Effects of Total Dissolved Solids in Streams of Southwestern Virginia

Anthony Timpano, Graduate Student, Environmental Sciences and Engineering, Virginia Tech

Stephen Schoenholtz, Director, Virginia Water Resources Research Center, Virginia Tech

David Soucek, Ecotoxicologist, Illinois Natural History Survey

Carl Zipper, Associate Professor, Crop and Soil Environmental Sciences, Virginia Tech

Background and Approach

Total dissolved solids (TDS) are the inorganic salts, organic matter, and other dissolved materials in water. Elevated TDS can be toxic to freshwater animals by causing osmotic stress and affecting the osmoregulatory capability of organisms (McCulloch et al. 1993). Several prior studies have concluded that toxicity of TDS is a function of the solution's ionic composition as well as the TDS concentration (Goetsch and Palmer 1997, Mount et al. 1997; Clements 2002; Goodfellow 2000; SETAC 2004; Kennedy et al. 2005) and organism sensitivity.

Under the Clean Water Act, water quality criteria are components of water quality standards. As defined by the Code of Federal Regulations, criteria are "… elements of State water quality standards, expressed as constituent concentrations, levels, or narrative statements, representing a quality of water that supports a particular use. When criteria are met, water quality will generally protect the designated use" [40 CFR 131.3(b)]. All Virginia waters are required to support a designated use defined by Virginia Department of Environmental Quality (DEQ) as "the propagation and growth of a balanced, indigenous population of aquatic life" (Virginia DEQ, 2007).

In 2006, Virginia DEQ initiated an evaluation of the potential to establish water quality standards for TDS as a response to total maximum daily load (TMDL) studies of streams draining watersheds affected by mining in southwestern Virginia (Maptech Inc 2004, 2005a, 2005b). Based on this evaluation, DEQ decided to proceed with an evaluation of the potential to establish a TDS water quality criterion.

Virginia DEQ currently uses a multimetric benthic macroinvertebrate community index, the Stream Condition Index (SCI), as its basis for water-quality assessment of benthic macroinvertebrate data (Burton and Gerritsen 2003; Virginia DEQ 2006). This research is using the Virginia SCI (VSCI) to evaluate TDS and/or component ion effects on benthic macroinvertebrate communities. Research goals are (1) to develop a database comprised of TDS-SCI relationships, and associated attributes such as habitat metrics, for freshwater streams that can support a recommended TDS criterion; and (2) to define relationships between TDS and/or component ion concentration levels and the VSCI.

Research Methods

1. Identify freshwater stream research sites that have elevated (i.e., above reference or background) TDS concentrations but appear to be otherwise relatively unaffected by non-TDS stressor effects.

   Research sites are being identified in consultation with VDMME, Virginia DEQ, and other cooperators. Virginia DMME databases are being accessed to identify streams draining current or former mining sites where TDS concentrations are elevated relative to background. GIS analyses, aerial photography and/or satellite imagery, and DEQ/DMME point-source discharge databases are being used in an effort to identify those high-TDS sites where non-TDS stressors do not appear to be present. Each potential site is visited to verify conditions.

2. Identify freshwater stream research sites that can serve as unstressed reference locations.

   These research sites are being used as reference sites for comparison with TDS-affected sites. Reference streams are selected based on similar geology and topography to the applicable non-reference streams in an effort to isolate TDS and the benthic population as the variables.

3. At each research site, sample benthic macroinvertebrates.

   Sampling is being conducted during the spring and fall benthic macroinvertebrate sampling seasons under baseflow conditions, avoiding time periods immediately following potentially scouring stormflow events, using Virginia DEQ biological monitoring procedures, which are similar to those described in Barbour et al (1999). DEQ biological monitoring personnel were consulted to assure comparable procedures. Benthic macroinvertebrate samples are identified to the genus/lowest practicable level with the exception of midges, which are identified to the tribe level

4. Characterize non-TDS stressor and other benthic macroinvertebrate community influences at all research sites by sampling habitat elements and water quality.

   A complete physical habitat assessment is being conducted at each sampling site according to protocols described in Barbour et al. (1999). Parameters characteristic of low-gradient streams like channel sinuosity, pool variability, and pool substrate characterization have been excluded.

   Water quality at each site is characterized at the time of benthic macroinvertebrate sampling for field parameters (pH, conductivity, temperature, dissolved oxygen) using a portable multi-probe sampler, major ions (Ca, Mg, K, Na, Cl, Sulfate), total dissolved solids, and metals (including Cu, Zn, Mn, Se, Al, Fe). Samples for metals analyses are field filtered. Inductively coupled plasma emission spectrometry (ICP) is used to measure dissolved Ca, Mg, K, Cu, Zn, Mn, Se, Al, Fe (APHA 1998). Ion chromatography (IC) is used to measure chloride and sulfate; TDS is measured via field filtration followed by drying at 180°C; and total alkalinity is measured via titration with standard acid, from which CO_3^{2-} and HCO_3^- are calculated.

5. Analyze data to determine relationships between TDS and VSCI.

   The VSCI will be the biotic indicator used to define an impairment threshold for use in data analysis. The impairment threshold used by Virginia DEQ (VSCI < 60) will be used in this study.

   The influences of TDS and component ions on the biotic indicator metric scores will be determined through a multiple regression approach. Component ion concentrations will be expressed on relative scales by summing all major cations and anions separately and expressing each component-ion concentration both as a percentage of the cation/anion concentration total and as a concentration. In this multiple regression procedure, the VSCI will be the dependent variable and (relative-) concentrations of component ions will be the independent variables. In this procedure, potential multicollinearity effects of component ion concentrations and TDS will be controlled.

Progress to Date

To date, 201 sites have been considered as candidates for study. This includes 22 potential reference sites and 179 potential test sites with elevated TDS that may meet the selection criteria. Of those 201 candidates, 148 have been visited and evaluated for inclusion in the study during site reconnaissance efforts to date. The visited sites were evaluated based on factors such as water quality, habitat quality, flow status, upstream landuses, and accessibility. Site information was reviewed to determine the best candidates for study. The 21 sites that were optimal for study were retained as primary candidates for sampling. Additional sites that met criteria but were less than optimal for study (e.g., unreliable access, marginal flow status, etc.) were reserved as secondary candidates for sampling. Table 1 presents a summary of reference and test site candidates, visited sites, those retained for study, and those sampled during Spring 2009.

Table 1. Site Selection Status as of July, 2009

Status	Ref	Test	Total
Candidate Sites	22	179	201
Sites Visited	8	140	148
Retained 1° Sites	3	18	21
Sampled Spring 2009	3	17	20

Figure 1 illustrates locations of the candidate reference and test sites visited and indicates which sites were retained as primary sites.

Figures 2-4 present photographs of typical reference and test site habitat.

Significant challenges remain in finding suitable sites. Much of Virginia's coalfield region has been developed for commercial, industrial, or residential purposes, with little public land remaining. Locating study sites free from residential or urbanization influences requires exclusion of nearly all streams larger than 2nd order. Finding suitable riparian and instream habitat becomes the next hurdle in the site selection process. Many of the remaining 1st and 2nd order streams have good forested riparian zones, but exhibit excessive sedimentation or substrate embeddedness, likely caused by legacy strip mining. Others have poor riparian vegetative zones, dominated by herbaceous species with little or no canopy over the stream channel. Additionally, regional seasonal dry conditions have led to many dry or nearly dry stream channels, even for some large 3rd order streams. One variable of influence that was not foreseen at the outset of this study is the relatively rapid and extensive proliferation of oil and natural gas wells and their associated access roads. The contribution of oil and natural gas well activities to stream sediment loads, while not currently quantified, is nonetheless a potential stressor to overall biological condition.

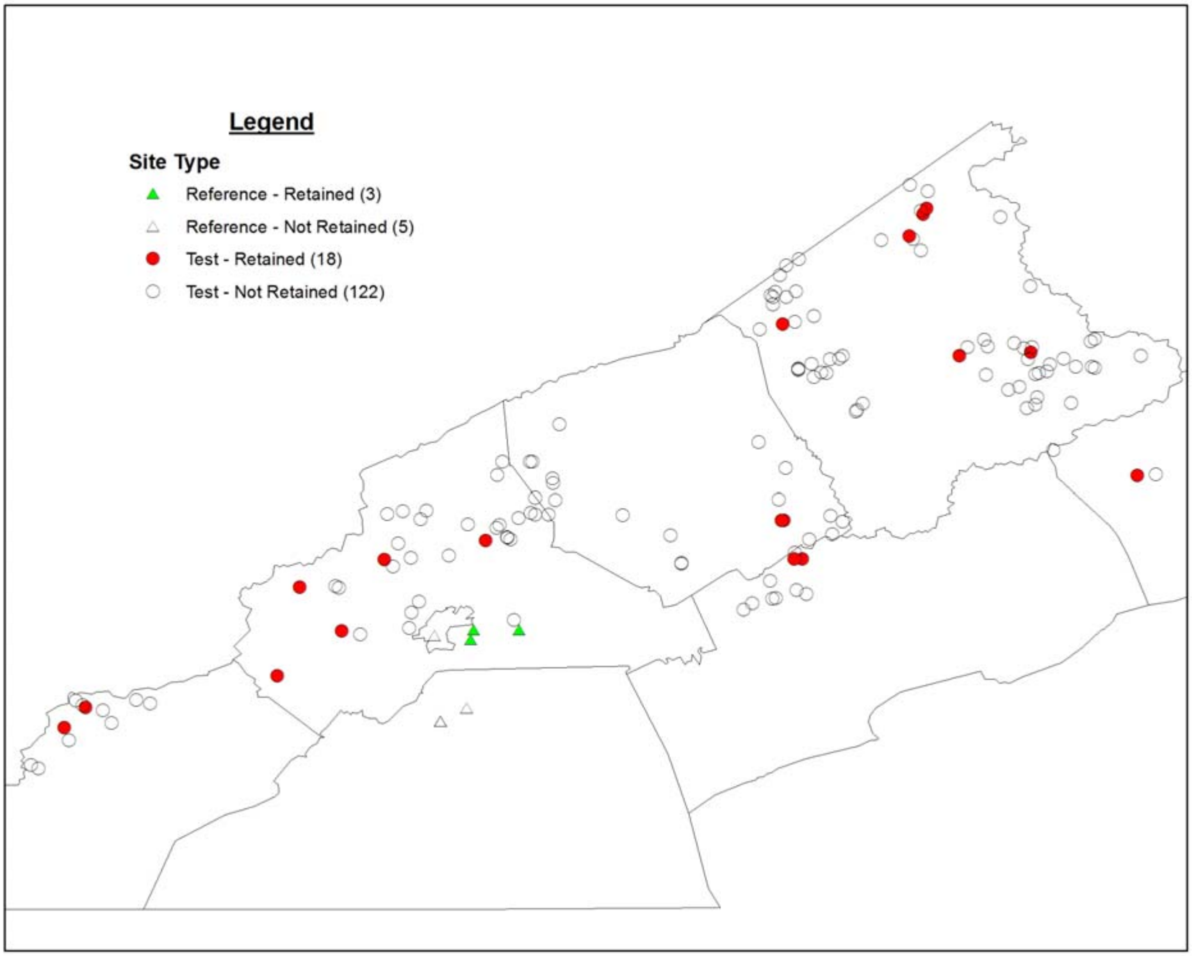

Figure 1. Sites Visited and Primary Sites Retained.

Data Summary

Three reference sites and five test sites were sampled for water chemistry and benthic macroinvertebrate populations in Fall 2008, and three reference sites and 17 test sites were sampled for water chemistry and benthic macroinvertebrate populations in Spring 2009. Tables 2 – 7 summarize data collected to date.

Schedule and Future Plans

Full-time activities were initiated in late July, 2008. The plans for the next four months (September-December, 2009) include evaluation of additional sites, sampling, sample processing, and taxonomic certification. The 20 sites from Spring 2009 will be sampled in Fall 2009 and Spring 2010, along with any additional sites that are found to be suitable. We plan to conclude sampling in Spring of 2010, and to conclude all analysis and report activities by December 2010.

Acknowledgements

The study is being conducted with financial support that combines resources from Virginia Department of Environmental Quality, Virginia Department of Mines, Minerals and Energy, and Powell River Project. The authors express sincere thanks to all who have assisted the project, including Virginia DEQ biologists Ed Cumbow and Chip Sparks for their assistance in development of benthic macroinvertebrate and habitat assessment protocols, and to Virginia coal industry personnel for their assistance in providing site access.

References

Barbour, M.T., J. Gerritsen, B.D. Snyder, and J.B. Stribling. 1999. Rapid Bbioassessment protocols for use in streams and wadable rivers: periphyton, benthic macroinvertebrates and fish, 2nd ed. EPA 841-B-99-002. Environmental Protection Agency; Office of Water; Washington, DC.

Burton, J, and J. Gerritsen. 2003. A Stream Condition Index for Virginia Non-Coastal Streams. Report prepared for Virginia DEQ and US EPA by Tetra-Tech, Inc. http://www.deq.virginia.gov/watermonitoring/pdf/vastrmcon.pdf

Clements, W.H. 2002. Final comments on draft environmental impact statement related to water quality. http://www.powderriverbasin.org/cbm/expert_clements.shtml

Goetsch, P.A., and C.G. Palmer. 1997. Salinity tolerances of selected macroinvertebrates of the Sabie River, Kruger National Park, South Africa. Archives of Environmental Contamination and Toxicology. 32: 32-41.

Goodfellow, W.L., L.W. Ausley, D.T. Burton, D.L. Denton, P.B. Dorn, D.R. Grothe, M.A. Heber, T.J. Norberg-King and J.H. Rodgers, JR. 2000. Major ion toxicity in effluents: a review with permitting recommendations. Environ. Toxicol. Chem. 19: 175-182.

Kennedy, A.J., D.S. Cherry and C.E. Zipper. 2005. Evaluation of ionic contribution to the toxicity of a coal-mine effluent using Ceriodaphnia dubia. Archives of Environmental Contamination and Toxicology. 48: 155-162.

Maptech, Inc. 2004. General Standard TMDL (Total Maximum Daily Load) Development for Dumps Creek Russell County, Virginia. http://www.deq.virginia.gov/tmdl/apptmdls/tenbigrvr/dumps.pdf

Maptech, Inc. 2005a. Fecal Bacteria and General Standard Total Maximum Daily Load Development for the Powell River Basin - Callahan Creek. http://www.deq.virginia.gov/tmdl/apptmdls/tenbigrvr/calla.pdf

Maptech, Inc. 2005b. Fecal Bacteria and General Standard Total Maximum Daily Load Development for the Powell River Basin - Straight Creek. http://www.deq.virginia.gov/tmdl/apptmdls/tenbigrvr/straight.pdf

McCulloch, W.L., W.L. Goodfellow Jr., and J.A. Black. 1993. Characterization, identification and confirmation of total dissolved solids as effluent toxicants. Environmental Toxicology and Risk Assessment. 2: 213-227.

Mount, D.R., D.D. Gulley, J.R. Hockett, T.D. Garrison and J.M. Evans. 1997. Statistical models to predict the toxicity of major ions to Ceriodaphnia dubia, Daphnia magna and Pimphales promelas (Fathead Minnows). Environmental Toxicology and Chemistry. 16: 2009-2019.

Virginia Department of Environmental Quality (DEQ). 2007. Water Quality Standards – Designated Use. http://www.deq.state.va.us/wqs/designated.html

Zipper, C.E., and J. Berenzweig. 2007. Total Dissolved Solids in Virginia Freshwater Streams: An Exploratory Analysis. A Report to Virginia Department of Environmental Quality

Table 2-F. Site Information – Fall 2008

Stream	Station ID	Type	Order	Dominant Geology	County	Lat	Long
Burns Creek (reference)	BUR	Ref	2	Lee	Wise	36.929	-82.535
Clear Creek (reference)	CLE	Ref	2	Mississippian	Wise	36.929	-82.589
Eastland Creek (reference)	EAS	Ref	1	Mississippian	Wise	36.917	-82.593
Birchfield Creek	BIR	Test	2	Wise	Wise	37.036	-82.575
Grape Branch	GRA	Test	2	Norton	Buchanan	37.257	-82.007
Mill Branch Left Fork	MIL	Test	2	Wise	Wise	36.927	-82.747
Powell River	POW	Test	1	Wise	Wise	37.013	-82.697
Spruce Pine Creek	SPC	Test	2	Norton	Buchanan	37.261	-81.922

Table 2-S. Site Information – Spring 2009

Stream	Station ID	Type	Order	Dominant Geology	County	Lat	Long
Burns Creek (reference)	BUR	Ref	2	Lee	Wise	36.929	-82.535
Clear Creek (reference)	CLE	Ref	2	Mississippian	Wise	36.929	-82.589
Eastland Creek (reference)	EAS	Ref	1	Mississippian	Wise	36.917	-82.593
Birchfield Creek	BIR	Test	2	Wise	Wise	37.036	-82.575
Callahan Creek West Fork	CAW	Test	1	Wise	Wise	36.980	-82.797
Fawn Branch	FAW	Test	1	Wise	Lee	36.811	-83.080
Fryingpan Creek	FRY	Test	2	Norton	Dickenson	37.060	-82.218
Fryingpan Creek Right Fork	RFF	Test	2	Norton	Dickenson	37.060	-82.220
Gin Creek	GIN	Test	3	Wise	Lee	36.836	-83.055
Grape Branch	GRA	Test	2	Norton	Buchanan	37.257	-82.007
Hurricane Fork	HUR	Test	2	Norton	Buchanan	37.400	-82.067
Jess Fork	JES	Test	2	Wise	Buchanan	37.295	-82.219
Laurel Branch	LAB	Test	2	Norton	Russell	37.014	-82.205
Laurel Fork	LAU	Test	2	Wise	Wise	36.874	-82.825
Mill Branch Left Fork	MIL	Test	2	Wise	Wise	36.927	-82.747
Powell River	POW	Test	1	Wise	Wise	37.013	-82.697
Race Fork UT	RAC	Test	1	Norton	Buchanan	37.427	-82.050
Roll Pone Branch	ROL	Test	1	Norton	Russell	37.014	-82.195
Spring Branch	SPR	Test	1	Norton	Buchanan	37.434	-82.046
Spruce Pine Creek	SPC	Test	2	Norton	Buchanan	37.261	-81.922

Table 3-F. Field Physicochemical Parameters – Fall 2008

Stream	Temp (°C)	pH (SU)	D.O. (mg/L)	Cond. (µmhos/cm)
Burns Creek (reference)	1.74	7.26	10.96	24
Clear Creek (reference)	3.98	6.64	11.81	21
Eastland Creek (reference)	5.16	6.66	9.67	17
Birchfield Creek	7.04	7.61	11.56	755
Grape Branch	4.16	7.63	10.8	546
Mill Branch LF	2.53	7.68	12.25	1183
Powell River	2.75	7.54	10.89	865
Spruce Pine Creek	3.17	8.49	10.97	575

Table 3-S. Field Physicochemical Parameters – Spring 2009

Stream	Temp (°C)	pH (SU)	D.O. (mg/L)	Cond. (µmhos/cm)
Burns Creek (reference)	11.96	6.11	10.11	22
Clear Creek (reference)	11.47	7.8	9.93	16
Eastland Creek (reference)	11.67	6.85	10.21	21
Birchfield Creek	17.54	7.9	8.09	736
Callahan Creek West Fork	10.85	7.93	9.36	304
Fawn Branch	13.5	8.02	na	265
Fryingpan Creek	13.38	8.15	9.03	462
Fryingpan Creek Right Fork	13.02	8.45	10.22	607
Gin Creek	14.8	8.39	9.55	706
Grape Branch	13	7.56	9.16	143
Hurricane Fork	12.1	7.26	9.68	490
Jess Fork	12.14	6.57	10.17	757
Laurel Branch	14.16	7.9	8.27	842
Laurel Fork	15.03	6.9	8.59	25
Mill Branch Left Fork	14.06	8.25	8.69	878
Powell River	13.99	7.95	8.55	970
Race Fork UT	12.64	7.67	9.36	340
Roll Pone Branch	12.24	7.62	9.83	594
Spring Branch	13.21	7.51	7.81	339
Spruce Pine Creek	14.99	7.73	9.75	332

Table 4-F. Rapid Bioassessment Protocol Habitat Scores – Fall 2008

Stream	Substrate/Cover	Embeddedness	Velocity/Depth	Sediment Dep.	Flow	Channel Alt.	Riffle Freq.	Bank Stability L	Bank Stability R	Veg. Protection L	Veg. Protection R	Rip. Veg. Width L	Rip. Veg. Width R	Total
Burns Creek (ref)	19	16	15	15	14	20	19	8	8	9	9	10	10	**172**
Clear Creek (ref)	20	18	18	15	17	20	19	8	8	8	8	10	10	**179**
Eastland Creek (ref)	18	16	16	14	16	20	19	8	8	8	8	10	10	**171**
Birchfield Creek	17	17	15	13	15	20	19	8	9	9	9	7	9	**167**
Grape Branch	18	14	10	13	15	20	19	8	8	9	9	9	10	**162**
Mill Branch Left Fork	16	14	15	12	15	20	18	8	7	9	9	10	8	**161**
Powell River	17	15	15	12	16	20	19	7	7	8	8	10	10	**164**
Spruce Pine Creek	18	16	15	14	16	20	18	9	9	9	9	10	9	**172**

Table 4-S. RBP Habitat Scores – Spring 2009

Stream	Substrate/Cover	Embeddedness	Velocity/Depth	Sediment Dep.	Flow	Channel Alt.	Riffle Freq.	Bank Stability L	Bank Stability R	Veg. Protection L	Veg. Protection R	Rip. Veg. Width L	Rip. Veg. Width R	Total
Burns Creek (reference)	20	17	20	16	20	20	18	9	9	9	9	10	10	**187**
Clear Creek (reference)	20	16	18	13	19	20	20	9	9	10	10	9	10	**183**
Eastland Creek (reference)	20	17	15	15	19	20	20	9	9	10	10	10	10	**184**
Birchfield Creek	18	15	16	12	19	20	18	7	6	9	9	10	9	**168**
Callahan Creek West Fork	18	16	20	12	18	20	20	9	8	10	10	8	10	**179**
Fawn Branch	18	16	15	13	18	19	20	9	8	10	10	10	9	**175**
Fryingpan Creek	19	16	15	11	18	20	20	9	9	10	10	10	10	**177**
Fryingpan Creek Right Fork	17	16	15	14	19	20	16	9	9	9	9	9	10	**172**
Gin Creek	18	15	16	12	20	20	20	7	7	10	9	10	6	**170**
Grape Branch	18	16	16	13	18	20	20	8	8	9	9	9	10	**174**
Hurricane Fork	15	11	20	12	18	20	17	7	5	10	10	10	10	**165**
Jess Fork	16	14	15	13	18	20	17	7	7	8	8	9	6	**158**
Laurel Branch	18	14	15	12	20	20	19	8	8	9	9	9	9	**170**
Laurel Fork	17	17	15	12	15	20	16	7	7	10	10	10	10	**166**
Mill Branch Left Fork	15	12	15	12	17	20	16	8	9	9	10	10	9	**162**
Powell River	18	13	15	12	18	20	19	7	9	10	10	10	10	**171**
Race Fork UT	20	16	15	14	17	20	20	7	7	9	9	10	10	**174**
Roll Pone Branch	17	12	15	11	15	20	19	7	7	10	10	10	10	**163**
Spring Branch	18	15	15	13	17	20	19	8	8	10	10	10	10	**173**

Table 5-F. Total Dissolved Solids, Major Anions, and Alkalinity – Fall 2008

Stream	TDS (mg/L)	Anions (mg/L)		Alkalinity (mg/L)		
		Cl^-	SO_4^{2-}	Total	CO_3^{2-}	HCO_3^-
Burns Creek (ref)	5.2	2.3	5.4	9.9	0	9.9
Clear Creek (ref)	5.0	0.9	4.3	9.3	0	9.3
Eastland Creek (ref)	11.0	0.8	3.6	8.3	0	8.3
Birchfield Creek	555.6	8.4	233.3	153.2	7.2	146.0
Grape Branch	351.6	6.0	204.6	63.3	0	63.3
Mill Branch LF	861.8	2.0	213.1	165.6	11.8	153.7
Powell River	694.2	1.0	249.9	127.0	2.4	124.6
Spruce Pine Creek	364.4	3.8	128.4	207.1	10.5	196.6

Table 5-S. Total Dissolved Solids, Major Anions, and Alkalinity – Spring 2009

Stream	TDS (mg/L)	Anions (mg/L)		Alkalinity (mg/L)		
		Cl^-	SO_4^{2-}	Total	CO_3^{2-}	HCO_3^-
Burns Creek (ref)	37.4	2.7	4.6	0.6	0.0	0.6
Clear Creek (ref)	24.8	0.8	3.7	2.9	0.0	2.9
Eastland Creek (ref)	26.2	0.8	3.2	5.7	0.0	5.7
Birchfield Creek	538.4	3.2	378.2	107.2	0.0	107.2
Callahan Creek West Fork	205.4	0.9	100.1	65.9	0.0	65.9
Fawn Branch	168	1.1	68.0	73.7	0.0	73.7
Fryingpan Creek	298	9.8	156.0	70.7	0.0	70.7
Fryingpan Creek Right Fork	360.6	7.7	152.1	158.5	0.6	157.9
Gin Creek	470	8.5	155.0	251.6	4.3	247.3
Grape Branch	63.4	4.2	39.4	22.0	0.0	22.0
Hurricane Fork	290	1.4	220.9	32.1	0.0	32.1
Jess Fork	566.6	1.4	456.2	4.2	0.0	4.2
Laurel Branch	558.4	8.8	311.1	109.4	0.0	109.4
Laurel Fork	27.8	0.9	4.2	7.2	0.0	7.2
Mill Branch Left Fork	632.8	1.9	396.8	131.3	0.0	131.3
Powell River	791.6	1.0	531.4	115.6	0.0	115.6
Race Fork UT	217.8	1.2	114.4	79.9	0.0	79.9
Roll Pone Branch	389.2	4.5	249.6	78.6	0.0	78.6
Spring Branch	205.4	1.1	138.0	38.8	0.0	38.8
Spruce Pine Creek	173.6	5.7	109.3	45.6	0.0	45.6

Table 6-F. Major Cations and Trace Metals – Fall 2008

Stream	Major Cations (mg/L)				Trace Metals (μg/L)					
	K	Na	Ca	Mg	Al	Cu	Fe	Mn	Se	Zn
Burns Creek (ref)	0.5	4.1	1.1	0.5	< 2.8	< 8.9	< 39.4	< 1.7	6.4	< 37.3
Clear Creek (ref)	0.6	1.0	*2.6*	0.7	< 2.8	< 8.9	< 39.4	< 1.7	6.3	< 37.3
Eastland Creek (ref)	0.4	0.6	*2.5*	0.6	< 2.8	< 8.9	< 39.4	< 1.7	< 4.9	< 37.3
Birchfield Creek	4.9	27.9	75.3	55.0	< 2.8	< 8.9	52.4	< 1.7	< 4.9	< 37.3
Grape Branch	2.3	45.3	53.5	21.5	< 2.8	< 8.9	< 39.4	< 1.7	< 4.9	< 37.3
Mill Branch LF	5.4	36.4	158.7	66.9	< 2.8	< 8.9	410.9	160.3	7.5	< 37.3
Powell River	3.5	12.7	120.9	67.3	7.5	< 8.9	< 39.4	2.6	5.3	< 37.3
Spruce Pine Creek	1.8	84.9	40.2	17.3	< 2.8	< 8.9	< 39.4	< 1.7	< 4.9	< 37.3

Table 6-S. Major Cations and Trace Metals - Spring 2009

Stream	Major Cations (mg/L)				Trace Metals (ug/L)					
	K	Na	Ca	Mg	Al	Cu	Fe	Mn	Se	Zn
Burns Creek (ref)	0.4	1.9	1.3	0.6	<9.8	<22.8	<22.2	<15.7	<24.1	<16.0
Clear Creek (ref)	0.3	0.4	1.7	0.6	41.9	<22.8	<22.2	<15.7	<24.1	<16.0
Eastland Creek (rer)	0.4	0.5	2.7	0.7	<9.8	<22.8	<22.2	<15.7	<24.1	<16.0
Birchfield Creek	3.8	20.1	71.7	54.8	<9.8	<22.8	51.5	44.7	<24.1	<16.0
Callahan Creek West Fork	2.2	7.9	35.6	17.0	<9.8	<22.8	<22.2	<15.7	<24.1	<16.0
Fawn Branch	2.3	10.4	28.5	14.3	<9.8	<22.8	<22.2	<15.7	<24.1	<16.0
Fryingpan Creek	3.9	20.3	46.4	24.6	<9.8	<22.8	<22.2	<15.7	<24.1	<16.0
Fryingpan Creek Right Fork	2.8	67.0	46.2	19.9	<9.8	<22.8	<22.2	<15.7	<24.1	<16.0
Gin Creek	4.6	135.9	32.4	14.4	<9.8	<22.8	<22.2	<15.7	<24.1	<16.0
Grape Branch	1.6	5.0	13.4	5.8	<9.8	<22.8	<22.2	<15.7	<24.1	<16.0
Hurricane Fork	2.9	9.4	45.2	33.4	<9.8	<22.8	<22.2	<15.7	<24.1	<16.0
Jess Fork	3.1	10.8	85.1	50.5	22.1	<22.8	74.8	787.9	<24.1	116.0
Laurel Branch	4.3	42.3	87.9	45.3	<9.8	<22.8	<22.2	<15.7	<24.1	<16.0
Laurel Fork	1.4	1.0	2.2	1.5	<9.8	<22.8	319.9	<15.7	<24.1	<16.0
Mill Branch Left Fork	5.0	19.5	107.3	54.9	34.9	<22.8	100.2	37.9	<24.1	<16.0
Powell River	4.2	10.0	119.9	75.4	15.6	<22.8	72.0	<15.7	<24.1	<16.0
Race Fork UT	3.2	21.5	36.5	18.4	<9.8	<22.8	<22.2	<15.7	<24.1	<16.0
Roll Pone Branch	2.9	18.5	65.3	33.4	<9.8	<22.8	<22.2	<15.7	<24.1	<16.0
Spring Branch	2.2	3.3	36.0	24.0	<9.8	<22.8	<22.2	<15.7	<24.1	<16.0
Spruce Pine Creek	1.9	18.5	29.0	14.9	40.8	<22.8	24.3	61.5	<24.1	<16.0

Table 7-F. VA SCI Metrics and Final Score (200 organism sample) – Fall 2008

Stream	# Taxa	# EPT Taxa	% E	% PT-Hyd.	% Scrapers	% Chiron.	% 2 Dom.	HBI	VA SCI Score
Burns Creek (ref)	21	12	12.7	26.5	5.3	49.8	61.6	5.0	60.0
Clear Creek (ref)	22	15	28.1	30.8	14.6	22.2	43.2	3.9	76.3
Eastland Creek (ref)	23	14	3.5	42.4	13.5	14.7	37.1	3.5	75.5
Birchfield Creek	8	5	0.5	85.6	0.0	3.1	91.2	1.8	49.0
Grape Branch	17	11	3.3	55.7	2.7	1.6	75.4	3.1	65.2
Mill Branch LF	12	6	1.6	80.2	0.0	2.7	81.9	1.9	54.4
Powell River	12	8	0.6	71.0	1.2	3.6	82.8	2.4	56.5
Spruce Pine Creek	17	10	2.1	50.5	6.7	8.2	62.9	3.6	65.5

Table 7-S. VA SCI Metrics and Final Score (200 organism sample) – Spring 2009

Stream	# Taxa	# EPT Taxa	% E	% PT-Hyd.	% Scrapers	% Chiron.	% 2 Dom.	HBI	SCI Score
Burns Creek (ref)	18	13	7.0	69.3	8.5	14.6	57.8	2.4	69.5
Clear Creek (ref)	24	17	42.6	39.1	26.4	2.0	42.1	2.7	87.8
Eastland Creek (ref)	22	17	29.4	50.2	20.4	3.8	46.0	2.5	82.7
Birchfield Creek	12	6	0.0	60.4	0.5	16.2	61.9	2.9	56.1
Callahan Creek West Fork	14	11	15.6	77.6	6.3	4.2	68.2	1.7	67.9
Fawn Branch	16	13	22.6	70.9	12.1	3.5	61.8	1.7	73.1
Fryingpan Creek	15	11	31.7	52.3	11.1	1.5	42.7	2.5	77.8
Fryingpan Creek Right Fork	20	14	19.3	67.3	15.7	1.3	35.9	2.5	80.5
Gin Creek	19	12	38.7	43.3	10.8	9.3	43.8	2.8	80.3
Grape Branch	17	13	15.1	62.7	2.7	2.7	58.4	2.2	70.6
Hurricane Fork	20	12	19.7	63.6	5.8	2.9	54.3	2.3	74.7
Jess Fork	13	6	14.2	70.8	0.0	1.8	68.9	1.8	60.0
Laurel Branch	17	7	10.5	65.2	2.9	3.3	68.6	1.8	63.2
Laurel Fork	24	17	16.0	35.4	5.0	27.6	38.7	4.0	73.1
Mill Branch Left Fork	7	4	6.3	75.7	0.0	8.5	75.7	2.0	50.7
Powell River	15	8	31.0	37.9	20.2	2.0	50.7	3.2	75.0
Race Fork UT	15	12	17.9	77.7	6.1	1.7	68.7	1.5	69.1
Roll Pone Branch	12	10	16.3	81.3	2.4	1.4	70.2	1.2	64.8
Spring Branch	18	13	28.3	63.9	2.6	1.0	47.1	2.2	76.0
Spruce Pine Creek	15	8	15.8	52.5	6.0	12.6	56.3	2.7	66.1

Figure 2. Clear Creek (reference), Wise County, Virginia.

Figure 3. Grape Branch (test), Buchanan County, Virginia.

Figure 4. Roll Pone Branch (test), Dickenson County, Virginia.

Appendix

Table A-8. Fall 2008 VSCI metrics and scores, 110 (±10%) organism subsample

Stream	# Taxa	# EPT Taxa	% E	% PT-Hyd.	% Scrapers	% Chiron.	% 2 Dom.	HBI	SCI Score (110 org)
Burns Creek (ref)	18	11	13.8	31.2	5.5	44.0	57.8	4.6	62.3
Clear Creek (ref)	18	12	30.5	26.3	17.9	20.0	42.1	3.9	74.3
Eastland Creek (ref)	22	13	5.2	39.2	16.5	11.3	37.1	3.5	76.9
Birchfield Creek	5	3	0.0	87.4	0.0	1.9	96.1	1.6	44.2
Grape Branch	14	9	4.0	54.8	3.2	2.4	73.0	3.2	61.8
Mill Branch LF	10	6	1.9	78.3	0.0	3.8	82.1	2.0	53.2
Powell River	9	6	0.0	69.1	2.1	3.1	83.5	2.6	52.5
Spruce Pine Creek	14	7	0.0	53.4	6.0	8.6	65.5	3.5	59.5

Table A-9. Spring 2009 VSCI metrics and scores, 110 (±10%) organism subsample

Stream	# Taxa	# EPT Taxa	% E	% PT-Hyd.	% Scrapers	% Chiron.	% 2 Dom.	HBI	SCI Score (110 org)
Burns Creek (ref)	14	10	8.0	64.6	7.1	18.6	58.4	2.6	65.3
Clear Creek (ref)	18	13	41.3	40.4	25.7	0.0	44.0	2.6	85.0
Eastland Creek (ref)	19	14	27.7	53.8	16.0	3.4	46.2	2.3	79.6
Birchfield Creek	10	6	0.0	58.0	0.0	18.8	61.6	3.1	54.6
Callahan Creek West Fork	14	11	15.7	78.7	6.5	3.7	63.9	1.7	68.8
Fawn Branch	16	13	18.8	74.1	9.8	2.7	61.6	1.7	71.9
Fryingpan Creek	14	11	28.9	53.5	14.0	0.9	38.6	2.5	78.2
Fryingpan Creek Right Fork	15	11	18.3	69.2	18.3	0.8	40.8	2.5	77.3
Gin Creek	19	12	39.3	42.6	13.1	8.2	41.0	2.8	81.6
Grape Branch	14	10	10.1	59.6	2.0	3.0	59.6	2.5	66.3
Hurricane Fork	15	10	22.4	62.1	6.0	4.3	53.4	2.3	71.3
Jess Fork	10	5	15.7	69.3	0.0	0.8	68.5	1.8	57.7
Laurel Branch	16	7	10.2	63.9	1.9	5.6	63.9	2.0	62.9
Laurel Fork	19	13	17.5	34.2	4.4	25.4	37.7	4.0	71.6
Mill Branch Left Fork	7	4	4.6	72.5	0.0	10.1	72.5	2.1	50.7
Powell River	13	7	30.0	35.8	20.8	3.3	49.2	3.3	72.5
Race Fork UT	14	11	21.2	72.1	6.7	1.9	65.4	1.6	69.9
Roll Pone Branch	10	8	17.4	78.9	0.0	2.8	71.6	1.3	60.6
Spring Branch	18	13	26.0	62.0	2.0	1.0	44.0	2.4	76.0
Spruce Pine Creek	11	6	17.0	52.8	7.5	13.2	58.5	2.5	61.7