Modifying Root-Zone Spoil Sampling Methods Using Vertical and Horizontal Composite Sampling Techniques[1]

C. Kent Applegate[2], Bruce A. Buchanan and Robert Postle

Abstract: Historically BHP Navajo Coal Company sampled regraded spoil on 330-foot centers (one sample/2.5 acres). Samples were collected from the center of each plot and analysis performed in 1-foot increments (0-1, 1-2, 2-3 and 3-4 foot) to a depth of 4 feet. In 1999 Navajo Mine proposed to revise the sampling procedures to collect spoil from the 0-1 foot interval and a single composite sample of the 1-4 foot interval. Navajo Mine also proposed to horizontally composite material from four equally spaced pits within the 2.5-acre sample plot. To support the proposal to vertically composite the 1-4 foot interval multifactor analysis of variance (MANOVA) was performed to determine if there were significant differences between the three intervals (1-2, 2-3, and 3-4) for the five parameters of concern, pH, electrical conductivity, sodium adsorption ratio, saturation percentage, and % clay. The MANOVA was performed using 6,784 individual one foot spoil samples from 1,697 sample pits collected at the mine between 1990-1998. Results of the MANOVA showed that for all parameters except % clay there were no significant difference between sample intervals. The significant differences in percent clay were determined to not be important biologically. The lack of significant statistical differences (except clay) in the means of specific parameters over the three intervals verified that the three intervals could be composited into a single sample. Simple linear regression was used to demonstrate the strength of the relationship between the three sampling intervals for the five parameters of interest. Regression models on all parameters were highly significant (0.0001). The coefficient of determination (R^2) ranged from 0.41 to 0.76. The results of the statistical analysis supported Navajo Mine's proposal to implement vertical compositing of the 0-4 foot interval. Horizontal compositing was determined to provide a more representative sample of the entire 2.5-acre plot. Therefore, OSM approved the modified sampling procedures. Modifications in spoil sampling methods have resulted in significant reductions in mitigation material required to achieve a suitable four-foot root-zone.

Additional Key Words: Spoil sampling, compositing,

Introduction

Site

Navajo Mine is a 20,000 acres surface coal mine operated by BHP Navajo Coal Company. It is located on the Navajo Nation Reservation in Northwestern New Mexico. Mining began in 1963. The mine supplies eight million tons of coal annually to the Four Corners Generating Station. After the enactment of SMCRA in1977 the mine was issued its first Permanent Program permit in 1989. As a result the mine is a combination of Pre-Law (Pre-SMCRA), Interim Program (1977 - 1989) and Permanent Program (post 1989) lands.

Problem

The mine is required to create and document a four-foot suitable root-zone on all interim and permanent program lands prior to seeding. Historically, the mine sampled regraded spoil on 330 foot centers (one sample per 2.5 acres) in 1 foot increments to a depth of 4 feet. The average volume of spoil per acre mitigated was 38% (2,500 cubic yards per acre). Mine personnel have generally believed that this sampling method resulted in excessive mitigation. It was believed that if a more representative method of sampling spoil could be justified, mitigation rate would be substantially reduced.

Proposed Change

In 1999, changes in spoil sampling methods were submitted to the Office of Surface Mining (OSM) for review and approval. These changes employed a

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combination of vertical and horizontal compositing sampling techniques. Navajo Mine proposed to use the same 2.5-acre sample plot. However, rather than collect one sample from the center of each plot, subsamples would be collected from four pits evenly distributed over the 2.5-acre plot and composited. The 0-1 foot interval would continue to be sampled independently but the 1-2, 2-3 and 3-4 foot intervals would be vertically composited into one (1-4 foot) sample. The justification for compositing the lower 3 feet of the root-zone is based on a statistical evaluation of historic root-zone data collected at Navajo Mine.

Methods

Historic Data

Between 1990 and 1998 Navajo Mine analyzed 6,784 individual one foot spoil samples for root-zone suitability. These samples were collected from 1,697 sample pits to a depth of four feet in one-foot intervals. Samples were collected from regraded areas and do not include post-mitigation sampling. Samples sites were distributed over the entire area of the mine. All samples were analyzed for nine chemical and physical parameters: Sodium Absorption Ratio (SAR), pH, Electrical Conductivity (EC), Acid-Base Accounting ($CaCO_3$)(Page et al., 1983), Saturation percent (SAT %)(Richards 1954), percent clay, Boron (Page et al., 1983), Total and Soluble Selenium (Bajo 1978).

BHP and OSM agreed, prior to any analysis, that if there were no statistically significant differences in mean values between the 1-2, 2-3 and 3-4 foot intervals for key parameters, then there would be sufficient justification to composite the three samples into one composite sample. OSM personnel were consulted to help identify which of the nine root-zone suitability parameters would be appropriate to use in statistical evaluations. The parameters selected were SAR, pH, EC, SAT % and percent clay (% clay). These parameters were selected because they were considered to have the greatest influenec on vegetation establishment and sustainability at Navajo Mine. Statistical evaluations were performed on these five parameters.

Statistical Analysis

Two statistical tests (MANOVA and Simple linear regression) were performed on sample data. MANOVA (SAS Institute 1989) was performed to determine if a significant difference (α = 0.05) existed between the mean values of the 1-2, 2-3 and 3-4 foot sampling intervals. MANOVA was run for each of the five selected parameters (pH, EC, SAR, SAT % and % clay). The MANOVA model was used to measure the influence of two factors, the variation between individual sample pit locations (between pit variation) and variation associated between the three individual sample intervals, simultaneously. Simple linear regressions were performed to determine the ability to predict a parameter value for a given sample depth interval based on parameter value from another interval. Three models based on sample depth were developed for each of the five parameters as follows:

Independent	Dependent
1-2feet	2-3feet
1-2feet	3-4feet
2-3feet	3-4feet

Results

Summary statistics are presented for the 1,697 samples by sampling interval and by parameter in Table 1. Based on skewness and kurtosis, the data for each parameter and depth interval generally exhibit relatively normal distributions. Two of the parameters have extreme values on the both high end for the 3-4 foot increment. EC and SAR are skewed to the right by a few higher values. The pH was slightly affected by a few extreme values on the lower end.

MANOVA

The MANOVA model (two-factor analysis) was developed to separate the variability between the sample pit locations (i.e., each pit is a location) from the variability between the three sample intervals within a pit. Samples were collected throughout the mine. There is expected to be variability between sample pits when data is collected from a large sampling area. If the model failed to account for the location variability, this variability would automatically be lumped into the error term, which would make it harder to detect a significant difference between sampling intervals. The model separates these two sources of variability, thus the analysis is more sensitive to detecting small differences between sample intervals. Separating the sources of variation results in a robust analysis and, consequently, when there is no significant difference between means, there is strong justification for compositing the three intervals.

The analysis showed there was a significant difference in sample locations (pit to pit variation) for all parameters, which was as expected. There was no significant difference between the sample intervals for all parameters, except % clay. Percent clay showed a significant difference with a p-value of 0.0002. Fisher's Least Significant Difference Test was used (Table 2) to determine which mean(s) were different.

TABLE 1. Summary statistics for 1,697 root-zone spoil samples taken at Navajo Mine between 1990 to 1998.

Percent Clay

	Sampling interval (ft)			
	0-1	*1-2*	*2-3*	*3-4*
Mean	32.90	32.45	32.41	32.01
Standard Error	0.19	0.21	0.21	0.22
Median	33.6	33.1	33.3	33.0
Standard Deviation	7.90	8.63	8.83	9.17
Sample Variance	62.48	74.41	77.91	84.17
Kurtosis	1.02	1.35	1.09	1.03
Skewness	-0.52	-0.65	-0.66	-0.71
Range	60.1	68	62	58.6
Minimum	0.9	0	0	0.4
Maximum	61	68	62	59

Sodium Absorption Ratio (SAR)

	Sampling interval (ft)			
	0-1	*1-2*	*2-3*	*3-4*
Mean	22.63	24.71	24.58	24.62
Standard Error	0.28	0.28	0.28	0.32
Median	24.1	25.6	25.7	25.4
Standard Deviation	11.74	11.64	11.54	13.32
Sample Variance	137.83	135.52	133.07	177.44
Kurtosis	-0.16	0.56	0.55	105.32
Skewness	0.02	0.16	0.15	5.19
Range	73.63	77.81	80.22	298.85
Minimum	0.37	0.39	0.38	0.15
Maximum	74	78.2	80.6	299

Saturation Percentage (SAT%)

	Sampling interval (ft)			
	0-1	*1-2*	*2-3*	*3-4*
Mean	64.20	64.02	64.31	63.94
Standard Error	0.48	0.49	0.51	0.50
Median	61.9	61.5	61.8	61.3
Standard Deviation	19.65	20.05	20.98	20.58
Sample Variance	386.30	402.10	440.34	423.46
Kurtosis	2.84	4.67	7.87	2.27
Skewness	1.04	1.30	1.53	1.03
Range	172.8	193.5	260.9	158.6
Minimum	19.2	16.5	16.1	9.4
Maximum	192	210	277	168

Electrical Conductivity (EC)

	Sampling interval (ft)			
	0-1	*1-2*	*2-3*	*3-4*
Mean	8.36	9.34	9.32	9.24
Standard Error	0.08	0.09	0.09	0.11
Median	8.54	9.32	9.28	9.19
Standard Deviation	3.24	3.78	3.86	4.42
Sample Variance	10.50	14.28	14.90	19.52
Kurtosis	1.17	7.19	7.23	85.34
Skewness	0.23	1.11	1.38	5.33
Range	25.53	43.35	37.85	93.61
Minimum	0.37	0.35	0.35	0.29
Maximum	25.9	43.7	38.2	93.9

PH	Sampling interval (ft)			
	0-1	*1-2*	*2-3*	*3-4*
Mean	7.12	7.07	7.07	7.06
Standard Error	0.02	0.02	0.02	0.02
Median	7.3	7.3	7.3	7.3
Standard Deviation	0.76	0.89	0.92	0.93
Sample Variance	0.57	0.79	0.85	0.87
Kurtosis	5.96	4.03	4.70	3.86
Skewness	-1.99	-1.75	-1.85	-1.65
Range	6.1	6.2	6.9	6.9
Minimum	2.8	3	2.2	2.3
Maximum	8.9	9.2	9.1	9.2

The results showed that the % clay in the 3-4feet interval was different. The three sample means for % clay are 1-2feet = 32.45, 2-3feet = 32.40 and 3-4feet = 32.00. Navajo Mine acknowledged there was a statistical difference for clay values at the 3-4feet interval. However, biologically, vegetation would not be affected by a 0.4% difference in % clay at the bottom of a four-foot root-zone. In addition, the error in laboratory analysis would be greater than 0.4% therefore, the difference is considered meaningless. Summaries of the ANOVA p-values are given in Table 2.

TABLE 2. ANOVA summary for all variables and Fisher's LSD results

Parameter	Type III SS	Mean Square	F Value	Probability > F
PH	0.19	0.09	0.53	0.586
EC	10.03	5.02	1.16	0.312
SAT	129.37	64.68	0.92	0.399
SAR	15.37	7.68	0.25	0.775
CLAY	202.34	101.17	8.35	0.0002

All Parameters have 2 degrees of freedom

Fisher's Least Significant Difference Results For % clay

Alpha = 0.05; df = 3392; MSE = 12.11; Critical T = 1.96; Least Significant Difference = 0.234

T Grouping	Mean	N	Depth
A	32.45	1697	1-2
A	32.40	1697	2-3
B	32.00	1697	3-4
Means with the same letter are not significantly different			

Regressions

Simple linear regression models were performed to demonstrate the strength of the relationship between the three sampling intervals for the five parameters of interest. A summary of all regression is given in Table 3. All models are positively correlated and highly significant (0.0001). The coefficient of determination (R^2) ranges from 0.412 to 0.768. This value measures the proportion or percent of the total variation of the dependent (Y) variable that can be explained by the independent (X) variable. It is important to note that all the regression slopes are approaching 1. This indicates that for every single unit change in the dependent variable there is nearly a single unit change in the dependent variable. The regression models evaluated were all highly significant and further support the justification to composite the lower three feet of root-zone material.

Discussion

Navajo Mine was able to demonstrate with the exception of % clay, that there is no statistical difference in collecting one 1-4 foot composite sample from collecting samples in individual one-foot increments. The statistical analysis demonstrated the validity of using vertical compositing techniques in spoil sampling methods at Navajo Mine. Based on the results of the statistical analysis for vertical compositing OSM approved the proposed spoil sampling method.

Navajo Mine first permit required than regraded spoil be sampled on a 330 foot centers. This sampling intensity results in one sample site per 2.5 acres. Samples were collected in 1-foot increments to a depth of 4 feet from the center of each sample plot. BHP changed the horizontal sampling by using the same 2.5-acre sample plot, however rather than collecting one initial sample from the center of the plot, subsamples are composited from 4 pits evenly distributed over the 2.5-acre plot. The justification for modifying the horizontal sampling method is to ensure a more representative sample of the entire 2.5-acre plot. OSM concurred with Navajo Mine's justification for horizontal compositing and approved the proposed spoil sampling method.

Economic Impacts of Sampling Changes

Historic spoil sampling (one sample per 2.5 acres) and Navajo Mine resulted in an average mitigation rate of 38% (2,452 cubic yards per acre) by volume per acre. In 1997 the sampling methods were modified to allow additional sampling within the 2.5 acres plot which would further delineate the extent of unsuitable material. These sampling changes resulted in an average mitigation rate of 25% (1606 cubic yards per acre) per acre. Vertical and horizontal composite sampling changes were approved in October 1999. Since then 154 sample locations (2.5 acre plots) have be collected and analyzed representing 385 acres.

TABLE 3. Summary of all regression models for all parameters

Parameter	Model		Regression Equation	R^2	Significance F
	Dependent	Independent			
pH	1-2	2-3	Y=1.53+0.78x	0.655	0.0001
	1-2	3-4	Y=2.31+0.67x	0.500	0.0001
	2-3	3-4	Y=1.22+0.83x	0.709	0.0001
EC	1-2	2-3	Y=2.01+0.79x	0.645	0.0001
	1-2	3-4	Y=4.26+0.55x	0.412	0.0001
	2-3	3-4	Y=3.02+0.68x	0.607	0.0001
SAT %	1-2	2-3	Y=10.76+0.83x	0.751	0.0001
	1-2	3-4	Y=15.41+0.76x	0.608	0.0001
	2-3	3-4	Y=8.74+0.87x	0.726	0.0001
SAR	1-2	2-3	Y=2.98+0.88x	0.767	0.0001
	1-2	3-4	Y=8.74+0.65x	0.550	0.0001
	2-3	3-4	Y=7.53+0.69x	0.639	0.0001
% Clay	1-2	2-3	Y=4.95+0.85x	0.754	0.0001
	1-2	3-4	Y=8.47+0.75x	0.634	0.0001
	2-3	3-4	Y=5.41+0.84x	0.768	0.0001

Of the 154 samples analyzed, 3 sites were unsuitable for one or more parameters. The average volume of spoil per acre mitigated is 2.1% (136 cubic yards per acre).

Ecological Impacts of Sampling Changes

One concern is that the reduction in mitigation material applied to reclaim areas could have a negative impact on the success of vegetation establishment and persistence. Navajo Mine believes the reduction of mitigation will not impact the success of revegetation for the following reasons.

Between 1975 and 1998, the mine has revegetated 3,500 acres of Pre-Law (pre-SMCRA) land that have received little or no mitigation. These pre-law areas, which received topdressing (topsoil), have no perceptible difference in vegetative cover or production compared to areas where mitigation occurred. There are some differences in the species diversity of the area, but these differences are believed to be the results of slight changes in cultural practices (seed mixtures, rate, irrigation) and quality of the seed used over time.

During the years when one sample was collected from the center of a 2.5-acre plot, 60% of the plots sampled received no mitigation. These areas surely had a portion of the 2.5 acres where spoil quality was unsuitable but received no mitigation. The revegatation in these areas show no signs of patchy or unusual failures that might be expected if areas were not mitigated sufficiently.

The native species used in reclamation have been documented to grow on non-mined areas, which have a broader range of physical and chemical than generally occurs in spoils at the mine.

Navajo mine is confident that the reduction in mitigation rates because of recent changes in sampling methods pose no adverse potential to revegetation success. The amount of historic mitigation was unnecessary.

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