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

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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 temporal reclamation requirements of 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 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 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.

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 10 to 66 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 mining sites. Skewness and chi-square testing on the flow, concentration, and loading data were performed, and it was observed that skewed data were mainly distributed and positively skewed. It was noted 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 re-mining 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 load rates are set during the re-mining permit application. A minimum of 6 monthly samples are required to perform these calculations, although 12 consecutive monthly samples are 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 acidity, iron, sulfate, 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) at a standard unit. 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).

When statistical analysis indicates the duration- or post-remining median pollutant load has been increased in comparison to the pre-remining median at the 95% 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 (item 5, Table 1) 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 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 re-mining permitting.

<table>
<thead>
<tr>
<th>Mine ID:</th>
<th>Mine Name:</th>
<th>Hydrologic Unit ID:</th>
</tr>
</thead>
<tbody>
<tr>
<td>FLOW (gpm)</td>
<td>ACIDITY</td>
<td>IRON</td>
</tr>
<tr>
<td>1. RANGE</td>
<td>LOW</td>
<td>HIGH</td>
</tr>
<tr>
<td>2. MEDIAN</td>
<td>LOW</td>
<td>HIGH</td>
</tr>
<tr>
<td>3. QUANTILES</td>
<td>LOW</td>
<td>HIGH</td>
</tr>
<tr>
<td>4. APPROXIMATE 95%</td>
<td>LOW</td>
<td>HIGH</td>
</tr>
<tr>
<td>5. 95% CONFIDENCE INT.</td>
<td>LOW</td>
<td>HIGH</td>
</tr>
</tbody>
</table>

* 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 reason the 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 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).

Stratigraphically, these operations include remining from the Pottsville Group (Hercy coal) up through the Monongahela Group (Redstone coal). These 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 methodology employed by the Pennsylvania Department of Environmental Resources (PADER). Acidity and iron were used in this study because they are 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\(_2\)O).

The sampling frequency ranged from less than 1 to 4 samples per month. The SES were established using the PADER system to characterize the discharge. The study required that each discharge have a minimum of one year of monitoring data for use in calculating the baseline pollution load for the period used to establish 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 required 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 mechanisms of the PADER system. The methodology of the second triggering method not only permits determination that the test period significantly exceeds thresholds, 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 test SES-test period.

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

<table>
<thead>
<tr>
<th></th>
<th>6</th>
<th>9</th>
<th>12</th>
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<tbody>
<tr>
<td>Pennsylvania Triggering System One</td>
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<td><strong>Acidity</strong></td>
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<tr>
<td>Exceeded SES</td>
<td>37</td>
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<td>Within SES</td>
<td>63</td>
<td>57</td>
<td>80</td>
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<tr>
<td><strong>Iron</strong></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Exceeded SES</td>
<td>27</td>
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<td>Within SES</td>
<td>73</td>
<td>78</td>
<td>81</td>
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<tr>
<td><strong>Sulfate</strong></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Exceeded SES</td>
<td>41</td>
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<tr>
<td>Within SES</td>
<td>59</td>
<td>65</td>
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Pennsylvania Triggering System Two
<p>| | | | |</p>
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<td>Within SES</td>
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<td>75</td>
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<td>14</td>
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<td>6</td>
</tr>
<tr>
<td><strong>Iron</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Exceeded SES</td>
<td>16</td>
<td>18</td>
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</tr>
<tr>
<td>Within SES</td>
<td>75</td>
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<td>74</td>
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<tr>
<td>Below SES</td>
<td>9</td>
<td>4</td>
<td>9</td>
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<tr>
<td><strong>Sulfate</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Exceeded SES</td>
<td>24</td>
<td>31</td>
<td>24</td>
</tr>
<tr>
<td>Within SES</td>
<td>65</td>
<td>61</td>
<td>67</td>
</tr>
<tr>
<td>Below SES</td>
<td>11</td>
<td>8</td>
<td>9</td>
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</table>

As the sampling interval 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 period. 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 indicate 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 length. 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.

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

<table>
<thead>
<tr>
<th></th>
<th>6 Months</th>
<th>9 Months</th>
<th>12 Months</th>
</tr>
</thead>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Treatment</td>
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<td>38</td>
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<td>27</td>
<td>23</td>
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</tr>
<tr>
<td>No Treatment</td>
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<tr>
<td>No Treatment</td>
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<tr>
<td>No Treatment</td>
<td>73</td>
<td>50</td>
<td>52</td>
</tr>
<tr>
<td><strong>Iron</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Treatment</td>
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<td>13-17</td>
<td>&gt;17</td>
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<td>No Treatment</td>
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<td>No Treatment</td>
<td>70</td>
<td>76</td>
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<td><strong>Sulfate</strong></td>
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<td></td>
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<tr>
<td>Treatment</td>
<td>&lt;13</td>
<td>18-23</td>
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<td>83</td>
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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 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 larger 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 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. It 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.

### 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.

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

<table>
<thead>
<tr>
<th>Months</th>
<th>Number of Samples</th>
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<th>7-10</th>
<th>&gt;10</th>
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<td>30</td>
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<tr>
<td>Within SES</td>
<td>82</td>
<td>71</td>
<td>60</td>
<td>55</td>
<td></td>
</tr>
<tr>
<td>Below SES</td>
<td>15</td>
<td>17</td>
<td>60</td>
<td>15</td>
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<tr>
<td>Iron</td>
<td>Exceeded SES</td>
<td>6</td>
<td>4</td>
<td>33</td>
<td>19</td>
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<tr>
<td>Within SES</td>
<td>82</td>
<td>96</td>
<td>57</td>
<td>70</td>
<td></td>
</tr>
<tr>
<td>Below SES</td>
<td>12</td>
<td>0</td>
<td>10</td>
<td>11</td>
<td></td>
</tr>
<tr>
<td>Sulfate</td>
<td>Exceeded SES</td>
<td>10</td>
<td>17</td>
<td>40</td>
<td>27</td>
</tr>
<tr>
<td>Within SES</td>
<td>73</td>
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<td>8</td>
<td>10</td>
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</tbody>
</table>

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.

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