
18	Lick Run		X		X		
19	Devils Run			X	X		
20	Trout Run				X		
21	Millstone Run	X	X	X	X	X	
22	Surveyor Run	X		X		X	
23	Bald Hill Run		X			X	X
24	Moravian Run			X	X		
25	Deer Creek	X	X	X	X	X	
26	Tributary 25976	X	X	X	X	X	X
27	Big Run						
28	Sandy Creek		X	X	X		
29	Alder Run	X	X	X	X	X	X
30	Rollingstone Run	X	X	X	X	X	X
31	Mowry Run	X		X	X		
32	Basin Run	X	X	X	X	X	
33	Rock Run	X	X	X	X	X	X
34	Potter Run	X	X	X	X	X	X
35	Tributary 25913	X	X	X	X	X	X
36	Rupley Run	X		X	X		
37	Moshannon Creek	X		X	X	X	
38	Redlick Run		X	X	X		
39	Tributary 25693	X	X	X	X	X	X
40	Mosquito Creek						
41	Laurel Run	X	X	X	X	X	
42	Tributary 25622	X	X	X		X	X
43	Saltlick Run	X	X	X		X	X

Appendix Table 2b *—DEP Chapter 93 water quality parameter exceeded in the summer of 2009 as documented by the Project. All parameters are reported as total.*

Site Number	Site Name	Aluminum >0.75 mg/L	Iron > 1.5 mg/L	Manganese >1.0 mg/L	pH < 6	Sulfate >250 mg/L	Dissolved Solids > 750 mg/L
44	Tributary 25611	X	X	X	X	X	
45	Sterling Run	X	X		X		
46	Loop Run	X		X	X	X	X
47	Birch Island Run		X		X		
48	Black Stump Run						
49	Sinnemahoning Creek	X		X			
50	Cooks Run	X	X	X	X		
51	Milligan Run	X	X	X	X	X	X
52	Kettle Creek						
53	Drury Run				X		
54	Tangascootak Creek	X	X				
55	Clearfield Creek at SR 1021			X		X	
56	Muddy Run		X	X		X	X
57	Clearfield Creek at Dimeling			X			
58	Chest Creek at Westover						
59	Moshannon Creek at Osceola Mills	X	X	X	X	X	
60	Moshannon Creek at Philipsburg	X		X	X	X	
61	Little Anderson Creek	X	X	X	X		
62	Kratzer Run						
63	Twomile Run	X	X	X	X		
64	Babb Creek						
65	Sterling Run (Sinnemahoning)	X		X	X		
66	Bennett Branch	X	X				
67	Beech Creek	X		X	X		
68	Dents Run	X		X	X	X	
R1	WB at Cherry Tree						
R2	WB at Burnside						
R3	WB at McGees Mills						
R4	WB at Bower						
R5	WB at Lumber City						
R6	WB at Curwensville						
R7	WB at 879 Bridge						
R8	WB at Karthaus						
R9	WB at Shawville						
R10	WB at Westport						
R11	WB at Renovo						
R12	WB at Lock Haven	X	X				