Water Research Institute
Annual Technical Report
FY 2003

Introduction

West Virginia Water Research Institute

Introduction

The West Virginia Water Research Institute (WVWRI) addresses the key water resource issues facing policy makers, agency staff and the public. Our research program is guided by the West Virginia Advisory Committee for Water Research. It includes representatives from the following:

West Virginia Department of Natural Resources West Virginia Bureau for Public Health West Virginia Division of Environmental Protection U.S. Federal Bureau of Investigation U.S. Geological Survey U.S. Environmental Protection Agency U.S. Department of Energy - National Energy Technology Laboratory U.S. Department of Agriculture - Natural Resources Conservation Service U.S. Army Corps of Engineers - Huntington, WV District Canaan Valley Institute

The Advisory Committee develops the Institutes research priority list, reviews its progress and selects startup projects at its annual meeting. With this direction, the Institute recruits new researchers to study emerging water research issues. Because the Advisory Committee understands future regulatory and economic driving factors, these issues tend to grow in importance and have often led to follow-on funding from their agencies.

Funding Strategy

The Institute receives a grant of roughly $92,000 annually through the U.S. Geological Survey CWA section 104b program. We use this funding to develop research capabilities in priority areas and to provide service to State agencies, its industry and citizen groups. As a result of successful leveraging, we supported a program with an average yearly value of $3.4M between 1998 - 2003.

Our strategy relies on using the USGS section 104b funding to develop competitive capabilities that, in turn, translate into successful proposals funded by a broad spectrum of Federal and State agencies. Over the past three years our leveraging against section 104b dollars has been about 40:1.

Our strategy also relies on maintaining a broad cadre of researchers within WVU and other institutions within the state. We also work with faculty from institutions across the country to form competitive research partnerships. As West Virginia University is the States flagship research institution, its researchers have played the dominant role. Over the past 15 years over 50 WVU faculty members have been supported by WVWRI projects while 25 faculty from other State institutions have participated in the program.

Our funding strategy relies on successful competition for Federal dollars while teaming with State agency and industry partners. The later provide test sites, in-kind support and invaluable background data.

Research Capability

The bulk of our research is undertaken by academic faculty. Since West Virginia University is the flagship research institution in the State, its faculty have received the bulk of Institute funding. Over 50 WVU researchers have been supported by the WVWRI representing 20 departments. In addition, the Institute has a staff of eight, with three research contractors. Roughly half of the Institute is directly engaged in research projects.

Key Findings

Determination of environmental effects of flooding in the Pittsburgh Basin coal mines. Development of a boron doped diamond electrode for rapid mercury speciation. Development of cost effective acid mine drainage treatment methods. Development of GIS based watershed modeling software. Commercialization of acid mine drainage design software package: AMDzine.

New Programs

Established in 2002, the Hydrology Research Center is dedicated to improving the understanding and management of West Virginias groundwater resources. The Centers researchers are actively studying applied water problems in the state, conducting research that addresses flooding and discharge from abandoned mines, groundwater supply and protection, and other watershed management issues. The HRC assembles multi-disciplinary research teams from West Virginia University and other higher education institutions to investigate current hydrologic science issues that are of interest to industry, government, and the general public.

Established in 2003, the Geo-Engineering Center is the newest addition to WVWRIs suite of water-related programs. This center focus on soil-related problems affecting the integrity of engineered systems and the engineering aspects of soil and groundwater remediation. The center is applying new and innovative technologies to current environmental issues affecting soil and groundwater safety security, and quality in West Virginia and other states. Already the center is performing full-scale demonstration projects that address the safety and environmental hazards of coal waste impoundments and contaminated Department of Defense sites. The center also serves as a Center of Excellence to the National Environmental Education and Training Center, a non-profit organization that provides environmental training and innovative technology management to protect workers and the environment.

Future Direction

Development of the Institutes Hydrology Research Center will allow us to contribute to West Virginias water supply and use initiatives while the new Geo-Engineering Center is already capturing significant funding through the Department of Defense, Army Corps of Engineering for military base closure. Both of these areas are likely to expand rapidly while our other programs such as the National Mine Land Center and the Combustion Byproducts Recycling Consortium are likely to remain stable or grow modestly.

Outreach

The WVWRI performs outreach through meetings, workshops, conferences, site visits, web site, newsletters, and publications.

West Virginia Water Conference 2002

In October, 2002, the WVWRI took the lead in sponsoring a state water conference in Charleston, West Virginia. Other sponsors included West Virginia EPSCoR, West Virginia Bureau for Public Health, the West Virginia Division of Environmental Protection and Marshall University. This was a 1-1/2 day event with speakers and panel sessions focusing on 1) Water use issues in West Virginia; 2) state water use policy direction; 3) water quality in West Virginia; 4) broadening West Virginias water research base; 4) identifying and developing water research project teams; and 5) a student poster award presentation.

West Virginia Water Conference 2003

Another water conference focusing on legal aspects of West Virginias source water protection took place in October 2003 at West Virginia Universitys law school. The law school was the lead sponsor. The WVWRI co-sponsored this event. This was a 2 day event with speakers and panel sessions. Approximately 200 attended.

West Virginia Water Conference 2004

A water conference is planned for October 2004 in which the WVWRI is the lead sponsor. This conference is supported in part by USGS 104b funds.

WVWRI Web Site

A web site (http://wvwri.nrcce.wvu.edu) contains information on all the WVWRI programs and projects. This site is updated on an on-going basis as new information becomes available.

WVWRI Brochure

A brochure on the WVWRI was developed in September, 2002 and distributed at the 2002 Water conference in Charleston. It has been distributed at other meetings and events as well.

Newsletter

The WVWRI puts out a free quarterly newsletter on one of its programs: the Combustion Byproducts Recycling Consortium. This newsletter, Ashlines, is available on the CBRC page of the WVWRI web site at http:wvwri.nrcce.wvu.edu/cbrc.

Publications

Some WVWRI publications are listed on the WVWRI web site. A searchable publications database is planned.

Research Program

WRI48-Impact of Longwall Mining on Headwater Streams in Northern West Virginia

Basic Information

Title:	WRI48-Impact of Longwall Mining on Headwater Streams in Northern West Virginia
Project Number:	2002WV5B
Start Date:	5/1/2002
End Date:	12/31/2003
Funding Source:	104B
Congressional District:	1
Research Category:	Biological Sciences
Focus Category:	Conservation, Ecology, Water Quantity
Descriptors:	headwater streams, stream ecology, aquatic insect, biological criteria, dewatering, perennial, intermittent, ephemeral
Principal Investigators:	Ben Stout

Publication

1. Impacts of longwall mining on the diversity, longevity and functionality of benthic macroinvertebrate communities in central Appalachian headwater streams. Presented at the 51st annual meeting of the North American Benthological Society, Athens, GA.
2. Longitudinal profiling of headwater streams; pg. 76-94 in Functions of Headwater Stream systems. Technical information workshop, North American Enthological Society, Athens, GA. Newspaper article: Charleston Gazette, Friday, May 10, 2002. "WVU to study stream standards".

Impact of longwall mining on headwater streams in northern West Virginia

Final Report, June 30, 2003

Prepared for:
West Virginia Water Research Institute

by:
Ben M. Stout III
Department of Biology
Wheeling Jesuit University
Wheeling, WV 26003
bens@wju.edu
(304) 243-2316

Abstract

The purpose of this study was to measure the impact of longwall mining on headwater streams in northern West Virginia. Physical, chemical, and biological measurements were collected at eight sites along the gradient of each stream from the source 0.65km (0.4 miles) downstream. Six longwall mined streams were compared to five reference streams that were unmined or had been room-and-pillar mined.

Physically, longwall mined headwater streams were significantly different in terms of stream width and temperature. Longwall mined streams were dry at 28% of sites, and all streams were impacted near their sources with stream width indicating remnant surface flow. Streams reemerged downstream, with most reappearing gradually along the downstream gradient. Stream width returned to reference conditions in four of six longwall mined streams in watersheds greater than 80 acres. Instantaneous stream temperatures were consistently 1-2°C cooler in longwall mined compared to reference streams, indicative of underground flow following stream subsidence.

Longwall mined streams were similar in terms of pH and hardness, but significantly different in terms of alkalinity, conductivity, and dissolved oxygen when compared to reference streams. Compared to reference streams, higher conductivity and oxygen demand are indicative of somewhat degraded conditions in longwall mined headwater streams. However, longwall mined streams were capable of supporting a diverse macroinvertebrate fauna at sites where water was present.

Reference streams had diverse and ubiquitous aquatic macroinvertebrate communities across the region. Semivoltine taxa, those requiring perennial flow conditions for multiple years, were collected at 98% of reference stream sites. In contrast, longwall mined streams were dry at 28% of sites and had semivoltine taxa at only 48% of sites. Longwall mining results in a 50% reduction in the omnipresence of perennial aquatic biological communities in headwater streams in Marshall County.

The functional disposition of the macroinvertebrate communities in longwall mined streams failed to follow the predicted trends exemplified by communities in reference streams. For instance, leaf shredders constitute ½ of all taxa and ½ of all individuals collected in the upper reaches near the source of reference streams. Shredders declined precipitously to 30% of the community in the lower reaches of reference streams. In longwall mined streams shredders often dominated in the mid-reaches of streams, with resurgence of surface water apparently mimicking the spring source condition. Predators were often out of balance with the community in longwall mined versus reference streams.

In conclusion, de-watering due to longwall mining results in a 50% reduction in the perennial headwater stream condition in Marshall County, West Virginia. Loss of headwater streams from an increasingly large area within the landscape could significantly disrupt ecosystem-level processes in the central Appalachian region.

Introduction

Longwall mining in the central Appalachian region results in loss of many springs and wells such that mining companies are generally required to replace water supplies. Studies of wetlands (Schmid & Kunz, 2000) and larger streams (Earth Science Consulants, 2001) in southwestern Pennsylvania, USA have addressed the impacts of full-extraction mining followed by subsidence on these respective landscape elements, but no studies have addressed impacts on spring-fed headwater streams in the region. These streams are often ignored or mistakenly referred to as "intermittent" or "ephemeral" due to their non-existence on widely-used 1:24,000 scale topographic maps. In fact, headwater streams can be expected to comprise greater than 80% of the total length of the stream network in a region draining a given watershed (Hynes, 1970).

Loss of headwater streams from the landscape could have significant ecosystem level consequences. Headwater streams are more recently being regarded as exceptional in terms of performance in energy flow and nutrient retention within the complex network of forest and stream interrelations (Wallace *et al*, 1997). For instance, the stream-dwelling seal, spring, and northern two-lined salamanders are the dominant vertebrate predators in these headwater streams, but many other amphibians also depend on headwater streams to provide suitable aquatic breeding sites in proximity to the forest. Other fauna, including birds, depend on the emergence of aquatic insects as a significant food source (Jackson & Fisher, 1986; Gray, 1993). Via their biological communities, headwater streams have the unique capacity to import low-quality, lignin and cellulose forest products (leaves and sticks) and convert that material into high-quality fats and proteins for export back to the forest in the form of insect emergence. Moreover, emerging insects are in a form readily consumed by a suite of forest species at a time coinciding with annual breeding and nesting cycles.

The purpose of this research is to measure potential impacts of longwall mining to headwater streams in northern West Virginia. In order to accomplish this we developed and evaluated a method for assessing damage to headwater streams based on attributes of the biological community along the headwater stream gradient. We tested the hypothesis of no significant difference in the diversity, longevity, functionality, and ubiquity of the aquatic macroinvertebrate communities when comparing longwall mined versus reference headwater streams.

Methods

Field studies consisted of sampling streams at their source and at measured downstream intervals. Selection of suitable study streams was accomplished by determining the presence or absence of longwall undermining from mining maps and permit records filed with State Department of Environmental Protection field offices. Within each mining region, longwall mined watersheds were paired with nearby reference watersheds that were geographically similar, but were either un-mined or room and pillar mined several decades prior to study. Studies were conducted in four Pennsylvania mining regions and one West Virginia mining region operated by different companies over the past two-decades.

In the field each stream was sampled by a four-person team on a single date. Each stream was followed to the primary source and the source location recorded using Global Positioning Systems. The source (spring, or seep) was sampled for pH, conductivity, dissolved oxygen, and temperature using standardized field meters. Stream width was measured 10 times using a ruler or tape. Three investigators collected aquatic macroinvertebrates from a ten meter reach using any means practical (hand-picking, nets, pans, forceps) for a total of 10 minutes (timed). The resulting 30-minute composite sample was stored in a pre-labeled 250 ml plastic container, preserved in 80% ethanol, and returned to the laboratory. The team measured fifty meters downstream with a tape, recorded the GPS location, and repeated the sampling. Sampling continued at 100 meter intervals for a total of eight samples per stream. Sampling was conducted in May through July, 2002, laboratory work in July through December, and analysis from January through June, 2003.

In the laboratory (210b Donahue Hall, WJU), macroinvertebrates from stream samples were sorted and identified to the lowest practical taxonomic level, generally genus. Chemical and biological data were compiled in spreadsheets and analyzed. Community-level metrics included taxa richness (number of kinds) as a measure of diversity, the number of EPT (mayfly, stonefly and caddisfly) taxa as an indication of the purely aquatic, relatively long-lived (generally >9 months aquatic) taxa, and the number of semivoltine taxa, those with aquatic larval life cycles that are greater than one-year in length as an additional biological measure of stream permanence. The percent abundance of each of four functional feeding groups (leaf shredders, fine particle collectors, algal grazers, predators) was calculated in order to compare the trophic status (energy balance) of communities at each site (Merritt & Cummins, 1996). Basin geomorphology including watershed area (Allan, 1995), stream elevation, slope, and aspect were measured for each site using GPS coordinates and MapTech Software with US Geological Survey 1:24,000 scale data.

In analysis 8 samples collected along the longitudinal stream gradient represented each stream. Samples site locations were randomly predetermined based on prescribed distance measurement from the source. Samples collected at regular (50, 100 meter) intervals were representative of the 0.65km (0.4 mile) headwater stream watershed-ecosystem. Six mined and five reference streams were compared using two-way general linear models analysis of variance of streams within regions. With the exception of six outliers, data met ANOVA assumptions of normality and homogeneity.

Index of ubiquity

Widespread occurrence, omnipresence, or ubiquity of macroinvertebrate taxa were measured mathematically by creating a Ubiquity Index. The purpose of the Ubiquity Index was to predict the occurrence of various macroinvertebrate taxa across the study region (Map 1), and to compare disturbed versus reference conditions to determine if any taxa appeared particularly responsive to longwall mining. The index is based on the presence or absence of taxa in samples (88) from streams (11) across replicate regions (4). Two replicate reference regions, separated by approximately 25 km, included 2 Dysart Woods compared to 3 Marshall County streams. Three recently disturbed streams in Marshall County, separated by approximately 2 km from 3 streams that were longwall mined 5-10 years ago, comprised the two replicate disturbed regions. Given the 25 and 2 km difference in scale, the ubiquity of a given taxa would be expected to favor the replicate disturbed regions.

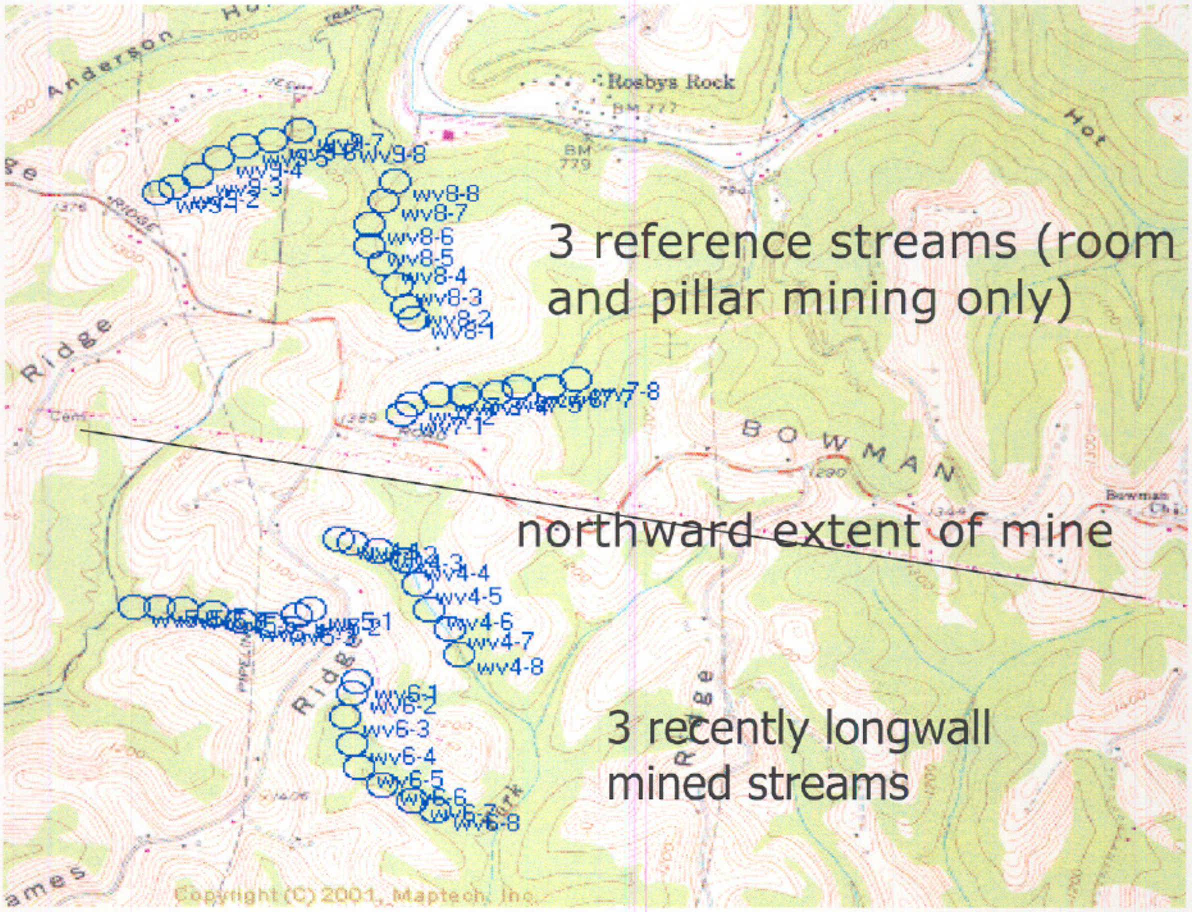
The Ubiquity Index was calculated separately for disturbed versus reference conditions for each of 60 macroinvertebrate taxa, as well as the summary variables EPT Taxa, Semivoltine Taxa, mayflies (Ephemeroptera), stoneflies (Plecoptera), and caddisflies (Trichoptera) using the formula:

$$U_{taxa} = (\ (\text{region } 1(f_{streams} * f_{samples}) + \text{region } 2\ (f_{streams} * f_{samples})\ )\ /2\ ) * f_{region}$$

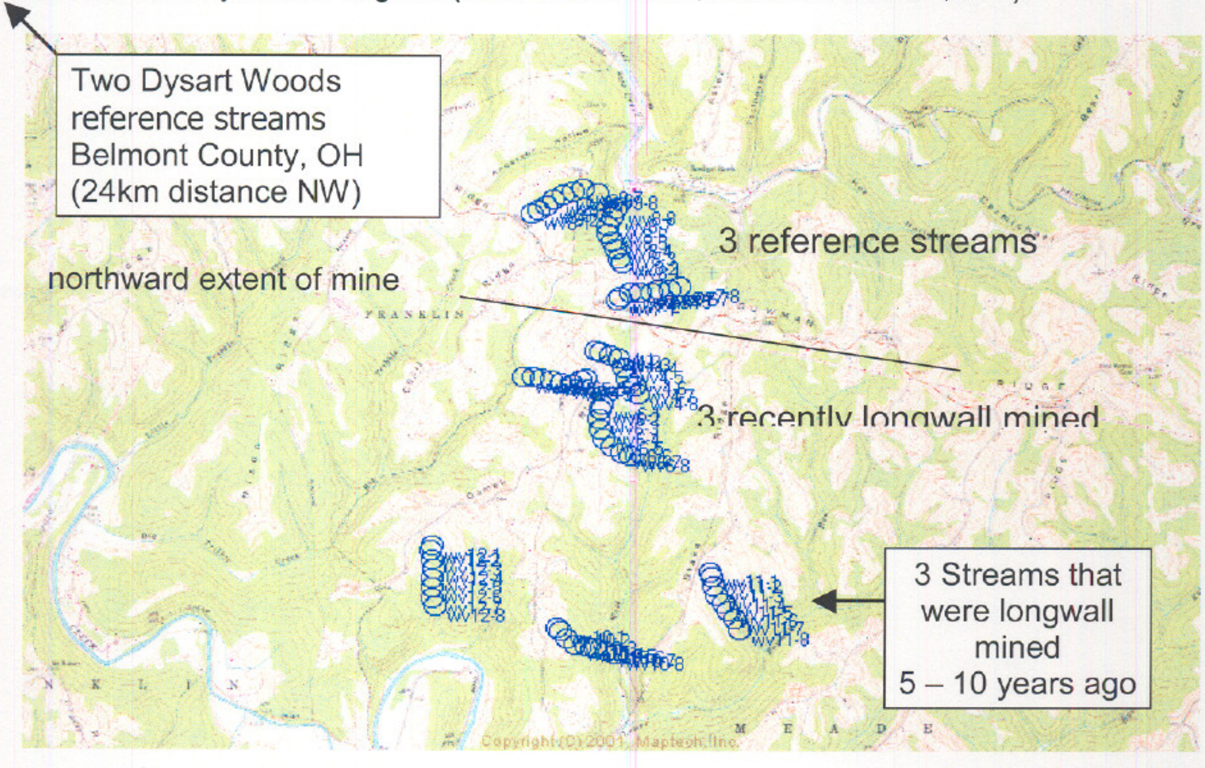
where the ubiquity of a given taxa (U_{taxa}) is the product of the precent frequency of occurrence (presence/absence) of the taxa in samples, streams, and regions. Frequency of occurrence in streams ($f_{streams}$) is equal to the percent of streams (3, except 2 in Dysart Woods Reference) in a region that a taxa was collected in. The variable $f_{samples}$ is the percent frequency in 24 samples (except 18 in Dysart Woods) within a region. The product of the stream and sample frequency is averaged for the two regions and multiplied by the frequency of occurrence of the taxa in the two regions (*i.e.* f_{region} = 100%, 50%, or 0% occurrence in the two regions).

Study sites

Three reference streams in Marshall County that had been room and pillar mined were compared to three streams that had been recently longwall mined (Map 1). Three Marshall County streams that had been longwall mined between 5 and 10 years prior to the study were also sampled (Map 2). Two unmined reference streams were sampled in Dysart Woods, approximately 26 km to the northwest of the Marshall County reference sites.



Maps 1 & 2. Sampling locations in recently longwall mined and reference streams in Marshall County, West Virginia (from USGS 1:24,000 Glen Easton, WV).



Results

Physical characteristics of study streams

Physical attributes of streams and their valleys were comparable between longwall mined and reference watersheds (Table 1). One of the Dysart Woods reference streams merged with a larger watershed resulting in a stream width of 2.5 meters, an extreme outlier (Figure 1). Otherwise, physical data were normally distributed and homogenous. One statistically significant physical difference was that longwall mined streams were on average 1.5° C cooler than reference streams at the time of sampling. Streams that had been longwall mined within the past two years had lower water temperatures than streams that had been longwall mined 5-10 years ago (Figure 1).

The average watershed area upstream of sampling sites was not significantly different in longwall mined versus reference streams (Table 1). Watershed drainage area ranged from 4.3 to 262 acres at sampling sites in reference watersheds and 3.7 to 116 acres at sites in longwall mined streams. The average sampling point in longwall mined watersheds was in a stream draining 47 acres of land surface area compared to 60 acres in reference streams. Dysart Woods reference streams (streams 1 & 2) joined larger streams to form 191 to 262 acre watersheds (Figure 1). Data from larger stream sites in Dysart Woods were not used in scatter plots because there were no sites in longwall mined streams representing watershed areas that large.

Table 1. Mean (and 1 Standard Deviation) physical attributes of samples from longwall mined (N=48) versus reference (N=40) watersheds (ANOVA, Dunnett's Test ,$^{*}p<0.01$).

	Reference streams		Longwall mined streams	
	Mean	(SD)	Mean	(SD)
Watershed area (acres)	60.4	(66.6)	47.4	(32.4)
Elevation (feet)	1098	(98)	1090	(90)
Stream slope (%)	11.3	(6.6)	11.1	(6.5)
Compass heading (degrees true N)	181	(109)	167	(50)
Median stream width (m)	0.88	(0.41)	*0.58	(0.45)
Water temperature (°C)	18.1	(1.5)	*16.5	(1.7)

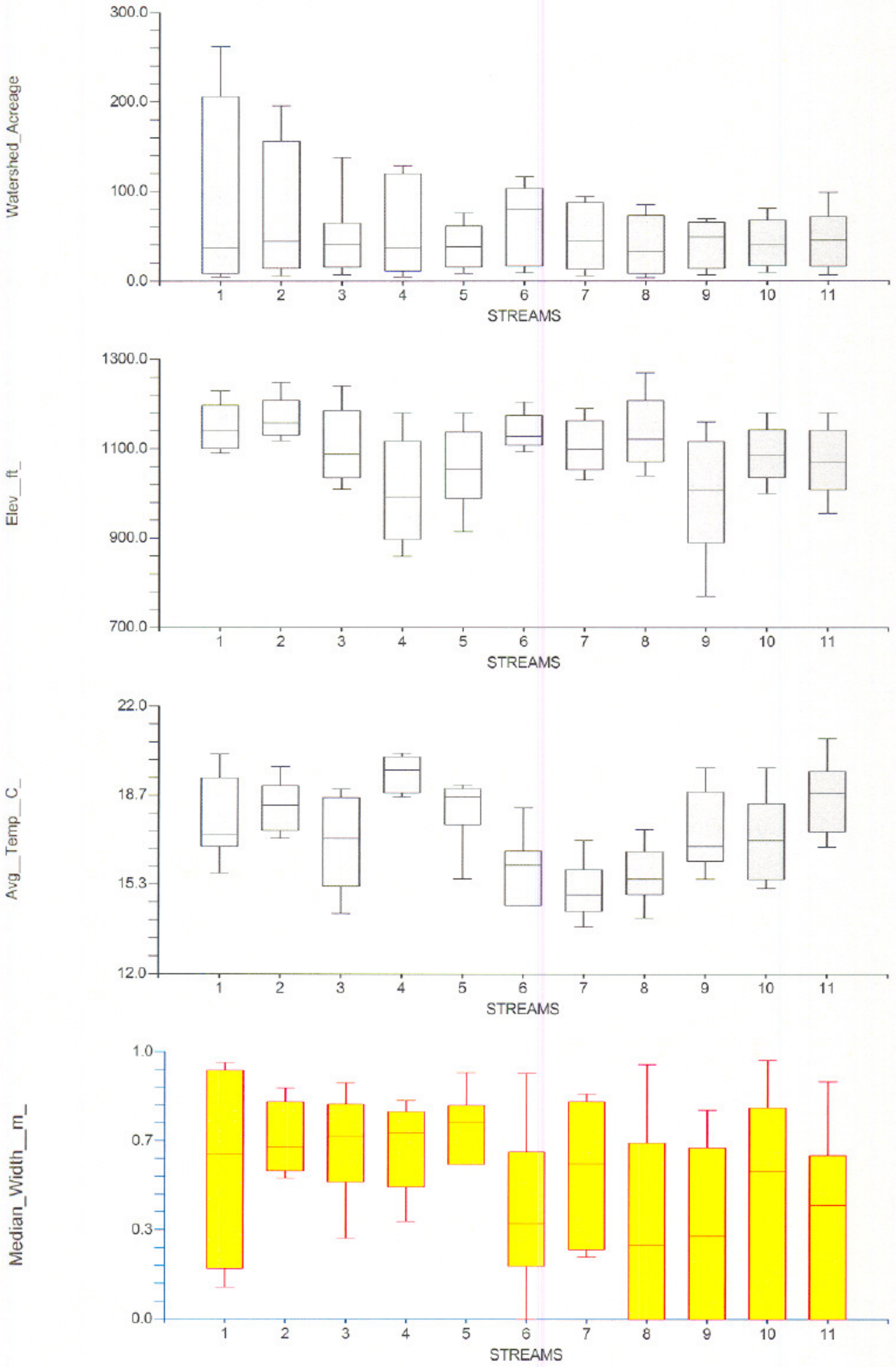


Figure 1. Box plots of median physical attributes of samples (N=8) from reference streams in Dysart Woods (streams 1-2) and Marshall County (3-5), and longwall mined streams that were recently longwall mined (6-8) or had been longwall mined over the past decade (9-11) in Marshall County.

Average stream slopes, elevations, and compass headings in longwall mined watersheds were comparable to reference watersheds, and standard deviations were indicative of sampling across variable terrain (Table 1). Elevation ranged from 1270' to 770' amsl, with mean elevation near 1100' in both disturbed and reference watersheds. Streams originated as spring seeps at approximately 1200' elevation. Reference stream 4 and disturbed stream 9 were the only watersheds with samples collected below 900' elevation, thus the scope this study includes relatively high elevation unnamed tributary streams. This study excluded larger, named streams within the region that occurred between 900' and 623', the mean pool elevation where Fish Creek enters the Ohio River.

Streams originated as spring seeps averaging less than 0.5 m width and draining 3.7 to 9.3 acre watersheds at elevations between 1160 to 1270' (Table 2, Figure 2). Watershed area at the point of flow origin was not statistically different when comparing longwall mined and reference streams (p=0.39). Reference watersheds drained 5.8 acres at the point of flow origin and longwall mined streams drained 6.9 acres. Four out of six origin points in longwall mined streams were dry. Some longwall mined streams were either dry, as indicated by zero stream width, or partially dewatered as evidenced by narrower stream widths in the upper reaches. Dry streambeds were conspicuous in the field and the former spring seep origins were obvious.

Table 2. Mean (and Standard Deviation) physical attributes of samples at the point-of-origin of longwall mined (N=6) versus reference (N=5) watersheds (ANOVA, Dunnett's Test ,*p<0.01).

	Reference streams		Longwall mined streams	
	Mean	(SD)	Mean	(SD)
Watershed area (acres)	5.8	(0.85)	6.9	(0.77)
Elevation (feet)	1198	(14.8)	1216	(16.2)
Stream slope (%)	0.217	(0.028)	0.183	(0.025)
Heading (degrees)	181	(40)	167	(37)
Median stream width (m)	*0.44	(0.09)	0.10	(0.90)

Excluding dry streams, median stream widths in longwall mined watersheds were not statistically different than stream widths in reference watersheds (Table 1). However, stream profiles indicate that where water was present stream width was notably less in streams that drained the upper 20 acres of longwall mined watersheds (Figure 2). Median stream widths ranged from 0 to 0.4 meters in the upper 20 acres of longwall mined watersheds, versus 0.1 to 1.4 meters in the upper 20 acres of reference watersheds. Most of the subsided longwall mined headwater streams re-emerged at points downstream as indicated by the steeply inclining regression line representing the relationship between stream width and watershed area in longwall mined streams (Figure 2). Re-emergence restored stream width to near-reference conditions in four of six longwall mined streams. The intersection of the regression lines for longwall mined versus reference streams indicates that stream width returned to background conditions once an average longwall mined watershed had achieved 80+ acres in drainage area.

The physical effects of dewatering were most apparent near the spring seep sources where all longwall mined streams were affected to some degree. Water returned to most longwall mined streams as their watersheds approached 20 acres in drainage area. In 20 acre watersheds longwall mined streams were about ½ the width of reference streams. Interpolating from Figure 2, longwall mined streams achieved 5/8 the width of reference streams in 40 acre watersheds, and 7/8 of reference stream widths in 60 acre watersheds. The gradual increase of stream width indicates that surface water re-emerges continuously along the gradient of longwall mined headwater streams.

Stream temperature at the time of sampling (instantaneous) was consistently lower in longwall mined versus reference streams (Figure 2). On average, stream temperature was approximately 1°C lower where water was present in the upper reaches of longwall mined streams, and 2°C lower in the lower portions of the watersheds. Statistically significant differences in water temperature are particularly compelling because the field sampling schedule eliminated seasonal effects by alternating randomly between longwall mined and reference streams.

In contrast, the tendency for stream temperature to increase with increasing stream size, as indicated by the slopes of the regression lines, was the result of two obvious factors. First, streams were sampled consistently starting at the point of origin in the morning and working downstream into the afternoon. Thus the apparent temperature increases actually reflect daily warming of the streams. Second, streams in the upper reaches of watersheds are proportionally dominated by groundwater and reflect a tendency toward mean annual temperature of 12°C. There was less of a tendency for longwall mined streams to exhibit the downstream temperature increases measured in reference streams. Consistently lower instantaneous temperatures in longwall mined streams is apparently due to subsidence which results in reduced exposure to the surface conditions evident in reference streams. Temperatures well above mean annual temperature in longwall mined streams also reflect a relatively short groundwater residence time which is further evidence that re-emergence of subsided headwater streams occurs continuously along the downstream greadient and mostly within the scope of this study, that is, watersheds less than 100 acres in drainage area.

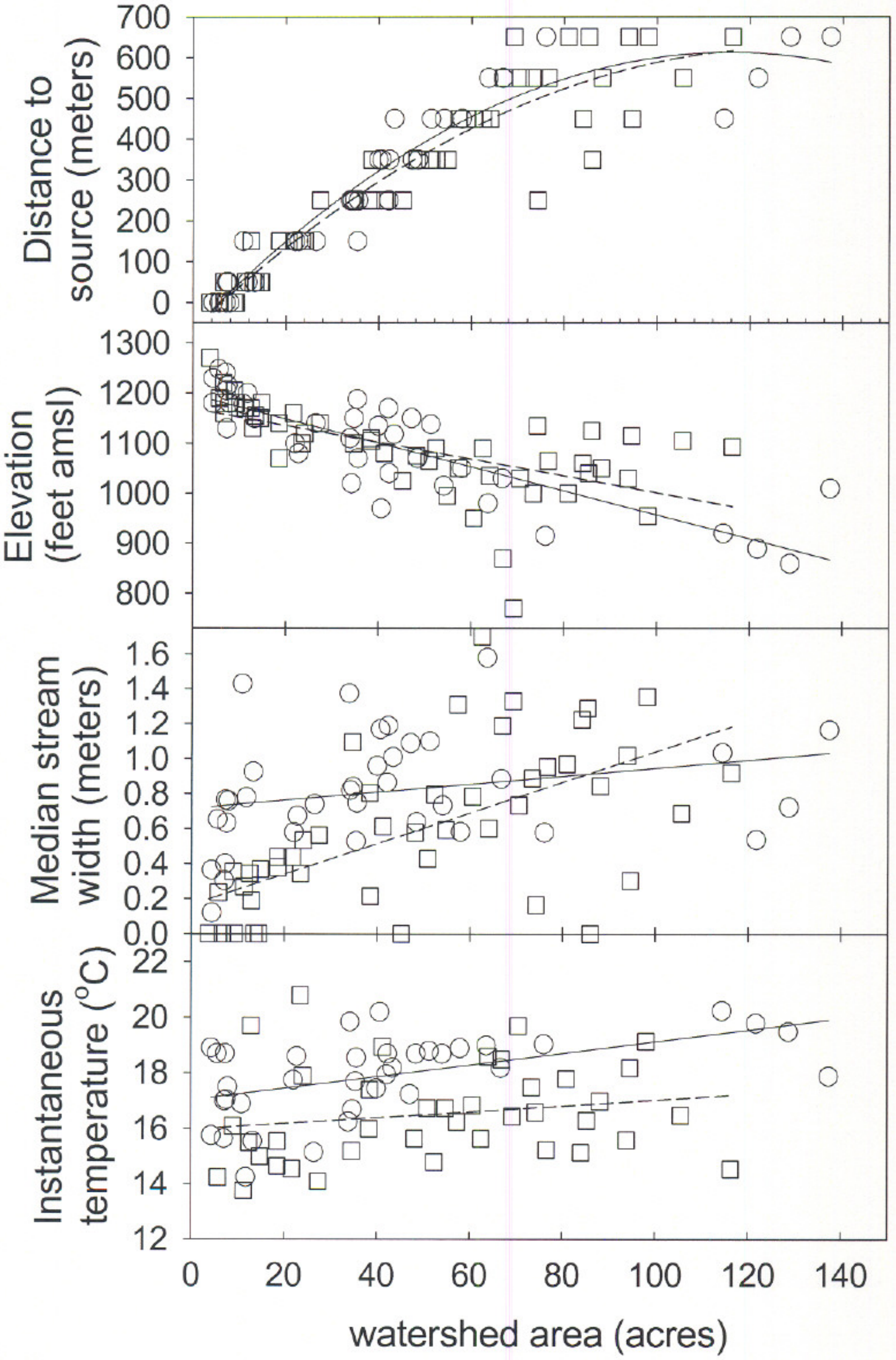


Figure 2. Profiles of physical attributes versus watershed area of longwall mined (squares) and reference streams (circles). Least squares means linear regression lines for longwall mined (dashed, N=48) and reference (solid, N=40) streams.

Chemical characteristics of study streams

Water chemistry was significantly different for three of the five chemical parameters measured in the field (Table 3). Stream water pH, compared as the mean of the log of the hydrogen ion content, was on average 7.7 in longwall mined and reference streams. Water hardness (Ca^{2+}, Mg^{2+}, Fe^{+2}, Mn^{2+}), primarily calcium, was not significantly different when comparing disturbed versus reference watersheds.

Mean conductivity, dissolved oxygen, and alkalinity showed statistically significant differences between longwall mined and reference streams (Table 3). Average conductivity values were approximately 100 micro mhos greater in longwall mined streams, indicating a 29% greater dissolved ion content in longwall mined streams. Reference streams were on average 88% saturated with dissolved oxygen, and longwall mined streams averaged 78% saturated. Alkalinity, primarily bicarbonate (HCO_3^-), averaged 79 parts per million greater in longwall mined streams, a 60% increase compared to reference streams.

Table 3. Mean (and 1 Standard Deviation) water chemistry in samples from longwall mined (N=48) versus reference (N=40) watersheds (ANOVA, Dunnett's Test ,*p<0.01).

	Reference streams		Disturbed streams	
	Mean	(SD)	Mean	(SD)
pH (mean H^+ conc.)	7.67	(0.32)	7.71	(0.31)
Conductivity (uhmos)	344	(89)	*446	(65)
Dissolved oxygen (% sat.)	87.8	(14.6)	*78.3	(16.7)
Alkalinity (ppm)	131	(35)	*210	(45)
Hardness (ppm)	175	(44)	161	(20)

There was little difference when comparing pH across regional streams (Figure 4). Most pH values were between pH 7 to pH 8. There was a significant ($p<0.05$), $r^2=0.33$) downstream trend of increasing pH with increasing stream size (Figure 5). There was a greater pH difference between the two Dysart Woods reference streams, streams 1 and 2, than there was across the region. Stream 1 had an average pH (as log H^+ concentration) of 7.8 versus 7.2 in stream 2 (Figure 4). Stream 2 also had comparatively low conductivity and alkalinity, particularly at the two uppermost sites near the source (Figure 5). Stream 2 pH, conductivity, and alkalinity achieved levels comparable to other reference streams at a distance of between 350 and 450 meters from the source. The increase in dissolved mineral content was accompanied by an exceptionally low dissolved oxygen reading 350 meters below the source. Greater oxygen demand at this site is indicative of mineral-laden spring water entering the stream system. The pH of longwall mined streams was within the range of natural differences in pH among regional reference streams. At the watershed-level, lower pH values near the source of streams are apparently the result of CO_2-charged groundwater at the source coupled with a relatively high oxygen demand by the heterotrophic stream community.

Significantly greater mean conductivity and alkalinity were indicative of greater dissolved mineral content in longwall mined versus reference streams (Table 3). Each stream, including reference streams, appeared to have a unique conductivity signature (Figure 4), but conductivity profiles indicated consistently greater total dissolved solids in longwall mined streams regardless of stream size (Figure 5). Conductivity was highly variable at the point of flow origin and became more consistent downstream. In any given longwall mined stream, resurgence of water downstream of subsided stream segments was accompanied by step-wise increases in conductivity that peaked at 450-550*u*mhos in approximately 80 acre watersheds. The stepped, or incremental pattern parallels that of stream width and helps confirm that most of the surface water lost to subsidence returned to the stream bed as graduated resurgence upwellings in streams draining 80+ acres. Conductivity remained consistently high in all longwall mined streams, with no recovery apparent.

Unlike conductivity, alkalinity showed a tendency toward recovery to background conditions as indicated by convergence of regression lines representing longwall mined versus reference streams. However, regressions of alkalinity versus watershed area for longwall mined and reference streams did not interact within the range of watershed sizes studied here. Therefore, any recovery indicated by convergence of regression lines is predicted to occur well downstream of the scope of this study.

Lower dissolved oxygen in many longwall mined streams near their point of flow origin appears to reflect the observed stagnation of water in partially dewatered stream segments. In the field, we sampled any available pocket of surface water within 5 m of the predetermined and measured sampling point. In larger stream segments somewhat lower dissolved oxygen may reflect chemical oxygen demand in resurgence areas. In a few isolated incidents in the field we noted black or red precipitates indicating formation of metal hydroxides on the streambed. Precipitates were generally confined to stream reaches less than 50 m in length, stream water was always >50% oxygen saturated, and pH was always >7. Lower dissolved oxygen in the headwaters of an average longwall mined stream would be expected to return to near-reference conditions of approximately 90% oxygen saturation as indicated by the interaction of the respective regression lines at a point of approximately 100 acres.

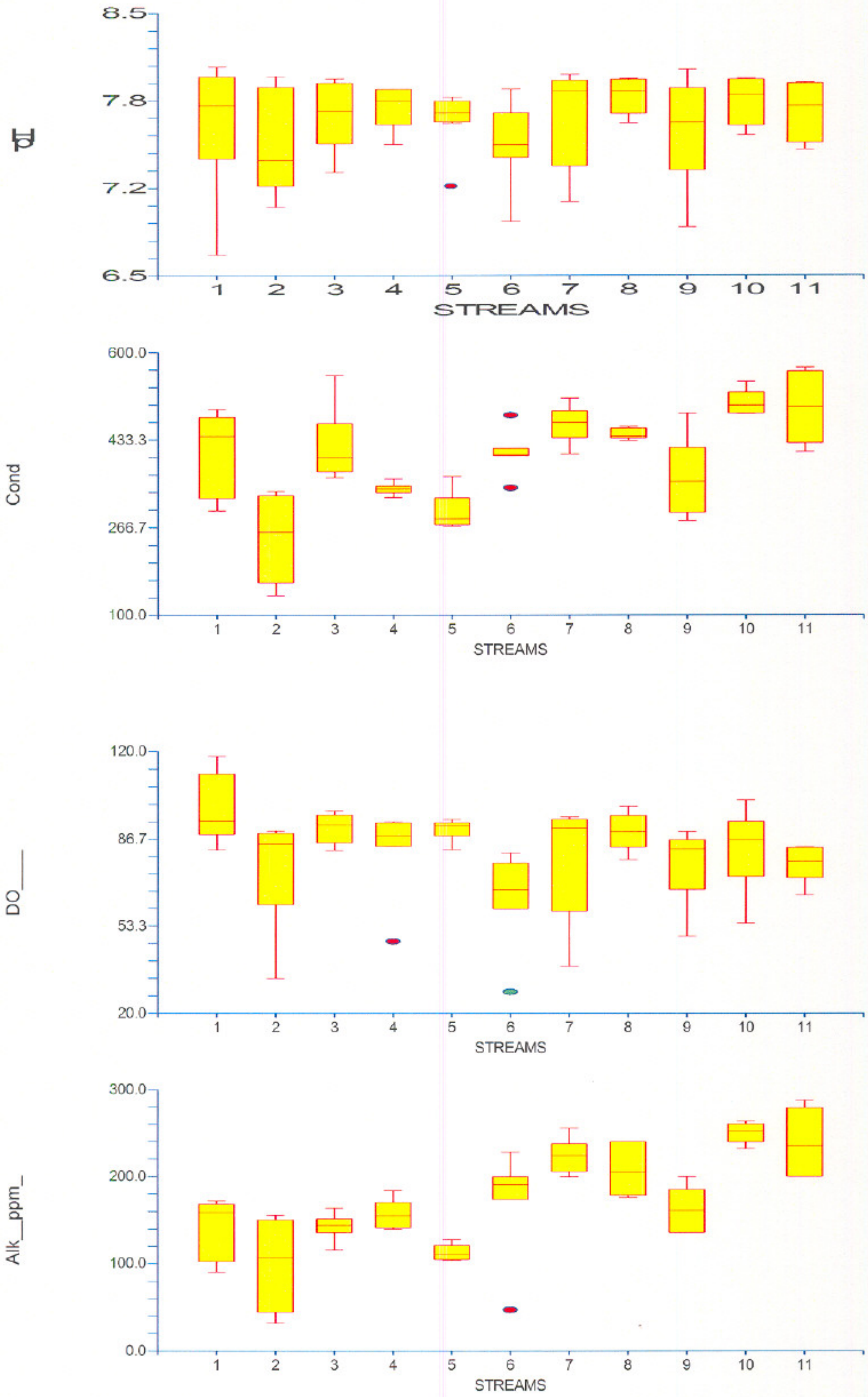


Figure 3. Box plots of median chemical attributes of samples (N=8) from reference streams in Dysart Woods (streams 1-2) and Marshall County (3-5), and longwall mined streams that were recently longwall mined (6-8) or had been longwall mined over the past decade (9-11) in Marshall County.

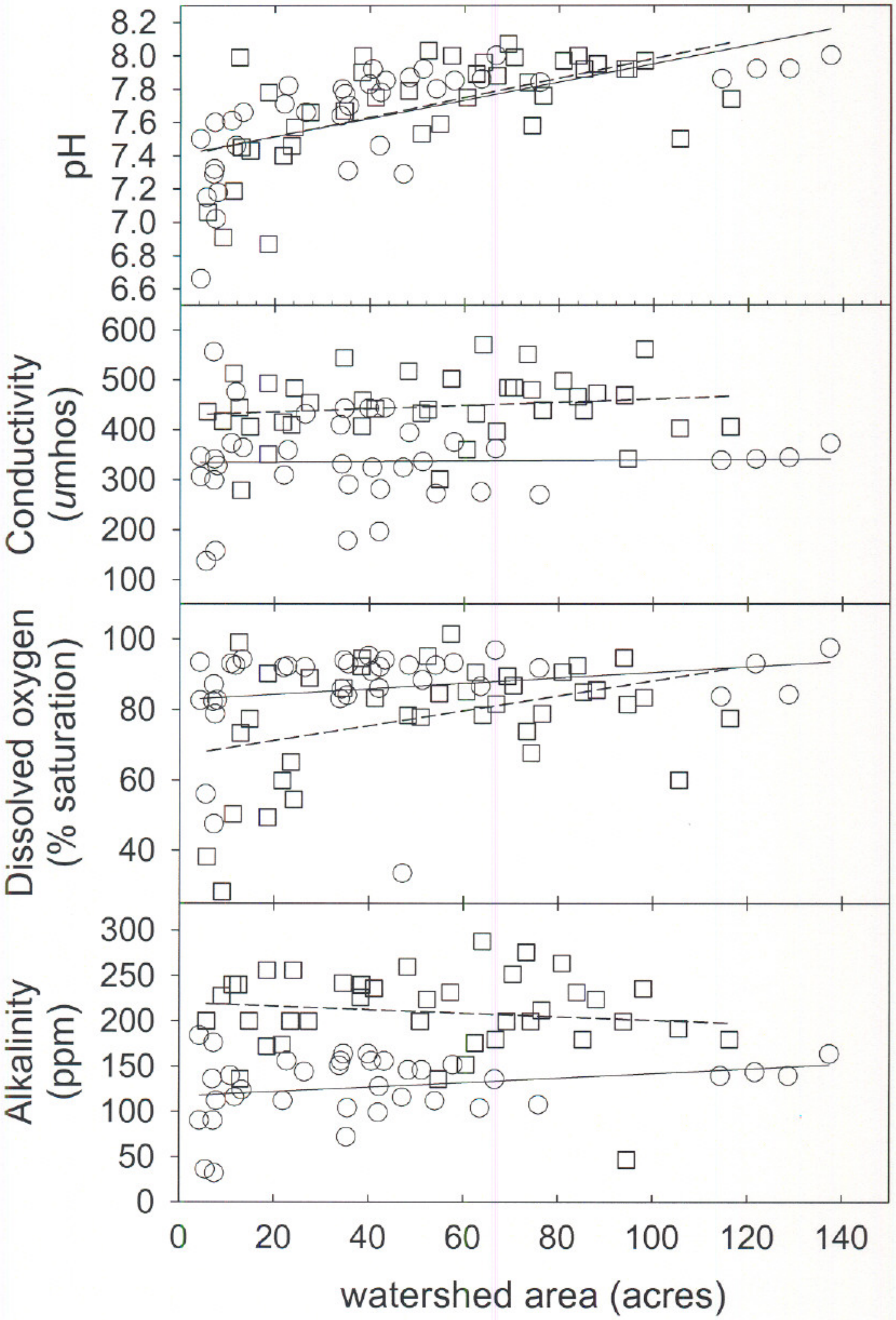


Figure 4. Profiles of chemical attributes versus watershed area of longwall mined (squares) and reference streams (circles). Least squares means linear regression lines for longwall mined (dashed, N=48) and reference (solid, N=40) streams.

Biological characteristics of study streams

Abundance, Diversity, and Longevity of Stream Communities

An average reference stream sample (N=40) was composed of 61 individuals representing 14 different kinds (taxa) of aquatic macroinvertebrates (Table 4). The majority of taxa were EPT Taxa, comprised of mayflies (Ephemeroptera), stoneflies (Plecoptera), and caddisflies (Trichoptera). The EPT taxa are relatively long lived, with aquatic development periods lasting from 6 months to more than one year (Anderson & Wallace, 1996). When considered collectively, the overlapping life cycles between 10 different EPT Taxa within the community indicate perennial flow conditions in the average reference streams. Longevity of the biotic community is further indicated by an average of 3 different semivoltine taxa collected in an average reference stream sample.

Significantly fewer organisms were collected from longwall mined than from reference watersheds (Table 4). No surface water was present at 7 of 24 sample locations in recently disturbed streams, and at 7 of 24 sample locations in streams that had been disturbed over the past decade. However, measures of abundance (total number collected), diversity (Richness and EPT Taxa), and longevity (EPT Taxa and Semivoltine Taxa) were reduced by about one-half in longwall mined versus reference streams overall, indicating that dewatering impacts extend beyond the 29% of stream sites that were dry at the time of sampling.

Table 4. Mean (and 1 Standard Deviation) for biological community metrics in samples from longwall mined (N=48) versus reference (N=40) watersheds (ANOVA, Dunnett's Test, *p<0.01).

	Reference streams		Longwall mined streams	
	Mean	(SD)	Mean	(SD)
Total number collected	61.35	(23.67)	*27.35	(28.27)
Taxa Richness (# of kinds)	13.95	(4.43)	*7.04	(5.99)
EPT Taxa (per sample)	9.65	(3.14)	*4.85	(4.57)
Mayflies (taxa per sample)	2.98	(1.39)	*1.63	(1.66)
Stoneflies (taxa)	3.68	(1.33)	*1.75	(1.91)
Caddisflies (taxa)	3.00	(1.41)	*1.48	(1.53)
Semivoltine taxa	3.18	(1.43)	*1.56	(1.76)

Box Plots show that macroinvertebrates were consistently abundant and diverse in samples collected throughout reference streams, but the response of longwall mined streams was more variable (Figure 5). With one exception, longwall mined streams had sample distributions indicating wide-ranging within-stream differences in macroinvertebrate abundance and diversity. In the most highly-impacted stream (Stream 6) less than 10 macroinvertebrates were collected in an average 30-minute composite sample, a collecting rate of one every three minutes compared to one every thirty-seconds in reference streams. In contrast, 10 of 16 samples from two of the least impacted longwall mined streams had abundance and diversity characteristics comparable to reference stream samples. Mean abundance and richness in two longwall mined streams was not significantly different than in two of the reference streams (ANOVA $p<0.05$, Dunnett's test).

All of the longwall mined streams appeared impacted to some degree, but some streams were more affected than others. The biological community in one of the recently mined streams(6) was nearly eliminated. Recently mined stream 7 and previously mined stream 10 were less impacted than other longwall mined streams, with some metrics approaching near-reference conditions. From the source downstream 0.65km, none of the longwall mined headwater streams studied in Marshall County disappeared completely, but all were impacted to some degree.

The EPT Taxa were sensitive to longwall mining. Only three of six longwall mined streams had sample distributions that overlapped reference streams. Recently disturbed stream 7 had between 4 and 10 EPT Taxa throughout the stream. Watershed 10, disturbed in the past, had few EPT Taxa in the uppermost reaches, but a particularly rich fauna at downstream sites resulting in the highest mean EPT Taxa of any stream, and a median EPT Taxa (9) comparable to reference streams. In contrast, the most highly impacted stream had an average of 1 EPT Taxa per sample, typically the mayfly *Paraleptaphlebia sp.* (Ephemeroptera: Leptophlebiidae), but also occasional individuals of the stonefly *Amphinemura delosa* (Plecoptera:Nemouridae), the caddisfly *Neophylax sp.* (Trichoptera:Odontoceridae), Isopods (Isopoda: Aseelidae), dixid and chironomid midges (Diptera: Dixidae, Chironomidae), and snails (Gastropoda: Planorbidae).

Semivoltine taxa, those that require greater than one year in the aquatic larval development phase, were particularly sensitive to dewatering (Figure 5). For instance, semivoltine taxa were completely eliminated from stream 6, and averaged one per sample in the other recently mined streams. Overall, semivoltine taxa comprised 19% of the total number of macroinvertebrates collected in the study, and 18% of the total number of kinds of invertebrates collected in the study. Semivoltine taxa were collected in 39 of 40 reference stream samples. Between 1 and 5 Semivoltine Taxa could be expected in reference stream samples, with an average of 2 to 4 taxa per sample (Figure 5). The most commonly encountered semivoltine taxa (Table 5) included the Dobbsonfly *Nigronia serricornis* (Megaloptera: Corydalidae), the stoneflies *Peltoperla arcuata* (Pelcoptera: Peltoperlidae), *Acroneuria carolinensis* (Plecoptera: Perlidae), and *Agnetina sp.,* (Plecoptera: Perlodidae), and the crayfish *Cambarus bartoni* (Decopoda: Cambaridae).

Streams that had been longwall mined in the past had several semivoltine taxa (Figure 5). Stream 10 was dry for the first 50, had 3 semivotine taxa 150 meters from the source, was dry again at 250 meters, and was well-watered with abundant and diverse benthic community for the next 300 meters including 3 or 4 semivoltine taxa per sample (Figure 6). Semivoltine taxa were absent from the upper reaches of all streams that had been longwall mined. One or two taxa were collected from the mid and lower reaches of two of the three recently mined streams. Two to five semivoltine taxa were collected in the mid to lower reaches of all streams that had been longwall mined in the past. Greater abundance of semivoltine taxa in streams that had been longwall mined sometime in the past is an encouraging indication of potential long-term recovery. However, the sample size is limited to 3 recent and 3 past disturbed streams, and between-stream variability is considerable.

Biological metrics reflecting the relative abundance, diversity, and longevity of macroinvertebrate communities gave consistently negative responses to longwall mining (Figure 6). Impacts appeared to be greatest near points of stream origin, and to lessen somewhat downstream. For instance, by interpolating best-fit regression lines for 10 acre watersheds, macroinvertebrates in longwall mined streams were 77% more difficult to collect, 65% less diverse, had 75% fewer EPT taxa, and had 72% fewer semivoltine taxa than comparable reference streams. Biological metrics in longwall mined streams gradually increased downstream so that in an average 100 acre watershed, again interpolating from regression models, abundance was 31% lower, richness 27% lower, EPT taxa 27% lower, and semivoltine taxa 26% lower than in 100 acre reference streams. Recovery of biological metrics to background conditions is indicated by the slope of the regression lines approaching, but not interescting within the scale of this study. Although risky because it is out of the range of this study, interaction between the longwall mined and reference regression lines, perhaps indicating biological recovery, is predicted to occur at a point somewhere between 158 acres (semivoltine taxa) and 178 acres (taxa richness) for each of the four biological metrics.

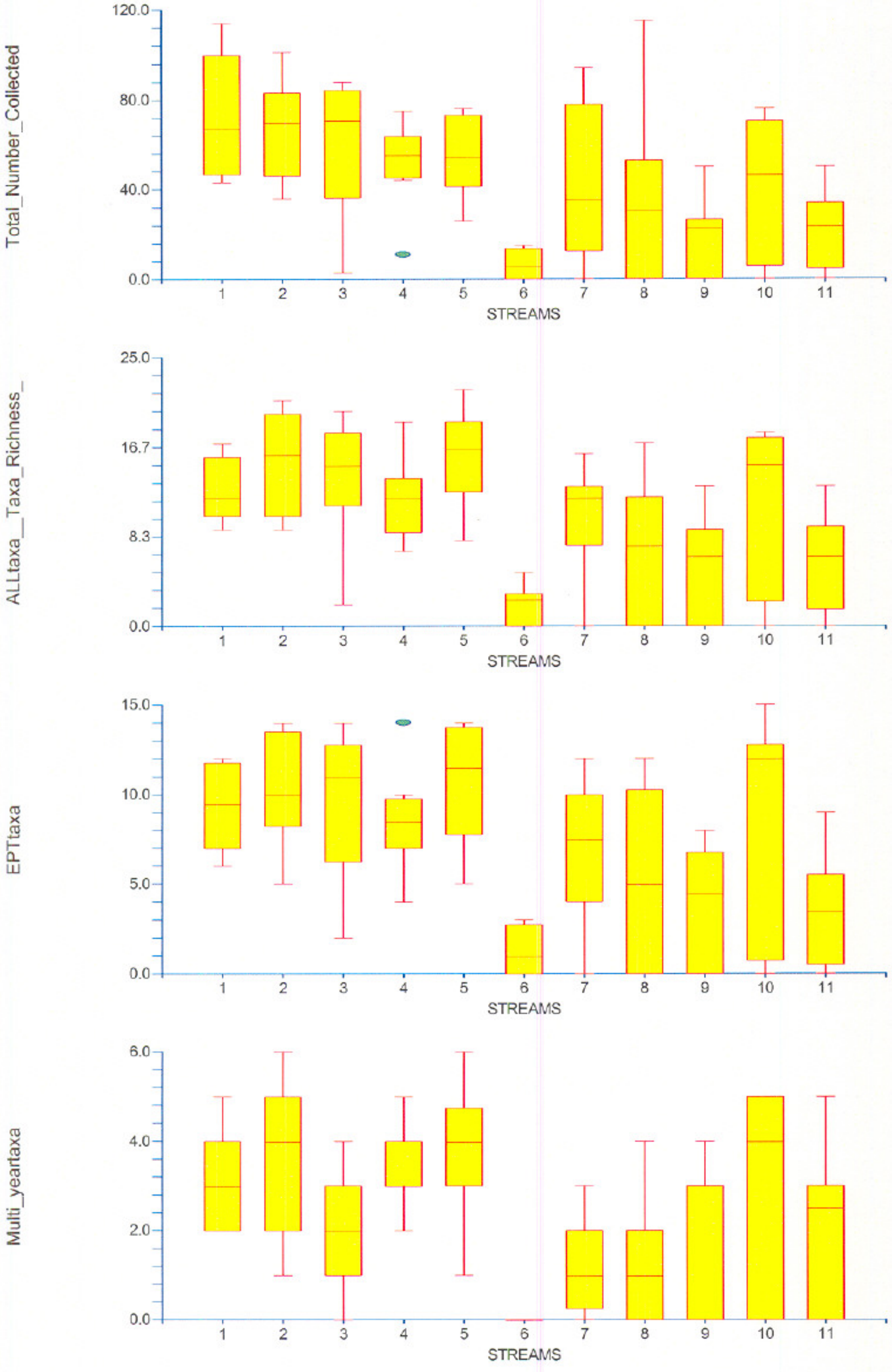


Figure 5. Box plots of median biological attributes of samples (N=8) from reference streams in Dysart Woods (streams 1-2) and Marshall County (3-5), and longwall mined streams that were recently longwall mined (6-8) or had been longwall mined over the past decade (9-11) in Marshall County.

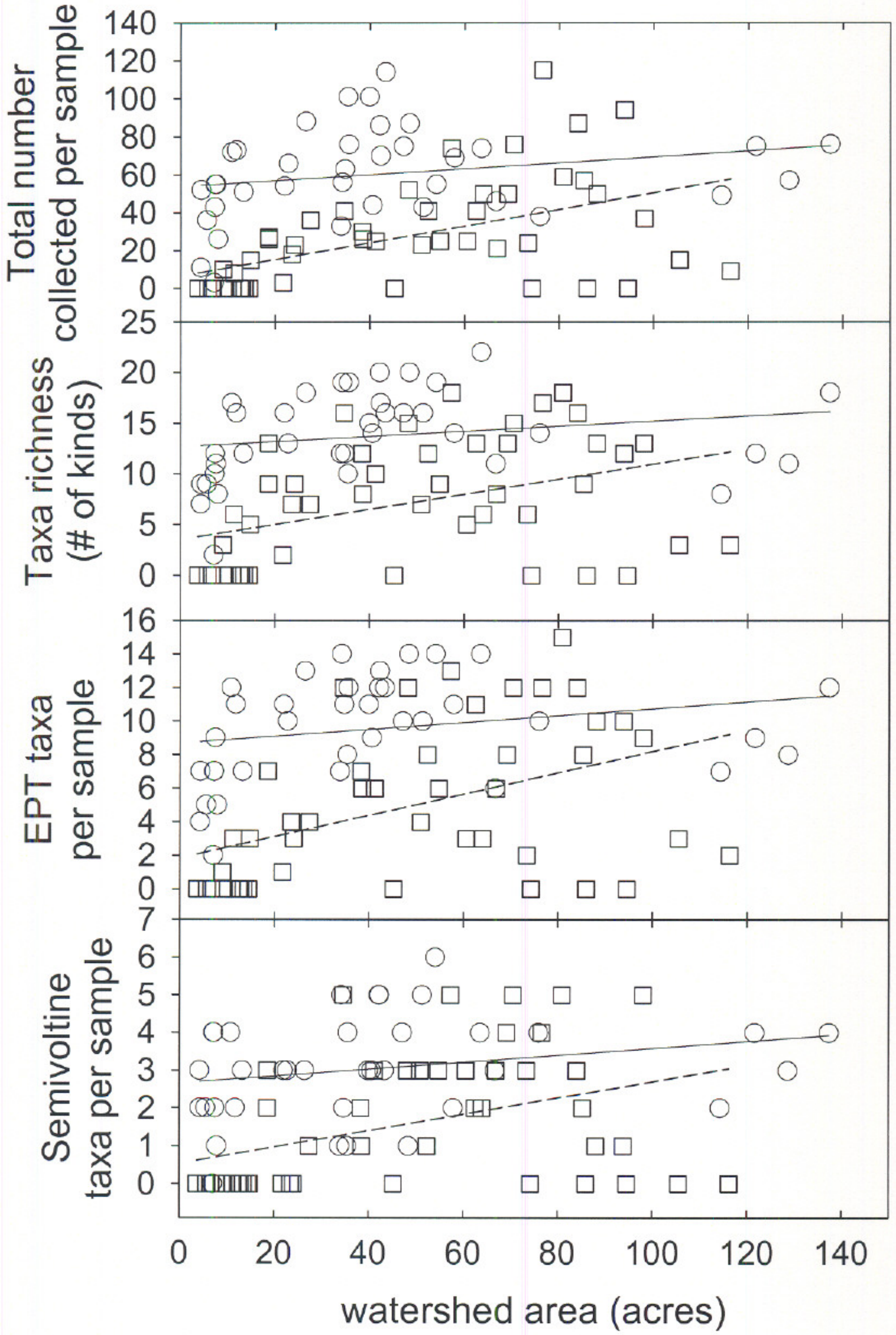


Figure 6. Profiles of biological attributes versus watershed area of longwall mined (squares) and reference streams (circles). Least squares means linear regression lines for longwall mined (dashed, N=48) and reference (solid, N=40) streams.

Table 5. Taxa collected in order of abundance during the study showing taxonomic affiliations, life cycle (univoltine=completes life cycle in 1 year, and semivoltine=two-year or longer aquatic larval development period), and functional feeding group assignment.

class or insect order	*Genus (species)*	life cycle	function
Ephemeroptera	*Paraleptaphlebia*	Univoltine	predator
Plecoptera	*Leuctra*	Univoltine	shredder
Trichoptera	*Diplectrona*	Univoltine	collector
Plecoptera	*Agnetina*	Semivoltine	predator
Ephemeroptera	*Heptagenia*	Univoltine	grazer
Plecoptera	*Peltoperla*	Semivoltine	shredder
Decopoda	*Cambarus*	Semivoltine	shredder
Plecoptera	*Amphinemura delosa*	Univoltine	shredder
Trichoptera	*Neophylax*	Univoltine	grazer
Ephemeroptera	*Stenonema*	Semivoltine	grazer
Amphipoda	*Gammarus*	Univoltine	shredder
Trichoptera	*Lepidostoma*	Univoltine	shredder
Ephemeroptera	*Baetis*	Univoltine	collector
Trichoptera	*Pycnopsyche*	Univoltine	shredder
Megaoptera	*Nigronia serricornis*	Semivoltine	predator
Isopoda	*Isopoda*	Univoltine	shredder
Plecoptera	*Acroneuria carolinensis*	Semivoltine	predator
Diptera	*Dicronota*	Univoltine	predator
Diptera	*Dixa*	Univoltine	collector
Plecoptera	*Isoperla*	Univoltine	predator
Plecoptera	*Perlesta*	Semivoltine	predator
Diptera	Chironomidae	Univoltine	collector
Plecoptera	*Ostracerca*	Univoltine	shredder
Ephemeroptera	*Ameletus*	Univoltine	collector
Diptera	*Limnophora*	Univoltine	collector
Diptera	*Tipula*	Univoltine	shredder
Coleoptera	*Dubiraphia*	Univoltine	collector
Plecoptera	*Sweltsa*	Semivoltine	shredder
Trichoptera	*Polycentropus*	Univoltine	collector
Ephemeroptera	*Epeorus*	Univoltine	grazer
Trichoptera	*Cyrnellus*	Univoltine	collector
Trichoptera	*Rhyacophila*	Univoltine	predator

Table 5 (cont.). Taxa collected in order of abundance during the study showing taxonomic affiliations, life cycle (univoltine=completes life cycle in 1 year, and semivoltine=two year or longer aquatic larval development period), and functional feeding group assignment.

class or insect order	*Genus (species)*	life cycle	function
Diptera	*Hexatoma*	Univoltine	predator
Annelida	*Oligochaeta*	Univoltine	collector
Ephemeroptera	*Ephemera*	Semivoltine	collector
Ephemeroptera	*Eurylophella temporalis*	Univoltine	collector
Molluska	*Gastropoda*	Univoltine	grazer
Coleoptera	*Dytiscus*	Univoltine	predator
Trichoptera	*Wormaldia*	Univoltine	collector
Odonata	*Cordulegaster*	Semivoltine	predator
Diptera	*Eubriidae*	Univoltine	predator
Megaloptera	*Sialis*	Univoltine	predator
Trichoptera	*Dolophilodes*	Univoltine	collector
Diptera	*Hydroporinae*	Univoltine	collector
Diptera	*Ormosia*	Univoltine	collector
Odonata	*Calopteryx*	Semivoltine	predator
Odonata	*Stylogomhus*	Semivoltine	predator
Diptera	*Hydrocantus*	Univoltine	predator
Diptera	*Stratiomys*	Univoltine	predator
Molluska	*Bivalvia*	Univoltine	collector
Plecoptera	*Clioperla clio*	Univoltine	predator
Trichoptera	*Hydropsyche betteni*	Univoltine	collector
Odonata	*Aeshna*	Univoltine	predator
Coleoptera	*Dytiscidae*	Univoltine	predator
Diptera	*Helochares*	Univoltine	collector
Diptera	*Hydroptilidae*	Univoltine	collector
Coleoptera	*Psephenus*	Univoltine	grazer
Diptera	*Limnophila*	Univoltine	predator
Diptera	*Simulium*	Univoltine	collector
Diptera	*Tabanus*	Univoltine	predator
Corixidae	*Corixa*	Univoltine	predator

Community function

Co-existence of the diverse taxa in these communities at any one time indicates a need for resource partitioning by specialization into various functional roles. Leaf shredders (36 and 37%) and fine particle collectors (40 and 35%) comprised the bulk of the community function in both disturbed and reference streams (Table 6). Only 13-14% of the communities in all streams were engaged in grazing biofilm (algal and fungal matrix) from the stream bottom. There were no significant overall differences in longwall mined versus reference streams in the proportional allocation of functional feeding groups. However, the variability within streams, as indicated by high standard deviations (Table 6) and box plot ranges (Figure 7) was consistently greater in longwall mined streams. In longwall mined streams the proportion of shredders, collectors, grazers, and predators were more widely ranging than in reference streams.

Whereas the mean functional disposition of longwall mined versus reference streams was not significantly different (Table 6), the pattern of change in community function along the stream gradient was significantly different (Figure 8). For instance, in reference streams shredders comprised 47% of the community in the upper stream reaches (10 acres) and declined to less than 30% of the community in larger streams draining the lower reaches of 100+ acre watersheds ($p<0.01$, $r^2=0.17$). The precipitous decline in shredder dominance was compensated for by subsequent increases in the collectors and grazers. In longwall mined streams these patterns failed to emerge. In longwall mined streams shredders were often most abundant in the mid-reaches of watersheds, apparently corresponding with resurgence of water into a streambed. Shredders populations were independent of watershed area and much less predictable in longwall mined streams compared to reference streams. Longwall mined streams had greater functional imbalance compared to reference streams, and they failed to achieve significant changes in functional allocations witnessed along the gradient of reference streams (Figure 8). The predator fauna comprised, on average, approximately 11-14% of the communities in streams. However, predators were absent or nearly absent in many sites in longwall mined streams.

Table 6. Mean (and 1 Standard Deviation) of biological community functional metrics where macroinvertebrate communities were present in samples from longwall mined (N=34) versus reference (N=40) watersheds (ANOVA, Dunnett's Test, *p<0.01).

Functional feeding group (% of total number collected)	Reference streams Mean	(SD)	Longwall mined streams Mean	(SD)
Leaf shredders	37	(15)	36	(23)
Fine particle collectors	35	(12)	40	(23)
Grazers	14	(9)	13	(10)
Predators	14	(11)	11	(13)

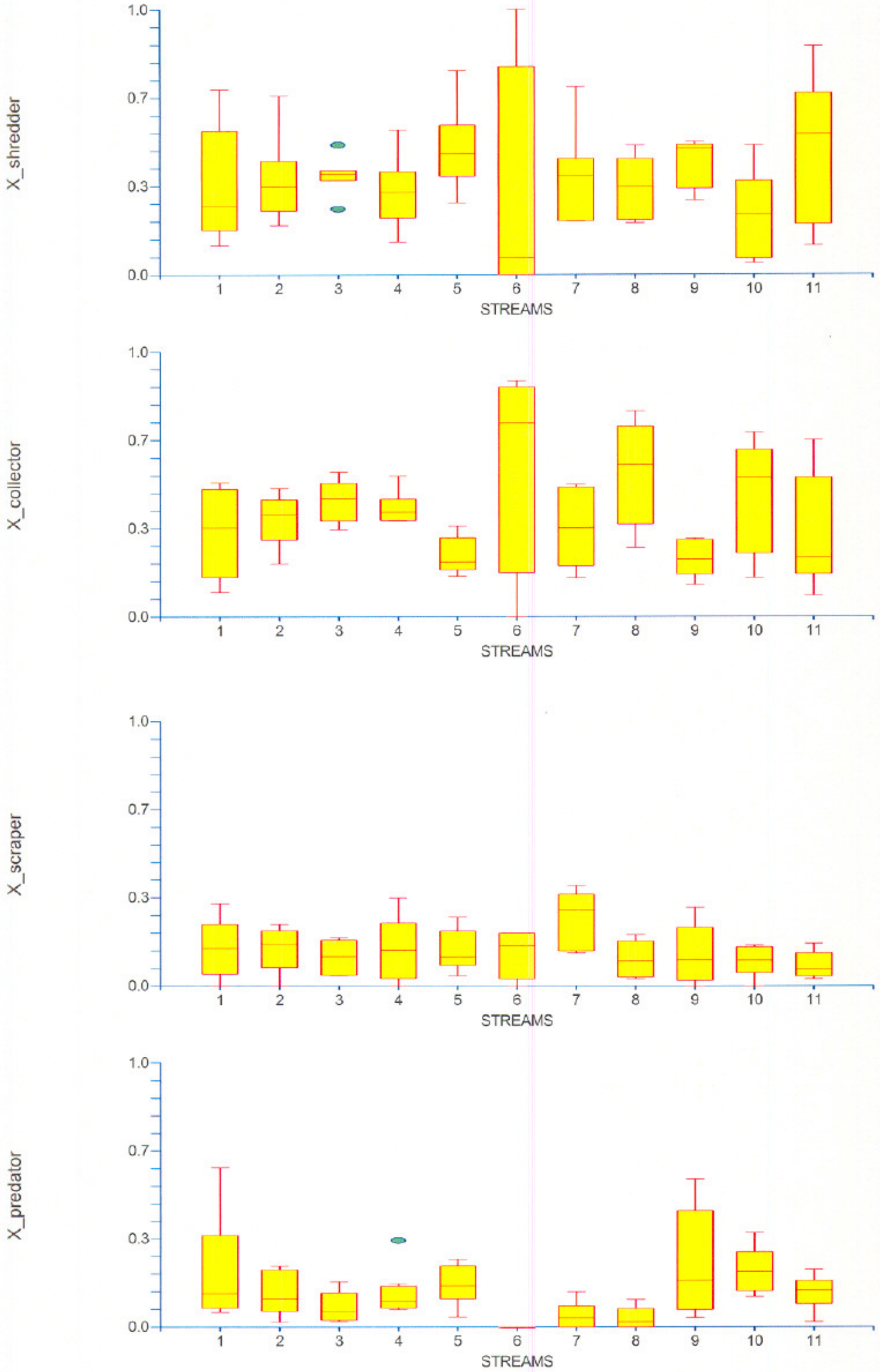


Figure 7. Box plots of median functional feeding group proportions in samples (N=8) from reference streams in Dysart Woods (streams 1-2) and Marshall County (3-5), and longwall mined streams that were recently longwall mined (6-8) or had been longwall mined over the past decade (9-11) in Marshall County.

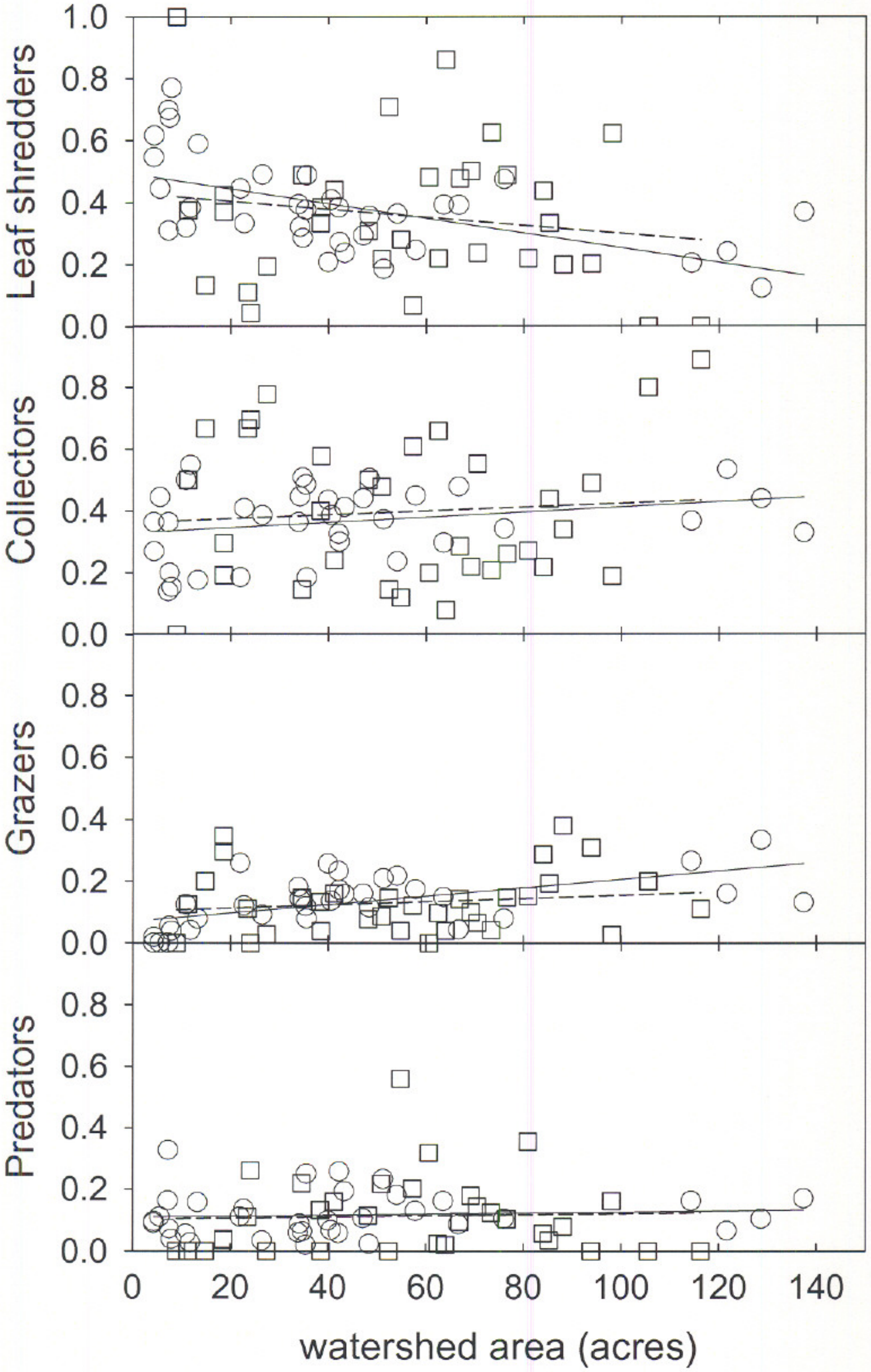


Figure 8. Profiles of functional feeding group proportions versus watershed area of longwall mined (squares) and reference streams (circles). Least squares means linear regression lines for longwall mined (dashed, N=48) and reference (solid, N=40) streams.

Taxa specific responses

Predominant macroinvertebrate taxa were plotted against watershed area to determine if any taxa-specific patterns emerged with respect to disturbance. The mayfly *Paraleptophlebia* was the most abundant organism in the study (Table 5). *Paraleptaphlebia* was collected at all reference sites, and was most abundant in the upper reaches of reference streams (Figure 9). *Paraleptaphlebia* was not abundant in the headwater reaches of most longwall mined streams, but was abundant at specific sties downstream. The return of *Paraleptophlebia* to the lower reaches of longwall mined streams appeared to coincide with re-emergence of sunken streams. *Paraleptophlebia* reached peak abundance in 10-50 acre reference streams compared to 60-100 acre longwall mined streams.

The stonefly *Leuctra* was the second-most abundant organism in the study, was collected at 85% of reference stream sites, and was most abundant at sites closest to the stream source. In longwall mined streams, however, *Leuctra* was virtually absent from the upper reaches of longwall mined streams, and peak abundance occurred at 5 specific sites further downstream in 80-100 acre, recently mined watersheds. *Leuctra* was nearly absent from streams that had been longwall mined several years prior to the study. Only one or two *Leuctra* were collected, and from only 5 of the 24 sites in streams that had been longwall mined in the past.

Diplectrona was the dominant caddisfly in headwater streams in this study (Table 5). *Diplectrona* is a net-spinning caddisfly that filter-feeds on suspended particulate matter in streams. *Diplectrona* were abundant in the upper reaches of most reference streams and common in the mid and lower reaches of all reference streams. *Diplectrona* were generally less abundant in longwall mined streams, and nearly absent from the recently disturbed streams.

The stonefly *Agnetina*, the mayfly *Heptagenia*, and the stonefly *Peltoperla* each showed a consistent bimodal distribution when comparing longwall mined versus reference streams (Figure 10). In reference streams these organisms dominate the upper reaches of streams. In contrast, these taxa are abundant only in the lower eaches of longwall mined streams. These organisms respond to dewatering of the upper reaches by inhabiting downstream resurgence areas of some streams much as they would a reference headwater spring seep. However, other taxa, such as *Lepidostoma* (Trichoptera: Lepidostomidae), the 12th most abundant organism collected, were common in reference streams but rare in longwall mined streams and did not exhibit the "resurgence pattern." Obviously, several taxa appear to be at disproportionate risk due to longwall mining. Other taxa, specifically isopods and amphipods, may actually benefit because they are associated with upwelling of stream water downstream of subsided stream segments (Figure 11). The question that arises is can these longwall mined streams, given the loss of a tremendous amount of habitat, provide adequate refuge to maintain regional populations of headwater stream-dependent organisms.

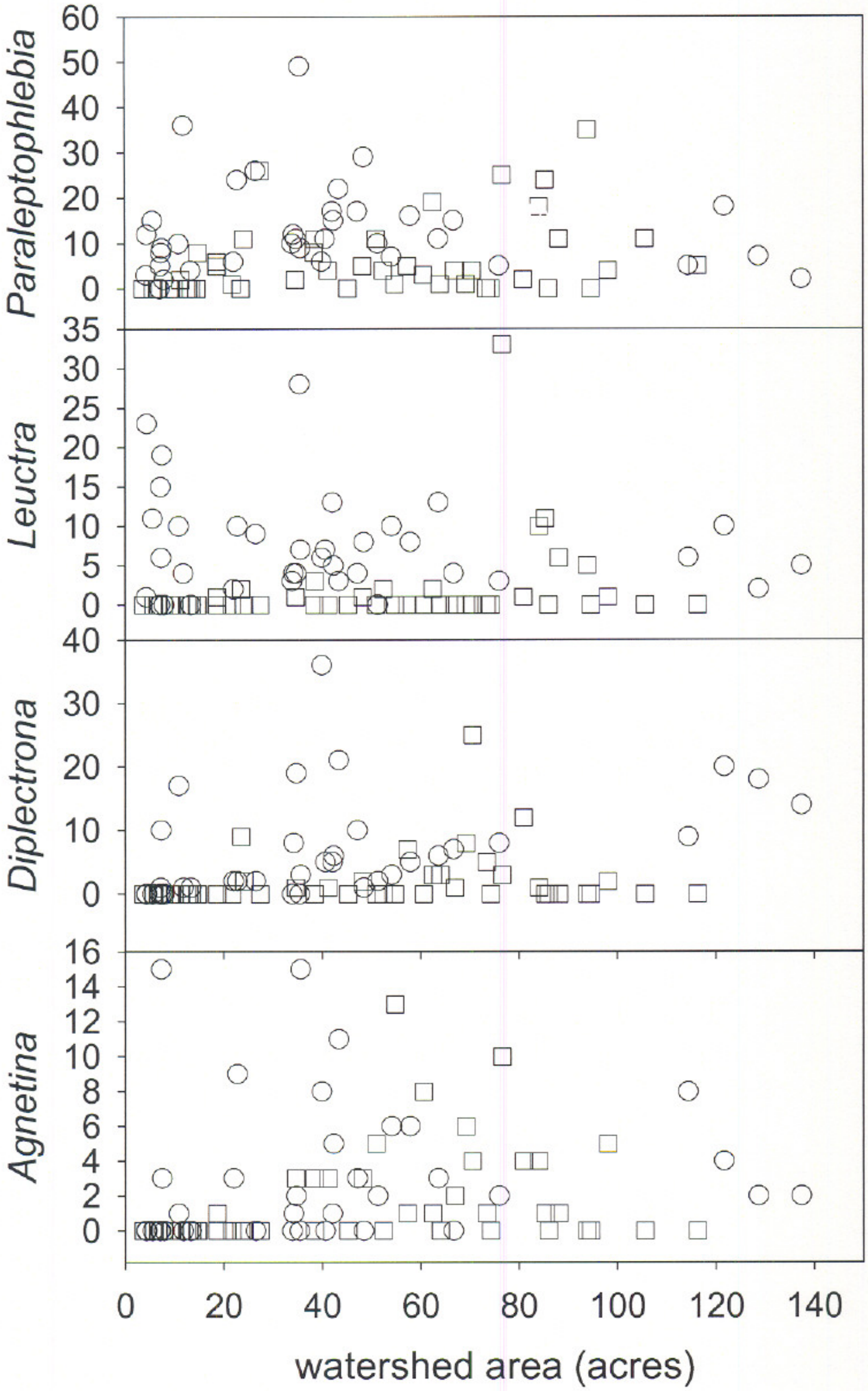


Figure 9. Profiles of the four most abundant taxa showing the number collected per sample versus watershed area of longwall mined (squares) and reference streams (circles).

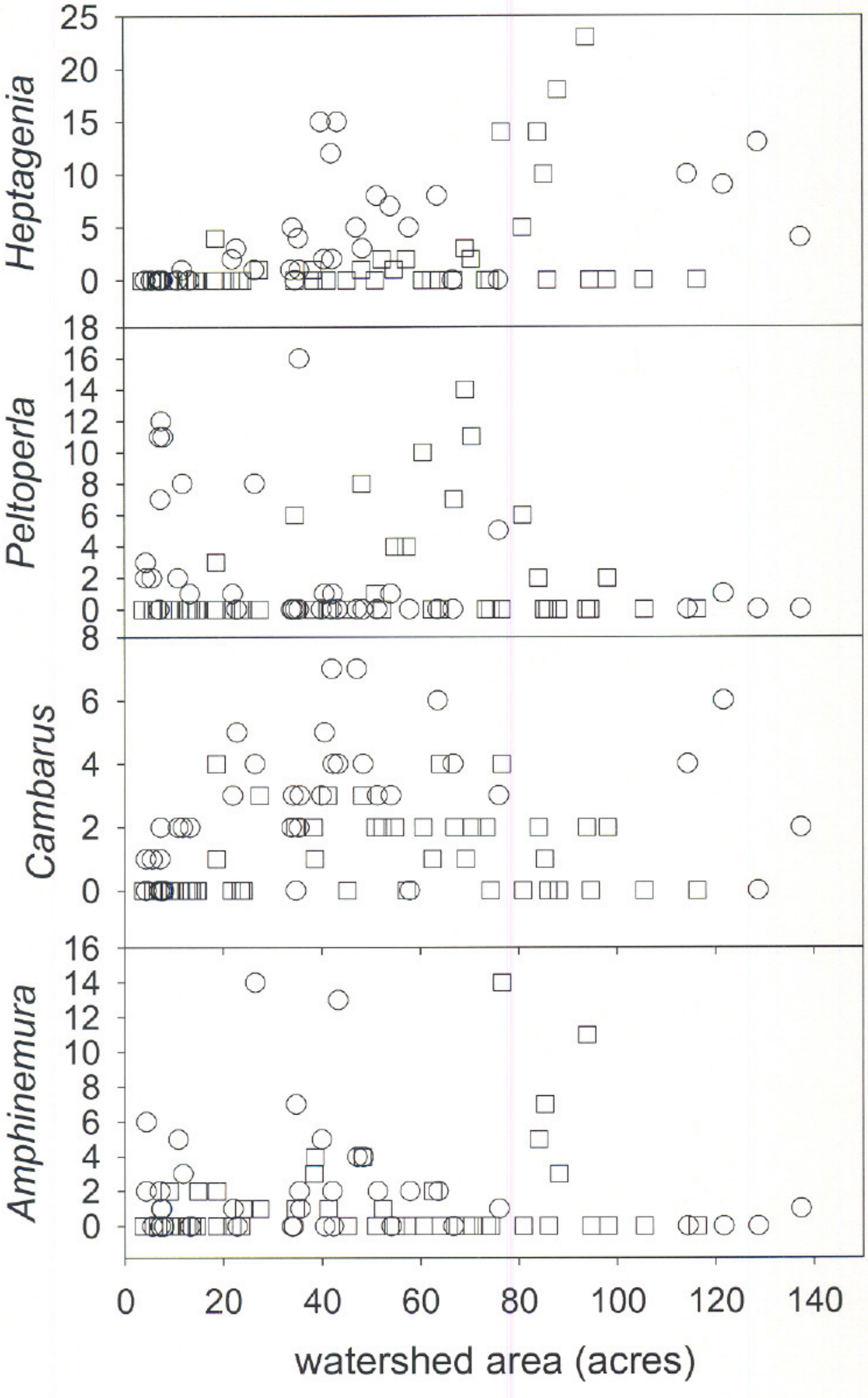


Figure 10. Profiles of the 5th through 8th most abundant taxa showing the number of individuals collected per sample versus watershed area of longwall mined (squares) and reference streams (circles).

Ubiquity of macroinvertebrate taxa

Widespread occurrence, omnipresence, or ubiquity of macroinvertebrate taxa was measured mathematically by formulating a Ubiquity Index. The Ubiquity Index value indicates the percent chance of finding an organism at any random site in a regional headwater stream. Ubiquity Index values were compared between disturbed and reference conditions (samples, streams, and regions) to determine the degree to which longwall mining affected regional macroinvertebrate distribution, and to assay for any taxa-specific responses.

As a group, the EPT Taxa (mayfly, stonefly, caddisfly) were omnipresent in reference streams. Stoneflies were collected in every reference stream sample (Table 7). Mayflies were present in all but one, and caddisflies were present in all but 2 of the 40 reference samples. Omnipresence of multiple EPT Taxa is perhaps the best indicator of perennial stream communities in the region. Additionally, Semivoltine Taxa, those requiring permanent aquatic conditions, where collected at 98% of reference sites.

The consistent presence of long-lived aquatic taxa across the region indicates perennial aquatic conditions originating at the stream source in watersheds draining areas as small as 5 acres. Spring seeps at the point of flow origin continue downstream as permanent water contiguous with the larger stream and river ecosystems indicated on USGS 1:24,000 scale data. It should be noted that, based on the biota, perennial aquatic conditions exist at all reference sites even though only 25% of sites were indicated as perennial streams designated by solid blue lines on USGS 1:24,000 scale data. Of the remaining reference stream samples, 2% were indicated as "intermittent" streams (dot-dash blue line) and 73% were not shown on USGS 1:24,000 scale data, and are often mistakenly referred to as "ephemeral" streams. In light of the ubiquitous biological community presence in streams in small watersheds across the region; the USGS 1:24,000 scale data is inaccurate with regard to stream designation as well as stream delineation.

Table 7. Ubiquity Index values (U) for reference streams versus longwall mined disturbed streams for taxa summary variables.

Taxa summary variables	U reference	U disturbed	U difference
EPT Taxa	1.000	0.708	-0.292
Mayflies	0.979	0.667	-0.313
Stoneflies	1.000	0.625	-0.375
Caddisflies	0.948	0.583	-0.365
Semivoltine taxa	0.979	0.465	-0.514

Macroinvertebrate communities were not always present in longwall mined headwater streams. Seven of 24 sampling sites in recently mined streams and 7 of 24 samples from streams mined over the past decade had no surface water. Therefore, only 71% of the habitat available in reference streams was also available in analogous disturbed streams, and for any given taxa a generalized decline of 29% in the Ubiquity Index scores would be expected. A 67% Ubiquity Index score indicates that, with 2 exceptions, mayflies were present wherever surface water was present in longwall mined streams. Any further declines would indicate that macroinvertebrates in the remaining 71% of the habitat are further impared, such as in the case of stoneflies and caddiflies, each showing 37% reductions in Ubiquity following longwall mining (Table 7). Semivoltine taxa appeared even more sensitive with Ubiquity Index scores reduced from 98% to 47% following longwall mining impacts to regional watersheds, streams, and stream reaches.

Ubiquity of the EPT Taxa in disturbed streams is mostly due to the presence of the mayfly *Paraleptophlebia* (Ephemeroptera: Leptophlebiidae), the most abundant and widely-distributed macroinvertebrate in regional headwater streams. In the genus *Paraleptophlebia*, the time required for nymphal development varies from six-months to one-year depending on species and latitude (Edmunds, *et al*, 1976). Of the dominant mayflies studied, *Paraleptophlebia* was the least responsive in terms of decline in ubiquity following mining (Figure 11).

The Heptageniid mayflies (Ephemeroptera: Heptageniidae) *Heptagenia* and *Stenonema*, characterized by somewhat longer nymphal development periods (Wallace & Anderson, 1996), had proportional reductions in ubiquity of 46, and 47%, respectively. Likewise, the most abundant and ubiquitous stonefly in this study, *Leuctra*, characterized by 1-2 year aquatic nymphal development periods (Wallace & Anderson, 1996; Stewart & Stark, 1988), had a 65% proportional reduction in ubiquity across the region following longwall mining (Figure11).

The stonefly *Acroneuria carolinensis* (Plecoptera: Perlidae) has a well-documented two-year aquatic larval development period in streams (Wallace & Anderson, 1996). Although *Acroneuria* was the sixteenth most commonly encountered macroinvertebrate in reference streams with a ubiquity index value of 31%, it was nearly eliminated from longwall mined streams, with a Ubiquity Index value of 5% (Figure 11). The Dobbsonfly *Nigronia Serricornis* (Megaloptera: Corydalidae) has a three-year aquatic development period in West Virginia streams (Tarter, 1976), was the fifteenth most commonly encountered macroinvertebrate in streams as well as the dominant predatory macroinvertebrate. *Nigronia* exhibited 22% ubiquity in the longwall mined watersheds versus 59% ubiquity in reference streams. *Nigronia* were common at the source and in the upper reaches of reference streams. In longwall mined streams Nigronia was restricted to the downstream reaches where *Nigronia* appears to be a good indicator of the resurgence of perennial stream conditions in the lower reaches of some longwall mined streams.

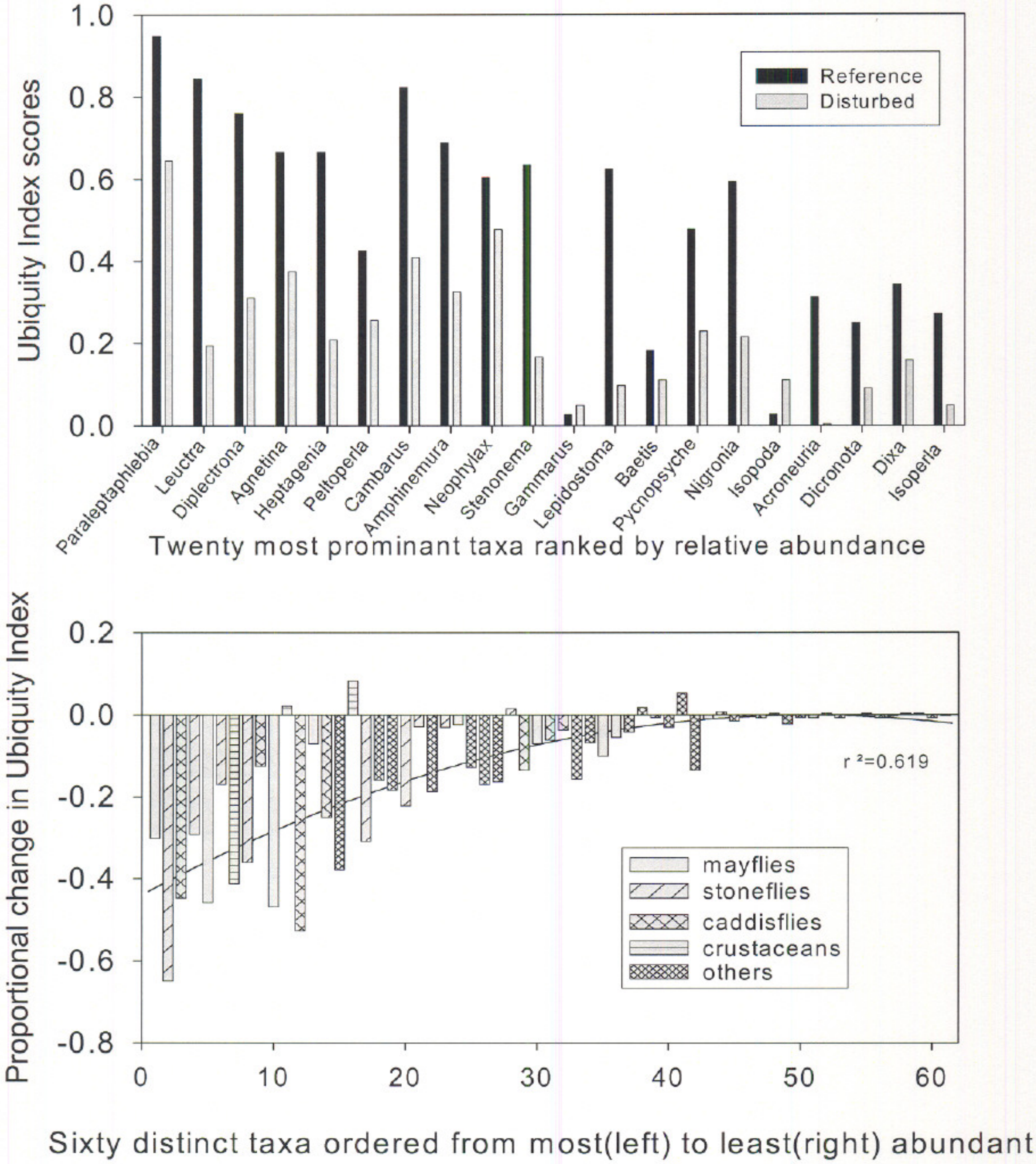


Figure 11. Comparison (top) of Ubiquity Index scores in disturbed versus reference conditions for the twenty most abundant macroinvertebrate taxa, and (bottom) the relationship (2^{nd}-order polynomial regression, $p<0.001$) between the proportional change in Ubiquity following longwall mining versus the relative abundance of macroinvertebrate taxa across the region.

Discussion

The physical dimensions of the 5 reference and 6 longwall mined watersheds were comparable with the exception of water temperature and stream width. Instantaneous water temperature at the time of sampling indicated significantly lower surface water temperature in longwall mined versus reference streams. Water temperatures were lower even though sampling of longwall mined streams was chronologically interspersed with reference stream sampling. Loss of water at the surface and longer underground residence time resulted in 1–2°C lower summer water temperatures in longwall mined streams.

Longwall mined streams were dry at 29% of study sites, most of which were within 100m of the point of flow origin. If dry streams with zero width were removed from the model, median stream width was not significantly different when comparing longwall mined streams with reference streams. However, where surface water did exist in longwall mined streams, streams were on average 2/7 the width of comparable reference streams. Recovery of surface flow in longwall mined streams occurred, as indicated by median stream widths compared to reference conditions, on average, in approximately 80 acre watersheds.

Three of five chemical measures showed significant differences when comparing longwall mined versus reference streams. Higher total dissolved solids, alkalinity, and oxygen demand are typical impacts associated with mining. Stream water quality was somewhat degraded as evidenced by higher conductivity in longwall mined streams. However, the presence of carbonate minerals in fractured rock strata helped buffer the dissolution of pyritic materials, thus pH remained similar to reference conditions.

Within the biological community the EPT Taxa represented 28 of the 60 kinds of macroinvertebrates collected, and 3,265 of the 3,932 total number of macroinvertebrates collected in this study. One can expect to collect between 6 and 14 different EPT Taxa at any site in any reference stream 95% of the time. The EPT Taxa are often used as indicators of good water quality because as a group they are particularly responsive to disturbance (Rosenberg & Resh, 1993). In this study the primary interest in EPT Taxa is their relatively long aquatic larval development period. With some exceptions, EPT Taxa typically require greater than 9 months residence in streams in order to complete their larval development and successfully emerge as adults (Wallace & Anderson, 1996). The co-existence of multiple EPT Taxa in these streams in the summer months is indicative of their permanence as consistent landscape elements. These streams, often mistakenly referred to as "ephemeral" or "intermittent" because of their inaccurate depiction on USGS 1:24,000 scale data, are indeed perennial entities.

The difference in the response of EPT Taxa, with a 29% proportional reduction in ubiquity following longwall mining, versus Semivoltine Taxa, with a 51% proportional reduction in ubiquity, was approximately 22%. The dynamic changes in headwater stream communities indicate that 29% of perennial headwater streams are "dewatered," lasting a few weeks at most following a storm event, sometimes providing isolated pockets of refuge, but incapable of supporting a sustained aquatic community. An additional 22% of longwall mined streams are "partially dewatered," supporting organisms with up to 9 month life cycles but failing to provide suitable conditions for the perennial macroinvertebrate communities observed in reference streams. Longwall mining results in a 50% reduction in the omnipresence of perennial aquatic biological communities in headwater streams across the region.

In many regions headwater streams harbor biodiversity that equals or exceeds that of larger downstream reaches (Feminella, 1996; Dieterich & Anderson, 2000; Williams, 1996). Many species live only in headwater streams, and loss of headwaters represents a significant threat to southern Appalachian fauna (Morse *et al*, 1993). Many other forest species depend on the close proximity of streams directly as breeding sites and water sources, and indirectly, for instance, the emergence of aquatic insects providing a high quality a food source in a form and at a time suitable for breeding birds. Loss of one-half of all headwater streams from the longwall mining region may have significant consequences for central Appalachian forest ecosystems.

Conclusion

Longwall mining results in a net loss of one-half of all headwater streams in Marshall County, West Virginia. Streams are particularly impacted near the source, and re-emerge downstream. Otherwise, aquatic macroinvertebrate communities in reference streams are ubiquitous across the region, rich in diversity, long-lived, and dependent on the surrounding terrestrial ecosystems for energy and nutrients.

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WRI47-Establishing Biological and Water Quality Criteria for Water Resource Management in Mining Impacted Watersheds

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Principal Investigators:	J Todd Petty

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3. Newspaper article: Charleston Gazette Friday, May 10, 2002. "WVU to study stream standards".

FINAL REPORT

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

Submitted by:
J. Todd Petty
Division of Forestry
West Virginia University

Submitted to:
West Virginia Water Research Institute

June 7, 2004

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 18th 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.

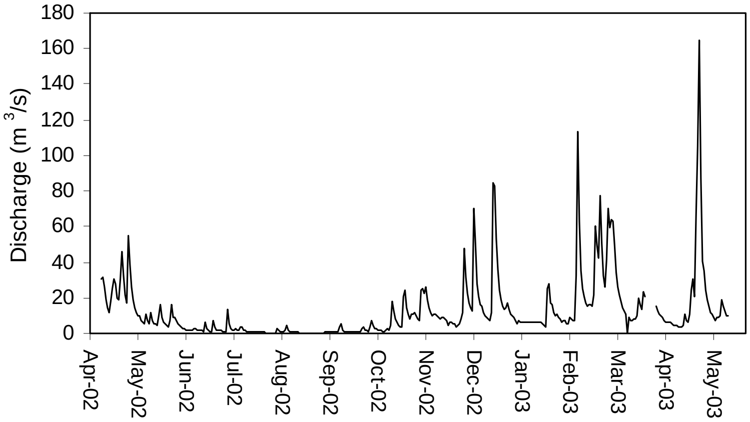


Figure 1. Daily mean discharge during the course of the study. Discharge was gauged continuously on Big Sandy Creek at Rockville, WV (USGS 03070500).

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).

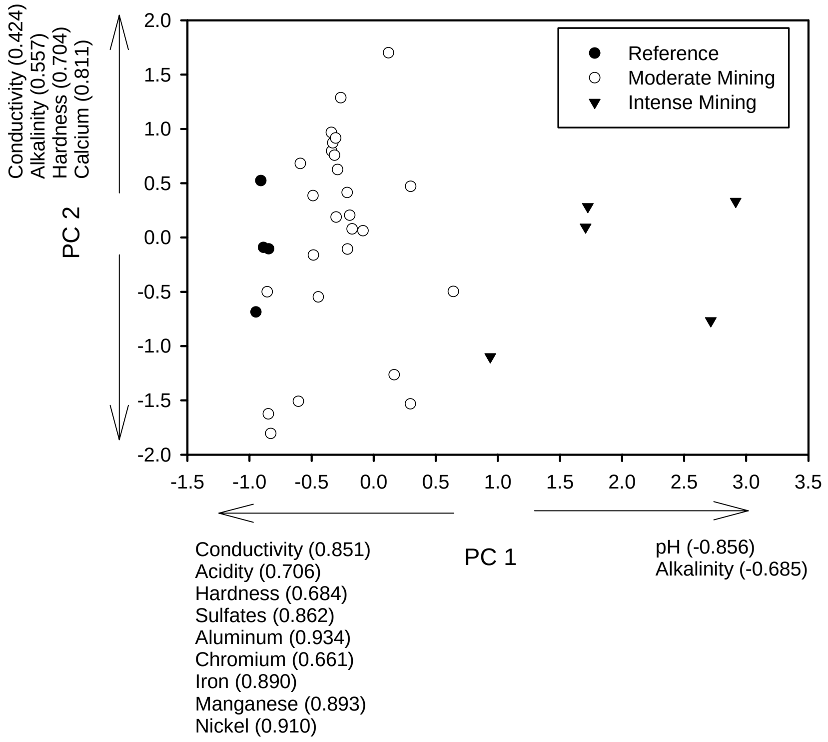
Table 1. Summary statistics for water chemistry variables from unimpaired, moderately impaired, and severely impaired stream segments. Mean values were calculated across all sample dates. Avg. CV refers to the average variability of stream segments within each category. The higher the value the more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

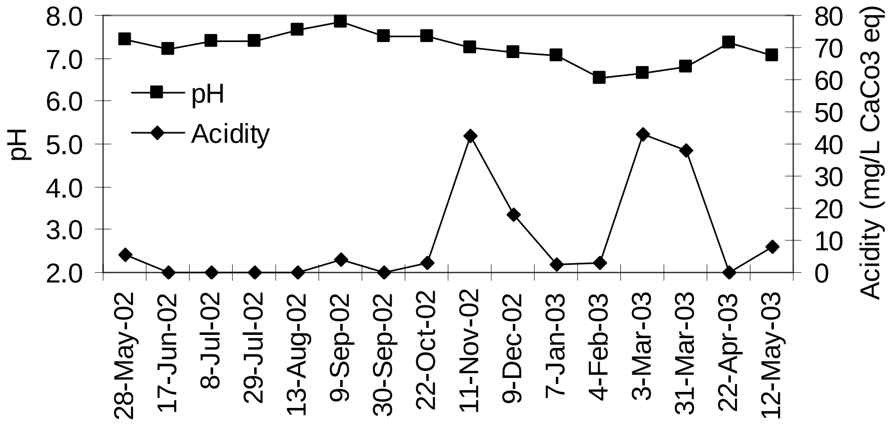


Water Quality Variability

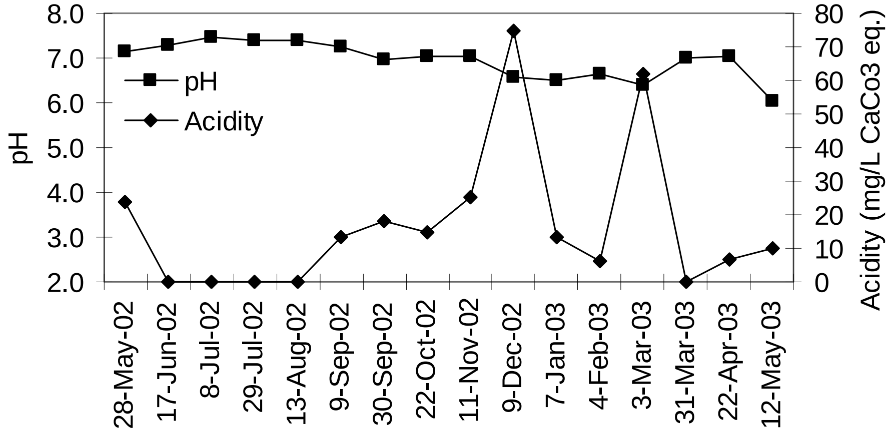
An important objective of our study was to quantify the degree of temporal variability in water quality in streams of the lower Cheat River watershed. Our analyses indicated that chemical conditions were highly variable in all streams studied, regardless of relative impairment level. Figures 3 – 5 illustrate 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

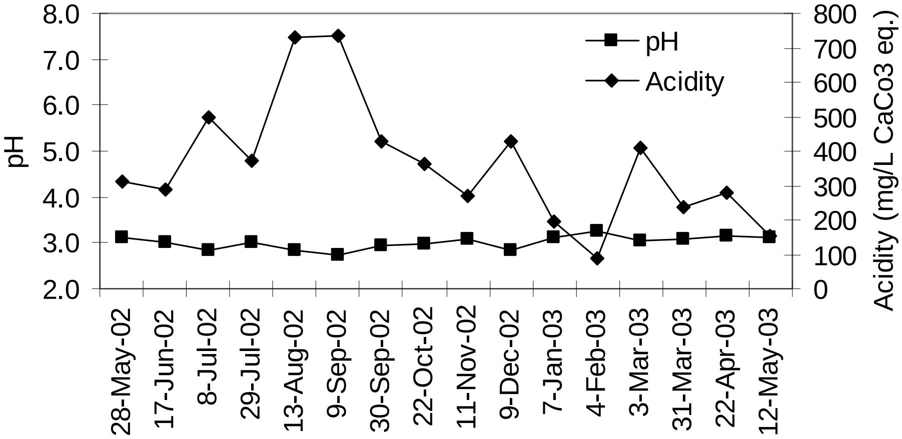
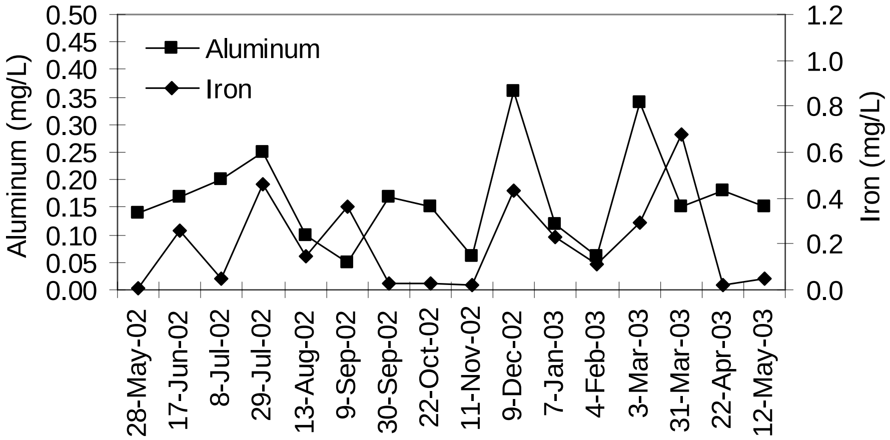
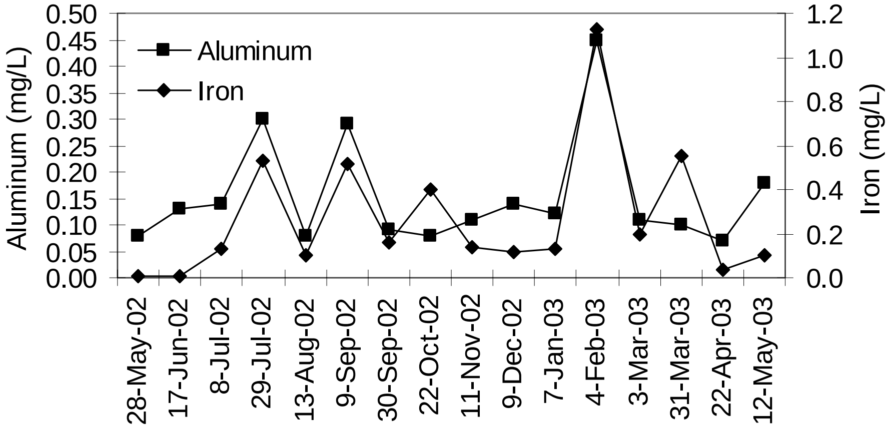


Figure 3. Variability in pH and Acidity within an unimpaired (A), a moderately impaired (B), and a severely impaired (C) stream segment of the lower Cheat River watershed.

A. Roaring Creek 1



B. Muddy Creek 4



C. Martin Creek

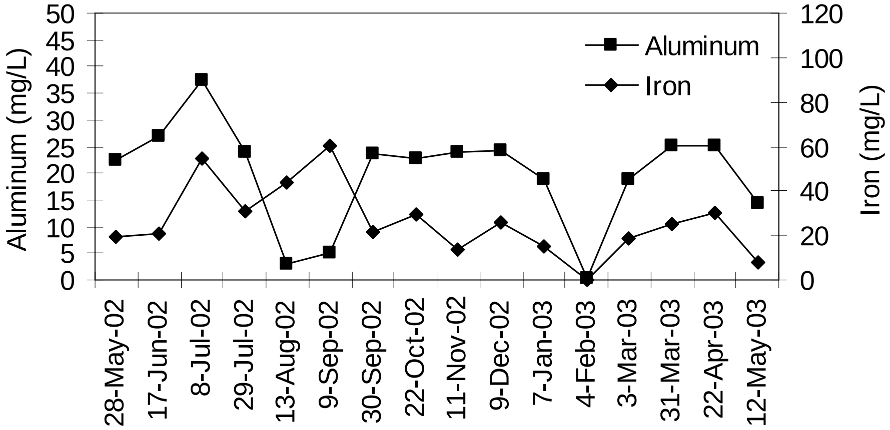
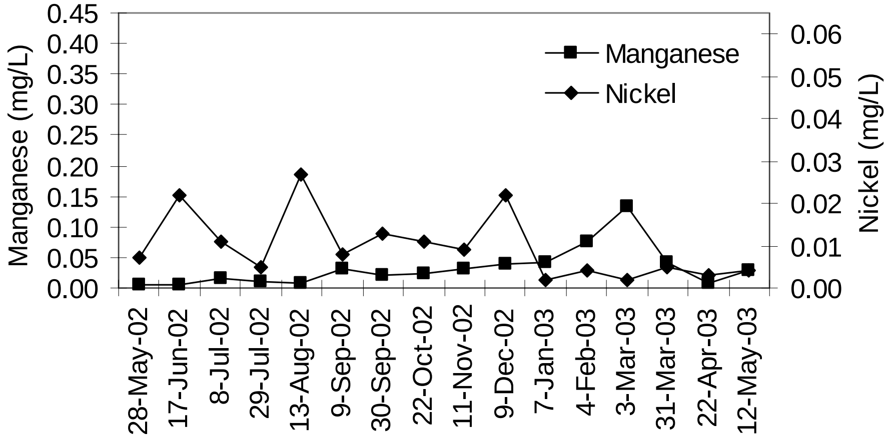
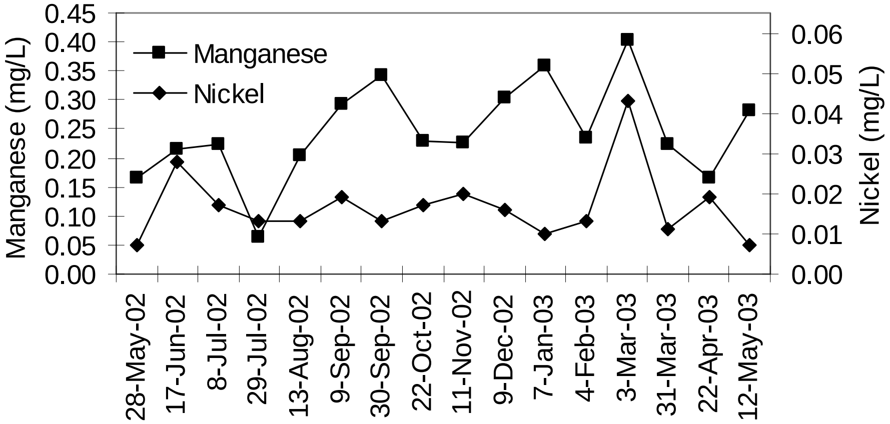


Figure 4. Variability in dissolved Aluminum and Iron concentrations within an unimpaired (A), a moderately impaired (B), and a severely impaired (C) stream segment of the lower Cheat River watershed.

A. Roaring Creek 1



B. Muddy Creek 4



C. Martin Creek

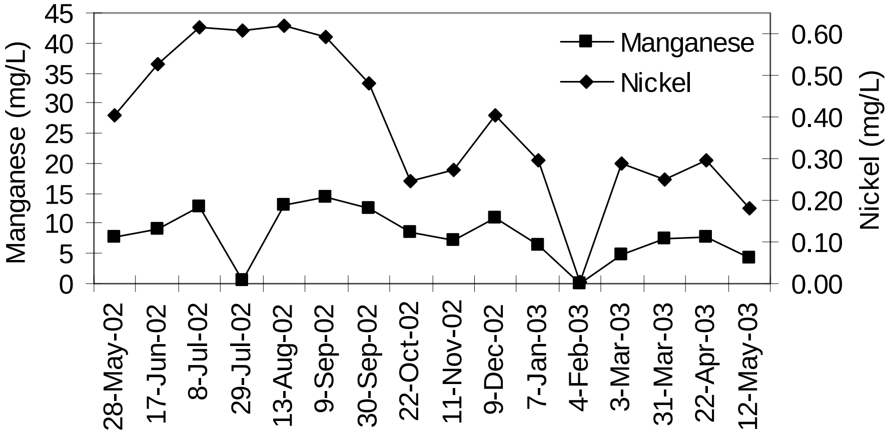


Figure 5. Variability in dissolved Manganese and Nickel concentrations within an unimpaired (A), a moderately impaired (B), and a severely impaired (C) stream segment of the lower Cheat River watershed.

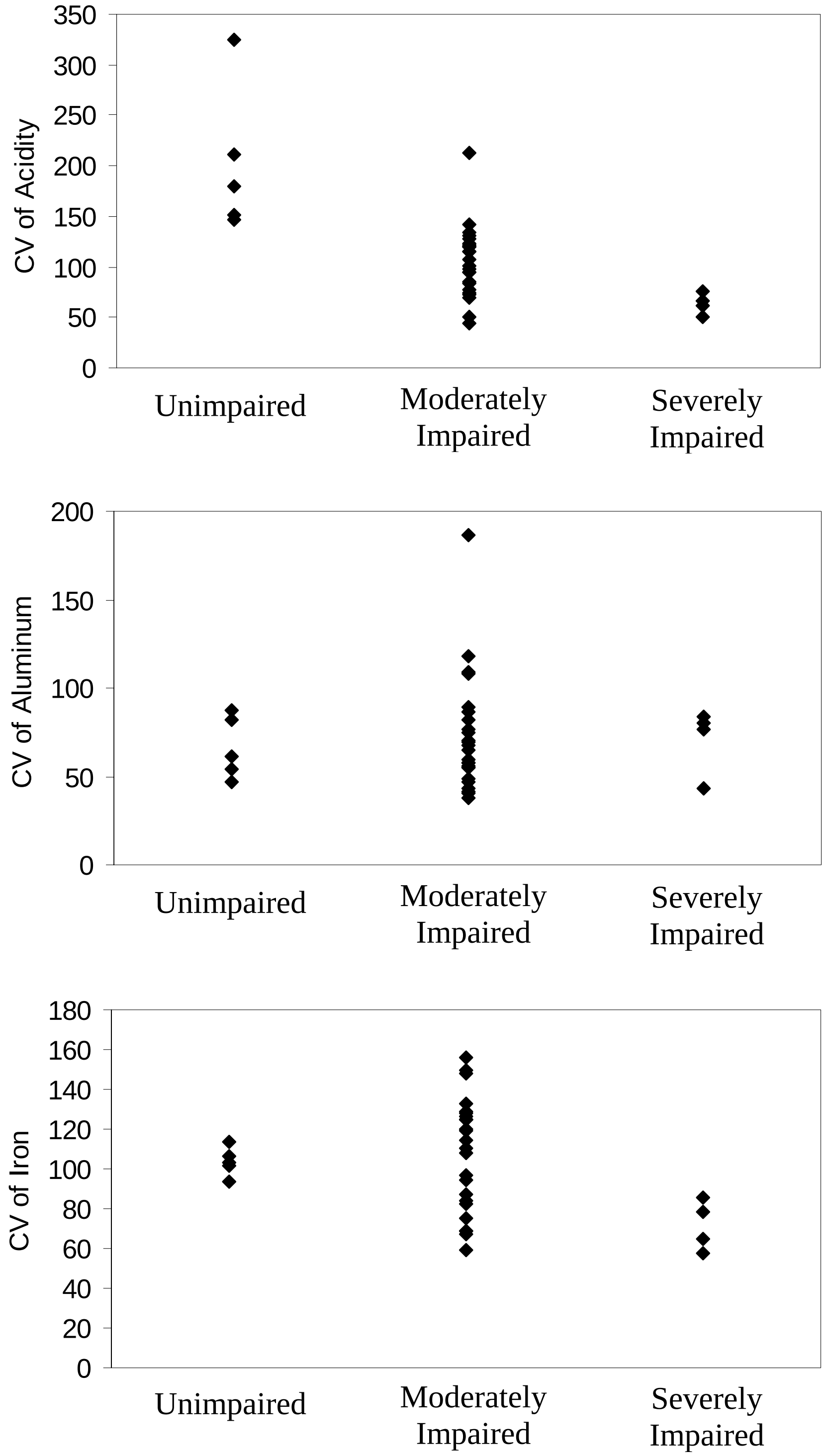


Figure 6. Temporal variability in acidity and dissolved aluminum and iron concentrations within unimpaired, moderately impaired, and severely impaired stream segments of the lower Cheat River watershed. Each symbol represents a relative measure of day-to-day variability in water chemistry at a specific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

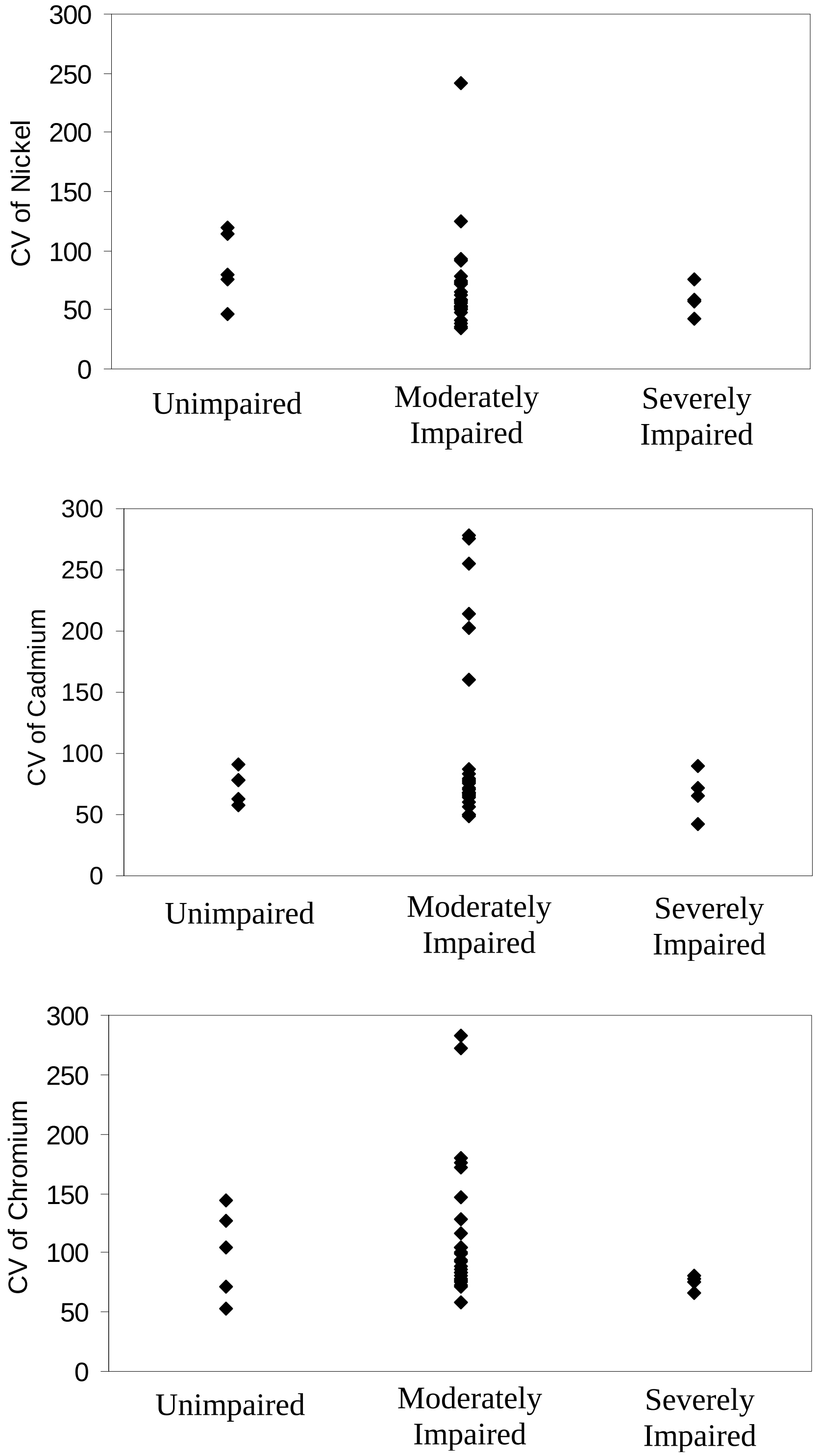


Figure 7. Temporal variability in dissolved trace metal concentrations within unimpaired, moderately impaired, and severely impaired stream segments of the lower Cheat River watershed. Each symbol represents a relative measure of day-to-day variability in water chemistry at a specific study site.

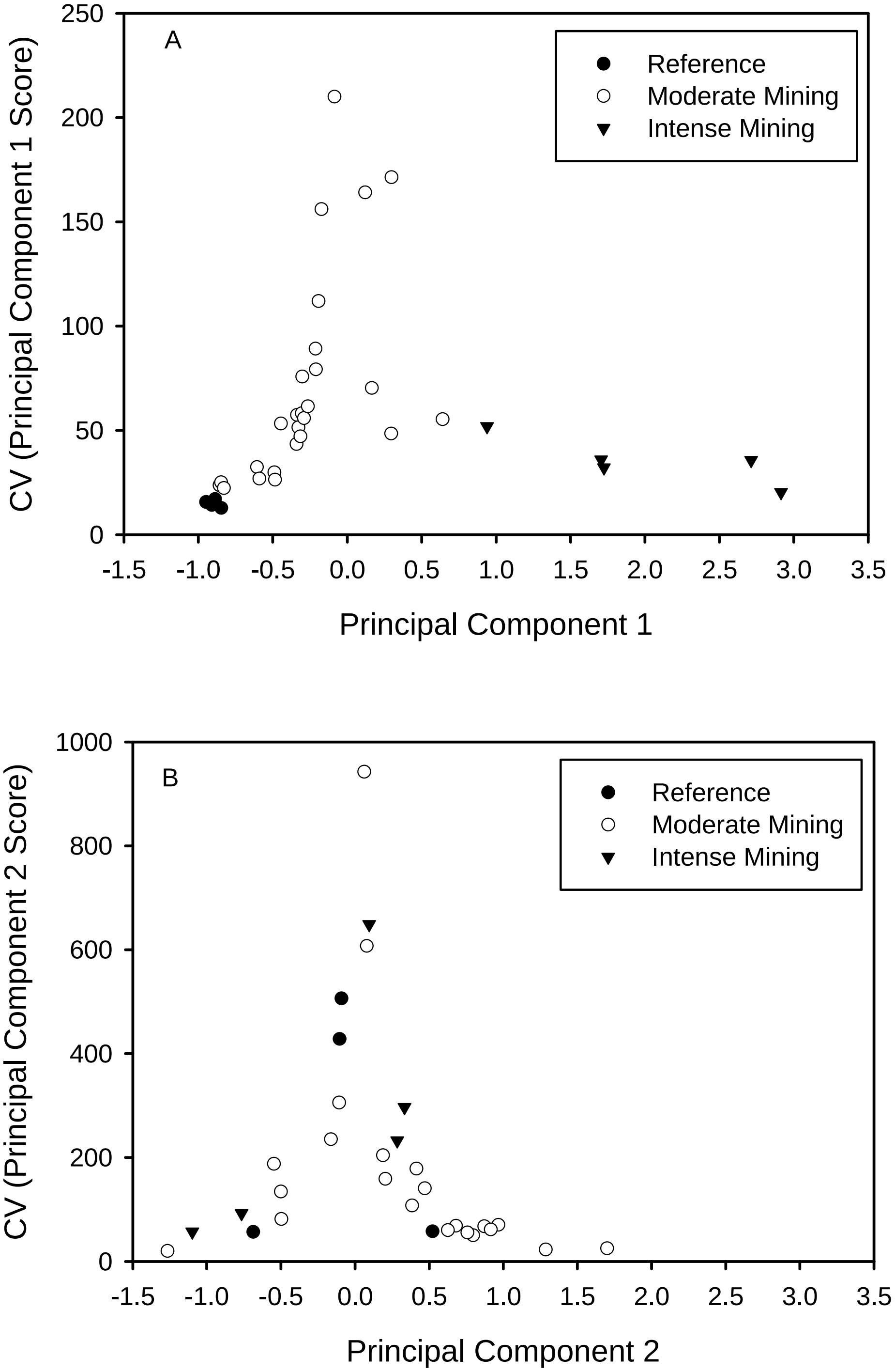


Figure 8. Relationship between water quality variability and mean water quality condition on both PC 1 (A) and PC 2 (B).

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)

Effects of Water Chemistry on Stream Ecological Condition

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.

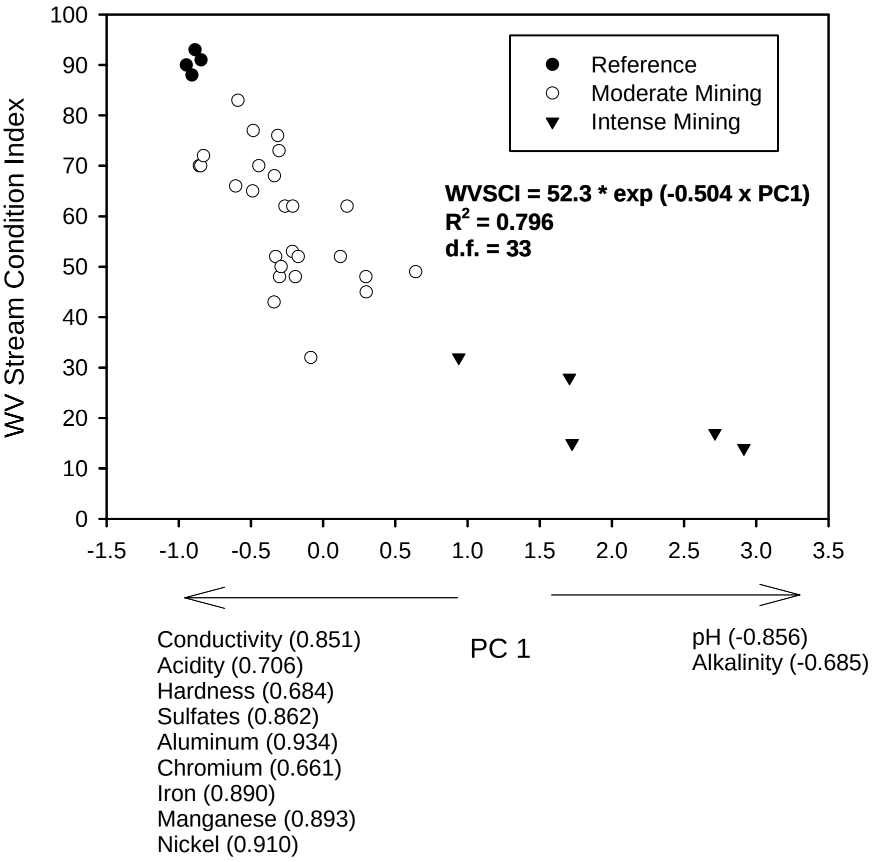


Figure 9. Relationship between WVSCI and water quality as measured by PC 1.

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.

Acknowledgements

We would like to thank Jason Freund, George Merovich, Roy Martin, and Brock Reggi for their help with field sampling. We also would like to thank Paul Ziemkiewicz for sharing his ideas regarding chemical variability in mined watersheds. This research was funded, in part, through grants from the WV Water Resarch Institute, Allegheny Energy Supply Co., and the Electrical Power Research Institute.

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WV DEP. 1999a. An ecological assessment of the Cheat River watershed. Watershed Assessment Program, Office of Water Resources. Report Number 0502004-1996.

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

WRI55: Hydrologic Connections and Impacts on Water Supply in the Great Valley Karst Aquifer. A Case Study in Martinsburg, West Virginia

Basic Information

Title:	WRI55: Hydrologic Connections and Impacts on Water Supply in the Great Valley Karst Aquifer. A Case Study in Martinsburg, West Virginia
Project Number:	2003WV15B
Start Date:	3/1/2003
End Date:	2/28/2004
Funding Source:	104B
Congressional District:	WV 1st
Research Category:	Water Quality
Focus Category:	Water Supply, Water Quantity, Water Quality
Descriptors:	water supply, water quantity, water quality, hydrology, ground water, surface water, hydrogeology
Principal Investigators:	Dorothy Vesper, Joseph Donovan

Publication

1. None.

Hydraulic Connections and Impacts on Water Supply in the Great Valley Karst Aquifer. A Case Study in Martinsburg, WV

D.J. Vesper and J.J. Donovan

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1. Synopsis of Accomplishments

This project includes two main types of data collection activities – continuous electronic logging and water quality sampling. Thus far the following has been accomplished:

- Logging equipment for stage, conductivity and temperature was installed in Water Street Spring (also known as Martinsburg Water Supply Spring) and Kilmer Spring during summer 2003. Data has been collecting continuously since that time.
- A pressure transducer (for measuring stage) was installed in Lake Thomas Fall 2003 and is currently collecting data.
- Discharge has been measured at Water Street Spring 6 times since the program began. These data allow the stage data to be converted into flow discharges.
- Field screening chemical data (temperature, pH, conductivity) has been collected numerous times at all springs
- Three rounds of water samples have been collected and analyzed (Nov 03, Feb 04, Apr 04) for Kilmer, Water Street, Big and Snodgrass Springs

In addition to these tasks, a relational database has been designed and populated for the project

2. Publications. – None.

3. Information transfer activities

- D.J. Vesper gave a public talk at the Berkeley Springs Festival of the Waters (February 2004): "The History, Mystery and Science of Springs" and incorporated data collected in the Martinsburg area. (J.T. Donovan was a preliminary judge at the same water-tasting competition)
- D.J. Vesper presented data-to-date at the WRI Advisory Committee annual meeting (December 2003): "Impacts on Water Supply in the Great Valley Karst Aquifer: A Case Study in Martinsburg, WV"
- D.J. Vesper presented an overview of this and related team projects at the U.S. Geological Survey Great Valley Water-Resources Science Forum (May 2004): "Karst Spring Research at WVU: An Update on Ongoing Work"

4. Student Worker Summary as follows:

Rachel Grand is conducting her M.S. Research on this and related work. The WRI Grant is supplying Grand's supper research stipend.

5. NIWR-USGS Student Interns (if any) – None.

6. Notable achievements and awards – None.

WRI54: Passive Treatment of Cl Contaminated Waters in NW West Virginia Using Passive Absorptive Technologies

Basic Information

Title:	WRI54: Passive Treatment of Cl Contaminated Waters in NW West Virginia Using Passive Absorptive Technologies
Project Number:	2003WV16B
Start Date:	3/1/2003
End Date:	2/28/2005
Funding Source:	104B
Congressional District:	1
Research Category:	Water Quality
Focus Category:	Water Quality, None, None
Descriptors:	chloride absorption
Principal Investigators:	Thomas Guetzloff, Paul F Ziemkiewicz

Publication

1. None.

WRI-54: Passive Treatment of Cl Contaminated Waters in NW West Virginia Using Passive Absorptive Technologies

Introduction

In West Virginia there currently exists no state specific surface water quality limit for chloride. The limit currently on record for chloride, 230 mg/L, comes from federal water quality standards and are currently not heavily regulated within the state. However, the WV Division of Environmental Protection has recently been discussing monitoring chloride concentrations in discharge waters and enforcing existing chloride limits. Chloride concentrations have been detected > 1000 mg/L (over 5x the current standard) in several underground mine discharges in northern West Virginia, which will require many operators in this region to continually treat for chloride removal. Unfortunately, passive treatment technologies exist to address chloride removal from contaminated waters. The only alternative is for operators to construct and maintain expensive active treatment facilities to remove chloride. In addition, since chloride limits have not been enforced in the past, there has been little research on passive treatment of chloride contaminated waters. The result is that little is known about the potential for and effectiveness of passive chloride treatment systems.

The ultimate result of this project will be a better understanding of the absorptive potential of various materials, including acidified AMD sludge, on anionic species present in acid mine drainage (AMD). Of particular interest is chloride and its affinity for sorption sites. Also of interest if the interaction between Cl and other anionic species, particularly sulfate, that may inhibit Cl absorption and favor $SO4^{2-}$ absorption or visa versa. The results of this project can then be used to make recommendations for Cl removal in the field.

Synopsis of Accomplishments

Due to a delay in getting a subcontract in place between West Virginia University and West Virginia State College, the project was delayed in starting. It is anticipated that a no cost extension for up to one additional year will be necessary to allow additional time for project completion.

During the spring of 2004, however, the ICP has been calibrated to detect chloride, potassium, iron, aluminum and manganese at experimentally relevant levels and 26 other elements at background levels. Brines of various concentrations have been allowed to interact with iron, aluminum and manganese hydroxide sludge samples. Typical chloride reduction observed in these experiments was 60%. In experiments employing manganese, unacceptable enrichment of the aqueous phase with manganese was observed along with chloride reduction. Future experiments will focus on sludges of iron, aluminum, and mixed composition sludges obtained from abandoned mine lands. A variety of interaction protocols will be examined.

Publications

None yet.

Information transfer activities

None yet.

Student Worker Summary

None yet. However, anticipate having one M.S. graduate student begin work on this project in the fall of 2004.

NIWR-USGS Student Interns

None

Notable achievements and awards

None

WRI-40 = Aquaculture Waste Control and Optimizing Nutrient Utilization through Diet Composition and Feeding Strategies

Basic Information

Title:	WRI-40 = Aquaculture Waste Control and Optimizing Nutrient Utilization through Diet Composition and Feeding Strategies
Project Number:	2003WV11B
Start Date:	3/1/2001
End Date:	2/28/2004
Funding Source:	104B
Congressional District:	1
Research Category:	Biological Sciences
Focus Category:	Nutrients, ,
Descriptors:	
Principal Investigators:	Jonathan C. Eya

Publication

1. Two manuscripts titled "The Impact of Feeding Strategy, Dietary Phosphorus and Varying Protein/Fat Contents on Juvenile Rainbow Trout Performances and Waste Output" and "Comparison of the effects of various sources of zeolites on growth, body composition and waste output in trout rearing systems" are being prepared and the manuscript will be submitted for publication to "Aquaculture" and "Journal of the World Aquaculture Society".

" FINAL REPORT OF ACCOMPLISHEMENTS AND RESULTS"

PROJECT SPECIFICATIONS:

Subcontract No. 68-211-WVSC
Project Sponsor: U.S. Geological Service
Project Title: Aquaculture Waste Control and Optimizing Nutrient Utilization through Diet Composition and Feeding Strategies" for the FY 2003.
Period of Performance: March 1, 2001 to February 28, 2004

Synopsis of Accomplishments

SUMMARY: The ultimate source of wastes in an aquaculture system is feed; and phosphorus and nitrogen are the major elements of concern in discharge from aquaculture operations. The discharged wastes significantly impact economic and environmental welfare. The project titled “Aquaculture Waste Control and Optimizing Nutrient Utilization through Diet Composition and Feeding Strategies" comprised of several experiments. Results from these studies will improve aquaculture waste management procedures and reduce wastes generated from fish culture operations.

PROJECT OBJECTIVES:

Study 1. Determine effects of feeding practices on waste load in trout culture systems.

Study 2. Determine the effects of dietary supplementation of various zeolites on growth, feed efficiency and health of rainbow trout

Study 3: Determine the effects of dietary supplementation of various zeolites on ammonia and nitrite concentrations in trout rearing system.

PRINCIPAL ACCOMPLISHMENTS:

Study 1: 2 X 2 X 3 factorial experiment design was conducted to determine the impact of feeding strategy, dietary phosphorus levels and varying protein/fat contents on juvenile rainbow trout performance and waste output.

MAIN EFFECT

1. Feeding practice did not have significant effect on percent weight gain but had significant role in feed consumption, feed conversion and phosphorus output.
2. Dietary phosphorus level did not play significant role in percent weight gain, feed consumption, food conversion and phosphorus output.
3. Varying protein and fat contents of the diets had significant impact on percent weight gain, food consumption, feed conversion, and phosphorus output.

TWO-FACTOR INTERACTIONS

1. There was no significant interaction between feeding strategy and dietary phosphorus or feeding strategy and varying protein and fat contents or dietary phosphorus level and varying protein and fat content for weight gain.
2. There was no significant interaction between feeding strategy and dietary phosphorus level or phosphorus level and varying protein and fat contents for feed consumption, feed conversion and phosphorus output.
3. There was significant interaction between feeding strategy and dietary phosphorus level and feeding strategy and varying protein and fat level for feed consumption, feed conversion, and phosphorus output.

THREE-FACTOR INTERACTION

1. There was significant interaction for weight gain, feed consumption, feed conversion.
2. There was significant interaction for phosphorus output during the first two months of the experiment but not during the last month.

OVERALL CONCLUSION

Use of restricted feeding, 0.5% dietary phosphorus level and 34:30 protein/fat content did not significantly impact growth but would significantly reduce feed cost and phosphorus output rainbow trout culture systems.

Study 2: Control diet with 0% zeolite, nine diets from three sources of zeolites (bentonite, clinoptilolite and mordenite) at three different levels of inclusion to the basal diet (0.5%, 2.5% and 5%), and two diets containing two levels of philipsite were formulated and fed to rainbow trout to determine their effects growth, feed efficiency, health and waste output in rainbow trout rearing system

BENTONITE

1. There was linear increase in weight gain with increasing levels of Bentonite but this increase was not statistically significant.
2. Food conversion increased with increasing levels of Bentonite.
3. There was no significant difference in survival, visceral fat content, viscerosomatic and hepatosomatic indices among different treatments.
4. Bentonite had no significant effect on the weekly measurements of total orthophosphate discharged from the trout rearing system.

CLINOPTILOLITE

1. Fish fed 0.5% clinoptilolite had higher weight gain, better food conversion and survival, and increased visceral fat content

which were not statistically significant compared to the fish that received 0%, 2.5% or 5% level.

2. Clinoptilolite had no significant effect on the weekly measurements of total orthophosphate discharged from the trout rearing system

MORDENITE

1. Mordenite had no significant effect on the weight gain, feed conversion, survival, visceral fat content, hepatosomatic and viscerosomatic indices.
2. There was no significance difference among the various treatment means for total orthophosphate discharged from the trout rearing system.

PHILIPSITE

1. Inclusion of philipsite had a significantly deleterious effect on the growth and feed conversion ($p<0.05$) but not on survival, visceral fat content, hepatosomatic and viscerosomatic indices.
3. Weekly measurements of total orthophosphate discharged from the trout rearing system did not follow any consistent pattern among the treatments.

OVERALL

Bentonite and clinoptilolite appeared to be good candidates for inclusion in the diets of rainbow trout since there were linear increases in weight gain and feed conversion among the various treatment means. Their inclusion levels used in this experiment did not appear to have been enough to produce significant effects. Higher levels of supplementation may produce a significant effect. Inclusion of philipsite in the diets impairs growth and feed conversion.

Study 3: Twelve diets containing 0%, 0.5%, 2.5%, 5% of zeolites (bentonite, clinoptilolite, mordenite and philipsite) were formulated and fed to rainbow trout to determine their effects on ammonia and nitrite concentrations in trout rearing system.

BENTONITE

1. There was significant accumulation of ammonia-nitrogen in tanks containing fish fed 0.5% bentonite at 0hrs and 8 hrs after reduction in the volume of water flow compared to the fish fed 0%, 2.5% or 5% ($p<0.5$).
2. Ammonia-nitrogen remained higher after 16 or 48 hours in tanks containing fish fed 0.5% bentonite but was not statistically significant ($p>0.5$).

CLINOPTILOLITE

1. Supplemental clinoptilolite had no significant effect on the ammonia-nitrogen concentration in the tanks at different sampling times.

MORDENITE

1. Mordenite had no significant effect on ammonia-nitrogen at 0, 8 or 16 hours after reduction of water flow volume but tanks containing fish fed 2.5% had significantly higher ammonia-nitrogen at 48 hours when compared to the other treatment means.

PHILIPSITE

1. There was no consistency in the means values for ammonia-nitrogen in tanks after reduction of water flow.

OVERALL

Inclusion of zeolites in the diets of trout did reduce accumulation of ammonia in trout culture systems.

PUBLICATIONS, MANUSCRIPTS OR PAPERS PRESENTED

PUBLICATIONS/MANUSCRIPTS

Two manuscripts titled “The Impact of Feeding Strategy, Dietary Phosphorus and Varying Protein/Fat Contents on Juvenile Rainbow Trout Performance and Waste Output” and “Comparison of the effects of various sources of zeolites on growth, body composition and waste output in trout rearing systems” are being prepared and the manuscript will be submitted for publication. The journals that these results will be published in will be “Aquaculture” and “Journal of World Aquaculture Society”.

PRESENTATIONS

Eya, J. C. and A. Parsons. 2004. The Impact of Feeding Strategy, Dietary Phosphorus and Varying Protein/Fat Contents on Juvenile Rainbow Trout Performance and Waste Output. West Virginia State University 10th Annual Research Symposium, April 30, 2004, Institute, WV. (**oral presentation).**

Eya, J.C., A. Parson, P. Jagidi and I. Haile. 2004. Comparison of the effects of various sources of zeolites on growth, body composition and waste output in trout rearing systems. To be presented at Aquaculture America, January 17-20, 2005, New Orleans, LA. (**poster).**

INFORMATION TRANSFER ACTIVITIES:

Information transfer activities have not commenced. Results are being compiled and the results will be made available to different stakeholders via diverse printed media, and possibly through television or video.

SUMMARY OF STUDENTS SUPPORTED WITH THE FUNDS

There were two undergraduate students and a research assistant supported with funds from the project. Each student was paid $6.73/hr. during the regular school period and $7.12/hr. during the summer school and the research assistant was paid $6.73/hr. The maximum number of hours per week per student was 20hrs. during regular school period and 40hrs. during the summer school. The research assistant was paid hourly and the maximum number of hours per week was less than 35 hrs.

Category	USGS WRI Award	NIWR-USGS Internship	Supplemental Award	Total
Undergrad	2	N/A	N/A	$0
Research assistant	1	N/A	N/A	$0
M.S.	N/A	N/A	N/A	N/A
Ph.D.	N/A	N/A	N/A	N/A
Post-Doc	N/A	N/A	N/A	N/A

NOTABLE ACHIEVEMENTS AND AWARDS/matching funds/supplemental grants

Notable achievements include the discovery that the use of appropriate feeding strategy (restricted feeding) with low phosphorus and low protein and high fat can increase body deposition of protein with minimal pollution. Also, there is the potential for using zeolites to increase nutrient utilization in trout. West Virginia State University has spent approximately $54,000 as a matching component to this project for the construction of the laboratory space and utilities ($20,000), salary for the release time for the PI ($16,000), and unrecovered indirect costs ($18,000).

ANTICIPATED IMAPCTS/BENEFITS

The results indicates that better protein deposition and food conversion ratio in rainbow trout can be achieved with restricted feeding containing 0.5% phosphorus and 38% protein and 25% fat diet. This suggests a potential for savings on the protein and phosphorus consumption, an increase in their utilization and resulting decrease in nitrogen and phosphorus output in trout production.

Also, there is the potential for the utilization of bentonite and clinoptilolite as a dietary supplements in the diets of fish for improved growth and feed efficiency that may ultimately offer opportunities to reduce the unretained nutrients in the culture systems.

WRI-46 Assessing Extent and Longevity of Degradation Following Coal Mining in West Virginia

Basic Information

Title:	WRI-46 Assessing Extent and Longevity of Degradation Following Coal Mining in West Virginia
Project Number:	2003WV12B
Start Date:	3/1/2002
End Date:	2/28/2004
Funding Source:	104B
Congressional District:	1
Research Category:	Water Quality
Focus Category:	Water Quality, ,
Descriptors:	degradation, coal mining, water quality, Appalachian Region
Principal Investigators:	Paul Ziemkiewicz

Publication

1. None.

WRI46 - Assessing Extent and Longevity of Degradation Following Coal Mining in West Virginia

Final Report

March 31, 2004

National Mine Land Reclamation Center
PO Box 6064
202 NRCCE Building
West Virginia University
Morgantown, WV 26506-6064

Summary of Accomplishments

Background:

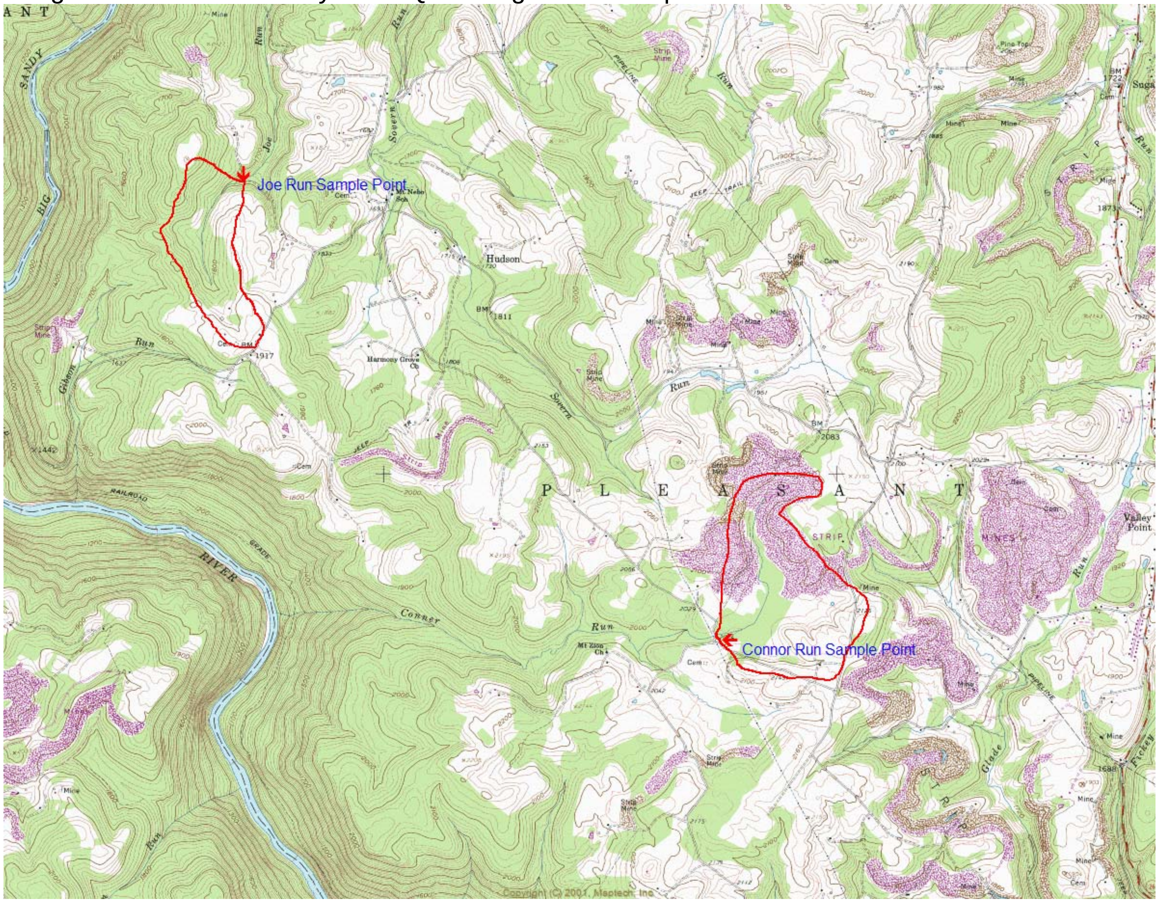
Coal mining has been a significant cause of long-term harm to streams in the Appalachians. However, a recent study at West Virginia University has shown that many of these acid impacted streams may be improved over time through the natural reduction in acid generation of the mine sources.

The purpose of this study was to compare two watersheds of similar size and geology, one of which was affected by acid mine drainage due to surface mining and the other of which was unmined. The mining that occurred in the mined watershed was to have been conducted at least 20 to 25 years previously and no mining was to have occurred since that time. The goal was to compare water chemistry and benthic macroinvertebrate life to determine how much, if any, natural amelioration of acid mine drainage has occurred in the mined watershed over time. Based on the lack of un-mined, undisturbed watersheds since the initial study, it was decided that we use an impacted watershed from the USFS study and an unimpacted watershed that was not used in the initial study. Due to these circumstances, our results and conclusions will be based on the hypothesis that the unmined watershed would have undergone little to no change in the last 20 to 25 years.

The benthic survey was conducted to develop correlations between chemical parameters and stream re-colonization. The data used for the past water chemistry was from the 1982 report “Stream Water Quality in the coal region of West Virginia and Maryland” produced by the US Forest Service. The streams chosen for this comparison are the upper sections of Connor Run and Joe Run, both located in Preston County. The impacted watershed, Connor Run, (no. 9212 in the Forest Service study) was surface mined from 1955 to 1979. The samples were collected at both sites on May 23, 2003. It should also be noted that the sample for Connor Run was collected at the approximate location where the US Forest Service Samples were collected.

Connor Run and Joe Run are both located in Preston County in north-central West Virginia. Both watersheds are shown in entirety on the Valley Point 7.5 minute USGS quadrangle. The topography of the area consists of an upland plateau of rolling hills that is well dissected by the larger regional streams and rivers that form well developed canyons. Figure 1 is a portion of the Valley Point Quadrangle detailing both sample locations and their respective watersheds.

Figure1. USGS 15' Valley Point Quadrangle with Sample Points and Watershed Limits in Red



Overall, Connor Run, the mined watershed, comprises a larger watershed than Joe Run. However, the sampling location was located in the upper reaches of the watershed along County Road 14/5. The drainage area above the sampling location is approximately 360 acres (map determined). Connor Run is a direct tributary to the Cheat River. While it has carved a fairly well defined, high gradient canyon as it approaches the Cheat, the upland area where the stream was sampled was of a fairly low gradient nature, with evidence of some wetland type vegetation in areas along the stream margins. The stream gradient was approximately 60 feet per mile. The relief in the sub-section of Connor Run being studied is approximately 126 vertical feet (map determined). It is possible that the historical relief and topography of the area may have been altered slightly by the surface mining.

Joe Run was sampled approximately 0.3 of a mile from its confluence with Big Sandy Creek just below the crossing of County Road 14/8. While Joe Run is a smaller watershed, the sampling point chosen represents the influence of a larger drainage area than that for Connor Run. The drainage area above the sampling point on Joe Run was approximately 560 acres. The gradient of approximately 170 feet per mile and relief of approximately 441 vertical feet was greater than that of the Connor Run sub-watershed being studied.

Both sub-watersheds represented a similar mixture of forested and open land. There was some evidence of relatively recent logging in both sub-watersheds. A high power electrical transmission line transects the Connor Run sub-watershed close to the sampling location. However, there was no evidence of use of herbicides for right-of-way clearing. The tree canopy appeared to be somewhat more open in the sampling area along Connor Run than it was in the sampling area along Joe Run. However, the canopy was not fully leafed out at the time of the sampling.

Methodology:

Water Sampling

Water sampling performed for the Joe and Connor Run watersheds involved the use of an Oakton pH meter to take pH readings. Flows were taken using a Marsh-McBirney flow meter. In addition to the pH and flow readings, two samples were collected at each site, one which was non-acidified and non-filtered, and the other acidified and filtered. The non-acidified, non-filtered samples were used for measurement of pH, acidity, alkalinity, Sulfates, total dissolved solids, and total suspended solids. The acidified, filtered samples were used for metals such as iron, aluminum, manganese, and magnesium. The pH and flows were recorded in a field book and the samples were sent off to Sturm Environmental Services, Inc., for analysis.

Benthic Macroinvertebrates

Benthic macroinvertebrates were collected in an identical manner at both sites. Three sub-samples were collected at each site using a Wildco kick seine with a 500 µm mesh size. An area of approximately one square meter of stream bottom was disturbed on the upstream side of the seine in a riffle area with the current carrying the invertebrates into the net and holding them there. The seine was positioned at an approximately 45° angle. Once the sub-sample was collected the net was carefully removed from the stream in such a way as to not lose any organisms. Three replicate sub-samples were collected at separate riffles along the same stretch of stream.

The larger organisms were removed from the net using forceps and placed into labeled jars containing 70 percent isopropanol. Once the larger organisms were removed, the remaining organisms, along with any debris and sediment on the net, were carefully scraped using a metal ruler into a wide-mouth Mason jar, which was then filled with 70 percent isopropanol. The collected organisms were then taken back to the laboratory for identification and quantity. Figures 2 and 2a were photographs taken during the sampling event.

Figure 2. Examining for Benthics on a sampling screen on Connor Run.

Figure 2a. Collecting Benthics in the Sampling Screen on Joe Run.

Results:

Stream Chemistry

The stream chemistry for Joe and Connor Run differed greatly. The water samples collected from Joe Run (the unimpacted watershed) had a pH of 6.6 with an acidity of 1 mg/L while having an alkalinity of 11 mg/L. Iron, aluminum, manganese, and magnesium concentrations were <0.05 mg/L, <0.05 mg/L, <0.01 mg/L and 2.45 mg/L, respectively. These metals values are indicative of an un-impacted stream and are typical for Clean Streams in West Virginia.

Connor Run was very different. The sample collected had a pH of 3.4, an acidity of 121 mg/L, and an alkalinity of 0 mg/L. Metal concentrations in the sample had measured 3.75 mg/L for iron, 11.6 mg/L for aluminum, and 4.9 mg/L for manganese. Based on the sample collected from Connor Run, the stream is still being impacted by acid mine drainage. Table 1 is a chart showing water chemistry values for Joe and Connor Run.

As part of the study, data was taken from the US Forest Service report and compared to the present day sampling event to determine what, if any improvements had been made over the last 20 to 25 years. Even though there were approximately 21 samples taken during the 1978-79 study, we used the data that had calculated lab acidity. This was done so that actual acidities could be compared and not estimated acidities which use pH, iron, aluminum, and manganese concentrations. Table 2 is a comparison of the selected samples from the 1978-79 study with the 2003 sampling event.

The data compiled from Connor Run in 1978-79 has an average pH of 2.96, an average estimated acidity of 321 mg/L, and 0 mg/L of alkalinity. Metal concentrations had an average value of 25 mg/L for iron, 31 mg/L of aluminum, 14 mg/L of manganese, as well as 30 mg/L of magnesium. Data from last years sampling event shows a pH increase to 3.4. The acidity decreased from 321 mg/L to 103 mg/L. There was still no alkaline generation in the stream. Metals in the sample also showed a significant decrease in concentration. Iron went from

25 mg/L in 78-79 to 3.75 mg/L, aluminum from 31 mg/L down to 11.6 mg/L, manganese from 14 mg/L to 14.9 mg/L and magnesium from 30 mg/L down to 16.5 mg/L.

Table 1. Water Chemistry for Connor and Joe Run

Sampling Station		Connor Run	Joe Run
date		5/23/2003	5/23/2003
Flow	gpm	305	536.7
pH		3.4	6.6
acidity	mg/L CaCO3	121	1
est. acidity	mg/L CaCO3	103	0
alkalinity	mg/L CaCO3	0	11
acid-alk	mg/L CaCO3	103	-11
acid load	tons/year	69	-12
TDS	mg/L	313	51
TSS	mg/L	2	2
Mg	mg/L	16.5	2.45
Fe	mg/L	3.75	0.05
Al	mg/L	11.6	0.05
Mn	mg/L	4.9	0.01
SO4	mg/L	197	16

In a 25 Year period, the acidity has decreased by 68%, iron, aluminum, manganese, and magnesium have seen decreases of 85%, 62.5%, 65%, and 52.8%, respectively. The pH has seen a dramatic improvement going from 2.96 in 78-79 to 3.4 in 2003. Acid load in Connor Run in 1978-79 had an average of 45.36 tons of acid per year. In the 2003 sampling, the acid load was approximately 69 tons per year. This higher acid load can be attributed to the higher flow. If you took the flow from the 1978-79 data and compared it with the 2003 sampling the acid load is only 18 tons per year, which would be a decrease of 60%.

Table 2. Water Quality For Site 9212 Preston County, West Virginia

Sampling Station		**9212**	**9212**	**9212**	**9212**	**9212**	**9212**	**9212**	**9212**	**9212**
date		10/18/1978	12/1/1978	2/14/1979	3/9/1979	5/31/1979	7/9/1979	10/24/1979	average	5/23/2003
Flow	gpm	40.39	134.63	44.88	67.3	67.3	22.44	180	79.56	305
pH		3	3	2.9	3	2.9	2.8	3.1	2.96	3.4
acidity	mg/L CaCO3	240	150	360	270	210	470	200	271.43	121
est. acidity	mg/L CaCO3	257	155	406	306	255	631	238	321.22	103
alkalinity	mg/L CaCO3	0	0	0	0	0	0	0	0.00	0
acid-alk	mg/L CaCO3	257	155	406	306	255	631	238	321.22	103
acid load	tons/year	23	46	40	45	38	31	94	45.36	69
TDS	mg/L	670	374	811	693	593	1420	639	742.86	313
TSS	mg/L	66	23	59	40	20	76	27	44.43	2
Mg	mg/L	28	18	37	27	27	43	30	30.00	16.5
Fe	mg/L	22	12	39	23	17	43	21	25.29	3.75
Al	mg/L	23	11	38	31	23	68	22	30.86	11.6
Mn	mg/L	11	6.5	15	12	10	32	11	13.93	4.9
SO4	mg/L	500	260	570	520	450	1100	460	551.43	197

Benthic Macroinvertebrates

Overall, the substrate in Joe Run tended to be better for collecting benthic macroinvertebrates. Riffle areas dominated by cobble size rocks are considered to be optimal habitat for collecting the widest diversity of benthic macroinvertebrates. Because of the higher gradient, Joe Run had more riffle areas than the area of Connor Run sampled. However, three near-optimal riffles were located along a roughly 100-meter section of Connor Run.

Connor Run, did however, contain noticeable iron sediments as part of the stream substrate. In some riffles, the iron sediment tended to fill some of the interstitial voids between rocks that form habitat for benthic macroinvertebrates. Also, during sampling on Connor Run, as the iron sediments were disturbed and carried into the net, they tended to clog the net. This caused the current to flow into and out of the net in something of an S-current, rather than to flow through the net as desired. This means that it is possible that some organisms were carried into and out of the net without being deposited and held on the net surface and that the total number of organisms recovered may represent less than the actual overall density of organisms. It is not expected however that this would have a significant effect, if any, on the number of taxa recovered.

Since there were no iron sediments evident in Joe Run, this type of clogging was not an issue. There tended to be more woody and leafy debris retained on the net in the Joe Run samples than in the Connor Run samples.

Benthic samples were processed by sorting the organisms from the debris and sediments. The larger organisms, which were removed by forceps and placed in small jars, were relatively easy to separate from the debris. The remaining material that was scraped from the net was sorted by taking a small amount of the material, about one teaspoon, and placing it in a shallow tray. The material was spread out in a thin layer and any visible organisms were separated and placed in a jar of alcohol. The tray was then scanned with a microscope until all smaller organisms were recovered. The remaining “scrapings” were similarly processed, one teaspoon at a time, until all organisms were recovered. Once all organisms were separated from the debris and sediment they were composited into one large collection for each sample site.

The quantification of the biological condition was conducted using the Stream Condition Index (SCI) methodology as developed for the West Virginia Division (now Department) of Environmental Protection by Tetra Tech, Inc. The methodology is described in “A Stream Condition Index for West Virginia Wadeable Streams” published in March 2000, and revised on July 21, 2000 by Tetra Tech.

The SCI is similar to other protocols such as Rapid Bioassessment Protocols (RBPs) or Invertebrate Condition Indexes (IBIs). These protocols use a series of biological measurements, called metrics, which have been determined to be reflective of the structure and function of benthic macroinvertebrate assemblages in rocky-bottomed streams. The metrics have been shown to generally change in predictable ways in response to human influence. The metrics compare conditions found in sampled streams to those found in non-impaired streams called reference streams.

The West Virginia SCI uses six core metrics. Identification of organisms for calculation of the SCI is primarily at the family taxonomic level. The core metrics used for the SCI are:

- EPT taxa — EPT taxa are three taxonomic orders of insects that are generally considered to be sensitive to pollution. Although some are actually relatively pollution-tolerant, because most are sensitive the number of EPT taxa is expected to be higher in non-impaired streams. EPT stands for Ephemeroptera (mayflies), Plecoptera (stoneflies), and Tricoptera (caddisflies).
- Total taxa — unpolluted streams are expected to have a greater diversity of organisms. The total number of taxa is expected to be higher in non-impaired streams.
- % EPT — the percentage of EPT organisms compared to the total number of organisms is expected to be higher in non-impaired streams.
- % Chironomidae — the percentage of Chironomidae (midge larvae) is expected to increase as human impacts increase.
- % Top 2 Dominant Taxa — the percentage of organisms represented by the two most numerous taxa is expected to increase as human impacts increase. That is, unhealthy streams are more likely to be dominated numerically by just one or two taxa of organisms.
- Hilsenhoff Biotic Index (HBI) — the HBI calculates a weighted average that represents the pollution sensitivity or tolerance for all of the organisms in a sample. A pollution sensitivity value on a 1 to 10 scale is assigned at the family level for each taxon. Lower numbers are considered to be more pollution-sensitive. The number of organisms within a given taxon is multiplied by the pollution-sensitivity value assigned to that taxon. Similar products are determined for each taxon. These are summed and divided by the total number of organisms to calculate an average pollution sensitivity number or HBI per organism. The HBI is expected to be higher in streams with higher human impacts.

The SCI uses standard or “best values” based on characteristics found in West Virginia references streams. Best values are based on either 5th or 95th percentile values, depending on the metric, calculated for 1268 benthic samples collected in West Virginia references streams form 1996 to 1998.

For this study, all organisms recovered were identified to get a total list of organisms recovered and their relative numbers. After all organisms were identified, the two composited sample sets were randomly sub-sampled to get a 200-organism sub-sample for each as required by the SCI protocol. The calculations for each metric were then conducted on the 200-organism sub-samples.

The total number of taxa and the number of organisms within each taxon for Joe Run are listed below. EPT taxa are marked with appropriate initials.

Total Taxa and Number of Individuals Organisms Recovered from Joe Run:

Capniidae	362	(P)
Baetidae	303	(E)
Amelitidae	247	(E)
Ephemerellidae	148	(E)
Nemouridae	92	(P)
Heptageniidae	89	(E)
Leptophlebiidae	84	(E)
Perlodidae	77	(P)
Glossosomatidae	47	(T)
Elmidae	44	
Tipulidae	26	
Gammaridae	24	
Cambaridae	21	
Chironomidae (non-red)	15	
Hydropsychidae	13	(T)
Ephemeridae	11	(E)
Chloroperlidae	8	(P)
Oligochaeta	7	
Limnephilidae	6	(T)
Perlidae	6	(P)
Psephenidae	3	
Lepidostomatidae	3	(T)
Rhyacophilidae	3	(T)
Sialidae	2	
Peltoperlidae	2	(P)
Hydrophilidae	2	
Philopotamidae	1	(T)
Simuliidae	1	
Chauliodinae	1	
Ceratopogonidae	1	
Asellidae	1	
Total	**1650**	

The total number of taxa and number of individuals recovered from Connor Run are shown below, with EPT taxa marked with appropriate initials.

Total Taxa and Number of Individual Organisms Recovered from Connor Run:

Chironomidae (red)	433	
Sialidae	25	
Capniidae	16	(P)
Dytiscidae	14	
Ceratopogonidae	2	
Perlodidae	1	(P)
Culicidae	1	
Total	**492**	

Sub-samples and Calculation of Metrics

The two sets of samples yielded the following random 200-organism sub-samples.

Joe Run:

Capniidae	50	(P)
Baetidae	32	(E)
Amelitidae	25	(E)
Ephemeridae	21	(E)
Nemouridae	15	(P)
Heptageniidae	10	(E)
Leptophlebiidae	9	(E)
Perlodidae	12	(P)
Glossosomatidae	4	(T)
Elmidae	3	
Tipulidae	6	
Gammaridae	3	
Cambaridae	4	
Hydropsychidae	2	(T)
Oligochaeta	1	
Perlidae	1	(P)
Psephenidae	1	
Sialidae	1	
Total	**200**	

Connor Run:

Chironomidae (red)	178	
Sialidae	9	
Capniidae	7	(P)
Dytiscidae	5	
Ceratopogonidae	1	
Total	**200**	

EPT taxa calculations — The standard or best value for EPT taxa is 13. That is, West Virginia reference streams would be expected to have 13 EPT taxa (family level) at the 95th percentile level and this number would decrease with stress. The metric score is 100 (X/13), where X is the metric value determined from the 200-organism sub-sample.

Eighteen EPT taxa where recovered from Joe Run. Once sub-sampled to 200 organisms, 11 EPT taxa remained. 100 (11/13) = 84.6.

Only two EPT taxa were recovered from Connor Run. Once sub-sampled, only one EPT taxon remained. 100 (1/13) = 7.7

Total taxa calculations — The standard or best value for total taxa is 21. West Virginia reference streams would be expected to have 21 total family level taxa at the 95th percentile level and this number would decrease with stress. The metric score is 100(X/21), where X is the metric value determined from the 200-organism sub-sample.

Thirty-one total taxa were initially recovered from Joe Run. Upon sub-sampling this number was reduced to 18 taxa. 100 (18/21) = 85.7

Seven taxa were originally recovered from Connor Run. Upon sub-sampling this number was reduced to five taxa. 100 (5/21) = 23.8.

Percent EPT calculations — The best value for percent EPT is 91.9 percent. West Virginia reference streams would be expected to have 91.9 percent EPT taxa at the 95th percentile level and this percentage would decrease with stress. The metric score is
100 (X/91.9), where X is the metric value determined in the sub-sample.

For Joe Run, 181 of the 200 organisms, or 90.5 percent, were EPT taxa. 100 (90.5/91.9) = 98.5.

For Connor Run, seven of the 200 organisms or 3.5 percent were EPT taxa. 100(3.5/91.9) = 3.8.

Percent Chironomidae calculations — The best value for percent Chironomidae is 0.98 percent. West Virginia reference streams would be expected to have 0.98 percent Chironomidae at the 5th percentile level and this percentage would be expected to increase with stress. The metric score is 100 [(100 - X) / (100 - 0.98)], where X is the metric value determined for the sub-sample.

For Joe Run, while there were 15 Chironomidae in the complete sample, there were none in the 200 organisms sub-sample. 100(100/99.02) = 100. Note that a score for any individual metric cannot exceed 100, even if the value for the sample exceeds the best value for a metric.

For Connor Run, 89 percent of the organisms in the sub-sample were Chironomidae.
100 [(100-89) / (100-0.98) =
100 (11/99.02) = 11.1

Percent Top 2 Dominant Taxa calculations — The best value for this metric is 36.9 percent. At the 5th percentile, West Virginia reference streams would be expected to have the two most numerous family level taxa make up 36.0 percent of the sample and this percentage would be expected to increase with stress. The metric score is
100 [(100 - X) / (100 - 36.0)], where X is the value determined for the sub-sample.

For the Joe Run sub-sample, the top two dominant taxa were Capniidae with 50 individuals and Baetidae with 32 individuals. Together these two taxa comprised 41 percent of the sub-sample. 100 [(100 - 41) / (100 -36) =
100 (59/64) = 92.2.

For the Connor Run sub-sample, the top two dominant taxa were Chironomidae, with 178 individuals and Sialidae with 9 individuals. Together these two taxa comprised 93.5 percent of the sub-sample. 100 [(100 - 93.5) / (100 - 36)] =
100 (6.5/ 64) = 10.2.
Hilsenhoff Biotic Index calculations — The best value for this metric is 2.9. At the 5th percentile level, West Virginia reference streams would be expected to have an HBI value of 2.9 and this number would be expected to increase with stress. The metric score is 100 [(10-X) / (10 - 2.9)], where X is the value determined for the sample.

For Joe Run the HBI is calculated as shown below

Taxa	# of organisms	HBI Value	# of organisms x HBI value
Capniidae	50	1	50
Baetidae	32	4	128
Amelitidae	25	4	100
Ephemerellidae	21	1	21
Nemouridae	15	2	30
Heptageniidae	10	4	40
Leptophlebiidae	9	2	18
Perlodidae	12	2	24
Glossosomatidae	4	0	0
Elmidae	3	4	12
Tipulidae	6	3	18
Gammaridae	3	6	18
Cambaridae	4	6	24
Hydropsychidae	2	4	8
Oligochaeta	1	8	8
Perlidae	1	1	1
Psephenidae	1	4	4
Sialidae	1	4	4
Totals	200		508

508/200 = 2.5

100 [(10 - 2.5) / (10 - 2.9) =
100 (7.5/ 7.1) = 100 Note that even though the HBI calculation exceeded 100, the maximum score of 100 was used.

For Connor Run the HBI is calculated as shown below.

Taxa	# of organisms	HBI Value	# of organisms x HBI value
Chironomidae	178	8	1424
Sialidae	9	4	36
Capniidae	7	1	7

Dytiscidae	5	5	25
Ceratopogonidae	1	6	6
Totals	200		1498

1498/200 = 7.5

100 [(10 - 7.5) / (10 - 2.9)] =
100 (2.5/7.1) = 35.2

The final SCI score is an average of each of the six metrics. The overall SCI scores for Joe Run and Connor Run are averaged below.

Metric	Joe Run	Connor Run
EPT Taxa	84.6	7.7
Total Taxa	85.7	23.8
% EPT	98.5	3.8
% Chironomidae	100.0	11.1
% Top 2 Dominant Taxa	92.2	10.2
HBI	100.0	35.2
Totals	561.0/6	91.8/6
SCI Score	93.5	15.3

Conclusions:

Water Chemistry

Based on the water samples collected on Joe Run, there is no reason to believe that the stream chemistry has changed much over the last 25 years. This is due to the fact that there has never been any mining in the watershed and that its location does not allow easy access onto the stream. The samples revealed a pH of 6.6 with virtually no acidity and approximately 11 mg/L of alkalinity. As far as metals concentrations in the channel, there was no iron, aluminum, or manganese. However, there was 2.45 mg/L of magnesium which is typical of streams around the state.

From the sampling done on Connor Run, it is apparent that the data collected in 2003 represents a significant change in the water chemistry since the initial sampling 25 years ago. The 2003 sample displayed a significant increase in pH from 2.96 to 3.4, while having a decrease in acidity from 321 mg/L during the last study to 103 mg/L for the 2003 sampling event. Figures 3 and 3a are graphical representations of the pH and acidity on Connor Run for the 1978-79 sampling event compared to the 2003 sampling event. These graphs were generated by taking the seven sampling events from the USFS study and comparing them to the single sampling event in 2003.

Figure 3. Acidity Values for 1978-79 data v/s 2003 sampling event

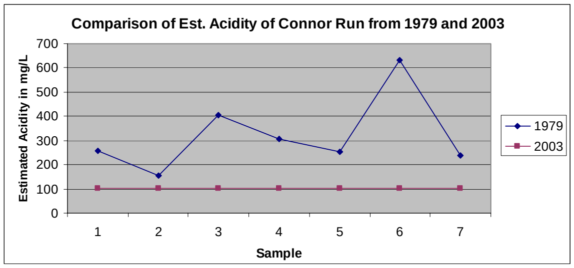
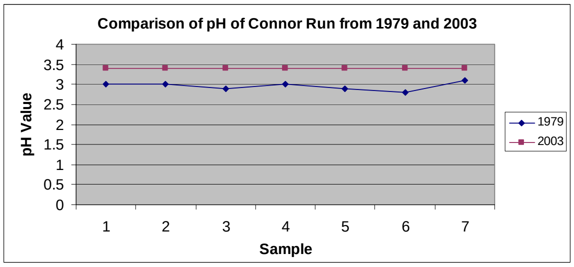
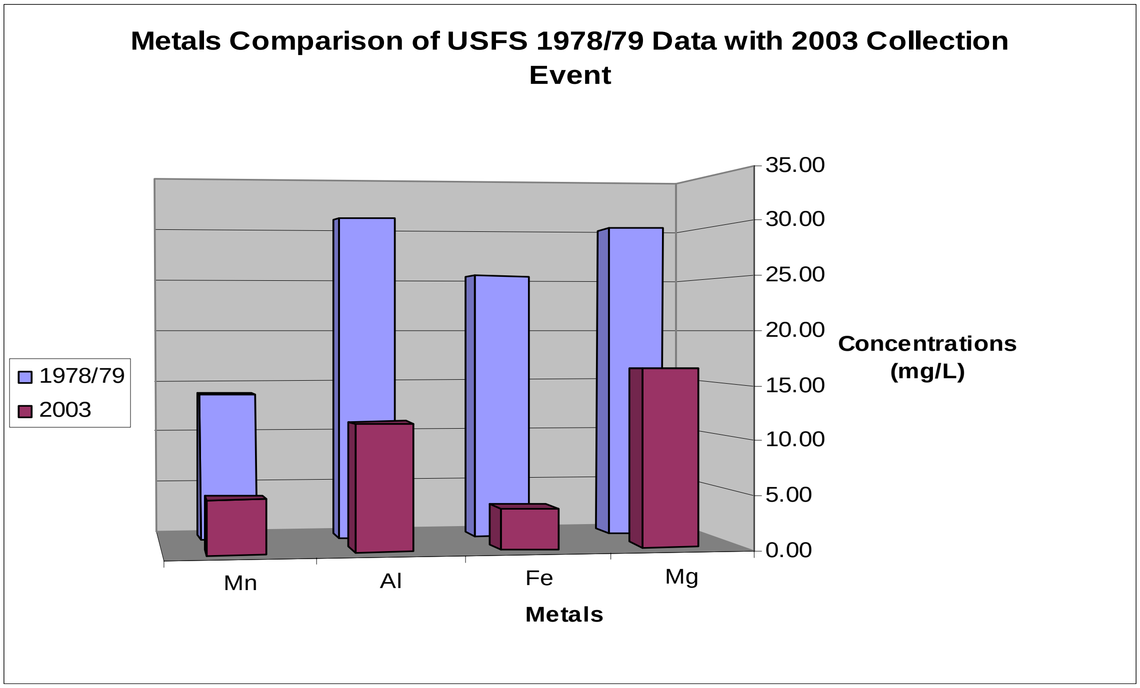


Figure 3a. pH values for 1978-79 data v/s 2003 sampling event



Metals concentrations on Connor Run have been reduced an average of 62.3%. Of the metals sampled, iron had the greatest reduction at 85% and magnesium had the least at 52.8%. Figure 4 is a graphical representation of the metals data respective to their change over time. This graph was made by using the average of the seven sampling events done in 1978-79 and compared against the one sampling event taken in 2003. The red indicates the 2003 sampling event while the blue represents sampling done in 1978-79.

Figure 4. Comparison of metals sampled from 1978-79 data with 2003 sampling event



Based on this data, amelioration of an acid impacted stream does occur over time. The extent to which reduction occurs will be dependent on the original AMD chemistry as well as the depositional environment in which the degradation occurs.

Benthic Macroinvertebrates

The final SCI scores of 93.5 for Joe Run and 15.3 for Connor Run demonstrate a wide difference in the stream quality of the two streams as reflected in their respective benthic macroinvertebrate assemblages. The higher the SCI, the more similar stream conditions are to those found in West Virginia reference streams. At 93.5, Joe Run shows good similarity to West Virginia reference stream conditions. At 15.3, Connor Run shows little similarity to West Virginia reference stream conditions or to Joe Run. The scores indicate that any natural amelioration that may have taken place was, from a perspective of benthic macroinvertebrate life, minimal. To get a better idea of over what time span natural recovery of benthic life occurs it would be necessary to compare a stream such as Connor Run to itself over time as well as to a reference quality stream. Unfortunately, no historical record of benthic macroinvertebrate life is documented for upper Connor Run so it is not possible to tell if the benthic life currently found in the stream represents a slight improvement over earlier post-mining conditions.

Publications: - None.

Information Transfer Activities:

This paper will be given in a talk for the Twentieth Annual Scientific Symposium of the Ohio River Basin Consortium for Research and Education (ORBCRE) in Athens, Ohio on August 18, 2004.

Student Worker Summary:

1. Undergraduate

NIWR USGS Student Interns: None

Notable Achievements and Awards: None yet

Information Transfer Program

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

PRESENTATIONS Eya, J. C. and A. Parsons. 2004. The Impact of Feeding Strategy, Dietary Phosphorus and Varying Protein/Fat Contents on Juvenile Rainbow Trout Performance and Waste Output. West Virginia State University 10th Annual Research Symposium, April 30, 2004, Institute, WV. (oral presentation).

Eya, J.C., A. Parson, P. Jagidi and I. Haile. 2004. Comparison of the effects of various sources of zeolites on growth, body composition and waste output in trout rearing systems. To be presented at Aquaculture America, January 17-20, 2005, New Orleans, LA. (poster).

INFORMATION TRANSFER ACTIVITIES: Information transfer activities have not commenced. Results are being compiled and the results will be made available to different stakeholders via diverse printed media, and possibly through television or video.

Student Support

Student Support					
Category	**Section 104 Base Grant**	**Section 104 RCGP Award**	**NIWR-USGS Internship**	**Supplemental Awards**	**Total**
Undergraduate	13,310	0	0	15,509	0
Masters	28,482	0	0	26,647	0
Ph.D.	23,160	0	0	23,160	0
Post-Doc.	0	0	0	0	0
Total	0	0	0	0	0

Notable Awards and Achievements

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

Publications from Prior Projects