Report for 2002WV6B: WRI47-Establishing Biological and Water Quality Criteria for Water Resource Management in Mining Impacted Watersheds

There are no reported publications resulting from this project.

Report Follows

FINAL REPORT

SPATIO-TEMPORAL VARIABLITY IN WATER CHEMISTRY AND ITS EFFECTS ON STREAM ECOLOGICAL CONDITION IN A MINED, APPALACHIAN WATERSHED

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West Virginia Water Research Institute

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1. SYNOPSIS OF ACCOMPLISHMENTS

During this project we completed sampling and analysis of water chemistry and invertebrate data from 34 tributaries of the lower Cheat River in West Virginia. Through our analyses, we quantified the degree of water quality variability in streams draining an intensively mined landscape. We also identified specific, quantitative relationships between water quality variability and stream ecological condition. To our knowledge, this is one of the first studies to examine how temporal variability in water quality affects biological communities in mining impacted streams. This type of information is critical when determining how best to design restoration programs in acid mine drainage impacted watersheds.

Results from this study have been used to guide decisions regarding a water quality trading program for the lower Cheat River basin. Specific relationships between water chemistry and ecological condition can be used to quantify the amount of ecological recovery that can be expected from a given restoration / management scenario. The relationships also provide a tool to project the rate and extent of watershed recovery for the Cheat River watershed following a series of restoration actions.

We also have used results from this study to obtain additional research funding from the US Environmental Protection Agency. We received a 3-year grant for $600,000 to study relationships between mining intensity, water chemistry, and ecological condition in several Appalachian watersheds. The new study will use approaches developed in the WRI project to identify restoration and protection priorities in intensively mined watersheds.

Details regarding specific research accomplishments can be found in the following technical report of methods and results for this project:

Introduction

There is a critical need for restoration action and more effective watershed management approaches in the Mid-Atlantic Highlands (MAH) region of the eastern U.S. (Jones et al. 1997). The MAH consists of the mountainous portions of Pennsylvania, Maryland, Virginia, and Kentucky, and the entire state of West Virginia. A recent assessment by the USEPA of stream ecological condition in the MAH found that more than 70% of streams are severely or moderately impaired by human related stressors (USEPA 2000a). Impairment to aquatic communities in this region extends from a range of human related activities, including agriculture, forestry, and urban development, but mining related impacts are unquestionably the most severe. For example acid mine drainage (AMD) from abandoned mines has degraded hundreds of miles of streams in West Virginia alone.

Several recent scientific advances and policy directives have improved the likelihood of effectively managing mining impacted watersheds in this region. First, the West Virginia Division of Environmental Protection (WVDEP) has worked in cooperation with the USEPA to conduct watershed assessments and develop Total Maximum Daily Load (TMDL) programs for AMD impacted watersheds throughout the state (WVDEP 1999, USEPA 2000b). The successful implementation of these programs would dramatically improve surface water chemistry and ecological integrity of aquatic ecosystems in the state. Second, the WV state legislature recently passed a stream Anti-Degradation policy, which theoretically will protect remaining high quality aquatic resources in the region. Third, West Virginia, with support from the USEPA, industry representatives, and local watershed organizations is exploring the feasibility of developing watershed specific and statewide water quality trading programs. If successful, the trading program could facilitate implementation of TMDL plans, produce significant improvements in water quality, and reduce the economic burden of meeting clean water goals in the region.

Despite these advances, our understanding of the fundamental physical, chemical, and biological processes in mined Appalachian watersheds remains incomplete. Most importantly, we lack a clear understanding of water quality variability in AMD impacted watersheds and how this variability may ultimately influence stream ecological condition. An understanding of the dynamics of metals and other solutes from mine drainage is essential to the successful management and remediation efforts in mined Appalachian watersheds.

Consequently, the specific objectives of this study were to: 1) quantify temporal variability in dissolved metals and other solutes within the lower Cheat River watershed, 2) quantify relationships between water chemistry, water quality variability, and specific levels of ecological impairment.

Methods

Study Area and Sampling Design

The Cheat River is part of the upper Ohio River basin and is formed by the confluence of the Shavers Fork and Black Fork in Parsons, WV. From this confluence, the Cheat River flows 135 km north to Point Marion, PA, where it enters the Monongahela River. The Cheat River drains a watershed of approximately 3,700 km^2, and is located almost entirely within north-central West Virginia. The economy in the northern portion of the watershed has been dominated by coal mining over the last century, and as a result, many streams in the lower Cheat River watershed have been degraded by acid mine drainage discharged from abandoned mines (Williams et al. 1999).

Sampling sites in this study were chosen based on their expected level of impairment from acid mine drainage. Thirty-four sites were chosen on 14 tributaries of the lower Cheat River: five sites were chosen as unimpaired reference sites (i.e., stream segments that drain watersheds without any mining activity), four sites were chosen as severely impaired sites (i.e., sites with extremely high acidity levels), and the remaining 25 sites were selected across a range from low to moderately high acidity levels. For brevity we refer to each group of sites as reference, intensive mining, and moderate mining, respectively.

Water Chemistry Sampling and Analysis

We sampled all study sites every three weeks, beginning May 2002 and ending May 2003. Water samples were taken regardless of flow level. Each sampling event generally spanned 2-3 consecutive days. We used area-velocity techniques to calculate stream flow (m^3/s) at each site at the time water sampling occurred. Daily variation in stream flow was also monitored at a single location (Big Sandy Creek) for the entire study period in order to document general flow conditions in the lower Cheat River watershed. Temperature (C), pH, specific conductivity, dissolved oxygen (mg/L), and total dissolved solids (mg/L) were measured on site using a YSI 650 unit with a 600XL sonde. At each site, two water samples were collected. A 500 mL water sample was filtered using a Nalgene polysulfone filter holder and receiver, using mixed cellulose ester membrane disc filters with a 0.45 µm pore size. Filtered samples were immediately treated with 5 mL 1:1 nitric acid to bring the pH below 2. This acidification prevented dissolved metals from dropping out of solution prior to analysis. These filtered water samples were used for analysis of aluminum, iron, manganese, nickel, cadmium, chromium, and hardness (mg/L). An unfiltered 1-liter grab sample was also collected for analysis of alkalinity, acidity, and sulfates. Unfiltered samples were kept on ice after collection, and stored in the laboratory at 4^{o} until analyses were complete.

All samples were analyzed at Black Rocks Test Lab in Morgantown, WV, using procedures from the 18^{th} edition of Standard Methods for the Examination of Water and Wastewater (Clesceri et al. 1992). Acidity and alkalinity as $CaCo_3$ were determined using the titration method (methods 2310 and 2320B, respectively). Sulfate was determined using the turbidimetric method (method 426C). Iron, manganese, nickel, cadmium and chromium were analyzed with an AAS (atomic absorption spectrophotometer) using method 3111B. Aluminum was analyzed using an AAS, using method 3111D. Hardness as $CaCo_3$ (SM18-2340B) was measured using an AAS, using calculations from method 3111B.

Stream Ecological Condition

We followed USEPA and WVDEP standard operating procedures to sample benthic macroinvertebrates at all locations in May 2003. At each location, we sampled riffle habitat with a modified kick net with 500µm mesh and dimensions of 335 x 508 mm (13 x 20 in.). A ¼-m square region (½ m x ½ m) of stream bottom was scoured in front of the kick net until sediment and rocks were completely disturbed. All samples were preserved in 95% ethanol and Rose Bengal solution and transported to the laboratory where individual macroinvertebrates were identified to family level resolution, where possible, and counted.

We used the West Virginia Stream Condition Index (WVSCI), as a measure of stream ecological condition. The WVSCI is a multi-metric index of ecological condition that integrates numerous measures of the benthic invertebrate community into a single value (USEPA 2000b).

The metrics included in the final index include: 1) total number of families (i.e., total family richness), 2) number of families in the orders Ephemeroptera, Plecoptera, and Trichoptera (i.e., EPT family richness), 3) percent of all families that are EPT taxa (i.e., % EPT), 4) percent of all families that are considered pollution tolerant (i.e., % tolerant taxa), and 5) percent of the total community of invertebrates that are in the top two dominant taxa (i.e., % dominant taxa). Metrics 1-3 of the WVSCI are expected to increase with decreasing levels of environmental impairment. In contrast, metrics 4 and 5 are expected to decrease with decreasing levels of environmental impairment. The final value is standardized, such that the highest quality stream segments in a watershed receive scores of 100. The lowest score possible is a WVSCI of 10 (USEPA 2000b). Although the WVSCI is currently the accepted index used to determine the biotic integrity of running waters in West Virginia, to our knowledge there have been no rigorous tests of its response to varying levels of water quality impairment from mining.

Statistical Analyses

Our statistical analyses addressed three broad objectives: 1) describe differences in water chemistry among reference, moderately mining, and intensively mined streams, 2) describe temporal variability in water chemistry among the stream types, 3) describe relationships among water chemistry, water quality variability, and ecological condition, and 4) identify specific chemical features leading to ecological degradation in mined watersheds. To meet these objectives we used a combination of univariate and multivariate statistical methods. First, we calculated the mean and variance of each water chemistry parameter for each site and used ANOVA to test for differences in water quality among the stream types. We also calculated coefficients of variation (CV) for each parameter as a measure of water quality variability. Principal Components Analysis (PCA) was used to summarize variance-covariance relationships among water quality parameters into interpretable factor scores for each site. We then used Chi-Square analysis to examine differences in overall water chemistry among stream types. Finally, we used Stepwise Descriminant Function Analysis and Classification-Misclassification Analyses to identify specific water chemistry parameters that distinguish reference streams from moderately and intensively mined streams.

We used multiple regression to examine the relationship between stream ecological condition and water quality. Specifically, natural log transformed WVSCI scores for each site (dependent variable) were related to mean factor scores and CV's of factor scores for both Principal Components 1 and 2 (PC1 and PC2). Because we found a wide range of variability in the ecological condition of moderately impaired streams, we reanalyzed data for reference and moderately mined streams only. We also conducted DFA in an effort to identify chemical characteristics of streams with good to moderate water chemistry but poor ecological condition.

Results

Streams in the lower Cheat River basin experienced significant day-to-day and seasonal variation in stream flow (Figure 1). Discharge patterns could be separated into three distinct phases. Phase 1 was a relatively wet Spring in April and May 2002. Phase 2 consisted of a prolonged dry period from June – October 2002. This dry period was then followed by an unusually wet Fall 2002 and Winter 2003 (Phase 3) (Figure 1). These alternating wet and dry periods provided a good opportunity to quantify changes in stream chemistry across a variety of hydrologic conditions.

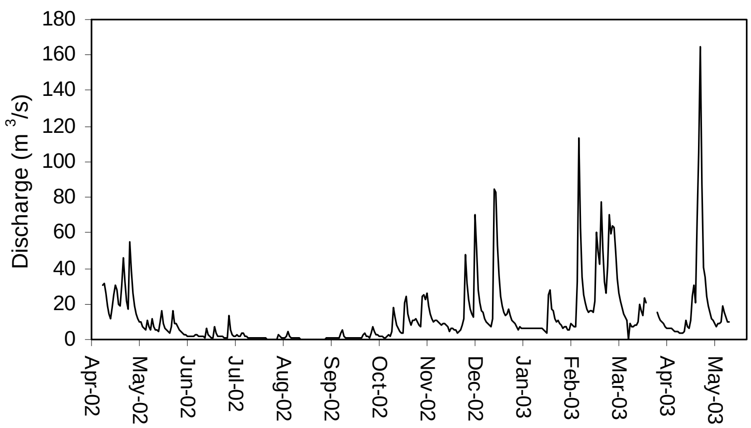


Figure 1. Daily mean discharge during the course of the study. Discharge was gauged continuously on Big Sandy Creek at Rockville, WV (USGS 03070500).

Water Chemistry in Reference, Moderately Mined, and Intensively Mined Streams

Each stream segment was sampled 17 times over the course of the one year study resulting in a total of 578 samples. Although water chemistry was highly variable, we observed consistent differences in chemical conditions among reference, moderately mined, and intensively mined stream segments (Table 1). Specifically, reference streams tended to possess the following characteristics relative to moderately and intensively mined segments: higher pH, lower conductivity, higher alkalinity, lower acidity and sulfate concentration, and lower concentrations of dissolved metals (Table 1). Interestingly, differences in dissolved iron and aluminum concentrations between reference and moderately mined streams were minor (e.g. mean iron concentrations were 0.18 mg/L in reference streams vs. 0.22 mg/L in moderately mined streams). However, trace metal concentrations (i.e., Mn, Ni, Cd, and Cr) differed between the two stream types by an order of magnitude (Table 1).

PCA extracted three significant components (i.e. eigenvalues exceeding 1.0) (Table 2). PC1 represents a continuum of mining related impairment where low values describe streams with high pH and alkalinity and high values describe streams with high conductivity and acidity and high concentrations of sulfates and metals (Table 2). PC2 represents a continuum between relatively hard-water and soft-water streams. Sites with high scores on PC2 were characterized by high alkalinities and hardness and high concentrations of calcium (Table 2). PC3 represented a continuum of cadmium concentration. Despite possessing an eigenvalue greater than 1.0, PC3 was deleted from further discussion for two reasons. First, the component was generated because of exceptionally high cadmium concentrations in three sites only and does not represent a true gradient across all streams. Second, PC3 was not found to be a significant determinant of ecological condition in subsequent analyses.

We observed significant differences in mean factor scores among reference and mined streams on both PC 1 and PC 2 (Figure 2). On PC 1, we found a relatively continuous relationship between mining intensity and water chemistry. Reference streams possessed high pH and extremely low concentrations of sulfates and dissolved metals, whereas the opposite was true for intensively mined streams. Water chemistry along PC 1 in moderately mined streams was intermediate to reference and intensively mined streams (Figure 2). Reference streams and intensively mined streams did not differ significantly along PC 2; both stream types possessed intermediate hardness levels. In contrast, moderately mined streams covered a wide range of hardness qualities, with some possessing exceptionally hard-water characteristics and others possessing soft-water characteristics (Figure 2).

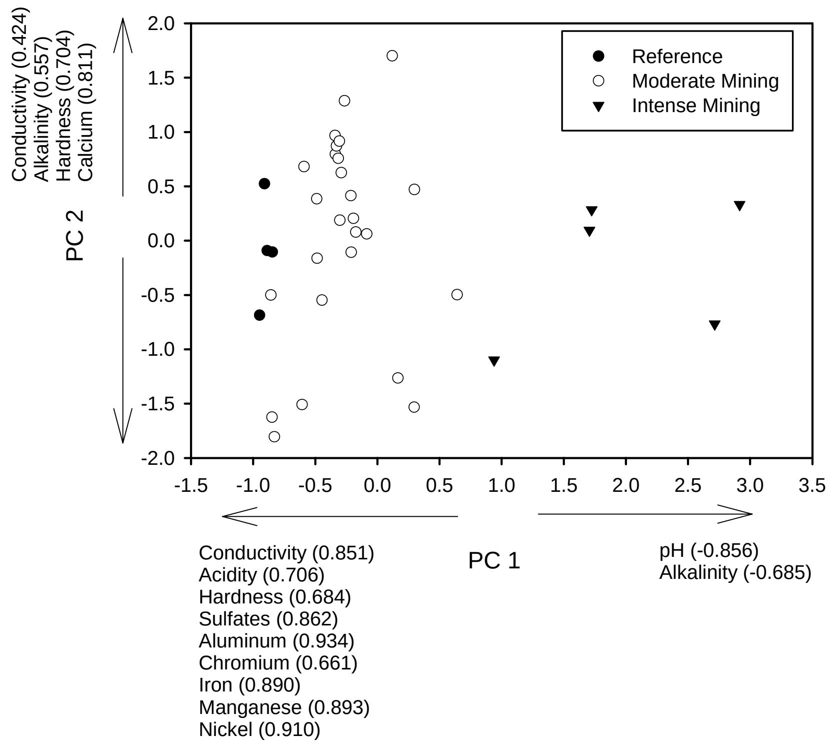
Table 1. Summary statistics for water chemistry variables from unimpaired, moderately impaired, and severely impaired stream segments. Mean values were calculated across all sample dates. Avg. CV refers to the average variability of stream segments within each category. The higher the value the more highly variable water chemistry was from sample date to sample date.

	Reference			Moderately Mined			Intensively Mined		
	Mean	Range	Avg. CV	Mean	Range	Avg. CV	Mean	Range	Avg. CV
pH	7.2	7.0 - 7.4	7	6.3	4.1 – 7.0	8	3.3	2.7 - 3.9	10
Temperature (^{0}C)	11.5	10.6 - 12.5	7	11.0	10.2 - 14.4	8	9.7	8.1 - 10.4	11
Sp. Conductivity (µS/cm)	103	71 - 154	32	198	35 - 527	53	1222	747 - 1757	38
Total Hardness (mg/L)	29.7	19.1 - 43.9	31	47.8	10.7 - 122.7	50	158.1	100.8 - 261.1	45
Alkalinity (mg/L $CaCO_3$ eq.)	24.7	15.7 - 36.4	40	11.1	0.0 - 25.6	75	0.0	0.0 - 0.0	.
Acidity (mg/L $CaCO_3$ eq.)	6.7	3.5 - 10.5	203	20.5	8.3 - 44.7	105	272.1	130.2 - 460.0	64
Sulfate (mg/L)	16.2	9.1 - 41.5	88	65.9	11.5 - 225.8	68	608.6	363.1 - 908.8	43
Iron (mg/L)	0.18	0.11 - 0.27	104	0.22	0.09 - 0.44	117	24.19	5.27 - 58.47	73
Aluminum (mg/L)	0.15	0.12 - 0.17	66	0.55	0.12 - 2.80	82	17.34	8.51 - 31.77	73
Cadmium (mg/L)	0.0014	0.0012 - 0.0016	74	0.0020	0.0010 - 0.0052	108	0.0029	0.0024 - 0.0038	67
Chromium (mg/L)	0.0009	0.0006 - 0.0012	100	0.0017	0.0006 - 0.0064	117	0.0073	0.0036 - 0.0146	75
Manganese (mg/L)	0.027	0.015 - 0.035	97	0.335	0.045 - 1.645	77	3.752	1.564 - 8.232	58
Nickel (mg/L)	0.009	0.008 - 0.010	87	0.022	0.009 - 0.083	73	0.240	0.147 - 0.390	60

Table 2. Factor loadings for water quality parameters on the first three significant principal components. Factor loadings $\geq |0.40|$ are presented for interpretation.

	PC 1	PC 2	PC 3
Eigenvalue	7.53	2.09	1.02
% Var. Expl.	58.0	16.1	7.9
pH	-0.858	---	---
Conductivity	0.851	0.423	---
Alkalinity	-0.685	0.557	---
Acidity	0.706	---	---
Hardness	0.684	0.704	---
Sulfates	0.862	---	---
Calcium	---	0.811	---
Aluminum	0.934	---	---
Cadmium	---	---	0.853
Chromium	0.661	---	---
Iron	0.890	---	---
Manganese	0.893	---	---
Nickel	0.910	---	---

Figure 2. Variation in mean PC 1 and PC 2 factor scores among mined and reference streams. PC 1 represents an acid mine drainage continuum, whereas PC 2 is a water hardness gradient.

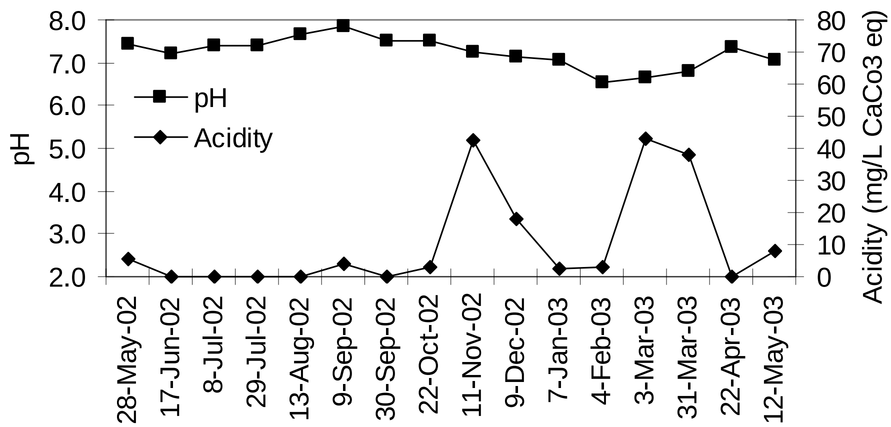


Water Quality Variability

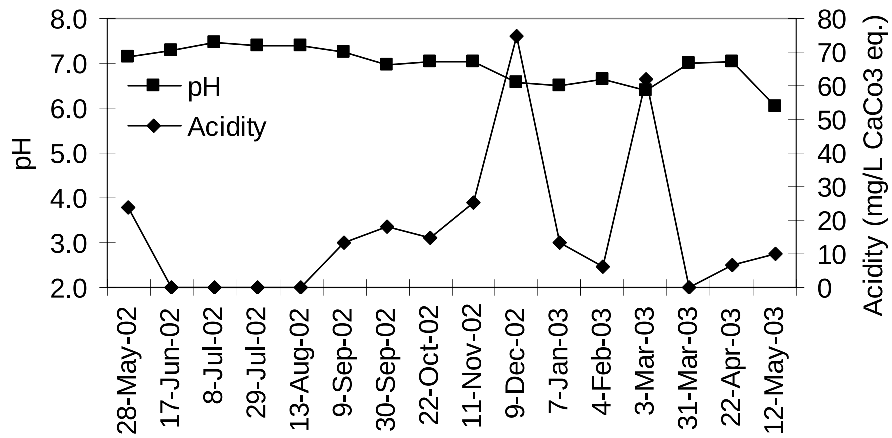
An important objective of our study was to quantify the degree of temporal variability in water quality in streams of the lower Cheat River watershed. Our analyses indicated that chemical conditions were highly variable in all streams studied, regardless of relative impairment level. Figures 3 – 5 illustrate the typical range of chemical variability in the three stream types examined: reference, moderately mined, and intensively mined. Two important findings emerge from these graphs. First, reference and moderately mined streams possessed good water quality for most of the year and variability was marked by pulses of poor chemical condition (Figure 3-5). This was especially true for acidity and dissolved aluminum and iron during periods of increased stream flow (Figure 3 and 4). In contrast, water chemistry in intensively mined streams tended to remain poor for most of the year and variability was marked by pulses of improved chemical condition, probably as a result of dilution from precipitation events (Figure 3-5). Second, reference and moderately mined streams exhibited similar water chemistry dynamics for pH, acidity, aluminum and iron (Figure 3 and 4). However, reference and moderately mined streams consistently displayed measurable differences in the dynamics of manganese and trace metals such as nickel (Figure 5). Specifically, dissolved manganese and trace metal concentrations in reference streams remained low throughout the year. However, chronic levels of manganese persisted throughout the year, and episodic doses of trace metals were common in moderately mined streams (Figure 5).

The degree of temporal variability in water chemistry varied as a function of stream type and depended on the chemical parameter of interest. Generally, we found that temporal variability in condition was highest in the moderately mined streams and lowest in reference and intensively mined streams (Figure 6 and 7). This pattern was especially true for trace metals such as cadmium and chromium (Figure 7). The only exception to this rule was for acidity for which reference streams exhibited the greatest amount of temporal variability (Figure 6). The low temporal variability in water chemistry observed in reference streams indicates that these streams possess good water quality under most flow conditions. Likewise, low variability in intensively mined streams indicates that these streams typically possess very poor water quality. In contrast, the moderately mined streams alternate between good and poor water quality, resulting in a high lever of temporal variability in chemical conditions.

A. Roaring Creek 1



B. Muddy Creek 4



C. Martin Creek

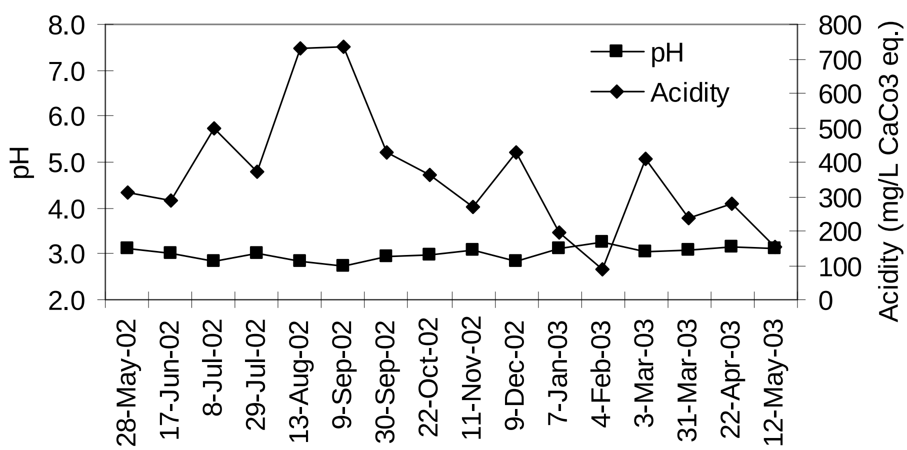
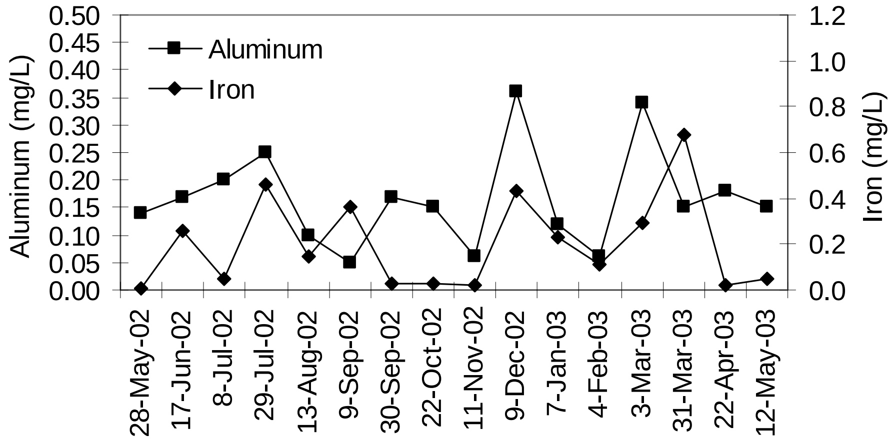
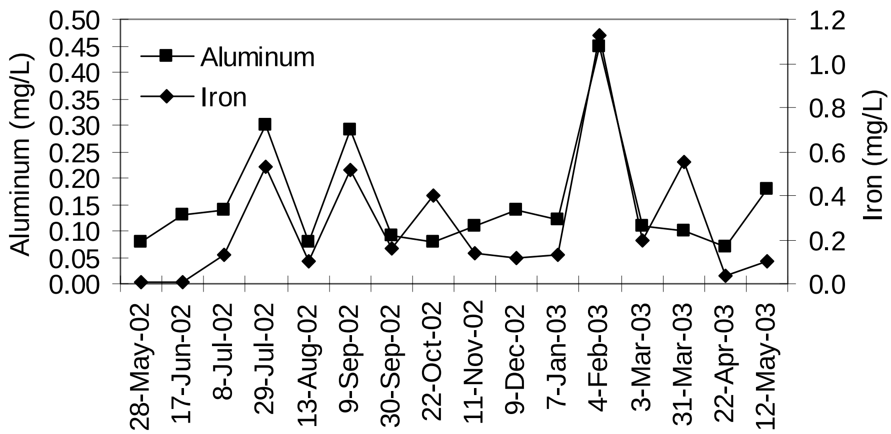


Figure 3. Variability in pH and Acidity within an unimpaired (A), a moderately impaired (B), and a severely impaired (C) stream segment of the lower Cheat River watershed.

A. Roaring Creek 1



B. Muddy Creek 4



C. Martin Creek

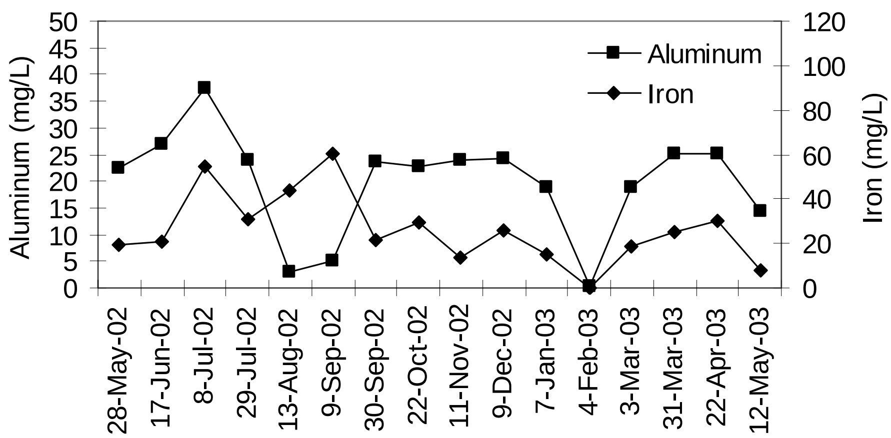
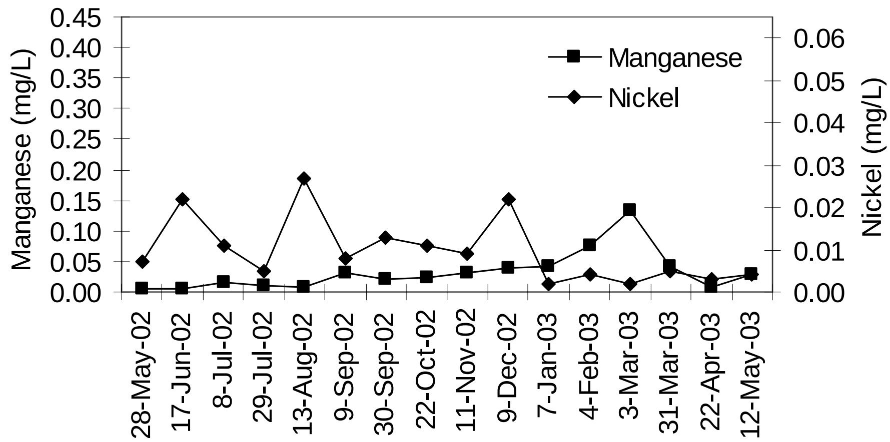
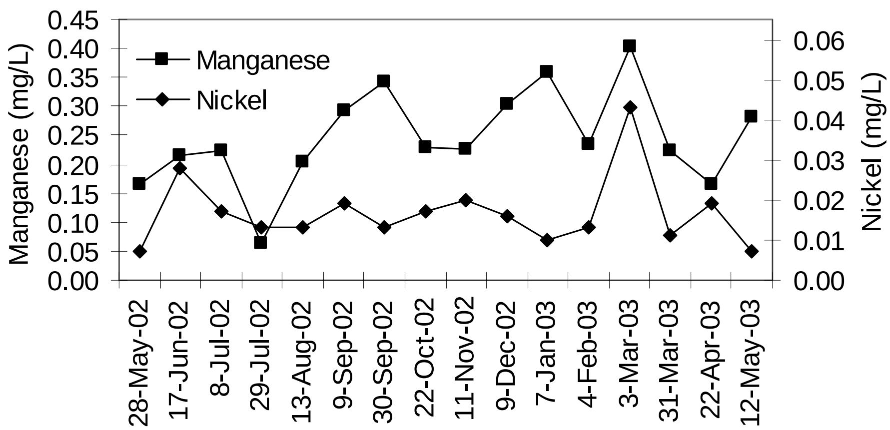


Figure 4. Variability in dissolved Aluminum and Iron concentrations within an unimpaired (A), a moderately impaired (B), and a severely impaired (C) stream segment of the lower Cheat River watershed.

A. Roaring Creek 1



B. Muddy Creek 4



C. Martin Creek

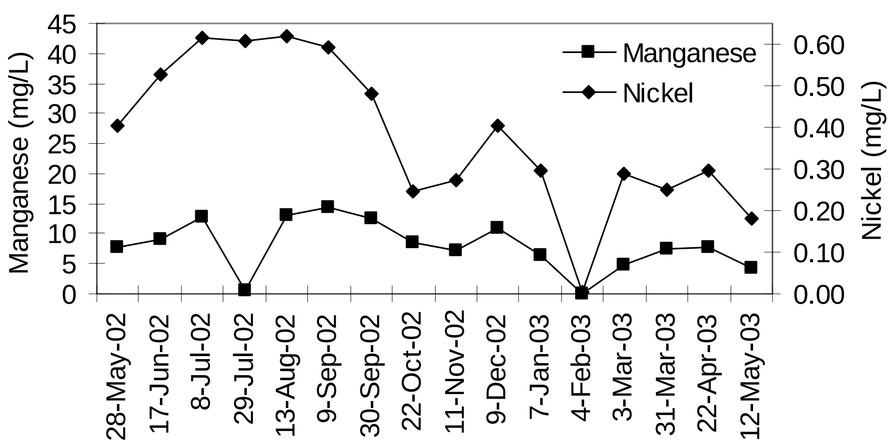


Figure 5. Variability in dissolved Manganese and Nickel concentrations within an unimpaired (A), a moderately impaired (B), and a severely impaired (C) stream segment of the lower Cheat River watershed.

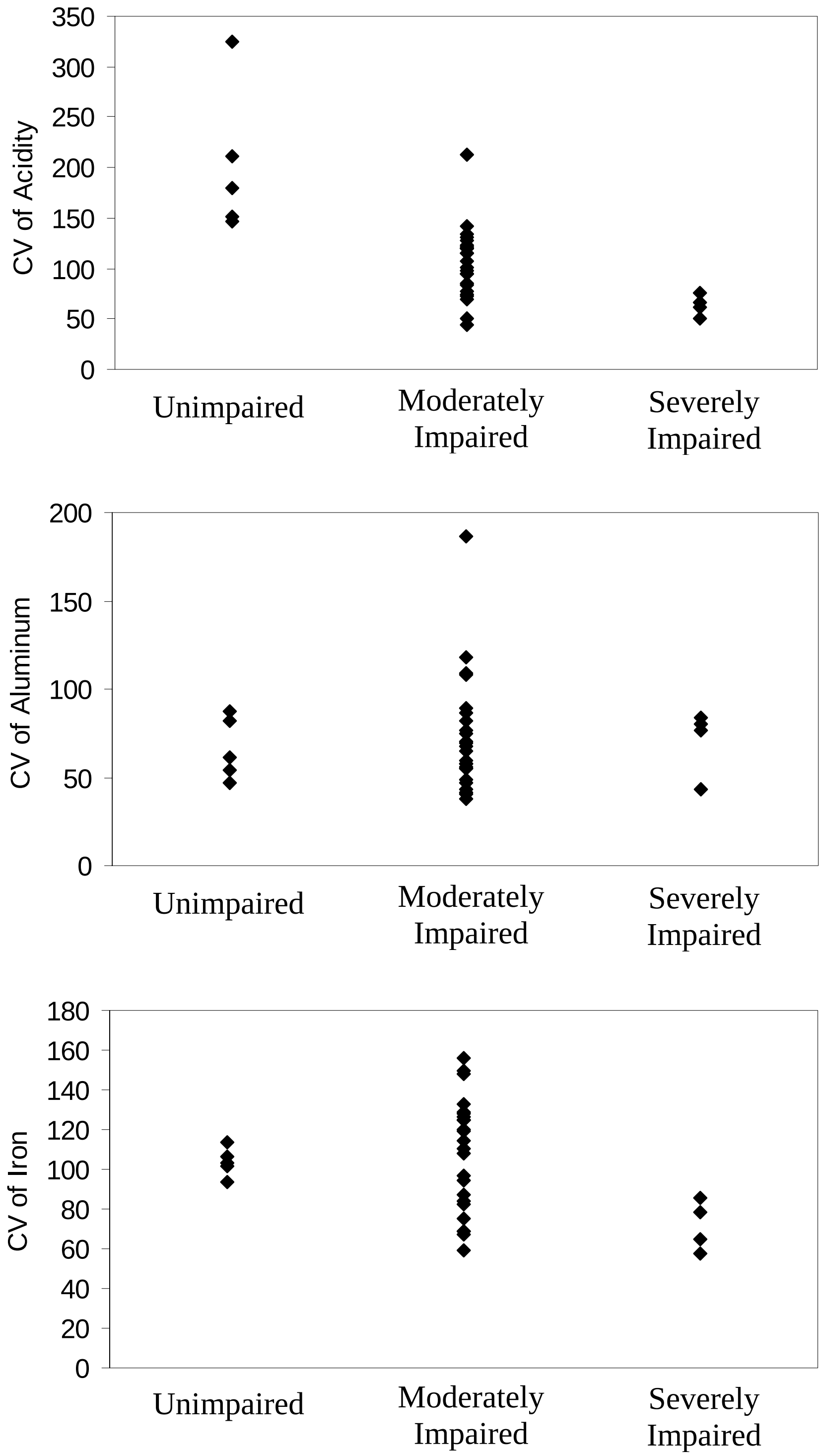


Figure 6. Temporal variability in acidity and dissolved aluminum and iron concentrations within unimpaired, moderately impaired, and severely impaired stream segments of the lower Cheat River watershed. Each symbol represents a relative measure of day-to-day variability in water chemistry at a specific study site.

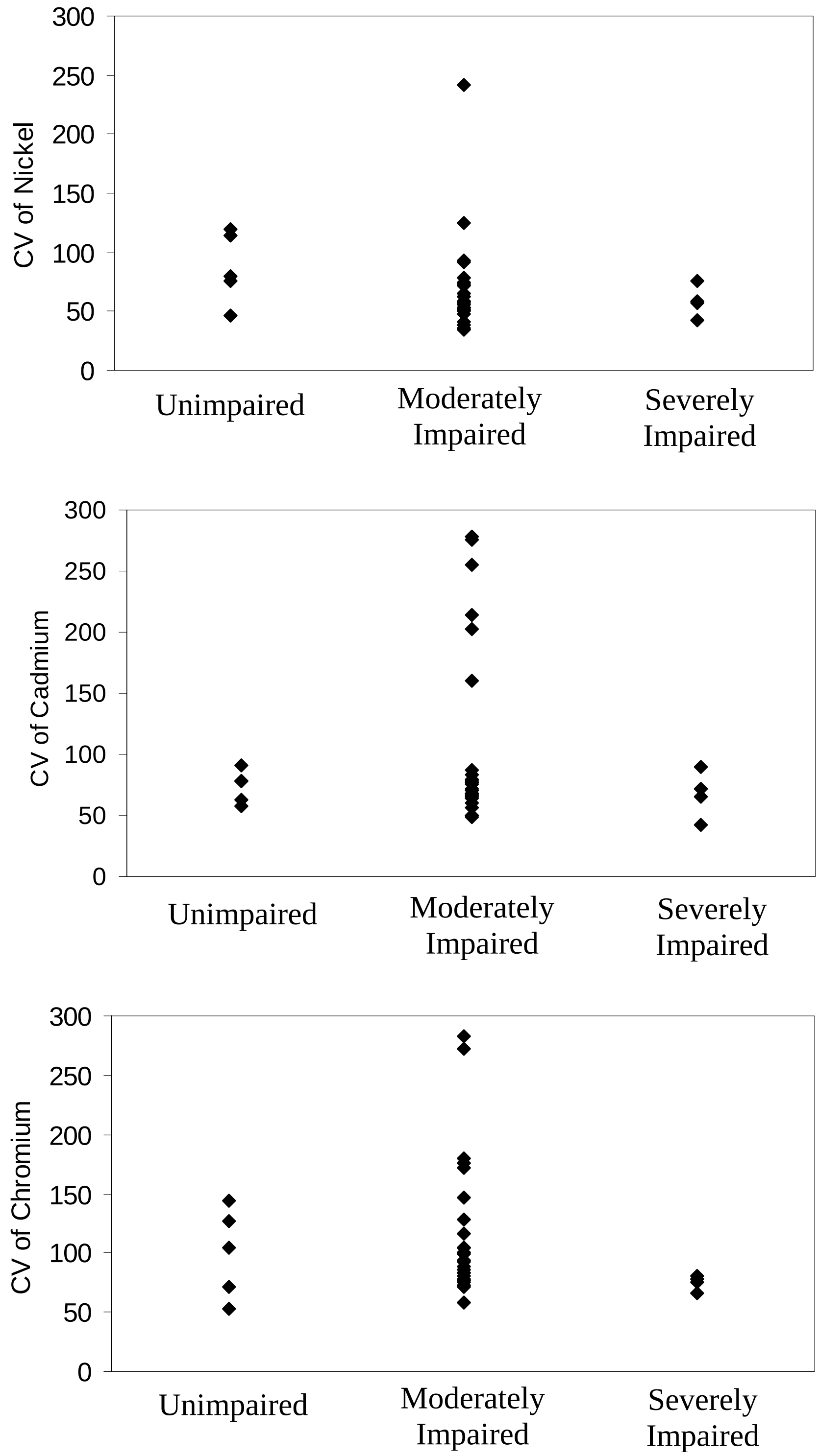


Figure 7. Temporal variability in dissolved trace metal concentrations within unimpaired, moderately impaired, and severely impaired stream segments of the lower Cheat River watershed. Each symbol represents a relative measure of day-to-day variability in water chemistry at a specific study site.

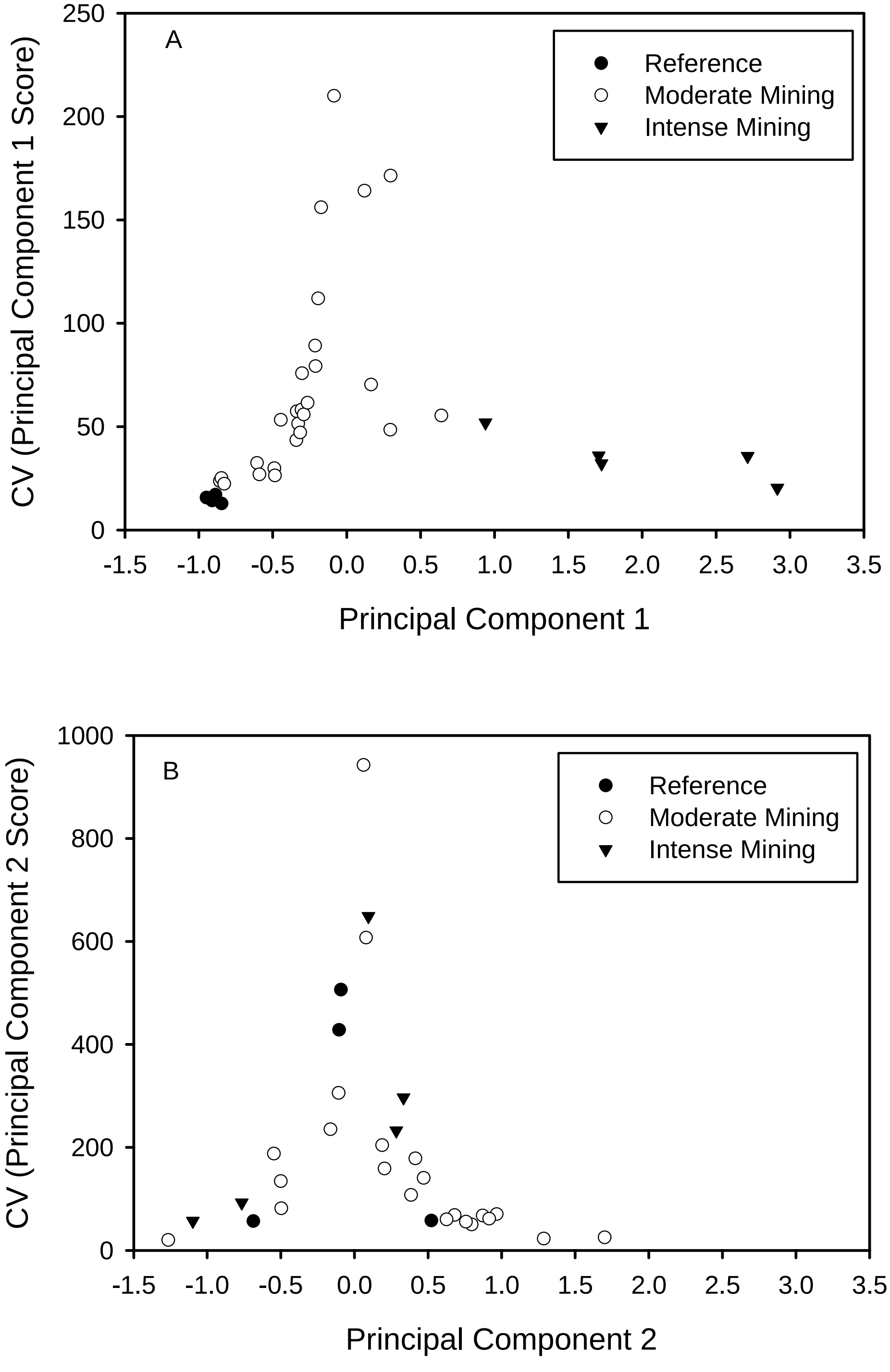


Figure 8. Relationship between water quality variability and mean water quality condition on both PC 1 (A) and PC 2 (B).

The general relationship between water quality variability and overall water chemistry is further illustrated in Figure 8, which demonstrates that the greatest variability in water quality along PC 1 was observed in the moderately impaired streams (Figure 8a). This pattern did not hold for PC 2, however, where reference and intensively mined streams exhibited substantial levels of temporal variability (Figure 8b)

<u>Effects of Water Chemistry on Stream Ecological Condition</u>

We observed a strong effect of water chemistry on stream ecological condition (Figure 9). Ecological condition declined exponentially with increasing levels of AMD impairment (as measured by PC 1) (Figure 9). Consequently, even slight to moderate levels of mining effluent produce ecological degradation.

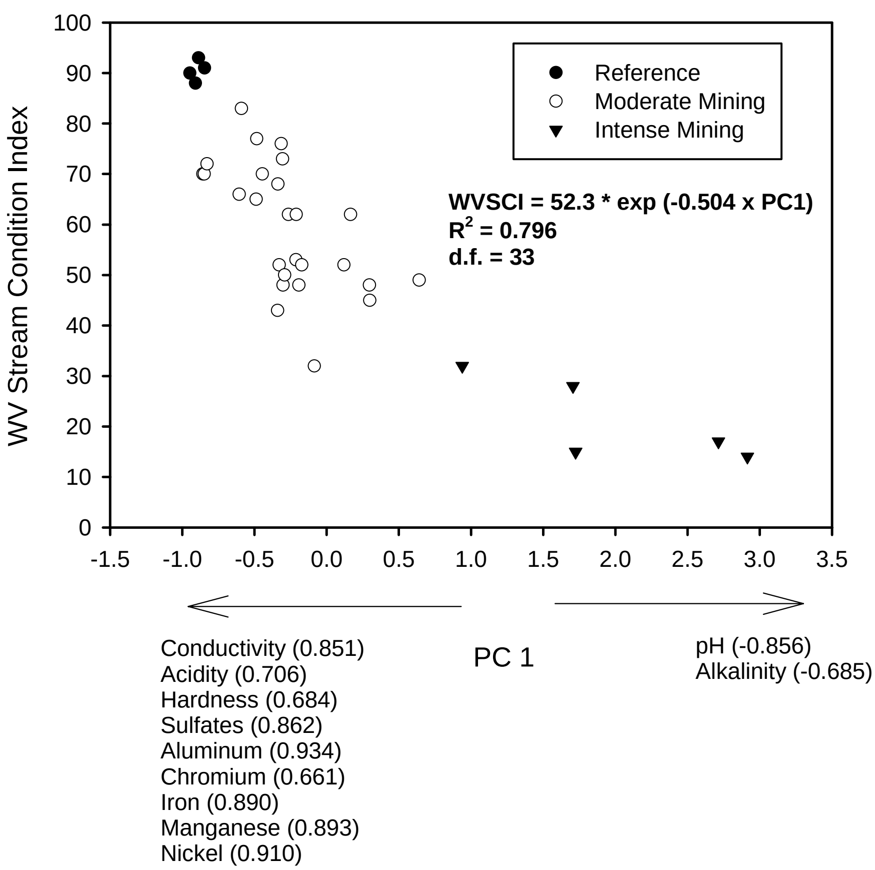


Figure 9. Relationship between WVSCI and water quality as measured by PC 1.

Despite such a strong relationship between PC 1 and ecological condition in this watershed, we observed substantial variability in the relative condition of streams with very similar water chemistry. For example, streams with nearly identical water chemistry scores on PC 1 varied as much as 30% with regard to WVSCI scores (Figure 9). To examine this phenomenon further, we conducted multiple regression analysis using data from reference and moderately mined streams only. This analysis found that ecological condition in moderately mined streams is significantly related to mean water chemistry and water chemistry variability along both PC 1 and PC 2 (Table 3). Specifically, we found that streams with poorer ecological condition than expected based on PC 1, possessed no alkalinity (i.e., had a low PC 2 score) and experienced highly variable chemical conditions on PC 1 and PC 2. This finding is consistent with the hypothesis that many streams in mined watersheds possess poor ecological condition as a result of episodic, precipitation driven pulses of poor water quality.

Table 3. Regression statistics relating mean water quality and water quality variability along Principal Components 1 and 2 to ecological condition (i.e. WVSCI).

	Effect Direction	Partial R^2	Model R^2	F-Value	P-Value
Mean PC 1	Negative	0.685	0.685	41.24	0.001
CV of PC 1	Negative	0.053	0.737	3.62	0.07
Mean PC 2	Negative	0.043	0.780	3.51	0.08

Discussion

Water chemistry was extremely variable in streams of the lower Cheat River watershed. Although this was true for all stream types examined, temporal variability in chemical condition was highest in the moderately impaired streams. Several factors influence spatial and temporal variability in water chemistry in streams that receive AMD. This variation results from both hydrologic inputs and instream processes (McKnight and Bencala 1990, Sullivan and Drever 2001). Hydrologic inputs can originate from precipitation, direct overland flow, subsurface flow through shallow soils, drainage from shallow and deep aquifers, as well as direct inputs from flooded deep mines. Instream processes include dilution, acid neutralization, metal release and adsorption from sediments, as well as precipitation and coprecipitation (Nordstrom and Ball 1986, McKnight and Bencala 1990, Jurjovec et al. 2002).

Water quality variability was lowest in the unimpaired streams. The variability that was observed resulted from elevated acidity from precipitation events. However, because these streams were moderately alkaline, pH remained high (i.e., >6.5), and dissolved metals remained at very low concentrations. Consequently, brief doses of elevated acidity are unlikely to have a significant effect on the overall condition of unimpaired streams. Water quality variability also was relatively low in severely impaired streams, but for different reasons. Most of the water in severely impaired streams originates from flooded deep mines. The effluent from these mines has extremely low pH (2-3) and high concentrations of dissolved metals. Because these inputs are relatively constant, instream conditions are almost always poor. Occasionally, however, large precipitation events or snow melt will dilute AMD and severely impaired streams will experience brief periods of relatively good water quality. Moderately impaired streams in the lower Cheat River watershed possessed much more variable water chemistry than either the severely impaired or unimpaired streams. There are several possible reasons for this variability. First, these streams possess a much lower alkalinity than unimpaired streams. Therefore, they are more likely to be impacted by acid precipitation events. Second, pH in these streams was depressed and more likely to move between 4.5 and 6.5. At this level, many metals move between conservative and non-conservative behavior resulting in dramatic variability in dissolved metal concentrations.

The high variability in trace metal concentrations that we observed in moderately impaired streams was particularly interesting. It is also interesting that some of the highest concentrations of dissolved cadmium and chromium were observed in moderately impaired rather than severely impaired streams. A possible explanation for these findings is that moderately impaired streams are receiving large inputs of trace metals from disturbed acidic soils in the surrounding watershed. During wet periods when vegetation is dormant, acidic soil water and water in shallow aquifers may mobilize trace metals and deliver them to the moderately impaired streams.

A poorly understood component of trace metal dynamics in the Cheat River watershed is the interaction between trace metals, sediments, and aluminum and iron precipitates. Trace metals are often removed from the water column during mixing by either adsorption to sediment particles such as clay or coprecipitation with aluminum and iron precipitates (Routh and Ikramuddin 1996, Jurjovec et al. 2002). These trace element complexes remain immobilized in the sediment and are only released when the pH decreases. Dissolved trace metal concentrations may be higher in moderately impaired streams than severely impaired streams because there is less iron and aluminum precipitate. Consequently, coprecipitation of trace metals may occur at a lower rate resulting in higher dissolved trace metal concentrations in the moderately impaired streams. Regardless of the mechanisms controlling trace metal dynamics, a more complete understanding of trace metal / sediment / precipitate interactions in the Cheat River watershed is needed.

Our results support numerous studies that have found that severely impaired streams in mined watersheds experience worst conditions during low flow periods (Filipek et al. 1987, Brake et al. 2001, Sulliven and Drever 2001). During these periods, severely impaired streams are dominated by mine water because surrounding soils and shallow aquifers are dry. To our knowledge, our study is one of the first to examine temporal variability in water chemistry across a wide range of moderately impaired streams. In contrast to the severely impaired streams, many of the moderately impaired streams experience their best conditions at low flows and their worst conditions during high flows. This pattern suggests that the dominant sources of impairment to moderately impaired streams come from surface mines and/or disturbed shallow aquifers. During dry periods, soils and shallow aquifers are dry and deeper, alkaline aquifers are the dominant water source to these streams. During wet periods, however, the shallow water sources become saturated and supply water to streams, especially in winter and early spring. It may be at this time that moderately impaired streams are receiving the highest loads of acidity and dissolved metals from the surrounding watershed. It also may be a time when trace metals are being released from the sediments because of lowered pH.

Variation in water chemistry had significant negative effects on stream ecological condition. WVSCI scores declined exponentially with increasing concentrations of mining generated solutes. As a consequence, we observed significant biological impairment in streams with only small to moderate amounts of mine drainage. The poorest conditions were observed in those streams that experienced wide fluctuations in water quality. This finding suggests that poor ecological conditions are generated in many streams as a result of periodic pulses of poor water quality. These pulses may be the result of precipitation driven effluent from deep mine pools. Or pulses of poor water quality may result from acidic rainfall on disturbed soils. Additional research is needed to identify the exact mechanisms causing poor ecological condition in streams with relatively good water quality.

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2. PUBLICATIONS

Petty, J. Todd, and J. Barker. 2004. Water quality variability, trace metals, and implications for restoring a mined Appalachian watershed. *Proceedings of the American Society of Mining and Reclamation* 21:1484-1504.

Petty, J. Todd, and J. E. Barker. In Preparation. Relationship between stream ecological condition and specific water quality characteristics in a mined Appalachian watershed. To be submitted to: *Environmental Management*.

3. INFORMATION TRANSFER ACTIVITIES

In addition to preparation and submission of written publications, we have been very active in presenting the results of our research at local, regional, and national meetings.

Petty, J. T.
"Ecological Considerations for a Water Quality Trading Program."
Special Meeting of the Cheat TMDL / Water Quality Trading Stakeholder Group
Morgantown, WV

Petty, J. T.
"Integrating Ecological Indices into Water Quality Trading Programs."
Annual Meeting of the Electrical Power Research Institute, Environmental Management
San Antonio, TX

Petty, J. T.
"Temporal Variability in Water Quality in a Mined Appalachian Watershed."
Annual Meeting of the WV Advisory Committee for Water Research
Stonewall Jackson Lake State Park Resort, WV

Petty, J.T., and J.E. Barker
"Water quality variability, trace metals, and implications for restoring a mined Appalachian watershed."
Annual Meeting of the American Society of Mining and Reclamation
Morgantown, WV

4. STUDENT WORKER SUMMARY

Category	USGS WRI Award	NIWR-USGS Internship	Supplemental Awards	Total
Undergrad	$4,950	$0	$8,584	$13,543
M.S.	$19,872	$0	$19,872	$39,744
PhD	$23,160	$0	$23,160	$46,320
Post Doc	$0	$0	$0	$0
Total	$47,999	$0	$51,616	$99,607

5. NIWR-USGS STUDENT INTERNS

Not Applicable

6. NOTABLE ACHIEVEMENTS AND AWARDS

Dr. Petty received the WVU Division of Forestry Hoyt Outstanding Faculty Award in May 2004.

We also received a $600,000 grant from the USEPA to continue research needed to fully recover mined watersheds