Total Dissolved Solids in Appalachian Coalfield Streams: Current Research Approaches

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Issues concerning total dissolved solids (TDS) in streams affected by mining operations are important to the coal industry. In this article, we present background concerning TDS as a water quality concern, and we describe ongoing Virginia Tech research approaches to address this issue.

Background:

The term "total dissolved solids" refers to the salts that are dissolved in a water sample. Total dissolved solids are measured by filtering a water sample to remove sediments and other suspended particles, and then evaporating a known quantity of water that passed through the filter. The residue that remains in the sample container after evaporation is weighed to measure the water sample's TDS content.

Total dissolved solids can also be estimated by measuring the ability of the water sample to conduct an electric current. Salts dissociate into positively charged and negatively charged ions in solution, so waters containing higher levels of dissolved salts conduct electric currents more effectively than more dilute waters. Because temperature also influences electrical conductivity, water conductivity data are often standardized at temperature 25^oC, a measure known as specific conductance or SC. Specific conductance can be determined by measuring the electrical conductivity of a water sample at 25^oC. More often, electrical conductivity is measured at existing water temperature and then converted to SC mathematically. Because this conversion is so common, most conductivity meters perform the conversion to SC automatically. Specific conductance, however, is not a reliable indicator of a water sample's precise TDS content, as the relationship of TDS to SC varies and is affected by the component ions that comprise the dissolved salts.

A reason for coal industry concern with TDS and SC is that mine discharge waters are often elevated in TDS, and aquatic biodiversity is often low in waters with elevated levels of TDS. There are many questions about (1) causality, (2) which water measure is the best indicator of potential aquatic effects, and (3) at what levels those effects can be expected.

One advantage of SC as a water quality indicator is that SC is much easier to measure than TDS, because it is measured in the field using a hand-held meter. It has also been suggested that another advantage of SC, compared to TDS, is that it may be a more direct measure of the mechanism that may be a primary cause of toxic effects that often occur at elevated salinities. An organism's ability to transfer ions across cellular membranes, an essential life process known as osmoregulation, is affected by salinity differences between the water and the organism's internal fluids. It is also possible that individual component ions, such as sulfate, are a better measure for use in assessing potential aquatic effects of mine discharge waters (Timpano et al. 2010). If the effects that occur at elevated levels are being caused by individual ions, TDS and SC will only be approximate measures of those effects. However, sulfate, TDS, and SC are highly correlated in Virginia's coalfields (Figure 1).

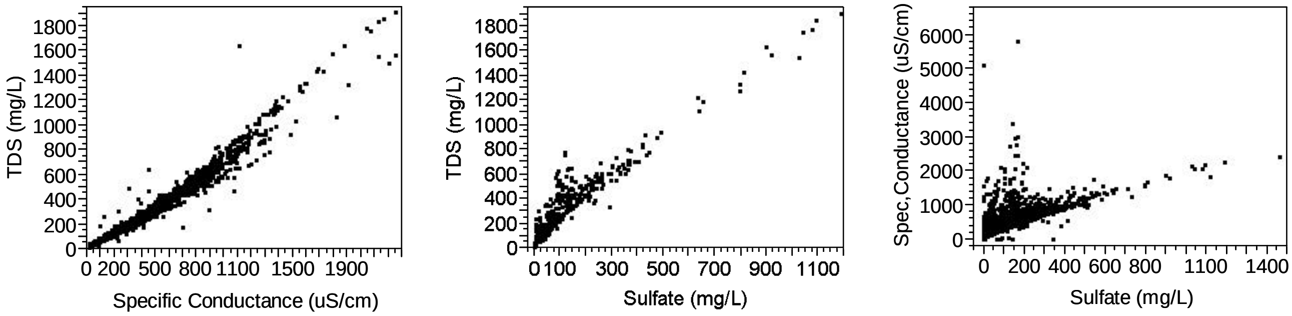

Figure 1. Relationships among total dissolved solids (TDS), specific conductance (SC), and sulfate in Virginia's Central Appalachian coalfield streams. Data from Virginia Department of Environmental Quality, 1989 - 2010. TDS data are combined as Storet 00515 (filterable residue) and 70300 (dissolved solids). Sulfate was measured less frequently than TDS or SC. All three variables (TDS, SC, sulfate) were only rarely measured together on the same date.

Coal mining often causes elevation of TDS, SC, and sulfate in mine discharge waters over levels common in streams that do not receive mine discharge waters. The salts that comprise TDS originate from the geologic materials affected by mining operations. These materials were formed as sedimentary rocks, and they release salts when the minerals that comprise them are exposed to oxygen and water by the mining process. Rocks close to the surface generally release fewer salts than rocks from greater depths, because percolating water and groundwaters have already removed some of the salts from the near-surface rock materials. Hence, waters that drain into underground mines are often elevated in TDS, and geologic materials disturbed by surface mines release TDS when affected by rainwaters. Water treatment of acid mine drainage with chemical reagents also increases TDS content.

Research Goals

Because recent regulatory activity has caused TDS to become a major concern for the coal industry, we have been studying dynamics of TDS, SC, and component ions and their effects on aquatic biota in streams receiving mine discharge waters. Our overall research goal is to identify and understand factors responsible for the biological conditions that occur in coalfield streams with elevated TDS.

Measuring and Monitoring Aquatic Ecosystem Effects

Our studies to date have been focused on associations between TDS and benthic macroinvertebrate community structure. Benthic macroinvertebrates are aquatic organisms that live on the stream bottom ("benthic"), lack a backbone ("invertebrate"), and are large enough ("macro-") to be seen with the naked eye. Most benthic macroinvertebrates are insects, but certain crayfish, snails, worms, and other organism types are also in this category.

We are studying benthic macroinvertebrates because they are used commonly as indicators of aquatic community condition ("bioindicators") for a variety of scientific and regulatory purposes. In the U.S., the Clean Water Act requires that freshwater streams be suitable for aquatic life; throughout the U.S., agencies monitor and assess benthic macroinvertebrates on a routine basis for the purpose of determining Clean Water Act compliance.

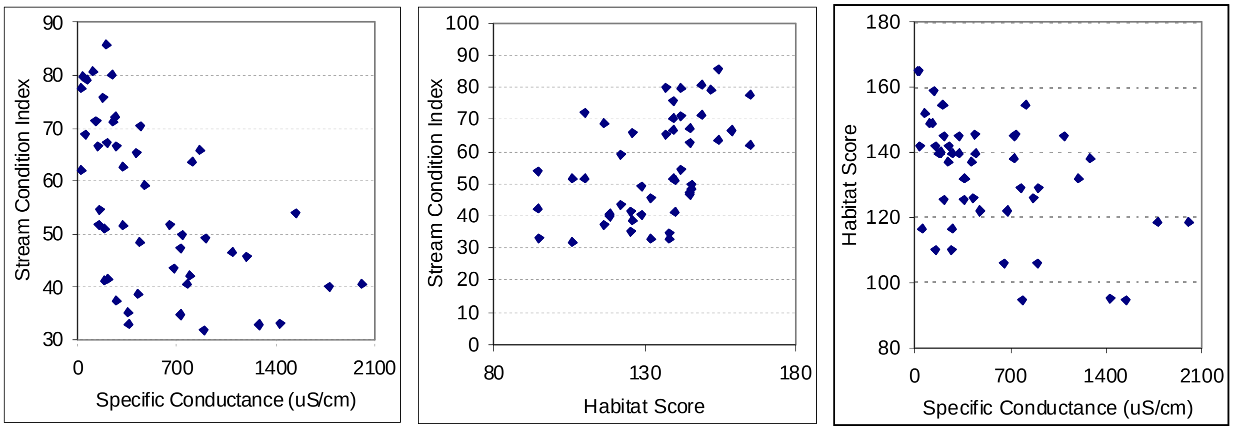

Figure 2. Relationships among specific conductance (SC), stream condition index, and habitat score in Virginia's Central Appalachian Coalfield streams. Data from Virginia Department of Environmental Quality's probabilistic monitoring program for 2001 – 2009. Left: Stream condition index declines with increasing SC, but the relationship is quite variable. Center: Stream Condition Index is also affected by the habitat score metric (0 to 200 scale, with 200 being ideal habitat). Right: Habitat score and specific conductance are negatively correlated.

Results of benthic macroinvertebrate surveys are commonly expressed using measures of community structure. A common metric, for example, is the number of different genera or families observed in a sample, called "richness," which is an indicator of the stream community's diversity. As another example, a metric called "%EPT" is the proportion of mayflies, caddisflies, and stoneflies, organisms comprised of types that are generally intolerant of pollution and stress. Agencies commonly determine if a stream's aquatic life satisfies the Clean Water Act requirements by comparing metrics from that stream to those measured in "reference streams" that have been "minimally influenced" by human activities. In order to define clear criteria for regulatory decisions, agencies often combine various metrics to calculate a "multimetric index" that can be expressed as a single number. In Virginia, for example, the Department of Environmental Quality (VADEQ) uses the Stream Condition Index, or SCI, to assess Clean Water Act compliance (Burton and Gerritsen 2003). Virginia SCI is scored on a scale of 0 to 100, and streams with SCIs less than 60 are defined as "impaired," meaning that they are considered to not satisfy the Clean Water Act requirement to support aquatic life (Virginia DEQ 2006).

Research Approaches

We have been conducting research addressing aquatic ecosystem effects of TDS for several years.

In 2006, VADEQ asked its Academic Advisory Committee for guidance concerning potential regulation of TDS. The resulting study (Zipper and Berenzweig 2007) reviewed scientific literature and analyzed water-monitoring data that had been collected by VADEQ, such as those displayed as Figure 2. No prior studies that directly addressed aquatic ecosystem effects of elevated TDS or defined protective TDS levels in the Appalachian coalfields were found. Analysis of water monitoring data collected by both VADEQ and West Virginia Department of

Environmental Protection found negative associations of SCIs with TDS (Virginia) and with conductivity (West Virginia), despite the fact that the two states calculate their SCIs differently. In other words, SCIs were generally lower for water samples with higher TDS levels in both Virginia and West Virginia datasets. However, those relationships were quite variable. The study also found that sites with high TDS often occurred in association with other water quality problems and/or poor habitat, making existing monitoring data a poor choice for evaluating TDS effects.

In mid-2008, we initiated a new study of TDS effects in Virginia coalfield streams that are minimally affected by non-TDS water quality problems and have excellent habitat, with support provided by Powell River Project, VADEQ, and Virginia Department of Mines, Minerals and Energy. An essential activity was location of sampling sites with a range of TDS concentrations that otherwise met the necessary criteria (excellent habitat, minimally affected by non-TDS water quality problems) for our research approach. The study was conducted using VADEQ sampling protocols. Both benthic macroinvertebrate and water samples were obtained during single site visits in fall and spring over a two-year period. Again, we observed a negative relationship between SCI and TDS concentration (Figure 3), despite selecting sites that minimized other non-TDS water and habitat quality problems. Although study results revealed statistically significant relationships between SCI and several water quality measures (TDS, SC, and sulfate), those effects were highly variable even in these carefully selected streams (Figure 3). Our interpretation is that one factor causing this variability was the sampling procedure. Whereas our data represented only two days per year, we observe that TDS varies throughout the year (Figure 4), and it is likely that the TDS concentrations during weeks and months prior to obtaining a benthic macroinvertebrate sample exert important influence on that sample.

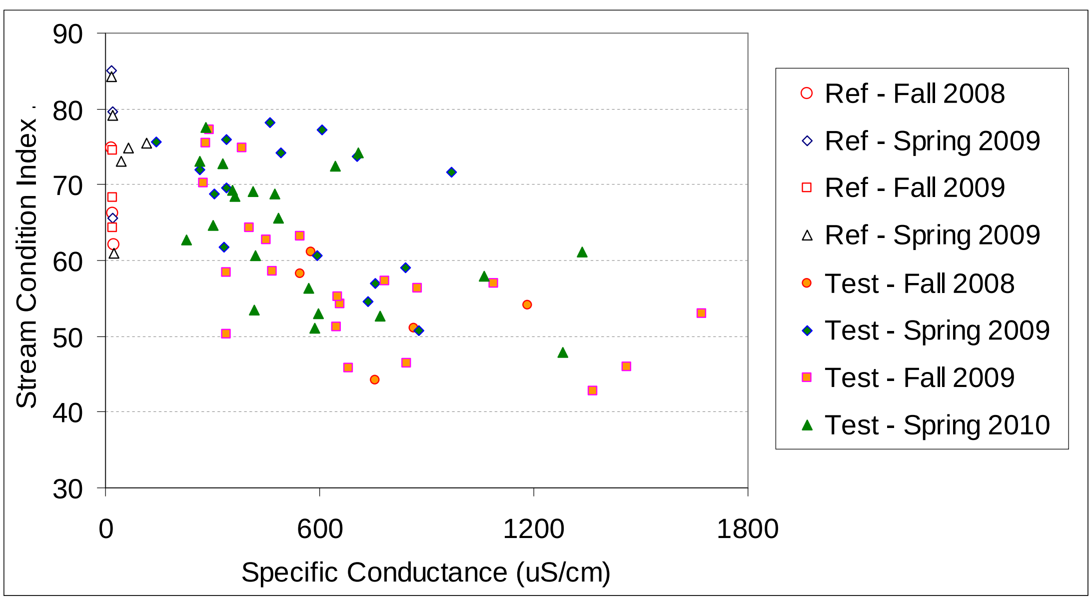

Figure 3. Relationship between specific conductance and stream condition index based on data collected by Timpano (2011) at Virginia coalfield streams with excellent habitat, and where non-TDS factors with potential to cause biological stress were minimized. "Ref" are reference sites, and "Test" are sites with elevated TDS, but with other stream characteristics similar to reference conditions.

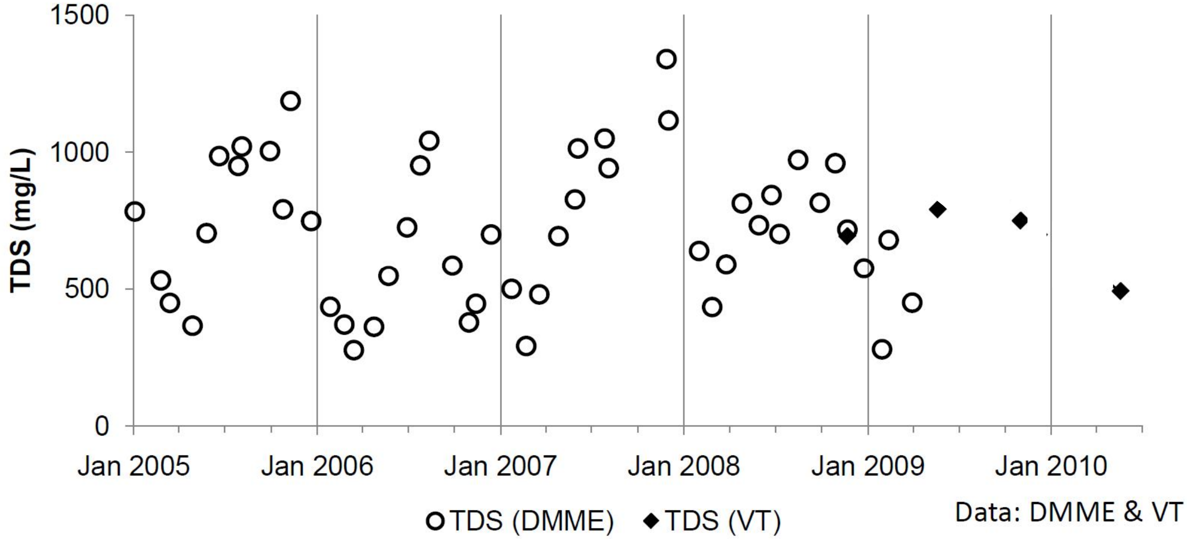

Figure 4. Total dissolved solids concentration in a Wise County stream at various points in time. Open circles are from Virginia Department of Mines, Minerals and Energy data; closed symbols are data points measured by Timpano (2011).

During the course of our study, TDS had become a much more contentious issue for the coal industry because of new regulatory activities. Fortunately, we have obtained new funding to apply more advanced research approaches.

A study supported by U.S. Office of Surface Mining is continuing the research at sites with elevated TDS where non-TDS stressors are not evident, as initiated by Timpano (2011). Most of the Virginia sites are being retained, but new study sites are being added in West Virginia and Kentucky. Specific conductance is being monitored continuously at these sites with *in situ* probes, and benthic macroinvertebrates are being sampled in both the spring and fall seasons. The goal is to determine how potential TDS effects should be measured and monitored as a means of protecting aquatic communities, as indicated by benthic macroinvertebrates as bioindicators. Will the average TDS concentration over some prior period be a better indicator of benthic macroinvertebrate community structure than the TDS concentration at the time of sampling? Will peak concentration experienced over some prior time period be a better indicator? Will the highest average concentrations sustained over a prior period (for example: the highest one-week average over the prior three months) be a better indicator? These are questions being addressed by this new study.

Our prior research makes it clear that biological variability at elevated TDS also presents questions that are relevant to our research goals. In order to help to answer these questions, we have initiated additional study with funding from Powell River Project and Virginia Department of Mines, Minerals and Energy. As demonstrated by Figure 5, SCI was quite variable at some research sites studied by Timpano (2011), and was far more variable at some sites than others. Stream condition index also varied among sampling events at reference sites, despite little change in TDS concentrations. This research will (1) characterize benthic macroinvertebrate community structure on multiple occasions during the period of continuous conductivity measurement described above, (2) enable us to answer questions concerning how benthic macroinvertebrate community structure responds to TDS, when TDS is variable during a time period prior to sampling; and (3) help us to determine if the time of sampling macroinvertebrates within a given season influences results.

We are also planning to initiate a third study, anticipating funds from Appalachian Regional Initiative for Environmental Science (ARIES). This study will attempt to identify environmental factors and in-stream processes that influence response of stream communities to elevated TDS. Benthic macroinvertebrate communities are highly variable, even in reference streams with ideal habitat conditions (Figure 5). With support from the ARIES program, we will be seeking answers to the question: What factors that vary among streams, both natural and human-caused, influence benthic macroinvertebrate community responses to elevated TDS?

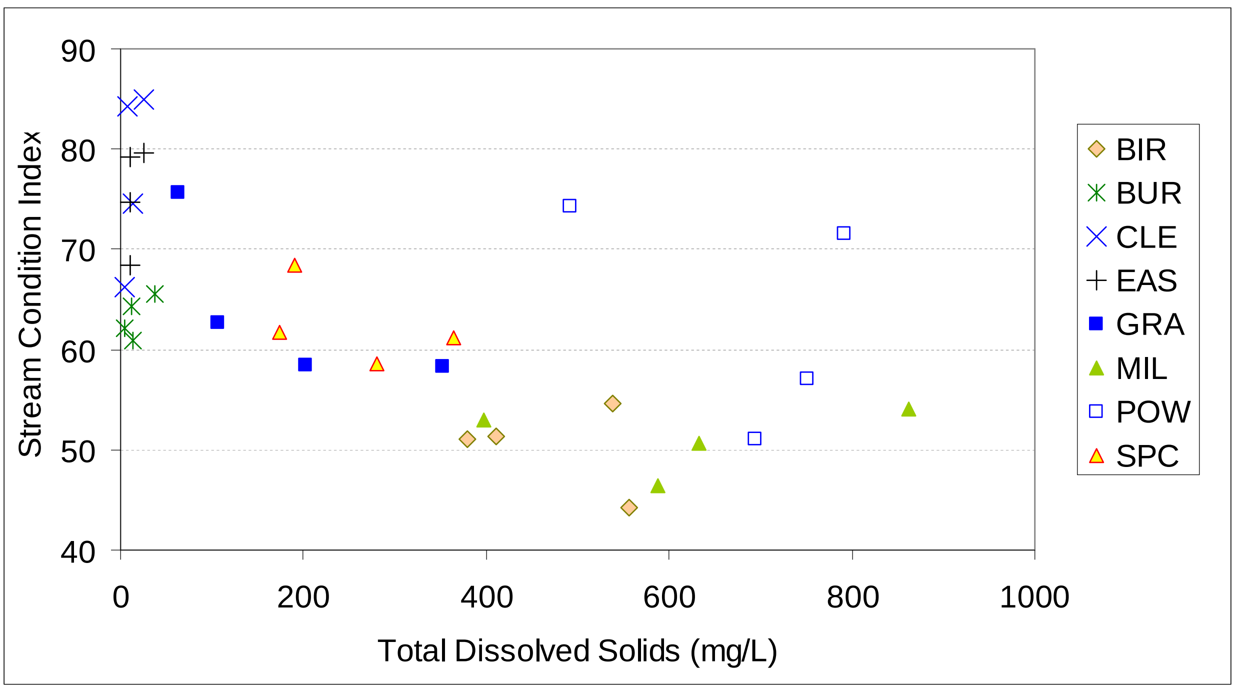

Figure 5. Relationship between total dissolved solids (TDS) and Virginia Stream Condition Index in fall 2008, spring 2009, fall 2009, and spring 2010 in eight streams monitored during all four seasons by Timpano (2011). The three streams with very low TDS are reference streams.

<u>Summary</u>

Elevated levels of TDS in streamwater is a new issue for the Appalachian coal industry. Because the ions that comprise TDS occur commonly in waters discharged by mining operations, successful resolution of the challenges posed by this issue is essential to the industry's future. Other Virginia Tech studies are addressing methods for characterizing and managing mine spoil materials for the purpose of controlling TDS, SC, and sulfate in mine discharge waters (e.g. see Orndorff et al. 2010).

We are conducting our studies recognizing that we are looking at only the scientific aspect of the TDS issue, as it is affecting the coal industry. Another essential question concerns policy interpretations. How “different” from reference streams can an elevated TDS stream be while remaining compliant with Clean Water Act requirements? Another way of asking that question would be: what are the standards by which stream impairments should be judged? That question occurs within the realm of environmental policy, and can be informed but not answered by technical studies such as those described above.

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