ASSESSMENT OF CONTAMINANT LOAD CHANGES CAUSED BY REMINING ABANDONED COAL MINES[1]

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Abstract: Determination of contaminant loading changes caused by remining of abandoned coal mines requires knowledge of the characteristics of the hydrologic data before and after remining. Under an approved remining program, a coal mine operator can remine abandoned coal mines without assuming treatment responsibilities of the previously degraded water, as long as these discharging waters are not further degraded. Normality tests performed on the hydrologic data from 57 mine discharges from 24 remining operations indicate generally nonnormal distributions and extreme right-skewness (toward the smaller values). Analysis of the differences among medians indicates that the water quality of underground mines was more highly degraded than that of surface mines. Analyses of pre- and post-remining mine discharge water quality and flow rates of the 57 discharges illustrate that most the sites exhibited either no change or a significant decrease in contaminant rate because of remining. The discharge flow rate was the dominant controlling factor when the post-remining pollution load was observed to be significantly better or worse than the pre-remining load, as was shown with the correlation and other analyses. Generally, when the mine discharges were degraded as a result of remining, this was caused by short-term changes in flow and/or concentration that occurred shortly after reclamation. Reduction of recharge from the surface and adjacent unmined strata should decrease the mine discharge flow rate and in turn the contaminant load.

Additional Key Words: remining, contaminant load, alternate effluent standards

Introduction

Remining, as it is used in this paper, is the surface mining of abandoned surface and/or underground mines that originally created and continue to possess discharges that fail to meet the applicable effluent standards. Under a regulated remining program, an operator can mine these sites without assuming legal responsibility for treatment of the previously degraded water, as long as the water is not further degraded. If the water is further degraded, the treatment level is based on site-specific pre-remining contaminant load levels and not legislatively promulgated effluent standards. To establish pre-remining pollution load levels, a mine operator must collect a consecutive series of pre-remining water samples and measure the flow rate. Remining contaminant loading rate effluent standards (baseline loading rate) are based on these data. However, the baseline loading rate is also dependent on the strength of the pollution abatement plan and the cost of conventional treatment. If, after remining, the contaminant loading rates are no worse than the pre-remining levels and all other physical and temporal reclamation requirements are satisfied, discharge monitoring ceases and the reclamation bonds are released.

This paper presents the results of univariate and bivariate statistical analyses of data from 57 mine discharges emanating from remining operations in the bituminous coalfields in Pennsylvania. The data were obtained from 24 remining permits of the Pennsylvania Department of Environmental Resources (PADER) that were selected from a larger group of 105 potential sites (fig. 1). The selected permits possessed sufficient post-remining hydrologic data (at least 1 yr, dating from rough backfilling) to allow comparison with the pre-remining data.

Acidity, total iron, sulfate, and flow rate are analyzed in this report. Under present Pennsylvania remining regulations, acidity and iron baseline loading effluent standards are required for all permits, regardless of the concentration. Sulfate is analyzed because it serves as a conservative indicator of acid mine drainage (AMD) production and can be used to evaluate changes in discharge quality. Increased sulfate levels, in the Appalachian basin, are generally indicative of AMD production. Discharge flow rate is needed along with concentration to calculate contaminant loads.

AMD is created when sulfide minerals (usually pyrite) oxidize and the oxidation products are subsequently mobilized. Ground water serves as the transport medium of these products.

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Recharge events tend to "flush out" the oxidation products as the wetting front moves through the unsaturated portion of the spoil. During surface mining, overburden material is broken into clay (<0.002 mm) to boulder (>256 mm) sized particles, exposing pyritic minerals to oxidation from atmospheric oxygen and iron-oxidizing bacteria. This promotes a state of geochemical flux during and after mining. Subsidence observations and aquifer testing indicate that mine spoil continues to undergo physical changes caused by compaction, shifting, and piping by ground water for at least 30 months after reclamation (Aljoe and Hawkins, 1992). Spoil continues to physically change well beyond 30 months after reclamation, but at a reduced rate.

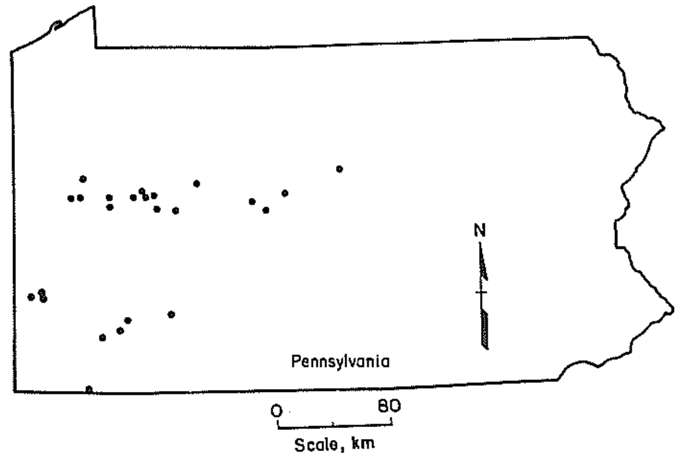

Figure 1. Location of the study sites.

The number of mine discharges at each site ranged from one to five. Mine operators report contaminant concentrations in milligrams per liter (mg/L) and flow in gallons per minute (gpm). The data are then transformed into loads of pounds of contaminant per day (lb/d), which is the effluent baseline pollution load unit used in Pennsylvania, as well as other States, for remining permits. The flows and loads were converted to liters per minute (L/min) and kilograms per day (kg/d), respectively. Table 1 summarizes these data. For portions of the statistical analyses, the data were further separated into underground and surface mine discharges.

Table 1. Summary of remining data. All data are median flow or concentration values, except n which is the number of samples.

	PRE-REMINING					POST-REMINING				
Site	n	flow	acid.	Fe	SO_4	n	flow	acid.	Fe	SO_4
1	17	8	19	0.2	339	13	4	30	0.2	420
2	21	1181	321	24.1	814	41	1283	261	20.5	852
3	22	23	511	62.0	1132	14	4	512	36.0	1089
4	10	144	43	2.9	92	45	155	162	21.9	602
5	38	193	18	0.1	151	19	182	11	0.1	118
6	21	110	143	2.7	732	16	140	128	2.3	722
7	31	469	1020	11.3	1077	11	466	850	12.8	1087
8	10	204	777	99.3	1695	40	117	294	37.6	2189
9	4	261	1447	58.1	2671	16	95	742	54.7	2230
10	9	250	4	0.6	53	33	144	3	0.5	51
11	6	280	302	10.9	991	17	38	262	6.7	882
12	12	462	58	0.2	NA	63	140	23	0.4	326
13	11	53	5	0.2	NA	56	30	10	0.2	649
14	28	11	9	1.2	159	46	15	9	0.8	204
15	9	19	136	3.5	236	24	8	299	1.6	876
16	3	189	456	295.0	1430	71	148	541	218.5	1202
17	26	64	80	1.0	515	43	45	2	1.7	690
18	24	265	2	0.4	153	33	348	10	0.3	270
19	18	34	16	0.2	74	36	42	83	1.1	446
20	8	140	208	3.3	740	7	4	19	0.5	749
21	16	42	90	2.5	231	21	61	90	2.6	379
22	28	238	231	4.8	931	10	428	151	5.9	779
23	8	344	89	4.6	253	25	220	127	9.8	374
24	18	11	566	64.1	673	12	0	677	176.8	1816

Tests for Normality

Discharge flow rate, contaminant concentration, and loading rate data before and after remining were tested for normality using the skewness test and the chi-square goodness-of-fit test. The results of these analyses are summarized in table 2. The data were tested for normality at the 5% significance level, and form of skewness (left or right) was determined.

The analysis indicates that the flow rate, concentration, and loading rate data are mainly nonnormally distributed at the 5% significance level. One exception is sulfate concentration, where the nonnormally distributed data for concentration nearly equal those that are normally distributed for both pre- and post-remining periods. For other parameters, nonnormally distributed data exceed the normally distributed data sets by at least a two-to-one margin. In total, the distribution of pre-remining variables is 277 nonnormal to 112 normal. The post-remining total is slightly less, 272 to 117. A strong influence of flow on the loading rate is indicated by the differences between the pre- and post-remining distribution of sulfate concentrations and sulfate loads. Sulfate loads are similar to the corresponding flow and dissimilar to the sulfate concentrations. This indicates that the flow influence on sulfate load is stronger than the concentration influence.

Table 2. Summary of normality testing results. A P value greater than 0.05 indicates the data were not normally distributed at the 5% significance level; a P value less than 0.05 indicates that the assumption of normality cannot be rejected with greater than 95% confidence. NA signifies that there were insufficient degrees of freedom to adequately conduct the chi-square test.

	Skewness test		Skewness		Chi-square test		
Pre-Remining	P<0.05	P>0.05	Left	Right	P<0.05	P>0.05	NA
Flow rate	45	12	12	45	12	1	44
Acid conc.	35	22	22	35	4	7	46
Acid load	42	15	8	49	9	2	46
Fe conc.	40	17	11	46	6	4	47
Fe load	45	12	10	47	10	4	43
SO_4 conc.	28	24	22	30	4	8	40
SO_4 load	42	10	12	40	11	1	40
Post-Remining							
Flow rate	41	16	7	50	21	7	29
Acid conc.	35	22	13	43	21	6	30
Acid load	40	17	3	54	24	5	28
Fe conc.	52	5	6	51	17	8	31
Fe load	42	15	5	52	25	4	28
SO_4 conc.	27	25	15	37	12	12	28
SO_4 load	35	17	2	50	15	8	29

Table 2 illustrates that the data are mainly skewed right (toward lower values). The ratio of right-to-left skewed data ranges from a low of about 1.4 to 1 for pre-remining sulfate concentration to a high of 25 to 1 for post-remining sulfate load. In general, the number of concentration data sets skewed right in the post-remining period exceeds that for the pre-remining period. This may be caused by the state of flux of the post-remining spoil aquifer, which yields periodic extreme concentration and flow values. Loading data skewness is more often to the right than either flow or concentration. This increase appears to be caused by the interdependence of concentration to flow (e.g., concentration increases caused by "flushing" or concentration decreases caused by dilution). The majority (629 of 777) of the pre- and post-remining data tend to be skewed right. Table 2 shows that the chi-square and the skewness tests produce similar results. However, because of the nonapplicability of the chi-square test in many cases, a direct comparison cannot be made. The chi-square test results illustrate that the majority of the data are nonnormally distributed at the 5% significance level. However, there are some inconsistencies within the concentration data sets before and after remining.

Chi-square testing of the pre-remining concentration data indicates that they are more often normally than nonnormally distributed. Conversely, the post-remining data tend to be more often nonnormally distributed than the pre-remining data. However, pre-remining iron concentration tends to be nonnormally distributed. The post-remining data are mainly nonnormal for acidity and iron concentrations. Post-remining sulfate concentration is equally likely to be normally or nonnormally distributed. The differences between pre- and post-remining concentration may be related to the lower number of tests that could be performed compared with the skewness tests. The chi-square testing indicates that the contaminant loads exhibit distributions similar to those of the corresponding flow data. This suggests that flow rate is the dominant influence on loading rates, as also observed by Smith (1988). This is especially evident with chi-square tests for the pre-remining acidity and sulfate.

Exploratory Data Analysis

One tool of exploratory data analysis is the "notched box-and-whisker" plot. These plots are used to graphically display basic statistical parameters to compare subsets of data. For more information on notched box-and-whisker plots, the reader is directed to McGill et al. (1978).

Figure 2 is a notched box-and-whisker plot representing the sum of the median flow rate measurements for each site classified by mine type (underground and surface) before and after remining. A comparison of surface and underground mine discharge flow rate characteristics before and after remining indicates that there is no significant difference at the 95% confidence level.

Figure 3 exhibits the mine average acidity concentration determined from the individual discharge medians. This figure shows that the pre- and post-remining median acidity concentration for underground mines is significantly higher than that for surface mines. The elevated acidity exhibited by the underground mines occurs because ground water flows almost exclusively through parts of the mine where AMD forms (relatively high sulfur coal, seat, and roof rock). Conversely, Hawkins and Aljoe (1991) observed that in surface mines, ground water flows through discrete paths in the spoil. Parts of the spoil may consist mainly of acid-forming materials (e.g., high-sulfur shales, sandstones, and spoiled coal), while other parts may be mostly alkaline-forming materials (e.g., limestones and carbonate-rich shales). Underground mine discharges generally exhibit a wider range of values than those from surface mines. Post-remining acidity concentration is similar to pre-remining, indicating little change occurred relative to mine type.

Figure 4 is a plot of the average iron concentration determined from the individual discharge medians. The shape is similar to the acidity, although more subdued. The underground mine concentration median is above that for surface mines, although the differences are not significant at the 95% level. The post-remining plot is not significantly different from the pre-remining data.

Figure 5 represents a plot of the average of the pre- and post-remining discharge sulfate concentration medians for each site. The underground mine median value is higher than that of surface mines. The difference between the pre-remining medians is not significant. The data range is likewise wide for the underground mines. Post-remining sulfate, on the other hand, shows a significant difference at the 95% level. This is caused by a rise in the underground mine median and a narrowing of the approximate 95% confidence interval about the median (notches) of the underground mine data. Daylighting of the abandoned underground mines may increase AMD production, but greatly reduces the variability of sulfate concentration.

Notched box-and-whisker plots (not shown) created for pre- and post-remining of the contaminant loads for underground and surface mines are similar to the corresponding concentration plot. The loadings did not show a difference at the 95% confidence level between mine types. The plots for flow pre- and post-remining also did not exhibit significant differences in the medians at the 95% confidence level. This indicates that flow rate may have a stronger influence on loading than concentration does, which mirrors trends exhibited by the normality tests.

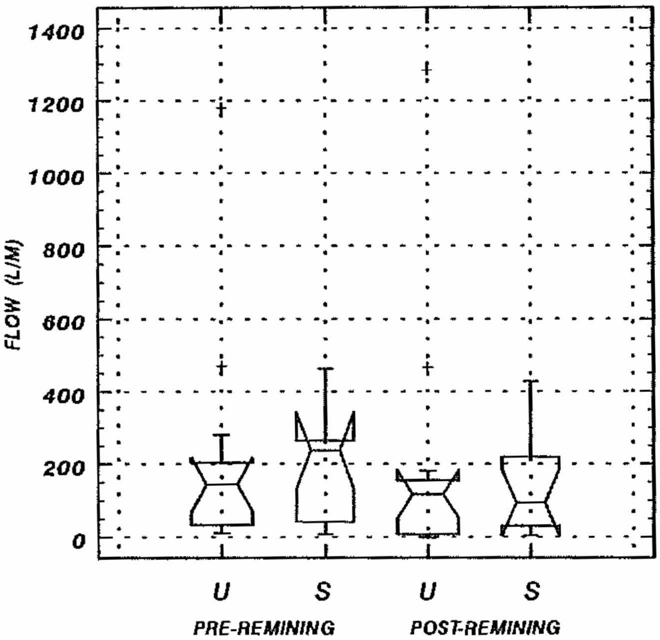

Figure 2. Median flow rate measurements of underground (U) and surface (S) mines before and after remining.

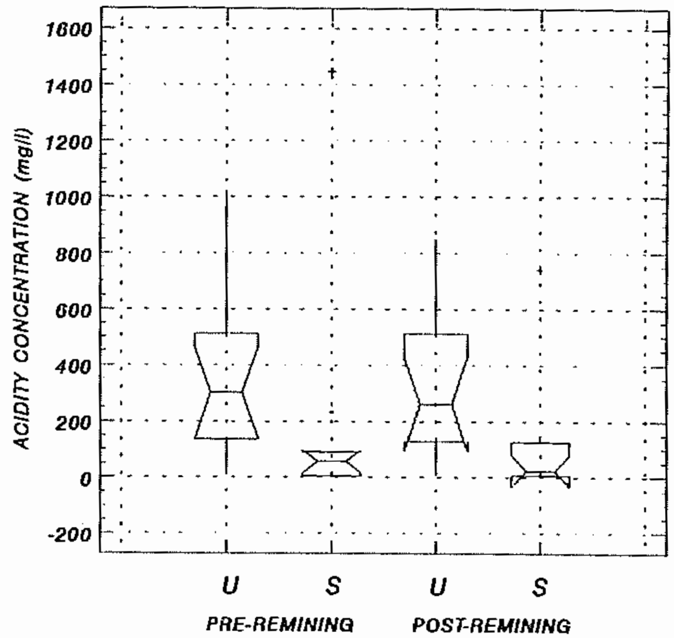

Figure 3. Acidity concentration medians of underground (U) and surface (S) mines before and after remining.

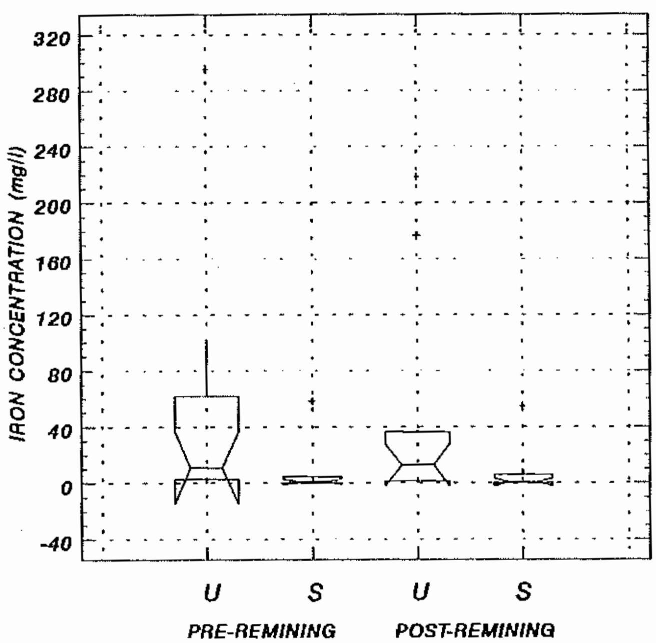

Figure 4. Iron concentration medians of underground (U) and surface (S) mines before and after remining.

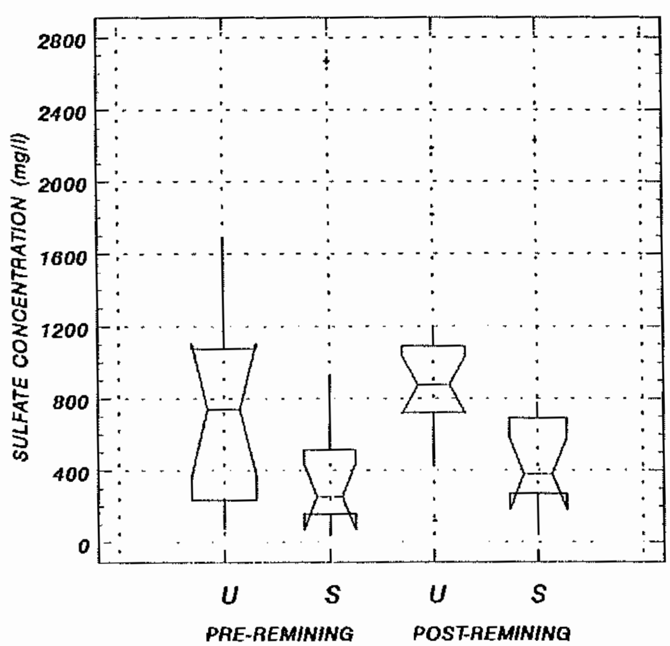

Figure 5. Sulfate concentration medians of underground (U) and surface (S) mines before and after remining.

Data Correlation

Correlation coefficient is a measure of the interrelationship between two variables from which the degree of statistical significance can be determined. Correlation coefficient is generally determined using parametric testing procedures (Davis 1986). Spearman's rank correlation is a nonparametric test used to calculate the correlation coefficient. For this study, the coefficient significance level was set at $P = 0.05$. Correlation coefficient values were calculated to show the effect that flow and concentration have on load. As summarized in table 3, flow is more often strongly correlated to the contaminant load than concentration.

Table 3.–Summary of significant correlations. The values are the number of data sets exhibiting a significant positive and negative correlation at the P=0.05 level.

	Pre-Remining			Post-Remining		
Flow vs Load	Acidity	Fe	SO_4	Acidity	Fe	SO_4
Positive	42	29	37	51	42	51
Negative	0	0	0	0	0	0
Concentration vs Load						
Positive	10	14	8	30	30	12
Negative	5	5	4	7	2	6

About 82% (93 of 114) of the total acidity loads are strongly correlated to flow, while the concentration exhibits a significant correlation to load in about half (52 of 114) the cases (table 3). Flow correlations are in all cases positive, indicating flow increases cause load increases. Strong correlations of flow to acidity load are increased moderately by remining. Pre-remining acidity concentration exhibits a positive correlation to contaminant load about 25% as often as flow. Post-remining acidity concentration was correlated positively to load three times more often than pre-remining, which may be caused by the state of flux that exists shortly after reclamation. In five cases, pre-remining acidity concentration exhibited a negative correlation to load. This may be caused by dilution from high-flow events. Negative acidity concentrations to load correlations for the post-remining data were not substantially different from those for pre-remining data.

Iron exhibited the lowest flow-to-contaminant-load correlation of the three contaminants. About 51% (29 of 57) of the pre-remining flow was strongly correlated to iron load, compared with 25% (14 of 57) of the cases in which concentration showed a significant positive correlation to load (table 3). Strong correlations of post-remining flow to iron load increased to 74% (42 of 57). The instances of positive correlation of iron concentration to load doubled after remining. The number of negative correlations of iron concentration to load was low and did not change significantly after remining.

Almost 89% (88 of 99) of both pre- and post-remining flow-to-sulfate-load correlations were positive. No negative flow-to-load correlations were noted (table 3). Flow-to-sulfate-load strong correlations increased after remining. Of all the contaminants, combined pre- and post-remining sulfate concentration to load showed the least number of strongly correlated data. Concentration to load correlation, both positive and negative, changed very little because of remining.

Significant positive correlations of flow to load exceeded concentration-to-load correlations by 252 to 104. The increase of the post-remining positive correlation of flow and concentration to load may be related to the previously discussed state of flux of mine spoil after remining.

All negative correlations were exhibited by concentration to load. This may be caused by contaminant dilution by increased flow or geochemical changes in ground water quality that can reduce concentrations through chemical reactions. During high-flow events, the sources and flow paths of the ground water can change, thus causing water quality changes. Chemical reactions, because of water quality changes, can reduce the acidity and iron content, but usually will not affect the sulfate content at the noted levels. Negative sulfate concentration to load correlations were similar to those for iron and acidity, indicating that dilution may be the main cause of most of the negative correlations.

Determination of Contaminant Load Reduction

To determine the effectiveness of remining to reduce contaminant load, the remining operation discharges were analyzed. The pre- and post-remining data were analyzed using an exploratory data analysis system (schematic summary), which is presently used by the PADER, and the Mann-Whitney U test.

PADER System

Initially, under the PADER system, a minimum of 6 monthly samples were required, although 12 consecutive monthly samples were strongly recommended. The PADER now requires 12 consecutive months of data. In theory, 12 monthly samples will include both low- and high-flow periods in the background data, which will more accurately characterize the preexisting discharges. For the analysis using the PADER system, all discharges from each site were combined into a single hydrologic unit to determine the effectiveness of remining on a site-by-site basis. Pre-remining water quality data are analyzed using some basic exploratory data analyses and nonparametric statistics (PADER 1988). Results for each discharge or hydrologic unit are presented in a table containing the loading data range, the median, the first and third quartiles, the approximate 95% tolerance limits, and the 95% confidence interval about the median for each of the regulated contaminants. Table 4 is an example of these results. Tukey (1976) and Velleman and Hoaglin (1981) present explanations of these values and how they are calculated. Under the PADER system, there are four mechanisms by which treatment of a discharge can be initiated (triggered) using the data in this table.

Table 4.–Example of PADER baseline contaminant load summary table. Units used in this table are as used for permitting by the PADER.

Mine ID:	Mine Name:		Hydrologic Unit ID:		
		Loading in Pounds Per Day			
Parameter:		Flow(gpm)	Acidity	Iron	Sulfate
Number of Samples (N):		43	43	43	43
1. Range	Low:	3.00	0.07	0.00	28.27
	High:	42.00	1.01	1.41	214.56
2. Median		12.00	0.29	0.21	99.53
3. Quartiles	Low:	9.00	0.22	0.15	70.98
	High:	17.00	0.41	0.60	132.63
4. Approximate 95% Tolerance Limits	Low:	3.00	0.07	0.02	31.01
	High:	34.00	0.82	1.29	210.47
5. 95% Confidence Int. about Median	Low:	10.22	0.25	0.11	85.77
	High:	13.78	0.33	0.31	113.28

The first triggering method requires a series of 6 consecutive samples to exceed the upper bound of the approximate 95% tolerance limit (item 4 in table 4). If two consecutive samples exceed the upper bound of the approximate 95% tolerance limits, during and after mining, this triggers weekly sampling. If 4 consecutive weekly samples exceed the approximate 95% tolerance limits, the operator initiates treatment within 30 days. If two consecutive weekly samples drop below the 95% tolerance limits at any time during the weekly sampling, monthly monitoring resumes and treatment is not required. If treatment is incurred, it is suspended if two consecutive weekly samples drop below the 95% tolerance limits.

Second, treatment is initiated when the statistical analysis indicates the during- or post-remining median contaminant load has increased in comparison to the pre-remining median at the 5% significance level. This is determined by comparison of the 95% confidence interval about the median (item 5 in table 4) of the pre- and post-remining data. The median is calculated on a complete water year (October 1 through September 30) basis.

The third triggering method uses the same method. However, the median is determined for water-year periods 1 (October 1 through April 30) or 2 (May 1 through September 30). Finally, treatment can be triggered if analyses, including but not limited to the means and variances of the data, indicate that the difference between water years or water-year periods is significant at the 1% level. The third and fourth triggering methods are seldom used.

Table 5.–Summary of weekly sampling and discharge treatment triggering from remining. "Yes" indicates that triggering occurred at least once to one or more discharges and/or hydrologic units for that site. "No" indicates triggering never occurred.

	Acidity		Iron		Sulfate	
	Yes	No	Yes	No	Yes	No
Weekly sampling	10	14	5	19	11	11
Treatment	3	21	3	21	5	17

Weekly sampling was initiated at least once after remining by acidity for 10 of 24 sites (table 5). Three of these sites subsequently triggered treatment. Iron triggered weekly sampling in 5 out of 24 sites. Of these 5 sites, 3 triggered discharge treatment. Of the 3 discharge treatment incidences, for acidity and iron, 2 occurred concurrently; therefore treatment was initiated at least once on 4 sites. The high load events that triggered treatment were in all cases transient. High-loads usually occurred shortly after reclamation (<1 yr) and usually declined to below tolerance limits within a short period (<6 months) after initiation. Site 8 was the only mine to initiate treatment more than 13 months after reclamation.

Sulfate would have triggered weekly sampling, if it was an effluent contaminant, for 50% of the sites. Almost half of the weekly sampling events would initiate treatment. The high number of sites where sulfate loads would initiate weekly sampling and then treatment may be caused by hydrologic and geochemical changes that occur in the spoil following remining. Pyritic material surface area exposed to oxidation is greatly increased by mining. This promotes AMD production, which is indicated by elevated sulfate levels. The increased rock surface area also increases the exposure of alkaline strata, when present, to weathering and dissolution, thus adding alkalinity to the ground water. This alkalinity reduces acidity levels and raises the pH, which increases the potential for dissolved iron to oxidize and precipitate out of solution. However, sulfate concentrations are little affected by increases in alkalinity and pH at the given sulfate and calcium levels.

For the second triggering method, the reason for using a water year is to ensure that the data used in the comparison are not biased by most of the sampling occurring during a protracted low- or high-flow period. The large number of possible water year periods for the 57 discharges precluded strict adherence to this part of the PADER system. Instead, the data for the entire post-remining period were compared with the pre-remining data. Any sampling bias of the data was minimized because each of the post-remining data sets included from 2 to over 10 of each low- and high-flow periods. The potential bias is also reduced by the use of the data median, which is less sensitive than the mean to extreme values (Snedecor and Cochran 1971).

The results using the second PADER system indicate that remining at most of the sites did not cause additional degradation. The median acidity and iron loads for 21 out of 24 sites were within or below the pre-remining 5% significance level. The one site where acidity was above pre-remining levels coincided with one of the iron excursions. Median loads for acidity from 7 of 24 sites and for iron from 4 of 24 sites were below the pre-remining 5% significance level. Three of the excursions coincided, making a total of 8 sites with significant decrease in load. Of these 11 excursions, 7 also exhibited a significant flow reduction at the 5% level. However, a 2-fold or greater increase in concentration coincided with 6 of the excursions.

Of the four excursions of the median acidity and/or iron loads above the 5% significance level, none exhibited a significant increase in flow. However, 3 of the 4 exhibited substantial increases in concentration (a factor of 5 or more).

Sulfate load comparison exhibits similar results to acidity and iron: 3 above, 15 within, and 4 below the pre-remining 5% significance level. Flow was a significant factor in 3 of 4 excursions below the 5% significance level, although concentration did not vary by more than 11%. However, flow was not a significant factor for the 3 excursions above the 5% level, while concentration increased by a factor of 6 or more in 2 out of the 3 cases.

Flow played a critical role in load rate excursions outside the 5% significance level, especially for decreases in load. The results indicate that concentration is a weaker factor than flow in causing excursions outside the 5% significance level. However, concentration changes were more often associated with excursions above (71%) rather than below (40%) the 5% level.

Table 6.-Summary of the results from the second PADER triggering method.

	Above	Within	Below
Acidity Load	1	16	7
Iron Load	3	17	4
Sulfate Load	3	15	4

Mann-Whitney U Test

The Mann-Whitney U (MW) test is a nonparametric version of the Student's t test that determines if the median (or mean) of two data sets come from different populations at the 5% significance level (Davis 1986). Mine water quality and flow can vary widely within a site. Therefore, the MW test was applied to individual discharges, rather than the entire mine, to provide a clearer determination of the effect of remining on flow and water quality.

The MW test results (table 7) indicate that acidity and iron concentration and load were unchanged or improved (decreased) at the 5% significance level for most of the discharges. The number of discharges above the 5% level (indicating degradation) is lower for acidity and iron loads than for concentrations. This may be related to the strong influence that flow has on the contaminant load. The test results for acidity and iron loading are similar to those for flow and dissimilar for concentration.

The number of discharges exhibiting increased sulfate concentration and load is higher than the number of discharges exhibiting increased acidity or iron values. Over 34% of the discharges show increased sulfate concentration and almost 20% have an increased sulfate load at the 5% significance level. This higher "failure" rate exhibited by sulfate is likely due to changes in ground water flow paths and material contacted after remining, as previously discussed.

Table 7.-Summary of the Mann-Whitney U test results. Below means the post-remining median was below pre-remining at the 5% significance level. Above means the median was above at the 5% level and within indicates that the data did not exceed the upper or lower 5% significance levels.

	Below	Above	Within
Acidity concentration	24	7	26
Acidity load	17	4	36
Iron concentration	18	9	30
Iron load	17	5	35
Sulfate concentration	9	18	25
Sulfate load	14	10	28
Flow rate	16	4	37

Summary and Conclusions

To accurately assess the success of remining in reducing discharge contaminant loads, a basic understanding of the hydrologic characteristics is required. Testing indicates that water quality and flow data are nonnormally distributed. Remining appears to increase the nonnormality of the data. The data are mainly skewed toward lower values. Trends exhibited by the test results indicate that flow is the dominant factor for determining the contaminant load rate.

Water discharging from underground mines is more degraded by AMD than that from surface mines. This may be caused by differences in the ground water flow regime of the two mine types.

Remining is generally successful in preventing additional ground and surface water degradation in terms of contaminant concentrations, load, and flow of mine discharges. Most discharges have post-remining contaminant loads that are equal to or below the pre-remining levels. Short-term transient changes (< 6 months) in flow and/or concentration are the main reasons that degradation appears to have occurred at some of the discharges.

When the analyses indicate that a significant change in terms of contaminant load occurred, a change in the discharge rate is the most common reason. If flow can be reduced through mining and/or reclamation practices, the probability that the operation will not incur permanent treatment liability is greatly increased. Concentration is a secondary factor in some cases.

Concentration may play a somewhat stronger role in load determination when a significant increase in load is indicated than when a significant decrease is indicated.

Discharge flow-reduction practices can be incorporated into the permit-application abatement plan. Flow reduction can be achieved by exclusion or diversion of ground and surface water away from the reclaimed site. Methods that decrease infiltrating surface water include installation of diversion ditches, capping the site with a low-permeability material, spoil regrading, and revegetation. Abandoned sites, prior to remining, commonly have unreclaimed pits and closed-contour depressions that serve as infiltration zones for surface water. For abandoned surface mines, regrading and revegetating spoil often will reduce surface water infiltration and increase runoff by eliminating these recharge zones.

Methods for decreasing ground water recharge to the spoil include drains and/or grout curtains installed near the final highwall, pit floor drains, horizontal free-draining dewatering wells, and sealing of adjacent underground mine entries.

Although this study was conducted exclusively in Pennsylvania, the geologic and hydrologic conditions in other Appalachian States are similar enough to those of the western Pennsylvania coalfields to expect similar levels of contaminant-load reduction.

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