Exploring Benthic Impairment and Total Dissolved Solids in the Dumps Creek Watershed

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ABSTRACT

This study looks at the Dumps Creek watershed located in Russell County, Virginia, which has a long history of mining and industrialization. Dumps Creek was placed on the first Commonwealth of Virginia 303(d) List of Impaired Waters in 1994 due to benthic impairment and has not been removed from this list to-date. The U.S. Environmental Protection Agency (EPA) and other regulators have used total dissolved solids (TDS) and/or conductivity as a metric to characterize overall stream health. Historically, other benthic indicators have also been used as a stream characterization metric. This study was conducted in Dumps Creek in Russell County, Virginia, used the Virginia Stream Condition Index (VSCI) as a rating for benthic community health and compared this rating to conductivity measurements in order to assess whether a correlation exists between these two measurements. Both historical data collected by the Commonwealth of Virginia and by mining companies and data collected for this study were used for these comparisons. This work suggests that the current practice of the universal use of conductivity as an indicator of stream health may be premature, without further understanding of how TDS/conductivity correlates to benthic health metrics.

INTRODUCTION

The southwest Virginia watershed of Dumps Creek is currently used for surface and underground mining and has been industrialized since the turn of the century. The watershed was placed on Virginia's 303(d) List of Impaired Waters when in the list was first established in 1994. The watershed was regarded as impaired due to poor benthic health. Due to the 303(d) listing, the state of Virginia also assigns total maximum daily load (TMDL) values for the watershed, in order to facilitate improvement of the impairment. Total dissolved solids (TDS) is one of the metrics that is listed on the TMDL and one that this watershed regularly exceeds due to the need to pump water out of an inactive underground mine. This water is then discharged near the headwaters of Dumps Creek. This study explores the historic and current relationship between TDS/conductivity and benthic health in this watershed.

PREVIOUS STUDIES

Using TDS/conductivity as a metric is a relatively new approach to understanding water chemistry in order to enforce regulation. In particular, based on the work of Pond and Passmore (2008), EPA and state water quality agencies have recently used conductivity in regulating the Appalachian coal mining industry. In contrast, the Illinois

Environmental Protection Agency (2006) and Iowa Department of Natural Resources (2009) concluded from their TDS studies that TDS (and conductivity) is an inappropriate indicator of toxicity to benthic organisms because toxicity is ion-specific. The Illinois study indicates that 2,000 milligrams per Liter (mg/L) TDS with chloride dominance is toxic, but the same level TDS with sulfate dominance is not. Many authors have suggested a direct correlation between conductivity and benthic health, mostly in relation to surface mining; currently the body of literature appears split on whether conductivity is a good stand-alone metric for regulatory purposes.

The EPA contracted various research consultants to study the environmental effects of mountaintop coal mining (MTM) in Appalachia. Conclusions of this research, which focused on a broad array of ecological impacts, were published in both the draft Programmatic Environmental Impact Statement (PEIS) (EPA 2003) and the final PEIS (U.S. EPA 2005) on mountaintop mining and valley fills. Much of this work indicated that surface coal mining resulted in impacts on stream biota, particularly benthic macroinvertebrates.

In a later work, Griffith et al. (2012) focused on studies included in both PEIS publications with respect to stream conductivity, individual ion concentrations and chemistry, in general. Their work concludes that a correlation was found between benthic health and conductivity levels below MTM valley fills as compared to nonmining areas. However, they concluded that, "no studies have quantified the change in conductivity, individual ion concentrations, pH or precipitates as the water progresses downstream" (Griffith et al. 2012). Although correlations are shown through much of the research published in the EPA produced draft and final PEIS, few specifics to understanding this correlation are explored in sufficient detail to explain the mechanisms for the correlations that were found.

Echols, et al. (2009) conducted controlled laboratory tests on a sensitive Ephemeroptera order species, concluding that in exposure to coal processing impoundment effluent, the threshold of impairment-inducing TDS/conductivity concentrations are higher than the benchmark value of 300–500 μS/cm selected by EPA.

Armstead, et al. (2004) collected quantitative and qualitative samples over four seasons. Statistical comparisons were made between the categories of "unmined" (reference), "valley filled," and "valley filled/residential" sampling sites. Results showed that water chemistry did change from a reference condition; however, those changes were not substantial in "valley filled" category streams, and biological impairment was most severe in "valley filled/residential" streams.

The Virginia Stream Condition Index (VSCI) is a multi-metric scoring protocol for benthic macroinvertebrates. This protocol was developed by the Virginia Department of Environmental Quality in order to identify biological impairment of non-coastal streams. The VDEQ used benthic macroinvertebrate data from both impacted and reference streams throughout Virginia in order to determine which family-level macroinvertebrate metrics best evaluated stream condition in all five Virginia ecoregions. The metrics chosen are shown in Table 1.

In order for the VSCI protocol to encompass all streams in Virginia, some resolution is often lost on local scales. For example, the VSCI is used on streams ranging from coastal Piedmont streams (Region 45) to central Appalachian streams (Region 69). Scores in central Appalachian streams, even on reference streams, tend to be lower than other regions of Virginia. This may be due to natural regional differences that the VSCI does not account for or it may be due to the low number of reference sites used in central Appalachia. Of the 62 reference sites used in the development of the VSCI, only five of these sites were in central Appalachia (Burton and Gerritsen 2003).

A study by Northington et al. (2011), assessed the physical habitat, water quality field parameters (including conductivity), and dissolved major ions and metals to evaluate relationships between TDS concentrations and the VSCI. VSCI scores, which are based on the

Table 1. Macroinvertebrate metrics use in 5 Virginia ecoregions (adapted from Burton and Gerritsen (2003))

Metrics, grouped by Category	Definition
Taxonomic Richness: Counts of different taxa within selected taxonomic groups	
Total Taxa	Number of distinct taxa in the entire sample; measures the overall variety of the macroinvertebrate assemblage
EPT Taxa	Sum of distinct taxa in the generally pollution-sensitive insect orders of Ephemeroptera (mayflies), Plecoptera (stoneflies), and Trichoptera (caddisflies)
EPT Taxa less Hydropsychidae	Sum of taxa in the insect orders Ephemeroptera, Plecoptera, and Trichoptera, not including the generally pollution-tolerant caddisfly family Hydropsychidae.
Ephemeroptera taxa	Number of Ephemeroptera taxa (mayfly nymphs)
Plecoptera taxa	Number of Plecoptera taxa (stonefly naiads)
Trichoptera taxa	Number of Trichoptera taxa (caddisfly larvae)
Trichoptera taxa less Hydropsychidae	Number of Trichoptera taxa not including the pollution tolerant caddisfly family Hydropsychidae
Diptera taxa	Number of Diptera taxa ("true" fly larvae and pupae)
Chironomidae taxa	Number of taxa in the family Chironomidae (midge larvae)
Composition: Percent abundance (of individuals in the sample) of...	
%EPT	... Ephemeroptera (mayfly nymphs), Plecoptera (stonefly naiads), and Trichoptera (caddisfly larvae)
%EPT less Hydropsychidae	... Ephemeroptera, Plecoptera, and Trichoptera not including pollution tolerant caddisflies in the family Hydropsychidae
% Ephemeroptera	... mayfly nymphs
% Plecoptera	... stonefly naiads
% Trichoptera	... caddisfly larvae
% Trichoptera less Hydropsychidae	... caddisfly larvae not including those in the pollution tolerant family Hydropsychidae
% Plecoptera plus Trichoptera less Hydropsychidae	... stonefly naiads plus caddisfly larvae not including those in the pollution tolerant family Hydropsychidae
% Diptera	... "true" fly larvae and pupae
% Chironomidae	... Chironomidae (midge) larvae and pupae
% Oligochaeta	... aquatic worms
Trophic Groups: Percent abundance of individuals in the sample, or number of taxa in the sample, whose primary functional mechanism for obtaining food (functional feeding group, FFG) is to...	
% Collectors	... collect/gather depositional organic matter
% Filterers	... filter and collect suspended organic matter
% Predators	... attack prey and ingest whole organisms or their parts
% Scrapers	... graze on substrate- or periphyton-attached algae and associated material
% Shredders	... shred and chew leaf litter and detritus
Scraper taxa	(number of taxa classified primarily as scrapers)
Diversity: Percent abundance in the sample of individuals belonging to...	
% Dominant	... the single most abundant taxon
% 2 Dominant taxa	... the two most abundant taxa
% 5 Dominant taxa	... the five most abundant taxa

(table continues)

Table 1. Macroinvertebrate metrics use in 5 Virginia ecoregions (adapted from Burton and Gerritsen (2003)) (continued)

Tolerance: Counts, proportions, or weighted scores of taxa based on ability to survive exposure to stressors	
Intolerant taxa	Number of taxa with Tolerance Values 3
% Tolerant	Percent abundance of organisms with a Tolerance Value 7
HBI	Abundance-weighted average tolerance of assemblage of organisms (Family taxonomic level)
Habitat: Organisms having the specified dominant behavior for moving and maintaining physical position in their habitat	
% Clingers	Percent abundance of insects having fixed retreats or adaptations for attachment to surfaces in flowing water
Clinger taxa	Number of taxa having fixed retreats or adaptations for attachment to surfaces in flowing water

Commonwealth of Virginia's implementation of stream condition assessment required under the Clean Water Act, assess stream quality based on the population of various organisms in the stream. Findings have shown that certain streams with elevated conductivity values maintain a better VSCI score than some reference streams with very low conductivity.

Pond and Passmore have collaborated on several scientific papers focused on this issue of conductivity. However, even their research appears to yield some different conclusions. Their study in the Straight Creek, Virginia, watershed (Passmore and Pond 2009) reached different results than an earlier Pond and Passmore et al. (2008) study. These differences include the toxicity impacts of conductivity, the comparative impacts of stressors, the ionic makeup of mine-related drainage, and the threshold value of conductivity-associated benthic impairment. The results of this recent investigation, and its contrasting findings to previous studies by the same investigators, shows that the science on these issues is unsettled.

The Passmore and Pond (2009) investigation found that residential land use with improper control of sewage is a major stressor of sensitive benthic life throughout the region. This study also concluded that stream sites near mines were often in better condition than at points farther downstream where residential and other land use impacts occur. The authors offer the opinion that conductivity may be useful as an indicator of general conditions and of trends. They also recommend the construction of sewage systems as an obvious first step to improve the streams studied. Further, the data in this report also confirms that some sites studied in that investigation had unimpaired conditions even with conductivities higher than the levels that had been considered in the previous study to definitely be associated with impairment. Reasons for that difference are discussed, but not fully explained, and may relate to the differences in ionic composition between areas.

Mount et al. (1997) evaluated specific ion effects on aquatic organism toxicity. The report evaluation indicates that sulfate, bicarbonate, calcium, magnesium, sodium, and potassium ions comprise 99% of the total ions in the MTM discharges studied (the ions above are listed from highest concentration to lowest concentration). Sulfate leads the ion composition by approximately six times the concentration of bicarbonate, the next leading ion in the test waters. That being said, the study's toxicity testing indicates that sulfate is the least toxic of the test ions. This study emphasizes the importance of analyzing what individual constituents are being collectively measured by TDS rather than looking at TDS as a singular value.

HISTORIC DATA

Dumps Creek is located in Russell County, Virginia, just northwest of the town of Cleveland. Dumps Creek was placed on the Commonwealth of Virginia's 1994 303(d) List of Impaired Waters

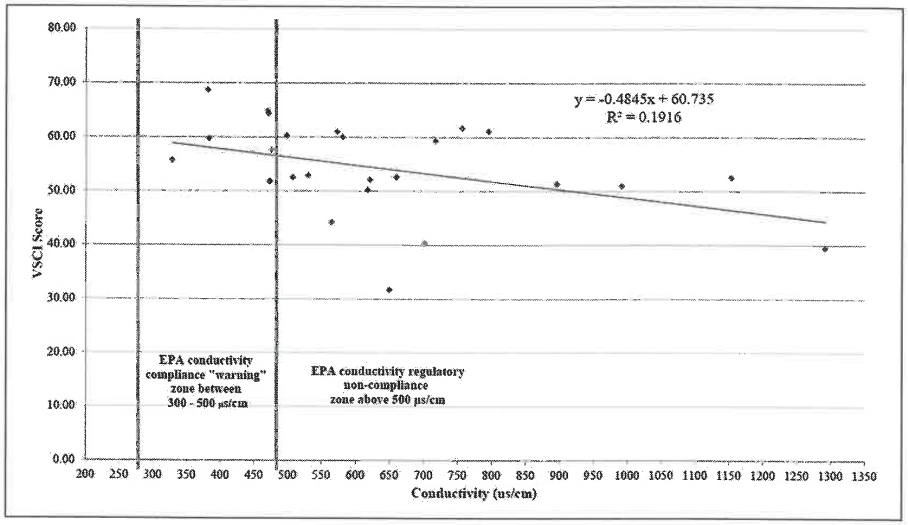

Figure 1. Historic VSCI scores and conductivity in Dumps Creek

because of repeated violations of the general standard based on benthic life criteria and is still on this list today. The impaired stream segment has a length of 3.40 miles, and extends from the Hurricane Fork Confluence to the mouth where Dumps Creek flows into the Clinch River. This stream confluence is near the Appalachian Power Plant in Russell County that discharges to the Clinch River. The land area of the Dumps Creek Watershed is approximately 20,300 acres, with forest and mining as the primary land uses. Dumps Creek has been heavily industrialized since the turn of the century, as a munitions manufacturing facility, and then was heavily surface and underground mined, with a processing facility also located along Dumps Creek. Most mining in Dump's Creek took place before the establishment of environmental protection legislation such as the Clean Water Act (CWA) of 1972 and the Surface Mining and Control Reclamation Act (SMCRA) of 1978.

Currently, there are two pumps staged in the headwaters region of Dumps Creek that help to maintain water levels in an inactive underground mine. The pumping is necessary to control methane levels that rising water could force into an active underground mine that lies stratigraphically above the inactive mine. Water is pumped on an as-needed basis and discharges directly into Dumps Creek.

Conductivity and VSCI data have been collected periodically, although not annually, from 2001 to 2012. We analyzed the historical data available from the Commonwealth of Virginia and other sources. A linear regression analysis of these data show an R^2 of 0.192, which indicates little direct correlation between conductivity and stream impairment as determined by the VSCI. Based on this low level of correlation, no additional regression analyses were conducted (Figure 1).

CURRENT SAMPLING DATA VERIFICATION

To verify the historic data collection and trends, Appalachian Technical Services (ATS) was contracted, as a third party, to collect water chemistry and benthic samples for five locations along Dumps Creek. ATS sent these samples to

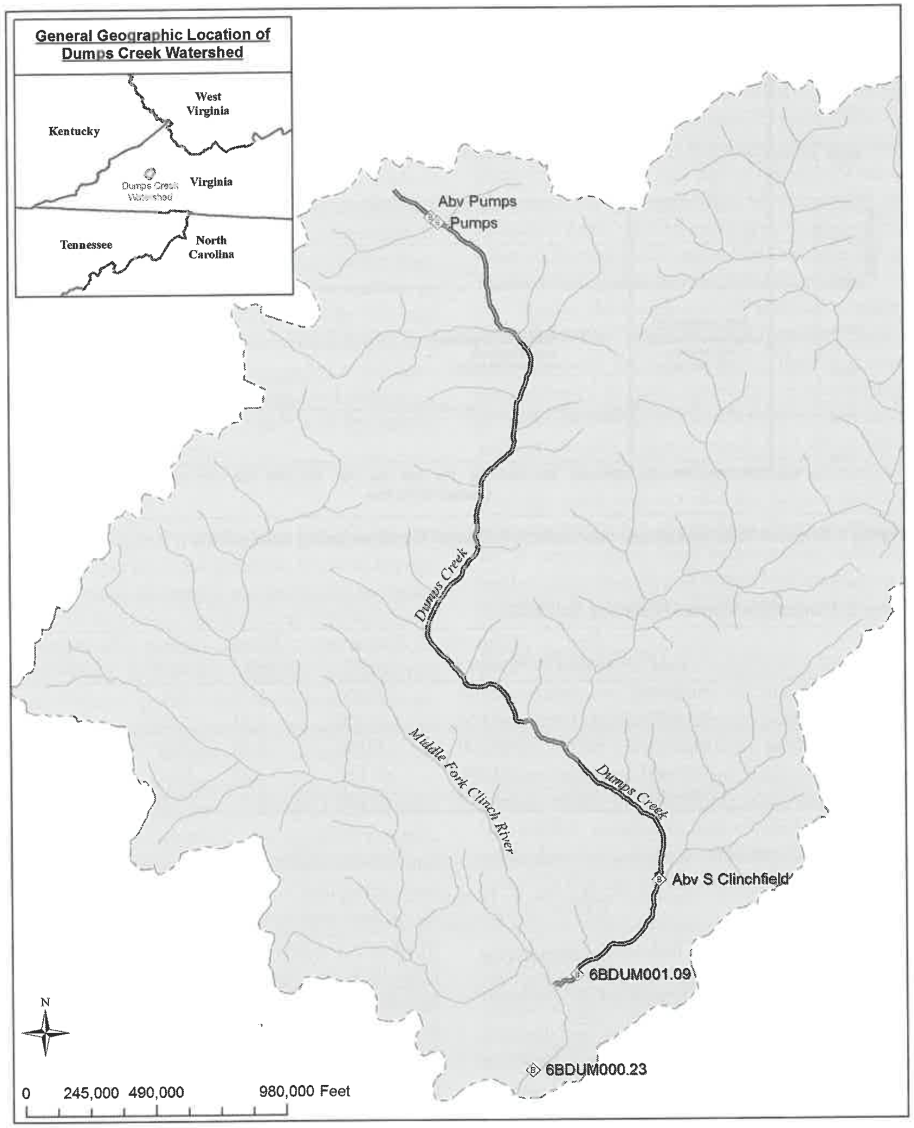

Figure 2. General map of Dumps Creek watershed and current sample locations

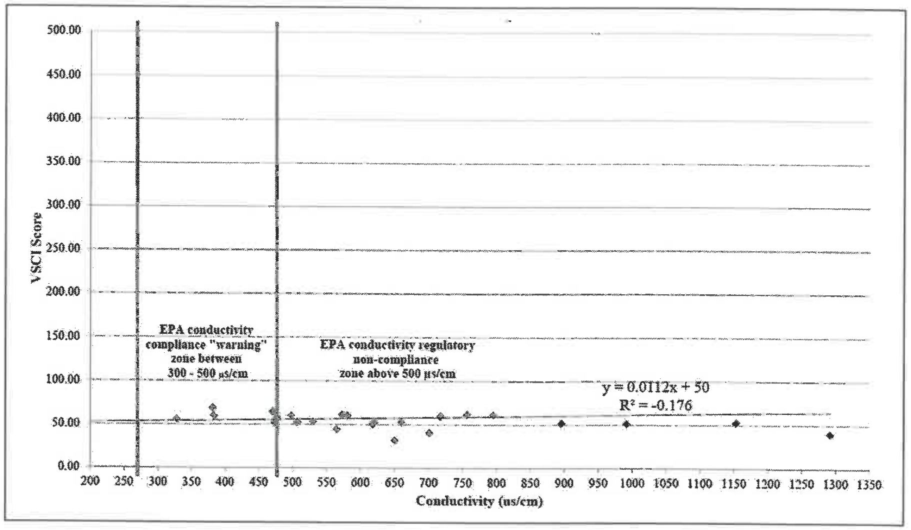

Figure 3. Graph of VSCI scores and conductivity in Dumps Creek including current data

Table 2. Dumps Creek water chemistry, Fall 2012

Sample ID	Date	Iron (mg/L)	Manganese (mg/L)	Aluminum (mg/L)	Chloride (mg/L)	Sulfate (mg/L)	Bicarbonate (mg/L)
6BDUM000.23	10/3/2012	<0.100	<0.100	<0.100	5.23	NA	128
6BDUM001.09	10/3/2012	0.103	<0.100	<0.100	4.54	71.0	132
ABVSClinchfield	10/3/2012	<0.100	<0.100	<0.100	4.39	60.8	132
ABVPUMPS	10/3/2012	0.241	<0.100	<0.100	2.07	89.2	85.6
PUMPS	10/3/2012	0.834	0.118	<0.100	18.1	25.0	540

Note:
mg/L—Milligrams per Liter.
NA—Not Analyzed.
<0.100—This shows that the constituent was less than the Practical Quantitation Limit.

Research Environmental Industrial Consultants, Inc. (REIC), in Beaver, West Virginia, for analysis. REIC is an accredited Virginia laboratory. Current sampling locations are depicted on Figure 2. The southernmost two locations (6BDUM000.23 and 6BDUM001.09) are in close proximity to the locations that are sampled by the Commonwealth of Virginia for the 303(d) listing; the next sample north in the watershed (Abv S Clinchfield) is located above a discharge that drains a community called South Clinchfield, and the two northernmost samples located near the headwaters of Dumps Creek focused on influence associated with pumped water from a nearby underground mine in the watershed. One sample was specifically of the pumped water (Pumps) and one sample was of the surface water in Dumps Creek, prior to reaching the pumps (Abv Pumps).

Water chemistry was taken of the discharged pump water and both water chemistry and benthic macroinvertebrates were sampled above the pump discharged water influence. When this data was added to 2001 to 2012 data, the trend also shows a low correlation between the conductivity and VSCI scores with an R^2 of –0.176 (Figure 3).

Again, based on this low level of correlation, no additional regression analyses were conducted.

WATER CHEMISTRY

The current five samples shown previously on Figure 2 were analyzed for metals, specific conductivity, TDS, and major ions and anions. Table 2 shows the results obtained for the major ions and anions. The data show that this watershed is characterized by bicarbonate anions (rather than sulfate or chloride) and has very low loading in iron, manganese and aluminum. While previous work has concluded that bicarbonate-dominated systems may demonstrate a correlation between conductivity and benthic community health (e.g., Timpano et al. 2011), Dumps Creek appears to show no such correlation.

CONCLUSIONS

The Dumps Creek watershed has a long history of activities that have had potential to cause impairment to water chemistry and the health of stream biota. Both mining operators and regulators have struggled with the impairment of the stream for many years. It has been difficult to adequately quantify and specify what is causing the identified impairment to benthic macroinvertebrate communities in the stream, as evidenced by low VSCI scores over many years.

Recently, the use of conductivity and/or TDS has been suggested as a regulatory metric to quantify stream health. However, historic and current conductivity data and VSCI scores show that, in this specific watershed, these metrics do not appear to have a correlation. This conclusion, while in contrast to the conclusion of Pond and Passmore (2008), is nonetheless consistent with work done by other researchers, including Passmore and Pond (2009). A lack of correlation between conductivity and benthic scores also contrasts with the work of Timpano et al. (2011) in a watershed with similar bicarbonate anion dominance.

Dumps Creek historic benthic and water chemistry data and current, third-party verified, benthic and water chemistry data did not show a correlation between conductivity and benthic health in a bicarbonate anion dominated watershed. This study analyzed data that was available, given the history of this watershed, and assessed whether improving the conductivity and therefore the load to this watershed would improve benthic health in order to remove the watershed from the Virginia 303(d) List of Impaired Waters. These conclusions suggest that benthic health, in this watershed, may be more greatly affected by other influences in the watershed that have yet to be identified, rather than high conductivity.

Finally, the conclusions of this work, again, underscore the inconsistencies between results of studies with this similar topic. There is a need for continued research related to the relationship of water chemistry, as measured by conductivity and specific ion concentrations, and the relative health of benthic macroinvertebrate communities. This work suggests that the current practice of the universal use of conductivity as an indicator of stream health may be premature, without further understanding of how TDS/conductivity correlates to benthic health metrics.

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