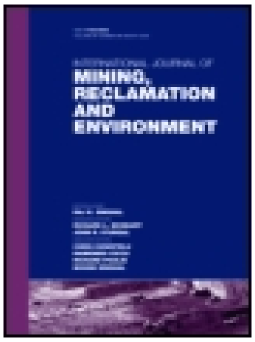

International Journal of Surface Mining and Reclamation

ISSN: 1389-5265 (Print) 1744-5000 (Online) Journal homepage: https://www.tandfonline.com/loi/nsme19

Adequacy of background sampling for coal remining permits: An empirical approach

Jay W. Hawkins

To cite this article: Jay W. Hawkins (1995) Adequacy of background sampling for coal remining permits: An empirical approach, International Journal of Surface Mining and Reclamation, 9:2, 73-78, DOI: 10.1080/09208119508964722

To link to this article: https://doi.org/10.1080/09208119508964722

International Journal of Surface Mining, Reclamation and Environment 9(1995):73-78

Adequacy of background sampling for coal remining permits: An empirical approach

Jay W. Hawkins
US Bureau of Mines, Pittsburgh, Pa., USA

ABSTRACT: Under an approved remining program, a mine operator can remine abandoned coal mines without assuming treatment liability of the existing degraded water, as long as the discharging waters are not raised above the revised effluent standards. A salient yardstick of the success of remining is reduction of the acidity and iron pollution load from pre-remining (baseline) conditions. The baseline sampling scheme, crucial to mine discharge characterization, is used to determine remining induced pollution load changes. To determine the optimum baseline sampling scenario in terms of water quality characterization, the pre-activation data from 115 discharges from 39 Western Pennsylvania remining permits were analyzed using the treatment initiation mechanism employed by the Pennsylvania Department of Environmental Resources. The best sampling duration was the maximum duration analyzed, 12 months. A year's worth of data will include data from both high and low flow conditions. The optimum sampling frequency was determined to be one sample per month. Sampling on a time-consistent basis eliminates the potential bias of oversampling high or low flow conditions. Sampling twice per month may improve the characterization, if performed on a consistent time interval. However, the improvement appears to be slight and the increased sampling may not be cost-effective.

1 INTRODUCTION

Remining, as the term is used in this paper, is the surface mining of abandoned surface and/or underground coal mines with existing discharge water that fails to meet applicable effluent standards. Remining objectives are to improve the post-remining water quality and promote the reclamation of abandoned mine lands. However, under the Pennsylvania regulated remining program, an operator can remine these sites without assuming legal responsibility for treatment of the existing degraded water, as long as the discharging waters are not further degraded below the revised effluent standards. If the water is further degraded, the treatment requirement is based on site-specific pre-remining pollution levels and not legislatively-promulgated effluent standards (Pennsylvania Bulletin, 1985). To establish baseline pollution load levels, the mine operator must collect a consecutive series of pre-remining discharge water samples and flow rate measurements. Remining pollution loading rate effluent standards (e.g. pounds of pollutant per day) are established based on analyses of these data. Baseline background sampling is crucial for the determination of changes to the discharges caused by remining. Technically, the operation must show an improvement in water quality. However, if the pollution loading rates are equal to or better than the baseline pollution loading rate after remining and all other physical and temporal reclamation requirements are satisfied, discharge monitoring ceases and the operator is essentially released of all further liability. Insufficient characterization of discharge pollution load could falsely indicate increased or decreased degradation caused by remining. This subsequently could cause a mine operator to be held responsible for treatment incorrectly or conversely, be released from treatment liability when the discharge quality has actually been degraded.

To determine the adequacy of pre-remining background sampling for discharge characterization, 105 files of remining operations from Pennsylvania were initially reviewed. From these files, 39 permitted operations with a total of 115 discharges were selected for this study. The study sites are located on figure 1. Site selection was based on the length of the pre-remining sampling period. The data were analyzed to ascertain the optimum sampling frequency and duration that most accurately characterizes the baseline pollution load. A maximum of one year sampling duration for the revised effluent standards was placed on this study. This is based on the assumption that 1 year is the maximum length of time that the majority of mine operators will find acceptable in terms of cost and extended permitting time. However, there is little question that longer sampling will better characterize the pollution load.

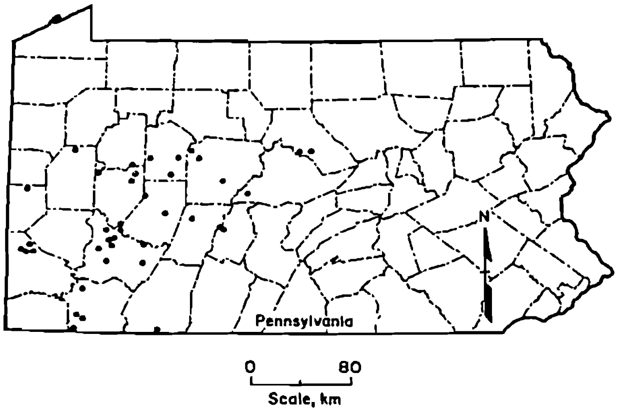

Figure 1. Location of the study sites.

The large number of discharges precluded the determination if baseline sampling of individual discharges occurred during a period of normal precipitation or an unusually wet or dry period. The lengthy period over which discharges were monitored should reduce the impact of abnormally wet and dry periods on the study. It is difficult to ascertain which time interval will accurately represent a discharge in terms of load. However, the sampling represents data collected randomly throughout an 11 year period from September 1980 through November 1991. The sampling of individual discharges ranged from 18 to 86 months. The large number of discharges sampled within the 11 year period will diminish the impact on the study that a protracted wet or dry period has on a few discharges. It was not the intent of this study to determine what sampling period accurately represents individual discharges, but rather to determine the optimal sampling scenario for remining based on actual data.

2 RELATED STUDIES

Smith (1988) analyzed flow rate, acidity concentration, and acid load of three mine discharges from Pennsylvania. He classified these discharges based on the relationship of flow to concentration. He determined that acid load was heavily dependent on flow. The study concluded that, "The baseline data collection must be of sufficient duration and frequency to adequately characterize the range of conditions," and that to avoid biasing the data, the sampling interval should be consistent throughout the baseline period.

Hawkins (1993a) characterized the hydrologic data from remining sites. Skewness and chi-square testing on the flow, concentration, and loading data before and after remining illustrated that these data were mainly nonnormally distributed and positively skewed. It was observed that underground mines are more severely degraded than surface mines. Acidity, iron, and sulfate loads were shown to be primarily determined by the flow rate.

Hawkins (1993b) reviewed the effectiveness of the Pennsylvania remining program in terms of pollution load reduction and observed that flow has a strong influence on acidity, iron, and sulfate load rate determination. The study indicated that most of the discharges exhibited post-remining acidity and iron loads that were within or below pre-remining levels. When discharges exhibited pollution load above pre-remining levels, this was generally a short-term event occurring within the first year after reclamation.

3 BASELINE LOADING RATE ANALYSIS METHOD

In Pennsylvania, pre-remining pollution effluent loading rates are set during the remining permit application process based on a consecutive series of water quality samples and measured discharge flow rates. Initially, a minimum of 6 monthly samples were required to perform these calculations, although 12 consecutive monthly samples were strongly recommended by the Pennsylvania Department of Environmental Resources (PADER). With a few exceptions, the PADER now requires 12 consecutive monthly samples. In theory, 12 consecutive monthly samples will include both low flow and high flow periods in the background data, which will more accurately characterize the existing discharges. At a minimum, water samples must be analyzed for concentrations of alkalinity, acidity, total iron, total manganese, aluminum, sulfate, total suspended solids and pH. The pollutants are generally reported in units of milligrams per liter (mg/L), except for pH, which is in standard units. Discharge flow rate, usually reported in gallons per minute (gpm), is gaged by a variety of means, such as a weir, flume, cross sectional area and flow meter, or bucket-stopwatch method. For this study, the flow rate was subsequently converted to liters per minute (L/m). The weir appears to be the most common method used for mine discharges over 38-76 L/m (10-20 gpm), while the bucket-stopwatch method appears to be the main method for discharges with lower flow rates. For remining permits, the loading rates in pounds per day (lbs/day) are calculated from the flow and concentration data. For this study, the data were converted to kilograms per day (kg/day).

The baseline loading rates are calculated using basic exploratory data analyses (schematic summary) and nonparametric statistics (PADER, 1988). The results for each discharge or hydrologic unit are presented in tables containing the loading data range, the median, the first and third quartiles, the approximate 95% tolerance limits (depth of 32nds values or C spread), and 95% confidence interval about the median for each of the regulated pollutants. Table 1 is an example of these analyses. Tukey (1977) and Velleman and Hoaglin (1981) present detailed explanations of the methods by which these values are calculated and what they represent. Under the PADER system, there are four mechanisms by which treatment of a discharge can be initiated (triggered) using the values in this table.

The first and main triggering method under this system requires a series of 6 consecutive samples to exceed the approximate 95% tolerance limit over a three month period. Discharge sampling, during and after mining, is conducted on a monthly basis until reclamation-performance bonds have been released. If, during this period, two consecutive samples exceed the upper bound of the approximate 95% tolerance limits for any of the specified pollutants (item 4, table 1), this immediately triggers weekly sampling. If 4 consecutive weekly samples exceed the approximate 95% tolerance limits, then the operator must initiate treatment within 30 days. If two consecutive weekly samples drop below the 95% tolerance limits at any time during the weekly sampling, then monthly monitoring resumes and treatment is not required at that time. Treatment is likewise suspended when two consecutive weekly samples drop below the 95% tolerance limits.

The first triggering system was modified slightly for this study, because the discharges were seldom sampled on a weekly basis. If a discharge exceeded the approximate 95% tolerance limit for three consecutive months this was considered a treatment initiation event under the first PADER triggering system. It is possible that this change may overestimate the number of regulatory treatment triggering events. However, the intent of this work was to determine the optimal baseline sampling scenario, and not to enforce compliance of regulations. If a discharge exceeds a 95% tolerance limit 3 successive months, this is indication that the background characterization was inadequate and/or a true change to the discharge has occurred.

A second mechanism for treatment initiation is when statistical analysis indicates the during- or post-remining median pollutant load has been 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, Table 1) of the pre- and post-remining data. The median is calculated on a complete water year (October 1 through September 30) basis.

As with the first treatment triggering system, the second system was modified slightly for application to this study. Rather than comparing the 95% confidence interval about the median for water years or water year periods, the 95% confidence interval about the median for the baseline period (6, 9 or 12 months) was compared to the 95% confidence interval about the median of the entire test period, which ranged from 12 to 80 months. However, the analyses must be viewed in the context that there is a potential to narrow the confidence interval about the median as the number of samples increases and vice versa.

Table 1. Example of baseline pollution load summary used by the PADER for remining permitting.*

Mine ID: Mine Name: Hydrologic Unit ID:

LOADING IN POUNDS PER DAY

PARAMETER: NUMBER OF SAMPLES (N):		FLOW(gpm) 43	ACIDITY 43	IRON 43	SULFATE 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

* - These units are as used for remining permitting by the PADER.

Other triggering methods, not used in this study, use a median determined for specified water-year periods or statistical analyses, including but not limited to the means and variances of the data, to indicate whether the difference between water years or water-year periods is significant.

For any of the triggering mechanisms, if the mine operator can demonstrate to the PADER that the apparent increase in pollution load is unrelated to the mining operation and is caused by factors beyond their control (e.g. adjacent unrelated mining operations or an extreme storm event), treatment of the discharge is not required.

Treatment standards are likewise based on the data in table 1. Monthly discharge pollution load average cannot exceed the pre-remining median and is calculated based on the samples collected weekly. The instantaneous maximum pollution load permitted is based on a "grab" sample and must be no greater than the upper quartile, ("HIGH" value of item 3 in table 1). Both parameters must be reported at least monthly.

This is the remining system as it was developed and is used in Pennsylvania. Requirements for background sampling and data analysis for other Appalachian coal-producing states range widely. Several states are just beginning to establish remining programs.

4 DATA ANALYSIS AND DISCUSSION

Pre-remining data from 115 discharges from 39 remining permit files were used to examine the effect of differing sampling frequencies and durations on the baseline pollution characterization. The number of discharges ranged from 1 to 10 per site with a median of 2. The mining operations were selected based on the criteria that they possessed 18 or more months of background hydrologic data prior to site activation. The sites geographically encompass the majority of the Pennsylvania bituminous coal fields (fig. 1).

Stratagraphically, these operations include remining from the Pottsville Group (Mercer coal) up through the Monongahela Group (Redstone coal). These mines are primarily remining of abandoned surface mines and/or daylighting (surface mining) of abandoned underground mines. However, a few of the operations were coal refuse reprocessing operations, where the residual coal is gleaned from coal refuse piles. The reject from these operations is replaced, regraded, and revegetated.

The basic goal of this study was to determine to what degree a discharge will, prior to remining and from natural processes, exceed a set of simulated effluent standards (SES) for acidity, iron, and sulfate loads established for 6, 9, and 12 month sampling periods and varying sampling frequencies. The background data were analyzed using the system presently employed by the Pennsylvania Department of Environmental Resources (PADER). Acidity and iron were used in this study because they are mandated effluent parameters under the Pennsylvania remining program. Sulfate was included because it is a relatively conservative indicator of acid mine drainage production. Sulfate is affected little by geochemical changes to the mine water and remains in solution to relatively high concentrations, governed primarily by the solubility of gypsum ($CaSO_4*2H_2O$).

The sampling frequency ranged from less than 1 to 4 samples per month. The SES were established using the PADER system to characterize the discharges. The study required that each discharge have a minimum of one year of monitoring data following the interval used to create the SES discharge standards and before the start of remining activities. In other words, if the SES is calculated for a 12 month sampling period, at least 24 months of preactivation data were required. The time interval between the SES calculation and site activation was used as a test period to determine how often a discharge will naturally initiate treatment using the first two triggering methods of the PADER using the SES. The methodology of the second triggering method not only permits determination that the test period significantly exceeds the SES, which triggers treatment, it also permits the determination that the test period is significantly below the SES standard. If the test period is significantly below the SES standard, this indicates that SES may have overestimated the contaminant load. Table 2 summarizes the data used to create the SES and the post SES-test period.

Table 2. Summary of test site and discharge data.

	Simulated Effluent Standard Period		
	6 Month	9 Month	12 Month
	Number of Samples used in the SES Calculations		
Mean	7.5	13.0	18.0
High	13.0	24.0	31.0
Low	2.0	6.0	6.0
	Number of Samples for the Post SES Testing Period		
Mean	36.0	40.0	35.0
High	114.0	107.0	101.0
Low	6.0	9.0	8.0
	Number of Months the Post SES Samples were Taken Over		
Mean	28.0	31.0	27.0
High	80.0	77.0	74.0
Low	12.0	12.0	12.0
	Number of Discharges that the SES was Calculated on		
	115	81	78

This study was divided into two parts. The data were first analyzed to determine the optimum sampling duration. One year was considered the maximum acceptable sampling period to the mining industry, because of increased permitting time and sampling expenses. Second, the data were analyzed to ascertain the frequency that would accurately characterize the pollutant load. The 6, 9, and 12 month sampling period data were divided into subgroups based on the number of samples collected in that interval. The two parts of this study were analyzed separately using the first two triggering methods of the PADER system.

5 DURATION ADEQUACY

The discharge data were analyzed to determine if treatment would be initiated if the SES were the actual permit baseline loading standard and the time interval between the SES establishment and actual site activation (a hypothetical period of mining activity) was the test period. Additionally, using the second PADER triggering method, the discharge data were analyzed to determine if the SES overestimated the baseline contaminant load. In theory, the longer the sampling period for the SES determination, the more accurate the characterization of the discharge should be. This is because the longest sampling interval should have the most samples (increasing the statistical validity) and includes both high and low flow periods in the characterization.

Table 3, using acid load, illustrates that with increased sampling time for the SES, the potential for treatment initiation decreased. At the 6 month sampling period, acidity loads from 37% of the discharges would initiate treatment using the first triggering method of the PADER. At 12 months, the number triggering treatment decreased to 20%. Similar trends were observed for iron and sulfate loads (Table 3).

The results of the first PADER triggering method indicate that the 12 month baseline sampling period best characterizes baseline pollution load of acidity, iron, and sulfate. This trend appears to be because the 12 month sampling interval generally included high and low flow periods. As the length of the SES is increased in 3 month increments, the length of the subsequent test period is reduced by an equal amount by default. It is possible that some of the observed decrease in triggering with increased sampling interval

Table 3.—Summary of the optimum sampling duration determination. All values are the percent of discharges using the first PADER triggering system.

	6	9	12
Pennsylvania Triggering System One			
Acidity			
Exceeded SES	37	33	20
Within SES	63	67	80
Iron			
Exceeded SES	27	22	19
Within SES	73	78	81
Sulfate			
Exceeded SES	41	35	27
Within SES	59	65	73
Pennsylvania Triggering System Two			
Acidity			
Exceeded SES	18	17	18
Within SES	68	75	76
Below SES	14	8	6
Iron			
Exceeded SES	16	18	17
Within SES	75	78	74
Below SES	9	4	9
Sulfate			
Exceeded SES	24	31	24
Within SES	65	61	67
Below SES	11	8	9

length is partially related to this shortening of the test period. However, a review of the data indicates that this effect was small. The mean test period length for the SES periods was over 2 years (table 2).

Increasing the number of samples within the sampling period does not significantly decrease the number of discharges initiating treatment, if sampling is not performed on a time-consistent basis. In fact, discharges that have 23 or more samples most often triggered treatment. Similar trends are exhibited by the 6 and 9 month sampling periods. The Frequency Adequacy section will present a detailed discussion of this aspect. However, this may be related to the narrowing of the confidence limits around the median resulting from an increase in the number of samples (n).

Table 3 illustrates that the acidity load of nearly a fifth of the discharges (18%) would trigger treatment at the 6 month sampling interval using the second PADER method. This number changed very little when the sampling interval was increased to 9 (17%) and then 12 (18%) months. The number of discharges where iron load triggered treatment with the second method was 16% for the 6 month sampling interval and changed little at the 9 or 12 month sampling level (table 3). Sulfate load triggered treatment 24% of the time for the 6 and 12 month sampling intervals (table 3), while being slightly higher (31%) at the 9 month interval.

With the second triggering method, the number of discharges with contaminant loads that were significantly below the SES were generally lower than the number exhibiting loads that were above. This is related, to some extent, to the precipitation and subsequent recharge during the SES period and test period. However, the large data base (115 discharges) and the lengthy period (11 years), over which the testing occurred, should minimize any potential bias. Acidity load exhibited a decreasing number of discharges that were significantly below the SES as the sampling period was increased. Iron and sulfate loads showed no definite trends with increased sampling period length.

Using the second triggering method of the PADER, it is somewhat inconclusive as to which of the SES sampling intervals best characterizes the mine discharges. However, the results generally do not contradict the results obtained using the first triggering method. Acidity and sulfate loads were within the SES for the most discharges at the 12 months sampling level. Iron, on the other hand, changed very little regardless of the sampling interval. The number of discharges exceeding the SES with the second triggering method were in all cases less than the first. Approximately a fifth of the acidity loads, 17% of the iron loads, and 26% of the sulfate loads (if sulfate was an effluent parameter) from the discharges would falsely initiate treatment using the second method.

6 FREQUENCY ADEQUACY

To determine an adequate sampling frequency, each of the SES periods was divided into four subgroups based on the number of samples collected. The SES periods were divided into nearly equal subgroup sizes and so that one of the subgroups for each period would have the number of samples collected equal the number of collection months (i.e. an average of a sample per month). As with the duration analysis, the frequency data were analyzed using the first two triggering methods of the PADER.

The frequency data for the first triggering method is summarized in table 4. The results illustrate that at the 6 month SES level there is little difference between the number of samples taken and initiation of treatment for either acidity or iron loads. However, sulfate (if it were an effluent standard) appears to have the potential to increase triggering with increasing sample size.

At the 9 month SES level, treatment triggering by acidity, iron, and sulfate loads occurred for the least number of discharges in the 13-17 sample

Table 4.—Summary of frequency adequacy data from the first PADER triggering mechanism. All values are in percent.

6 Months	Number of Samples	<6	6	7-10	>10
Acidity	Treatment	38	33	40	37
	No Treatment	62	67	60	63
Iron	Treatment	27	25	23	33
	No Treatment	73	75	77	67
Sulfate	Treatment	27	42	50	48
	No Treatment	73	58	50	52
9 Months	Number of Samples	<10	10-12	13-17	>17
Acidity	Treatment	43	29	24	38
	No Treatment	57	71	76	62
Iron	Treatment	22	29	12	31
	No Treatment	78	71	88	69
Sulfate	Treatment	30	41	24	50
	No Treatment	70	59	76	50
12 Months	Number of Samples	<13	13-17	18-23	>23
Acidity	Treatment	25	17	8	40
	No Treatment	75	83	92	60
Iron	Treatment	25	13	12	33
	No Treatment	75	87	88	67
Sulfate	Treatment	23	26	17	47
	No Treatment	77	74	83	53

range (24%). The next lowest number of discharges triggering treatment were the 10-12 range for acidity load and the <10 level for iron and sulfate load. No definite trends are exhibited at the 9 month SES level as the sample set size changes.

The 18-23 sample size range at the 12 month SES level exhibited the least number of discharges triggering treatment (under 20%) for all three pollutants. However, the triggering levels for the 13-17 range and the <13 level were similar, roughly 25% or less. The >23 level exhibited the highest triggering rate (one third or more) for all three pollutants, indicating that larger sample set sizes the in this case did not accurately characterize mine discharges. This may be caused by a narrowing of the confidence limits about the median as the number of samples increases. Another explanation is that the >23 level, in some cases, had an inconsistent sampling frequency, which permitted unequal weighting of wet or dry periods.

The results of triggering based on the second PADER method differ somewhat from that of the first triggering method. The least number of triggering events for the three pollutants occurred mainly in the smallest sample set sizes (<6, <10, and <13) for each of the three SES periods (Table 5). However at the 6 month SES, the results for the 6 sample size are similar to the <6 sample size. This could be related to the broad confidence interval about the median with decreasing size of the test period data set.

The results for the number of discharges below the SES levels using the second method is somewhat inconsistent for the three sampling intervals. For the 6 month SES, the 6 sample set size yielded the least number of discharges below the iron and sulfate SES. However, for acidity, the lowest number of excursions below the SES was in the 7-10 sample set size for the 6 month SES. On the other hand, the 9 and 12 month sampling intervals exhibited the least number of excursions below the SES for acidity, iron, and sulfate loads in the higher sample set sizes for each sample interval.

The results from the second triggering method, although somewhat mixed, appear to indicate that sampling on a consistent monthly basis may be optimal. At the 6 month SES period, the lowest number of excursions above or below the SES for acidity, iron, and sulfate were in the <6 and 6 sample sizes. The least number of excursions occurred in the smallest sample set sizes for 9 and 12 month SES periods, which are primarily composed of sample sets where a sample per month was taken. Furthermore, the highest number of discharges that were within the SES standards at all levels occurred when the sampling interval averaged once per month (Table 5).

It is probable that sampling twice or 4 times per month at a consistent time interval will yield better results. There were an insufficient number of discharges where the sampling was 2 or 4 times per month to yield conclusive results. However, given the good results when sampling once per month, it may not be cost effective to increase the frequency to gain a slight advantage in discharge characterization.

This triggering method indicates that sampling on a consistent basis yields the best characterization of the discharges. This method should avoid overemphasizing either a wet or dry period. This is especially true if the sampling is performed over a complete water year. The results of the first triggering method, although somewhat dissimilar, do not contradict this assertion. In either case, the highest sampling frequency did not yield the best characterization results. This may be because the highest sampling frequency can allow unequal sampling during a wet or dry period, thus biasing the data.

Table 5.—Summary of frequency adequacy data from the second PADER triggering mechanism. All values are in percent.

6 Months	Number of Samples	<6	6	7-10	>10
Acidity	Exceeded SES	3	12	30	30
	Within SES	82	71	60	55
	Below SES	15	17	10	15
Iron	Exceeded SES	6	4	33	19
	Within SES	82	96	57	70
	Below SES	12	0	10	11
Sulfate	Exceeded SES	10	17	40	27
	Within SES	73	75	50	65
	Below SES	17	8	10	8

9 Months	Number of Samples	<10	10-12	13-17	>17
Acidity	Exceeded SES	8	23	13	31
	Within SES	84	65	83	63
	Below SES	8	12	4	6
Iron	Exceeded SES	13	23	13	31
	Within SES	83	71	83	69
	Below SES	4	6	4	0
Sulfate	Exceeded SES	19	47	29	31
	Within SES	72	41	67	63
	Below SES	9	12	4	6

12 Months	Number of Samples	<13	13-17	18-23	>23
Acidity	Exceeded SES	13	22	8	33
	Within SES	67	69	92	67
	Below SES	20	9	0	0
Iron	Exceeded SES	20	13	16	20
	Within SES	67	74	76	80
	Below SES	13	13	8	0
Sulfate	Exceeded SES	8	22	28	33
	Within SES	75	61	72	60
	Below SES	17	17	0	7

7 SUMMARY AND CONCLUSIONS

The testing results indicate that the optimum sampling duration of the three intervals analyzed (6, 9, and 12 months) is a complete year. With an entire year's worth of data, both low and high flow periods will be included in the discharge characterization. Time-consistent sampling should prevent either of these periods from being overemphasized. It is probable that sampling for 2 or 3 years will yield a better characterization, but this may not be a economically feasible option.

Determination of the optimum sampling frequency illustrates consistently that the highest number of samples for each SES was not the best characterization of the discharges. The results using the two triggering methods exhibited some dissimilarities. However, a consistent sampling frequency on a monthly basis appears to adequately characterize the pollution load. If cost is not a consideration, a bimonthly rate should be at least as good as a monthly rate, if the sampling is consistent with regard to time (e.g. samples collected at the first and third monday of the month). If the sampling is conducted without respect to a consistent time interval, increasing the number of samples may not improve the discharge characterization.

ACKNOWLEDGEMENTS

The author is indebted to Keith B.C. Brady and Michael W. Smith of the Pennsylvania Department of Environmental Resources and Liane Kadnuck and Frank Lanzetta of the U.S. Bureau of Mines for their critical review and discussion of the manuscript.

REFERENCES

Hawkins, J.W. 1993a. Statistical Characteristics of Coal-Mine Discharges on Western Pennsylvania Remining Sites. Water Resources Bulletin. 30(5):861-869.

Hawkins, J.W. 1993b. The Effectiveness of Remining of Abandoned Coal Mines to Reduce the Effluent Contaminant Load. International Journal of Surface Mining, Reclamation and Environment. 8:101-109.

Pennsylvania Bulletin, June 29, 1985, pp. 2377-2389.

Pennsylvania Department of Environmental Resources, The Pennsylvania State University, Kohlmann Ruggiero Engineers, 1988. REMINE.

Smith, M.W. 1988. Establishing Baseline Pollution Load From Preexisting Pollutional Discharges for Remining in Pennsylvania. In Proceedings: 1988 Mine Drainage and Surface Mine Reclamation Conference Vol. II: Mine Reclamation, Abandoned Mine Lands and Policy Issues. U.S. Bureau of Mines IC 9184. Pittsburgh PA:311-318.

Tukey, J.W., 1977. Exploratory Data Analysis. Addison-Wesley Publishing Co. Reading, MA.

Velleman, P.F. and D.C. Hoaglin, 1981. Applications, Basics, and Computing of Exploratory Data Analysis. Duxbury Press, Wadsworth, Inc., Belmont CA.