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THE USE OF A PRIORITIZATION INDEX TO RANK MINE DISCHARGES AND TRIBUTARY STREAMS FOR REMEDIATION CONSIDERATION[1]

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Abstract. The Pittsburgh, Pennsylvania, project office of the U.S. Geological Survey (USGS) has been involved in various studies of the effects of mine drainage on stream water quality. Two of these studies focused on prioritizing the severity of mine discharges and the relative impairment of streams. One study located and sampled abandoned coal-mine discharges in the Stonycreek River Basin in Pennsylvania and prioritized the mine discharges for remediation. This priority ranking system, or prioritization index (PI) developed for mine discharges, also was used to prioritize tributary streams and reaches of the mainstem throughout the lower Cheat River Basin in northern West Virginia. The major difference between the PIs of the studies was that the Stonycreek River Basin index was applied to chemical loadings of point-source mine discharges, whereas the Cheat River Basin index was applied to mainstem river sites, tributary stream sites, and subbasin stream sites within the major tributaries in terms of chemical yields. The PIs for both studies were based on a site-to-site water-quality comparison of the loads and yields of selected chemical constituents that included total iron, total manganese, dissolved aluminum, total heated acidity, and dissolved sulfate. Water discharge was an important physical measurement used to calculate the loads and yields of the chemical constituents. Water discharge and pH were used as "tiebreakers" in developing the PI. All of these factors are related either directly or indirectly to the effects of coal-mine drainage on water quality. A computerized spreadsheet of the water-quality data was used to simplify the PI calculations. The PI, developed to assist water-resource managers in considering remediation possibilities at specific mine discharges in the Stonycreek River Basin or in the many tributary basins and subbasins throughout the lower Cheat River Basin, is suitable for application in other watersheds affected by mine drainage. Some potential modifications to improve the index method are discussed.

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Introduction

Coal is Pennsylvania's and West Virginia's most important mineral resource. Much of the Stonycreek River Basin, which is primarily in Somerset County and part in Cambria County, is underlain by low-volatile bituminous coal deposits that are an important economic mineral resource. With the onset of the Industrial Revolution in the late 1800s, extensive commercial mining of these coal resources began with almost no concern for the protection of the land surface and water resources. Consequently, the water quality in the Stonycreek River and its tributaries has been severely degraded for many decades by acid mine drainage (AMD) from abandoned coal mines and coal-refuse piles.

Likewise, the economy of the Lower Cheat River Basin has been dominated by coal mining over many decades. As a result, many abandoned deep and surface mines discharge untreated AMD, which degrades water quality, into the Cheat River and many of its tributary streams. Approximately 60 regulated mine-related discharges (West Virginia Department of Environmental Protection, 1996) and 185 abandoned mine sites (U.S. Office of Surface Mining, 1998) discharge treated and untreated AMD into the Cheat River and its tributaries. The AMD problem has been recognized as one of the most serious and persistent water-quality problems not only in Pennsylvania and West Virginia, but in all of Appalachia, extending from New York to Alabama (Biesecker and George, 1966). Thousands of stream and river miles in Appalachia are currently affected by the input of mine drainage from sites mined and abandoned before strict effluent regulations were implemented (Kleinmann and others, 1988).

The USGS, recognizing that AMD is a major water-quality issue in all of Appalachia, cooperated with the Somerset Conservation District in Pennsylvania and the West Virginia Department of Environmental Protection (WVDEP) in West Virginia to study the effects of AMD on the water quality of the Stonycreek River in southwestern Pennsylvania (Williams and others, 1996) and the Lower Cheat River in northern West Virginia (Williams and others, 1999). The USGS designed a prioritization index (PI) to rank the severity of mine discharges and tributary streams with respect to AMD loading of the receiving streams. A primary goal of the Somerset Conservation District was to prioritize individual mine discharges in the Stonycreek River Basin by a method that would show their relative severity with respect to all sampled discharges throughout the basin. In the Stonycreek River Basin, the USGS located, measured flows, and sampled 270 mine discharges (Fig. 1) during low flow from 1992 through 1994 and assigned instantaneous contaminant loads for five constituents.

The goal of the WVDEP was to obtain baseline water-quality information necessary to evaluate instream treatment and alternative methods for remediating AMD in the Cheat River Basin. The USGS, in cooperation with the WVDEP, collected water samples and measured streamflow at 111 sites throughout the Lower Cheat River Basin (Fig. 2) during low-flow conditions from July 16-18, 1997.

This paper describes the PI that was developed to rank mine discharges in the Stonycreek River Basin and tributary streams in the Cheat River Basin for remediation consideration. Possible refinements to the PI are suggested for future use.

Prioritization Index

A ranking system, or prioritization index (PI), was developed to identify mine discharges and tributary streams that have the greatest detrimental effect on the receiving streams and that should be given a high priority for remediation. The PI was based on a site-to-site comparison of loads of selected water-quality constituents. Loadings of the specific constituents were determined by multiplying the concentration in milligrams per liter or micrograms per liter by the flow rate in cubic feet per second or gallons per minute and a constant to convert the units to pounds per day or tons per day. The constituent discharge in pounds per day or tons per day divided by the drainage area in square miles for the Cheat River Basin sites gives the yield in pounds per day per square mile or tons per day per square mile. Most mine discharge samples were collected during base-flow conditions. Because of funding limitations, sampling all 270 mine discharges at different flow conditions was not feasible. However, approximately 48 of the mine discharges were resampled 1 to 5 times and constituent concentrations varied at the resampled sites. Data from the first sample collected at each mine discharge site were used for the PI calculations. All 111 sites sampled throughout the Lower Cheat River Basin were sampled one time during low- flow conditions and these data were used for the PI calculations. Computation of the PI was the same for each river basin. The major difference between the two indexes was that the Stonycreek River Basin index was applied to point-source mine discharges, whereas the Cheat River Basin index was applied to mainstem river sites, tributary stream sites, and subbasin stream sites within the major tributaries.

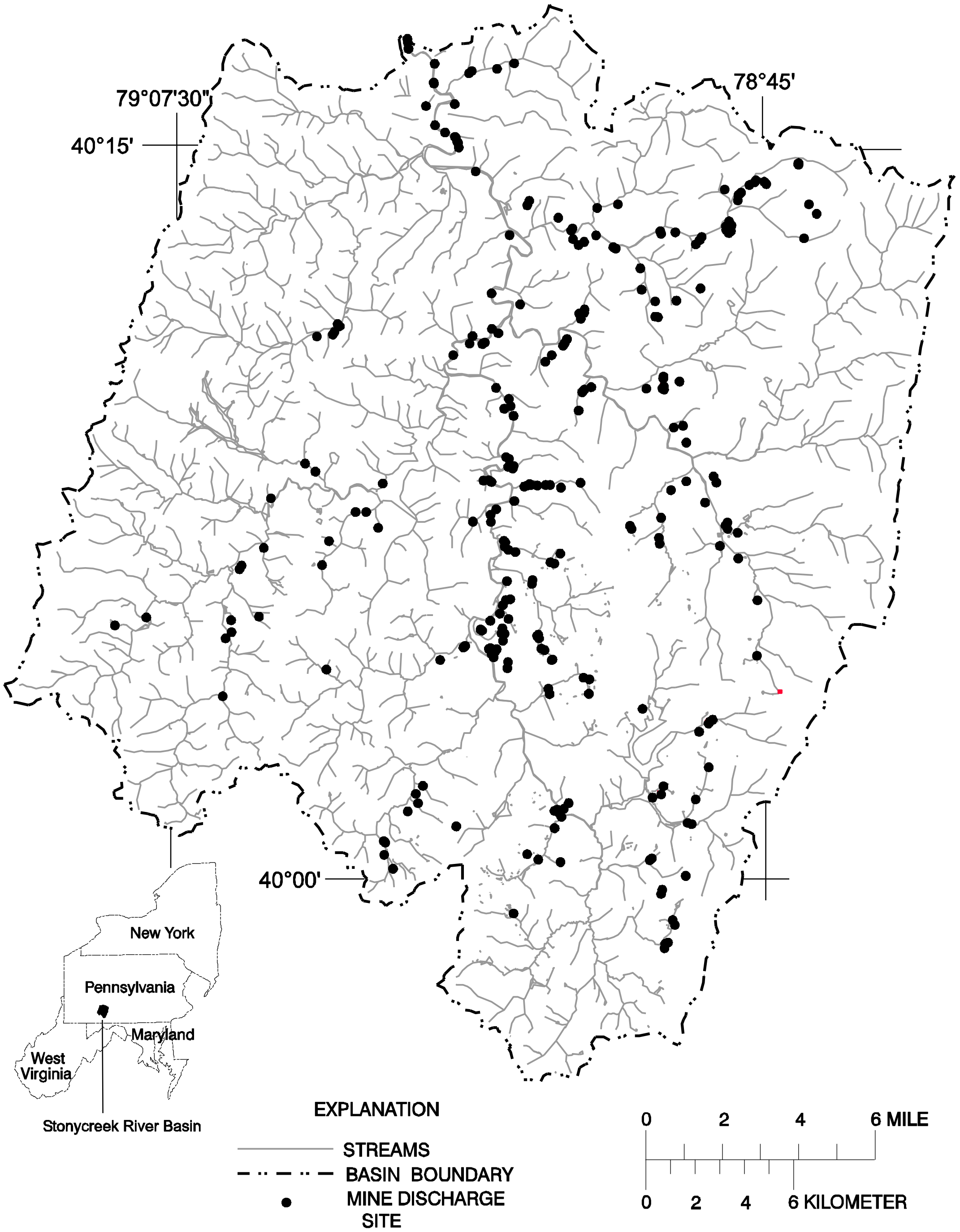

Figure 1. Location of the Stonycreek River Basin and coal-mine-discharge sites (from Williams and others, 1996).

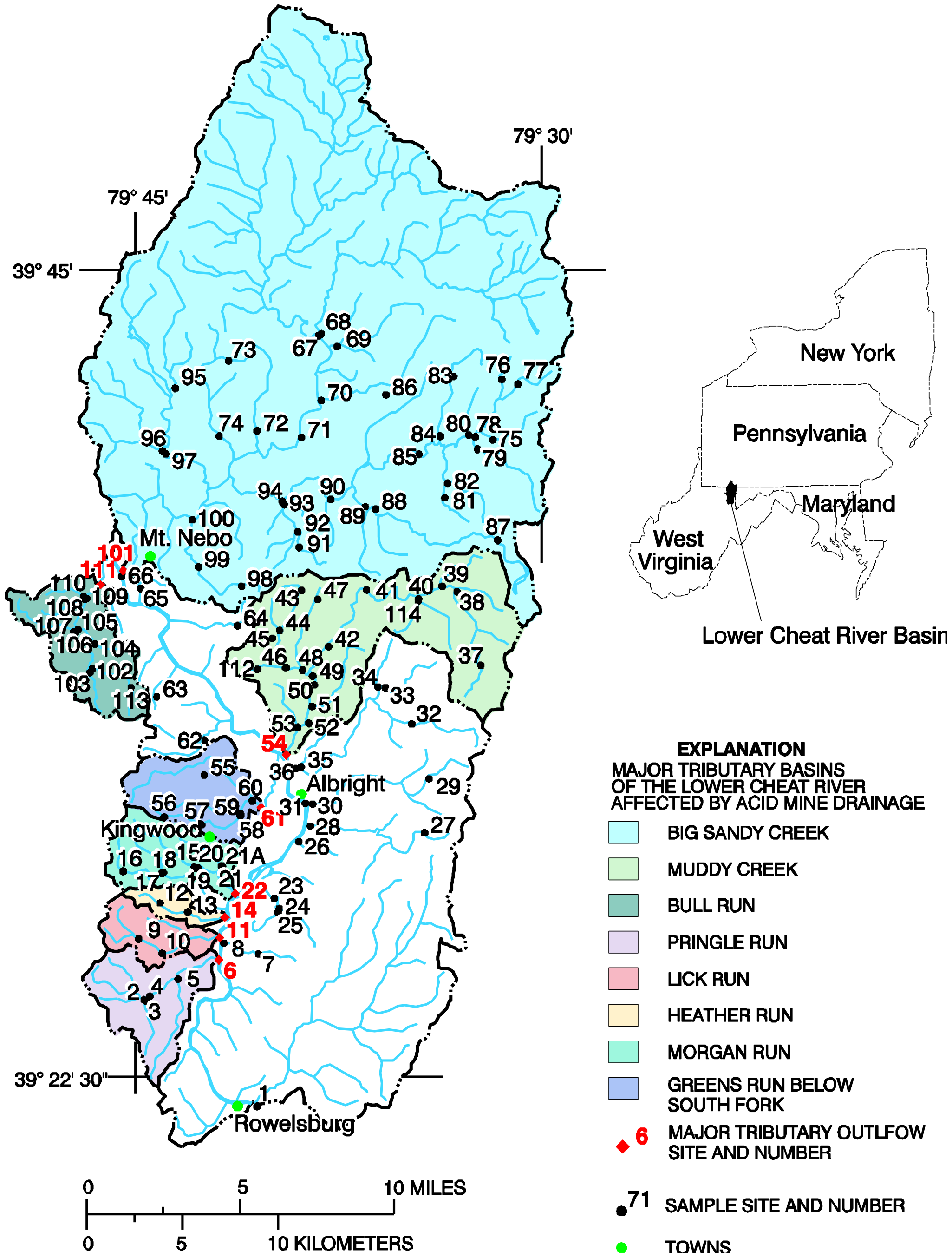

Figure 2. Location of the Lower Cheat River Basin, major tributary stream basins, and sampling sites (from Williams and others, 1999).

Required Measurements of Flow Rate and Water Quality

The data required to calculate the PI included accurate flow measurements, pH and concentrations of total iron, total manganese, dissolved aluminum, total-heated acidity, and dissolved sulfate. These factors are related either directly or indirectly to the effects of coal-mine drainage on water quality. Low pH and high acidities are common to the most severe mine discharges. Total iron, total manganese, and pH in coal-mine drainage are limited by Federal regulations (U.S. Department of the Interior, 2002). The sulfate loading is a reliable indicator of mine drainage because the neutralization processes that can occur in a mine discharge or stream do not greatly affect sulfate concentrations (Tolar, 1982). Dissolved aluminum in waters having low pH affects fish and some other forms of aquatic life (Driscoll and others, 1980). Flow rate is a significant factor in the computation of the PI for a site because the flow rate multiplied by the concentration of a constituent determines the constituent loading.

Spreadsheet Calculations

A computerized spreadsheet of the water-quality and flow-rate data at all sites was used to simplify the PI calculations. The spreadsheet was used to complete a primary sort on the discharges of each constituent in order of ascending or improving water quality. The following examples are those used for the Cheat River Basin sites. Constituent loadings per square mile of drainage (known as “yield”) were used for the calculations. The yields of each constituent were sorted in order of ascending or improving water quality. For example, the sorted, ranked, and scored total-iron data are listed in table 1. The left four columns of table 1 show the unsorted total-iron data for sites 1 through 25. The right six columns of table 1 show how the 24 sites with the highest total-iron yields were sorted, ranked, and scored. The text below refers to the sorted total-iron data in table 1. A rank number was assigned to each total-iron yield in a descending order; rank 1 was for the largest total-iron yield (1,980 lb/d/mi^2 (pounds per day per square mile)), and rank 24 was for the smallest total-iron yield (9.7 lb/d/mi^2). Each yield was then given a score on the basis of the rank. A score of 1 to 10 was assigned to each yield by subdividing all 111 sites into 10-percent groups. The first 10-percent group (rank 1-11) received a score of 10. The next 10-percent group (rank 12-22) received a score of 9, and so on. The final 10-percent group (rank 100-111) that received a score of 1 contained 12 sites instead of 11.

Yields for all five chemical constituents were sorted, ranked, and scored by this method. The final score for each site was then calculated by adding the scores for the five chemical constituents. For example, the final score and PI for sites 20, 58, 44, and 22 are listed in table 2. The final rank or PI was determined by assigning the largest final score the number 1, the second largest score the number 2, and so forth through all 111 sites.

Streamflow was used as the first tie breaker for identical final scores. The site with the largest streamflow received the lower rank number. In table 2, sites 20 and 58 had final scores of 48, but site 20 had the largest streamflow and was assigned the lower PI number. Larger streamflows can potentially produce greater discharges of the chemical constituents that can be detrimental. Stream pH was used as the second tiebreaker for sites with identical final scores and identical streamflows. The site with the lowest pH received the lower rank number. The final PI shows which sites have the greatest potential effect per square mile on the water quality of the receiving streams.

The PI calculations for the 270 mine discharges in the Stonycreek River Basin were done in a similar fashion and were ranked from 1 to 270. Drainage areas were not associated with these 270 mine discharges, so the PI was calculated on the basis of load rather than yield. A PI also was established for abandoned mine discharges located in six subbasins in the Stonycreek River Basin that were moderately to severely effected by mine drainage (Fig. 3). This was done so that water-resource managers could work on a subbasin approach in designing remediation plans.

Table 1. Unsorted total-iron data for 24 sites and sorted, ranked, and scored total-iron data for the top 24 sites based on yield used for the prioritization index calculations

Unsorted total-iron data				Sorted, ranked, and scored total-iron data					
Site number	Stream-flow (ft^3/s)	Total-iron concen-tration (ug/L)	Total-iron yield (lb/d/mi^2)	Site number	Stream-flow (ft^3/s)	Total-iron concen-tration (ug/L)	Total-iron yield (lb/d/mi^2)	Rank	Score
1	128	70	0.05	48	1.2	450,000	1,980	1	10
2	.20	5,200	1.5	57	.69	100,000	517	2	10
3	.24	12,000	9.8	11	1.7	190,000	357	3	10
4	.96	4,000	3.7	49	3.3	64,000	152	4	10
6	.97	980	.52	20	1.2	100,000	121	5	10
7	.06	640	.19	50	11	31,000	93	6	10
8	.16	100	.04	58	.64	51,000	89	7	10
9	.25	2,700	2.1	106	2.2	8,700	83	8	10
10	.20	50,000	19	12	.31	22,000	66	9	10
11	1.7	190,000	357	59	.23	70,000	59	10	10
12	.31	22,000	66	22	1.7	41,000	58	11	10
14	.65	6,700	11	19	.45	71,000	51	12	9
15	.17	21,000	10	60	.65	48,000	31	13	9
16	.12	4,500	3.4	54	11	17,000	30	14	9
17	.07	18,000	26	17	.07	18,000	26	15	9
18	.08	6,600	4.6	43	.77	3,800	26	16	9
19	.45	71,000	51	10	.20	50,000	19	17	9
20	1.2	100,000	121	61	.90	34,000	18	18	9
21	.05	210	.01	56	.03	20,000	15	19	9
21A	.12	220	.10	46	1.8	4,600	12	20	9
22	1.7	41,000	58	14	.65	6,700	11	21	9
23	.64	20	.01	15	.17	21,000	10	22	9
24	1.1	90	.20	3	.24	12,000	9.8	23	8
25	.10	50	.02	44	.19	6,900	9.7	24	8

[ft ^{3}/s, cubic feet per second; ug/L, micrograms per liter; lb/d/mi^2, pounds per day per square mile]

Table 2. Individual constituent ranks, scores, final scores, and prioritization index for sites 20, 58, 44, and 22, based on yields

Site number	Sulfate, dissolved	Rank	Score	Iron, total	Rank	Score	Manganese, total	Rank	Score
20	0.6	16	9	121	5	10	4.2	21	9
58	0.76	13	9	89	7	10	5.8	18	9
44	1.2	9	10	9.7	24	8	46	2	10
22	0.48	18	9	58	11	10	3.5	26	8

Site number	Aluminum, dissolved	Rank	Score	Acidity, total as $CaCO_3$	Rank	Score	Streamflow	Final score	Prioritization index
20	59	9	10	0.41	7	10	1.2	48	9
58	48	11	10	.36	9	10	.64	48	10
44	57	10	10	.22	14	9	.19	47	11
22	40	12	9	.27	11	10	1.7	46	12

[Yields of total iron, total manganese, and dissolved aluminum are in pounds per day per square mile; yields of dissolved sulfate and total acidity as $CaCO_3$ are in tons per day per square mile; streamflow is in cubic feet per second]

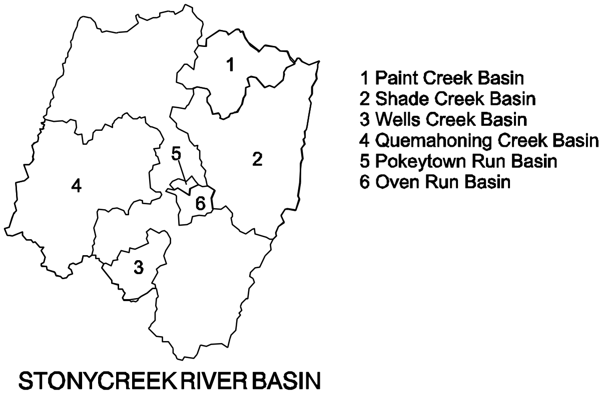

Figure 3. Six subbasins in the Stonycreek River Basin where a PI was developed for the mine discharges sampled in each subbasin.

Modifications to the PI for Consideration

In its present form, the PI is a useful tool that provides a scientific basis for prioritizing remediation steps. However, some changes to the PI model could possibly make it a more reliable tool for prioritizing mine discharges or streams for remediation. Sulfate is a very good indicator of mine drainage, but it is not detrimental to the aquatic community and its toxicity is low. When a mine discharge or stream is remediated, sulfate frequently remains in solution and the high sulfate concentrations could be misleading as a priority indicator. Therefore, sulfate should be either removed from the PI or weighted in a manner that makes it less important than iron, manganese, aluminum, and acidity.

Total iron and total manganese concentrations in treated mine discharges are limited by Federal regulation. However, total iron and total manganese generally are not available to aquatic organisms, whereas dissolved iron and dissolved manganese are available and are toxic. On the other hand, total iron and total manganese precipitates could be associated with habitat degradation and, therefore, may be more detrimental to the aquatic community than are the toxic effects of dissolved iron and dissolved manganese. Because total iron and total manganese concentrations in treated mine discharges are limited by Federal regulation, it would probably be advisable to retain the total phases in the PI and possibly assign a weighting factor of 1.0. Acidity concentrations are a very good indicator of AMD. High acidities generally are associated with severe AMD. Water having a pH below 4.0, which is common for many mine discharges, can have a very high concentration of dissolved aluminum. This can have a very detrimental effect on fish and other forms of aquatic life. Therefore, to enhance the PI model, it may be desirable to assign a weight factor of 1.5 to both the acidity and dissolved aluminum loads. Other modifications to the PI are possible, but, as presently formulated, the PI offers a meaningful, easily applied method to prioritize discharges for remediation.

Use of Prioritization Index Results by Water-Resource Mangers

Water-quality information collected on the 270 mine discharges in the Stonycreek River

Basin and the associated PI have been used by the Somerset Conservation District and the U.S. Department of Agriculture, Natural Resource Conservation Service (NRCS) in obtaining over 5 million dollars in grant money from Federal, State, and local sources for reclamation purposes throughout the basin. Approximately 15 passive treatment systems have been designed and constructed, are under construction, or have been planned throughout the Stonycreek River Basin to treat abandoned mine discharges. The remediation efforts throughout the Stonycreek River Basin have had a significant positive effect on the water quality of many tributary streams and on the mainstem of the Stonycreek River. These efforts have greatly reduced the cost of treatment for water withdrawn from the Stonycreek River for water supply purposes and have significantly increased the fishery resource value of the river, primarily the lower 12 to 15 mile reach of the river.

The PI developed for the Lower Cheat River Basin has been used by the WVDEP to prioritize these subbasins for remediation efforts. The water-quality data collected at the 111 sites also have been used as background data for total maximun daily load (TMDL) assessments.

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