Abandoned Mine Drainage Remediation Strategy for the West Branch Susquehanna River Watershed[1]

Thomas J. Clark, Jeffrey L. Zimmerman, and Andrew J. Gavin[2]

Abstract. The Susquehanna River Basin Commission (SRBC), in partnership with the Commonwealth of Pennsylvania and Trout Unlimited, developed a remediation strategy recommending water quality improvements in areas affected by abandoned mine drainage (AMD) in the West Branch Susquehanna Subbasin.

In developing the strategy, SRBC compiled a geo-referenced data inventory of AMD discharges for the watershed using ArcGIS version 9.2 and Pennsylvania's 1:24,000 scale National Hydrography Dataset (NHD) stream layer. With nearly 2,000 discharges identified, the inventory represents the most comprehensive effort to date in Pennsylvania for a watershed area of this size. SRBC used this GIS data inventory to determine the extent and severity of AMD impacts. Additionally, through the use of several analytical approaches coupled with GIS data manipulation, a subset of the inventory served as the basis for determining: (1) existing water-quality conditions, (2) the potential for improving those conditions through remediation, and (3) the resulting downstream effects. The data inventory also will be available to provide guidance for a range of management-related decisions. Examples could include identifying water-quality improvements for discharges associated with Priority I and II Health and Safety Problem sites, identifying opportunities for industrial treatment and use, or targeting optimal areas for ecological restoration.

SRBC and its partners will endeavor to maintain and enhance the use of the GIS data inventory as Pennsylvania proceeds with its efforts to remediate the vast legacy abandoned mine lands problem.

Additional Key Words: water quality, national hydrography dataset.

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[1]Paper presented at the "Incorporating Geospatial Technologies into SMCRA Business Processes," Conference, March 25 – 27, 2008, Atlanta, GA.

[2]Thomas J. Clark, Abandoned Mine Drainage Project Coordinator, Susquehanna River Basin Commission, Harrisburg, PA 17102.

Jeffrey L. Zimmerman, GIS Specialist, Susquehanna River Basin Commission, Harrisburg, PA 17102.

Andrew J. Gavin, Chief, Restoration and Protection Section, Susquehanna River Basin Commission, Harrisburg, PA 17102.

Introduction

Despite the enormous legacy of pollution from abandoned mine drainage (AMD) in the West Branch Susquehanna Subbasin, there has been mounting support and enthusiasm for a fully restored subbasin (Figures 1 and 2). Under the leadership of Governor Edward G. Rendell and with support from Trout Unlimited (TU), Pennsylvania Department of Environmental Protection (PADEP) Secretary Kathleen McGinty established the West Branch Susquehanna River Task Force (Task Force) in 2004 with the goal to assist and advise PADEP and its partners as they work toward the long-term goal to remediate the subbasin's AMD.

The Task Force is composed of commonwealth, federal, and regional agencies, Trout Unlimited, and other conservation and watershed organizations. The Task Force first convened on September 10, 2004, and among its early actions, recognized the need for a comprehensive AMD remediation strategy for the West Branch Susquehanna Subbasin.

The Susquehanna River Basin Commission (SRBC) was contracted to develop an approach to review remediation alternatives and their impact on improving water quality in the West Branch Susquehanna Subbasin. SRBC developed the strategy using pre-existing (historical) data and information compiled from a wide range of sources. These data were organized in a geodatabase to characterize existing conditions and project future improvements after areas of the West Branch Susquehanna Subbasin are restored from AMD impacts.

Figure 1. The forested and mountainous terrain of the West Branch Susquehanna Subbasin (M. Smith).

Figure 2. The confluence of “Red” Moshannon Creek with the West Branch Susquehanna River (M. Smith).

Study Area

West Branch Susquehanna Subbasin Characterization

The West Branch Susquehanna Subbasin drains an area of 6,978 square miles in northcentral Pennsylvania, and is the largest of the six major subbasins in the Susquehanna River Basin (Figure 3).

The subbasin is dominated by forested land, which covers approximately 5,800 square miles, or 83 percent, of the subbasin (Figure 4). Agriculture accounts for about 10 percent of the subbasin, or around 700 square miles. The remaining 7 percent, or 500 square miles, of land use is developed and disturbed land where abandoned mine land (AML) impacts exist.

The land use is very rural, containing 2,190 square miles of public forests, 43.7 square miles of state park land, and 438.9 square miles of state game lands, while only containing a population of 475,356 (68 people per square mile) according to the 2000 census (Environmental Systems Research Institute, 2006 and United States Department of Commerce, 2001).

Figure 3. The Location of the West Branch Susquehanna Subbasin (J. Zimmerman).

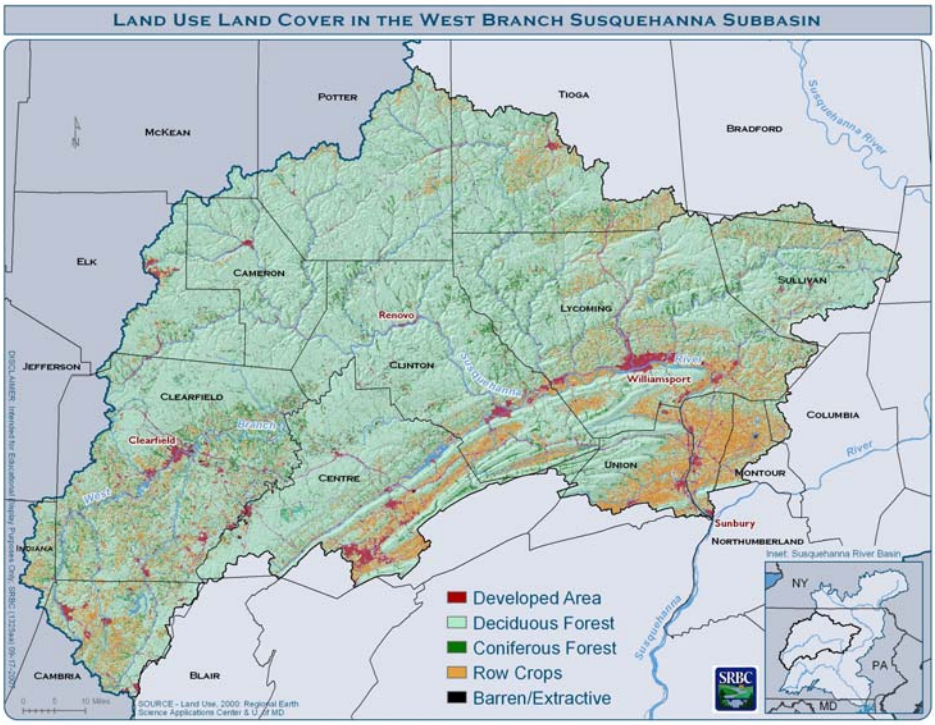

Figure 4. Land Use in the West Branch Susquehanna Subbasin (J. Zimmerman).

AMD Impacts

The West Branch Susquehanna Subbasin contains about 12,442 stream miles. A majority of those stream miles (11,924 or 96 percent) have been assessed for pollution impacts. AMD is the cause of impairment for approximately nine percent (1,040 stream miles) of the assessed stream miles in the West Branch Susquehanna Subbasin (Figure 5).

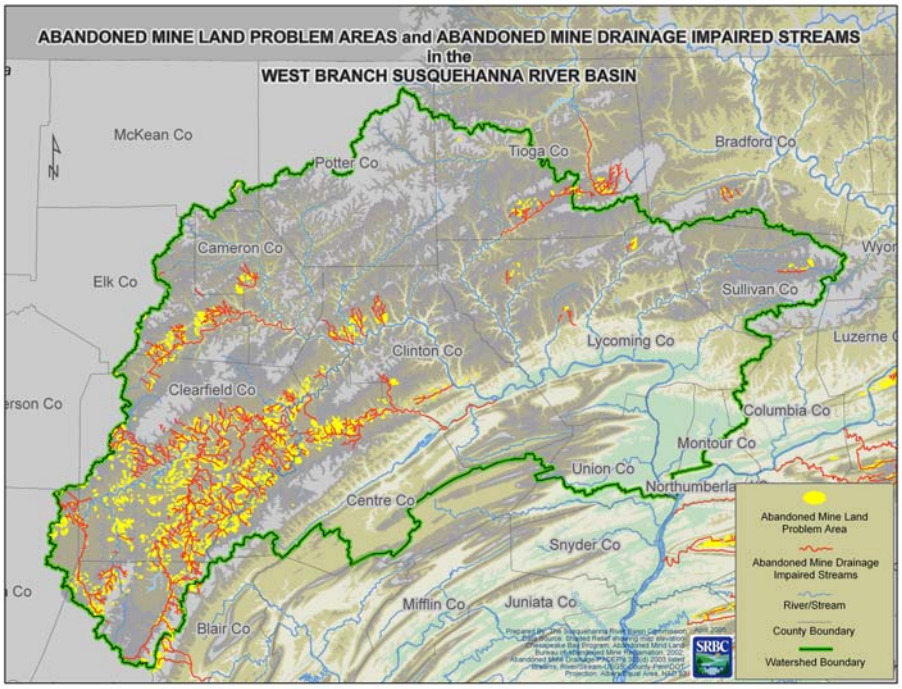

Figure 5. Abandoned Mine Land Problem Areas and Abandoned Mine Drainage Impaired Streams in the West Branch Susquehanna Subbasin (J. Zimmerman).

In addition, the West Branch Susquehanna Subbasin contains 65.7 square miles of un-reclaimed AML features, nearly 23 percent of Pennsylvania's share. Approximately 10.1 of those square miles are considered Priority I and II Health and Safety Problem sites as designated by the United States Office of Surface Mining (OSM).

Methods

Database Collection

SRBC staff concentrated its effort on gathering flow and chemistry information from water samples collected both from AMD discharges and instream locations. It is important to note that no new water quality samples were collected as part of the strategy development.

The two primary sources of information at the regional scale, in terms of the number of water quality and flow observations, were PADEP mining permit information and SRBC monitoring data. However, there were numerous other monitoring efforts that proved invaluable when investigating at the finer scale. Sources for other datasets included county conservation districts, watershed groups, TU chapters, mining companies, water quality laboratories, engineering firms, federal water quality databases, and land conservancy organizations.

Regarding mining permit information, there are more than 1,400 active or completed mining permits within the West Branch Susquehanna Subbasin. As part of their permit requirements, mining companies are responsible for reporting information related to any discharges within the extent of their affected areas, whether or not the discharge was a result of the permitted operation or existed on the site previously. Basic water quality information commonly includes data on metals, alkalinity, acidity, pH, and either a measured or estimated flow. SRBC also collected information associated with the discharge location (latitude and longitude), receiving waterbody, treatment status, date sampled, data source, and other information when available.

Data and information from more than 400 permits were reviewed by staff and compiled electronically. Additionally, discharge and instream water quality information from more than 450 permits was acquired from PADEP's Sample Information System (SIS). PADEP SIS data includes samples routinely collected by PADEP personnel. Data from the remaining permits with documented discharges were compiled from various watershed Total Maximum Daily Load (TMDL) studies that were either completed, or under development, at the time of database creation.

All water quality data collected prior to 1990 were excluded from the collection process assuring that the most recent water quality data available were being utilized for review and analyses.

Data Screening

SRBC staff created a database to manage the vast amount of information gathered as part of the solicitation and collection process. Currently, there are 12,565 unique stations in the database, containing 108,641 individual samples. The database includes information on discharges, instream stations, springs, wells, pits, ponds, and impoundments. However, only 6,271 instream stations and 2,119 discharge stations were utilized for the analyses. Instream and discharge stations represent 8,390 of the 12,565 unique stations (Figure 6).

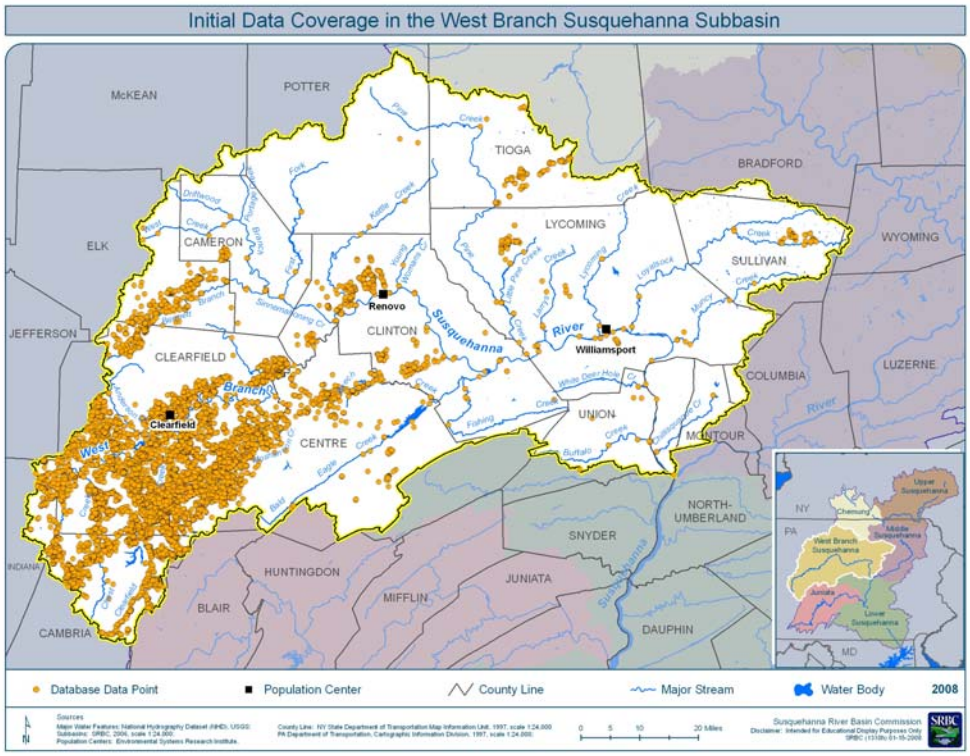

Figure 6. Location of the 12,565 unique stations comprising the West Branch Susquehanna Subbasin water quality database.

Data from these unique instream or discharge stations were screened to identify those containing four or more samples collected for metal concentrations (iron and aluminum in particular), pH, acidity, and flow. Although a minimum of four observations is not optimal from a statistical standpoint, SRBC staff believes that analytical criterion represents an acceptable representation for a management level study of this scale. When these criteria were applied to the entire dataset, about 28 percent of the data (24 percent of the instream stations and 37 percent of the discharge stations) remained available for use in the analyses. These analyses identified

nearly 1,596 instream stations and nearly 788 discharges meeting the analytical criteria, out of the totals of 6,271 instream stations and nearly 2,119 discharges (Figure 7). The amount of data meeting the analytical criteria is expected to increase as new data are added to the geodatabase.

The three main reasons for data not meeting analytical criteria include no geo-referenced location (no latitude or longitude), no flow measurements, and no aluminum analyses.

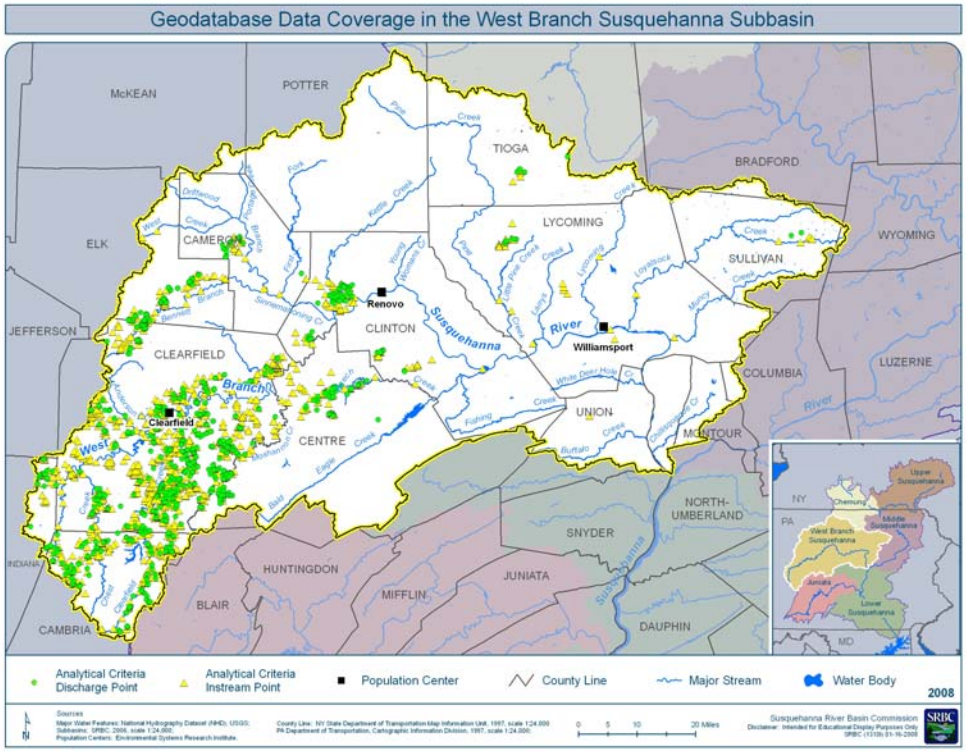

Figure 7. The location of the 1,596 instream stations and nearly 788 AMD discharge stations meeting analytical criteria.

Geodatabase Creation

All instream and discharge stations containing latitude and longitude information were compiled in a geodatabase. Environmental Systems Research Institute's (ESRI) ArcGIS Desktop 9.2 software provides the geodatabase framework, which is a relational database that stores Geographic Information System (GIS) data. GIS data compiled within a geodatabase are more intuitive than traditional GIS data (i.e., coverages and shapefiles) because topology/networking is maintained between datasets (Law et al., 2004). Topologies and geometric networks are two ways in which geodatabases can be used to model spatial

relationships. These relationships enable different GIS datasets to become connected to one another just as they are in the real world (Law et al., 2004).

A geometric network uses connectivity between lines and points to model flow. Some types of geometric networks include utility lines, sewer systems, streets, and hydrology. Hydrology is made up of streams, rivers, ponds, lakes, and any other water feature that exist in a given area. It can be used to model the way water flows over the land. The United States Geologic Survey (USGS) maintains the National Hydrography Dataset (NHD), which is a geometric network of hydrology at a scale of 1:24,000. The NHD for the West Branch Susquehanna Subbasin was obtained from USGS and used as the basis for the West Branch AMD Remediation Strategy geometric network geodatabase.

Instream and discharge stations collected for this study had to be linked or connected to the NHD. The NHD depicts streams by using a centerline, which means that in most cases study data will not directly intersect the hydrology. ArcMap contains a tool that will automatically link points to the hydrology by sending out a search radius along the NHD and snapping any point data found close to the stream segment.

The automated process may generate errors, so all study data linked to the NHD were checked for accuracy. In some cases, point data snapped to the wrong stream segment simply because the tool uses proximity solely as its mechanism. Tabular information associated with discharge or instream station data had to be used to ensure that the data were linked properly. Discharge data also had to be checked for duplicates since there were a large number of data points collected from many different sources. The geometric network improved the speed and efficiency associated with the process since only one data point can link to one point along a stream. Therefore, any points that did not snap were checked as a possible duplicate. Furthermore, points found in close proximity to one another were also inspected due to possible Global Positioning System (GPS) collection errors.

The resulting geometric network now provides the best available model of AMD impacts occurring in the West Branch Susquehanna Subbasin.

Data Analysis

Management Units. SRBC divided the West Branch Susquehanna Subbasin into 34 Management Units (MUs) comprising nearly 4,663 square miles, or slightly more than 65 percent, of the total West Branch Susquehanna Subbasin (Figure 8).

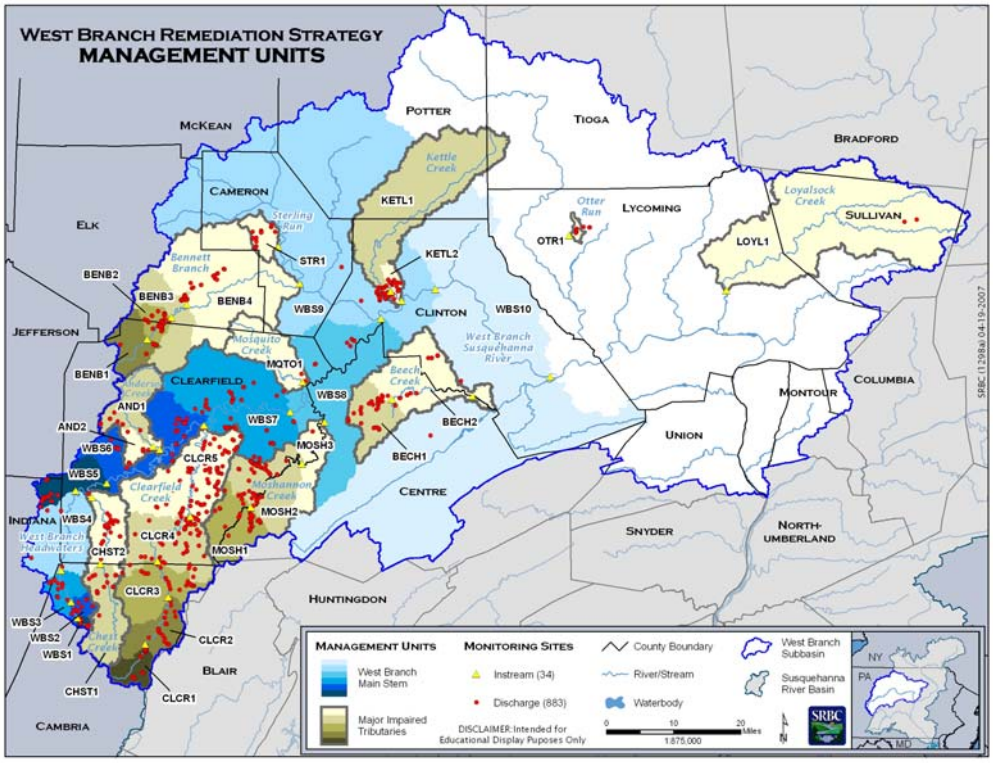

Figure 8. The 34 Management Units of the West Branch Susquehanna Subbasin, the 788 Analytical Criteria Discharges, and the 34 Management Unit Endpoint Water Quality Stations (J. Zimmerman).

MUs are named by an alpha numeric system. The alpha portion consists of the abbreviated name of the watershed where the MU is located, and the numeric portion describes where the MU is located in the watershed (Table 1). The number "1" represents the headwaters, with numbers increasing sequentially downstream.

MUs were designed to capture clusters of discharges that meet the analytical criteria, as well as represent changing conditions in the West Branch Susquehanna Subbasin.

For each MU, cumulative acidity, iron, and aluminum loads and yields were calculated using the analytical criteria discharge data in each MU. Using the geodatabase, these loads and yields were used to determine the relative AMD impacts for MUs in the West Branch Susquehanna Subbasin.

Table 1. The Alpha Numeric Nomenclature of the Significant AMD Impacted Watersheds of the West Branch Susquehanna Subbasin.

Watershed	Alpha Numeric Nomenclature
West Branch Susquehanna River	WBS1-10
Anderson Creek	AND1-2
Clearfield Creek	CLCR1-5
Moshannon Creek	MOSH1-3
Bennett Branch Sinnemahoning Creek	BENB1-4
Beech Creek	BECH1-2
Kettle Creek	KETL1-2

AMD Treatment Model. The Watershed Restoration Analysis Model (WRAM), developed by Water's Edge Hydrology Inc., was used to simulate treatment for all 788 discharges meeting the analytical criteria. For the WRAM treatment model to function properly, discharge data were ordered from upstream to downstream. ESRI's ArcHydro extension automated this task by accumulating study data downstream within each MU. A numeric attribute was applied to each discharge point whereby lower numbers represented headwater locations, and higher numbers represented locations near a stream's mouth. Discharge points could then be entered into the treatment model appropriately.

The model conceptualized both passive and active (chemical) AMD treatment system solutions. The data outputs used for the strategy included predictions for the available acidity, iron, and aluminum loading reductions at each discharge, as well as costs associated with the capital funding necessary to construct an adequate passive or active AMD treatment system. Predicted available loading reductions, passive and active treatment system construction capital costs, and yearly operation and maintenance (O&M) fees were estimated for each MU to allow comparison.

A uniform set of defaults was applied to all analytical criteria discharges (Rightnour, 2007). Each discharge was treated with successive WRAM selected treatment options until all predicted system effluent water quality defaults were realized.

System construction costs were based on unit sizing costs derived from OSM's AMDTreat Version 4.1b program (Office of Surface Mining, 2006).

O&M costs for passive treatment systems are estimated at 3.5 percent of the construction cost annually. The active system O&M cost estimates also include a 3.5 percent accrual for component replacement, plus the annual chemical consumption and labor costs.

AMD Discharge Linkage to Priority I and II AML Sites. Due to the 2006 Surface Mining Control and Reclamation Act (SMCRA) reauthorization, West Branch Susquehanna Subbasin remediation efforts could be enhanced by focusing attention on possible links between water infiltration occurring on some Priority I and II Health and Safety Hazard sites, and AMD discharges occurring "adjacent" to such sites. If possible hydrologic links can be proven, OSM rule-making through the SMCRA reauthorization may allow for remediation of these AMD discharges in conjunction with Priority I or II land reclamation. Normally this Priority I and II reclamation funding would not be available for water quality improvements since those activities are designated as Priority III problems (Acid Mine Drainage).

In order to assess this possible opportunity, some initial analyses were performed to determine the number of discharges within an arbitrary one-quarter mile buffer of a Priority I or II site using the PADEP Abandoned Mine Land Information System (AMLIS) database in conjunction with the West Branch Susquehanna Subbasin water quality geodatabase. Based on the density of AMD discharges, reclamation activities may have the potential for improving environmental conditions beyond the immediate health and safety concerns associated with the Priority I and II sites.

Restoration Recommendations and Projections. Utilizing WRAM data outputs for the 788 analytical criteria discharges, hypothetical examples for remediation were simulated for the West Branch Susquehanna River by completing AMD treatment projects in: (1) the headwaters section of the subbasin, and (2) the major tributaries contributing a majority of the AMD pollution. All simulations focused on the impact of reducing available acidity, iron, and aluminum loadings.

The West Branch Susquehanna River headwaters example focuses restoration from the extreme headwaters of the West Branch in Cambria County, to the entry of Clearfield Creek in Clearfield County. This example includes the completion of three headwater projects (Barnes and Watkins Coal Refuse Pile Removal Project, Lancashire #15 Mine AMD Treatment Plant,

and restoration of the Bear Run Watershed) and restoration of four headwater MUs (WBS1, WBS2, AND1, and AND2).

The West Branch Susquehanna River major tributaries example addresses impacts from the top ten ranked tributary MUs based upon AMD loading and yields. These ten MUs include four from the Clearfield Creek Watershed (CLCR1, CLCR2, CLCR4, and CLCR5), two from the Moshannon Creek Watershed (MOSH1 and MOSH2), two from the Bennett Branch Sinnemahoning Creek Watershed (BENB1 and BENB2), one from the Kettle Creek Watershed (KETL2), and one from the Beech Creek Watershed (BECH2).

Instream Improvement Modeling. A simple mass balance approach was used to predict changes in water quality conditions for the West Branch Susquehanna River after completion of each remediation example. The predicted AMD loading reduction outputs from WRAM were subtracted from the West Branch Susquehanna River instream stations directly downstream of the restoration effort, as well as every instream point thereafter. The reduction in AMD loading was then used to calculate a projected AMD concentration that could exist after the completion of remediation efforts.

Results

Management Units

The 34 MUs captured discharges with predicted available loading reductions of 102,964 pounds per day (lbs/day) of acidity, 21,065 lbs/day of iron, and 6,991 lbs/day of aluminum.

The first analyses were completed on AMD loading yields (lbs/day/area). Concentrated acidity loading is located primarily in MUs WBS1, WBS2, CLCR1, CLCR4, MOSH1, MOSH2, BENB2, and KETL2, and to a lesser extent in MUs CLCR2, CLCR5, and BENB1 (Figure 9).

Concentrated iron loadings are located primarily in MUs WBS2, CLCR4, MOSH2, BENB2, and KETL2, and to a lesser extent in MUs WBS1, CLCR1, MOSH1, and BENB1 (Figure 10).

Concentrated aluminum loadings are located primarily in MUs WBS2, CLCR1, MOSH1, MOSH2, BENB2, and KETL2, and to a lesser extent in MUs WBS1 and CLCR4 (Figure 11).

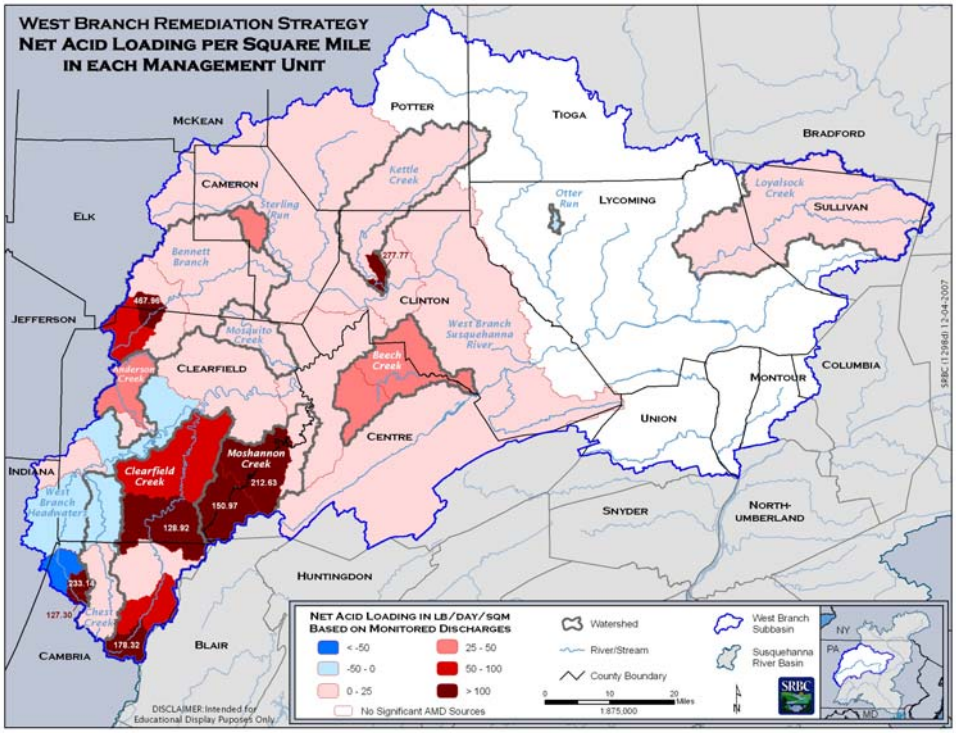

Figure 9. Acid Loading Yield in each West Branch Susquehanna Subbasin MU (J. Zimmerman).

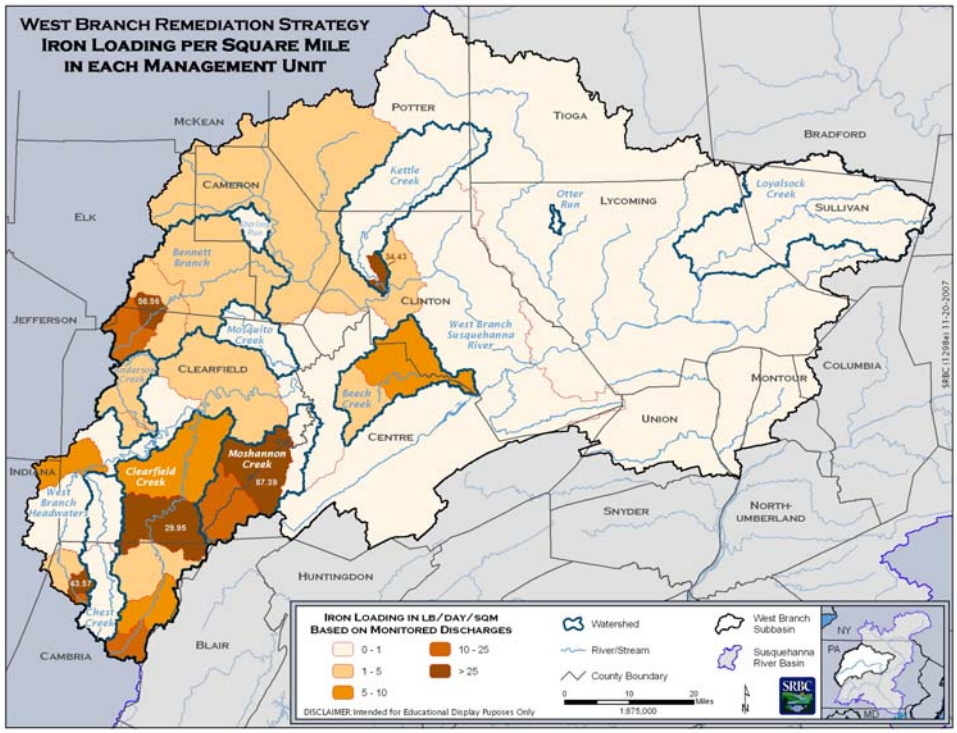

Figure 10. Iron Loading Yield in each West Branch Susquehanna Subbasin MU (J. Zimmerman).

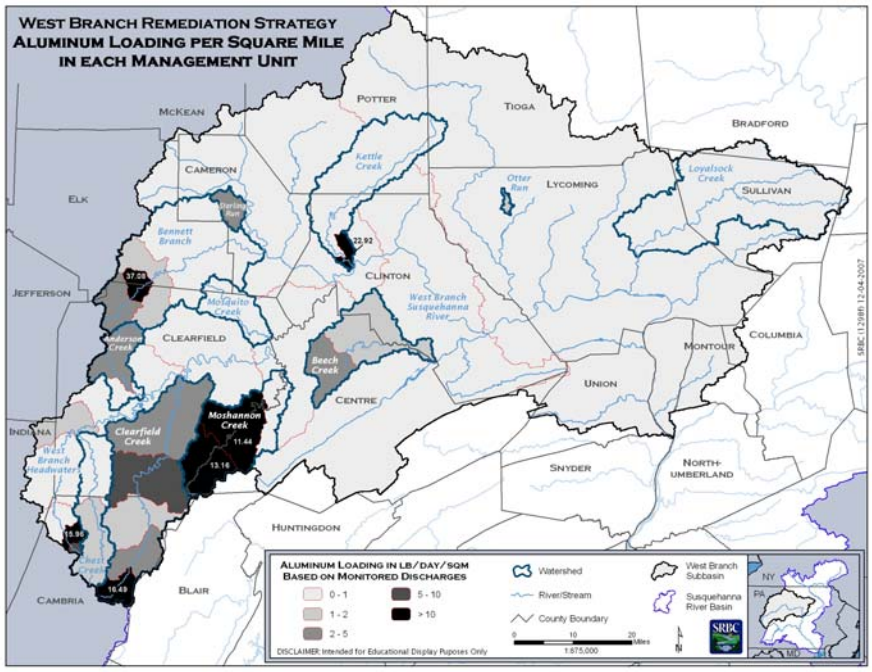

Figure 11. Aluminum Loading Yield in each West Branch Susquehanna Subbasin MU (J. Zimmerman).

Upon completion of the final analyses, 11 MUs, covering only ten percent of the West Branch Susquehanna Subbasin, contained available loading reductions of more than 79 percent for acidity (81,474 lbs/day), nearly 84 percent for iron (17,691 lbs/day), and nearly 78 percent for aluminum (5,418 lbs/day) (Table 2).

Table 2. The 11 MUs, Covering only 10 Percent of the West Branch Susquehanna Subbasin that Contain Nearly 80 Percent of the AMD Loading.

MU	Acid Load	Percentage	Fe Load	Percentage	Al Load	Percentage
	lbs/day		lbs/day		lbs/day	
CLCR1	4,943	4.80	622	2.95	457	6.54
CLCR2	2,737	2.66	460	2.18	176	2.52
CLCR4	13,123	12.75	3,049	14.47	749	10.71
CLCR5	8,060	7.83	1,111	5.27	482	6.89
MOSH1	10,381	10.08	694	3.29	905	12.95
MOSH2	19,862	19.29	8,163	38.75	1,069	15.29
BENB1	3,067	2.98	905	4.30	189	2.70
BENB2	9,200	8.94	1,112	5.28	729	10.43
KETL2	3,661	3.56	453	2.15	302	4.32
BECH2	3,577	3.47	587	2.79	164	2.35
WBS2	2,863	2.78	535	2.54	196	2.80
Predicted Reductions	**81,474**	**79.13**	**17,691**	**83.98**	**5,418**	**77.50**
Remaining 24 MUs	**21,490**	**20.87**	**3,374**	**16.02**	**1,573**	**22.50**

As shown in Table 2, eight of the 11 priority MUs are located in only three watersheds of the West Branch Susquehanna Subbasin: Moshannon Creek, Clearfield Creek, and Bennett Branch Sinnemahoning Creek. These three watersheds alone contain more than 69 percent of the available acidity loading, more than 76 percent of the available iron loading, and more than 68 percent of the available aluminum loading.

Of the 65.7 square miles of un-reclaimed AML features in the West Branch Susquehanna Subbasin, 10.1 square miles are considered Priority I or II Health and Safety Problem sites, as designated by OSM. Priority I and II areas are concentrated primarily in MUs WBS2, CLCR3, MOSH1, BENB2, and STR1, and to a lesser extent in MUs WBS3 and MOSH3 (Figure 12).

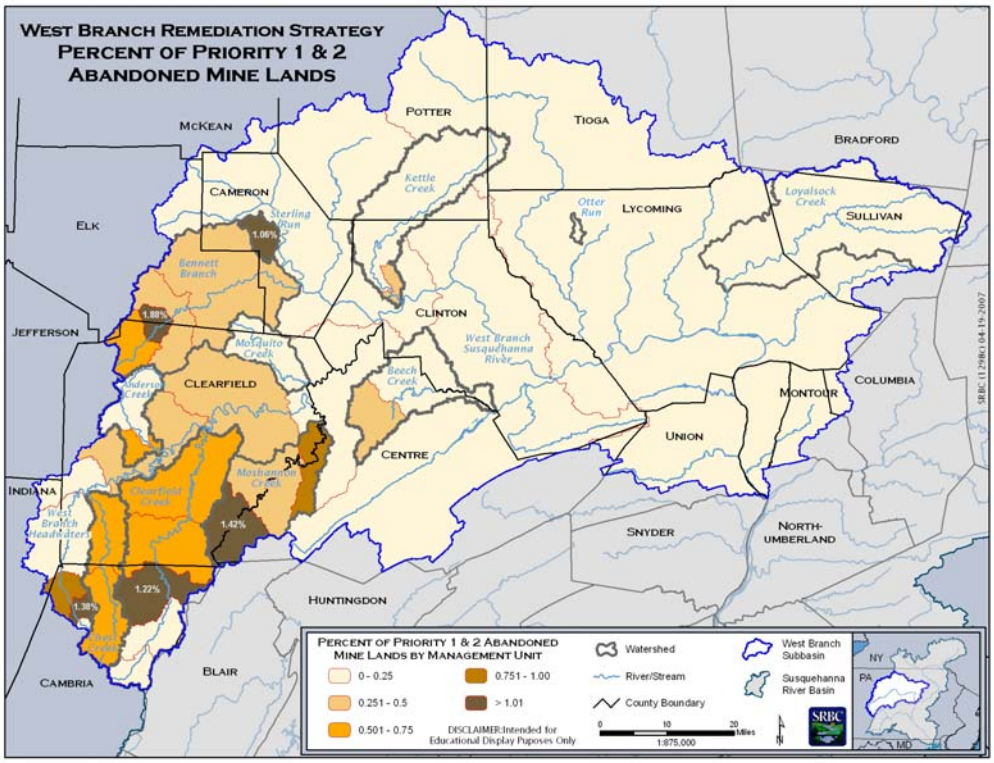

Figure 12. Percent Land Coverage of Priority I and II Health and Safety Problem Sites in each of the West Branch Susquehanna Subbasin Management Units (J. Zimmerman).

Total AML coverage (Priority I, II, and III sites) is generally concentrated in the same areas as the AMD loading. The Moshannon Creek, Clearfield Creek, and Bennett Branch Sinnemahoning Creek Watersheds contain 51 percent of the total AML area in the entire West

Branch Susquehanna Subbasin. The 11 priority MUs in Table 1, which cover only 10 percent of the West Branch Susquehanna Subbasin, contain 46 percent of the AML area.

AMD Discharge Linkage to Priority I and II AML Sites

Of the 788 discharges meeting the analytical criteria, 213 (27 percent) are within one-quarter mile of a Priority I or II site. These 213 discharges contribute 14,535 gallons per minute (GPM) of flow, with predicted available loading reductions of 31,453 lbs/day of acidity, 3,279 lbs/day iron, and 2,410 lbs/day of aluminum.

A majority of the analytical criteria discharge flow and loading located within one-quarter mile of a Priority I or II site are found in only 5 of the 34 MUs. CLCR4, MOSH1, AND1, BENB2, and BENB3 contain 66 percent of the flow, 81 percent of the acidity loading, 87 percent of the iron loading, and 81 percent of the aluminum loading within one-quarter mile of a Priority I or II site (Table 3).

Table 3. The 5 MUs Containing the Majority of the Analytical Criteria Discharge Flow and Loading within One-Quarter Mile from a Priority I or II Site.

MU	**Watershed**	**Flow**	**Acid Load**	**Fe Load**	**Al Load**
		GPM	**lbs/day**	**lbs/day**	**lbs/day**
CLCR4	Clearfield Creek	3,265	9,745	1,857	598
MOSH1	Moshannon Creek	2,072	8,599	575	757
BENB2	Bennett Branch Sinnemahoning Creek	3,440	4,572	172	383
AND1	Anderson Creek	447	1,458	164	130
BENB3	Bennett Branch Sinnemahoning Creek	381	1,077	76	77
	Total	**9,605**	**25,451**	**2,844**	**1,945**
	Remaining 29 MUs Total	**4,930**	**6,002**	**435**	**465**

Restoration Recommendations and Projections

Water quality conditions for the West Branch Susquehanna River show great potential for improvement after the completion of AMD restoration efforts in the headwaters and select major tributaries.

Currently, 4 river miles of the approximately 245 mile long West Branch Susquehanna River are net acidic, and 88 river miles are considered acid sensitive with net alkalinities less than 20 mg/l. After completion of the restoration recommendations, all sections of the river are projected to be net alkaline. However, the number of river miles with a significant amount of buffering capacity (>20 mg/l of alkalinity) could improve dramatically (Figure 13 and Table 4).

Currently, 49 river miles of the West Branch Susquehanna River exceed the 1.50 mg/l water quality standard for iron. After completion of the restoration recommendations, the entire West Branch Susquehanna River could meet the water quality standard for iron (Figure 14 and Table 4).

Currently, 188 river miles of the West Branch Susquehanna River exceed the 0.75 mg/l water quality standard for aluminum. After completion of the restoration recommendations, more than 134 river miles (55 percent) of the West Branch Susquehanna River could meet the water quality standard for aluminum (Figure 15 and Table 4).

Conclusions

The West Branch Susquehanna River Headwaters, and select MUs in the Clearfield Creek, Moshannon Creek, and Bennett Branch Sinnemahoning Creek Watersheds, contain a majority of the AMD pollution impacting the West Branch Susquehanna Subbasin. The remediation example, outlined in this document, targets these areas and results in a nearly restored West Branch Susquehanna River. Additional sampling of the discharges not meeting analytical criteria (63 percent of the total discharges) would be needed to determine the effort required for complete restoration.

The West Branch Susquehanna River headwaters and major tributaries examples show alkaline conditions for the length of the mainstem, as well as iron concentrations meeting or exceeding water quality standards. Aluminum poses a greater challenge, but the remediation examples show where further efforts are needed to locate the problems and propose solutions, particularly for sources generating loads between Clearfield Creek and Bald Eagle Creek. It is also important to note that net alkaline conditions for the West Branch Susquehanna River, as a result of the remediation examples from headwaters to mouth, would precipitate dissolved aluminum and reduce its toxicity.

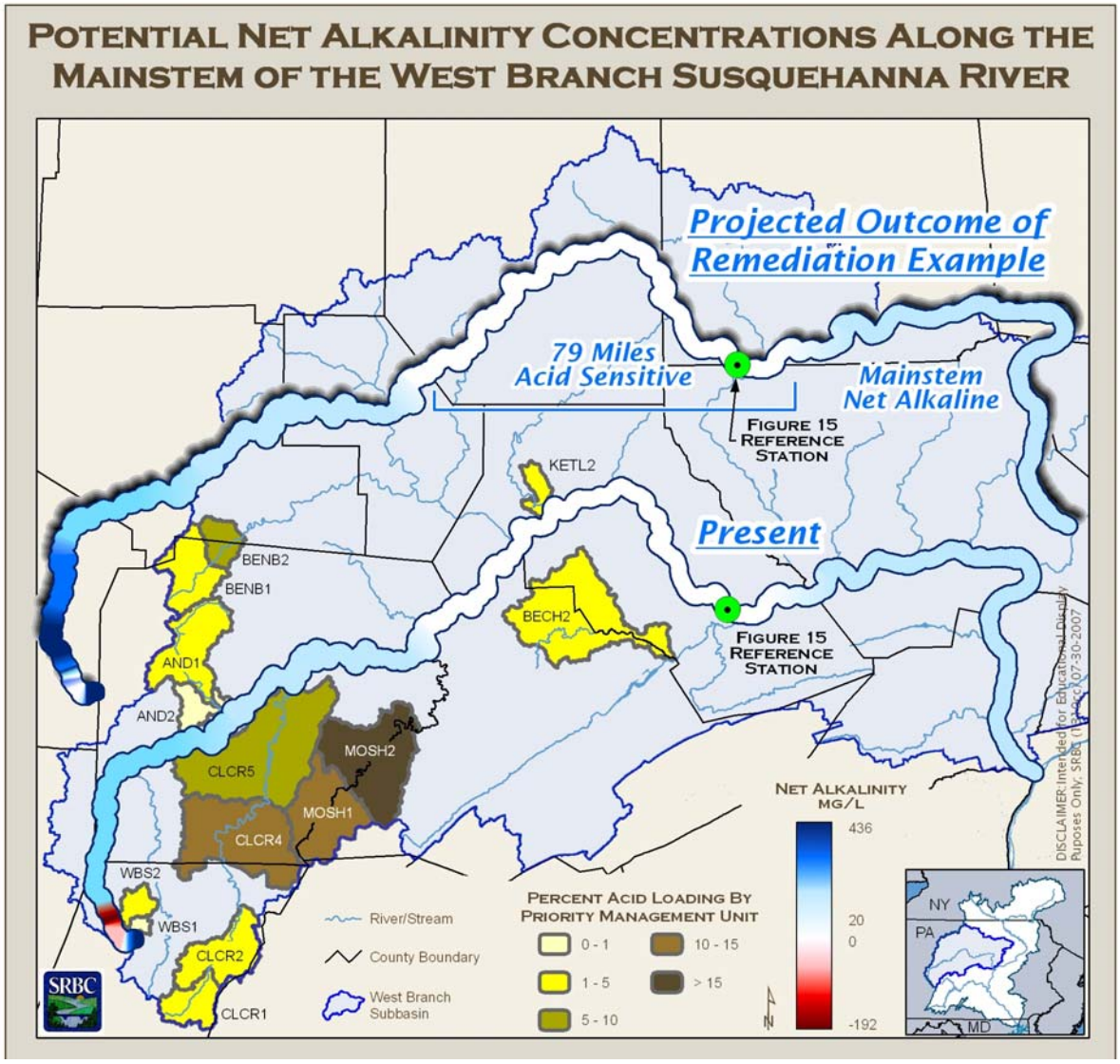

Figure 13. Map Showing Changes in Net Alkalinity Concentration from Present Conditions to Completion of Headwaters and Major Tributaries Remediation Examples (J. Zimmerman).

Table 4. Description of the Headwaters and Major Tributaries Remediation Examples with Predicted Load Reductions, Capital Cost Ranges, and Yearly Operation and Maintenance Cost Ranges.

West Branch Susquehanna River Headwaters							
Project	Watershed	Acid Load	Fe Load	Al Load	Removal Cost	Construction Capital	O&M Costs
		lbs/day	lbs/day	lbs/day	Million $	Million $	Million $/Year
Barnes and Watkins	West Branch	9,217	594	1,143	4.80		
Lancashire #15	West Branch	16,695	-	-		8.00-11.00	na*
Bear Run	West Branch	2,052	298	62		0.77-1.67	0.08-0.12
WBS1	West Branch	471	49	34		0.55-0.73	0.03-0.11
WBS2	West Branch	2,863	535	196		1.05-4.24	0.19-0.20
AND1	Anderson Creek	1,472	163	131		0.63-2.26	0.11-0.12
AND2	Anderson Creek	192	21	19		0.34-0.40	0.02-0.06
Total		**32,962**	**1,660**	**1,585**	**4.80**	**11.34-20.30**	**0.43-0.61+**
Major Tributaries							
Project	Watershed	Acid Load	Fe Load	Al Load	Removal Cost	Construction Capital	O&M Costs
		lbs/day	lbs/day	lbs/day	Million $	Million $	Million $/Year
CLCR1	Clearfield Creek	4,943	622	457		2.57-11.06	0.40-0.53
CLCR2	Clearfield Creek	2,737	460	176		1.36-4.18	0.20-0.25
CLCR4	Clearfield Creek	13,123	3,049	749		3.32-23.06	0.72-1.10
CLCR5	Clearfield Creek	8,060	1,111	482		6.29-12.68	0.60-1.18
MOSH1	Moshannon Creek	10,381	694	905		3.28-15.87	0.72-0.75
MOSH2	Moshannon Creek	19,862	8,163	1,069		4.39-41.76	1.05-1.98
BENB1	Bennett Branch	3,067	905	189		0.71-4.42	0.16-0.21
BENB2	Bennett Branch	9,200	1,112	729		2.65-15.93	0.53-0.76
KETL2	Kettle Creek	3,661	453	302		1.67-5.43	0.25-0.34
BECH2	Beech Creek	3,577	587	164		1.06-5.24	0.22-0.25
Total		**78,611**	**17,156**	**5,222**	**0.00**	**27.30-139.63**	**4.85-7.35**
Complete Total		**111,573**	**18,816**	**6,807**	**4.80**	**38.64-159.93**	**5.28-7.96+**

* Exact operation and maintenance costs for the Lancashire #15 (Barnes and Tucker) Discharge Active Treatment Plant are not known at the time of remediation strategy publication.

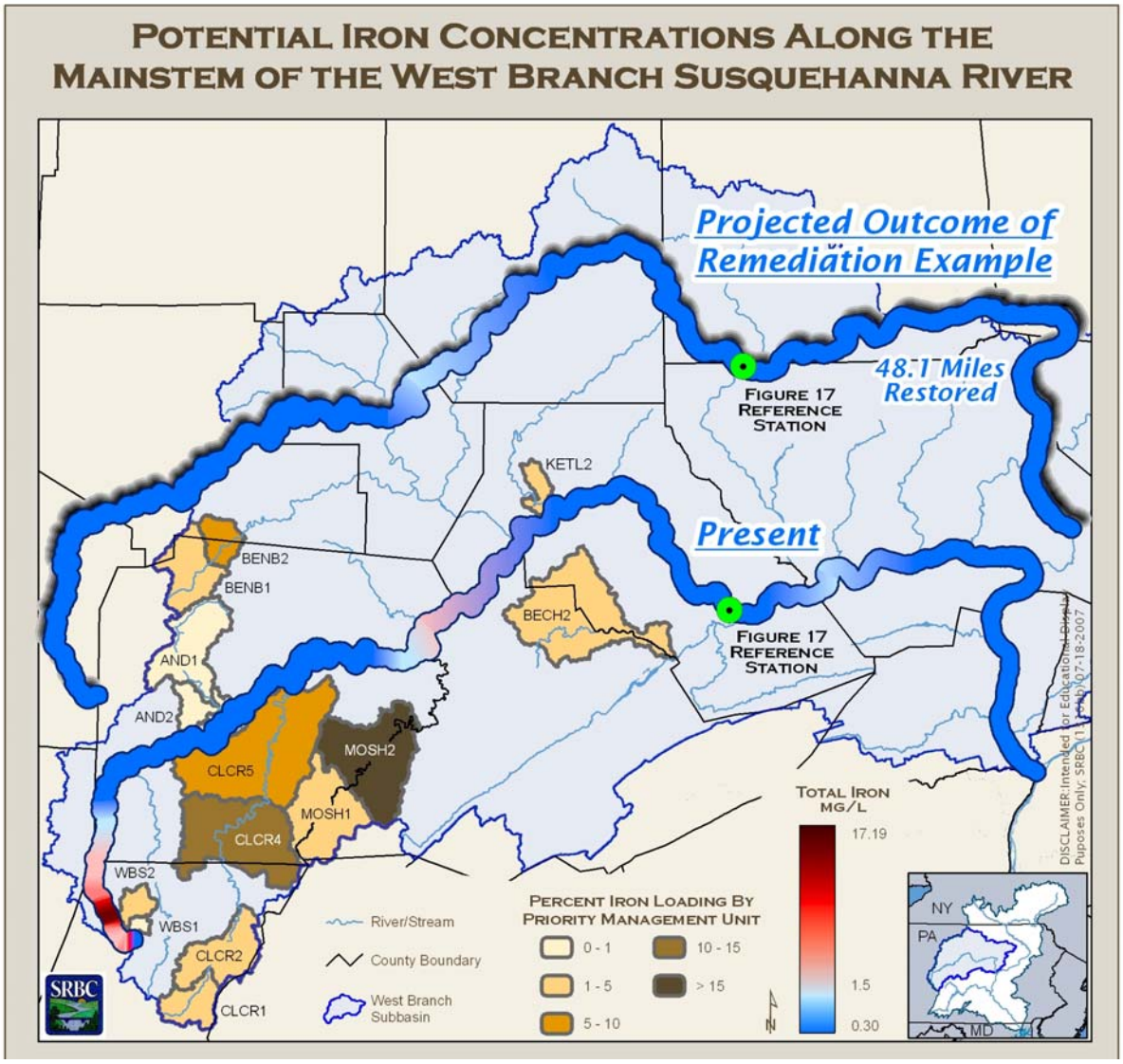

Figure 14. Map Showing Changes in Iron Concentration from Present Conditions to Completion of Headwaters and Major Tributaries Remediation Examples (J. Zimmerman).

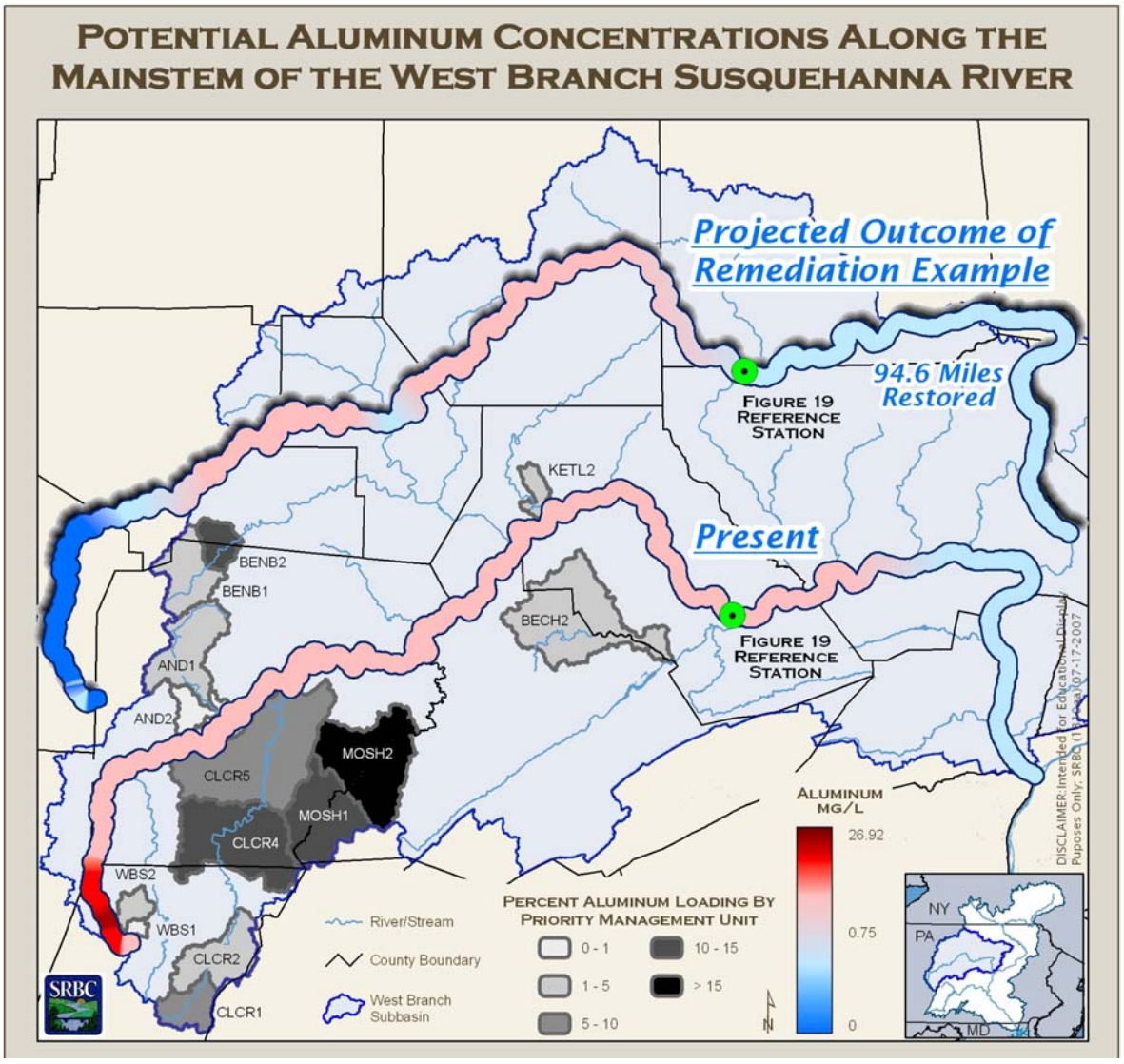

Figure 15. Map Showing Changes in Aluminum Concentration from Present Conditions to Completion of Headwaters and Major Tributaries Remediation Examples (J. Zimmerman).

With respect to treatment costs, this strategy outlines one possible remediation example with WRAM estimated capital construction costs between $43 and $165 million dollars, depending on the selection of passive or active treatment technologies. An additional estimated $5 to $8 million, and possibly more with the addition of the Lancashire #15 (Barnes and Tucker) discharge active treatment plant, would be needed annually for operation and maintenance of those systems. It is important to note that these costs are based on the best available data, particularly those discharges with water quality data meeting analytical criteria. In addition, the examples discussed in this document do not provide for complete restoration of the West Branch Susquehanna River Subbasin. At sites where remining and mine land reclamation are viable options to eliminate or reduce AMD loading, projected restoration costs could be decreased, especially as they relate to annual operation and maintenance.

Cost estimates only address the 788 discharges that met the analytical criteria defined for this study. These discharges only comprise 37 percent of the total discharges compiled for this project. Adding in the 63 percent of the discharges that did not meet analytical criteria, total West Branch Susquehanna Subbasin restoration costs could be in the realm of $400 million, which are comparable to PADEP estimates (West Branch Susquehanna River Task Force, 2005).

In terms of the discharges "adjacent" to Priority I and II sites, there are opportunities to improve conditions significantly within five MUs through reclamation of these hazard sites. Reclamation of AMLs often has proven to be an effective method in improving water quality conditions. AML reclamation focused in select areas of the Clearfield, Moshannon, Bennett Branch, and Anderson Watersheds (CLCR4, MOSH1, BENB3, BENB2, and AND1) could directly improve the West Branch Susquehanna River since these MUs contain a majority of the discharge loading located within one-quarter mile of a Priority I or II site.

Continued water quality monitoring is critically important to support the West Branch Susquehanna Subbasin restoration effort. Within areas of the West Branch Susquehanna Subbasin, water quality monitoring data are still needed to properly characterize AMD impacts (Figure 16). In addition, sites need to be monitored as restoration occurs. Instream monitoring sites, such as those used in this strategy, could help document improvement and support future restoration planning.

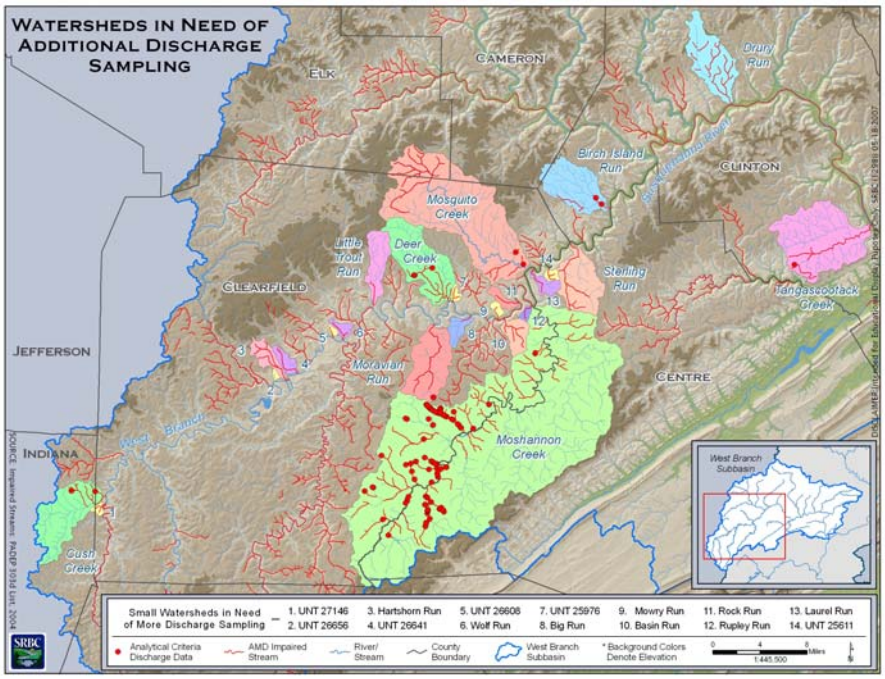

Figure 16. West Branch Susquehanna Subbasin Watersheds in need of Additional Discharge Sampling (J. Zimmerman).

Acknowledgements

SRBC wishes to thank the following entities that provided funding for development of the West Branch Susquehanna Subbasin Remediation Strategy.

Pennsylvania Department of Conservation and Natural Resources

Pennsylvania Department of Environmental Protection

Trout Unlimited

SRBC also wishes to thank all members of the West Branch Susquehanna River Task Force who contributed to the West Branch Susquehanna Subbasin Remediation Strategy.

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