Long-Term Mine Soil Weathering and Treatment Effects: Do Topsoil Substitutes Really Mimic Natural Soils?

2008/2009 Powell River Project Annual Progress Report

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Introduction and Background

The Surface Mine Control and Reclamation Act (SMCRA) of 1977 contained a number of contentious provisions including return to original contour (AOC), long-term liability bonding periods, and return to "equal or better" post-mining land use conditions. However, one of the more stealthy provisions was SMCRA's allowance for use of pre-selected overburden materials as topsoil substitutes when (A) the native A+E horizon materials are less than 6 inches thick, and (B) the physical and chemical properties of the proposed substitute spoil materials are deemed suitable for such use. Since native topsoil layers throughout the Appalachian coalfields are usually less than six inches thick, and removing them from steep slopes is difficult and expensive, the vast majority of coal mined lands in the region have employed topsoil substitutes.

In 1982, the USDI Office of Surface Mining and the Powell River Project co-funded the installation of the Controlled Overburden Placement (COP) experiment to objectively assess the viability of the topsoil substitute concept and to determine whether or not organic amendments would be beneficial. In one component of the COP experiment we are directly comparing five mixes of sandstone:siltstone (SS:SiS) overburden while in a separate experiment we are following the effects of topsoil return, sawdust addition and four incremental loading rates of biosolids. All treatments are replicated four times and the plots are split between herbaceous (dominantly tall fescue) and forest (red oak following pine) vegetation. We intensively monitored those two side-by-side experiments through the late 1980's, and our results can be reviewed at the PRP web site and at http://www.cses.vt.edu/revegetation/minereclam.html. In summary, we found that (A) properly selected and placed spoil materials provided an outstanding soil medium for tall fescue production and allowed vigorous invasion of native herbaceous species; (B) higher pH spoils such as the siltstone strata employed were deleterious to pine tree growth; and (C) higher rates of biosolids amendments drove high fescue production while suppressing the pines. The COP experiment remains the longest intact and continuously monitored study of mine soil genesis in the World. Follow-up studies by our group at other sites in the 1990's and early 2000's also characterized the wider effects of biosolids applications and the nature of inherent variability in mine soil properties in the Research & Education Center. However, very little detailed soil analyses have ever been performed on the native pre-mining soils in the Research & Education Center area for direct comparison.

Over the past decade, the concept of topsoil substitution has been directly and indirectly criticized from a number of perspectives. First of all, advocates of the return of Appalachian mined lands to native forest covers have pointed to the lack of topsoil salvage and the inclusion of higher pH unweathered spoils as directly inhibiting effective reforestation. These objections have been raised by citizens and certain well-trained scientists alike. Secondly, the fact that relatively unweathered spoils (such as those employed in the COP study) release significant total dissolved solids (TDS) loads to drainage waters over time has been implicated as a component of mining related surface water degradation under both low and moderate pH conditions. In fact, it now appears that mining discharges will be directly regulated for TDS over time and reducing bulk TDS may be a much more difficult water treatment proposition for the coal industry than limiting more conventional parameters such as total Fe and Mn. Finally, the ability of these mine soils to accumulate organic matter, maintain a stable and viable microbial biomass and available nutrient pools, and overall productivity potentials beyond the requisite five-year performance liability period is also questioned by many citizens' groups.

In 2007, we proposed to directly address a number of these challenges by initiating a new program of mine soil sampling and analysis utilizing our established baseline experiments at the Research and Education Center, and at other locations where long-term baseline data sets are available, that will allow us to study changes in mine soil properties and productivity relationships over prolonged periods of time. Furthermore, we will directly compare mine soil properties for a range of important parameters (e.g. pH, organic matter content, P-forms, microbial biomass) with a suite of unmined native soils forming out of the same rocks. Thus, by a combination of direct and differential analysis, we propose to meet the following objectives:

Research Objectives

1. To determine the long-term (20+ years) effects of overburden rock type and surface treatments on important mine soil morphological, physical, chemical and microbiological properties.

2. To directly compare the properties of weathering mine soils of varying age with unmined native soils formed from the same strata.

3. To measure the net TDS elution potential of a range of fresh, partially weathered and well-weathered topsoil substitute materials.

4. To predict the ability of selected overburden materials to weather and transform into mine soils suitable for the support of native hardwoods and hayland/pasture vegetation, and to estimate the rate of transformation.

Methods and Procedures

Overall Approach

We are fortunate to have an array of well-characterized, documented and "preserved" research sites throughout the Powell River Project Research & Education Center area and the surrounding region. These include the COP experiment, areas to the north of Powell River that have been minimally disturbed since 1990, and certain limited locations south of Powell River that have not been re-mined since 1990. While much of the 1990 aged mine soil surface received a uniform treatment of biosolids+compost, there are significant areas of that surface that did not. By differentially sampling across these contrasting treatment areas, we will be able to directly determine the net effect of organic matter additions on long term soil development process and important mine soil productivity parameters.

Furthermore, the recent re-mining activity to the south of Powell River will allow us to sample and “pair up” mine soil pedons that are very young (1 to 10 years) with much older mine soils (25+ years) to the north that formed out of identical parent materials. Finally, we also have access to a range of relatively intact native forest soils in the overall Powell River area that occur between mining disturbances.

We are now completing the second year (of three) of this study. In years one and two, we focused field work on collecting a wide range of unweathered and weathered spoil types in the region and on sampling pedons within the immediate vicinity of the Research & Education Center as described above. In the laboratory we focused on characterizing the chemical and physical properties of these soils, as well as on column leaching studies to characterize the potential leaching behavior of various mine spoil materials. In the upcoming final year, we will complete all laboratory work, sample or re-sample additional pedons to fill out the data set, and construct a qualitative model of how basic mine soil morphological, chemical, physical and microbiological properties respond to (A) initial spoil type and (B) initial surface treatments over extended periods of time.

For all soil pedons sampled in the area of the Research & Education Center and beyond, each morphological horizon and selected depth increment samples will be analyzed for the parameters listed below. Archived samples from 1981 and 1990 for matching pedons will be similarly analyzed, allowing us to determine both the mass leaching that has occurred over time within pedons and the net amount lost over 15 to 25 years.

pH and total titratable acidity
Saturated paste electrical conductance (EC) and solid salts species (cations + anions)
Total organic carbon (TOC) and Walkley-Black organic matter (OM)
Organic matter fractions
Microbial biomass
Bulk microbial activity (incubation/CO_2 evolution)
Total-P and Total-N
Exchangeable cations
Dilute acid extractable nutrients and metals
Extractable Fe and Mn oxides
Total-S and S-forms if $S \geq 0.2\%$
Calcium carbonate equivalence (CCE)
% Rock fragments
Particle size analysis
Aggregate stability
Moisture desorption/water holding capacity on < 2mm fractions

Progress to Date (August 2009)

Our efforts during the second year of this study have focused on 1) continued work in the field and laboratory to describe, sample, and characterize soil profiles developed in both undisturbed materials and in various spoil types, and 2) conducting leaching column studies to characterize the potential leachate characteristics of various mine spoils. Our column leaching studies have focused on detailed characterization of TDS elution with time and ionic species composition.

Soil Profiles

In the first year of this study ten soil profiles, including 3 unmined native soils and 7 mine soils, were described and sampled in the field. In year two an additional 2 mine soils were described and sampled, and several of the soil characterization procedures (listed above) were completed in the laboratory.

One objective of our study is to compare the properties of unmined native soils with weathering mine soils formed from the same strata. As an example, Tables 1 and 2 provide some chemical and physical data for a native soil and a mine soil which both formed from Taggart sandstone. These two soil profiles are illustrated in Figure 1. Although a deeper profile was exposed for the mine soil, the thicker solum of the native soil (51 cm vs. 24 cm) was readily apparent. The surface horizons (A and ^A1) of the two soils were similar in terms of depth, color, pH, CEC, TOC, and water holding, while their most notable differences included 1) texture (<2 mm) was coarser in the native soil, 2) rock fragments were more abundant in the mine soil, 3) EC was higher in the mine soil, and 4) extractable nutrients, with the exception of K and Fe, were higher in the mine soil. These differences, with few exceptions, were observed throughout the subsoil horizons as well. Of particular note, the pH of the parent material in the mine soil (pH > 5.4) was noticeably higher than that of the native soil (pH < 4.6).

Table 1. Some chemical properties of a native soil (PRP-2) and a mine soil (PRPS-5) formed from Taggart sandstone at Powell River Project.

horizon	**EC**	**pH**	**N**	**C**	**CEC**	**P**	**K**	**Ca**	**Mg**	**Zn**	**Mn**	**Cu**	**Fe**	**B**
	dS/m		**%**	**%**	**cmol+/kg**	**------------------------ mg/kg ------------------------**								
PRP-2 (native soil developed over Taggart sandstone)														
A	0.09	4.60	0.23	4.70	20.70	6	83	248	46	1.5	19.4	0.6	86.9	0.1
Bw	0.06	4.39	0.03	0.71	13.26	2	40	44	14	0.4	5.5	0.3	26.8	0.1
CB	0.05	4.49	0.03	0.48	6.82	2	49	46	22	0.3	2.5	0.3	23.0	0.1
C	0.04	4.57	0.03	0.36	10.78	2	47	59	49	0.4	3.0	0.3	24.6	0.1
PRPS-5 (mine soil developed from Taggart sandstone spoil)														
^A1	1.36	4.65	0.31	4.44	21.91	27	76	1062	280	3.5	28.7	0.8	31.0	0.3
^Bw	0.18	5.81	0.05	1.26	10.42	47	35	744	264	1.9	13.2	2.0	30.1	0.1
^2C	0.15	5.84	0.18	6.54	33.92	10	34	1894	506	5.4	14.0	0.5	8.3	0.1
^3C	0.13	5.46	0.01	0.31	4.74	2	31	249	120	0.6	12.5	0.4	23.3	0.1

Table 2. Some physical properties of a native soil (PRP-2) and a mine soil (PRPS-5) formed from Taggart sandstone at Powell River Project.

horizon	**> 2mm**	**sand**	**silt**	**clay**	**water holding capacity**	
	-------------------- % --------------------				**-0.03 MPa**	**-1.5 MPa**
PRP-2						
A	8.5	64.0	23.4	12.6	23.13	7.52
Bw	19.0	67.2	21.1	11.7	14.26	4.80
CB	10.5	65.3	23.4	11.3	14.20	4.53
C	14.0	65.0	25.6	9.4	15.43	6.31
PRPS-5						
^A1	47.3	49.4	35.5	15.1	21.39	8.10
^Bw	52.2	45.4	40.8	13.8	20.33	7.34
^2C	36.1	38.3	43.7	18.0	21.13	7.63
^3C	34.7	74.5	15.5	10.0	18.63	6.69

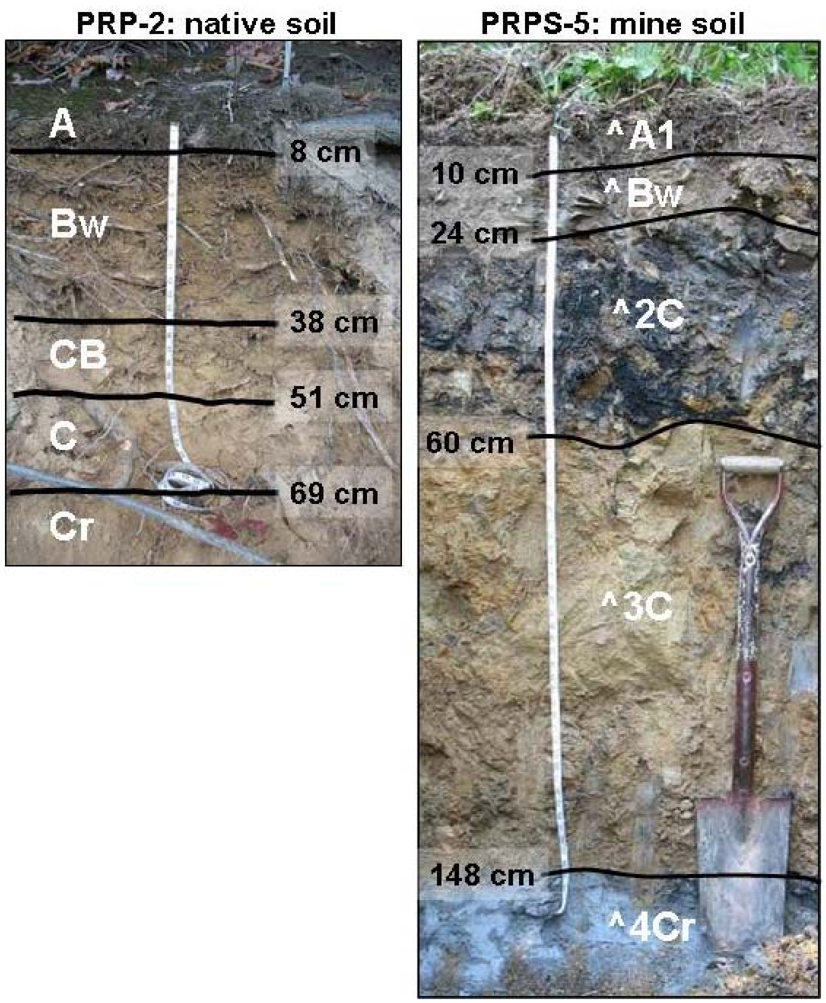


Figure 1. Two soil profiles - a native soil (PRP-2) and a mine soil (PRPS-5) - formed from Taggart sandstone at Powell River Project.

Spoil Characterization and Leaching/Weathering Trials

In year one of this study, fifteen samples representing fresh, partially weathered and well-weathered topsoil substitute materials were collected from PRP and other mines in southwest Virginia and eastern Kentucky. These samples represented a variety of spoil types including sandstone, siltstone and mudstones in different proportions and at various degrees of weathering.

A leaching column study was established in July 2008 to characterize bulk TDS and specific elemental release from a subset of the spoil materials. Three spoil samples (OSM 2, OSM 3, and OSM 11) were selected to represent a mudstone, a sandstone, and a mix of materials. Some geologic, chemical and physical characteristics of these three samples are presented in Tables 3 and 4. The leaching columns were built from PVC pipe with a diameter of 7.6 cm and a length of 40 cm (volume = 1200 cm^3). The samples were run in triplicate under saturated and unsaturated conditions (18 columns total), and were leached and sampled twice a week for 8 months using a simulated rainfall solution (pH 4.8). Leachate solution samples were analyzed for pH, electrical conductivity (EC), total dissolved solids (TDS), total organic carbon (TOC), cations, metals, Cl and SO_4.

After the first leaching study was completed (March, 2009) the columns were re-established in an identical manner as described above with a second set of spoil samples to more completely represent the various spoil types at various degrees of weathering. These columns are being leached and sampled twice a week using the simulated rainfall solution, and the leachate samples are being analyzed for pH, EC, and selected cations and metals.

From the first leaching study, the plotted data for EC and TDS (Fig. 2) were nearly identical other than the scale of the y-axis. The major difference between the two parameters was that EC was determined on the bulk unfiltered leachate sample and TDS was determined on a filtered sample with corresponding possible reduction/changes in the solution composition. As indicated in Figure 2, all three spoil samples experienced an initial TDS flush ranging from approximately 750 to >4000 mg/L. Leachate EC and TDS from the unweathered mine spoil (OSM #2) was consistently higher than from the partially oxidized and weathered samples. Initial values dropped quickly to a steady state of relatively low levels for the remainder of the leaching trial. No treatment effect of saturated versus unsaturated conditions was observed. The high correlation coefficient of r=0.98 between EC and TDS is not surprising, and underpins the regulatory assumption that EC can be used as an effective proxy for TDS.

The large elution of bulk EC and TDS from the mudstone spoil probably reflects the presence of a highly reactive sulfide (framboidal?). Although present in relatively low amounts (0.23% S), the sulfides reacted quickly with substrate carbonates to produce sulfates and prolonged sulfate release over the extent of this experiment. Acid-base reaction control on leachate chemistry was also reflected in leachate bicarbonate and sulfate as discussed below.

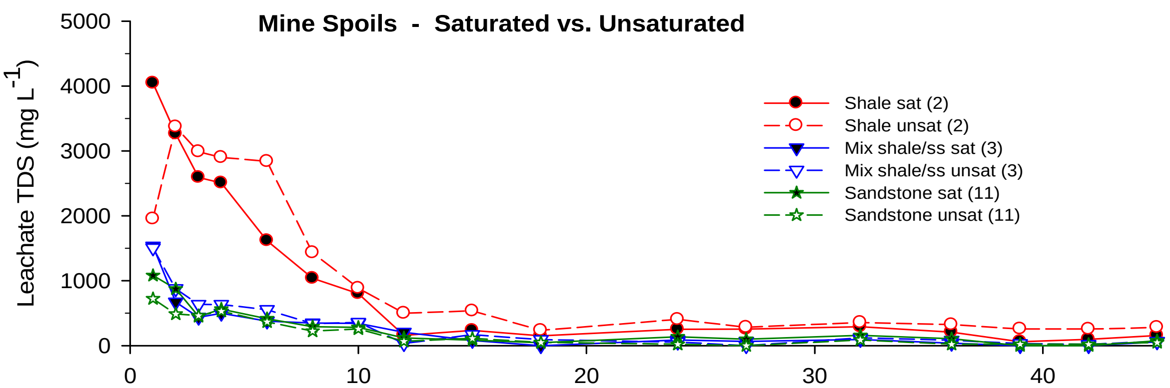
Table 3. Geologic description of topsoil substitute materials.

Lab-ID	Geologic Description	Coal Seam
OSM 2	93% dark gray, carbonaceous, silty mudstone; 6% unweathered, gray, fine-grained sandstone and siltstone; 1% coal.	Hazard #7 and #8
OSM 3	50% highly weathered, gray and orange, fine grained and medium to coarse grained, feldspathic sandstone; 30% unweathered, gray, silty mudstone ; 10% unweathered, feldspathic sandstone; 8% unweathered, gray, silty mudstone; 2% coal.	Kelly/ Imboden
OSM 11	99% weathered sandstone; 1% silty mudstone; trace coal.	Taggart

Table 4. Some chemical and physical characteristics of topsoil substitute materials.

Lab-ID	<1 cm	>1 cm	pH	EC	PPA[1]	CCE	S	C
	-------- % --------			dS/m		%	%	%
OSM 2	60	40	7.0	3.48	0.00	4.6	0.23	4.73
OSM 3	87	13	6.9	0.94	3.58	1.3	0.07	3.25
OSM 11	68	32	6.3	0.56	0.28	3.7	0.02	0.78

[1] PPA = Peroxide Potential Acidity: results expressed in tons of $CaCO_3$ lime demand per 1000 tons material.



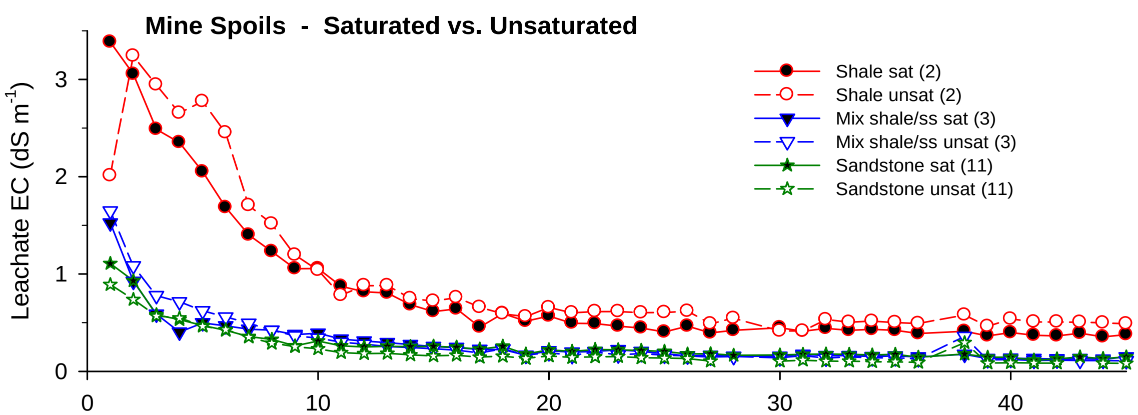


Figure 2. Leachate TDS from three mine spoils under saturated and unsaturated conditions. The 45 leachate events occurred over 153 days.

The relationship of leachate TDS to its mass elemental composition (mg L^{-1}) was evaluated periodically during the leaching period. Examples of these data are graphically presented in Figure 3. Six elements, Ca, K, Mg, Na, S, and C were found to be either quantitatively and/or functionally the major components of the leachate solutions. In all but one instance, the sum of the elements in the leachate solution exceeded the TDS values, and was likely due to methodological (filtering) differences. We believe that the mass leachate concentrations probably contained colloidal suspended phases allowing the sum of elements to exceed TDS typically in the range of 20 to 40% (approached 90% for certain samples not shown here).

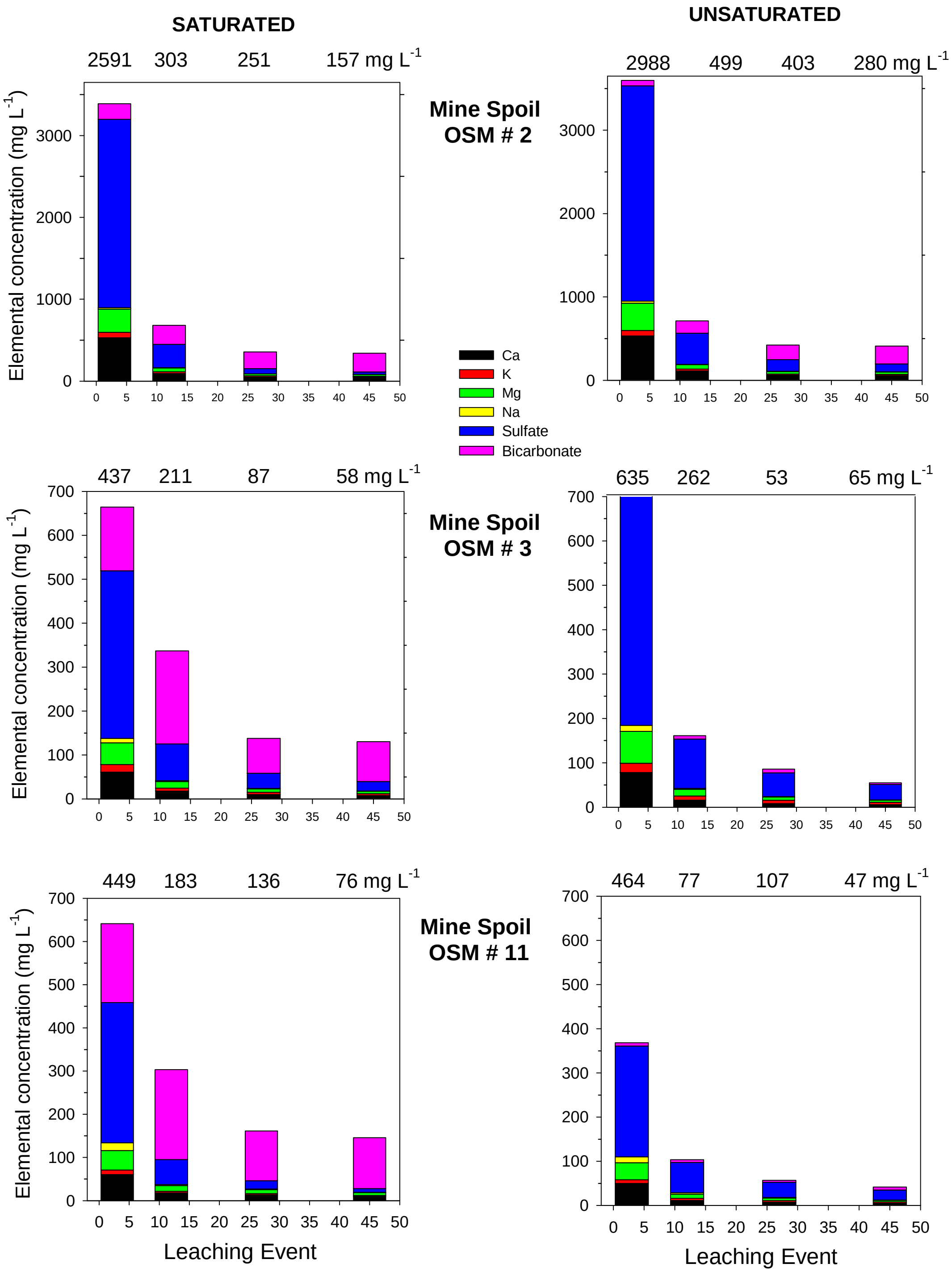
The elemental composition from the three samples under saturated conditions was dominated by sulfate and bicarbonate (Figure 3). The sulfate component decreased over the course of the leaching trial while the bicarbonate component remained approximately the same in mass, and thus became the dominant anion. The release of bicarbonate for OSM-2 under unsaturated conditions was approximately equal to that under saturated conditions. For the other two mine spoils, however, the elemental composition was dominated by the elution of sulfate, and bicarbonate was nearly absent due to acid neutralization reactions. The release of all other elements, which contributed only minor amounts to TDS, was very similar under saturated and unsaturated conditions.

The TDS x ion species data and insights summarized here are drawn from a much larger data set that is currently under review and will be reported fully in next year's final report. We are also currently analyzing additional mine spoil samples in the laboratory to expand the data set. However, we can make the following preliminary conclusions about TDS elution over time from these materials.

The mine spoils sampled in this study were typical of surface mined overburden in the central and southern Appalachians in that they were largely non-acid forming and moderate (> 6.0) in initial pH and prolonged leachate pH effects. Mine spoils that were significantly pre-weathered were lower in pH and Ca as expected. The samples appear to represent a broad range in elemental content, yet they did not include extreme values for any of the elements analyzed.

Due to their relatively high carbonate content (CCE), the majority of samples tested maintained a moderate pH (6.0 to 8.0) in leachates over the full study period (22 weeks). However, all samples eluted considerable levels (> 500 mg L^{-1}) of TDS (with high EC) over their initial leaching cycles and samples that contained significant reactive sulfides continued to elute high TDS levels for the duration of the study, regardless of their leachate pH values. However, prolonged and significant TDS release was observed from a mudstone spoil from Kentucky (saturated and unsaturated), and relatively high initial release occurred from one mixed mine spoil from Virginia. These differences in TDS release were all clearly related to basic sulfide oxidation reactions with subsequent generation of sulfate and other reaction and dissolution products.

This study also generated full leaching data sets on As, Mo, Se and several other ions of emerging regulatory interest which will be reported in full in next year's research report.



* Value are those of TDS measured from a filtered subsample of the leachate

Figure 3. Quantitative distribution of major elements in leachate solutions and the respective TDS values from mine spoil. Samples represent leaching events # 3, 12, 27, and 45. Values within charts represent total leachate analyses while TDS value is given at top of charts.

Summary Work Planned for Year 3

In year 3, we will complete the remaining column leaching studies described above for an additional set of mine spoils from SW Virginia of varying lithologies and weathering/oxidation extent. We will also complete sampling and laboratory analyses of the 25+ year old mine soils from the COP experiment and compare their bulk physical and chemical properties with those of the original spoil samples taken from the plots in 1982.

Data Analysis, Synthesis and Expected Results

At the end of year three (2009/2010), we will be able to directly determine and report the relative effect of rock type and surface treatments in the COP experiment on 25 years of mixed herbaceous vegetation and tree growth. We will also be able to contrast the differential effects of the two different vegetative cover conditions on surface soil properties. Similarly, by comparing the properties of the biosolids treated/untreated 15 year-old Taggart mine soils, we will be able to confirm overall rates of important mine soil transformation such as pH reduction and organic matter accumulation in an initially high pH sandstone system. By the comparing the bulk salt and acid extractable nutrient+metal data for each pedon with depth, we will be able to calculate the mass “TDS leaching potential” of each mine spoil material and assess how much of the TDS load appears to have leached over 15 and 25 year time spans and from what depth. These data and findings will be reinforced by our spoil leaching column trials which were originally established in 2008 and are being continued with a new set of spoil samples for at least six months into early 2010. Finally, we will directly compare and contrast all mine soil pedons with nearby natural soils over the same strata.

At the completion of the study, we will integrate all data sets from all components of the study to specifically address and meet our first three objectives. The latter part of the final project year will be focused upon constructing a qualitative (but well quantified!) model of how SW Virginia mine soil properties change with time, and the relative effects of original spoil type and surface treatments on those processes.