ACID-BASE ACCOUNTING (ABA) – WORKED EXAMPLES

This guidance document discusses acid-base accounting (ABA) and provides worked examples of borehole ABA and the addition of supplemental alkaline material (SAM) as listed in Table 1. The worked examples are to be used in conjunction with Publication 293, Chapter 10 – Acid-Producing Rock.

Table 1 – Worked Examples

Example Type	No.	Example Case
Borehole ABA	1	Discrete horizontal rock layers of high-NP and high-MPA materials
	2	Interbedded horizontal rock layers of high-MPA and high-NP materials
	3	Horizontal layers of less definitive MPA and NP materials
	4	Cut through steeply dipping rock strata striking perpendicular to the roadway
	5	Cut through steeply dipping rock strata striking parallel to the roadway
SAM Addition	6	Uniform rock type assuming all materials can adequately be blended
	7	Multiple rock types assuming all materials can be adequately blended
	8	Multiple rock types assuming high-MPA materials are managed separately
	9	Alternative approach based on thorough characterization of a rock mass

1.0 ABA Calculations

The premise of acid-base accounting is that the ability for material at a given location to produce excessive acid or alkaline drainage can be predicted by determining the total amount of acidity and alkalinity that the various rock layers have the potential to produce. Calculations for the accounting process are managed well with a spreadsheet. ABR testing data from the gINT Project file can be viewed using the Output/Fences tab and the PennDOT Acid Bearing Rock Fence Report, using the Output/Graphic Table tab and the PennDOT Lab Summary Acid Bearing Rock report. The ABR data can be exported to a spreadsheet using the Output/Test table PennDOT Rock Test Summary report.

For a more thorough description of ABA procedures, refer to Coal Mine Drainage Prediction and Pollution Prevention in Pennsylvania and Evaluation of Acid Base Accounting Using Computer Spreadsheets.

2.0 Specification and Payment of Supplemental Alkaline Material (SAM)

The Calcium Carbonate Equivalent (CCE) of alkaline material is directly related to its purity. Pure calcite, ($CaCO_3$) has a CCE value of 100 percent whereas pure dolomite ($CaMg(CO_3)_2$ has a CCE of 109 percent. The quality of aglime sold in Pennsylvania is regulated by state law, and Agricultural Liming Materials Rules and Regulations require product labels to state the minimum CCE value of the aglime material. The CCE of commonly available aglime materials are shown in Table 2.

Table 2– Chemical Composition and % CCE of Common Aglime Materials

Alkaline Material Type	Chemical Formula	% CCE
Pure calcitic limestone	$CaCO_3$	100
Dolomitic limestone	$CaMg(CO_3)_2$	109
Calcium oxide; lime, burnt, lump, or unslaked lime; quicklime	CaO	179
Calcium hydroxide; hydrated, slaked, or builders' lime	$Ca(OH)_2$	136

The three sizes of agronomic liming materials recognized in Pennsylvania are shown in Table 3. Alkaline materials are generally more reactive when crushed or pulverized to a finer particle size; however, reactivity rate does not increase greatly for particle sizes smaller than 100 mesh. Although dolomitic limestone reacts more slowly than calcitic limestone, when ground to the required fineness, relatively little difference exists in the reaction time of the two materials. Mixing aglime with coarser limestone aggregate (2A) to limit migration of the SAM is permitted as discussed in Chapter 10 – Acid-Producing Rock, Section 10.9.1.1 Alkaline Addition.

Table 3 – Fineness of Aglime Materials

Fineness Classification	Percent Passing through Sieve		
	20-Mesh Sieve	60-Mesh Sieve	100-Mesh Sieve
Fine-sized Materials	95	60	50
Medium-sized Materials	90	50	30
Coarse-sized Materials	All liming materials failing to meet one of the above minimums for fineness		

Agricultural Liming Materials Rules and Regulations require the product label to state the maximum moisture content by weight of the material. The following worked examples assume neutralization by addition of calcitic lime $CaCO_3$ having a moisture content of 15 percent. The CCE adjusted for moisture content ($\%CCE_{ma}$) is:

$$\%CCE_{ma} = \frac{100 - \%moisture}{100} \times \%CCE$$

Using calcitic limestone having a CCE of 100 percent and a moisture content of 15 percent, the CCE adjusted for moisture content is:

$$\%CCE_{ma} = \frac{100 - 15}{100} \times 100 = 85\%$$

Thus, the following worked examples assume addition of calcitic lime with a CCE_{ma} value of 85 percent. Other forms of alkaline material can be used for neutralization based on cost and local availability.

The contract provisions must specify the $CaCO_3$ equivalency value and assumed moisture content used in determining alkalinity addition rates. The contractor must recalculate alkalinity addition rates if materials with lower $CaCO_3$ equivalency values and/or higher moisture contents are used during construction. The tonnage payment for SAM used in construction must also consider the CCE_{ma} value of the material used. For example:

A contract requires 1,000 tons of SAM having CCE_{ma} = 85%. The contractor bids $20.00/ton for this item, and supplies/uses a SAM having a CCE_{ma} = 80%. This is permitted, but the tonnage and payment will need to be adjusted. The required tonnage of the lower-quality SAM is: 1,000 tons x (85/80) = 1062.5 tons. Although the actual tonnage used in this case must be greater than planned quantity, the required neutralizing capacity is equal, and must be reflected in the unit payment, as follows:

1,062.5 tons was the minimum required. 1,080 tons was actually used. The correct payment would be: 1,080 tons x (80/85) x $20/ton = $20,329.41.

3.0 Worked Examples for Borehole ABA and Alkaline Addition

When evaluating the possible treatment requirements of the site materials, it is necessary to anticipate how the materials can be excavated. In particular, excavations that must be blasted using pre-split methods are limited to lift heights of 30 feet in accordance with Publication 408, Section 207.3. Therefore, to assure constructability and reasonable material management, the ABA assessment should consider material in increments (excavation lift thicknesses) no greater than 30 feet.

For the examples shown in this section, a weighted Neutralization Potential (NP_W) represents the Neutralization Potential (NP) for each sample increment within a managed zone. NP_W is in units of parts per thousand (ppt) $CaCO_3$ equivalent (CCE), and is determined by multiplying the NP of a sample by the proportion of the lift thickness represented by the sample.

$$NP_w = \frac{(NP\ of\ Sample)(Increment\ Thickness)}{Lift\ Thickness}$$

Summing the NP_W values for the number of samples (N_S) within the anticipated lift thickness yields the NP of the entire anticipated lift.

$$NP_{Lift} = \sum_{i=1}^{N_S} NP_W$$

In a similar manner, a weighted Maximum Potential Acidity (MPA_W) is calculated for each sample increment within the anticipated lift.

$$MPA_w = \frac{(MPA\ of\ Sample)(Increment\ Thickness)}{Lift\ Thickness}$$

Summing the MPA_W values for the number of samples (N_S) within the anticipated lift thickness yields the MPA of the entire anticipated lift.

$$MPA_{Lift} = \sum_{i=1}^{N_S} MPA_W$$

For simplification, the borehole ABA examples shown assume flat-bedded geology (minimal dip), with the horizontal extent of each increment being equal. With these assumed conditions, the increment thickness is directly proportional to the increment volume. This will not usually be the case. The actual excavation geometry and depositional geometry of the rock strata need to be considered when calculating excavation volumes. Each project will differ. Worked examples 4, and 5 provide examples where the strata are not horizontal.

The chemistry of adjacent borings should also be compared carefully. When ABA chemistry of adjacent holes differs, judgment should be applied to extrapolate horizontal trends. In some cases, additional testing may be needed if initial test data is not sufficiently conclusive.

For the alkaline addition examples, the rock material and supplemental alkaline material (SAM) is assumed to be well-blended and uniform. If well blending and uniformity cannot be assured, consideration should be given to applying a higher factor of safety to the alkalinity addition calculation.

IMPORTANT NOTES about the following Worked Examples:

Borehole ABA (Examples Nos. 1, 2, and 3):
It should be understood that each of the borehole ABA examples shown in this section calculate the ABA for only one borehole. A complete site ABA would involve multiple borings, with the appropriate volume of excavation assigned to each hole. The geometry of the planned excavation and the original site topography would have to be factored in for a complete volumetric analysis. Sites that involve inclined and folded bedding may require mapping or preparation of sections for a complete and accurate accounting of all materials present. A good identification and description of the rock materials, approximate elevations that the materials are expected to be encountered and approximate thickness of the strata, must be provided. The site exploration boreholes and any other pertinent field data should be obtained by a survey crew and mapped. Accurate position and vertical elevation of the boreholes is essential for accurate strata correlation.

Alkaline Addition (Examples Nos. 6, 7, and 8):
These examples show the general steps for determining the total volume of supplemental alkaline material (SAM) needed based on the fill chemistry, fill volume, and purity of the SAM source. These examples assume all excavated materials will be mixed sufficiently to be considered uniform fill. This may not be a reasonable assumption for very large volumes of excavation involving different types of segmented rock deposits that cannot be blended together. In such cases, alkalinity addition rates shall be calculated separately for each type of material that is expected to be excavated and handled separately (see Example 6).

Worked Example 1 – Borehole ABA: Discrete horizontal layers of high-NP and high-MPA materials

This example includes both high-NP and high-MPA in discrete depositional layers.

Boring R-12 Depth (ft.)	Thickness (ft.)	Fizz	FR	Total Sulfur (%)	NP (ppt)	MPA (ppt)	PR	NNP (ppt)
0.0 – 1.5	1.5	-	-	-	-	-	-	-
1.5 – 4.5	3.0	N	0	0.08	3.5	2.5	1.4	1.0
4.5 – 7.5	3.0	N	0	0.06	5.3	1.9	2.8	3.4
7.5 – 9.0	1.5	SL	1	0.08	17.0	2.5	6.8	14.5
9.0 – 12.0	3.0	N	0	0.06	4.6	1.9	2.5	2.7
12.0 – 15.0	3.0	SL	1	0.04	43.0	1.3	34.4	41.8
15.0 – 18.0	3.0	M	2	0.04	71.3	1.3	57.0	70.1
18.0 – 20.0	2.0	N	0	0.04	12.4	1.3	9.9	11.2
20.0 – 23.0	3.0	ST	3	0.04	98.2	1.3	78.6	97.0
23.0 – 26.0	3.0	M	2	0.02	42.2	0.6	67.5	41.6
26.0 – 28.0	2.0	N	0	0.08	13.7	2.5	5.5	11.2
28.0 – 30.0	2.0	N	0	0.12	5.4	3.8	1.4	1.7
30.0 – 32.0	2.0	N	0	0.04	19.5	1.3	15.6	18.3
32.0 – 34.0	2.0	N	0	0.12	5.5	3.8	1.5	1.8
34.0 – 36.0	2.0	N	0	0.20	8.0	6.3	1.3	1.8
36.0 – 39.0	3.0	N	0	0.03	7.2	0.9	7.7	6.3
39.0 – 42.0	3.0	N	0	1.23	3.4	38.4	0.1	-35.0
42.0 – 45.0	3.0	N	0	2.20	2.2	68.8	0.0	-66.6
45.0 – 47.0	2.0	N	0	2.54	1.5	79.4	0.0	-77.9
47.0 – 49.0	2.0	N	0	2.75	3.5	85.9	0.0	-82.4
49.0 – 51.0	2.0	N	0	0.35	3.5	10.9	0.3	-7.4
51.0 – 53.0	2.0	N	0	1.98	3.5	61.9	0.1	-58.4
53.0 – 55.0	2.0	N	0	0.09	11.2	2.8	4.0	8.4

Figure 1 – Borehole ABA (Example 1)

In this example, the drill column contains areas of both high alkaline potential (shaded blue) and high potential acidity (shaded orange). Because the zone of high potential acidity is isolated (39.0 to 53.0 feet) this scenario is a good candidate for segregated excavation and handling of that material. When this material is excavated, it must be mitigated in some manner, to prevent the production of acid-rock drainage. The mitigation may be accomplished by treating the excavated APR with a supplemental high-alkaline material. As an added measure, the treated rock may also then be encapsulated "high and dry" in an on-site fill, if possible. Mitigation options are discussed in Chapter 10 – Acid-Producing Rock, Section 10.9 Acid-Producing Rock and Soil Mitigation Methods.

See the ABA calculations on the next page for this scenario. Figure 2 shows the result of calculating ABA corresponding to a series of anticipated excavation lifts. The top lift has high-NP layers and the bottom lift has high-MPA layers.

	Boring R-12 Depth (ft.)	Thickness (ft.)	Fizz	FR	Total Sulfur (%)	**NP** (ppt)	**MPA** (ppt)	**PR**	**NNP** (ppt)	Volume % (*)	NPw (ppt) (**)	MPAw (ppt) (***)
Lift 1	1.5 – 4.5	3.0	N	0	0.08	3.5	2.5	1.4	1.0	*10.5*	*0.37*	*0.26*
	4.5 – 7.5	3.0	N	0	0.06	5.3	1.9	2.8	3.4	*10.5*	*0.56*	*0.20*
	7.5 – 9.0	1.5	SL	1	0.08	17.0	2.5	6.8	14.5	*5.3*	*0.89*	*0.13*
	9.0 – 12.0	3.0	N	0	0.06	4.6	1.9	2.5	2.7	*10.5*	*0.48*	*0.20*
	12.0 – 15.0	3.0	SL	1	0.04	43.0	1.3	34.4	41.8	*10.5*	*4.53*	*0.13*
	15.0 – 18.0	3.0	M	2	0.04	71.3	1.3	57.0	70.1	*10.5*	*7.51*	*0.13*
	18.0 – 20.0	2.0	N	0	0.04	12.4	1.3	9.9	11.2	*7.0*	*0.87*	*0.09*
	20.0 – 23.0	3.0	ST	3	0.04	98.2	1.3	78.6	97.0	*10.5*	*10.34*	*0.13*
	23.0 – 26.0	3.0	M	2	0.02	42.2	0.6	67.5	41.6	*10.5*	*4.44*	*0.07*
	26.0 – 28.0	2.0	N	0	0.08	13.7	2.5	5.5	11.2	*7.0*	*0.96*	*0.18*
	28.0 – 30.0	2.0	N	0	0.12	5.4	3.8	1.4	1.7	*7.0*	*0.38*	*0.26*
									Sums =	**100%**	**31.33**	**1.78**

NNP of Lift 1 = $NP_w - MPA_w$ = **29.6 ppt**

PR of Lift 1 = NP_w / MPA_w = **17.6**

	Boring R-12 Depth (ft.)	Thickness (ft.)	Fizz	FR	Total Sulfur (%)	**NP** (ppt)	**MPA** (ppt)	**PR**	**NNP** (ppt)	Volume % (*)	NPw (ppt) (**)	MPAw (ppt) (***)
Lift 2	30.0 – 32.0	2.0	N	0	0.04	19.5	1.3	15.6	18.3	*8.0*	*1.56*	*0.10*
	32.0 – 34.0	2.0	N	0	0.12	5.5	3.8	1.5	1.8	*8.0*	*0.44*	*0.30*
	34.0 – 36.0	2.0	N	0	0.20	8.0	6.3	1.3	1.8	*8.0*	*0.64*	*0.50*
	36.0 – 39.0	3.0	N	0	0.03	7.2	0.9	7.7	6.3	*12.0*	*0.86*	*0.11*
	39.0 – 42.0	3.0	N	0	1.23	3.4	38.4	0.1	-35.0	*12.0*	*0.41*	*4.61*
	42.0 – 45.0	3.0	N	0	2.20	2.2	68.8	0.0	-66.6	*12.0*	*0.26*	*8.25*
	45.0 – 47.0	2.0	N	0	2.54	1.5	79.4	0.0	-77.9	*8.0*	*0.12*	*6.35*
	47.0 – 49.0	2.0	N	0	2.75	3.5	85.9	0.0	-82.4	*8.0*	*0.28*	*6.88*
	49.0 – 51.0	2.0	N	0	0.35	3.5	10.9	0.3	-7.4	*8.0*	*0.28*	*0.88*
	51.0 – 53.0	2.0	N	0	1.98	3.5	61.9	0.1	-58.4	*8.0*	*0.28*	*4.95*
	53.0 – 55.0	2.0	N	0	0.09	11.2	2.8	4.0	8.4	*8.0*	*0.90*	*0.23*
									Sums =	**100%**	**6.03**	**33.15**

NNP of Lift 2 = $NP_w - MPA_w$ = **-27.1 ppt**

PR of Lift 2 = NP_w / MPA_w = **0.2**

* The volumes must sum to 100% for each lift evaluated

** Summing the weighted-NP values yields the NP value for the lift

*** Summing the weighted-MPA values yields the MPA value for the lift

Figure 2 – Lift ABA (Example 1)

Notice that the materials shown in Figure 2 are identical to Figure 1 except that they are now divided into two separate lifts. The lift thicknesses were selected based on: 1) the notably different chemistry between the top and bottom of the boring and; 2) the anticipated excavation sequence and ability to efficiently handle the material. Lift-1 can therefore be managed separately from the materials deposited below it. Accordingly, separate ABA calculations are completed for each lift. Lift-1 (1.5 – 30 ft.) NNP is calculated to be 29.6 ppt $CaCO_3$. This material, as a whole, is net-alkaline and should require addition of no supplemental alkaline material (SAM). Lift-2 (30 -55 ft.) has a calculated NNP value of -27.1 ppt $CaCO_3$ and will most certainly require addition of SAM.

The top 1.5 ft. is topsoil to be used elsewhere on the project and is not to be mixed with the fill; therefore, it is excluded from the calculations.

Worked Example 2 – Borehole ABA: Interbedded horizontal layers of high-MPA and high-NP materials

This example looks at a column with interbedded layers of high-MPA and high-NP materials, and then considers the necessary alkaline addition.

Boring R-13 Depth (ft.)	Thickness (ft.)	Fizz	FR	Total Sulfur (%)	NP (ppt)	MPA (ppt)	PR	NNP (ppt)
0.0 – 1.5	1.5	-	-	-	-	-	-	-
1.5 – 4.5	3.0	N	0	0.08	3.5	2.5	1.4	1.0
4.5 – 7.5	3.0	N	0	1.23	3.4	38.4	0.1	-35.0
7.5 – 9.0	1.5	SL	1	0.08	17.0	2.5	6.8	14.5
9.0 – 12.0	3.0	ST	3	0.04	98.2	1.3	78.6	97.0
12.0 – 15.0	3.0	N	0	0.06	5.3	1.9	2.8	3.4
15.0 – 18.0	3.0	N	0	0.06	4.6	1.9	2.5	2.7
18.0 – 20.0	2.0	N	0	0.04	12.4	1.3	9.9	11.2
20.0 – 23.0	3.0	N	0	2.20	2.2	68.8	0.0	-66.6
23.0 – 26.0	3.0	M	2	0.02	42.2	0.6	67.5	41.6
26.0 – 28.0	2.0	N	0	0.08	13.7	2.5	5.5	11.2
28.0 – 30.0	2.0	N	0	0.12	5.4	3.8	1.4	1.7
30.0 – 32.0	2.0	N	0	0.04	19.5	1.3	15.6	18.3
32.0 – 35.0	3.0	M	2	0.04	71.3	1.3	57.0	70.1
35.0 – 38.0	3.0	N	0	0.03	7.2	0.9	7.7	6.3
38.0 – 40.0	2.0	N	0	2.54	1.5	79.4	0.0	-77.9
40.0 – 42.0	2.0	N	0	0.20	8.0	6.3	1.3	1.8
42.0 – 44.0	2.0	N	0	2.75	3.5	85.9	0.0	-82.4
44.0 – 46.0	2.0	N	0	0.12	5.5	3.8	1.5	1.8
46.0 – 49.0	3.0	SL	1	0.04	43.0	1.3	34.4	41.8
49.0 – 51.0	2.0	N	0	0.35	3.5	10.9	0.3	-7.4
51.0 – 53.0	2.0	N	0	1.98	3.5	61.9	0.1	-58.4
53.0 – 55.0	2.0	N	0	0.09	11.2	2.8	4.0	8.4

Figure 3 – Borehole ABA (Example 2)

In Example 2, the drill column contains increments of both high-alkaline potential (shaded blue) and high-acid potential (shaded orange). The increments are identical to those shown in Example 1 except for the vertical sequence in which they occur. Because the zones of high potential acidity are now interbedded throughout the column in this scenario, this would not be a good candidate for segregated excavation and handling of specific acidic zones. If the buffering from the interbedded alkaline zones is not sufficient, the entire volume of material must be mitigated to prevent the production of ARD.

Figure 4 shows the result of calculating ABA corresponding to a series of anticipated excavation lifts. Lift-1 is slightly net-alkaline and may require some SAM to provide buffering. Lift-2 is clearly net-acidic with NNP = -1.5 ppt and PR = 0.9. Separate SAM addition rates should be calculated for both lifts.

	Boring R-13 Depth (ft.)	Thickness (ft.)	Fizz	FR	Total Sulfur (%)	**NP** (ppt)	**MPA** (ppt)	**PR**	**NNP** (ppt)	**Volume % (*)**	**NPw** (ppt) **(**)**	**MPAw** (ppt) **(***)**
Lift 1	1.5 – 4.5	3.0	N	0	0.08	3.5	2.5	1.4	1.0	*10.5*	*0.37*	*0.26*
	4.5 – 7.5	3.0	N	0	1.23	3.4	38.4	0.1	-35.0	*10.5*	*0.36*	*4.05*
	7.5 – 9.0	1.5	SL	1	0.08	17.0	2.5	6.8	14.5	*5.3*	*0.89*	*0.13*
	9.0 – 12.0	3.0	ST	3	0.04	98.2	1.3	78.6	97.0	*10.5*	*10.34*	*0.13*
	12.0 – 15.0	3.0	N	0	0.06	5.3	1.9	2.8	3.4	*10.5*	*0.56*	*0.20*
	15.0 – 18.0	3.0	N	0	0.06	4.6	1.9	2.5	2.7	*10.*	*0.48*	*0.20*
	18.0 – 20.0	2.0	N	0	0.04	12.4	1.3	9.9	11.2	*7.*	*0.87*	*0.09*
	20.0 – 23.0	3.0	N	0	2.20	2.2	68.8	0.0	-66.6	*10.5*	*0.23*	*7.24*
	23.0 – 26.0	3.0	M	2	0.02	42.2	0.6	67.5	41.6	*10.5*	*4.44*	*0.07*
	26.0 – 28.0	2.0	N	0	0.08	13.7	2.5	5.5	11.2	*7.0*	*0.96*	*0.18*
	28.0 – 30.0	2.0	N	0	0.12	5.4	3.8	1.4	1.7	*7.0*	*0.38*	*0.26*
									Sums =	**100%**	**19.88**	**12.80**

NNP of Lift 1 = $NP_w - MPA_w$ = **7.1 ppt**

PR of Lift 1 = NP_w / MPA_w = **1.6**

	Boring R-13 Depth (ft.)	Thickness (ft.)	Fizz	FR	Total Sulfur (%)	**NP** (ppt)	**MPA** (ppt)	**PR**	**NNP** (ppt)	Volume % (*)	NPw (ppt) (**)	MPAw (ppt) (***)
Lift 2	30.0 – 32.0	2.0	N	0	0.04	19.5	1.3	15.6	18.3	*8.0*	*1.56*	*0.10*
	32.0 – 35.0	3.0	M	2	0.04	71.3	1.3	57.0	70.1	*12.0*	*8.56*	*0.15*
	35.0 – 38.0	3.0	N	0	0.03	7.2	0.9	7.7	6.3	*12.0*	*0.86*	*0.11*
	38.0 – 40.0	2.0	N	0	2.54	1.5	79.4	0.0	-77.9	*8.0*	*0.12*	*6.35*
	40.0 – 42.0	2.0	N	0	0.20	8.0	6.3	1.3	1.8	*8.0*	*0.64*	*0.50*
	42.0 – 44.0	2.0	N	0	2.75	3.5	85.9	0.0	-82.4	*8.0*	*0.28*	*6.88*
	44.0 – 46.0	2.0	N	0	0.12	5.5	3.8	1.5	1.8	*8.0*	*0.44*	*0.30*
	46.0 – 49.0	3.0	SL	1	0.04	43.0	1.3	34.4	41.8	*12.0*	*5.16*	*0.15*
	49.0 – 51.0	2.0	N	0	0.35	3.5	10.9	0.3	-7.4	*8.0*	*0.28*	*0.88*
	51.0 – 53.0	2.0	N	0	1.98	3.5	61.9	0.1	-58.4	*8.0*	*0.28*	*4.95*
	53.0 – 55.0	2.0	N	0	0.09	11.2	2.8	4.0	8.4	*8.0*	*0.90*	*0.23*
									Lift 2 Sum:	**100%**	**19.08**	**20.59**

NNP of Lift 2 = $NP_w - MPA_w$ = **-1.5 ppt**

PR of Lift 2 = NP_w / MPA_w = **0.9**

* The volumes must sum to 100% for each lift evaluated

** Summing the weighted-NP values yields the NP value for the lift

*** Summing the weighted-MPA values yields the MPA value for the lift

Figure 4 – Lift ABA (Example 2)

Worked Example 3 – Borehole ABA: Horizontal layers of less definitive MPA and NP materials

This is an example where the ABA results are less definitive relative to whether APR is a problem and whether treatment is required.

Boring R-14 Depth (ft.)	Thickness (ft.)	Fizz	FR	Total Sulfur (%)	**NP** (ppt)	**MPA** (ppt)	**PR**	**NNP** (ppt)
0.0 – 1.0	1.0	N	0	0.00	0.28	0.00	-0.51	0.28
1.0 – 4.0	3.0	N	0	0.00	0.31	0.00	0.49	0.31
4.0 – 7.0	3.0	N	0	0.01	-0.20	0.31	-1.94	-0.51
7.0 – 10.0	3.0	N	0	0.01	0.30	0.31	0.87	-0.01
10.0 – 13.0	3.0	N	0	0.01	0.62	0.31	1.87	0.31
13.0 – 16.0	3.0	N	0	0.01	0.72	0.31	1.55	0.41
16.0 – 19.0	3.0	N	0	0.01	0.59	0.31	1.10	0.28
19.0 – 22.0	3.0	N	0	0.02	0.88	0.63	0.33	0.26
22.0 – 25.0	3.0	N	0	0.03	-0.22	0.94	-1.05	-1.16
25.0 – 28.0	3.0	N	0	0.02	0.56	0.63	0.57	-0.06
28.0 – 31.0	3.0	N	0	0.02	0.18	0.63	-0.22	-0.45
31.0 – 34.0	3.0	N	0	0.01	-0.12	0.31	-0.23	-0.43
34.0 – 37.0	3.0	N	0	0.00	0.45	0.00	0.33	0.45
37.0 – 40.0	3.0	N	0	0.00	1.09	0.00	0.29	1.09

Figure 5 – Borehole ABA (Example 3)

In this example, there is no single layer that is anticipated as a significant acid producer since the total sulfur ranges only from 0.00 to 0.03 percent. And while there are several negative PR's, NP's and NNP's, and no significant sources of alkaline, the MPA is very low. While some values are in ranges indicating a potential for APR (relative to values indicated in Chapter 10 – Acid-Producing Rock ,Table 10.7.5-1 – Interpretation of ABA Results, there is also little source for acidity. Situations of this nature must be scrutinized closely, to assess the need for treatment or mitigation.

Figure 6 shows the result of calculating ABA corresponding to a series of anticipated excavation lifts. Both Lift-1 and Lift-2 are essentially acid-base neutral. Neither has elevated sulfur contents. Situations such as this would not typically require alkaline addition unless other factors, such as experience in similar geology, have proven otherwise. Rock type and color can also help predict the acid-base chemistry in these cases.

LIFT 1

Boring R-14 Depth (ft.)	Thickness (ft.)	Fizz	FR	Total Sulfur (%)	NP (ppt)	MPA (ppt)	PR	NNP (ppt)	Volume % (*)	NP_w (ppt) (**)	MPA_w (ppt) (***)
0.0 – 1.0	1.0	N	0	0.00	0.28	0.00	-0.51	0.28	*5.3*	*0.01*	*0.00*
1.0 – 4.0	3.0	N	0	0.00	0.31	0.00	0.49	0.31	*15.8*	*0.05*	*0.00*
4.0 – 7.0	3.0	N	0	0.01	-0.20	0.31	-1.94	-0.51	*15.8*	*-0.03*	*0.05*
7.0 – 10.0	3.0	N	0	0.01	0.30	0.31	0.87	-0.01	*15.8*	*0.05*	*0.05*
10.0 – 13.0	3.0	N	0	0.01	0.62	0.31	1.87	0.31	*15.8*	*0.10*	*0.05*
13.0 – 16.0	3.0	N	0	0.01	0.72	0.31	1.55	0.41	*15.8*	*0.11*	*0.05*
16.0 – 19.0	3.0	N	0	0.01	0.59	0.31	1.10	0.28	*15.8*	*0.09*	*0.05*
							Sums =		**100%**	**0.38**	**0.25**

NNP of Lift 1 = $NP_w - MPA_w$ = **0.1 ppt**

PR of Lift 1 = NP_w / MPA_w = **1.6**

LIFT 2

Boring R-14 Depth (ft.)	Thickness (ft.)	Fizz	FR	Total Sulfur (%)	NP (ppt)	MPA (ppt)	PR	NNP (ppt)	Volume % (*)	NP_w (ppt) (**)	MPA_w (ppt) (***)
19.0 – 22.0	3.0	N	0	0.02	0.88	0.63	0.33	0.26	*14.3*	*0.13*	*0.09*
22.0 – 25.0	3.0	N	0	0.03	-0.22	0.94	-1.05	-1.16	*14.3*	*-0.03*	*0.13*
25.0 – 28.0	3.0	N	0	0.02	0.56	0.63	0.57	-0.06	*14.3*	*0.08*	*0.09*
28.0 – 31.0	3.0	N	0	0.02	0.18	0.63	-0.22	-0.45	*14.3*	*0.03*	*0.09*
31.0 – 34.0	3.0	N	0	0.01	-0.12	0.31	-0.23	-0.43	*14.3*	*-0.02*	*0.04*
34.0 – 37.0	3.0	N	0	0.00	0.45	0.00	0.33	0.45	*14.3*	*0.06*	*0.00*
37.0 – 40.0	3.0	N	0	0.00	1.09	0.00	0.29	1.09	*14.3*	*0.16*	*0.00*
							Sums =		**100%**	**0.40**	**0.45**

NNP of Lift 2 = $NP_w - MPA_w$ = **0.0 ppt**

PR of Lift 2 = NP_w / MPA_w = **0.9**

* The volumes must sum to 100% for each lift evaluated

** Summing the weighted-NP values yields the NP value for the lift

*** Summing the weighted-MPA values yields the MPA value for the lift

Figure 6 – Lift ABA (Example 3)

Worked Example 4 – Borehole ABA: Cut through steeply dipping rock strata striking perpendicular to the roadway

This example considers a proposed cut through steeply dipping rock strata striking perpendicular to the roadway. The proposed cut is 55 feet deep, 300 feet long, and passes through sedimentary rock strata striking perpendicular to the roadway and uniformly dipping 45 degrees. Five test borings, inclined 30 degrees from vertical, were drilled and encountered shale, siltstone, and sandstone as shown in profile parallel to the roadway in Figure 7.

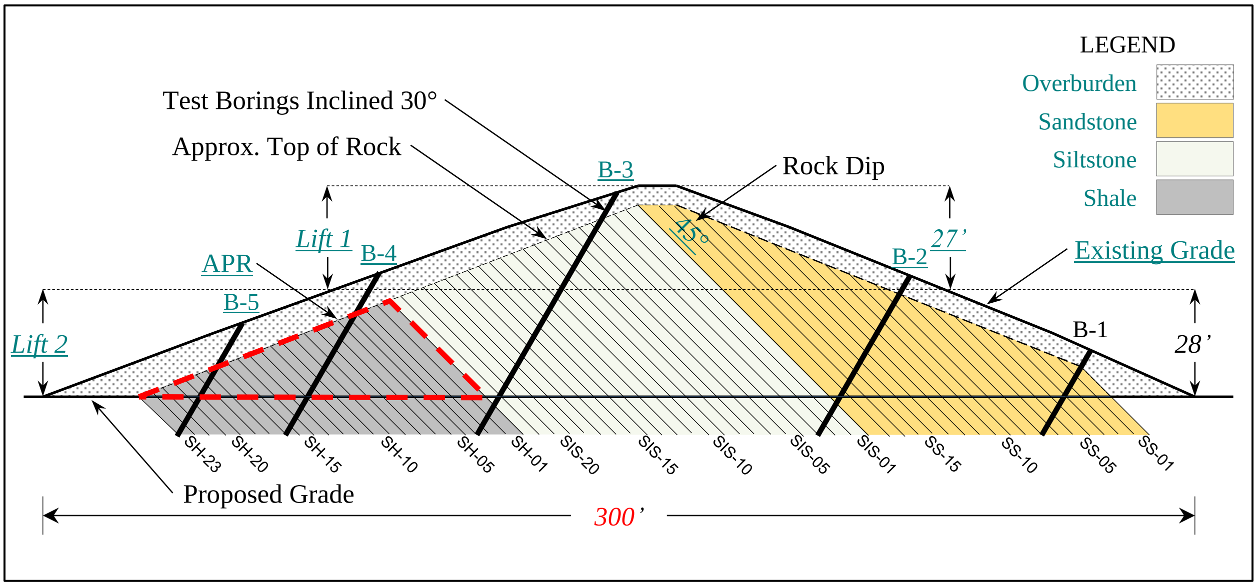

Figure 7 – Profile of Proposed Cut through Steeply Dipping Rock Strata Striking Perpendicular to the Roadway

The borings extended 10 feet below the proposed roadway grade and provided complete sampling of the entire stratigraphic succession. Note that existing surface topography, bedding dip, and overburden thickness were factored into the borehole spacing, which resulted in an irregular borehole spacing yet still provided stratigraphic overlap between the borings. Other factors being equal, inclining borings in an up dip direction will permit increased spacing between borings.

Results of the laboratory analyses of the rock samples collected from the boreholes were tabulated by rock unit. Because the beds are steeply dipping, as shown in Figure 7, a rock unit ID is assigned to each sampled interval to indicate the primary rock type and the position of the increment with respect to the top of the rock unit within the proposed cut. The tabulation of test results for the sandstone unit (Figure 8) indicates PR values are all greater than 1, and NNP values range from 0.75 to 17.38 ppt $CaCO_3$.

Results of the 22 tested siltstone samples are tabulated in Figure 9. All the siltstone samples have PR values greater than 1. NNP values for the siltstone range from 1.25 to 21.56 ppt $CaCO_3$. The results suggest the sandstone and siltstone units may produce acidity or alkalinity; however, alkalinity appears to be more likely for much of the sandstone and siltstone material.

Results of the 23 tested shale samples are tabulated in Figure 10. PR values for the shale samples range from 0.04 to 4.00; however, only four samples have PR values greater than 1, and only one sample has a value greater than 2. NNP values of the shale samples ranged from -44.94 to 5.63 ppt $CaCO_3$, and 19 of the 23 samples have negative NNP values. The test results indicate the shale is likely to produce acidity.

Boring	Depth (ft.) Top	Depth (ft.) Bottom	Core Length (ft.)	Rock Unit ID	Fizz	FR	Sulfur (%)	NP (ppt)	MPA (ppt)	PR	NNP (ppt)
B-1	5.1	7.7	2.6	SS-01	None	0	<0.04	0.75	0.00	∞	0.75
B-1	7.7	10.7	3.0	SS-02	None	0	<0.04	2.75	0.00	∞	2.75
B-1	10.7	13.7	3.0	SS-03	None	0	<0.04	6.00	0.00	∞	6.00
B-1	13.7	16.7	3.0	SS-04	None	0	<0.04	4.00	0.00	∞	4.00
B-1	16.7	19.7	3.0	SS-05	None	0	<0.04	2.00	0.00	∞	2.00
B-1	19.7	22.7	3.0	SS-06	None	0	0.07	14.00	2.19	6.40	11.81
B-1	22.7	25.7	3.0	SS-07	None	0	0.10	20.50	3.13	6.56	17.38
B-2	5.4	8.4	3.0	SS-08	None	0	<0.04	2.75	0.00	∞	2.75
B-2	8.4	11.4	3.0	SS-09	None	0	<0.04	3.00	0.00	∞	3.00
B-2	11.4	14.4	3.0	SS-10	None	0	<0.04	3.25	0.00	∞	3.25
B-2	14.4	17.4	3.0	SS-11	None	0	<0.04	3.25	0.00	∞	3.25
B-2	17.4	20.4	3.0	SS-12	None	0	<0.04	3.25	0.00	∞	3.25
B-2	20.4	23.4	3.0	SS-13	None	0	<0.04	2.25	0.00	∞	2.25
B-2	23.4	26.4	3.0	SS-14	None	0	0.21	8.75	6.56	1.33	2.19
B-2	26.4	29.4	3.0	SS-15	None	0	0.08	11.00	2.50	4.40	8.50
B-2	29.4	32.4	3.0	SS-16	None	0	0.05	8.75	1.56	5.60	7.19
B-2	32.4	35.4	3.0	SS-17	None	0	<0.04	6.25	0.00	∞	6.25
B-2	35.4	38.5	3.1	SS-18	None	0	<0.04	4.25	0.00	∞	4.25

Figure 8 – Borehole Sandstone ABA (Example 4)

Boring	Depth (ft.) Top	Depth (ft.) Bottom	Core Length (ft.)	Rock Unit ID	Fizz	FR	Sulfur (%)	NP (ppt)	MPA (ppt)	PR	NNP (ppt)
B-2	38.5	41.8	3.3	SIS-01	None	0	0.07	15.75	2.19	7.20	13.56
B-2	41.8	45.1	3.3	SIS-02	None	0	0.07	23.75	2.19	10.86	21.56
B-2	45.1	48.3	3.2	SIS-03	None	0	0.09	23.00	2.81	8.18	20.19
B-3	7.9	10.9	3.0	SIS-04	None	0	<0.04	9.00	0.00	∞	9.00
B-3	10.9	13.9	3.0	SIS-05	None	0	0.06	12.50	1.88	6.67	10.63
B-3	13.9	16.9	3.0	SIS-06	None	0	0.21	11.25	6.56	1.71	4.69
B-3	16.9	19.9	3.0	SIS-07	None	0	0.25	9.50	7.81	1.22	1.69
B-3	19.9	22.9	3.0	SIS-08	None	0	0.09	18.50	2.81	6.58	15.69
B-3	22.9	25.9	3.0	SIS-09	None	0	0.11	13.75	3.44	4.00	10.31
B-3	25.9	28.9	3.0	SIS-10	None	0	0.09	14.00	2.81	4.98	11.19
B-3	28.9	31.9	3.0	SIS-11	None	0	0.08	12.00	2.50	4.80	9.50
B-3	31.9	34.9	3.0	SIS-12	None	0	<0.04	1.25	0.00	∞	1.25
B-3	34.9	37.9	3.0	SIS-13	None	0	<0.04	2.25	0.00	∞	2.25
B-3	37.9	40.9	3.0	SIS-14	None	0	<0.04	2.00	0.00	∞	2.00
B-3	40.9	43.9	3.0	SIS-15	None	0	<0.04	4.00	0.00	∞	4.00
B-3	43.9	46.9	3.0	SIS-16	None	0	<0.04	3.00	0.00	∞	3.00
B-3	46.9	49.9	3.0	SIS-17	None	0	<0.04	4.00	0.00	∞	4.00
B-3	49.9	52.9	3.0	SIS-18	None	0	<0.04	5.00	0.00	∞	5.00
B-3	52.9	55.9	3.0	SIS-19	None	0	<0.04	7.00	0.00	∞	7.00
B-3	55.9	58.9	3.0	SIS-20	None	0	<0.04	6.00	0.00	∞	6.00
B-3	58.9	61.9	3.0	SIS-21	None	0	0.05	4.25	1.56	2.72	2.69
B-3	61.9	64.9	3.0	SIS-22	None	0	<0.04	4.00	0.00	∞	4.00

Figure 9 – Borehole Siltstone ABA (Example 4)

Boring	Depth (ft.) Top	Bottom	Core Length (ft.)	Rock Unit ID	Fizz	FR	Sulfur (%)	NP (ppt)	MPA (ppt)	PR	NNP (ppt)
B-3	64.9	67.9	3.0	SH-01	None	0	0.73	5.00	22.81	0.22	-17.81
B-3	67.9	70.9	3.0	SH-02	None	0	0.65	6.00	20.31	0.30	-14.31
B-3	70.9	73.3	2.4	SH-03	None	0	0.20	6.50	6.25	1.04	0.25
B-4	12.3	14.0	1.7	SH-04	None	0	0.06	7.50	1.88	4.00	5.63
B-4	14.0	17.0	3.0	SH-05	None	0	1.15	7.00	35.94	0.19	-28.94
B-4	17.0	20.0	3.0	SH-06	None	0	1.18	6.50	36.88	0.18	-30.38
B-4	20.0	23.0	3.0	SH-07	None	0	0.69	1.25	21.56	0.06	-20.31
B-4	23.0	26.0	3.0	SH-08	None	0	0.72	2.25	22.50	0.10	-20.25
B-4	26.0	29.0	3.0	SH-09	None	0	0.45	1.50	14.06	0.11	-12.56
B-4	29.0	32.0	3.0	SH-10	None	0	1.14	9.25	35.63	0.26	-26.38
B-4	32.0	35.0	3.0	SH-11	None	0	1.56	9.00	48.75	0.18	-39.75
B-4	35.0	38.0	3.0	SH-12	None	0	1.54	5.75	48.13	0.12	-42.38
B-4	38.0	41.0	3.0	SH-13	None	0	1.63	6.00	50.94	0.12	-44.94
B-4	41.0	44.0	3.0	SH-14	None	0	0.29	11.50	9.06	1.27	2.44
B-4	44.0	47.0	3.0	SH-15	None	0	0.85	8.25	26.56	0.31	-18.31
B-4	47.0	49.0	2.0	SH-16	None	0	1.26	9.00	39.38	0.23	-30.38
B-5	13.6	16.6	3.0	SH-17	None	0	1.62	6.75	50.63	0.13	-43.88
B-5	16.6	19.6	3.0	SH-18	None	0	1.29	1.75	40.31	0.04	-38.56
B-5	19.6	22.6	3.0	SH-19	None	0	0.50	3.50	15.63	0.22	-12.13
B-5	22.6	25.6	3.0	SH-20	None	0	0.42	9.00	13.13	0.69	-4.13
B-5	25.6	28.6	3.0	SH-21	None	0	0.45	14.25	14.06	1.01	0.19
B-5	28.6	31.6	3.0	SH-22	None	0	0.84	7.75	26.25	0.30	-18.50
B-5	31.6	34.5	2.9	SH-23	None	0	0.92	9.50	28.75	0.33	-19.25

Figure 10 – Borehole Shale ABA (Example 4)

Because the acidity potential of the shale contrasts sharply with that of the siltstone and sandstone, the upper lift is reduced to 27 feet from the maximum allowable lift thickness of 30 feet, so as to isolate the shale excavation to the lower lift, which is 28 feet thick as shown in Figure 7. Isolating the acid-producing shale to the second lift reduces the period that the shale will be exposed during construction and the amount of potential acidic runoff from the cut slope in the shale that will need to be treated during construction prior to final treatment of the exposed cut slope.

The results of ABA for the sandstone portion of Lifts 1 and 2 are shown in Figure 11. Note that the volumes are not directly proportional to the length of core samples (as was the case in the previous examples) because this example considers the dip of the beds (45 degrees in this example) and the varying top of rock elevation as shown in Figure 7. To determine the weighted volume in this example the total volume of rock within the lift is determined and the volume of rock represented by the sample interval within the lift. The latter volume is determined by projecting the sample interval (typically 3 ft thick) inclined at 45 degrees within the lift limits. Also note that the sandstone samples are from Lift 2, but the results are applied to Lift 1 by projection along bedding. Such a projection may not be appropriate or applicable when the boring and test results indicate a significant oxidized cap rock (OCR) layer is present below top of rock. Additional shallow borings to delineate the OCR may be useful to avoid excessive treatment of APR. The NNP of the sandstone unit is 4.94 ppt $CaCO_3$ and 5.24 ppt $CaCO_3$ for Lifts 1 and 2, respectively, which suggests the material may produce acidity or alkalinity. The PR of the sandstone unit is 4.74 and 6.25 for Lifts 1 and 2, respectively, which suggests that the material should produce alkaline. The sandstone unit should require no alkaline addition for either lift unless previous experience with the sandstone unit and other factors indicate otherwise.

L (ft.)	Rock Unit ID	Fizz	FR	Sulfur (%)	NP (ppt)	MPA (ppt)	PR	NNP (ppt)	LIFT 1 Vol. (%) (*)	LIFT 1 NP_w (ppt) (**)	LIFT 1 MPA_w (ppt) (***)	LIFT 2 Vol. (%) (*)	LIFT 2 NP_w (ppt) (**)	LIFT 2 MPA_w (ppt) (***)
2.6	SS-01	N	0	<0.04	0.75	0.00	∞	0.75	-	-	-	1.94	0.01	0.00
3.0	SS-02	N	0	<0.04	2.75	0.00	∞	2.75	-	-	-	2.74	0.08	0.00
3.0	SS-03	N	0	<0.04	6.00	0.00	∞	6.00	-	-	-	3.36	0.20	0.00
3.0	SS-04	N	0	<0.04	4.00	0.00	∞	4.00	-	-	-	3.98	0.16	0.00
3.0	SS-05	N	0	<0.04	2.00	0.00	∞	2.00	-	-	-	4.60	0.09	0.00
3.0	SS-06	N	0	0.07	14.00	2.19	6.40	11.81	-	-	-	5.23	0.73	0.11
3.0	SS-07	N	0	0.10	20.50	3.13	6.56	17.38	-	-	-	6.12	1.25	0.19
3.0	SS-08	N	0	<0.04	2.75	0.00	∞	2.75	0.23	0.01	0.00	6.61	0.18	0.00
3.0	SS-09	N	0	<0.04	3.00	0.00	∞	3.00	1.89	0.06	0.00	6.52	0.20	0.00
3.0	SS-10	N	0	<0.04	3.25	0.00	∞	3.25	3.81	0.12	0.00	6.52	0.21	0.00
3.0	SS-11	N	0	<0.04	3.25	0.00	∞	3.25	5.72	0.19	0.00	6.52	0.21	0.00
3.0	SS-12	N	0	<0.04	3.25	0.00	∞	3.25	7.63	0.25	0.00	6.52	0.21	0.00
3.0	SS-13	N	0	<0.04	2.25	0.00	∞	2.25	9.54	0.21	0.00	6.52	0.15	0.00
3.0	SS-14	N	0	0.21	8.75	6.56	1.33	2.19	11.45	1.00	0.75	6.52	0.57	0.43
3.0	SS-15	N	0	0.08	11.00	2.50	4.40	8.50	13.36	1.47	0.33	6.52	0.72	0.16
3.0	SS-16	N	0	0.05	8.75	1.56	5.60	7.19	15.09	1.32	0.24	6.52	0.57	0.10
3.0	SS-17	N	0	<0.04	6.25	0.00	∞	6.25	15.39	0.96	0.00	6.52	0.41	0.00
3.1	SS-18	N	0	<0.04	4.25	0.00	∞	4.25	15.89	0.68	0.00	6.74	0.29	0.00
								Sums =	100.00	6.26	1.32	100.00	6.24	1.00

	LIFT 1		LIFT 2
NNP of Lift = NP_w – MPA_w =	4.94	SANDSTONE	5.24
PR of Lift = NP_w / MPA_w =	4.74		6.25

L = length of core tested.

* The volumes must sum to 100% for each lift evaluated.

** Summing the weighted-NP values yields the NP value for the lift.

*** Summing the weighted-MPA values yields the MPA value for the lift.

Figure 11 – Lifts 1 and 2 Sandstone ABA (Example 4)

The results of ABA for the siltstone portion of Lifts 1 and 2 are shown in Figure 12. The NNP of the siltstone is 10.70 ppt $CaCO_3$, and 7.84 ppt $CaCO_3$ for Lifts 1 and 2, respectively, which suggests the material may produce acidity or alkalinity, but alkalinity is more likely. The PR of the siltstone is 5.25 and 5.67 for Lifts 1 and 2, respectively, which suggests that the material should produce alkaline. The siltstone unit should require no alkaline addition for either lift unless previous experience with the siltstone unit and other factors indicate otherwise.

									LIFT 1			LIFT 2		
L (ft.)	Rock Unit ID	Fizz	FR	Sulfur (%)	NP (ppt)	MPA (ppt)	PR	NNP (ppt)	Vol. (%) (*)	NP_w (ppt) (**)	MPA_w (ppt) (***)	Vol. (%) (*)	NP_w (ppt) (**)	MPA_w (ppt) (***)
3.3	SIS-01	N	0	0.07	15.75	2.19	7.20	13.56	10.90	1.72	0.24	4.90	0.77	0.11
3.3	SIS-02	N	0	0.07	23.75	2.19	10.86	21.56	10.63	2.52	0.23	5.08	1.21	0.11
3.2	SIS-03	N	0	0.09	23.00	2.81	8.18	20.19	9.23	2.12	0.26	4.70	1.08	0.13
3.0	SIS-04	N	0	<0.04	9.00	0.00	∞	9.00	8.22	0.74	0.00	4.45	0.40	0.00
3.0	SIS-05	N	0	0.06	12.50	1.88	6.67	10.63	7.84	0.98	0.15	4.54	0.57	0.09
3.0	SIS-06	N	0	0.21	11.25	6.56	1.71	4.69	7.30	0.82	0.48	4.54	0.51	0.30
3.0	SIS-07	N	0	0.25	9.50	7.81	1.22	1.69	6.76	0.64	0.53	4.54	0.43	0.35
3.0	SIS-08	N	0	0.09	18.50	2.81	6.58	15.69	6.22	1.15	0.18	4.54	0.84	0.13
3.0	SIS-09	N	0	0.11	13.75	3.44	4.00	10.31	5.68	0.78	0.20	4.54	0.62	0.16
3.0	SIS-10	N	0	0.09	14.00	2.81	4.98	11.19	5.15	0.72	0.14	4.54	0.64	0.13
3.0	SIS-11	N	0	0.08	12.00	2.50	4.80	9.50	4.61	0.55	0.12	4.54	0.54	0.11
3.0	SIS-12	N	0	<0.04	1.25	0.00	∞	1.25	4.07	0.05	0.00	4.54	0.06	0.00
3.0	SIS-13	N	0	<0.04	2.25	0.00	∞	2.25	3.53	0.08	0.00	4.54	0.10	0.00
3.0	SIS-14	N	0	<0.04	2.00	0.00	∞	2.00	2.99	0.06	0.00	4.54	0.09	0.00
3.0	SIS-15	N	0	<0.04	4.00	0.00	∞	4.00	2.45	0.10	0.00	4.54	0.18	0.00
3.0	SIS-16	N	0	<0.04	3.00	0.00	∞	3.00	1.91	0.06	0.00	4.54	0.14	0.00
3.0	SIS-17	N	0	<0.04	4.00	0.00	∞	4.00	1.37	0.05	0.00	4.54	0.18	0.00
3.0	SIS-18	N	0	<0.04	5.00	0.00	∞	5.00	0.84	0.04	0.00	4.54	0.23	0.00
3.0	SIS-19	N	0	<0.04	7.00	0.00	∞	7.00	0.30	0.02	0.00	4.54	0.32	0.00
3.0	SIS-20	N	0	<0.04	6.00	0.00	∞	6.00	-	-	-	4.46	0.27	0.00
3.0	SIS-21	N	0	0.05	4.25	1.56	2.72	2.69	-	-	-	4.27	0.18	0.07
3.0	SIS-22	N	0	<0.04	4.00	0.00	∞	4.00	-	-	-	4.09	0.16	0.00
								Sums =	100.00	13.22	2.52	100.00	9.52	1.68

	Lift 1		Lift 2
NNP of Lift = $NP_w - MPA_w$ =	10.70	SILTSTONE	7.84
PR of Lift = NP_w / MPA_w =	5.25		5.67

L = length of core tested.

* The volumes must sum to 100% for each lift evaluated.

** Summing the weighted-NP values yields the NP value for the lift.

*** Summing the weighted-MPA values yields the MPA value for the lift.

Figure 12 – Lifts 1 and 2 Siltstone ABA (Example 4)

The results of ABA for the portion of Lift 2 within the shale unit are shown in Figure 13. The ABA for the shale indicates a NNP of -21.08 ppt $CaCO_3$ a PR of 0.22. The results suggest that the shale should produce acidity, so alkaline addition for the shale portion of Lift 2 is required. The extent of the shale unit requiring alkaline addition within the proposed cut should be clearly indicated in the project drawings along with areas suitable for placement of the excavated and treated shale material. Blending the shale with excavated sandstone and siltstone material is not an option since the sandstone and siltstone have variable and inadequate neutralizing potential.

Because of the relatively high acid potential indicated by the ABA for the shale, consideration should be given to treating the runoff from the cut-slope in shale by Condition A (see Section 10.9.4.1) or covering the cut slope face by Condition B or C (see Sections 10.9.4.2

and 10.9.4.3) Chapter 10 – Acid-Producing Rock. Collection and treatment of runoff from the shale unit prior to final treatment may also be required during construction. Consideration should be given to means to temporarily reduce the shale's exposure to oxygen and moisture during and immediately following its excavation so as to reduce the amount of runoff requiring storage and treatment during construction.

L (ft.)	Rock Unit ID	Fizz	FR	Sulfur (%)	NP (ppt)	MPA (ppt)	PR	NNP (ppt)	LIFT 1 Vol. (%) (*)	LIFT 1 NP_w (ppt) (**)	LIFT 1 MPA_w (ppt) (***)	LIFT 2 Vol. (%) (*)	LIFT 2 NP_w (ppt) (**)	LIFT 2 MPA_w (ppt) (***)
3.0	SH-01	N	0	0.73	5.00	22.81	0.22	-17.81	-	-	-	8.93	0.45	2.04
3.0	SH-02	N	0	0.65	6.00	20.31	0.30	-14.31	-	-	-	8.27	0.50	1.68
2.4	SH-03	N	0	0.20	6.50	6.25	1.04	0.25	-	-	-	6.43	0.42	0.40
1.7	SH-04	N	0	0.06	7.50	1.88	4.00	5.63	-	-	-	4.46	0.33	0.08
3.0	SH-05	N	0	1.15	7.00	35.94	0.19	-28.94	-	-	-	7.43	0.52	2.67
3.0	SH-06	N	0	1.18	6.50	36.88	0.18	-30.38	-	-	-	7.03	0.46	2.59
3.0	SH-07	N	0	0.69	1.25	21.56	0.06	-20.31	-	-	-	6.62	0.08	1.43
3.0	SH-08	N	0	0.72	2.25	22.50	0.10	-20.25	-	-	-	6.22	0.14	1.40
3.0	SH-09	N	0	0.45	1.50	14.06	0.11	-12.56	-	-	-	5.81	0.09	0.82
3.0	SH-10	N	0	1.14	9.25	35.63	0.26	-26.38	-	-	-	5.41	0.50	1.93
3.0	SH-11	N	0	1.56	9.00	48.75	0.18	-39.75	-	-	-	5.00	0.45	2.44
3.0	SH-12	N	0	1.54	5.75	48.13	0.12	-42.38	-	-	-	4.60	0.26	2.21
3.0	SH-13	N	0	1.63	6.00	50.94	0.12	-44.94	-	-	-	4.19	0.25	2.13
3.0	SH-14	N	0	0.29	11.50	9.06	1.27	2.44	-	-	-	3.78	0.44	0.34
3.0	SH-15	N	0	0.85	8.25	26.56	0.31	-18.31	-	-	-	3.38	0.28	0.90
2.0	SH-16	N	0	1.26	9.00	39.38	0.23	-30.38	-	-	-	2.11	0.19	0.83
3.0	SH-17	N	0	1.62	6.75	50.63	0.13	-43.88	-	-	-	2.75	0.19	1.39
3.0	SH-18	N	0	1.29	1.75	40.31	0.04	-38.56	-	-	-	2.28	0.04	0.92
3.0	SH-19	N	0	0.50	3.50	15.63	0.22	-12.13	-	-	-	1.87	0.07	0.29
3.0	SH-20	N	0	0.42	9.00	13.13	0.69	-4.13	-	-	-	1.46	0.13	0.19
3.0	SH-21	N	0	0.45	14.25	14.06	1.01	0.19	-	-	-	1.06	0.15	0.15
3.0	SH-22	N	0	0.84	7.75	26.25	0.30	-18.50	-	-	-	0.65	0.05	0.17
2.9	SH-23	N	0	0.92	9.50	28.75	0.33	-19.25	-	-	-	0.25	0.02	0.07
								Sums =	-	-	-	100.00	6.00	27.08

	LIFT 1		SHALE (LIFT 2)
NNP of Lift = $NP_w - MPA_w$ =	-		-21.08
PR of Lift = NP_w / MPA_w =	-		0.22

L = length of core tested.

* The volumes must sum to 100% for each lift evaluated.

** Summing the weighted-NP values yields the NP value for the lift.

*** Summing the weighted-MPA values yields the MPA value for the lift.

Figure 13 – Lift 2 Shale ABA (Example 4)

Worked Example 5 – Borehole ABA: Cut through steeply dipping rock strata striking parallel to the roadway

This example considers a proposed cut through steeply dipping rock strata striking parallel to the roadway. The proposed cut is 60 feet deep, 324 feet wide, and passes through sedimentary rock strata striking parallel to the roadway and uniformly dipping 45 degrees. Three test borings, inclined 30 degrees from vertical, were drilled and encountered limestone and sandstone as shown in the section perpendicular to the roadway Figure 14. A fourth boring (B-4) was drilled to obtain a second location of the limestone contact. Boring B-4 was drilled vertically to permit observation with a borehole televiewer and installation of a monitoring well for collecting groundwater samples.

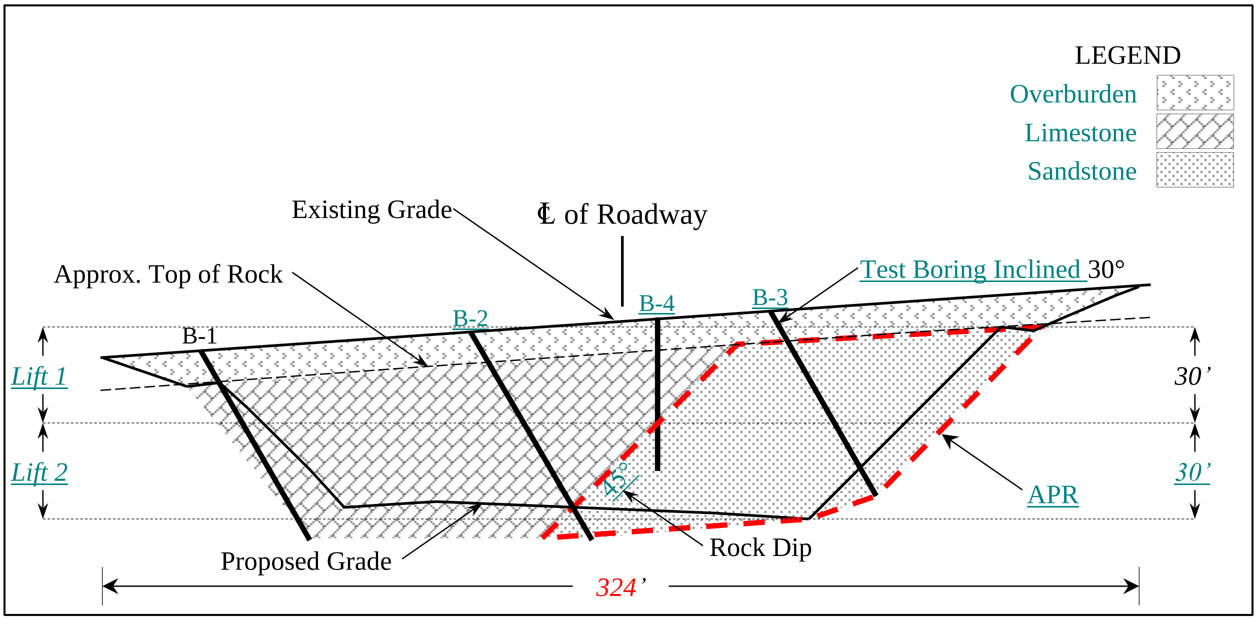

Figure 14 – Section of Proposed Cut through Steeply Dipping Rock Strata Striking Parallel to the Roadway

The borings extended below the proposed roadway grade or proposed cut slope faces and provided complete sampling of the entire stratigraphic succession. The existing surface topography, bedding dip, and overburden thickness were factored into the borehole spacing to provide stratigraphic overlap between the borings. Extending the borings below the proposed cut slope faces permits sampling of the rock that will be exposed in the slope face after construction.

Results of the laboratory analyses of the rock samples collected from the boreholes were tabulated by rock unit. Because the beds are steeply dipping, a rock unit ID is assigned to each sampled interval to indicate the primary rock type and the position of the increment with respect to the top of the rock unit within the proposed cut. The tabulation of the 36 test results for the limestone unit (Figure 15) indicates all but one of the PR values are greater than 1, and NNP values range from -7.75 to 313.75 ppt $CaCO_3$. With the exception of sample LS-18, the limestone appears to be highly alkaline. In this case, testing LS-18 for pyritic sulfur would be helpful to determine whether its sulfur content is due to acid producing pyrite or a non-acid producing sulfur species (e.g., gypsum).

Boring	Depth (ft.)		Core Length (ft.)	Rock Unit ID	Fizz	FR	Sulfur (%)	NP (ppt)	MPA (ppt)	PR	NNP (ppt)
	Top	Bottom									
B-1	11.3	14.3	3.0	LS-01	None	0	0.04	2.50	1.25	2.00	1.25
B-1	14.3	17.3	3.0	LS-02	None	0	0.15	7.50	4.69	1.60	2.81
B-1	17.3	20.3	3.0	LS-03	None	0	0.2	12.50	6.25	2.00	6.25
B-1	20.3	23.3	3.0	LS-04	None	0	0.28	26.75	8.75	3.06	18.00
B-1	23.3	26.3	3.0	LS-05	Slight	1	0.45	49.75	14.06	3.54	35.69
B-1	26.3	29.3	3.0	LS-06	Slight	1	0.66	51.00	20.63	2.47	30.37
B-1	29.3	32.3	3.0	LS-07	None	0	0.59	18.75	18.44	1.02	0.31
B-1	32.3	35.3	3.0	LS-08	Slight	1	0.77	54.50	24.06	2.27	30.44
B-1	35.3	38.3	3.0	LS-09	Slight	1	0.82	58.00	25.63	2.26	32.37
B-1	38.3	41.3	3.0	LS-10	Slight	1	0.86	56.75	26.88	2.11	29.87
B-1	41.3	44.3	3.0	LS-11	Slight	1	0.77	58.25	24.06	2.42	34.19
B-1	44.3	47.3	3.0	LS-12	Slight	1	0.77	56.50	24.06	2.35	32.44
B-1	47.3	50.3	3.0	LS-13	Slight	1	0.96	51.00	30.00	1.70	21.00
B-1	50.3	53.3	3.0	LS-14	Slight	1	0.97	53.00	30.31	1.75	22.69
B-1	53.3	56.4	3.1	LS-15	Slight	1	0.93	52.50	29.06	1.81	23.44
B-1	56.4	59.5	3.1	LS-16	Slight	1	1.1	45.00	34.38	1.31	10.62
B-1	59.5	62.6	3.1	LS-17	None	1	1.18	45.00	36.88	1.22	8.12
B-1	62.6	65.7	3.1	LS-18	Slight	0	1.16	28.50	36.25	0.79	-7.75
B-1	65.7	68.8	3.1	LS-19	Slight	1	0.14	40.75	4.38	9.31	36.38
B-1	11.3	14.3	3.0	LS-20	Slight	1	0.12	45.00	3.75	12.00	41.25
B-1	14.3	17.3	3.0	LS-21	Slight	1	0.17	36.25	5.31	6.82	30.94
B-1	17.3	20.3	3.0	LS-22	Slight	1	0.29	53.50	9.06	5.90	44.44
B-1	20.3	23.3	3.0	LS-23	Moderate	2	0.08	77.50	2.50	31.00	75.00
B-2	23.3	26.3	3.0	LS-24	Moderate	2	0.29	108.75	9.06	12.00	99.69
B-2	26.3	29.3	3.0	LS-25	Moderate	2	0.16	125.00	5.00	25.00	120.00
B-2	29.3	32.3	3.0	LS-26	Moderate	2	0.16	100.00	5.00	20.00	95.00
B-2	32.3	35.3	3.0	LS-27	Moderate	2	0.28	150.00	8.75	17.14	141.25
B-2	35.3	38.3	3.0	LS-28	Moderate	2	0.28	150.00	8.75	17.14	141.25
B-2	38.3	41.3	3.0	LS-29	Moderate	2	0.29	127.50	9.06	14.07	118.44
B-2	41.3	44.3	3.0	LS-30	Moderate	2	0.36	135.00	11.25	12.00	123.75
B-2	44.3	47.3	3.0	LS-31	None	2	0.28	102.50	8.75	11.71	93.75
B-2	47.3	50.3	3.0	LS-32	Moderate	0	0.17	10.25	5.31	1.93	4.94
B-2	50.3	53.3	3.0	LS-33	Moderate	2	0.16	318.75	5.00	63.75	313.75
B-2	53.3	56.3	3.0	LS-34	Moderate	2	0.33	145.00	10.31	14.06	134.69
B-2	56.3	59.3	3.0	LS-35	Moderate	2	0.75	152.50	23.44	6.51	129.06
B-2	59.3	62.3	3.0	LS-36	Moderate	2	0.75	142.50	21.56	6.61	120.94

Figure 15 – Borehole Limestone ABA (Example 5)

The tabulation of the 22 test results for the sandstone unit (Figure 16) indicates six samples have PR values less than 1, and NNP values range from -20.25 to 14.69 ppt $CaCO_3$. The sandstone may produce acidity or alkalinity. With the exception of a few samples, limited neutralization potential appears to be available in the sandstone.

Boring	Depth (ft.)		Core Length (ft.)	Rock Unit ID	Fizz	FR	Sulfur (%)	NP (ppt)	MPA (ppt)	PR	NNP (ppt)
	Top	Bottom									
B-2	62.3	65.5	3.2	SS-01	None	0	<0.04	0.25	0.00	∞	0.25
B-2	65.5	68.7	3.2	SS-02	None	0	<0.04	1.25	0.00	∞	1.25
B-2	68.7	71.9	3.2	SS-03	None	0	<0.04	0.00	0.00	∞	0.00
B-2	71.9	75.1	3.2	SS-04	None	0	<0.04	0.25	0.00	∞	0.25
B-3	11.3	14.3	3.0	SS-05	None	0	<0.04	0.00	0.00	∞	0.00
B-3	14.3	17.3	3.0	SS-06	None	0	<0.04	0.00	0.00	∞	0.00
B-3	17.3	20.3	3.0	SS-07	None	0	<0.04	1.25	0.00	∞	1.25
B-3	20.3	23.3	3.0	SS-08	None	0	<0.04	0.75	0.00	∞	0.75
B-3	23.3	26.3	3.0	SS-09	None	0	<0.04	1.00	0.00	∞	1.00
B-3	26.3	29.3	3.0	SS-10	None	0	<0.04	2.25	0.00	∞	2.25
B-3	29.3	32.3	3.0	SS-11	None	0	<0.04	1.75	0.00	∞	1.75
B-3	32.3	35.3	3.0	SS-12	None	0	<0.04	0.75	0.00	∞	0.75
B-3	35.3	38.3	3.0	SS-13	None	0	<0.04	0.75	0.00	∞	0.75
B-3	38.3	41.4	3.1	SS-14	None	0	0.6	1.25	18.75	0.07	-17.50
B-3	41.4	44.5	3.1	SS-15	None	0	0.27	12.25	8.44	1.45	3.81
B-3	44.5	47.6	3.1	SS-16	None	0	0.96	9.75	30.00	0.33	-20.25
B-3	47.6	50.7	3.1	SS-17	None	0	0.61	3.75	19.06	0.20	-15.31
B-3	50.7	53.8	3.1	SS-18	None	0	0.19	2.75	5.94	0.46	-3.19
B-3	53.8	56.9	3.1	SS-19	Slight	1	0.73	37.50	22.81	1.64	14.69
B-3	56.9	60.0	3.1	SS-20	None	0	0.53	2.75	16.56	0.17	-13.81
B-3	60.0	63.1	3.1	SS-21	None	0	0.76	3.50	23.75	0.15	-20.25
B-3	63.1	66.2	3.1	SS-22	None	0	<0.04	4.25	0.00	∞	4.25

Figure 16 – Borehole Sandstone ABA (Example 5)

The results of ABA for the limestone portion of Lifts 1 and 2 are shown in Figure 17. The volumes are not directly proportional to the length of core samples and factor in the dip of the beds (45 degrees in this example), the top of rock, and the geometry of the proposed cut as shown in Figure 14. When beds are steeply dipping, ignoring the dip of the beds and performing the ABA in horizontal increments may yield results that poorly represent reality, especially when dealing with syngenetic pyrite deposits. The dip of the beds will result in strata encountered higher in the boring to occur lower in the cut (perhaps in lower lifts) and strata encountered deeper in the boring to occur higher in the cut (perhaps in upper lifts). In this example, because of the dip of the beds, the results for the limestone samples collected within proposed Lift 2 are factored into the ABA of Lift 1 since they will also occur within that lift.

The NNP of the limestone unit is 72.53 ppt $CaCO_3$ and 96.41 ppt $CaCO_3$ for Lifts 1 and 2, respectively. The PR of the limestone unit is 5.66 and 6.82 for Lifts 1 and 2, respectively. The weighted NNP and PR values suggest that the limestone material should produce alkaline. No alkaline addition is required, and consideration may be given to the use of the limestone material to mitigate APR issues in other areas of the project.

									LIFT 1			LIFT 2		
L (ft.)	Rock Unit ID	Fizz	FR	Sulfur (%)	NP (ppt)	MPA (ppt)	PR	NNP (ppt)	Vol. (%) (*)	NP_w (ppt) (**)	MPA_w (ppt) (***)	Vol. (%) (*)	NP_w (ppt) (**)	MPA_w (ppt) (***)
3.0	LS-01	N	0	0.04	2.50	1.25	2.00	1.25	0.19	0.00	0.00	-	-	-
3.0	LS-02	N	0	0.15	7.50	4.69	1.60	2.81	0.57	0.04	0.03	-	-	-
3.0	LS-03	N	0	0.2	12.50	6.25	2.00	6.25	0.95	0.12	0.06	-	-	-
3.0	LS-04	N	0	0.28	26.75	8.75	3.06	18.00	1.33	0.35	0.12	-	-	-
3.0	LS-05	S	1	0.45	49.75	14.06	3.54	35.69	1.70	0.85	0.24	-	-	-
3.0	LS-06	S	1	0.66	51.00	20.63	2.47	30.37	2.08	1.06	0.43	-	-	-
3.0	LS-07	N	0	0.59	18.75	18.44	1.02	0.31	2.36	0.44	0.44	0.10	2.59	0.00
3.0	LS-08	S	1	0.77	54.50	24.06	2.27	30.44	2.42	1.32	0.58	0.43	11.02	0.00
3.0	LS-09	S	1	0.82	58.00	25.63	2.26	32.37	2.47	1.43	0.63	0.77	19.67	0.00
3.0	LS-10	S	1	0.86	56.75	26.88	2.11	29.87	2.52	1.43	0.68	1.11	28.31	0.00
3.0	LS-11	S	1	0.77	58.25	24.06	2.42	34.19	2.57	1.50	0.62	1.45	36.96	0.00
3.0	LS-12	S	1	0.77	56.50	24.06	2.35	32.44	2.62	1.48	0.63	1.79	45.60	0.00
3.0	LS-13	S	1	0.96	51.00	30.00	1.70	21.00	2.67	1.36	0.80	2.13	54.25	0.00
3.0	LS-14	S	1	0.97	53.00	30.31	1.75	22.69	2.71	1.44	0.82	2.47	62.91	0.00
3.1	LS-15	S	1	0.93	52.50	29.06	1.81	23.44	2.86	1.50	0.83	2.90	74.07	0.00
3.1	LS-16	S	1	1.1	45.00	34.38	1.31	10.62	2.91	1.31	1.00	3.26	83.31	0.00
3.1	LS-17	N	1	1.18	45.00	36.88	1.22	8.12	2.96	1.33	1.09	3.63	92.54	0.00
3.1	LS-18	S	0	1.16	28.50	36.25	0.79	-7.75	3.01	0.86	1.09	3.99	101.77	0.00
3.1	LS-19	S	1	0.14	40.75	4.38	9.31	36.38	3.12	1.27	0.14	4.43	113.01	0.00
3.0	LS-20	S	1	0.12	45.00	3.75	12.00	41.25	2.99	1.35	0.11	4.31	109.86	0.00
3.0	LS-21	S	1	0.17	36.25	5.31	6.82	30.94	3.07	1.11	0.16	4.29	109.59	0.00
3.0	LS-22	S	1	0.29	53.50	9.06	5.90	44.44	3.12	1.67	0.28	4.25	108.43	0.00
3.0	LS-23	M	2	0.08	77.50	2.50	31.00	75.00	3.17	2.45	0.08	4.20	107.28	0.00
3.0	LS-24	M	2	0.29	108.75	9.06	12.00	99.69	3.22	3.50	0.29	4.16	106.13	0.00
3.0	LS-25	M	2	0.16	125.00	5.00	25.00	120.00	3.26	4.08	0.16	4.11	104.98	0.00
3.0	LS-26	M	2	0.16	100.00	5.00	20.00	95.00	3.31	3.31	0.17	4.08	104.03	0.00
3.0	LS-27	M	2	0.28	150.00	8.75	17.14	141.25	3.36	5.04	0.29	4.09	104.47	0.00
3.0	LS-28	M	2	0.28	150.00	8.75	17.14	141.25	3.41	5.12	0.30	4.12	105.15	0.00
3.0	LS-29	M	2	0.29	127.50	9.06	14.07	118.44	3.46	4.41	0.31	4.15	105.83	0.00
3.0	LS-30	M	2	0.36	135.00	11.25	12.00	123.75	3.51	4.74	0.39	4.17	106.51	0.00
3.0	LS-31	N	2	0.28	102.50	8.75	11.71	93.75	3.56	3.65	0.31	4.20	107.20	0.00
3.0	LS-32	M	0	0.17	10.25	5.31	1.93	4.94	3.61	0.37	0.19	4.23	107.88	0.00
3.0	LS-33	M	2	0.16	318.75	5.00	63.75	313.75	3.66	11.66	0.18	4.25	108.56	0.00
3.0	LS-34	M	2	0.33	145.00	10.31	14.06	134.69	3.71	5.37	0.38	4.28	109.24	0.00
3.0	LS-35	M	2	0.75	152.50	23.44	6.51	129.06	3.76	5.73	0.88	4.31	109.93	0.00
3.0	LS-36	M	2	0.75	142.50	21.56	6.61	120.94	3.80	5.42	0.82	4.33	110.61	0.00
								Sums =	100.0	88.08	15.55	100.0	96.41	14.15

	Lift 1		Lift 2
NNP of Lift = $NP_w - MPA_w$ =	72.53	LIMESTONE	82.27
PR of Lift = NP_w / MPA_w =	5.66		6.82

L = length of core tested.

* The volumes must sum to 100% for each lift evaluated.

** Summing the weighted-NP values yields the NP value for the lift.

*** Summing the weighted-MPA values yields the MPA value for the lift.

Figure 17 – Lifts 1 and 2 Limestone ABA (Example 5)

The results of ABA for the sandstone portion of Lifts 1 and 2 are shown in Figure 18. The NNP of the sandstone unit is -1.77 ppt $CaCO_3$ and -1.74 ppt $CaCO_3$ for Lifts 1 and 2, respectively. The PR of the sandstone unit is 0.69 for both Lifts 1 and 2. The weighted NNP and PR values suggest that the sandstone material should produce acidity, and alkaline addition is required. Although rock units SS-20, SS-21, and SS-22 are not factored in to the ABA analysis for the cut, the test results indicate that this material, which will be exposed or at shallow depth within the cut slope face, will produce alkalinity. Provisions will be required for addressing runoff from the cut slope face during construction and post-construction. Alternatively, provided adequate right-of-way is available, consideration could be given to flattening the proposed cut slope in the sandstone so that treatment using Condition A and C may be applied as discussed in Chapter 10 – Acid-Producing Rock Sections 10.9.4.2 and 10.9.4.3.

									LIFT 1			LIFT 2		
L (ft.)	Rock Unit ID	Fizz	FR	Sulfur (%)	NP (ppt)	MPA (ppt)	PR	NNP (ppt)	Vol. (%) (*)	NP_w (ppt) (**)	MPA_w (ppt) (***)	Vol. (%) (*)	NP_w (ppt) (**)	MPA_w (ppt) (***)
3.2	SS-01	N	0	<0.04	0.25	0.00	∞	0.25	4.97	0.01	0.00	5.23	0.01	0.00
3.2	SS-02	N	0	<0.04	1.25	0.00	∞	1.25	5.04	0.06	0.00	5.26	0.07	0.00
3.2	SS-03	N	0	<0.04	0.00	0.00	∞	0.00	5.10	0.00	0.00	5.30	0.00	0.00
3.2	SS-04	N	0	<0.04	0.25	0.00	∞	0.25	5.18	0.01	0.00	5.34	0.01	0.00
3.0	SS-05	N	0	<0.04	0.00	0.00	∞	0.00	4.87	0.00	0.00	4.99	0.00	0.00
3.0	SS-06	N	0	<0.04	0.00	0.00	∞	0.00	4.97	0.00	0.00	5.06	0.00	0.00
3.0	SS-07	N	0	<0.04	1.25	0.00	∞	1.25	5.03	0.06	0.00	5.09	0.06	0.00
3.0	SS-08	N	0	<0.04	0.75	0.00	∞	0.75	5.09	0.04	0.00	5.12	0.04	0.00
3.0	SS-09	N	0	<0.04	1.00	0.00	∞	1.00	5.15	0.05	0.00	5.15	0.05	0.00
3.0	SS-10	N	0	<0.04	2.25	0.00	∞	2.25	5.21	0.12	0.00	5.18	0.12	0.00
3.0	SS-11	N	0	<0.04	1.75	0.00	∞	1.75	5.26	0.09	0.00	5.21	0.09	0.00
3.0	SS-12	N	0	<0.04	0.75	0.00	∞	0.75	5.32	0.04	0.00	5.24	0.04	0.00
3.0	SS-13	N	0	<0.04	0.75	0.00	∞	0.75	5.38	0.04	0.00	5.28	0.04	0.00
3.1	SS-14	N	0	0.6	1.25	18.75	0.07	-17.50	5.47	0.07	1.03	5.51	0.07	1.03
3.1	SS-15	N	0	0.27	12.25	8.44	1.45	3.81	5.69	0.70	0.48	5.56	0.68	0.47
3.1	SS-16	N	0	0.96	9.75	30.00	0.33	-20.25	5.75	0.56	1.73	5.60	0.55	1.68
3.1	SS-17	N	0	0.61	3.75	19.06	0.20	-15.31	5.82	0.22	1.11	5.65	0.21	1.08
3.1	SS-18	N	0	0.19	2.75	5.94	0.46	-3.19	5.88	0.16	0.35	5.70	0.16	0.34
3.1	SS-19	S	1	0.73	37.50	22.81	1.64	14.69	4.68	1.76	1.07	4.53	1.70	1.03
3.1	SS-20	N	0	0.53	2.75	16.56	0.17	-13.81	-	-	-	-	-	-
3.1	SS-21	N	0	0.76	3.50	23.75	0.15	-20.25	-	-	-	-	-	-
3.1	SS-22	N	0	<0.04	4.25	0.00	∞	4.25	-	-	-	-	-	-
								Sums =	100.0	3.99	5.76	100.0	3.90	5.63

NNP of Lift = NP_w – MPA_w =	-1.77	SANDSTONE	-1.74
PR of Lift = NP_w / MPA_w =	0.69		0.69

L = length of core tested.

* The volumes must sum to 100% for each lift evaluated.

** Summing the weighted-NP values yields the NP value for the lift.

*** Summing the weighted-MPA values yields the MPA value for the lift.

Figure 18 – Lifts 1 and 2 Sandstone ABA (Example 5)

Worked Examples 5 and 6 show how ABA may be performed for steeply dipping beds striking perpendicular to and parallel to the roadway. When the bedding strikes obliquely to the roadway, a similar approach may be used; however, the sections and profiles should show the apparent dip of the bedding. More complicated projects involving curved roadways and varying bedding orientation may require 3D modeling to perform the ABA required to assess the acid-generating capacity of materials to be disturbed by transportation projects.

Worked Example 6 – SAM Addition: Uniform rock type assuming all materials can be adequately blended

This calculation anticipates all materials, including Supplemental Alkaline Material (SAM), can be adequately blended together.

This example determines the total quantity of SAM needed for neutralization of APR waste material involving only one, uniform rock deposit. This scenario is likely to occur with a smaller volume, shallow excavation such as a structure foundation

Step 1: Tabulate the laboratory testing results:

Site Material	Quantity to be Excavated (tons)	NP (ppt $CaCO_3$)	% Sulfur	Fizz Rating
Carbonaceous Black Shale	1,000	0.34	0.55	0

Step 2: Calculate MPA of the APR:

MPA_{Shale} = (% $Sulfur_{Shale}$)(31.25 ppt $CaCO_3$/1% Sulfur)
= (0.55% Sulfur)(31.25 ppt $CaCO_3$/1% Sulfur)
= <u>17.19 ppt $CaCO_3$</u>

Step 3: Calculate NNP of the APR:

NNP_{Shale} = NP_{Shale} - MPA_{Shale}
= 0.34 ppt $CaCO_3$ – 17.19 ppt $CaCO_3$
= <u>-16.85 ppt $CaCO_3$</u> *(<0, therefore, likely to be acidic)*

Step 4: Calculate PR of the APR:

PR_{Shale} = NP / MPA
= 0.34 ppt $CaCO_3$ / 17.19 ppt $CaCO_3$
= <u>0.02</u> ppt $CaCO_3$ *(<1, therefore, likely to be acidic)*

Step 5: Calculate required alkaline addition:

To help assure ARD will not be generated, set the target site NNP equal to a minimum of 12.0 ppt $CaCO_3$. A higher target NNP can be selected based on local experience or regulatory guidance.

$NNP_{Deficit}$ = NNP_{Target} – NNP_{Shale}

$= 12.0 \text{ ppt } CaCO_3 - -16.85 \text{ ppt } CaCO_3$
$= \underline{28.85 \text{ ppt } CaCO_3}$

Apply a factor-of-safety (FS = 2.0) to assure adequate alkalinity is available. This helps to offset the effect of imperfect mixing.

$NNP_{Required} = (NNP_{Deficit})(FS)$
$= (28.85 \text{ ppt } CaCO_3)(2.0)$
$= \underline{57.7 \text{ ppt } CaCO_3}$ or $\underline{57.7 \text{ tons of pure lime / 1000 tons of rock}}$

Step 6: Determine the quantity of the SAM selected for the project.

This is a function of the purity of the imported alkaline material. In this case, an 85 percent $CaCO_3$ equivalent (CCE) material (NP = 850 ppt $CaCO_3$, MPA = 0 ppt $CaCO_3$) is selected:

Total SAM required for the project $= (NNP_{Required})(\text{Overburden mass}) / CCE$
$= (57.7 \text{ tons/1000 tons})(1{,}000 \text{ tons}) / 0.85$
$= \underline{68 \text{ tons}}$

Worked Example 7 – SAM Addition: Multiple rock types assuming all materials can be adequately blended

This calculation anticipates all materials (including SAM) can be adequately blended together.

This example determines the total quantity of SAM needed for neutralization of APR waste material involving deposits with more than one rock type which can be adequately blended during excavation and placement. This scenario could occur when excavating deposits of changing or multiple lithologies, or when interbedded or steeply-dipping deposits of different lithologies are excavated.

Step 1: Tabulate site overburden quantity and laboratory testing results:

Site Material	Quantity to be Excavated	NP (ppt $CaCO_3$)	% Sulfur	Fizz Rating
Shale	20,000 tons (40% of site volume)	0.6	0.52	0
Sandstone	30,000 tons (60% of site volume)	5.0	0.02	0

Step 2: Calculate NP of Site:

$NP_{Site} = (\%_{Shale})(NP_{Shale} + (\%_{Sandstone}) NP_{Sandstone})$
$= (0.40)(0.6 \text{ ppt } CaCO_3) + (0.60)(5.0 \text{ ppt } CaCO_3)$
$= 0.24 \text{ ppt } CaCO_3 + 3.0 \text{ ppt } CaCO_3$

$= \underline{3.24 \text{ ppt } CaCO_3}$

Step 3: Calculate MPA of Shale and Sandstone:

$$\begin{aligned} MPA_{Shale} &= (\%\ Sulfur_{Shale})(31.25 \text{ ppt } CaCO_3/1\% \text{ Sulfur}) \\ &= (0.52\% \text{ Sulfur})(31.25 \text{ ppt } CaCO_3/1\% \text{ Sulfur}) \\ &= \underline{16.25 \text{ ppt } CaCO_3} \end{aligned}$$

$$\begin{aligned} MPA_{Sandstone} &= (\%\ Sulfur_{Sandstone})(31.25 \text{ ppt } CaCO_3/1\% \text{ Sulfur}) \\ &= (0.02\% \text{ Sulfur})(31.25 \text{ ppt } CaCO_3/1\% \text{ Sulfur}) \\ &= \underline{0.63 \text{ ppt } CaCO_3} \end{aligned}$$

Step 4: Calculate MPA of Site:

$$\begin{aligned} MPA_{Site} &= (\%_{Shale})(MPA_{Shale}) + (\%_{Sandstone})(MPA_{Sandstone}) \\ &= (0.40)(16.25 \text{ ppt } CaCO_3) + (0.60)(0.63 \text{ ppt } CaCO_3) \\ &= 6.5 \text{ ppt } CaCO_3 + 0.38 \text{ ppt } CaCO_3 \\ &= \underline{6.88 \text{ ppt } CaCO_3} \end{aligned}$$

Step 5: Calculate NNP of Site:

$$\begin{aligned} NNP_{Site} &= NP_{Site} - MPA_{Site} \\ &= 3.24 \text{ ppt } CaCO_3 - 6.88 \text{ ppt } CaCO_3 \\ &= \underline{-3.64 \text{ ppt } CaCO_3} \end{aligned}$$ *(<0, therefore, likely to be acidic)*

Step 6: Calculate PR of the APR:

$$\begin{aligned} PR_{Site} &= NP / MPA \\ &= 3.24 \text{ ppt } CaCO_3 / 6.88 \text{ ppt } CaCO_3 \\ &= \underline{0.47 \text{ ppt } CaCO_3} \end{aligned}$$ *(<1, therefore, likely to be acidic)*

Step 7: Calculate required alkaline addition:

To help assure ARD will not be generated, set the target site NNP equal to a minimum of 12.0 ppt $CaCO_3$. A higher target NNP can be selected based on local experience or regulatory guidance.

$$\begin{aligned} NNP_{Deficit} &= NNP_{Target} - NNP_{Site} \\ &= 12.0 \text{ ppt } CaCO_3 - -3.64 \text{ ppt } CaCO_3 \\ &= \underline{15.64 \text{ ppt } CaCO_3} \end{aligned}$$

Apply a factor-of-safety (FS = 2.0) to assure adequate alkalinity is available. This helps to offset the effect of imperfect mixing.

$$\begin{aligned} NNP_{Required} &= (NNP_{Deficit})(FS) \\ &= (15.64 \text{ ppt } CaCO_3)(2.0) \end{aligned}$$

= <u>31.28 ppt $CaCO_3$</u> or <u>31.28 tons lime / 1000 tons fill</u>

Step 8: Determine the quantity of the SAM selected for the project:

This is a function of the purity of the imported alkaline material. In this case, an 85 percent $CaCO_3$ equivalent (CCE) material (NP = 850 ppt $CaCO_3$, MPA = 0 ppt $CaCO_3$) is selected:

Total SAM required for the project = $(NNP_{Required})$(Overburden mass) / CCE
= (31.28 tons/1000 tons)(50,000 tons) / 0.85
= <u>1,840 tons</u>

Worked Example 8 – SAM Addition: Multiple rock types assuming high-MPA materials are managed separately

This calculation anticipates conditions when excavations must be zoned (e.g. when encountering isolated zones of high acid potential) and deposits will not be blended together, but managed separately.

This example determines the total quantities of SAM needed for neutralization of APR waste material where excavations must be zoned, having deposits of substantially different acid potential, which must be excavated, treated and placed separately.

Step 1: Tabulate site overburden quantity and laboratory testing results:

Site Material	Deposit Thickness (ft)	Quantity to be Excavated & Treated	NP (ppt $CaCO_3$)	% Sulfur	Fizz Rating
Black Shale	15	15,000 tons (25% of site volume)	10.0	0.56	0
Coal*	6	5,000 tons (<1% of site volume, include only 10% 'loss' volume in SAM calculations)	0.0	2.2	0
Gray Siltstone	45	45,000 tons (75% of site volume)	12.0	0.11	0

***Note:** In this example the coal deposit is of sufficient thickness such that the coal should be excavated separately and hauled to a coal facility for disposal or marketing, and it should not be blended with the other fill materials. It is not possible to remove 100 percent of the coal deposit. Assume 90 percent of the material can be removed, i.e., 10 percent loss. If the very high sulfur content material were not coal, or it is not practical to mine or separate the coal, appropriate calculations for SAM would be conducted, and the material would be excavated, treated and placed in a separate operation from the overlying shale and underlying siltstone materials, to the extent possible.

Step 2: Calculate MPA of Each Rock Type:

MPA_{Shale} = (% $Sulfur_{Shale}$)(31.25 ppt $CaCO_3$/1% Sulfur
= (0.56% Sulfur)(31.25 ppt $CaCO_3$/1% Sulfur)
= <u>17.50 ppt $CaCO_3$</u>

MPA_{Coal} = (% $Sulfur_{Coal}$)(31.25 ppt $CaCO_3$/1% Sulfur
= (2.2% Sulfur)(31.25 ppt $CaCO_3$/1% Sulfur)
= <u>68.75 ppt $CaCO_3$</u>

$MPA_{Siltstone}$ = (% $Sulfur_{Siltstone}$)(31.25 ppt $CaCO_3$/1% Sulfur)
= (0.11% Sulfur)(31.25 ppt $CaCO_3$/1% Sulfur)
= <u>3.44 ppt $CaCO_3$</u>

Step 3: Calculate NNP of Each Rock Type:

NNP_{Shale} = NP_{Shale} – MPA_{Shale}
= 10.0 ppt $CaCO_3$ – 17.50 ppt $CaCO_3$
= <u>-7.5 ppt $CaCO_3$</u> *(<0, likely to be acidic)*

NNP_{Coal} = NP_{Coal} – MPA_{Coal}
= 0.0 ppt $CaCO_3$ – 68.75 ppt $CaCO_3$
= <u>-68.75 ppt $CaCO_3$</u> *(<<0, acidic)*

$NNP_{Siltstone}$ = $NP_{Siltstone}$ – $MPA_{Siltstone}$
= 12.0 ppt $CaCO_3$ – 3.44 ppt $CaCO_3$
= <u>8.56 ppt $CaCO_3$</u> *(Between 0 and 20, may be acidic or alkaline; however, local experience indicates the siltstone will be acidic and require a higher NNP target for neutralization)*

Step 4: Calculate required alkaline addition for Each Rock Type:

To help assure ARD will not be generated, set the target site NNP equal to a <u>minimum</u> of 12.0 ppt $CaCO_3$. A higher target NNP can be selected based on local experience or regulatory guidance. Apply a factor-of-safety (FS = 2.0) to the NNP deficit to assure adequate alkalinity is available. This helps to offset the effect of imperfect mixing.

NNP $Required_{Shale}$ = (NNP_{Target} – NNP_{Shale})(FS)
= (12.0 ppt $CaCO_3$ – -7.5 ppt $CaCO_3$)(2.0)
= (19.5 ppt $CaCO_3$)(2.0)
= <u>39.0 ppt $CaCO_3$</u> or <u>39.0 tons lime / 1000 tons fill</u>

NNP $Required_{Coal}$ = (NNP_{Target} – NNP_{Coal})(FS)
= (12.0 ppt $CaCO_3$ – -68.75 ppt $CaCO_3$)(2.0
= (80.75 ppt $CaCO_3$)(2.0)
= <u>161.5 ppt $CaCO_3$</u> or <u>161.5 tons lime / 1000 tons fill</u>

For this example, the target NNP for the siltstone layer material is increased from 12.0 ppt $CaCO_3$ to 20.0 ppt $CaCO_3$ based on local experience with this rock type.

$$
\begin{aligned}
\text{NNP Required}_{\text{Silstone}} &= (\text{NNP}_{\text{Target}} - \text{NNP}_{\text{Siltstone}})(\text{FS}) \\
&= (20.0 \text{ ppt } CaCO_3 - 8.56 \text{ ppt } CaCO_3)(2.0) \\
&= (11.44 \text{ ppt } CaCO_3)(2.0) \\
&= \underline{22.9 \text{ ppt } CaCO_3} \quad \text{or} \quad \underline{22.9 \text{ tons lime / 1000 tons fill}}
\end{aligned}
$$

Step 5: Determine the quantity of the selected SAM needed for Each Rock Type:

This is a function of rock volume and the purity of the imported alkaline material. In this case, an 85 percent $CaCO_3$ equivalent (CCE) material (NP = 850 ppt $CaCO_3$, MPA = 0 ppt $CaCO_3$) is selected:

$$
\begin{aligned}
\text{SAM}_{\text{Shale}} &= (\text{NNP Required}_{\text{Shale}})(\text{Shale mass}) / \text{CCE} \\
&= (39.0 \text{ tons/1000 tons})(15{,}000 \text{ tons}) / 0.85 \\
&= \underline{688 \text{ tons}}
\end{aligned}
$$

The example assumes ten percent of the coal will remain as loss, so in the case of the coal, SAM is required to treat only the coal loss of 500 tons (i.e., 10 percent of the 5,000 tons of coal to be excavated). No SAM is required for the other 4,500 tons of coal to be removed and hauled to a coal facility.

$$
\begin{aligned}
\text{SAM}_{\text{Coal (loss)}} &= (\text{NNP Required}_{\text{Coal(loss)}})(\text{Coal loss mass}) / \text{CCE} \\
&= (161.5 \text{ tons/1000 tons}) \times (500 \text{ tons}) / 0.85 \\
&= \underline{95 \text{ tons}}
\end{aligned}
$$

$$
\begin{aligned}
\text{SAM}_{\text{Siltstone}} &= (\text{NNP Required}_{\text{Siltstone}})(\text{Siltstone mass}) / \text{CCE} \\
&= (22.9 \text{ tons/1000 tons})(45{,}000 \text{ tons}) / 0.85 \\
&= \underline{1{,}212 \text{ tons}}
\end{aligned}
$$

Step 6: Determine the total quantity of the selected SAM needed for the excavation:

$$
\begin{aligned}
\text{SAM}_{\text{Total}} &= \text{SAM}_{\text{Shale}} + \text{SAM}_{\text{Coal(loss)}} + \text{SAM}_{\text{Siltstone}} \\
&= 688 \text{ tons} + 95 \text{ tons} + 1{,}212 \text{ tons} \\
&= \underline{1{,}995 \text{ tons}}
\end{aligned}
$$

In the above example, if the middle layer were a 12-foot thickness of high-acid potential rock, overlain by a 5-foot thickness of high-alkaline potential rock, and underlain by a 3-foot thickness of high-alkaline potential rock, and the materials can be excavated during the same blasting shot, then the three materials can be included in a single acid-base accounting calculation to determine the required SAM. The high-alkaline rock materials can serve to reduce the required SAM, so long as the materials are thoroughly mixed during placement, and the anticipated particle sizes of the shot materials is taken into account.

Worked Example 9 – SAM Addition: Alternative approach based on a robust characterization of the rock mass

This example introduces an alternative approach for mitigating syngenetic pyrite based on a robust characterization of the rock mass. The alternative approach uses the decision flow path shown in Figure 19. The flow path involves two options for the calculation of the amount of SAM required (SAM_{req}) and the SAM addition rate (SAM_{rate}). Option 1 uses a weighted NNP value and factor of safety of 1.5, and Option 2 uses the lowest NNP value and a factor of safety of 1.3. The results of the two options are then compared to determine an appropriate SAM_{rate}.

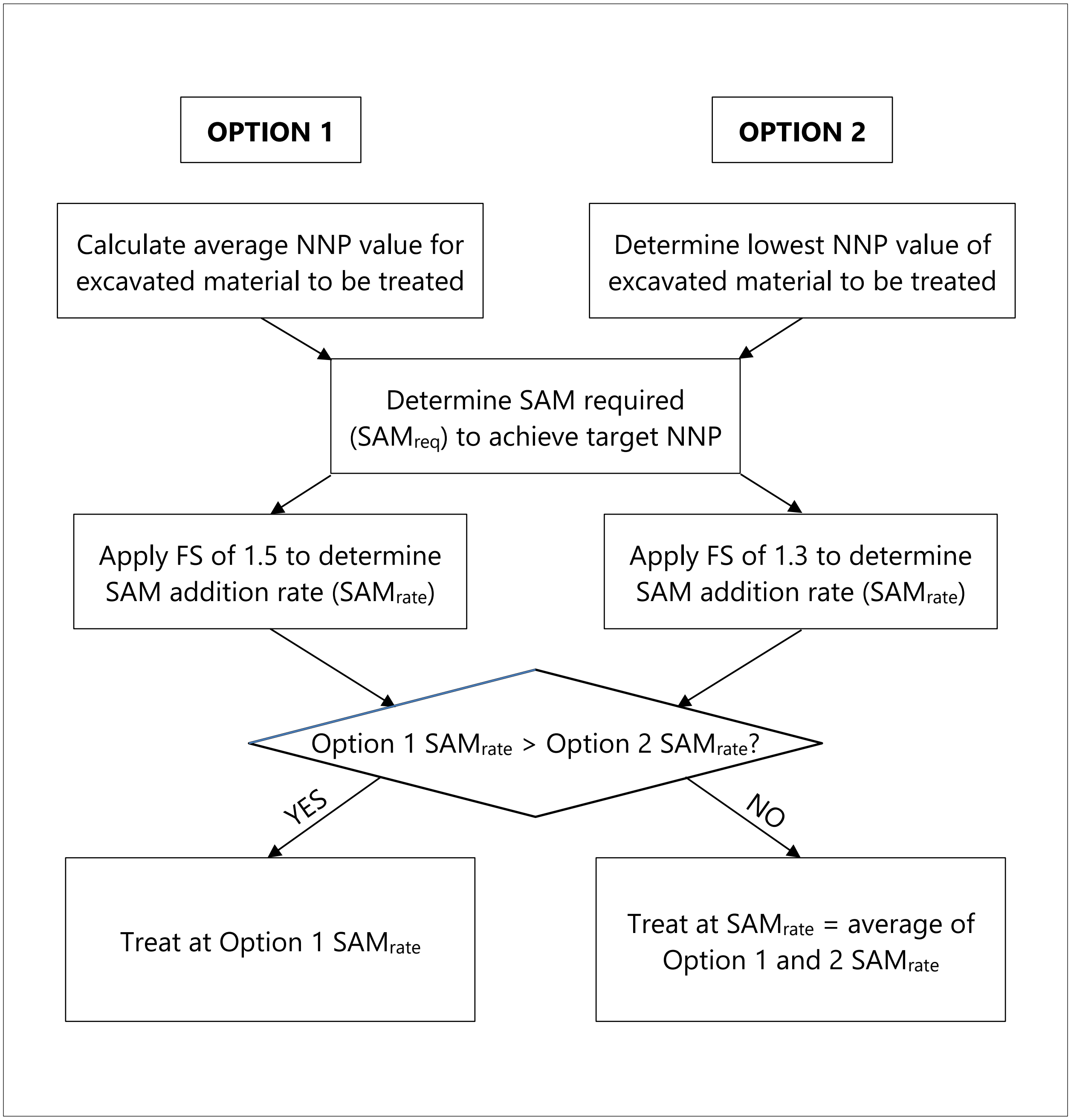

Figure 19. Decision tree for determining required SAM addition rate.

The example consists of a proposed rock cut approximately 950 feet long and having a maximum height of nearly 70 feet. To characterize the rock mass, 15 test borings were located along three sections perpendicular to the roadway alignment to provide a robust sampling and analysis of the entire section of rock strata to be excavated in the roadway cut. The rock strata consisted of siltstone with a few interbeds of claystone. Selected boreholes were also imaged using an optical televiewer (OTV) to further assess rock quality and obtain structural data. Rock core measurements and stereographic analysis of the OTV discontinuity data indicated a relatively uniform bedding dip angle of 40 degrees to the northwest and a bedding strike direction virtually parallel to the proposed roadway alignment.

Rock cores from the 15 test borings were collected, described, and analyzed for Total %Sulfur, Maximum Potential Acidity (MPA), Neutralization Potential (NP), and Fizz Intensity. Based on the results, the Potential Ratio (PR) and Net Neutralization Potential (NNP) were calculated. A total of 191 rock cores were analyzed. The core sample intervals ranged in length from 2 to 10 feet, with 162 samples (85 percent) having an interval length of 3 feet. Eight sample intervals were less than 3 feet, and 21 sample intervals were more than 3 feet. Longer sample intervals were used only in the upper portions of the borehole because of core recovery or because of observations regarding oxidation.

The lab reported a fizz intensity of "None" for all the samples, which indicates limited available natural alkalinity. The %Sulfur analyses indicated a concentration of <0.04 percent in 122 samples (64 percent) and concentrations ranging from 0.04 to 1.89 percent in 69 samples. The table in Figure 20 lists the minimum value, first, second, and third quartile values, maximum value, and mean value for Total %Sulfur, MPA, NP, and NNP. With the exception of the maximum value, a range of values is indicated for %Sulfur and MPA because of the lack of precision introduced by the 122 results indicating <0.04% Sulfur, which may correspond to a %Sulfur ranging from zero to 0.039%. The lower end of the range assumes <0.04% Sulfur corresponds to zero %Sulfur, and the higher end of the range assumes <0.04% Sulfur corresponds to 0.039% Sulfur. So, the true value lies somewhere within the indicated range. Note that the mean %Sulfur range is higher than the 3rd quartile range, which suggests a subset of high results is skewing the mean upward so that the mean is at least three times the median value. A range of values is also indicated for NNP except for the minimum and maximum values.

Value	Total %Sulfur	Maximum Potential Acidity (ppt $CaCO_3$)	Neutralization Potential (ppt $CaCO_3$)	Net Neutralization Potential (ppt $CaCO_3$)
Minimum	0 – 0.04	0 – 1.22	-0.25	-49.06
1st Quartile	0 – 0.04	0 – 1.22	0.75	-0.97 – 0.25
Median	0 – 0.04	0 – 1.22	2.25	0.28 – 1.50
Mean	0.12 – 0.15	3.86 – 4.64	4.07	-0.57 – 0.21
3rd Quartile	0.08 – 0.08	2.50 – 2.50	5.88	2.03 – 2.75
Maximum	1.89	59.06	18.75	16.88

Figure 20. Summary of laboratory analytical results for 191 core samples tested.

The upper half of Figures 21, 22, and 23 illustrate the %Sulfur concentrations measured in the core samples from the 15 borings along the three cross sections through the proposed cut. In the sections, lines have been added to approximate the bedding layers dipping 40 degrees to the northwest. The bedding lines are color-coded by the measured %Sulfur concentrations as indicated in the legend. The Option 1 (weighted NNP value) is developed first.

Step 1: Analyze for the presence of Oxidized Cap Rock (OCR):

The first step is to analyze the data to determine the possible presence and depth of an oxidized cap rock (OCR). In this example, one might first choose to consider the majority of the material having a %Sulfur concentration of <0.04 since the less than detection limit values are largely concentrated in the upper portions of the borings where the rock is likely to be more oxidized. The MPA of the %Sulfur <0.04 material is less than 1.25 ppt $CaCO_3$ as shown by the calculation below.

$$MPA = Total\ \%\ Sulfur\left(\frac{31.25\ ppt\ CaCO_3}{1\%\ Sulfur}\right) = 0.04\%S\left(\frac{31.25\ ppt\ CaCO_3}{1\%S}\right) = 1.25\ ppt\ CaCO_3$$

The table in Figure 24 summarizes the results of the Neutralization Potential (NP) testing on the %Sulfur <0.04 material. In all three sections the median NP value is 1.25 or higher, and the mean NP value is 1.53 or higher, which suggests the average Potential Ratio is at least 1.2 or higher. The combination of a %Sulfur <0.04 and an average PR greater than at least 1.2 suggests that this material will generally be self-neutralizing and is within the OCR zone, so no special treatment is necessary. The approximate bottom of the OCR is thus shown by a red line in each section in the upper half of Figures 21, 22, and 23.

Station	Number of Samples	Neutralization Potential			
		Minimum	Median	Mean	Maximum
658+00	37	-0.25	1.25	1.53	6.75
661+00	55	0.00	1.50	1.90	9.00
663+00	30	0.00	1.50	2.04	11.75

Figure 24. Summary of Neutralization Potential results for %S <0.04 ppt $CaCO_3$ material.

Note that the boring spacing may significantly affect the delineation of the bottom of the OCR zone. For example, if Boring B-8 had not been drilled along the Station 661+00 section, and only the results from Borings B-7 and B-9 were used, then the bottom of OCR zone would have been delineated about 7.5 feet lower at the location of Boring B-8 than what is shown in Figure 22.

Step 2: Analyze the effect of bedding:

In this example, the rock core was fairly uniform and classified as siltstone, so gross lithologic variation is not of concern; however, the bedding orientation must still be considered. In the upper part of Figures 21, 22, and 23, the bedding orientation is represented by lines sloping 40 degrees attached to the tops and bottoms of the sample intervals and color-coded by sample result as indicated in the figure legend. In this case, since the roadway is parallel to

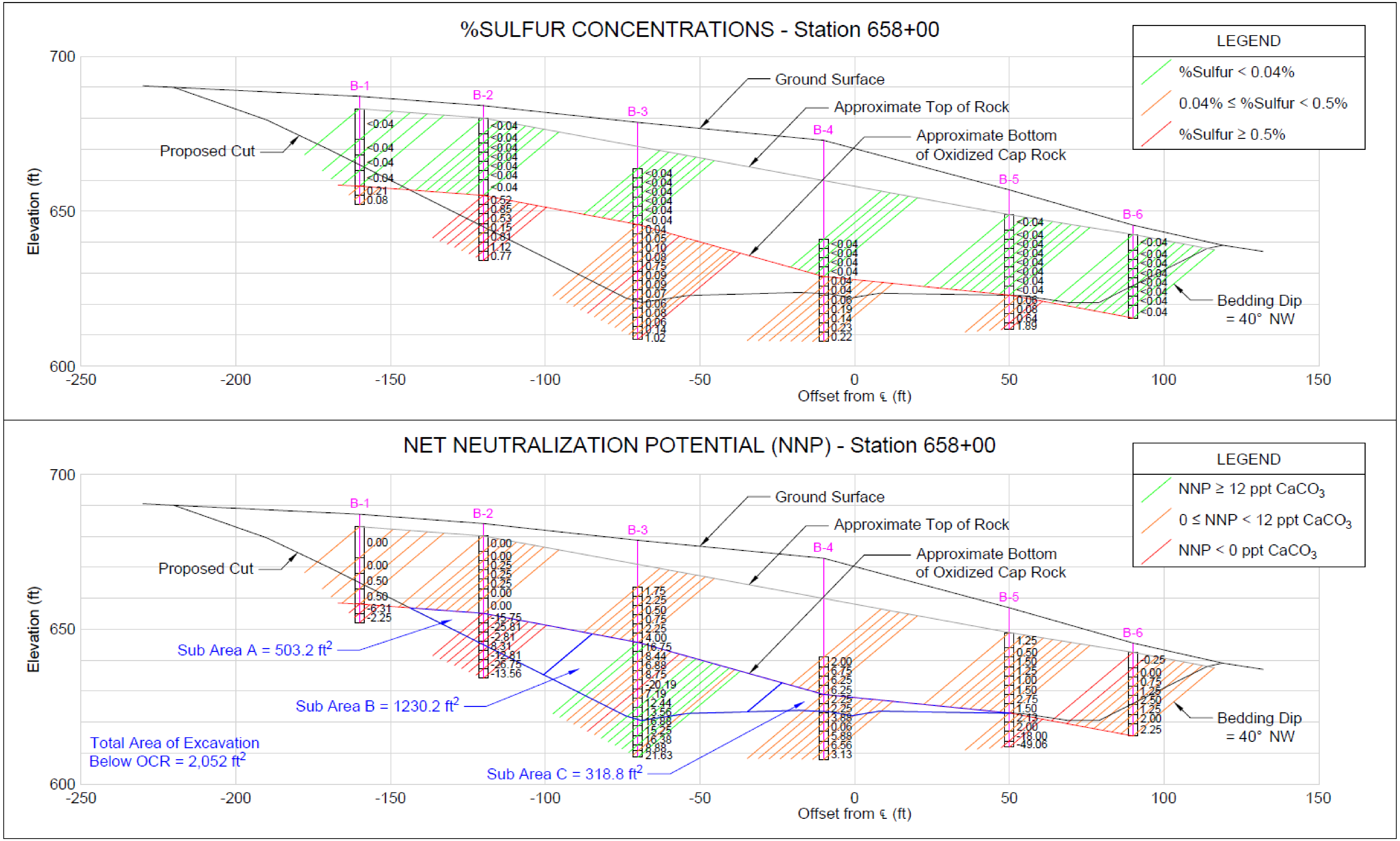

Figure 21. %Sulfur concentrations (top) and net neutralization potential (NNP) values (bottom) at Station 658+00.

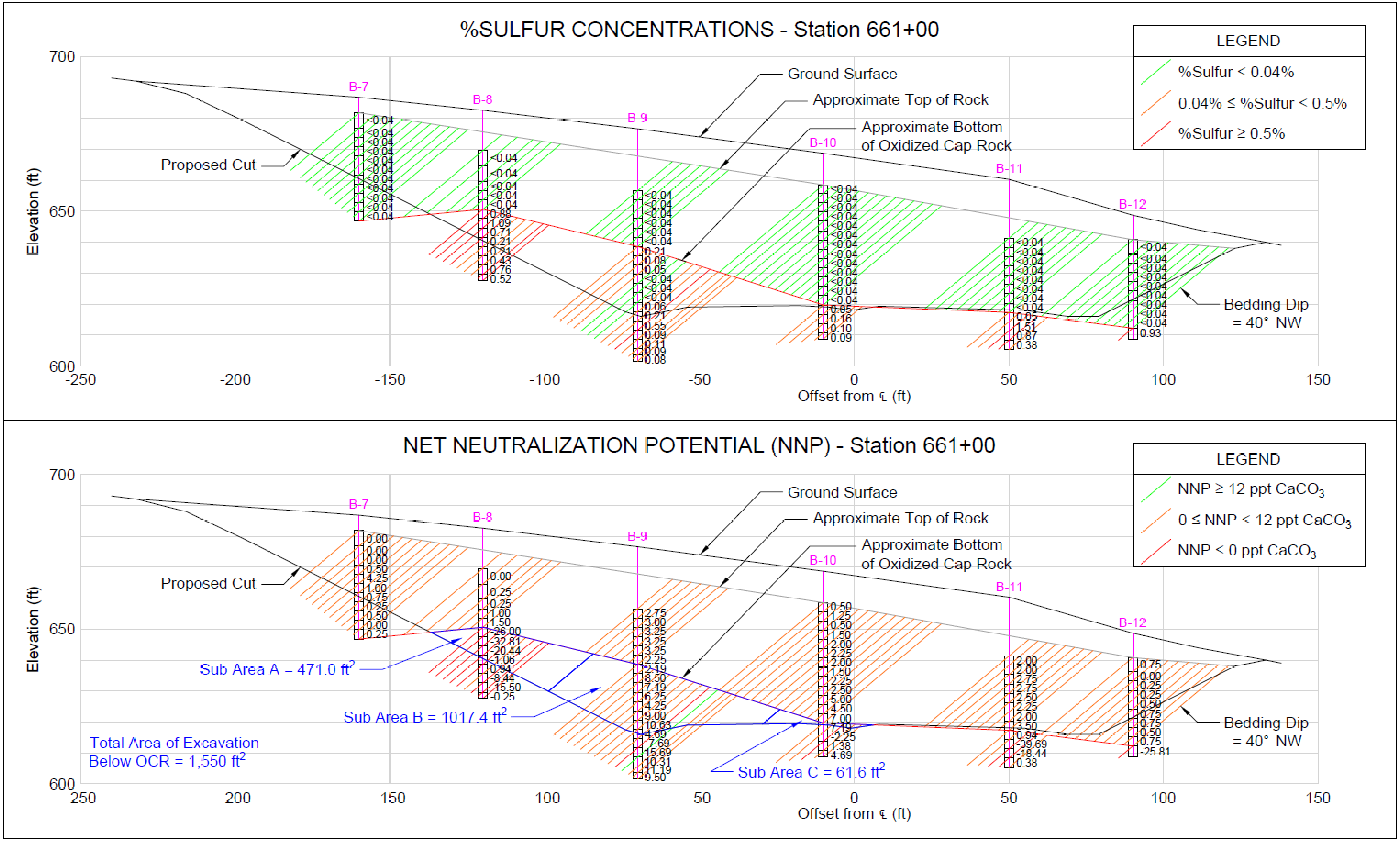

Figure 22. %Sulfur concentrations (top) and net neutralization potential (NNP) values (bottom) at Station 661+00.

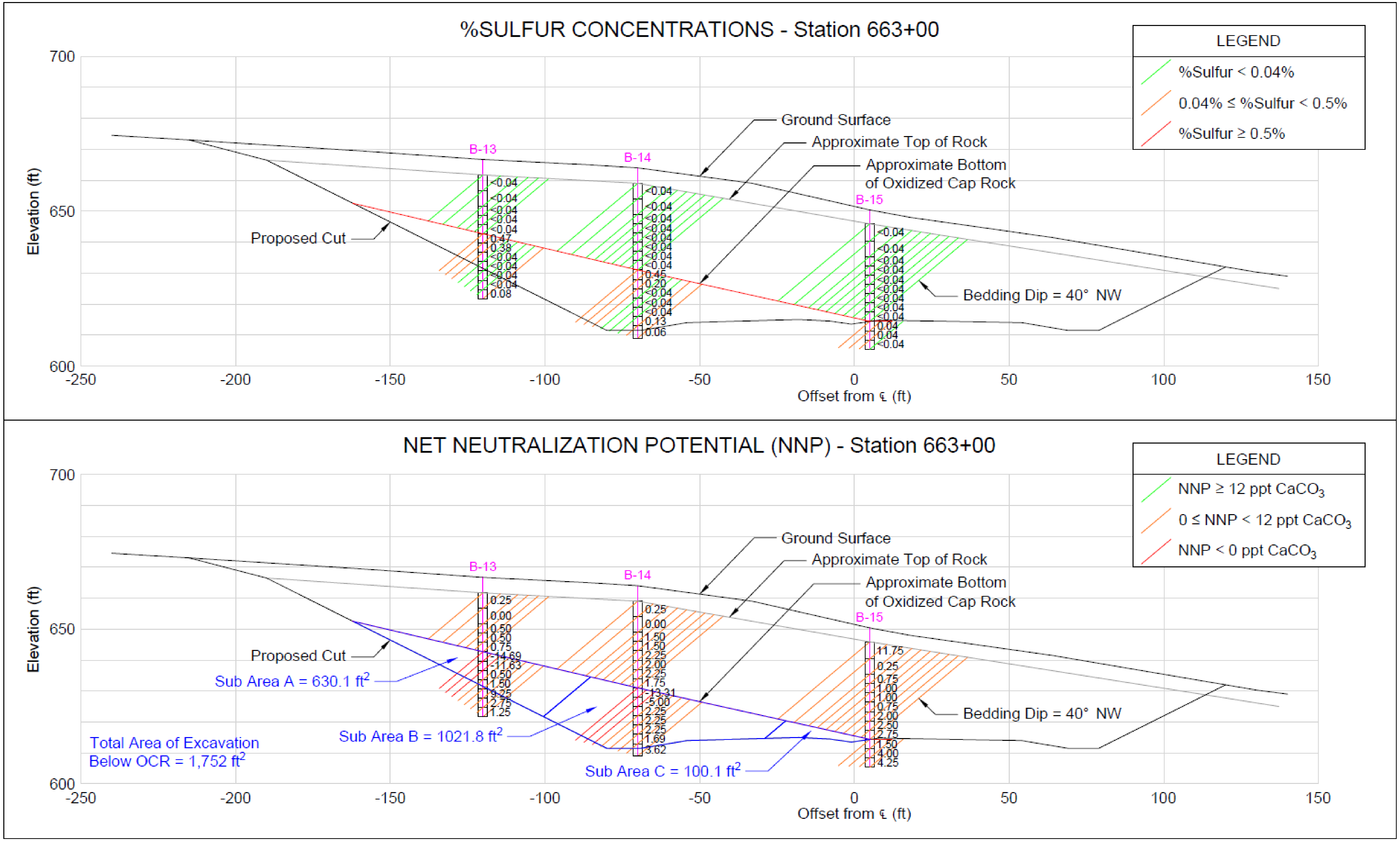

Figure 23. %Sulfur concentrations (top) and net neutralization potential (NNP) values (bottom) at Station 663+00.

bedding strike, the true dip of 40 degrees is used to draw the bedding planes. If the roadway were oblique to the bedding strike, then a smaller angle representing the apparent bedding dip angle would be used. If the roadway were trending perpendicular to bedrock strike, then horizontal lines would represent the bedding planes. Note that the bedding lines are truncated along the bottom of OCR line so that sample results from the OCR are not projected below the OCR zone and vice versa.

Also note the areas between the borings lacking bedding lines both above and below the bottom of OCR line. These white spaces indicate the data gaps where a rock bed was not tested either above or below the bottom of OCR line or both. So, despite the relatively close spacing of the borings, a complete sampling of the stratigraphic succession has not been achieved. Although the sampling effort is considered to be adequate in this case, the thoroughness of the sampling could have been enhanced in at least two ways. First, the borings could have been inclined from vertical and drilled on a southeasterly bearing to sample more beds per linear foot of coring. Angled borings also provide a better representation of steeply dipping and vertical fractures, which vertical borings may encounter less frequently or not at all depending on fracture spacing. The premium a contractor may charge for drilling angled core borings must be weighed against the expense of drilling additional vertical borings to reduce the data gaps. Second, the borings could have been drilled deeper beneath the bottom of the proposed cut in order to sample additional beds. The downside with this option is that the lab results from the deeper beds may be less representative of the actual material to be excavated; however, the deeper boring option is thought to be a conservative approach.

Step 3: Determine the weighted Net Neutralization Potential (NNP_w) of each sample:

The calculation of the weighted average for each sample excludes the samples from the portion of the boring within the OCR. Also excluded are the samples from the borings located where the OCR extends below the proposed cut line (Borings B-5 and B-6 at Station 658+00 and Borings B-11 and B-12 at Station 661+00).

NNP_W is in units of parts per thousand (ppt) $CaCO_3$ equivalent (CCE) and is determined for each sample by multiplying the NNP of the sample by the proportion of the sampled boring length represented by the sample.

$$NNP_w = \frac{(NNP\ of\ Sample)(Sample\ Length)}{Total\ Length\ of\ Sampling}$$

Since only samples below the OCR are being considered, the total length of sampling is the portion of the boring sampled below the bottom of OCR line. The results of the calculations are shown in Figures 25, 26, and 27. In each figure, the NNP_w values of the samples are listed in Column L.

Step 4: Determine the NNP of each boring (NNP_{Boring}):

Summing the NNP_W values for the number of samples (N_S) within the boring below the OCR yields the NNP of the boring below the OCR.

$$NNP_{Boring} = \sum_{i=1}^{N_S} NNP_W$$

The results of the calculations are shown in Figures 25, 26, and 27. In each figure, the NNP_{Boring} values are listed in Column M.

Step 5: Determine the weighted NNP of each sub area ($NNP_{Sub\ Area}$):

The portion of the proposed cut beneath the OCR within each section was subdivided into three sub areas (A, B, and C) as shown in the lower part of Figures 21, 22, and 23. The sub areas were delineated by finding the midpoint bedding plane within the data gaps between the borings. The area of the sub areas was determined as indicated by the callouts in the figures. The $NNP_{Sub\ Area}$ is determined for each sub area by multiplying the NNP of each boring by the proportion of the excavation below the OCR the boring represents.

$$NNP_{Sub\ Area} = \frac{(NNP_{Boring})(Area\ of\ Sub\ Area)}{Sectional\ Area\ of\ Excavation\ Below\ OCR}$$

The results of the calculations are shown in Figures 25, 26, and 27. In each figure, the $NNP_{Sub\ Area}$ values are listed in Column P.

Step 6: Determine the NNP of each section ($NNP_{Section}$):

Summing the $NNP_{Sub\ Area}$ values for the number of sub areas (N_S) within the section yields the NNP of the section below the OCR.

$$NNP_{Section} = \sum_{i=1}^{N_S} NNP_{Sub\ Area}$$

The results of the calculations are shown in Figures 25, 26, and 27. In each figure, the $NNP_{Section}$ values are listed in Column Q.

Step 7: Determine the weighted NNP of each proposed cut sub volume below the OCR ($NNP_{Sub\ Volume}$):

In this step, the volume of excavation below the OCR represented by each section is approximated and its weighted NNP determined. The sectional area of excavation below the OCR is shown for each section in the lower left of Figures 21, 22, and 23. In plan view, the proposed cut is subdivided into three segments: Station 356+00 to 359+50, Station 359+50 to 362+00, and Station 362+00 to 364+50 based on the midpoints between the three sections and the approximate beginning and ending points of the significant portion of the cut. The volumes of excavation are approximated by multiplying the area of each section below the OCR by the segment length. The results of the calculations are shown in Figure 28.

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q
				Sample Depth		Lab Results			Calculations		Sample Interval Weight			Sub Area (ft^2)	Sub Area Weight		
	Station	Boring	Sample	Top	Bottom	Total % Sulfur	MPA (ppt $CaCO_3$)	NP (ppt $CaCO_3$)	Potential Ratio	NNP (ppt $CaCO_3$)		NNP_W	NNP_{Boring}			$NNP_{Sub\ Area}$	$NNP_{Section}$
1		B-2	8	29.0	32.0	0.52	16.25	0.50	0.03	-15.75	0.1667	-2.63					
2		B-2	9	32.0	35.0	0.85	26.56	0.75	0.03	-25.81	0.1667	-4.30					
3		B-2	10	35.0	38.0	0.53	16.56	13.75	0.83	-2.81	0.1667	-0.47					
4		B-2	11	38.0	41.0	0.15	4.69	13.00	2.77	8.31	0.1667	1.39	-14.86	503.2	0.2452	-3.64	
5		B-2	12	41.0	44.0	0.81	25.31	12.50	0.49	-12.81	0.1667	-2.14					
6		B-2	13	44.0	47.0	1.12	35.00	8.25	0.24	-26.75	0.1667	-4.46					
7		B-2	14	47.0	50.0	0.77	24.06	10.50	0.44	-13.56	0.1667	-2.26					
8		B-3	7	33.0	36.0	0.04	1.25	18.00	14.40	16.75	0.0811	1.36					
9		B-3	8	36.0	39.0	0.05	1.56	10.00	6.40	8.44	0.0811	0.68					
10		B-3	9	39.0	42.0	0.10	3.13	10.00	3.20	6.88	0.0811	0.56					
11		B-3	10	42.0	45.0	0.08	2.50	11.25	4.50	8.75	0.0811	0.71					
12		B-3	11	45.0	48.0	0.75	23.44	3.25	0.14	-20.19	0.0811	-1.64					
13		B-3	12	48.0	51.0	0.09	2.81	10.00	3.56	7.19	0.0811	0.58					
14	658+00	B-3	13	51.0	54.0	0.09	2.81	15.25	5.42	12.44	0.0811	1.01	7.61	1230.2	0.5995	4.56	0.38
15		B-3	14	54.0	57.0	0.07	2.19	15.75	7.20	13.56	0.0811	1.10					
16		B-3	15	57.0	60.0	0.06	1.88	18.75	10.00	16.88	0.0811	1.37					
17		B-3	16	60.0	63.0	0.08	2.50	17.75	7.10	15.25	0.0811	1.24					
18		B-3	17	63.0	66.0	0.06	1.88	18.25	9.73	16.38	0.0811	1.33					
19		B-3	18	66.0	68.0	0.14	4.38	13.25	3.03	8.88	0.0541	0.48					
20		B-3	19	68.0	70.0	1.02	31.88	10.25	0.32	-21.63	0.0541	-1.17					
21		B-4	14	44.0	47.0	0.04	1.25	3.50	2.80	2.25	0.1429	0.32					
22		B-4	15	47.0	50.0	0.04	1.25	3.50	2.80	2.25	0.1429	0.32					
23		B-4	16	50.0	53.0	0.06	1.88	5.75	3.07	3.88	0.1429	0.55					
24		B-4	17	53.0	56.0	0.19	5.94	6.00	1.01	0.06	0.1429	0.01	3.43	318.8	0.1553	-0.53	
25		B-4	18	56.0	59.0	0.14	4.38	10.25	2.34	5.88	0.1429	0.84					
26		B-4	19	59.0	62.0	0.23	7.19	13.75	1.91	6.56	0.1429	0.94					
27		B-4	20	62.0	65.0	0.22	6.88	10.00	1.45	3.13	0.1429	0.45					

Figure 25. Calculation results for the Net Neutralization Potential for the section at Station 658+00.

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q
				Sample Depth		Lab Results			Calculations								
	Station	Boring	Sample	Top	Bottom	Total % Sulfur	MPA (ppt $CaCO_3$)	NP (ppt $CaCO_3$)	Potential Ratio	NNP (ppt $CaCO_3$)	Sample Interval Weight	NNP_W	NNP_{Boring}	Sub Area (ft^2)	Sub Area Weight	$NNP_{Sub Area}$	$NNP_{Section}$
28	661+00	B-8	6	32.0	35.0	0.88	27.50	1.50	0.05	-26.00	0.1304	-3.39	-13.50	471.0	0.3039	-4.10	0.51
29		B-8	7	35.0	38.0	1.09	34.06	1.25	0.04	-32.81	0.1304	-4.28					
30		B-8	8	38.0	41.0	0.71	22.19	1.75	0.08	-20.44	0.1304	-2.67					
31		B-8	9	41.0	44.0	0.21	6.56	5.50	0.84	-1.06	0.1304	-0.14					
32		B-8	10	44.0	47.0	0.21	6.56	7.50	1.14	0.94	0.1304	0.12					
33		B-8	11	47.0	50.0	0.43	13.44	5.00	0.37	-8.44	0.1304	-1.10					
34		B-8	12	50.0	53.0	0.76	23.75	8.25	0.35	-15.50	0.1304	-2.02					
35		B-8	13	53.0	55.0	0.52	16.25	16.00	0.98	-0.25	0.0870	-0.02					
36		B-9	7	38.0	41.0	0.21	6.56	8.75	1.33	2.19	0.0811	0.18	6.88	1017.4	0.6564	4.51	
37		B-9	8	41.0	44.0	0.08	2.50	11.00	4.40	8.50	0.0811	0.69					
38		B-9	9	44.0	47.0	0.05	1.56	8.75	5.60	7.19	0.0811	0.58					
39		B-9	10	47.0	50.0	<0.04	0.00	6.25	∞	6.25	0.0811	0.51					
40		B-9	11	50.0	53.0	<0.04	0.00	4.25	∞	4.25	0.0811	0.34					
41		B-9	12	53.0	56.0	<0.04	0.00	9.00	∞	9.00	0.0811	0.73					
42		B-9	13	56.0	59.0	0.06	1.88	12.50	6.67	10.63	0.0811	0.86					
43		B-9	14	59.0	62.0	0.21	6.56	11.25	1.71	4.69	0.0811	0.38					
44		B-9	15	62.0	65.0	0.55	17.19	9.50	0.55	-7.69	0.0811	-0.62					
45		B-9	16	65.0	68.0	0.09	2.81	18.50	6.58	15.69	0.0811	1.27					
46		B-9	17	68.0	71.0	0.11	3.44	13.75	4.00	10.31	0.0811	0.84					
47		B-9	18	71.0	73.0	0.09	2.81	14.00	4.98	11.19	0.0541	0.60					
48		B-9	19	73.0	75.0	0.08	2.50	12.00	4.80	9.50	0.0541	0.51					
49		B-10	14	49.0	52.0	0.05	1.56	8.75	5.60	7.19	0.2727	1.96	2.57	61.6	0.0397	0.10	
50		B-10	15	52.0	55.0	0.16	5.00	2.75	0.55	-2.25	0.2727	-0.61					
51		B-10	16	55.0	58.0	0.10	3.13	4.50	1.44	1.38	0.2727	0.38					
52		B-10	17	58.0	60.0	0.09	2.81	7.50	2.67	4.69	0.1818	0.85					

Figure 26. Calculation results for the Net Neutralization Potential for the section at Station 661+00.

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q
				Sample Depth		Lab Results			Calculations		Sample Interval Weight			Sub Area (ft^2)	Sub Area Weight		
	Station	Boring	Sample	Top	Bottom	Total % Sulfur	MPA (ppt $CaCO_3$)	NP (ppt $CaCO_3$)	Potential Ratio	NNP (ppt $CaCO_3$)		NNP_W	NNP_{Boring}			$NNP_{Sub Area}$	$NNP_{Section}$
53	663+00	B-13	6	24.0	27.0	0.47	14.69	0.00	0.00	-14.69	0.1429	-2.10	-1.58	630.1	0.3596	-0.57	-0.78
54		B-13	7	27.0	30.0	0.38	11.88	0.25	0.02	-11.63	0.1429	-1.66					
55		B-13	8	30.0	33.0	<0.04	0.00	0.50	∞	0.50	0.1429	0.07					
56		B-13	9	33.0	36.0	<0.04	0.00	1.50	∞	1.50	0.1429	0.21					
57		B-13	10	36.0	39.0	<0.04	0.00	9.25	∞	9.25	0.1429	1.32					
58		B-13	11	39.0	42.0	<0.04	0.00	2.75	∞	2.75	0.1429	0.39					
59		B-13	12	42.0	45.0	0.08	2.50	3.75	1.50	1.25	0.1429	0.18					
60		B-14	9	33.0	36.0	0.45	14.06	0.75	0.05	-13.31	0.1364	-1.82	-0.69	1021.8	0.5832	-0.40	
61		B-14	10	36.0	39.0	0.20	6.25	1.25	0.20	-5.00	0.1364	-0.68					
62		B-14	11	39.0	42.0	<0.04	0.00	2.25	∞	2.25	0.1364	0.31					
63		B-14	12	42.0	45.0	<0.04	0.00	2.25	∞	2.25	0.1364	0.31					
64		B-14	13	45.0	48.0	<0.04	0.00	2.25	∞	2.25	0.1364	0.31					
65		B-14	14	48.0	51.0	0.13	4.06	5.75	1.42	1.69	0.1364	0.23					
66		B-14	15	51.0	55.0	0.06	1.88	5.50	2.93	3.62	0.1818	0.66					
67		B-15	10	36.0	39.0	0.04	1.25	2.75	2.20	1.50	0.3333	0.50	3.25	100.1	0.0571	0.19	
68		B-15	11	39.0	42.0	0.04	1.25	5.25	4.20	4.00	0.3333	1.33					
69		B-15	12	42.0	45.0	<0.04	0.00	4.25	∞	4.25	0.3333	1.42					

Figure 27. Calculation results for the Net Neutralization Potential for the section at Station 663+00.

Section	$NNP_{Section}$	Section Area (ft^2)	Profile Length (ft)	Sub Volume (ft^3)	Volume Weight	$NNP_{Sub\ Volume}$	NNP_{Cut}
358+00	0.38	2,052	350	718,279	0.4653	0.18	0.08
361+00	0.51	1,550	250	387,500	0.2510	0.13	
363+00	-0.78	1,752	250	438,000	0.2837	-0.22	

Figure 28. Calculation results for NNP of the proposed cut material below OCR.

$NNP_{Sub\ Volume}$ is determined for each sub volume by multiplying the NNP of the section by the proportion of the excavated volume represented by the sub volume.

$$NNP_{Sub\ Volume} = \frac{(NNP_{Section})(Sub\ Volume)}{Volume\ of\ cut\ below\ the\ OCR}$$

The $NNP_{Sub\ Volume}$ in ppt $CaCO_3$ is 0.18 for the first segment represented by the section at Station 358+00, 0.13 for the middle segment represented by section at Station 361+00, and -0.22 for the third segment represented by the section at Station 363+00.

Step 8: Determine the NNP of the proposed cut below the OCR (NNP_{Cut}):

Summing the $NNP_{Sub\ Volume}$ values for the three segments indicates the NNP_{Cut} is 0.08 ppt CaCO3.

Step 9: Determine the SAM_{req} for Option 1:

The target NNP is 12 ppt $CaCO_3$, so the SAM_{req} is calculated:

$$SAM_{req} = 12\ ppt\ CaCO_3 - 0.08\ ppt\ CaCO_3 = 11.92\ ppt\ CaCO_3$$

Step 10: Determine the SAM_{rate} for Option 1:

A Factor of Safety of 1.5 is used to determine the SAM_{rate}:

$$SAM_{rate} = 11.92\ ppt\ CaCO_3 \times 1.5 = 17.88\ ppt\ CaCO_3$$

Step 11: Determine the SAM_{req} for Option 2:

The minimum NNP value of -49.06 ppt $CaCO_3$ was measured on the bottom sample from Boring B-5 in Section 658+00 as shown in Figure 21. At the location of Boring B-5, the proposed excavation is within the OCR, so this minimum value is not used. Instead, the NNP of -32.81 measured in the seventh sample from Boring B-8 at Station 661+00 is considered the minimum NNP value as the proposed cut extends below the OCR at the location of Boring B-8.

The target NNP is 12 ppt $CaCO_3$, so the SAM_{req} is calculated:

$$SAM_{req} = 12\ ppt\ CaCO_3 - -32.81\ ppt\ CaCO_3 = 44.81\ ppt\ CaCO_3$$

Step 12: Determine the SAM_{rate} for Option 2:

A Factor of Safety of 1.3 is used to determine the SAM_{rate}:

$$SAM_{rate} = 44.81\ ppt\ CaCO_3 \times 1.3 = 58.26\ ppt\ CaCO_3$$

Step 13: Determine the SAM_{rate} to be used:

The Option 1 SAM_{rate} is less than the Option 2 SAM_{rate}. Per the flow chart in Figure 19, the SAM_{rate} is calculated by averaging the Option 1 and 2 SAM_{rate} values:

$$SAM_{rate} = (17.88 + 58.26)/2 = 38.07\ ppt\ CaCO_3$$

Based on the Option 1 SAM_{req}, the SAM_{rate} provides a Factor of Safety of 3.19:

$$38.07\ ppt\ CaCO_3/11.92\ ppt\ CaCO3 = 3.19$$

The recommended SAM_{rate} of 38.07 ppt $CaCO_3$ would apply to the entire rock cut. If the analyses had identified discrete zones having significantly lower NNP values than others, then the calculation of a SAM_{rate} for the discrete zones may be appropriate depending on the size of the zones and the anticipated excavation methods. Having one SAM_{rate} for the entire cut is desirable since it simplifies the contractor's excavation sequencing, material tracking, and construction operations. In this case, the treatment zone could be delineated in project drawings to include a buffer zone above the OCR in order to account for the uncertainty due to the data gaps between the borings. The OCR material from the buffer zone included in the potential APR to be treated will have a higher NNP and thus further increase the average NNP of the treated material and the Factor of Safety of the treatment.