

Predicting TDS Release from Appalachian Mine Spoils

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ABSTRACT

The Appalachian coal industry faces increasing regulatory pressures to limit discharge of total dissolved solids (TDS) from surface runoff and fill drainage into headwater streams. Unweathered overburden materials in the region contain varying amounts of reactive carbonates, feldspars and traces of pyrite which can oxidize, react and leach to produce significant TDS loads under both low and circumneutral pH conditions. Thus, there is a clear need for the development of new efficient laboratory techniques to predict the TDS elution of mine spoils. The objective of this study was to evaluate a simple column leaching approach for this purpose and to study acid-base interactions and overall TDS elution relationships from a variety of spoil materials. Ten spoils typical of those used as topsoil substitutes or placed into valley fills were characterized and subjected to leaching in columns for 22 weeks under saturated and unsaturated conditions. Leachates were analyzed for pH, electrical conductance (EC), Ca, sulfate and other major ions. The pH of the bulk samples (prior to leaching) was typically near-neutral to alkaline. Bulk leachate EC produced by fresh spoils was initially moderate ($\leq 1,000 \mu\text{S}/\text{cm}$), although one value ranged up to $\sim 3,500$. Relatively low total S ($< 0.15\%$) in conjunction with calcium carbonate equivalent (CCE) levels

of 1.3–6% resulted in low (or no) potential acidity levels. Leachate pH increased noticeably for most materials over the first few leachings, but after approximately one month, the majority of samples showed no major changes. Leachate EC decreased over the first several leachings and most samples achieved a relatively steady state with relatively low levels (< 500 to $1,000 \mu\text{S}/\text{cm}$) within several pore volumes. Leachate pH, EC, Ca, and sulfate elution were directly related to internal acid-base reactions and to a lesser extent, water saturation regime. While the column technique evaluated here may provide a viable option for TDS prediction, it is both resource- and time-intensive and needs to be tested and calibrated against actual field scale data from the same or similar strata. Current research conducted by the Appalachian Research Initiative for Environmental Science (ARIES) is focused on (1) conducting column leaching trials on a much wider array of regional spoils, (2) developing new quick static tests to predict both peak and long-term TDS production, and (3) determining appropriate scaling factors to relate both column and static test data to predict field conditions.

INTRODUCTION AND BACKGROUND

The Surface Mine Control and Reclamation Act (SMCRA) of 1977 contained a number of

contentious provisions including the allowance for use of pre-selected overburden materials as topsoil substitutes when the native A+E horizon materials are less than 15 cm (6") thick, and 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 15 cm 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. Thus, the final graded and revegetated surfaces usually consist of overburden derived topsoil substitutes that are commonly much higher in pH and weatherable minerals, including carbonates, than native soil profiles and rock saprolites. Similarly, SMCRA requires the isolation of acid-forming materials (≥ 5 tons CCE/1,000 tons net acid-forming) away from contact with surface runoff and isolation away from internal drainage in mining fills. However, where acid-forming strata are thin relative to adjacent net alkaline strata or where they can be blended with sufficient volumes of other net alkaline materials in the blasting-hauling-placement sequence, the industry has relied upon appropriate application of acid-base-accounting procedures (Skousen et al. 2002) to ensure that the drainage from highwall backfills and valley fills is non-acidic and below discharge limits for Fe, Mn and SO_4^{2-} . As described below, both of these practices (topsoil substitution and acid/alkaline spoil blending) have more than likely led to enhanced levels of total dissolved solids (TDS) in Appalachian coal mine discharge waters vs. undisturbed pre-mine conditions.

The dominant constituent ions of TDS released by weathering of central Appalachian mine spoil materials are typically Ca, K, Mg, Na, SO_4^{2-} and HCO_3^- , in circumneutral waters and higher amounts of Al, Fe and Mn in strongly acidified systems (Daniels et al. 2009; Skousen et al. 2000). All of these components are released by various chemical weathering reactions, particularly when deeper unweathered and unoxidized strata are uncarthed and exposed to rapid

oxidation, hydrolysis, hydration and dissolution reactions in the surfaces and fills of active coal mines. The upper 5 to 15 m of overburden is typically weathered and oxidized to some extent by long-term geochemical weathering (Haering et al. 2004) and leaching and is therefore much less likely to generate significant TDS after blasting and placement. However, deeper strata commonly contain significant amounts of reactive sulfides, carbonates, feldspars and other mineral phases that rapidly produce varying loads of soluble ions to percolating water and runoff, particularly as they interact with their initial pore volumes of bathing waters.

Essentially, surface coal mining in the Appalachian region creates a set of "weathering conditions" whereby generation of significant loads of TDS to leaching waters and runoff is significant and largely unavoidable. That being said, the fact that current regulations and mining practice mandate that all potentially acid forming materials (potential acidity >5 tons/1,000 tons CCE net acid) must be isolated away from the surface and from significant ground water interaction certainly eliminates the largest potential source of net TDS release. However, the fact that many strata contain significant amounts of reactive sulfides that are essentially balanced by carbonates in terms of their acid-base account (ABA) means that these materials will contribute substantially to TDS loadings (particularly Ca, Mg, and SO_4^{2-}) as they weather while maintaining moderate to circumneutral pH conditions in that drainage (Daniels et al. 2009). In addition to these acid-base reactions, fresh spoils can also contribute significantly to TDS due to simple dissolution reactions of carbonate cements, hydrolysis weathering of feldspars and other primary mineral grains and traces of entrained Cl salts.

Over the past decade, the concept of topsoil substitution has been criticized from a number of perspectives including potential effects on water quality due to inclusion of higher pH and more chemically reactive overburden in contact with surface water runoff. Similar concerns about elevated long-term emission of TDS from backfills

and valley fills have also emerged. In a series of actions between 2009 and 2011, the US EPA attempted to use its Clean Water Act Section 404 authority that to establish 500 $\mu\text{S}/\text{cm}$ electrical conductivity (equivalent to about 350 mg/L TDS) as a potential or *de facto* standard, at least within heavily mined watersheds. For example, citing Pond et al. (2008), an EPA official testified to the US Congress that "These dissolved ions are not readily sequestered by the surrounding geology and may ultimately emanate from the fills for decades. ... This impairs the use of the streams and ultimately leads to listing of these streams as 'impaired water bodies' in EPA's water quality reports ..." (Pomponio, 2009). Several recent studies (Chapman et al. 2000; Goodfellow et al. 2000; Pond et al. 2008; Timpano 2010) have addressed the issue of TDS as a major stressor upon receiving streams in mined watersheds. More recent EPA guidance (issued in 2011) was based on the belief that mine discharges with EC levels <300 $\mu\text{S}/\text{cm}$ generally will not cause significant degradation of the aquatic ecosystem, while in-stream conductivity levels >500 $\mu\text{S}/\text{cm}$ are likely to be associated with significant adverse impacts on the aquatic ecosystem. The proposed guidelines suggested that projects expected to increase conductivity to levels >300 $\mu\text{S}/\text{cm}$ should require adaptive remedial action to prevent conductivity from rising to levels that may contribute to water quality degradation and sites with discharges >500 $\mu\text{S}/\text{cm}$ should not be allowed to continue to operate. While the ability of US EPA to directly implement this guidance was recently rejected in U.S. Federal Court, the decision (Walton 2012) left it open for OSM and the states to develop and establish TDS regulatory limits based upon the "best available science." Thus, we feel it likely that coal mining discharges will be directly regulated for TDS (via measurement of EC) at some point in time.

Historically, pre-mining overburden analysis to minimize water quality impacts has focused upon conventional ABA (Sobek et al. 2000) since discharge pH, SO_4^{2-} , Fe and Mn levels have been the principal compliance parameters. Little, if any, work has been reported to date on

the utility of either ABA or other techniques to predict bulk TDS. We believe that other relatively simple laboratory techniques such as variations upon saturated paste electrical conductance (EC; Rhoades et al. 1982) or abrasion/hydrolysis pH measurements may also be helpful in predicting short-term bulk TDS elution potential for a given material. We also feel it likely that a combination of typical ABA measures such as pyritic-S and CCE coupled with an appropriate EC measurement on a ground sample may give an accurate of both total long-term mass (from the ABA) and short-term initial pore volume (from EC) TDS elution potential.

The primary focus of this paper is to present a summary of our recent preliminary findings on the characteristics and potential leaching behaviors of selected central Appalachian mine spoils in terms of pH, EC, and ions of interest (Ca and SO_4^{2-}) in relation to the TDS discharge issues discussed above. This paper also describes the column leaching technique that we have employed in detail and our current estimation of its predictive capabilities and limitations. Finally, we use this paper to present the current framework for a much larger study on the topic that is currently being conducted by the Appalachian Research Initiative for Environmental Science (ARIES).

MATERIALS AND METHODS

Sample Collection and Geology

Fifteen mine spoils associated with major surface mining activity and valley fills in southwest Virginia and eastern Kentucky were collected from six different coal mine sites. The Virginia strata were derived from the Wise, Norton and Lee Formations and the Kentucky samples from the Breathitt Formation; all middle to upper Pennsylvanian. The original sampled materials were all approved for use as either topsoil substitutes or for placement into durable rock hollow fills. Thus, none of these materials were expected to be net acid-forming. A subset of ten spoil samples was selected for use in a more detailed column leaching study. These subsequent column study samples were selected based on results from static testing and representation of diverse spoil

types including sandstones, siltstones and mudstones, as well as different degrees of weathering for paired spoil samples.

Spoil and Refuse Characterization Methods

All analyses were conducted in triplicate unless specifically noted otherwise. Electrical conductance (EC) (Rhoades, 1982) and pH were determined on saturated paste extracts on ground (≤ 2 mm) subsamples from each spoil. Each spoil or refuse sample was mixed with deionized (DI) water until it formed a glistening paste, equilibrated for ≥ 2 hours, then filtered and analyzed. As opposed to using a defined quantity of water, this method allows comparison of materials under similar levels of saturation (i.e., coarser materials will require less water than fine materials to achieve saturation). For comparison, pH was also determined on a 2:1 water to sample solution. Peroxide potential acidity (PPA) was determined by a modified hydrogen peroxide oxidation technique as described by Orndorff et al. (2008). The method oxidizes all sulfides with 30% H_2O_2 and assumes net internal reaction of acids formed with carbonates and other neutralizers. Total net potential acidity is determined by whole sample titration following full reaction. Total-S was determined via combustion on an Elementar CNS analyzer. The calcium carbonate equivalent (CCE) of each spoil was determined via AOAC method 955.01 (AOAC International, 2002).

Experimental Procedures for Column Leaching Trial

All samples were air-dried prior to processing. To eliminate preferential flow within the columns, coarse and large fragments of mine spoil and coal refuse were crushed to pass a 1 cm sieve and then carefully back-blended. The leaching columns were built from 7.6 cm PVC pipe with an inside diameter of 7.4 cm, length of 40 cm, and a concave PVC endcap (see Figure 1). The column was drained through a 1 cm PVC pipe nipple fitted and glued with two-component adhesive into the center of the endcap. An attached Tygon

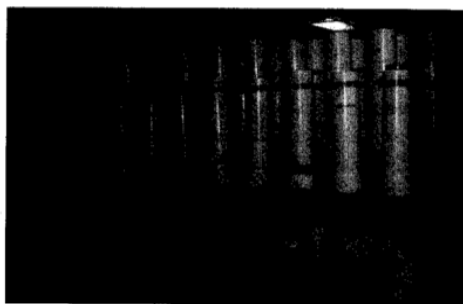


Figure 1. Photo of leaching column array in laboratory. All sample treatments were run in triplicate and dosed with 2.5 cm (1 inch) of simulated precipitation twice per week.

tube drained the leachate and provided the flexibility to create anaerobic conditions in the saturated columns by preventing drainage and gas exchange via a saturated loop at the bottom of the column. To prevent leaching losses of particulate matter and blockage of the drainage hole by particulates, a 0.1 mm nylon mesh circle was glued into the endcap and covered with a 7.6 cm diameter Whatman #1 filter paper. The filter paper was covered with a 2.5 cm layer of acid-washed coarse sand to promote uniform drainage. The sand layer also served as a leachate reservoir to ensure that the bottom section of the sample material remained unsaturated in those treatment columns. The column was then filled with a sample volume of 1,200 cm^3 , and capped with a 2.5 cm sand layer to facilitate uniform distribution of the applied leaching solution. Each sample was run in triplicate under saturated and unsaturated conditions (six columns per sample).

Simulated rainfall (pH 4.6; prepared according to Halvorson and Gentry 1990) was applied twice per week to provide 2.5 cm of rainfall per event (100 ml per leaching event). The water was dispensed into a perforated cup placed on top of the sand to uniformly apply the solution to the sample material. During the first week of the experiment the dosing cycle was accelerated to satisfy the hydration demand to a point where leachates were generated in essentially a "piston flow" response over 48 to 72 hours in response to

Table 1. Selected chemical properties of the ten column leaching study samples

Lab-ID	Material	2:1 pH	Saturated Paste		PPA*		Total S %
			pH	EC dS/m	Tons CCE/ 1,000 Tons	CCE† %	
1	Unweathered SS‡	7.98	6.88	1.27	0	2.7	0.06
2	Unweathered SiS	7.14	7.04	3.48	0	4.6	0.23
3	Partly weathered Sh-SS	5.24	6.93	0.94	3.58	1.3	0.07
4	Weathered SiS	5.22	6.46	0.29	0.22	1.6	0.03
6	Unweathered SiS-Sh	7.02	7.26	1.40	0	2.1	0.14
7	Weathered SiS	7.03	7.66	0.20	0.12	4.7	0.03
10	Unweathered SiS	8.14	7.85	0.66	0	6.0	0.11
11	Weathered SS	5.24	6.28	0.56	0.28	3.7	0.03
12	Unweathered SS	8.64	7.84	0.40	0	5.3	0.12
14	Weathered SS	5.74	7.49	0.36	0.12	3.4	0.03

* Potential Peroxide Acidity (PPA) via H_2O_2 oxidation. Values shown represent net acidity/lime demand.

† Calcium Carbonate Equivalent (CCE).

‡ SS = Sandstone; SiS = Siltstone/Mudrocks; Sh = Shale.

the surface dosing regime. Our intent was to keep the bulk of the unsaturated columns at approximately "field capacity" so that after a precipitation event, an equal volume (~100 ml) of leachate would drain freely into the collection bottles. The saturated columns were kept saturated to the surface. After the addition of simulated precipitation, the Tygon tubing at the bottom of the column was opened long enough to collect 100 ml of leachate. As needed, small amounts of simulated rainfall water were added to the saturated columns to compensate for evaporative losses and to assure that the top of the columns remained saturated.

The leachate samples were analyzed and/or preserved after an 18 hour leaching/collection period. This precipitation/sampling procedure was repeated every three or four days; simulated acid precipitation was applied Mondays and Thursdays, samples were collected and analyzed on Tuesdays and Fridays. The samples were analyzed immediately for pH and EC, and subsamples were analyzed by ICPES for several elements including Ca and S. The leachates were also analyzed for all other major ions as described by Daniels et al. (2009), but the full data set is not presented here.

RESULTS AND DISCUSSION

Characterization of Chemical Properties

Selected chemical properties of the sample set are presented in Table 1. The pH of the samples was generally in the neutral to alkaline range which is typical of fresh, relatively unweathered materials from this region due to hydrolysis reactions involving broken primary mineral grains and carbonate dissolution. Only a few of the mine spoils were slightly acidic with no sample pH below 6.2. The soluble salt content, as indicated by saturated paste EC, produced by fresh spoils was generally low (< 1.0 dS/m or 1,000 $\mu S/cm$), although one sample ranged up to 3,500 $\mu S/cm$. Further discussion of the relationship between soluble salt content and EC is provided with the leaching column results. Samples with elevated EC values appeared well-related to either their potential acidity (as estimated by PPA) and/or CCE. Only four out of the ten samples had a total sulfur content of $> 0.10\%$, which is not unusual for the region sampled. A comparison of the pH values determined by saturated paste (pH_{sp}) versus in a 2:1 water to sample mix (Table 1) indicated lower pH values by the 2:1 method for near-neutral to acidic samples. This may be due to the difference in equilibration time (much longer for the

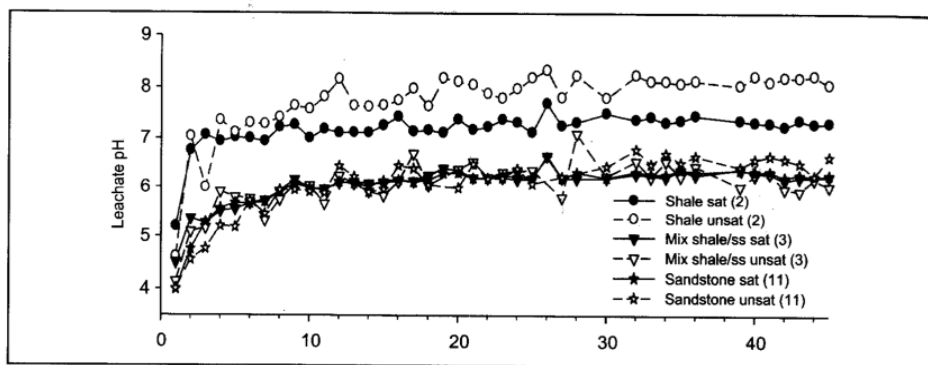


Figure 2. Leachate pH from selected mine spoils under saturated and unsaturated conditions. The 45 leachate events (x-axis) occurred over 22 weeks. One pore volume was approximately equivalent to 7 to 9 leaching doses.

saturated paste method) allowing some of the alkaline mineral surfaces to react with acidic components. Direct comparison of properties from weathered mine spoils versus unweathered mine spoils showed that weathered mine spoils tended towards lower pH (Table 1) as expected. Only one weathered sample (7) had a neutral 2:1 pH, 7.03; the other weathered samples all had 2:1 pH values between 5.22 and 5.74. The pH among the partially weathered/unweathered mine spoils followed the trend that those with higher percentages (via visual observation of rock oxidation/color) of weathered material generated lower pH.

Leaching Column Trial

The data presented in Figures 2–6 report results from 45 leaching events over a 22 week period. The data are presented here are selected from a larger sample set ($n=15$; Daniels et al. 2009) and demonstrate typical spoil type responses. We highlight pH, EC, Ca and sulfate because they are particularly relevant to acid-base reactions. All data presented in Figures 2–6 represent the mean observations from three replicate columns. Details on column replicability (which was very good) can be found in Daniels et al. (2009). For example, relative treatment differences discussed here for pH and EC by treatment \times date were separated by at least two standard errors.

pH

Unweathered overburden in southwestern Virginia can contain significant amounts (0.5 to >3.0%) of carbonates (Howard 1979) which occur primarily as secondary cementing agents and to a more limited extent, reactive pyrite (Sobek et al. 2000). Depending on the distribution and quantity of these minerals, the pH of unoxidized overburden is between 6.5 and 8.0 (Roberts et al. 1988) while that of weathered/partially weathered overburden is generally between 4.5 and 6.0. For most materials used in this study, leachate pH (Figure 2) from the first leaching events was substantially lower than the initial saturated paste pH data on the fresh bulk materials (pH). We presume this was simply due to the initially low pH of the simulated precipitation used and lack of chemical equilibration time in the columns. With few exceptions, leachate pH increased over the first few leaching events, and achieved a relatively stable equilibrium within 10 to 20 leaching events. Under saturated conditions, only three samples (1, 2 and 11) equilibrated to pH values near their saturated paste extract pH, while the remaining seven samples (saturated) maintained pH values that were approximately 0.3 to 1.0 pH unit less than saturated paste EC. The higher pH levels from unsaturated conditions could be due to the effects of increased CO_2 partial pressures

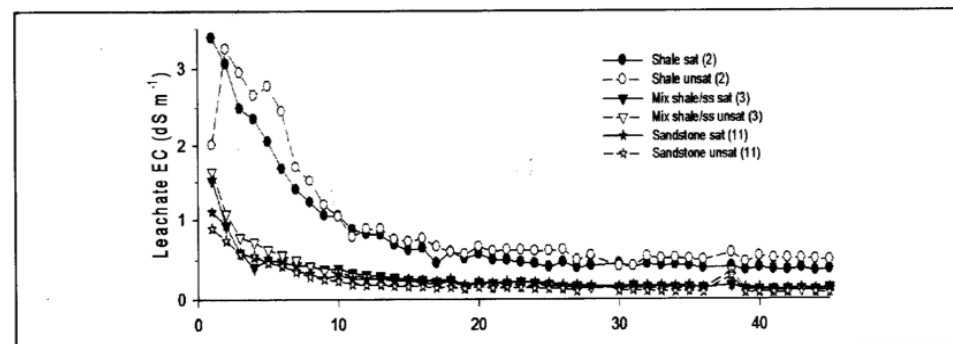


Figure 3. Mine spoil leachate electrical conductivity (EC) from selected spoil materials of different rock types. The 45 leachate events (x-axis) occurred over 22 weeks. $1.0 \text{ dS/m} = 1,000 \text{ }\mu\text{S/cm}$.

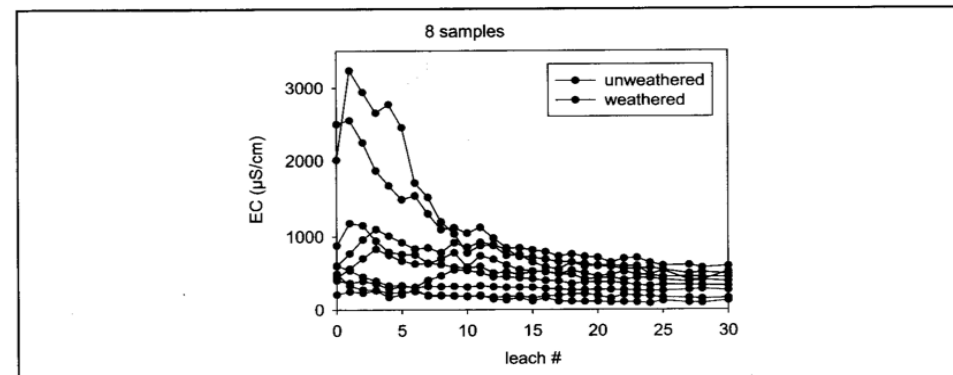


Figure 4. Mine spoil leachate electrical conductivity (EC) for finer textured mudstone/siltstone samples from 30 leaching cycles for unsaturated leaching conditions. Data reported here include several samples in addition to those described in Table 1 from parallel studies sponsored by the Powell River Project.

on carbonate dissolution in the unsaturated columns or perhaps siderite (FeCO_3) formation in the saturated columns.

Electrical Conductance (EC)

Parallel studies completed in conjunction with the results presented here (Daniels et al. 2009) indicated a high correlation coefficient ($r = 0.98$) between EC and TDS, as expected, indicating that EC can be used as an effective proxy for TDS. However, actual TDS recovery values did not always agree well with those predicted by saturated paste EC and/or the sum of ion mass leached. Leachate EC from unweathered mine

spoil varied by rock type with finer textured rocks generally producing higher EC levels (Figure 3). There were also dramatic differences between partially oxidized and weathered samples of similar geology. The difference in results between weathered and unweathered samples was most pronounced for siltstone/mudstone (Figure 4) samples. Interestingly, saturated vs. unsaturated conditions had minor effects, except for sample 2, which was clearly more reactive as discussed later. In all samples, initial EC values dropped quickly, and typically achieved a steady state within 10 to 20 leaching events, maintaining relatively low levels for the remainder of the leaching trial. Most

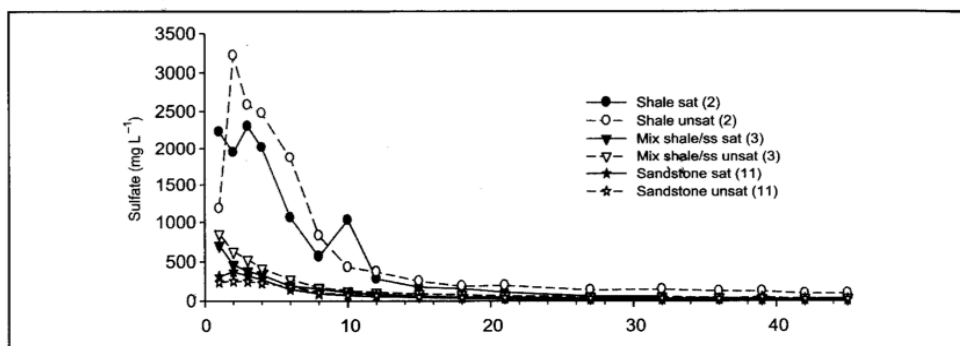


Figure 5. Mine spoil leachate sulfate from selected materials of different types. The 45 leachate events (x-axis) occurred over 22 weeks.

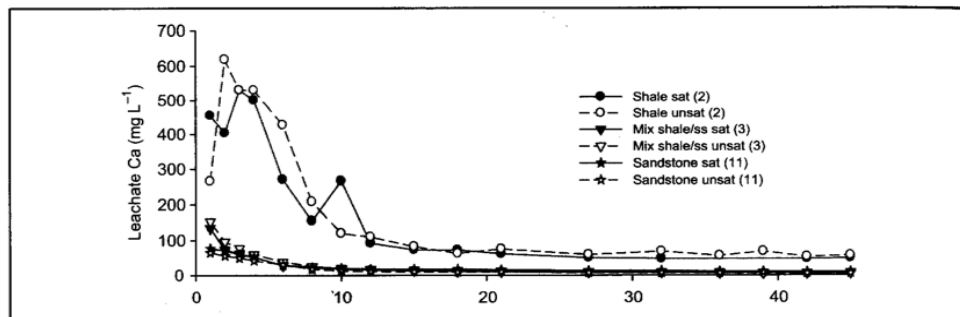


Figure 6. Mine spoil leachate Ca from selected materials of different types. The 45 leachate events (x-axis) occurred over 22 weeks.

notable among the spoil materials were samples 2 (shown) and 6 (not shown), both unweathered mudstones, which maintained values greater than $1,000 \mu\text{S}/\text{m}$ through the first 10 leachings.

The high EC/TDS values generated by samples 2 and 6 probably represent the presence of highly reactive sulfides that, even though present in relatively low amounts (0.23% and 0.14% S), reacted quickly with substrate carbonates to produce prolonged sulfate release over the extent of this experiment. We presume that pyrite in these samples may have been finely divided and framboidal. Collectively, this acid-base reaction control on leachate chemistry was also reflected in leachate-sulfate and Ca concentrations as discussed below.

Sulfate

Sulfate release patterns (Figure 5) reflect the acid-base reactions due to fundamental differences in the geology/mineralogy among the samples and primarily reflect the total-S content of the materials (Table 1). In SW Virginia, where most of these samples originated, the vast majority of strata within the Pennsylvanian system are fluvial-deltaic facies which are generally low in pyritic-S. Many of the massive sandstones that dominate the Lee, Norton, and Wise formations contain secondary carbonate cementing agents (Howard et al., 1988) which offset the relatively minor amounts of sulfidic minerals found in most geologic sections (like #11). Significant accumulations of sulfides do occur in coal seams and

underclays throughout the region; however, these seams are relatively thin (<3 m). For most spoil samples used in this study, the majority of sulfate release occurred within the first pore volume (7 to 9 leaching events). The greatest sulfate release occurred from sample 2, a mudstone from the Breathitt Formation in eastern Kentucky. This formation has been noted and studied for its acid-forming potential (Barnhisel and Massey, 1969). For this material (#2), saturated conditions did appear to somewhat retard the rate of pyrite oxidation and S release as also reflected in the EC results shown in Figure 3.

Calcium and Other Ions

Calcium leaching patterns (Figure 6) for the mine spoils followed the pattern of sulfate very closely. This further amplifies our conclusion that the majority of net TDS release in these materials is controlled by acid-base neutralization reactions. As expected, unweathered spoil materials released greater amounts of Ca than did the weathered materials (data not shown). Sulfate and Ca generally accounted for over 70% of the mass of ions leached, although significant amounts of Mg and K were eluted from most treatments and bicarbonate release was also significant in the saturated unweathered mine spoil treatments (Daniels et al. 2009).

SUMMARY AND CONCLUSIONS

The mine spoils sampled in this study were typical of surface mined overburden employed in the central and southern Appalachians for topsoil substitutes and placed into valley fills in that they were non-acid forming and moderate (>5.5) in initial pH and prolonged leachate pH. All of the mine spoils maintained a moderate pH (5.7 to 8.0) in leachates over the full study period (22 weeks). As expected, mine spoils that were significantly pre-weathered were lower in pH than unweathered materials of similar geology. Most unweathered spoil samples eluted moderate initial EC levels ($\geq 1.0 \text{ dS}/\text{m}$ or $1,000 \mu\text{S}/\text{cm}$) over their initial leaching cycles. Although EC values dropped rapidly for most samples, this behavior would produce TDS loadings to discharge waters

on active operations that continue to disturb and place fresh spoils in direct contact with surface runoff and ground water over extended periods of time. Differences in TDS release appear to be clearly related to sulfide oxidation reactions with subsequent generation of sulfate and other reaction and dissolution products. The relative concentrations of sulfate, Ca and other major ions in the leachates over time were controlled primarily by acid-base reactions, pH solubility controls, and water saturation regime to a more limited extent. Calcium and sulfate release patterns were very similar to each other; this was most apparent in sample 2 due to its noticeable fluctuations.

Overall, results from this study and others cited herein indicate that identification and isolation of high TDS producing strata could potentially be utilized as a part of pre-mine planning and permitting procedures to minimize TDS release to receiving streams. We suggest that active mine operations should be modified to place high TDS producing materials in ways that reduce contact with percolating drainage waters. It is also clear from our data and from related studies that near-surface pre-oxidized and weathered strata will be much lower in their TDS producing potentials and their use as topsoil substitutes should be emphasized and encouraged. We believe that this practice would minimize TDS of surface runoff waters.

Of course, all of these suggested practices need to be tested and validated in full scale field settings. The effects of field hydrogeologic conditions such as seasonal water flux vs. the constant leaching conditions imposed by our column technique also need to be assessed. Regardless of these concerns, we believe that the utilization of simple column leaching procedures such as those employed in this study can provide viable and useful data for the purposes of TDS prediction.

Unresolved Questions and Further Research Needs Addressed by ARIES

While the column technique evaluated here provides a viable option for TDS prediction, it serves primarily as a useful research tool and may not be practical for routine application in pre-mine

overburden analysis. First of all, the technique requires at least three to six months to complete, with considerable laboratory labor and analytical costs. Even if converted over to commercial scale and run without replication and with limited effluent analyses (e.g., EC and pH), we doubt that the cost per sample could be lowered below \$500 (U.S.) per sample. Secondly, in order for the columns to run without a dominance of macropore flow (to ensure uniform replication), the spoil must be sized down to ≤ 1 cm, which means the reactive surface area per unit mass is much higher than would be found in run-of-mine spoils. Thus, we assume that the technique over-predicts the short term TDS peak concentrations and may also over-predict the longer term equilibrium TDS release potentials for a given spoil. Finally as noted earlier, our conclusions regarding the predictive nature of our column technique need to be validated against larger scale field leaching data with the same or similar spoils.

Therefore, a major new research program currently being conducted by the Appalachian Research Initiative for Environmental Science (ARIES; <http://www.energy.vt.edu/index.html>) is focused on (1) conducting column leaching trials on a much wider array of regional spoils, (2) developing new quick lab and field static tests to predict both peak and long-term TDS production and (3) determining appropriate scaling factors to better relate and scale both column and static test data to actual field discharge conditions. The current ARIES work effort is cooperative with researchers at the University of Kentucky and West Virginia University.

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