West Virginia Water Resources Research Institute Annual Technical Report FY 2004

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 Chamber of Commerce - West Virginia Coal Industry - West Virginia Division of Environmental Protection - West Virginia Farm Bureau - 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 - 2004.

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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 over 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

In January, 2005, these representatives formed the West Virginia Water Gaging Council to serve as a statewide collaborative body enhancing effective collection and dissemination of environmental data applicable to the full range of West Virginias water resources. These water resources include ground- and surface-water and precipitation gaging. Collaboration began in 2003 when funding cuts threatened the operation of 18 gages, and users throughout the state expressed concern. The organization provides a forum for communication, cooperation, and collaboration among its membership. The mission of the Council is to ensure that reliable water resources gaging data are available to meet the needs of the States varied stakeholders. The organization accepts private donations to assist funding these objectives. Council members meet at least twice a year and the public is invited to attend. Members of the Council include the U.S. Geological Survey, U.S. Army Corps of Engineers, National Oceanic and Atmospheric Administration, WV Department of Environmental Protection, WV Water Research Institute, WV Division of Natural Resources, WV Conservation Agency, WV Office of Emergency Services, WV Department of Transportation, WV Rivers Coalition, Michael Baker Corporation, and Canaan Valley Institute. The WV Water Research Institute was instrumental in developing a memorandum of understanding for the Council and setting up an account to accept private donations through the West Virginia University Foundation. In addition to be a member of the Council, WVWRI manages the activities of the Council and WVWRI staff serve as secretary/treasurer. The WVWRI is assisting other water resources research institute directors to develop similar water gaging councils within their own states.

Future Direction

The following programs of the WVWRI are expected to continue to remain stable and grown modestly into the future:

- National Mine Land Reclamation Center - Combustion Byproducts Recycling Consortium - Hydrology Research Center - Geo-Engineering Center - WV Water Gaging Council

Outreach

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

West Virginia Water Conference 2004

A water conference focusing on water issues... science and solutions was held October 2004 in which the WVWRI was the lead sponsor. This conference was supported in part by USGS 104b funds. The conference was a 2 day event with presentations and panel sessions held at the Stonewall Resort and Conference Center in Roanoke, West Virginia. Approximately 150 attended.

West Virginia Water Conference 2005

A conference is planned for October, 2005 in which the WVWRI is co-sponsoring a watershed restoration conference with Canaan Valley Institute. This conference is to be 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 new brochure on the WVWRI was developed in 2003 and distributed at the 2004 Water conference in Roanoke, WV. 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/programs/cbrc.

Publications

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

A portion of the administrative budget was used to assist the Indian Creek Watershed in Monroe County to: 1) conduct a spring study of the Peters Mountain area and 2) develop a plan using existing state law whereby the county can protect their water resources. The following is a summary of the work on these two tasks to date.

Title: Hydrogeology and Geochemistry of the Peters Mountain aquifer, Monroe County, WV

Start date: March 1, 2004

End date: February 28, 2005

Descriptors/keywords: hydrogeology, geochemistry, groundwater flow systems

Primary P.I.: Dr. Joe Donovan, Dept. of Geology/Geography, West Virginia University

Other co-investigators : Geoff Richards (M.S. candidate), Dept. of Geology and Geography, West Virginia University

Dr. Dorothy Vesper, Dept. of Geology and Geography, West Virginia University

Outline This investigation is examining groundwater availability and chemistry in a rural, non-developed region of West Virginia where concern has been expressed regarding adequacy of groundwater supply and its susceptibility to contamination. In this screening investigation, groundwater resources and its style of occurrence are being inventoried over a representative portion of the Peters Mountain valley, which lies along the VA-WV border. The locations of groundwater discharge are being identified within the Second Creek and Indian Creek, WV, watersheds. Chemical analysis of these discharges are being used to examine differences in chemistry between high-elevation springs discharging from shallow depth and low-elevation springs discharging from deeper conduit aquifers. The temperature, specific conductance, pH, alkalinity, and major cation/anion concentrations of water are used to identify potential preferential flow pathways within the regional aquifer. Results will be applied to long-term planning for development and protection of these water resources.

This research is the basis of the Master's thesis of Geoff Richards in the geology program at WVU. He began his research in summer 2004 and is polishing up fieldwork and assembling/interpreting results in summer 2005. Completion of the thesis is expected in December 2005. His advisor is Dr. Joe Donovan. Committee members are Dorothy Vesper and Eberhard Werner. Given the status of the research, results and conclusions are still preliminary at this time.

Objectives The projects objectives are:

·to locate, map, and quantify discharge of all springs,

·to compile geologic mapping, structural features, and hydrologic information (spring and stream locations) onto a GIS platform,

·to sample water from springs and available wells, for analysis of Specific Conductance (Sc), pH, alkalinity, temperature, molar ratios of Ca/Mg, major cations,

·to calculate equilibria for water chemistry, partial pressure of carbon dioxide, and the saturation indices for calcite and dolomite (PCO2, SIcal, SIdol) using MINTEQ,

·to execute a seepage run of Kitchen Creek, sampling water and measuring flow at 80 locations over the 3-mile extent,

·to apply statistical analyses to test for relationships between spring occurrence and stratigraphy or elevation, and

·to apply statistical analyses to test for relationships between spring elevation and water chemistry (pH, Qest, SIcal, SIdol, PCO2, molar rations of Ca/Mg, Sc).

Methods

§ Groundwater discharges on Peters Mountain are being identified on foot in a series of cross-strike transects. The flow rate is being crudely estimated, due to the remote nature of each site and difficulty in carrying in measurement equipment. The location of each site is being identified using a WAAS-enabled handheld GPS unit which is capable of being downloaded.

§ Baseline geochemical parameters are being measured in the field, including specific conductance (SC), pH, alkalinity and, temperature. They will then be used in conjunction with GIS to create maps showing the distribution of these attributes.

§ Water samples will be analyzed for major cations/anions at the lab using inductively coupled plasma (ICP). This process is a rapid spectroscopic multi-element analysis. The results will be entered into the program MINTEQ where equilibria partial pressure of carbon dioxide and the saturation indices of calcite and dolomite will be calculated.

§ A seepage run will be preformed along the mainstream section of Kitchen Creek. Measurement of flows will be taken at 200-foot intervals using a pygmy or swoffer flow meter. Baseline geochemical data will also be recorded at each measuring station.

Results

§ Springs are being classified according to stratigraphic occurrence. Three spring groups have been discriminated; 1) clastic springs, 2) springs discharging from the Martinsburg shale (Ordovician), and 3) carbonate springs. The statistical characteristics within and between each group will be tested using graphical plots (box and whisker) plots, frequency, correlation, and regression analysis.

§ Residence time and flow pathway will be determined by proxy using statistical analysis of the laboratory and MINTEQ results. The proposed statistics methods include box and whisker, regression, Piper diagram, and principal component analysis.

Conclusions This research is producing a classification of springs on Peters Mountain into three different categories according to their hydrochemical signatures. Local high level springs discharging from shallow aquifers are differentiated from regional low-level springs discharging from deeper conduit aquifers through comparative statistical analysis. Using the spatial geochemical variability of these springs as a proxy to flow-path and residence time underscores the strong influence structure and stratigraphy has on a carbonate aquifer. This provides the underpinning for a conceptual model of the hydrogeologic regime of this montane headwater area.

Publications, conference proceedings, other reports: none to date

Information Transfer Program

The investigators have made contact with and presentations to 3 citizen's groups in Monroe County, WV: the Second Creek Watershed Association, Indian Creek Watershed Association, and Monroe County Commission. They have also made state agencies (WV Department of Environmental Protection; WV Bureau for Public Health; WV Rural Water) aware of the progress of the work

Student Support

one M.S. student sponsored by project; grant covers 2 summers of support plus travel expenses and chemical analyses costs for Geoff Richards

Matching/supplemental awards: none to date

Notable achievements and awards: Richards has received the Charles Coffindaffer Memorial Fund award as a grad student working on a meritorious field project within West Virginia.

Joyce McConnell with the WVU Law School has been assisting the Indian Creek Watershed in understanding WV State Law as it pertains to water rights. As a result, the County Commission is in the process of setting up a committee to study the need for a planning commission. It is anticipated that an official Planning Commission for the County will be implemented before the end of 2005. The members of the planning commission with input from the Indian Creek Watershed will develop a Comprehensive Land Use Plan in accordance with WV Law.

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:	3/1/2002
End Date:	12/31/2003
Funding Source:	104B
Congressional District:	1
Research Category:	Water Quality
Focus Category:	Water Quality, Treatment, None
Descriptors:	Impact Longwall Mining Headwater Streams in Northern West Virginia
Principal Investigators:	Ben Stout, Ben Stout

Publication

Do headwater streams recover from longwall mining impacts in northern West Virginia?

Final Report, August 30, 2004

Prepared for:
West Virginia Water Research Institute

by:
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Abstract

The purpose of this study was to measure the extent of longwall mining impacts on headwater streams in northern West Virginia and address the question: do streams recover? This report encompasses two years of field research and compliments the report of June 30, 2003 entitled: Impact of longwall mining on headwater streams in northern West Virginia (Stout, 2003). During the first-year study it was found that approximately one-half of all headwater streams were impacted, resulting in dry stream segments, narrow stream widths, chemical imbalances, and depauperate biological communities compared to unmined or room-and-pillar mined reference streams. During the second year of field work two unmined and three room-and-pillar mined reference streams were re-sampled, and one unmined stream was added to the study design. Three streams that had been longwall mined five to six years ago were also re-sampled to assess repeatability of results and to look for signs of possible recovery. Three streams that had been longwall mined nine, ten, and twelve years prior to fieldwork were added to the study to look for evidence of temporal recovery.

Physical, chemical, and biological measurements were collected at six to eight sites along the gradient of each stream beginning at the source and working at measured downstream intervals. General Linear Models Analysis of Variance was used to compare average longwall mined versus reference streams in their physical, chemical, and biological dimensions. The interaction term in two-way analysis of variance was used to determine if spatial recovery occurred along the course of longwall mined headwater stream gradients, after testing for the two main effects: reference versus longwall mined, and distance from the source. Regression analysis was used to assess temporal recovery based on changes that may occur over the time elapsed since mining, and to see if physical, chemical, and biological conditions got better, stayed the same, or got significantly worse a decade after mining occurred.

Significant physical differences in average longwall mined versus reference streams included 31% less stream width and 0.8^{o}C lower temperature. Eighteen percent of sampling sites in longwall mined streams were dry. Stream width did not recover to reference conditions spatially along the headwater stream gradient. Stream width did not recover temporally when comparing recently mined streams to those that had been mind over one decade prior to sampling. Differences in stream temperature between longwall mined and reference streams did not change over the stream gradient, but did appear to recover somewhat over time.

Longwall mined streams averaged 100 *u*mhos higher conductivity, 11% lower dissolved oxygen, and 64 ppm greater alkalinity than reference streams. None of these conditions changed significantly over the course of the headwater stream gradient. Over time, conductivity and alkalinity in longwall mined streams remained elevated above reference conditions. Dissolved oxygen was lower in streams that had been longwall mined in the past compared to streams that had been longwall mined more recently. The chemistry of headwater streams did not recover to

reference conditions either spatially or temporally, and appeared to get worse over time in terms of dissolved oxygen concentrations.

Macroinvertebrate communities, the primary biological entities in headwater streams, were significantly degraded by longwall mining. For instance, macroinvertebrate abundance was 44% lower, diversity was 47% lower, and long-lived taxa were 51% fewer in longwall mined versus reference streams. No water was present at 18% of samples from longwall mined streams. An additional 17% of samples failed to support a minimum viable community of at least two individuals (minimum population) from each of two kinds of macroinvertebrates (minimum community) even though water was present at the time of sampling. Overall, our second year of field studies confirms the first year findings that longwall mined streams fail to support biological communities in approximately one-half of the headwater streams across the region.

Spatially, it was found that macroinvertebrate abundance was impacted more at the source than in the downstream reaches of longwall mined streams. On average most, but not all, longwall mined headwater streams had as many macroinvertebrates as reference streams once streams re-emerged in larger, 120 acre watersheds. No such recovery was evident temporally, and streams mined nearly a decade prior to sampling continued to exhibit the lower abundance characteristic of recently longwall mined streams. Diversity and longevity of the biological community failed to exhibit any evidence of recovery over space or time. Compared to reference streams, taxa richness remained consistently low along the longwall mined stream gradient and failed to recover in streams that had been mined over a decade prior to study. The EPT taxa, with life cycles requiring 9 to 22 months of residence as larvae in streams, failed to show signs of recovery over spatial or temporal gradients. The semivoltine taxa, which require 2 to 5 years of residence in atreams to complete the larval stage of their life cycles, also failed to recover spatially or temporally. Functionally, macroinvertebrate communities were similar regardless of longwall mining history. Leaf shredders and fine particle collectors dominated headwater stream communities, and algal grazers and predators were proportionally less abundant. The macroinvertebrate communities in longwall mined streams maintained their trophic balance even though they do not occur in one-half the headwater streams that they previously occupied across the longwall mining region of northern West Virginia.

Introduction

Longwall mining in the central Appalachian region fractures bedrock and results in loss of most springs and wells, and mining companies are generally required to replace household water supplies. Studies of wetlands (Schmid & Kunz, 2000) and large 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 (Meyer, et al, 2003). 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 for large rivers and for the surrounding forest. Headwater streams are 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). Forest litter sustains the energy and nutrient budgets of Appalachian headwater streams (Fisher & Likens, 1972; Likens, et al, 1970). Leaf shredding is the key industry in headwaters (Cummins, et al 1989), and the resulting downstream transport of energy and nutrients helps sustain larger river systems (Vannote, et al, 1980). The bulk of the energy assimilated by fine particle collectors in large rivers appears to originate in terrestrial ecosystems (Winterbourne, et al, 1984).

Stream-dwelling seal, spring, and northern two-lined salamanders are permanent residents and dominant vertebrate predators in West Virginia headwater streams, but many other amphibians also depend on headwater streams to provide suitable aquatic breeding sites in proximity to the forest (Green & Pauley, 1987). 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 (Smith & Smith, 1996).

The purpose of this research was to measure impacts of longwall mining on headwater streams in northern West Virginia, and to determine if streams recover from longwall mining either spatially or temporally. Three hypotheses were tested. First, if longwall mining impacts on streams were benign, then the physical, chemical, and biological characteristics of longwall mined streams would not be significantly different than reference streams because streams were not completely dewatered. Second, if streams were dewatered near their sources then they would recover in their downstream reaches because subsided stream reaches eventually return to the surface. Finally, if streams are impacted by subsidence during longwall mining then they will return to reference conditions over time because continued subsidence over a period of years following longwall mining causes stream beds to heal themselves.

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 available at West Virginia Geological Survey, permit records filed with State Department of Environmental Protection, and county tax maps. Within each mining region, longwall mined watersheds were compared with nearby reference watersheds that were geographically similar, but were either un-mined or room-and-pillar (bord and pillar) mined.

In the field, each stream was sampled by a four-person team on a single date. Each stream was sampled at the source (furthest upstream spring, or seep) and location recorded using Global Positioning Systems. The source 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 was continued at 100 meter downstream intervals for a total of six to eight samples per stream.

In the laboratory, macroinvertebrates from stream samples were sorted and identified to the lowest practical taxonomic level, generally genus. Prominent taxa were reared to determine species. 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). Functional group composition was calculated only for samples containing communities as defined by a minimum of two individuals in each of two taxa. 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, 6-8 samples collected at regular intervals along the longitudinal stream gradient were representative of the entire headwater reach of each stream.

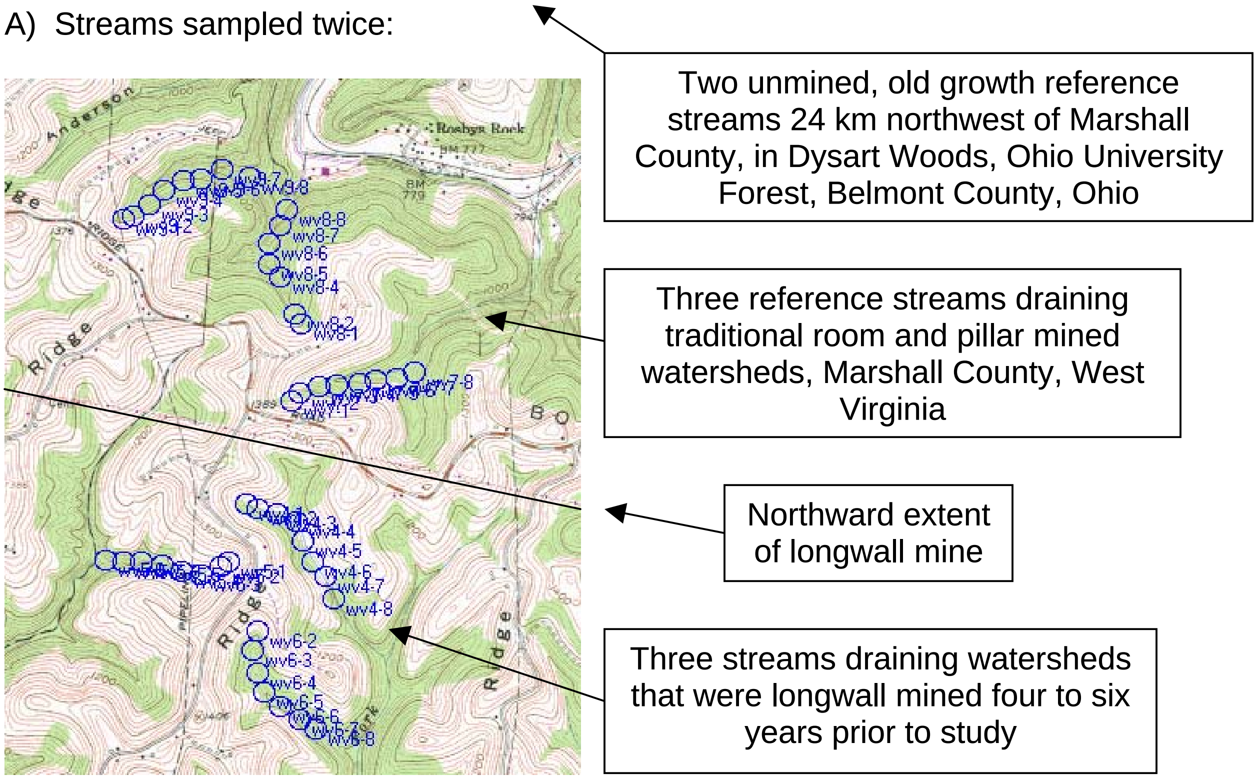
Samples site locations were randomly predetermined based on the source and prescribed downstream distance measurements. Average physical, chemical, and biological conditions of twelve longwall mined and eleven reference streams were compared using one-way General Linear Models Analysis of Variance followed by Dunnett's Test (NCSS, 2003). Two additional analyses were conducted to determine if streams recover from longwall mining either spatially or temporally. Spatially, the potential recovery of longwall mined versus reference streams along the downstream gradient was based on a significant interaction term ($p<0.05$) using two-way Analysis of Variance and testing for the main effects: distance from the source, and longwall mined versus reference stream. Temporally, regression analysis was performed to determine if significant changes occurred in longwall mined streams over time; an effect that would indicate whether streams recovered, stayed the same, or declined during the twelve-year period after mining.

<u>Study sites</u>

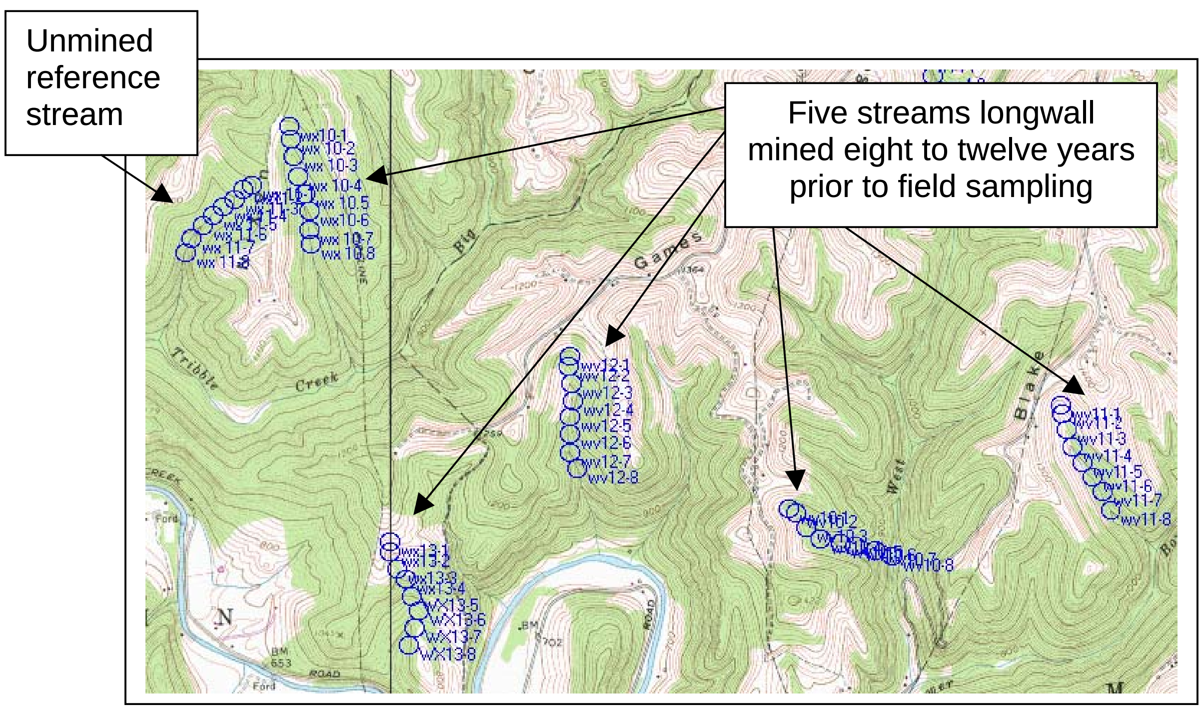
Fourteen different streams were sampled including 6 reference and 8 longwall mined streams (Map 1). Streams sampled once in June 2003 or June 2004 in Marshall County included 5 streams that had been longwall mined between eight and twelve years prior to study and one unmined reference stream.

Three longwall mined and five reference streams were sampled twice, once in June 2003 and again in June 2004. The three longwall mined streams sampled twice in Marshall County, West Virginia, had been longwall mined in 1997 and 1998. Three reference streams sampled twice in Marshall County were in a watershed adjacent to the longwall mined streams and had been room and pillar mined more than ten years prior to study. Two reference streams sampled twice in Dysart Woods, Belmont County, Ohio, drained an unmined, old-growth forest 26 km northwest of the Marshall County sites. Only six samples were collected from Dysart Woods streams.

A) Streams sampled twice:



B) Streams sampled once:



Powhatan Point Quad:Glen Easton Quadrangle

Map 1. Sampling locations in longwall mined and reference streams in Marshall County, West Virginia (1:24,000 United States Geological Survey data).

Results

<u>Average physical characteristics of headwater streams</u>

Reference and longwall mined watersheds had similar physical features with the exception of stream width and temperature (Table 1). Watershed drainage area above sampling points ranged from 1.1 to 137 acres and average watershed size was 43 acres. Streambed slope ranged from 30.5% near the top of basins to 3% in the downstream reaches. Average slope was 12 and 11% in reference and disturbed streams, respectively.

The width of streams draining longwall mined versus reference watersheds was significantly different. Longwall mined streams were on average 0.64 meters wide, whereas average reference streams were 0.93 meters wide. Water was present in all 79 samples from reference streams, whereas 16 of 88 samples (18%) from longwall mined streams were dry.

Instantaneous stream temperatures (at the time of sampling) were significantly different with averages of 16.1 and 16.9^{o}C in longwall mined and reference streams, respectively. Additionally, temperatures of 11.2 ^{o}C minimum to 21.4^{o}C maximum were more extreme in reference streams compared to a range of 13.7 to 20.8^{o}C in longwall mined streams.

Table 1. Mean (and 1 standard error) physical characteristics of streams and probability of no significant physical difference in samples from longwall mined (N=88) versus reference streams (N=79), and (ANOVA, Dunnett's Test ,*p<0.05).

Physical measurement	Reference streams Mean	(SE)	Longwall mined streams Mean	(SE)	Probability
Watershed area (acres)	41.5	(3.8)	43.8	(3.6)	0.646
Elevation (feet)	1091	(11)	1093	(10)	0.924
Stream slope (%)	12.1	(0.8)	10.9	(0.8)	0.277
Compass heading (degrees true N)	184	(9.3)	173	(8.8)	0.364
Median stream width (meters)	0.93	(0.06)	0.64	(0.05)	0.000*
Water temperature (^{o}C)	16.9	(0.2)	16.1	(0.3)	0.022*

<u>Physical characteristics along headwater stream gradients</u>

Streams originated as springs and seeps at elevations of 1140 to 1280 feet above mean sea level (Figure 1). Watershed drainage area ranged from 1.1 to 10.8 acres at the points where streams originated as springs or spring seeps. Average drainage area was 5.5 acres at the origin of reference streams and 6.0 acres at the origin of longwall mined streams.

Longwall mined streams were narrow compared to reference streams. On average, streams at their origin had median stream widths of 0.24 m in longwall mined streams and 0.47 m in reference streams. The width of average longwall mined streams did not achieve the width of average reference streams over the respective downstream gradients. Longwall mined streams were 1.1 m wide and reference streams 1.3 m wide in downstream reaches representing 100 acre watersheds. Lack of a significant interaction term (p=0.82) between the main effects indicated that longwall mined stream width did not recover to reference stream width over the course of the headwater stream gradients studied.

Instantaneous stream temperature was collected over the course of each day, starting at the top and working toward the bottom of watersheds. Temperature generally increased with increasing watershed size in reference streams due in part to increasing air temperature during the day, and in part to increasing distance of surface waters from their groundwater sources. In longwall mined watersheds, stream temperature remained relatively constant from the top to the bottom of the watersheds. As noted in the field and further indicated by stream width data, many of the longwall mined streams subsided in the upper reaches and resurfaced at some point downstream. Subsurface flow in subsided sections likely contributed to 1-2^{o}C lower summer daytime stream temperatures in areas where longwall mined streams resurfaced downstream. Instantaneous water temperature in 60 to 120 acre longwall mined streams was consistently lower than in analogous reference streams. Lack of interaction between main effects (p=0.26) indicated that instantaneous temperature of longwall mined streams did not achieve reference conditions.

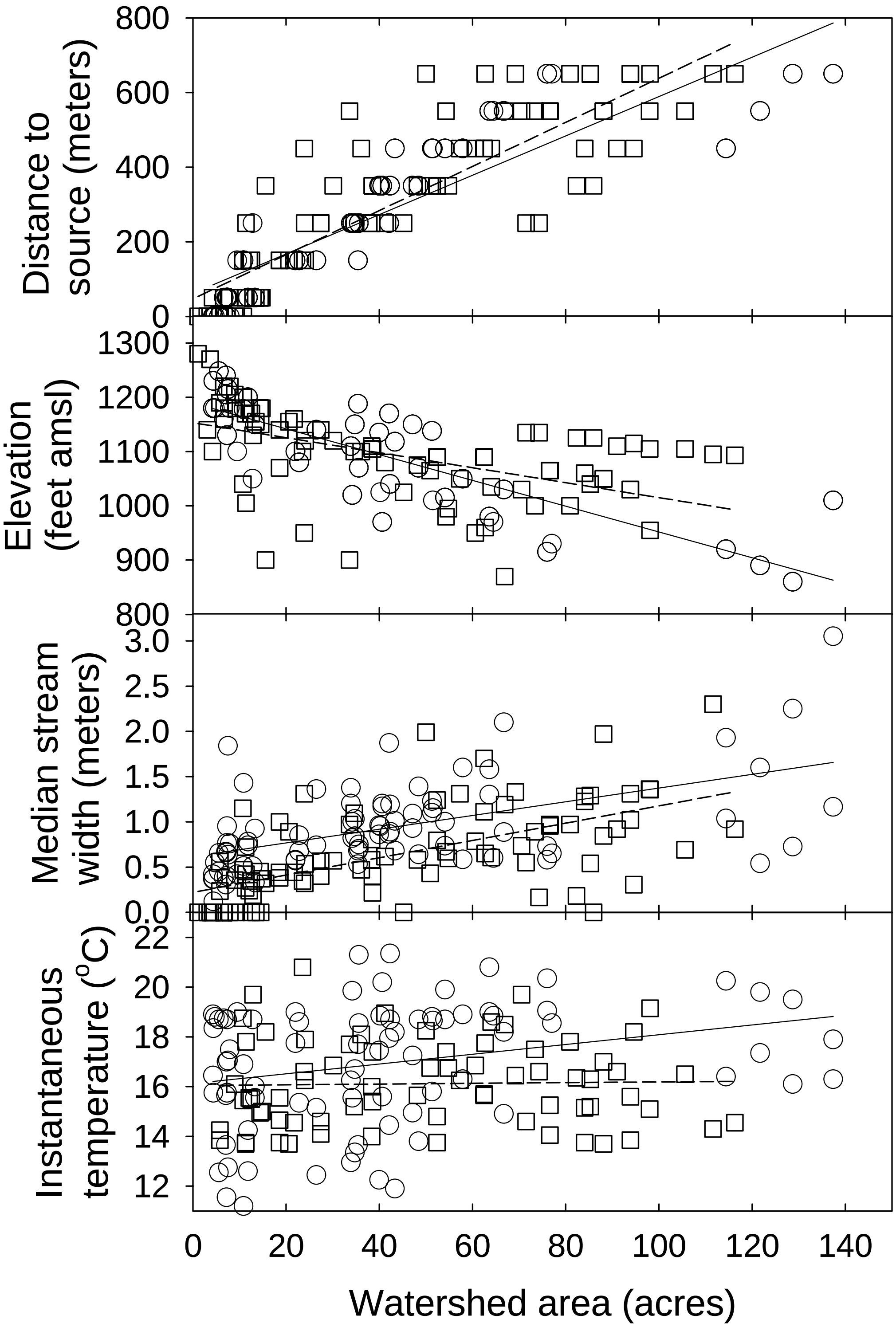


Figure 1. Scatterplot of physical attributes measured along headwater stream gradients comparing longwall mined (squares) and reference streams (circles). Least square means regression lines for samples from longwall mined (dashed, N=88) and reference (solid, N=79) streams (except temperature of longwall mined streams had only 72 samples due to dry stream beds at 16 of 88 sites).

Physical changes in longwall mined streams over time

The potential for temporal physical recovery of longwall mined streams was analyzed by comparing stream width and temperature because these attributes were significantly impacted by longwall mining. In this analysis, best fit regression lines were used to determine if time-induced trends existed among the longwall mined streams studied, and to determine if longwall mined streams had tendencies toward reference conditions over the decade after longwall mining occurred (Figure 2). Because average stream width was less in longwall mined versus reference streams, it was anticipated that if streams recover over time then stream width would be greater in streams that were mined nearly a decade prior to sampling than in streams that were longwall mined more recently.

A regression of stream width over the time elapsed since mining was not significantly different from zero ($p=0.48$), indicating no change in the width of longwall mined streams over time. Some longwall mined streams had widths similar to reference streams and others did not, but there was no trend in stream width with regard to elapsed time since mining. Regression analysis indicated that in longwall mined streams width does not change over time, and therefore physical recovery of longwall mined streams over time is not apparent. Some longwall mined steams are simply impacted more than others.

Stream temperature was lower when comparing average longwall mined versus reference streams (Table 1), and differences in stream temperature along the respective headwater stream gradients indicated that longwall mined streams did not achieve reference conditions (Figure 1). However, there did appear to be a trend to increasing temperature of longwall mined streams over time (Figure 2). Over 40% of the variation in summer daytime stream temperature could be explained by the time elapsed since mining occurred. Longwall mined streams appeared to achieve reference stream temperature approximately one decade after mining occurred. Although the width of longwall mined streams remains less than reference conditions, stream temperature patterns may reflect increased surface exposure following continued settling of the stream bed a decade post mining.

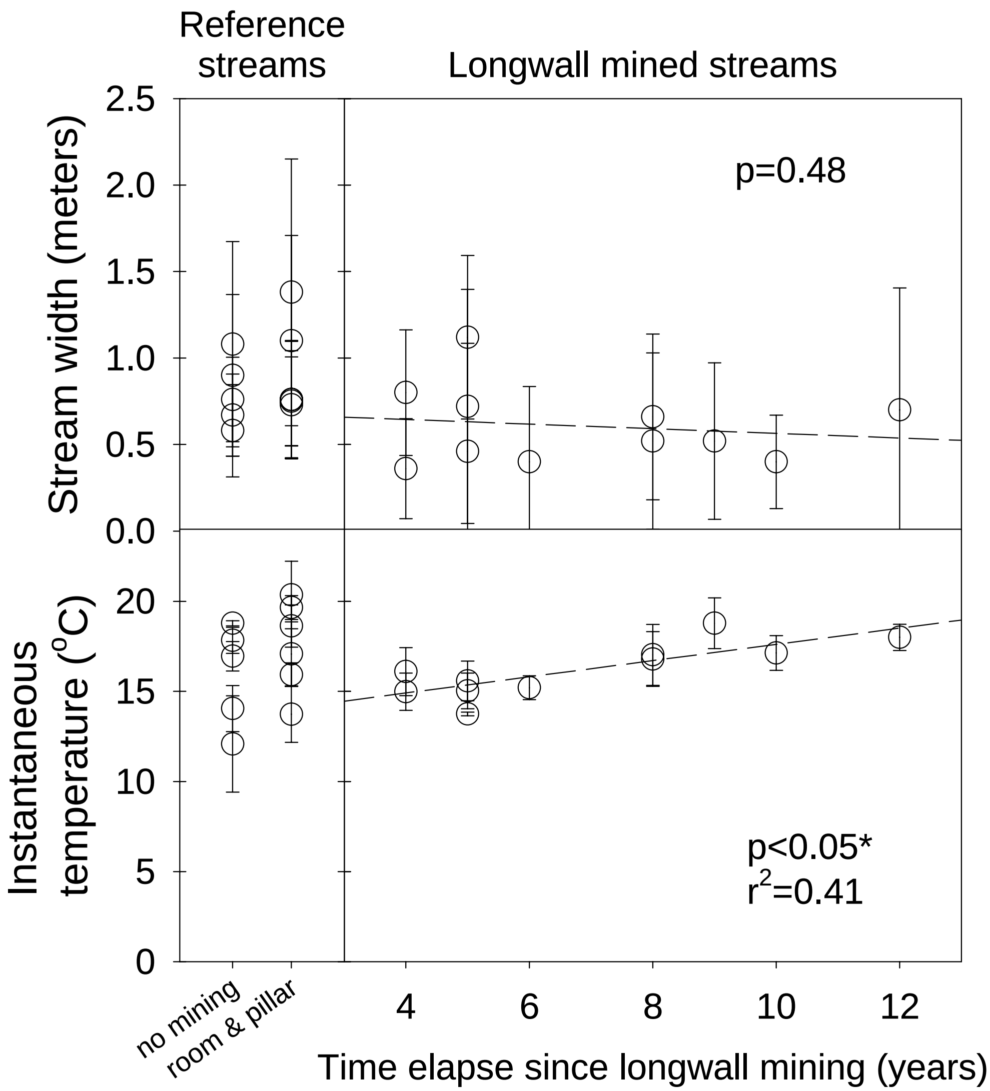


Figure 2. Comparison of mean (and 1 S.D.) physical measurements in reference and longwall mined streams. Trend lines indicate changes in longwall mined streams over time (* indicates trend significantly different than zero).

<u>Average chemical characteristics of study streams</u>

Longwall mined and reference streams were similar in terms of pH and hardness, but statistically different in conductivity, dissolved oxygen, and alkalinity (Table 2). Stream pH ranged from 5.8 to 8.2 in reference and 6.5 to 8.1 in longwall mined streams. Hardness ranged from 54 to 300 in reference streams, and 104 to 240 in disturbed streams. Average pH was 7.65 and average hardness was 177 ppm in all streams.

On average, conductivity was 100 *u*mhos greater in longwall mined streams and alkalinity was 61 ppm greater compared to reference streams. Conductivity ranged from 137 to 582 *u*mhos in reference streams, and 192 to 641 *u*mhos in disturbed streams. Dissolved oxygen saturation averaged 11.4% lower in longwall mined than in reference streams. Dissolved oxygen ranged from 12.9 to 109% saturation in reference streams, and 28.2 to 103.2% saturation in longwall mined streams.

Table 2. Mean (and 1 standard error) chemical characteristics of streams and probability of no significant chemical difference in samples from longwall mined (N=72) versus reference streams (N=79), and (ANOVA, Dunnett's Test ,*p<0.05).

	Reference streams		Longwall mined streams		
Chemical measure	Mean	(SE)	Mean	(SE)	Probability
Ph	7.65	0.04	7.65	0.04	0.955
Conductivity (*u*mhos)	344.8	9.8	444.9	10.2	0.000*
Dissolved oxygen (percent saturation)	86.1	1.9	77.1	2.0	0.010*
Alkalinity (ppm)	134	5	198	5	0.000*
Hardness (ppm)	182	5	172	5	0.150

Chemical characteristics along headwater stream gradients

The pH of headwater streams changed significantly along the stream gradient, but there were no longwall mining induced significant differences in pH along stream gradients (Figure 3). All streams showed a positive increase from pH 7.4 near the source to pH 8.0 in 120 acre watersheds. In contrast, conductivity did not change along stream gradients and longwall mined streams consistently had 100 *u*mhos greater conductivity than reference streams. Alkalinity patterns were similar to conductivity with 64 ppm greater alkalinity in longwall mined streams compared to reference streams along the headwater stream gradient.

Although dissolved oxygen appeared to increase along the stream gradient in both longwall mined and reference streams, any trend was not significantly different than zero (ANOVA, p=0.07) and interaction between the trend lines was not statistically significant (ANOVA, p=0.73). Lack of significant interaction between longwall mined and reference stream dissolved oxygen indicated that longwall mined streams did not achieve reference conditions within the scope of the study.

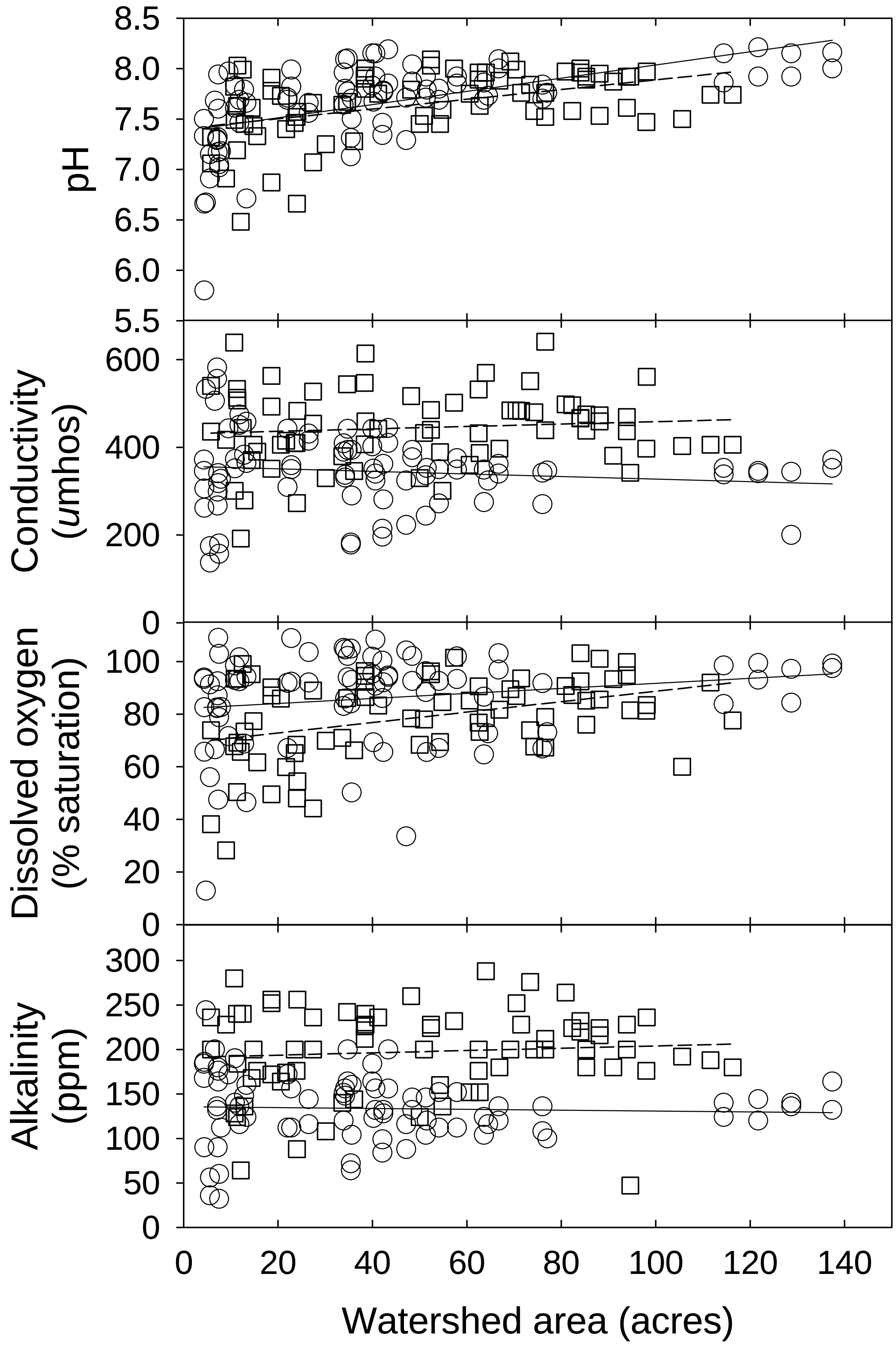


Figure 3. Scatterplots of chemical attributes measured along headwater stream gradients comparing longwall mined (squares) and reference streams (circles). Least square means regression lines for longwall mined (dashed, N=72) and reference (solid, N=79) streams.

Changes in chemical characteristics of longwall mined streams over time

The potential for chemical recovery of longwall mined streams over time was assessed by plotting chemical composition of streams versus time elapsed since mining occurred (Figure 4). Regression analysis was performed to determine if there were any trends in water chemistry in older longwall mined streams versus those that had been mined more recently.

The regression of conductivity over time elapsed since mining was not significantly different than zero, indicating that conductivity did not recover to reference conditions within the twelve years that elapsed since longwall mining occurred in study streams (ANOVA, $p=0.19$). Since longwall mined streams had an average of 100 *u*mhos greater conductivity than reference streams, it is unlikely that streams could achieve reference conditions over time.

Dissolved oxygen averaged 11% lower saturation in longwall mined streams (Table 2), and recovery to reference conditions was not apparent along the headwater stream gradient (Figure 3). Regression analysis of dissolved oxygen saturation over time elapsed since mining (Figure 4) indicated a downward trend that was significantly different than zero ($p=0.02$). Therefore, it appears that oxygen levels decrease over time rather than improving to reference conditions. The relationship between alkalinity and time elapsed since mining was not significantly different than zero ($p=0.10$). It does not appear that alkalinity in streams changes appreciably over twelve-years since mining had occurred in study streams.

Some streams appeared to be less impacted than others, but spatial or temporal recovery to reference water chemistry conditions was not apparent for any of the parameters tested.

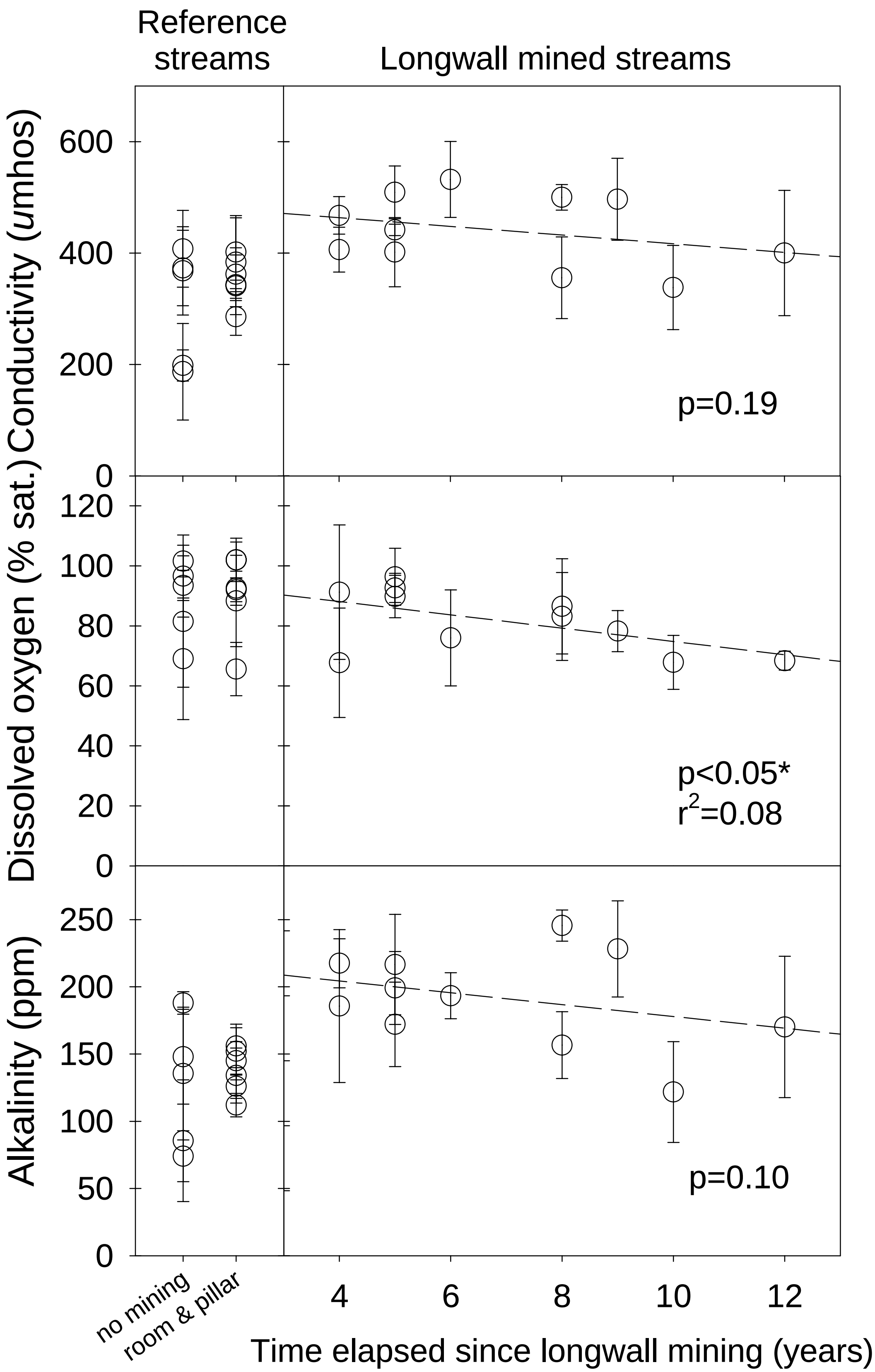


Figure 4. Comparison of mean (and 1 S.D.) chemical measurements in reference and longwall mined streams. Trend lines indicate changes in longwall mined streams over time (* indicates trend significantly different than zero).

Biological characteristics of study streams

Aquatic macroinvertebrate communities were significantly different in all structural dimensions when comparing longwall mined versus reference streams (Table 3). For instance, the probability of no significant difference between the total number of organisms collected in samples from longwall mined versus reference streams was two one-thousandths of a percent, thus the null hypothesis of no significant difference was rejected because it was below the *a priori* threshold of 5% probability. The number of organisms collected in 30-minute composite samples ranged from 3 to 131 in reference streams and 0 to 163 in disturbed streams. On average, 60.4 organisms were collected in reference stream samples and 34.1 organisms were collected in samples from longwall mined streams. Thus, 44% fewer organisms were collected in longwall mined streams. Compared to reference streams, longwall mined streams had 47% fewer kinds of organisms, 49% fewer EPT taxa, and 51% fewer semivoltine taxa. Longwall mining caused mayfly, stonefly, and caddisfly taxa to be reduced by 42%, 52%, and 52% respectively, compared to reference streams.

In general, longwall mining resulted in streams harboring about one-half the abundance and diversity of reference streams. No water was present at 18% of sample sites in longwall mined streams at the time of sampling, therefore, stream communities were impaired at approximately 32% of sites even though water was present at the time of sampling.

Table 3. Mean (and 1 standard error) biological characteristics of streams and probability of no significant biological difference in samples from longwall mined (N=88) versus reference streams (N=79), and (ANOVA, Dunnett's Test ,*p<0.05).

	Reference streams		Longwall mined streams		
Biological measure	Mean	(SE)	Mean	(SE)	Probability
Total number of organisms collected per sample	60.4	3.8	34.1	3.6	0.000*
Taxa richness	12.8	0.6	6.8	0.5	0.000*
EPT taxa	9.0	0.4	4.6	0.4	0.000*
Semivoltine taxa	2.7	0.2	1.3	0.2	0.000*
Mayfly taxa	3.0	0.2	1.7	0.2	0.000*
Stonefly taxa	3.6	0.2	1.7	0.2	0.000*
Caddisfly taxa	2.4	0.2	1.1	0.1	0.000*

Biological characteristics along headwater stream gradients

Biological communities appeared to exhibit greater impacts near the source of longwall mined streams than in downstream reaches (Figure 5). For instance, an average of 10 organisms were collected in samples near the source of longwall mined streams, but 30 organisms were collected in samples where watershed area was greater than 50 acres, and over 60 organisms were collected in samples from longwall mined watersheds that were at least 100 acres. A note of caution: the total number of organisms collected is a measure of relative abundance and is not a measure of how many organisms inhabit the stream.

For the number of organisms collected per sample, both of the main effects were significant (ANOVA, $p<0.05$), including: longwall mined versus reference streams, and distance from the stream source. A significant interaction term ($p=0.02$) indicated a relationship between the main effects. The scatterplot of the total number of organisms collected versus watershed area indicates convergence of longwall mined and reference stream patterns once the watersheds achieved approximately 120 acres in size. Interaction indicates recovery of the relative abundance of macroinvertebrates in downstream reaches of average longwall mined streams. Interestingly, macroinvertebrates were particularly abundant in samples collected from many of the 60 to 100 acre longwall mined streams, whereas macroinvertebrates were absent or nearly absent in many other similar sized longwall mined streams. It is possible that resurgence of water in 60-100 acre longwall mined streams acts as a refuge for a number of macroinvertebrates subjected to dewatering in the upstream reaches.

Diversity in terms of the number of different kinds of macroinvertebrates collected in samples along the headwater stream gradient showed significant main effects in terms of reference versus longwall mined, and distance from the source. Taxa richness did not show significant interaction between main effects ($p=0.49$), indicating the downstream patterns were essentially parallel in longwall mined and reference streams. Therefore, the diversity of macroinvertebrate communities in longwall mined streams failed to recover to reference conditions along the downstream gradient. Spatially, diversity of longwall mined streams did not achieve the diversity of reference streams within the range of the stream size studied. This finding does not rule out the possibility that longwall mined streams may recover to reference conditions in larger, 3rd or 4th order streams outside the scope of this study.

The EPT taxa included mayflies, stoneflies, and caddisflies were significantly impacted by longwall mining (Table 3). The EPT taxa also increased downstream (Figure 5). Lack of a significant interaction ($p=0.26$) indicated that recovery of the longwall mine impacted EPT fauna did not occur within the headwater study streams. Likewise, semivoltine taxa, those that require greater than one year in stream residence to complete their larval stages, did not recover to reference conditions within the spatial dimensions of this study ($p=0.26$). Furthermore, the low numbers of semivoltine taxa in the lower reaches of most longwall mined streams brings into question whether these streams are able to maintain flow conditions necessary for long-lived organisms.

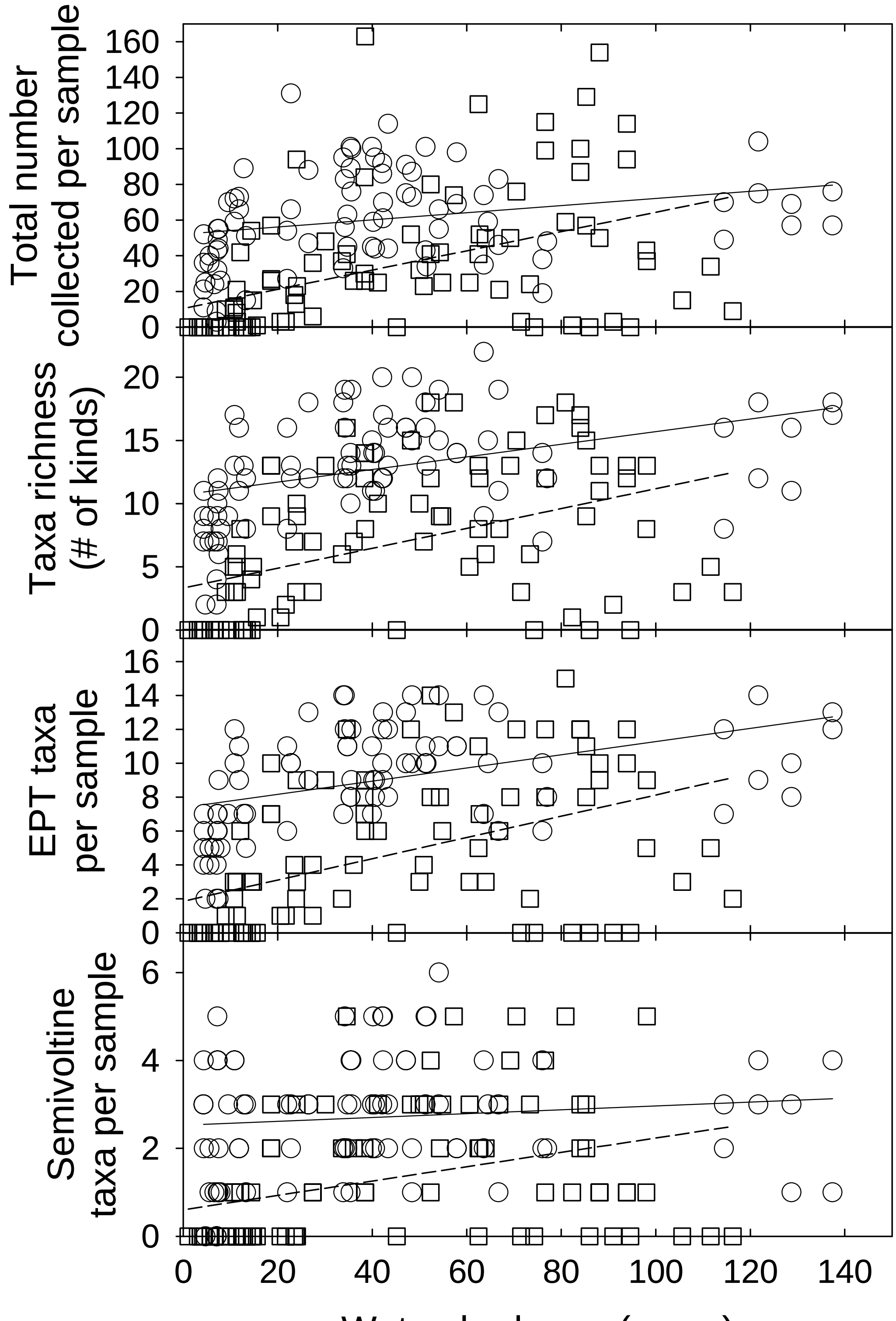


Figure 5. Scatterplots of biological community attributes measured along headwater stream gradients comparing longwall mined (squares) and reference streams (circles). Least square means regression lines for longwall mined (dashed, N=88) and reference (solid, N=79) streams.

In longwall mined streams semivoltine taxa were collected in only 49 of 88, or 56% of samples, whereas reference streams had semivoltine taxa in 76 of 79, or 96% of samples. It was also noted from scatterplots that in many of the samples from 60 to 100 acre longwall mined watersheds where some organisms were collected, semivoltine taxa were absent and EPT taxa were limited in number. In general, EPT taxa have aquatic life histories requiring 9 to 12 months residence.

<u>Biological changes in longwall mined streams over time</u>

The relative abundance, diversity, and longevity of the biological communities in streams did not appear to improve over the twelve-year interval since mining occurred in Marshall County, West Virginia (Figure 6). In regression analysis the number of organisms collected in samples from longwall mined streams was not significantly different over the time elapsed since mining ($p=0.17$). Likewise, the relationship between taxa richness and time elapsed since mining was not significantly different than zero ($p=0.51$). The relatively long-lived EPT taxa and the multi-year aquatic semivotine taxa did not respond to any change in condition of streams over the twelve-year period represented by study streams. The structure of the biological communities in longwall mined streams remained essentially unchanged over time. Twelve years after longwall mining, biological communities failed to achieve the abundance, diversity, or longevity of unmined or room-and-pillar mined reference streams.

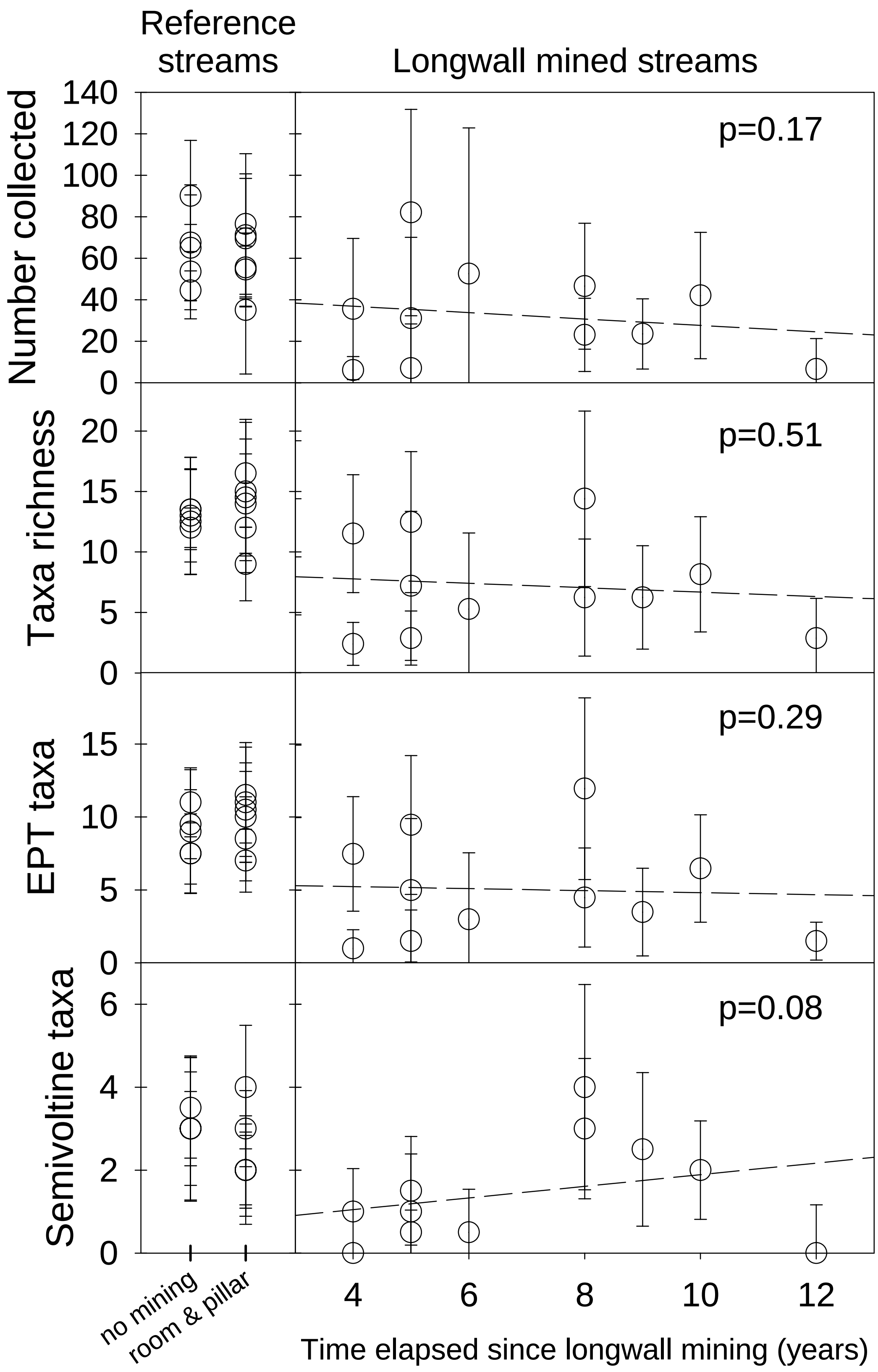


Figure 6. Comparison of mean (and 1 S.D.) biological measurements in reference and longwall mined streams. Trend lines indicate changes in longwall mined streams over time (* indicates trend significantly different than zero).

Community organization and average functional groups in headwater streams

Macroinvertebrate functional feeding groups were assessed for samples where viable communities were present. For functional group analysis at least two individuals (minimum population) from each of two taxa (minimum community) must have been present in a sample. Communities were present in 78 of 79 (99%) reference stream samples and 57 of 88 (65%) longwall mined stream samples. Sixteen samples from longwall mined streams were dry at the time of sampling, and 15 additional samples failed to contain viable communities even though water was present at the time of sampling.

There were no significant differences in the average functional group composition of streams draining longwall mined versus reference watersheds (Table 4). It was noted, however, that average functional group composition for shredders and collectors would be considered different at α=0.10, the 90% probability level. Leaf shredders and fine particle collectors dominated headwater streams in the region. Shredders ranged from 12-80% of the community in reference streams and 0-100% of the community in longwall mined streams. Collectors ranged from 7-84% of the community in reference streams and 0-91% of the community in longwall mined streams. Grazers made up less than 15% of the average community, and predators made up 10-13% of average stream communities.

Table 4. Mean (and 1 standard error) functional group composition of streams and probability of no significant functional difference in samples from longwall mined (N=57) versus reference streams (N=78), and (ANOVA, Dunnett's Test ,*p<0.05).

	Reference streams		Longwall mined streams		
Functional group	Mean	(SE)	Mean	(SE)	Probability
Leaf shredders	39.4%	2.0	34.3%	2.4	0.098
Collectors	34.5%	2.1	40.1%	2.5	0.083
Grazers	12.9%	1.5	15.3%	1.7	0.282
Predators	13.2%	1.2	10.3%	1.4	0.114

Functional group composition along headwater stream gradients

The proportion of leaf shredders in samples declined from greater than 40% near stream sources to approximately 30% in the downstream reaches, a relationship that was significantly different than zero (p<0.05). Whereas there were no significant differences in shredder composition between longwall mined and reference streams, a significant interaction term between the main effect and the gradient effect distance from the source indicated that the pattern of shredder population decline along the stream gradients was significantly different (two-way ANOVA, p<0.05). Notably, scatterplots indicate relatively low shredder populations at the head of some longwall mined streams, and high shredder populations in 50 – 100 acre longwall mined compared to reference streams. This pattern appears to correspond with the resurgence of some longwall mined streams in the lower stream reaches, and may indicate that resurgence areas mimic the spring sources of reference streams in terms of their functional group balance.

Fine particle collectors were 35-40% of the population in streams, with no significant differences between longwall mined and reference streams and no significant pattern of change along the downstream gradient (Figure 7). It was noted that collector proportions were uncharacteristically high in samples from the largest (>100 acre) longwall mined streams, and that shredders were proportionally lower in those samples. Both shredder and collector proportions in samples from longwall mined streams tended to have greater variation from the mean (trend line) than samples from reference streams.

Grazers were not significantly different between longwall mined and reference streams, but the increase in grazer proportions along the downstream gradient was significantly different than zero ($p<0.05$). Grazers increased from about 10% of the community near stream sources to about 20% in the lower reaches. Predators were not significantly different in longwall mined versus reference streams, and remained a constant 10-15% of the communities along stream gradients.

<u>Functional changes in longwall mined streams over time</u>

Although functional group composition of communities was not impacted by longwall mining, there were some changes over time in the functional composition of longwall mined streams (Figure 8). For instance, fine particle collectors declined ($p<0.05$, $r^2=0.12$) and predators increased ($p<0.05$, $r^2=0.21$) over time elapsed since longwall mining occurred in streams. Leaf shredder and algal grazer proportions appeared to remain constant in stream communities regardless of the amount of time that had elapsed since longwall mining had occurred. It was noted that collector proportions declined from nearly 60% of the community in recently mined streams to 20-30% of communities in streams that had been mined 8 to 12 years prior to sampling. Since reference streams had about 35% collectors, the downward shift may signify that macroinvertebrate communities tended to come more into trophic balance a decade after longwall mining. Likewise, predators were nearly absent from recently mined streams but achieved 10-20% of the community in streams mined nearly a decade prior to sampling. Predator proportion in older-aged longwall mined streams compares more favorably with the 13% proportion measured in average reference streams.

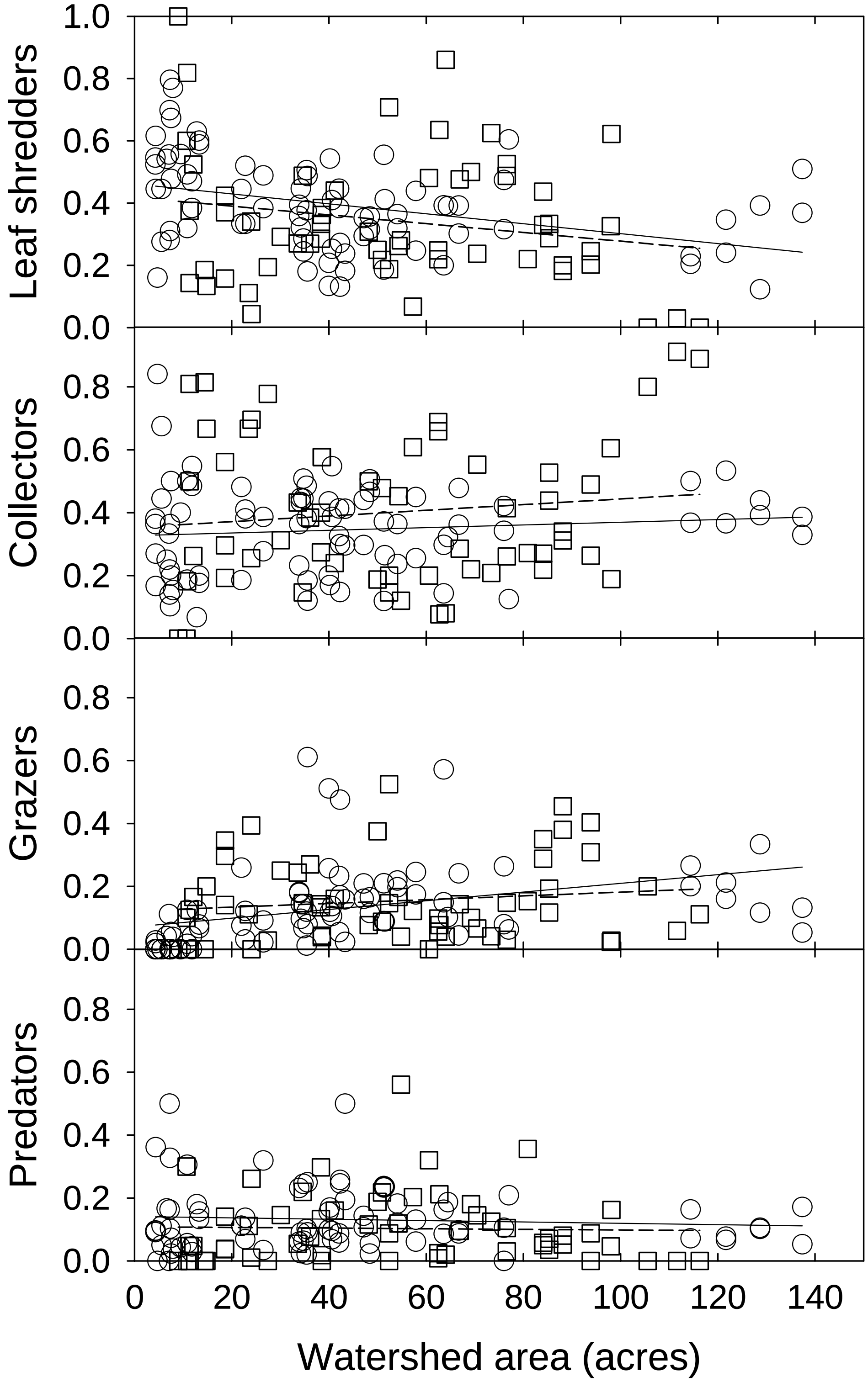


Figure 7. Scatterplots of the proportion of macroinvertebrates in each of four functional feeding groups along headwater stream gradients comparing longwall mined (squares) and reference streams (circles). Least square means regression lines for longwall mined (dashed, N=57) and reference (solid, N=78) streams.

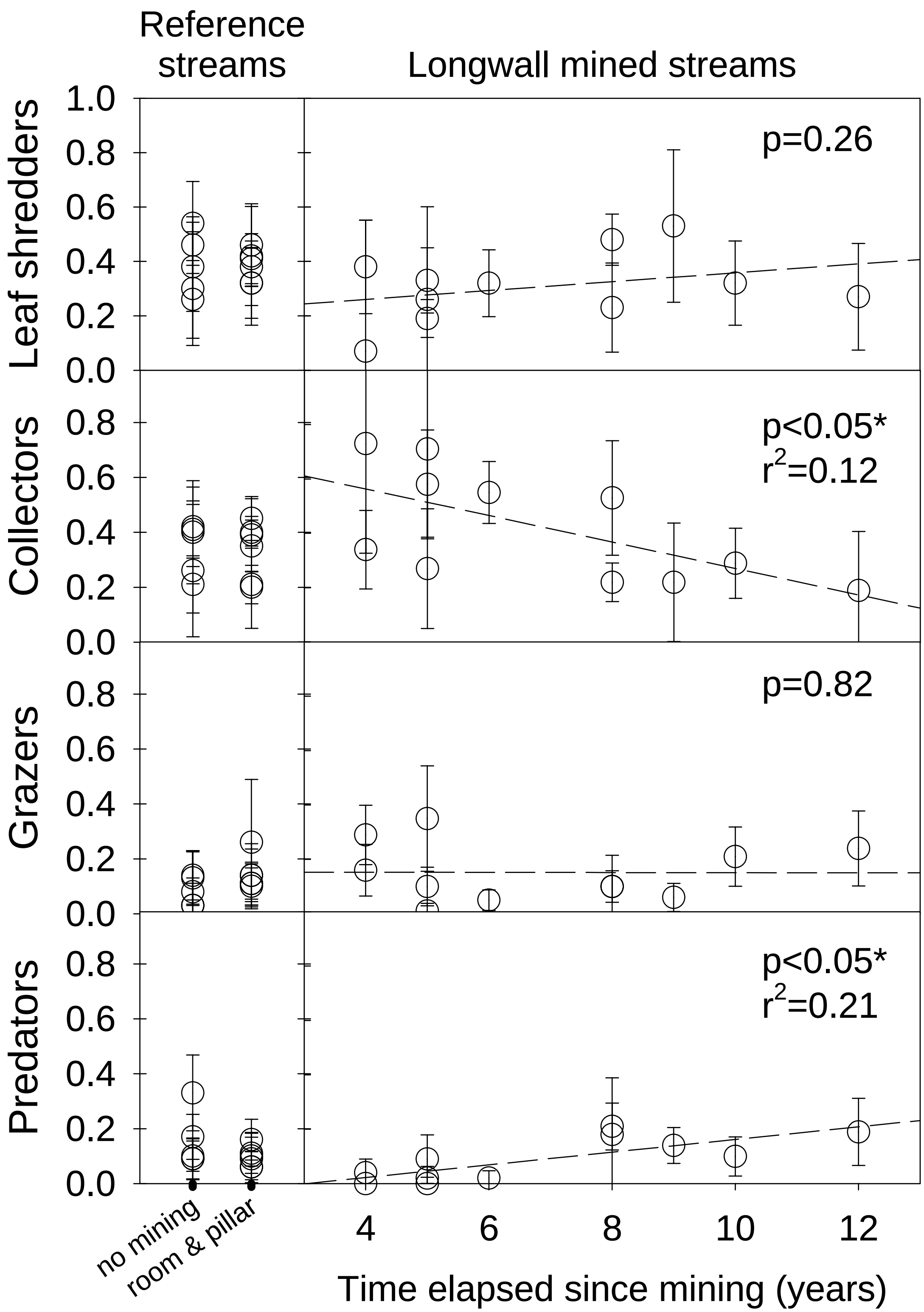


Figure 8. Comparison of mean (and 1 S.D.) functional group composition in reference and longwall mined streams. Trend lines indicate changes in longwall mined streams over time (* indicates trend significantly different than zero).
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Table 5. Taxa collected 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

Discussion

The physical dimensions of the reference and longwall mined watersheds were comparable with the exception of stream width and water temperature. Longwall mined streams were dry at 18% of study sites, most of which were within 150m of the point of flow origin. Frequent dewatering of streams near their sources is consistent with the findings of Leavitt & Gibbens (1992) and Johnson (1992) that upland wells in the Pittsburgh seam are more likely to drawdown than wells in valley bottoms. All longwall mined streams appeared to re-emerge at some point downstream of the source, but re-emergence was not sufficient for full recovery of stream width for many of the longwall mined streams. Resurgence of some streams but not others is consistent with the variable responses measured in aquifers overlaying Pennsylvanian coal in Illinois (Booth, 2002) and West Virginia (Cifelli & Rauch, 1986; Tieman & Rauch, 1987). Fractured aquitards causes water to drain from upper-level aquifers to lower-level aquifers. Resurgence of streams depends on the connection of lower-level aquifers to recharge zones and the ability of aquifers to transmit water back into the stream bed (Booth, 2002).

Instantaneous water temperature averaged 0.8 ^{o}C lower in longwall mined streams and remained consistently lower than temperatures in reference streams along the headwater stream gradient. As watersheds achieved 100 acres in size, summer daytime water temperatures were 1–2^{o}C lower in longwall mined streams than in reference streams. Lower stream temperature appeared to be related to loss of water at the surface and longer underground residence time. This was further evidenced by water temperatures being less variable in longwall mined than in reference streams.

Three of five chemical measures showed significant differences when comparing longwall mined versus reference streams. Higher total dissolved solids and alkalinity have been reported previously in longwall impacted groundwater in Pennsylvanian coal (Booth & Bertsch, 1999; Rauch, 1989). Stream water quality appeared 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. Compared to reference conditions, lower dissolved oxygen concentrations may be in part due to higher chemical oxygen demand, and in part due to lower atmospheric contact in subsided longwall mined streams.

Within the biological community the EPT Taxa represented 28 of the 60 kinds of macroinvertebrates collected, and 83% 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 nine 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 during summer months is indicative of stream permanence. These streams, often mistakenly referred to as "ephemeral" or "intermittent" because of their inaccurate depiction on USGS 1:24,000 scale data (Meyer, et al, 2003), are indeed perennial landscape elements.

In prior studies 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% (Stout, 2003). 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 nine 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 this study, there was little evidence of streams recovering from the dewatering effects of longwall mining. Spatially, the number of organisms collected per sample increased in downstream reaches where subsided streams re-emerged into the streambed. However, diversity and longevity of stream communities remained well-below reference conditions in stream reaches downstream of resurgence areas. Temporally, there was no evidence of stream recovery over the twelve-year period of time that had elapsed since longwall mining occurred in Marshall County streams. Lack of temporal recovery appears to be the case in other regions of the world (Holla & Barclay, 2000).

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). In study streams the seal, longtail, two-lined, and spring salamanders dominated the obligate aquatic amphibian community, but many other amphibians in this region depend on headwater streams as breeding sites (Green & Pauley, 1987).

Headwater streams provide critical services to consumers in the surrounding forest and in downstream reaches. Headwater communities convert imported low quality forest products such as leaves and sticks into high quality products in the form of insect tissue. Primarily fats and protein, insects emerge from streams in a form that is consumable by a plethora of forest species at a time that coincides with breeding a rearing of subsequent generations. By-products, in the form of insect frass, are exported downstream where they become a resource of a host of invertebrates that filter the water column and eventually contribute to higher trophic levels. Headwater streams are functionally critical landscape elements and the loss of one-half of all headwater streams to longwall mining could have significant consequences for the health of central Appalachian forest ecosystems.

Conclusion

Aquatic macroinvertebrate communities in reference streams are ubiquitous across the region, rich in diversity, long-lived, and dependent on the surrounding terrestrial ecosystem for energy and nutrients. Longwall mining resulted in a net loss of approximately one-half of all headwater streams in Marshall County, West Virginia. Streams were particularly impacted near the source, and most re-emerged downstream. Macorinvertebrate abundance appeared to recover to reference conditions in the lower reaches of longwall mined streams. However, neither diversity or longevity of the macroinvertebrate community recovered along the stream gradient. There was no indication that the physical, chemical, or biological impacts of longwall mined streams recover over time.

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

Basic Information

Title:	WRI47-Establishing Biological and Water Quality Criteria for Water Resource Management in Mining Impacted Watersheds
Project Number:	2002WV6B
Start Date:	3/1/2002
End Date:	2/28/2004
Funding Source:	104B
Congressional District:	1
Research Category:	Biological Sciences
Focus Category:	Water Quality, Ecology, Management and Planning
Descriptors:	aquatic ecosystem integrity, biotic degredation, water quality criteria, biological criteria, benthic macroinvertebrates, stream condition indices
Principal Investigators:	J Todd Petty

Publication

FINAL REPORT

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

Submitted by:
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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.

<u>Statistical Analyses</u>

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.

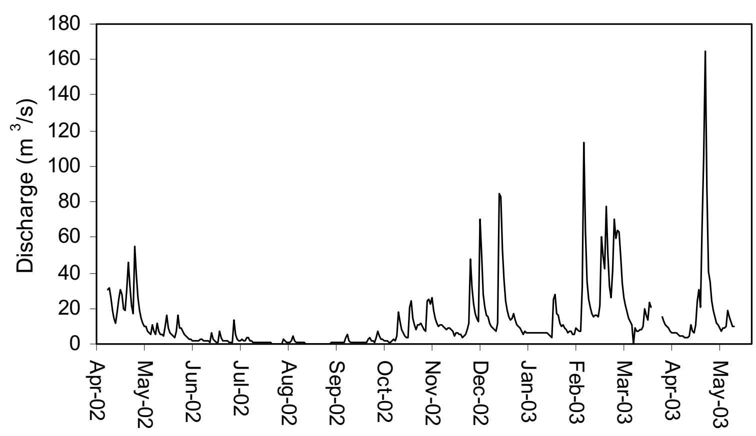


Figure 1. Daily mean discharge during the course of the study. Discharge was gauged continuously on Big Sandy Creek at Rockville, WV (USGS 03070500).

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).

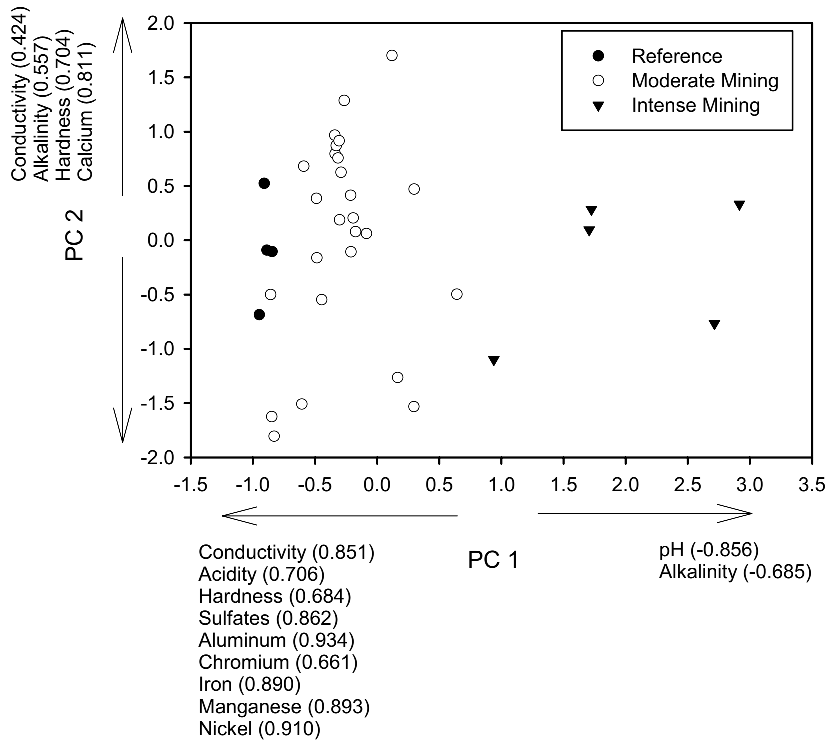
Table 1. Summary statistics for water chemistry variables from unimpaired, moderately impaired, and severely impaired stream segments. Mean values were calculated across all sample dates. Avg. CV refers to the average variability of stream segments within each category. The higher the value the more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

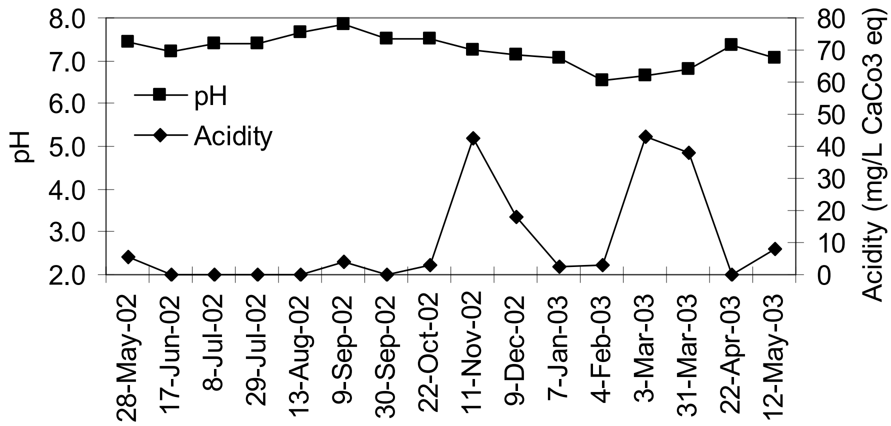


Water Quality Variability

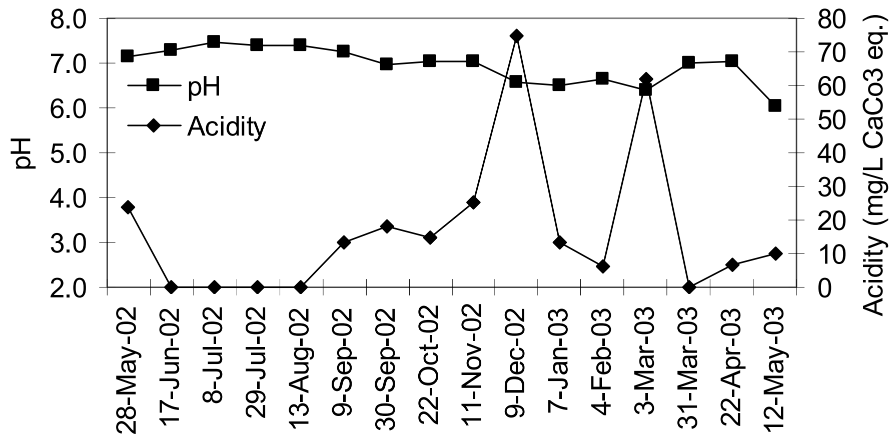
An important objective of our study was to quantify the degree of temporal variability in water quality in streams of the lower Cheat River watershed. Our analyses indicated that chemical conditions were highly variable in all streams studied, regardless of relative impairment level. Figures 3 – 5 illustrate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

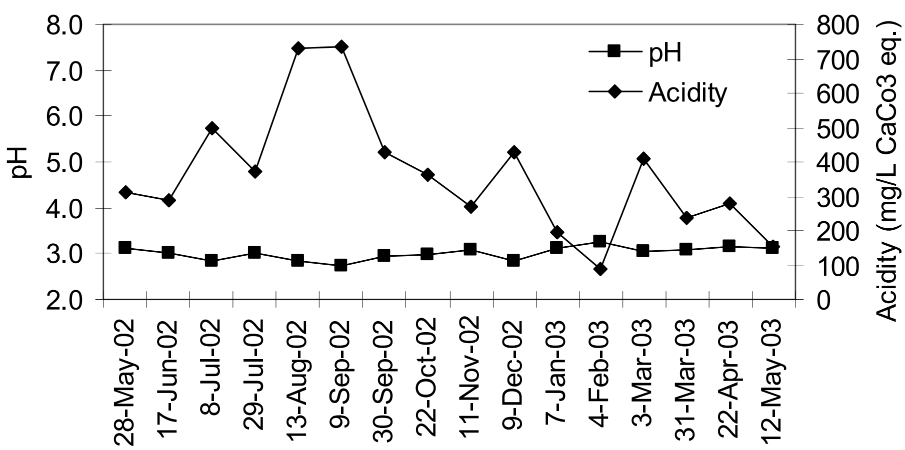
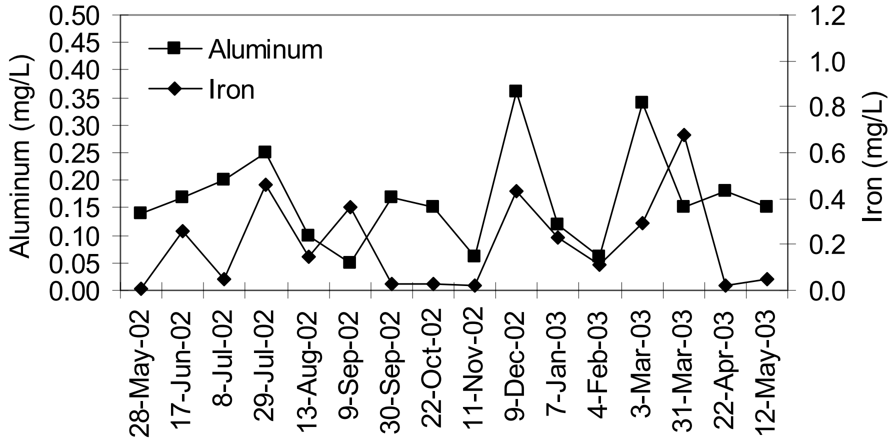
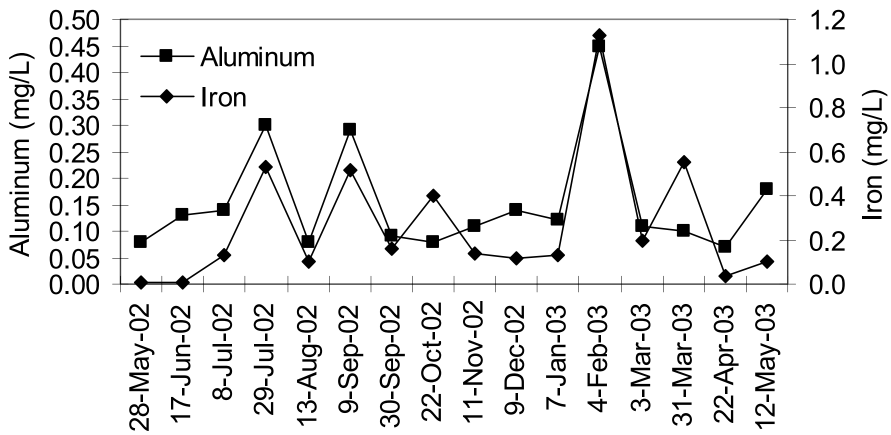


Figure 3. Variability in pH and Acidity within an unimpaired (A), a moderately impaired (B), and a severely impaired (C) stream segment of the lower Cheat River watershed.

A. Roaring Creek 1



B. Muddy Creek 4



C. Martin Creek

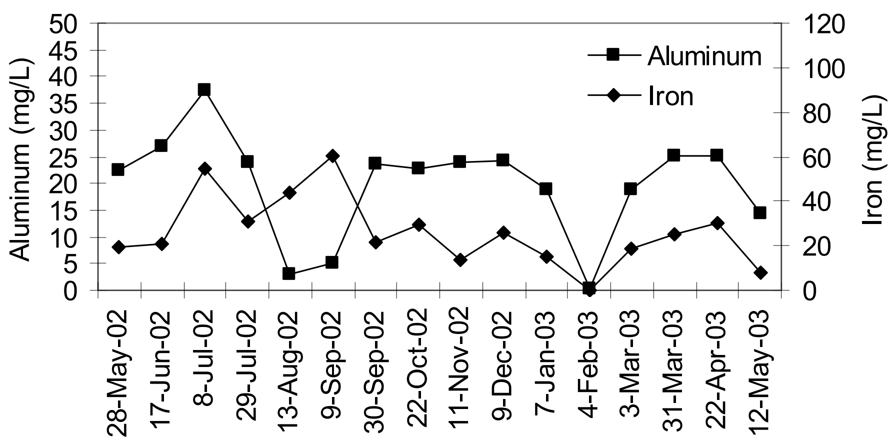
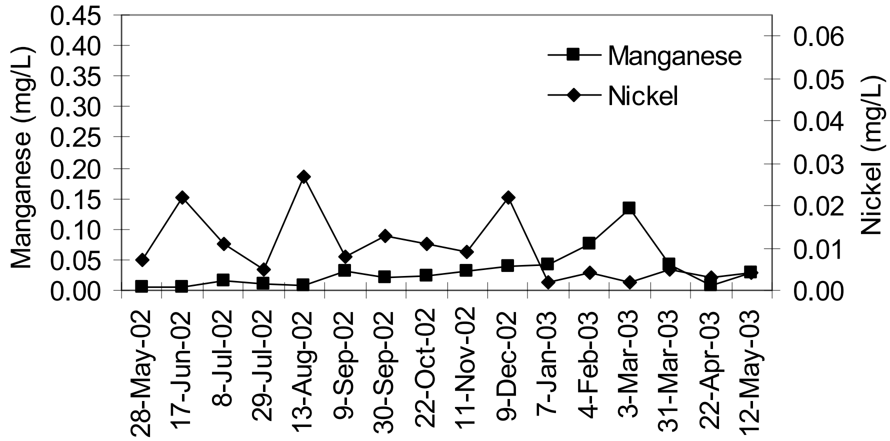
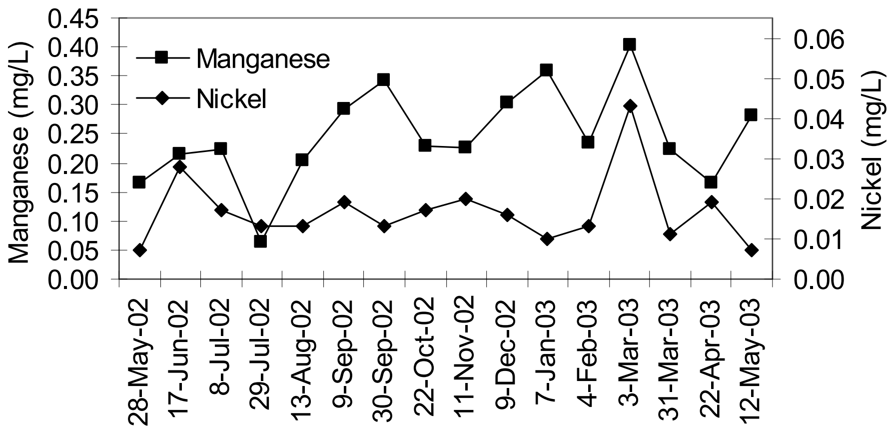


Figure 4. Variability in dissolved Aluminum and Iron concentrations within an unimpaired (A), a moderately impaired (B), and a severely impaired (C) stream segment of the lower Cheat River watershed.

A. Roaring Creek 1



B. Muddy Creek 4



C. Martin Creek

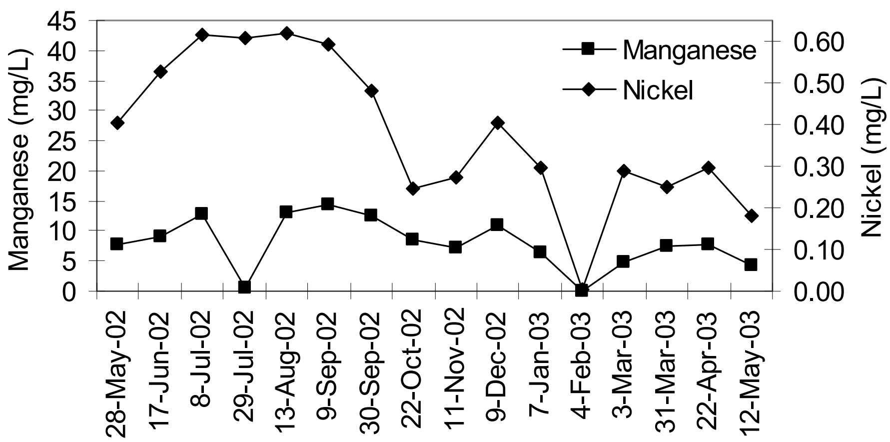


Figure 5. Variability in dissolved Manganese and Nickel concentrations within an unimpaired (A), a moderately impaired (B), and a severely impaired (C) stream segment of the lower Cheat River watershed.

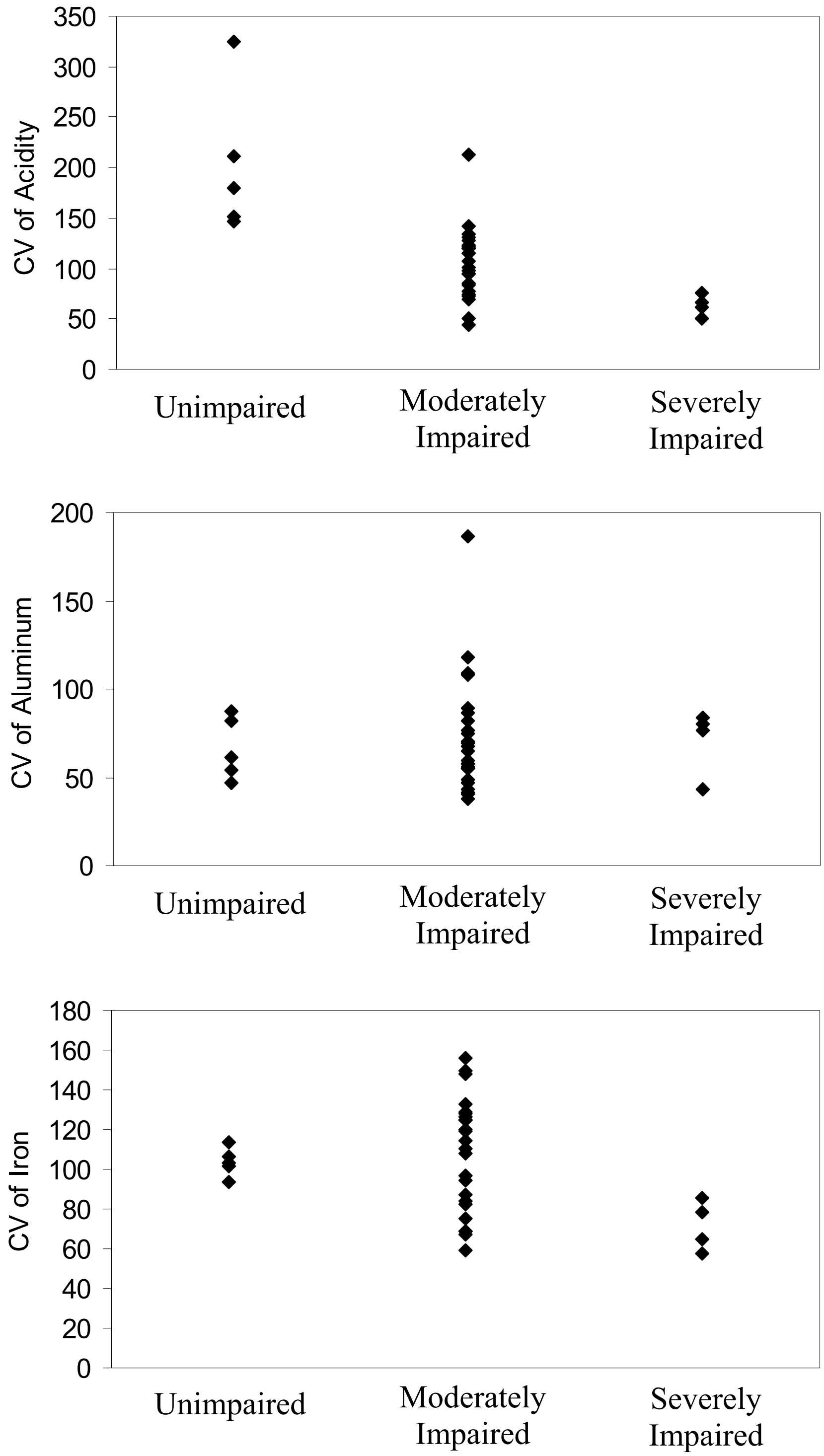


Figure 6. Temporal variability in acidity and dissolved aluminum and iron concentrations within unimpaired, moderately impaired, and severely impaired stream segments of the lower Cheat River watershed. Each symbol represents a relative measure of day-to-day variability in water chemistry at a specific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

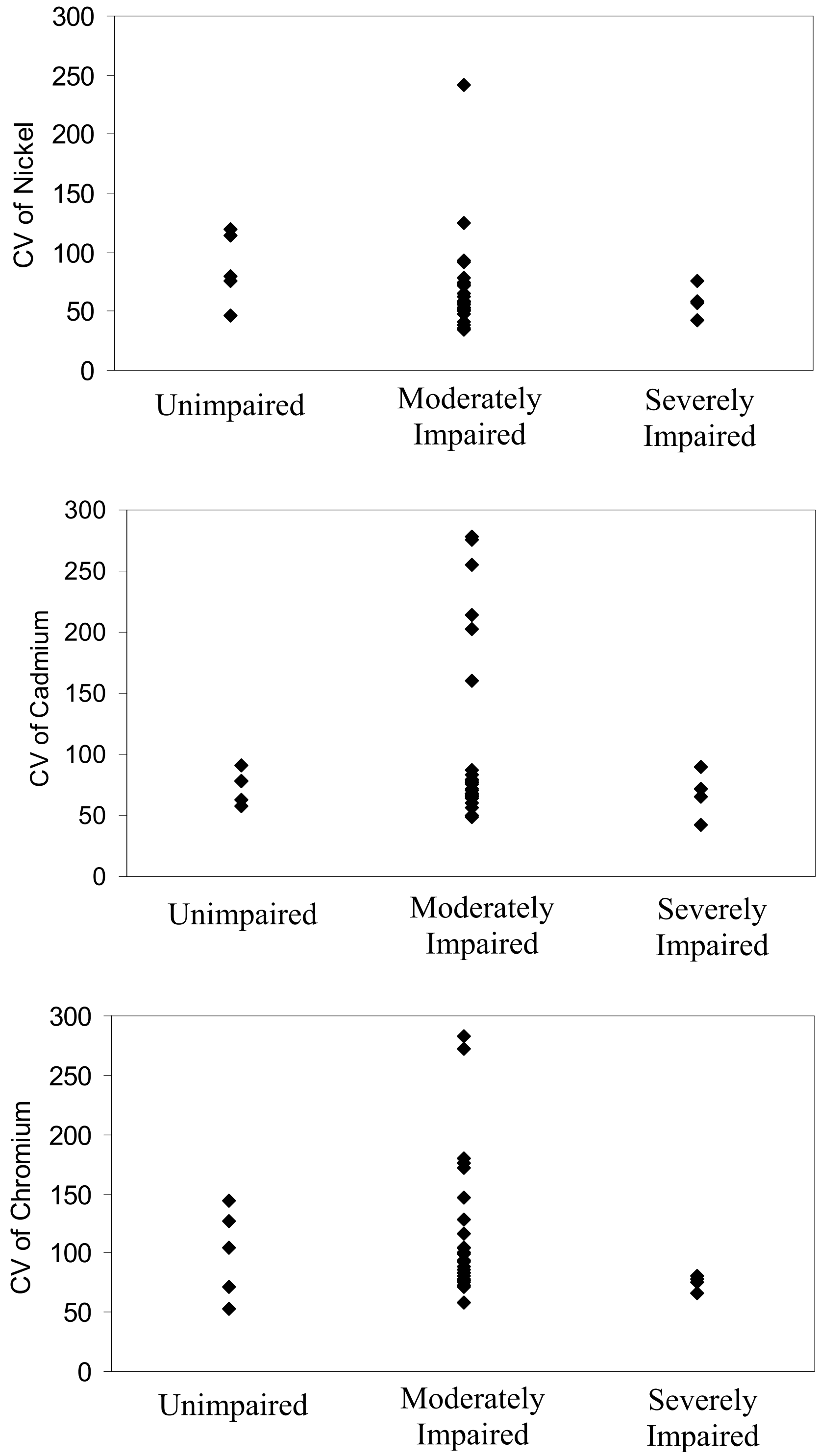


Figure 7. Temporal variability in dissolved trace metal concentrations within unimpaired, moderately impaired, and severely impaired stream segments of the lower Cheat River watershed. Each symbol represents a relative measure of day-to-day variability in water chemistry at a specific study site.

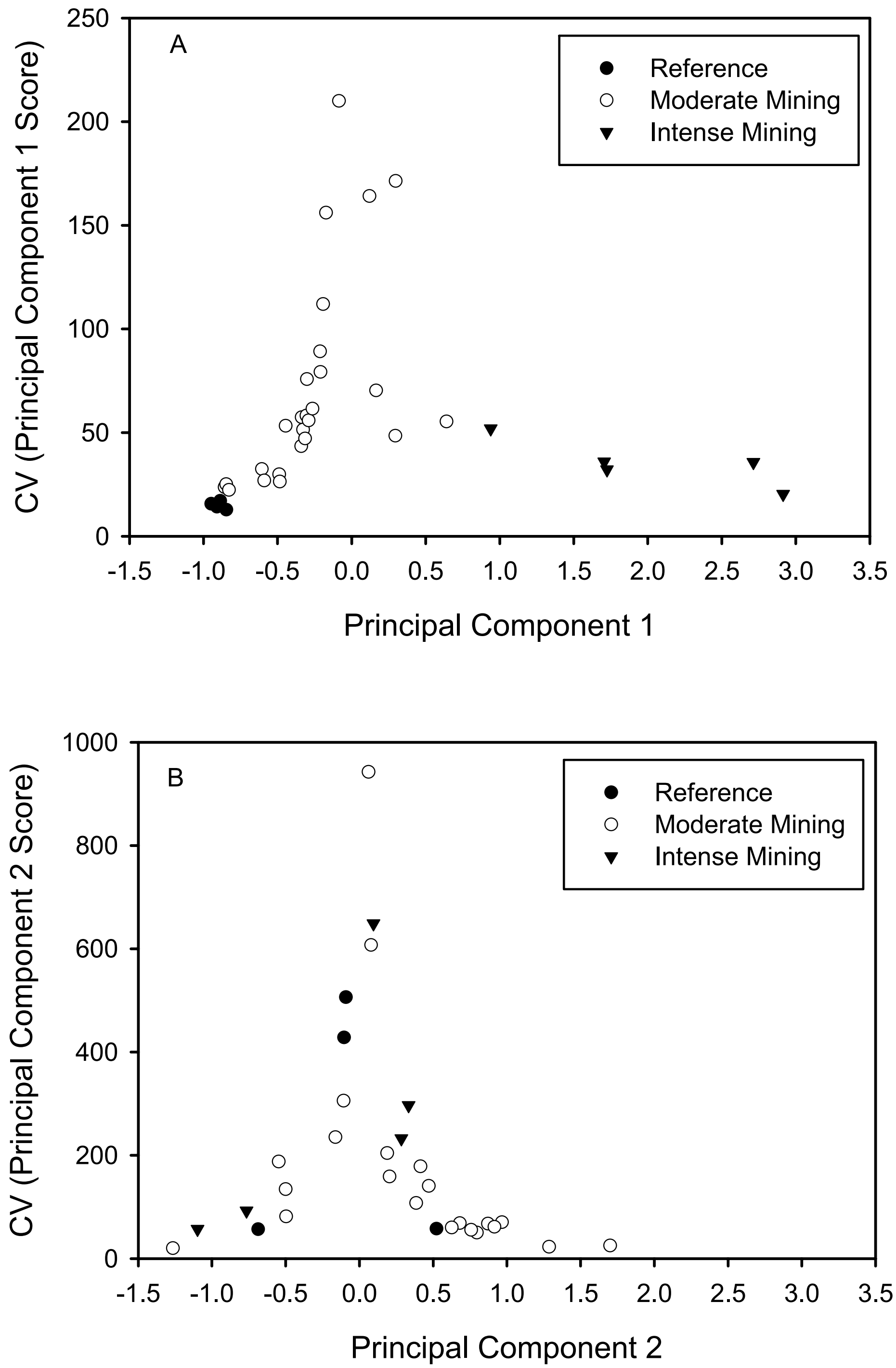


Figure 8. Relationship between water quality variability and mean water quality condition on both PC 1 (A) and PC 2 (B).

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.

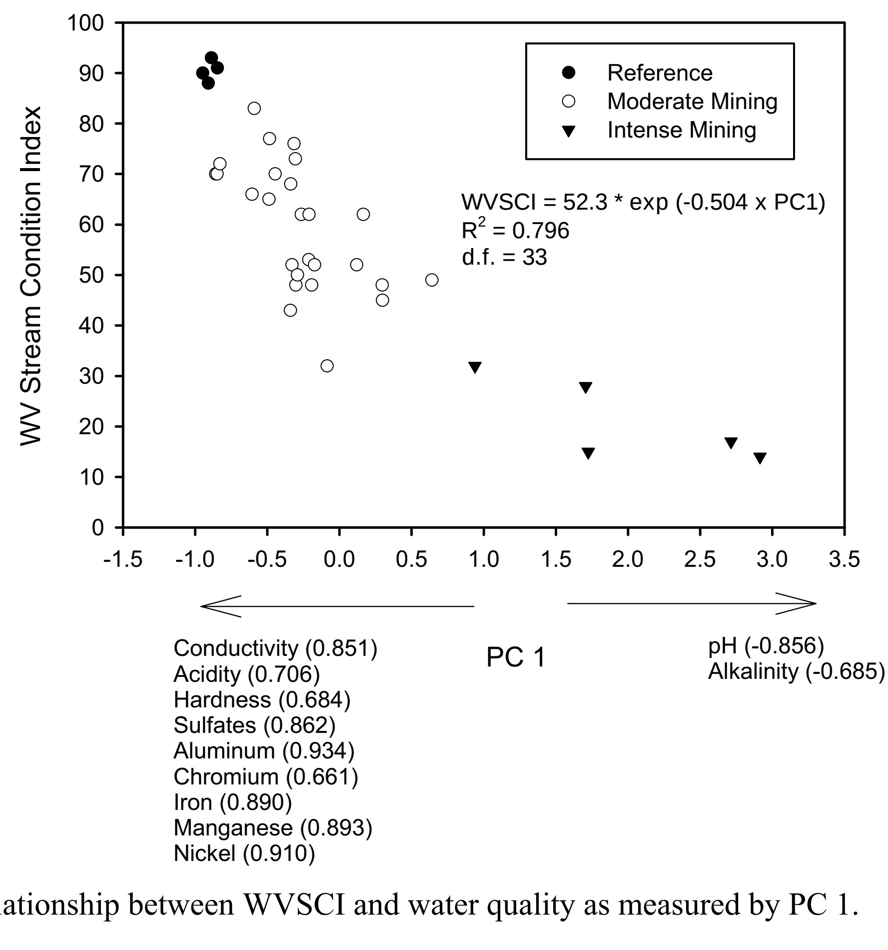


Figure 9. Relationship between WVSCI and water quality as measured by PC 1.

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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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:	2/28/2006
Funding Source:	104B
Congressional District:	WV 1st
Research Category:	Ground-water Flow and Transport
Focus Category:	Water Supply, Water Quantity, Water Quality
Descriptors:	ground water, hydrology, surface water
Principal Investigators:	Dorothy Vesper, Joseph j. Donovan

Publication

ANNUAL REPORT

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

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:

   - Data logging equipment for stage, conductivity and temperature was installed in Big Spring. The data loggers in this location, as well as Water Street Spring (also known as Martinsburg Water Supply Spring) and Kilmer Spring, are continuous operating.
   - 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.
   - A total of 10 rounds of water samples have been collected and analyzed since November 2003. Seven of those rounds have been conducted since the last progress report.

2. Publications.
   - RACHEL V. GRAND and DOROTHY J. VESPER <u>Controls, characterization and small scale chemical variation of Tuscarora Creek watershed, Berkeley County, West Virginia</u>. Poster presentation at the WV Academy of Sciences, April 2005.

3. Information transfer activities
   - <u>Hydrogeochemistry of Karst Aquifers and Springs: Case Studies from Three WV Aquifers</u> Talk presented by Dorothy Vesper at the 3rd Annual West Virginia Water Conference, 10/29/04, Stonewall Jackson Resort WV, regional meeting

4. Student Worker Summary as follows:

   Rachel Grand is conducting her M.S. Research on this and related work. The WRI Grant is paid for her summer research stipend. She is expected to graduate in August 2005.

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

6. Notable achievements and awards

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:	2/28/2004
Funding Source:	104B
Congressional District:	WV 1st
Research Category:	Water Quality
Focus Category:	Water Quality, None, None
Descriptors:	aquatic ecosystem integrity
Principal Investigators:	Thomas Guetzloff, Paul Ziemkiewicz

Publication

DRAFT

Treatment of Chloride Contaminated Mine Water in NW West Virginia
WVWRI Project wri 54

James Mayhugh, West Virginia State University
Paul Ziemkiewicz, West Virginia University

31 May 2005

Introduction

As underground coal mining recovers coal at greater depths in the Pittsburgh Coal Basin, increasing concentrations of chloride are appearing in the infiltrating water. This, in turn, is typically pumped for discharge and may or may not requirement with hydrated lime to control acid mine drainage parameters such as acidity, iron, aluminum and manganese. In-stream and drinking water limits for chloride are generally 250 mg/L. Chloride is a highly soluble anion and it does not respond to the typical hydroxide precipitation used in the mining industry. However, it is known that both iron and aluminum hydroxide flocs will, under a range of pH conditions develop anion exchange. The objective of this study was to evaluate the potential to remove chloride from solution by using readily available metal flocs produced in treating acid mine drainage. Specifically, we sought to identify the pH range in which anion exchange developed on the metal hydroxide flocs would effectively remove chloride ion, the removal rates of iron vs. aluminum hydroxides and the degree of chloride loading that each of these hydroxide flocs could sustain.

This project investigated the ability of flocculent hydroxide precipitates of aluminum and iron (III) to absorb chloride ions from aqueous solutions developed in the laboratory. Gravimetric analysis was used as the benchmark to monitor the amount of chloride partitioned between the aqueous layer and the precipitate. Both iron and aluminum hydroxide flocs were evaluated: those formed through precipitation prior to and after addition of chloride ion and several sources that were formed in the field as a result of acid mine drainage treatment. The efficacy of ICP as an analytical method to apply to these samples was investigated and compared to the gravimetric results.

Three treatment schemes were tested:

1. floc precipitation prior to chloride addition
2. floc precipitation after chloride addition
3. addition of metal hydroxide flocs collected in the field

Experimental methods are discussed below.

Methods

Sample preparation:

Stock solutions were prepared as follows. The aluminum solution was made by dissolving 100.0 g of $Al_2(SO_4)_3 \bullet 18H_2O$ in a 1 liter volumetric flask. The iron(III) solution was made by dissolving 100.0 g of $Fe_2(SO_4)_3 \bullet 9H_2O$ in a 1 liter volumetric flask. The chloride solution was made by dissolving 31.54 g of KCl in a 1 liter volumetric flask. Deionized water was used to make all solutions.

All samples were prepared by pipeting 25 mL of a metal solution and then 25 mL of the chloride solution into a beaker. Precipitation was accomplished by the addition of small quantities of saturated NaOH to bring the pH up into the target range of $4 < pH < 9$. The NaOH was added before the chloride in some samples and after the chloride in others. Each sample thus prepared contains 2.5 grams of the hydrated metal sulfate and 0.375 g chloride in a total volume of approximately 50 mL.

After equilibrating, the sample was filtered. The filtrate was sealed in a labeled sample tube and the precipitate was transferred to a beaker. The filter paper was washed with four 25mL portions of 5% nitric acid and the washings are added to the beaker. The precipitate was redissolved by heating on a hot plate adding additional 5% nitric acid if necessary. The solution was filtered again to remove any remaining particulate matter.

Preparation of Controls:

Three DI water samples (18 MOhm/cm) were run through the method to determine effects of contamination and method errors. Zero AgCl recovery was the theoretical result. The actual result was 0.001067g +/- 0.001804g so method errors are minimal on the order of 1mg.

One goal of the initial experiments was to determine if the high throughput ICP at WVSU could be used for experiments of this type. As this was unknown an independent standard like gravimetric analysis was desirable. The ICP consumes the aqueous samples during testing. I wanted to know how reliable it would be to analyze the sludge not sent through the ICP and independently determine the chloride content in the ICP sample by subtraction from the total original chloride present.

Recovery Tests:

A set of eleven samples were selected and the ICP was not used at all. Both the sludge and the aqueous layer were tested for chloride gravimetrically. The theoretical recovery calculated by formulation is 1.5160g AgCl. One experiment showed up as an obvious outlier. After removing this data point the actual recovery was 1.545g +/- 0.033g.

Independent determination of chloride content in samples sent into the ICP should be reliable to within 8mg (33mg AgCl).

Although not set up for this purpose this spreadsheet data shows that a ballpark figure of 35% +/- 5% of aqueous chloride was taken up by the aluminum or iron hydroxide sludges.

Gravimetric analysis:

Samples were diluted to a total volume of 250 mL and mixed with 50 mL of saturated Ag_2SO_4 . The precipitate was digested on a hotplate until the solution was transparent. Additional saturated Ag_2SO_4 was added as a test for completeness. The AgCl precipitate is collected on a weighed filter paper, dried and weighed again.

Three DI water samples (18 MOhm/cm) were run through the method to determine effects of contamination and method errors. Zero AgCl recovery was the theoretical result. The actual result was 0.001067g $\pm$ 0.001804g so method errors are minimal on the order of 1mg.

A set of eleven samples was selected and both the precipitate and the aqueous layer were tested for chloride gravimetrically. The theoretical recovery calculated by formulation was 1.5160g AgCl. One experiment showed up as an obvious outlier. After removing this data point the actual total recovery was 1.545g $\pm$ 0.033g.

In experiments where the aqueous layer was analyzed using the ICP, independent determination of chloride content in the aqueous layer was made by analyzing the precipitate gravimetrically and subtracting the AgCl found from 1.545 g. Samples sent into the ICP had an independent chloride measurement reliable to within 8mg.

ICP analysis:

The model used to analyze the ICP results assumes that chloride is taken up by the metal hydroxide precipitates but potassium is not. Potassium acts as an internal standard. The ratio of the chloride measurement to the potassium measurement in a set of standard KCl solutions provides a reference quotient $Cl_{ref}/K_{ref} = Q_{ref}$. The aqueous phase of a sample yields a sample quotient

$Cl_{samp}/K_{samp} = Q_{samp}$. The percent chloride absorption as a function of the ICP signals is = $100\%*(1- Q_{samp/}\ Q_{ref})$.

Using the ICP is much faster and more convenient than doing gravimetric analysis on the samples but there is currently an unknown systematic error in effect that causes the ICP results to show % chloride absorptions that are on average 11.6% larger that those indicated by gravimetric analysis. When plotted together the results of both methods seem to track each other well except for the offset which seems larger than the estimated error bars would permit. Further refinement of this method is suggested before relying on it as a sole source of chloride concentration measurements

Summary of Results

Chloride absorption was observed for both aluminum and iron hydroxides. 14 aluminum samples showed an average absorption of 35.9% $\pm$ 6.6% and 14 iron samples showed an average absorption of 40.5% $\pm$ 6.9% . There is an apparent stoichiometry of M_2Cl . There is not enough evidence to support the formation of a compound but it is useful to quantify the observed chloride absorbing capacity. The actual mole ratios observed were Al:Cl = 1.98:1 and Fe:Cl = 2.08:1.

Samples were equilibrated between 50-150 hours. Absorption increased with equilibration time but not significantly enough compared to the experimental uncertainty to obtain reliable kinetic information. The data suggests that the reaction occurs at a rate fast enough that in the first two days these systems absorb roughly 3-4 times as much chloride as they do in the following 4 days.

Adding the chloride to a preexisting precipitate vs. precipitating the metal in the presence of the chloride showed no significant effect compared to experimental error when measurements were taken 50-150 hours after mixing. The precipitation method is suspected to have an impact if measurements are made at shorter times after mixing.

The absorption did not show a strong pH dependence, however at pH values of 4 and lower and 9 and higher the iron or aluminum concentrations in the aqueous phase began to rise above the 1 ppm level. An operating range of $4.5 < pH < 8.5$ is recommended to reduce chloride levels without enriching the aqueous phase in metal ions.

Environmental samples of AMD precipitates displayed no activity. The average measured absorption from the aqueous phase of six different samples was -2.7%. However, digested natural precipitates had a chloride content comparable to artificial samples that had absorbed 45.6% of the chloride provided. A hypothesis is that natural AMD precipitates have already saturated themselves with chloride and only newly precipitated metal hydroxides can display measurable chloride uptake.

ICP analysis of the chloride absorption process yielded results 11.6% higher than the gravimetric control. It is suspected that the chloride response is significantly nonlinear and that narrowing the concentration range of the standards used would be helpful.

Conclusions

Both iron and aluminum hydroxide flocs were effective at scavenging between 35 and 50% of chloride over a pH range of 4 to 9. Iron hydroxide had higher affinities for chloride, accounting for higher removal rates. Iron hydroxide flocs had slightly higher chloride removal rates at higher pH while NaOH addition had no effect either on aluminum hydroxide solution pH nor chloride removal rates. Removal rates were about two moles of either iron or aluminum to each mole of chloride removed. It is noted that the concentrations of both metal ions and chloride used in this laboratory study are about an order of magnitude higher than the highest concentrations normally encountered in mine drainage in West Virginia.

Precipitating the metal flocs prior to or after chloride addition to the solution had no effect on removal rates.

Four mixtures of iron and aluminum hydroxides were collected from an acid mine drainage treatment site in Putnam County, WV. While they removed less than 3% of solution chloride, it was found that they were already saturated with chloride.

The results were surprisingly positive and hold the prospect of a cost effective chloride removal method. It will first be necessary to identify the extent to which metal flocs formed in treating acid mine drainage are saturated with chloride. Those that are not should be evaluated for their potential to remove chloride through simple kinetic/mixing experiments. These will form the basis for designing a full scale field treatment process.

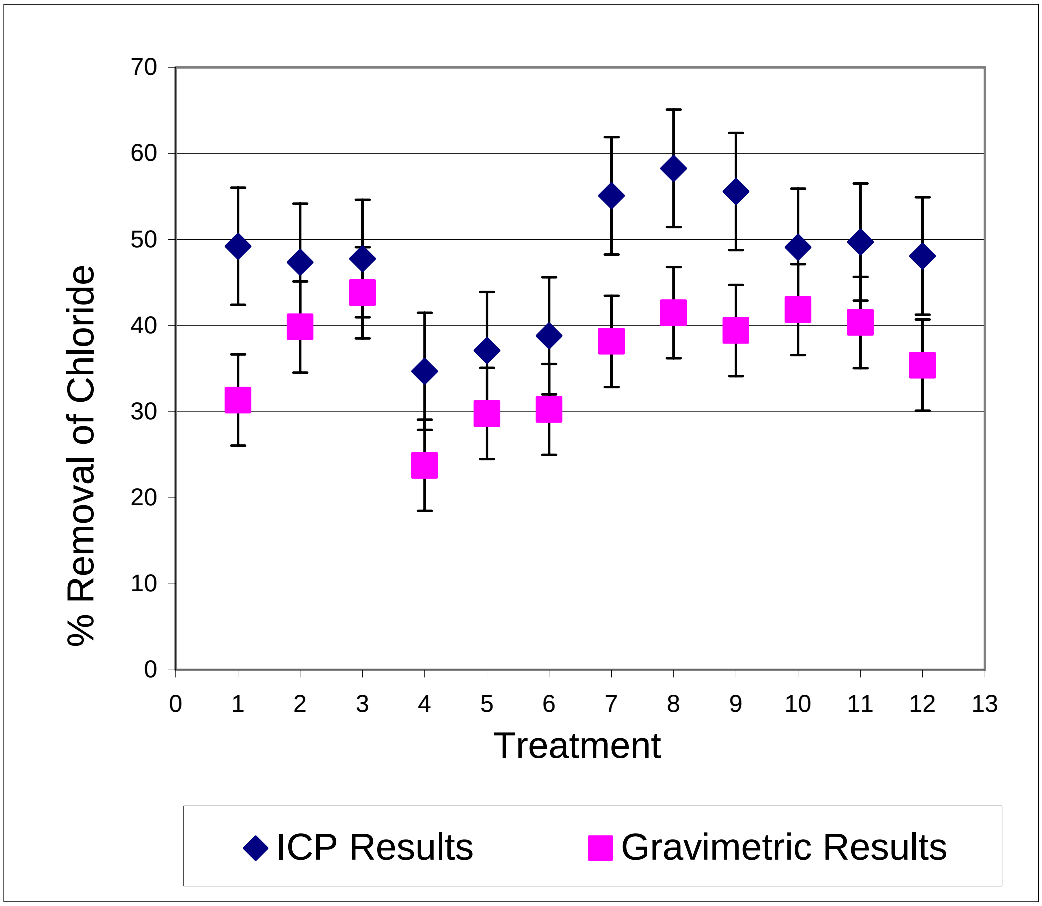


Figure 1. Chloride removal was influenced by the nature of the metal flocs while ICP method apparently introduced a positive bias. Each number on the X axis represents an treatment combination as subjected to increasing base additions. Table 1 explains the treatment numbers and solution pHs.

Table 1. Development of the test solutions and resulting ion concentrations.

Source (amount added to 1 L water)	target element	stock solution mg/L	test solution mg/L	test solution mmoles
100g $Al_2(SO_4)_3$ 18(H_2O))	Al	8,108	4,054	150
100g $Fe_2(SO_4)_3$ 9(H_2O)	Fe	19,872	9,936	178
31.54g KCl	K	16,531	8,266	211

Table 2. Proportional chloride removed by twelve experimental combinations. The pH data indicate the realized solution values when the researchers added three increasing amounts of NaOH to each treatment. Note that while base additions increased the pH of the iron flocs they had no effect on the aluminum flocs.

experiment no.	pH	sample ID	treatment description	% Chloride removed ICP	% Chloride removed Gravi-metric
1	4.22	fepre1	Iron flocs precipitated prior to Chloride addition	49.2	31.3
2	4.93	fepre5	Iron flocs precipitated prior to Chloride addition	47.4	39.8
3	9.32	fepre6	Iron flocs precipitated prior to Chloride addition	47.8	43.8
4	4.01	alpre4	Aluminum flocs precipitated prior to Chloride addition	34.7	23.8
5	4.01	alpre5	Aluminum flocs precipitated prior to Chloride addition	37.1	29.8
6	4.01	alpre6	Aluminum flocs precipitated prior to Chloride addition	38.8	30.3
7	4.03	feco1	Iron flocs precipitated after Chloride addition	55.1	38.2
8	6.49	feco4	Iron flocs precipitated after Chloride addition	58.3	41.5
9	8.96	feco5	Iron flocs precipitated after Chloride addition	55.6	39.4
10	3.95	alco4	Aluminum flocs precipitated after Chloride addition	49.1	41.9
11	3.93	alco5	Aluminum flocs precipitated after Chloride addition	49.7	40.4
12	3.93	alco6	Aluminum flocs precipitated after Chloride addition	48.1	35.4
		average		47.6	36.3

WRI 60: Changes to In-Stream Suspended Sediment and Turbidity Following Improvements to a Forest Road in West Virginia

Basic Information

Title:	WRI 60: Changes to In-Stream Suspended Sediment and Turbidity Following Improvements to a Forest Road in West Virginia
Project Number:	2004WV26B
Start Date:	5/1/2004
End Date:	2/28/2006
Funding Source:	104B
Congressional District:	WV 01
Research Category:	Not Applicable
Focus Category:	Non Point Pollution, Sediments, Water Quality
Descriptors:	suspended sediment, tubidity, forest road construction, sediment delivery, road improvements, best management practices
Principal Investigators:	Jingxin Wang, Pamela Edwards, Joseph F. McNeel

Publication

Progress Report

Title: Changes to In-Stream Suspended Sediment and Turbidity Following Improvements to a Forest Road

Start Date: Fall 2003 (for this portion of the study)

End Date: Projected completion date July 2006

Descriptors: Suspended sediment, turbidity, forest road construction, sediment delivery, road improvements, best management practices

Principal Investigator: Dr. Jingxin Wang, Division of Forestry, WVU

Co-Investigator: Dr. Pamela Edwards, Research Hydrologist, US Forest Service and Adjunct Assistant Professor, WVU
phone: 304-478-2000 ext. 129

Objectives:

A forest road was constructed through a watershed in summer 2002. It was left in poor condition from fall 2002 through mid-summer 2003. In mid-summer 2003 its condition was improved through the installation of more and better water control features, sediment traps, seeding of the fill slopes and cut banks, and graveling of the driving surface.

Turbidity and suspended sediment levels in both the control and treatment watersheds fell within expected ranges during the 3 pretreatment years prior to road construction. By contrast, both parameters increased to very high levels on the treatment watershed during the spring and early summer 2003 before the road condition was improved and finalized. After road improvements were finalized, reductions in turbidity and suspended sediment were observed on the treatment watershed. The control watershed stayed within the pretreatment turbidity and suspended sediment ranges during the entire posttreatment period.

The purpose of this study is to continue stream water sampling through spring 2006 to specifically determine whether:

1) the rapid recovery is real or simply an artifact of the numbers and characteristics of the storms that have occurred since the road has been completed and improved,
2) storms with certain attributes, particularly very large ones, continue to result in extremely elevated turbidity and suspended sediment (presumably due to sediment stored in the channel), even if more “average” storms no longer have elevated sediment,
3) recovery is linear, exponential, or it levels off at some point in time, and

4) suspended sediment and turbidity increase again in the future as some situations develop over time, such as extension of erosion features below culvert outlets toward the stream channel.

Methods:

A paired watershed approach is being used for this study. The two watersheds are located along the Left Fork of Clover Run, on the Monongahela National Forest, Tucker County, WV. One watershed is used as the treated watershed and one as the control watershed. Many parameters are being monitored as a part of this study; in this report we describe only those associated with the objectives given above.

Near the mouth of both watersheds, a stream monitoring station was established in 1999. At each site, stream stage is measured every 5 minutes with an American Sigma depth/velocity probe. Rating curves to establish the relationship between stage and discharge measurements are currently under development for both watersheds. These are being developed by measuring velocity and discharge using a USGS type pygmy AA current meter over a range of stages. If reasonable rating curves cannot be developed, discharge will be estimated using Manning's n to determine velocity across a variety of stages, and discharge will be determined as the product of velocity x cross sectional area (determined from surveying the stream cross section where velocity is measured).

Two automatic stream samplers (ISCO and American Sigma) are housed in shelters at the mouth of each watershed. One of the samplers collects a sample every 24 hours, while the other sampler is actuated during storms using precipitation actuation (Edwards and Owens 1995). Storm samplers are programmed to collect a stream water sample every half hour during the summer when stormflow responses are flashy and peak sediment occurs early in the event, or hourly during the dormant season when stormflow responses are less flashy and require a substantially longer time to return to baseflow. Each ISCO or Sigma case has 24 1-L bottles. If the storm is continuing, new cases of bottles are placed in the field in order to characterize the sediment characteristics throughout the storm. The time that each sample is collected is recorded internally in the automatic collector's memory.

Most storms have been sampled since 1999 on both watersheds. The principal reasons that some storms have not been sampled or have not been sampled during the entire event are that equipment has malfunctioned or the flow in the 5 fords that must be crossed is too high to traverse safely, even in a full sized truck.

The samplers and data loggers are operated using separate 12-V marine batteries that are changed regularly, when the voltage drops to approximately 10 V. This assures that sufficient charge is available to operate the sampler or loggers throughout each storm or over the required time period. During the winter, the shelters are heated to above freezing using small propane lights. The heat given off by the lights is sufficient to 1) keep the collected samples above freezing, avoiding bottle cracking, 2) keep the instruments in a temperature range to assure operation, and 3) provide sufficient light to allow the technician to service them easily in the limited light situations commonly experienced during the winter.

Samples are processed at the US Forest Service's Timber and Watershed Laboratory. Each stream water sample is processed first for turbidity and then for suspended sediment. Turbidity is determined using a Hach Ratio Turbidimeter. The sample is agitated in the bottle to distribute sediment particles evenly throughout the sample. An appropriate amount of the agitated sample is immediately poured into the sample vial and then placed into the turbidimeter. After approximately 10 seconds, the reading is recorded. The appropriate scale on the turbidimeter is used, depending upon the degree of turbidity in the sample. Results expressed at Nepholometric Turbidity Units (NTU).

After the reading is taken, the sample is poured back into the original bottle and then suspended sediment concentrations are determined. The bottle (and lid) with the sample is weighed, and the bottle and lid weight are then subtracted to obtain the weight and volume of the sample. Following standard protocols, the volume in ml is assumed to be equal to the weight in g, since the density of water is approximately 1 g/cm^3, and 1 ml = 1 cm^3. Each sample is vacuum filtered through one or more pre-dried and pre-weighed ashless GF/C glass microfiber filters. Most samples require only 1-3 filters, depending upon the level of suspended sediment and amount of organic material present, though some require more. Each bottle is rinsed with water as many times as needed to remove all of the suspended material. The rinse water also is filtered. The filter(s) from each sample are dried at 100 ºC for 2 hours and then re-weighed after cooling in a dessicator. This weight, minus the initial dry filter weight, is the total weight of suspended material (mineral + organic) in the sample (g/L). Once weighed, the filters then are burned in a muffle furnace at 550 ºC for 1 hour and then re-weighed. The burned weight, minus the initial filter weight, is the weight of the mineral material only (mg/L), or suspended sediment. These data are recorded along with the sample number, and time and date of sample collection so that stream discharge can be applied to the suspended material and suspended sediment values to determine the total suspended material and total suspended sediment that were exported from the watershed during the storm or over the time period (e.g., annually) in question.

Pretreatment samples were collected from fall 1999 through summer 2002 from both watersheds. A forest road was pioneered through the treatment watershed in summer 2002; essentially no BMPs were applied to the road until summer-fall 2003, when the road in the watershed was completed. Stream water samples continued to be collected daily and during storms after the pretreatment period on both watersheds, and are expected to continue to be collected until spring/early summer 2006.

Results:

Data analyses on the turbidity and suspended sediment samples have just begun. However, initial review of the data show that turbidity and suspended sediment levels in both the control and treatment watersheds were in expected ranges during the 3 pretreatment years prior to road construction. Generally turbidity levels remained below 50 NTU for all but the largest storms (e.g., storms with peakflow recurrence intervals of 5-10 years). Even for the largest storms, turbidities rarely exceeded 100 NTUs on either watershed prior to road construction. By contrast, both parameters increased to very high levels during the spring and early summer 2003 before the road condition was improved. After road improvements were finalized, cursory evaluation of the data suggest that reductions in turbidity and suspended sediment have occurred, though turbidity and suspended sediment reductions during storm events often still appear to be elevated for a longer period of time than prior to road construction. However, these results will be verified with more rigorous statistical analyses conducted between June 2005 and Spring 2006.

Conclusions: Because data analysis is incomplete, no conclusions concerning the objectives have yet been made.

Publications: To date, no publications have resulted from this work. A masters thesis and one or more subsequent journal articles are anticipated within the next ~12-15 months.

Information Transfer Program: None to date.

Student Support: Will Sharp, a M.S. student, is being supported by this project.

Notable Achievements and Awards: None to date.

Information Transfer Program

West Virginia Water Conference 2004

Basic Information

Title:	West Virginia Water Conference 2004
Project Number:	2004WV31B
Start Date:	3/1/2004
End Date:	2/28/2005
Funding Source:	104B
Congressional District:	WV 1st
Research Category:	Not Applicable
Focus Category:	Water Quantity, Water Quality, Water Use
Descriptors:	water, economics, education, policy, research, conference
Principal Investigators:	Tamara Vandivort

Publication

State: WV
Project Number: 2004WV31B
Title: West Virginia Water Conference 2004
Project Type: Information Transfer
Focus Category: Water Quantity, Water Quality, Water Use
Keywords: Water, Conference, Policy, Research, Education, Economics
Start Date: 3/1/04
End Date: 11/30/04
Congressional District: WV 1st
PI: Tamara Vandivort
Co-PI's: None

Background

West Virginia has an abundant and valuable resource: water. Until recently, West Virginia essentially had no water law but was used on a first come first use basis. With rapid growth in the eastern panhandle and the large populations in Maryland, Virginia, and Washington, DC, the rising need for more and more water in these areas may soon focus on West Virginia's water resources. As the Potomac River works its way into these areas, who really owns the water–those at the source or the end users? How can the state protect its water rights? Water is something we all use and take for granted until there is a shortage. We all want it for our own needs. It's free or cheap now but that could change as it has in the western states. If users in other states manage to get legal rights to West Virginia's water, there could be serious economic impacts.

These are some of the issues raised and addressed at the West Virginia Water Conference 2004 held in October in Roanoke, West Virginia. This was the third state water conference at which water rights have been much debated. These conferences have served as an avenue for networking among various groups including U.S. Environmental Protection Agency, U.S. Geological Survey, WV Division of Environmental Protection, West Virginia Board of Public Health, academia, watershed groups, and private citizens.

Objectives

1. Objectives for the 2004 conference included:
2. Expanding the awareness of water issues in the state
3. Providing attendees with an awareness of on-going water research
4. Providing attendees with an awareness of on-going legislation underway to protect the State's water resources
5. Networking of the State's water stakeholders
6. Revisiting the issues listed above and prioritizing them in order of importance from the viewpoints of the participants
7. Presenting the prioritized listing of issues to the West Virginia Advisory Committee for possible inclusion in future WVWRI RFPs.

Methods, Procedures, Facilities

Lessons learned from the past two conferences were considered through the planning and development of this third conference.

Conference Planning Committee

This committee was comprised of representatives of key stakeholders from the following organizations:

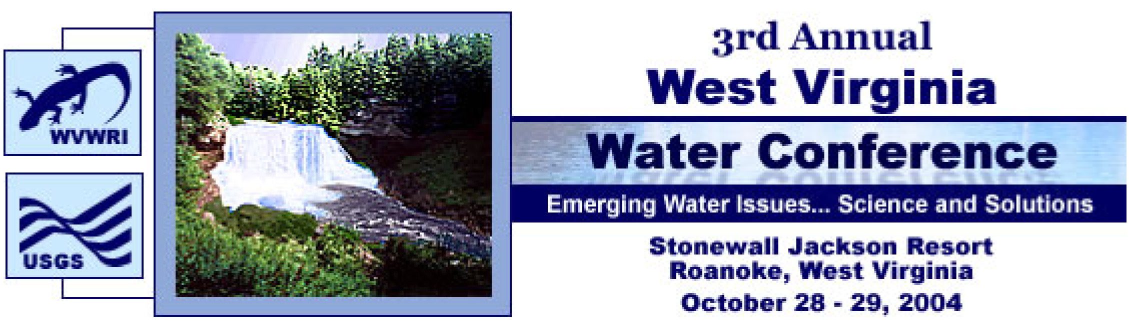
8. West Virginia Water Research Institute
9. West Virginia University College of Law
10. West Virginia Board of Public Health
11. West Virginia Division of Environmental Protection
12. Marshall University
13. Canaan Valley Institute
14. U.S. Environmental Protection Agency
15. U.S. Geological Survey

Communications included physical meetings, conference calls, and email. This group worked together to achieve the following:

16. Developed a theme
17. Created an agenda
18. Selected a location
19. Selected and invited moderators and speakers
20. Enhanced the mailing list from the previous 2 conferences
21. Selected avenues for promoting the conference

The theme of the 2004 conference was *Emerging Water Issues... Science and Solutions.* The following is the final agenda:

Agenda



AGENDA

Thursday, October 28

7:15 AM	**Registration**
8:00 - 9:30 AM	**Plenary Session: Emerging Water Issues... Science and Solutions** *Welcome and Introductory Remarks*, Paul Ziemkiewicz, Director, West Virginia Water Research Institute, West Virginia University **Joyce McConnell, Professor, Law Center, West Virginia University, Moderator** *Water security approaches and strategies*, Jerry G. Schulte, Manager, Source Water Protection and Emergency Response, ORSANCO *Current water law in West Virginia*, David Flannery, Jackson Kelley PLLC *Responding to Emerging Power Plant-Water Issues: DOE-NETL's R&D Program*, Tom Feeley, Technology Manager, U.S. Department of Energy–National Energy Technology Laboratory
9:30 - 10:00 AM	**Break**
10:00 - 11:30 AM	**Session I. Urban Sprawl and Land Use Planning: David Clark, Watershed Circuit Rider, Canaan Valley Institute, Moderator** *An update on water issues as development increases in Berkeley County*, William Stubblefield, Board of Directors, Berkeley County PSC Water District *Water resource asset protection through green infrastructure planning and investment*, Joe Hankins, Vice President, the Conservation Fund, and Director, the Freshwater Institute *The Wastewater Treatment Coalition of McDowell County – Community-Based Assessment and Planning*, Matthew Sherald, Senior GIS Specialist, Canaan Valley Institute
11:30 AM - 1:00 PM	**Lunch provided by the West Virginia Water Research Institute-Stillwaters**
1:00 - 3:10 PM	**Session II. Water Security and Contamination: Gary Wick, Unit Chief, U.S. Federal Bureau of Investigation, Moderator** *Coal slurry impoundments in southern West Virginia*, Davitt McAteer, Attorney at Law and Director, Coal Impoundment Program, Robert C. Byrd National Technology Transfer Center, Wheeling Jesuit University *Protecting our public water supplies*, Robert Hart, West Virginia Department of Health and Human Resources *Coordinating emergency services in West Virginia*, Steve Kappa, Emergency Management Advisor, Office of Emergency Services *Emerging contaminants in surface waters*, Frank Borsuk, Aquatic/Fisheries

	Biologist, U.S. Environmental Protection Agency Region III *Wastewater issues and alternative sanitation systems*, Clement Solomon, Program Coordinator, National Small Flows Clearinghouse, West Virginia University *Nutrient criteria*, Ed Snyder, Director, Institute of Environmental Studies, Shepherd College
3:10 - 3:30 PM	**Break**
3:30 - 5:00 PM	**Session III. Next Steps, Paul Ziemkiewicz, Director, West Virginia Water Research Institute, West Virginia University, Moderator** *Next steps: What will it take to protect West Virginia's water resources* • George Constantz, Canaan Valley Institute • Stephanie Timmermeyer, Cabinet Secretary, West Virginia Division of Environmental Protection • David Flannery, Jackson Kelly PLLC • Senator John Unger, West Virginia Legislature
5:00 PM	**Closing Remarks: Paul Ziemkiewicz, Director, West Virginia Water Research Institute, West Virginia University**
5:15 PM	**Adjourn**

Friday, October 29, 2004	
7:15 AM	**Registration**
8:00 - 9:30 AM	**Session IV: Topical Research Presentations: John Quaranta, Associate Director, West Virginia Water Research Institute, West Virginia University, Moderator** **On-going Research:** *Finding Solutions through on-going research*, Paul Ziemkiewicz, Director, West Virginia Water Research Institute, West Virginia University and Tony Szwilski, Chair, Division of Environmental Science and Safety Technology, Marshall University **Hydrology:** *The hydrogeochemistry of karst aquifers and springs: Case studies from three different West Virginia aquifers*, Dorothy Vesper, Research Professor, Geology, West Virginia University **Landscape mapping:** *Tools, mapping, and analysis for the urban sprawl landscape*, Julie Svetlik, PhD Student and Research Assistant, Natural Resource Analysis Center, West Virginia University
9:30 - 10:00 AM	**Break**
10:00 - 11:30 AM	**Session V: Topical Research Presentations: Joseph Donovan, Director, Hydrogeology Research Center, West Virginia Water**

	Research Institute, West Virginia University, Moderator **Mine Pools:** *How much water is in our underground mines and how can we use it?* Bruce Leavitt, Consulting Hydrogeologist, Washington, Pennsylvania **Surface Water Gaging:** *The West Virginia Water Gaging Council and the Water Gaging Program*, Hugh Bevans, District Chief, U.S. Geological Survey **Droughts and Low Flow:** *Water quantity assessments and trends in low flow*, Jeff Wiley, Hydrologist, U.S. Geological Survey
11:30 AM - 1:00 PM	**Lunch provided by the West Virginia Water Research Institute-Stillwaters**
1:00 - 2:30 PM	**Session VI: Topical Research Presentations: Rick Herd, Program Coordinator, West Virginia Water Research Institute, Moderator** **Agriculture:** *Handling agriculture pollution*, Tom Basden, Nutrient Management Specialist, West Virginia University Extension Service **DNA Tracking:** *The latest on DNA tracking*, Pam Staton, Marshall University **MTBE:** *MTBE in West Virginia*, Dawn Newell, Geologist, West Virginia Department of Health and Human Resources
2:30 - 3:00 PM	**Break**
3:00 - 5:00 PM	**Session VII: Topical Research Presentations: William Toomey, Manager, West Virginia Department of Health and Human Resources, Moderator** **Mercury:** *Dealing with mercury from power plants*, Lynn Brickett, Project Manager, U.S. Department of Energy - National Energy Technology Laboratory **Mercury:** *Mercury in Fish-Regional Study*, Patrick Campbell, Assistant Director, West Virginia Division of Environmental Protection **Endocrine Disrupters:** *Endocrine Disruptors*, John Cicmanec, Veterinary Medical Officer, US Environmental Protection Agency, Cincinnati, Ohio **Land Use Planning:** *Land Use Planning*, Nancy Ailes, Executive Director, Cacapon Land Trust
5:00 PM	**Closing Remarks: Paul Ziemkiewicz, Director, West Virginia Water Research Institute, West Virginia University**
5:15 PM	**Adjourn**

Speakers, panelists, and moderators all volunteered their time and covered their own expenses. The WVWRI provided speakers with AV equipment and assistance.

Facility

The Stonewall Resort and Conference Center was selected as the venue for this conference due to its location and availability. The Stonewall is located roughly in the center of the State making it within approximately 4 hours driving time maximum from anywhere in the State.

Registration and Materials

Registration was free to attendees. Lunches and materials were provided to approximately 150 attendees free of charge. Materials included a brochure on the activities of the WVWRI.

Exhibits

Although exhibits were not initially considered and never solicited for the conference, a few attendees requested that they be allowed to set up an exhibit of their organization. Those few were accommodated at no charge by having their exhibits placed in the back of the conference room.

Publicity/Technology Transfer

The conference was publicized and information disseminated in a number of ways as follows:

22. Press releases to television, newspapers, and radio.
23. West Virginia University and WVWRI web sites.
24. Post cards mailed to WVWRI conference mailing list.
25. Announcements provided to all on planning committee to distribute via their own agency web sites and mailing lists.
26. Channel 12 news, Clarksburg, WV attended the conference and interviewed WVWRI Director, Paul Ziemkiewicz, regarding the conference; a video clip was aired the evening of the second day of the event.
27. The conference agenda, directions to the facility, an on-line registration form, and presentations were placed on the WVWRI web site.

Student Support

One Ph.D. student presented at the conference.
One M.S. student assisted speakers and ran AV equipment.
One undergraduate student assisted with web site development and getting presentations on the web page.

Student Support

Student Support					
Category	**Section 104 Base Grant**	**Section 104 RCGP Award**	**NIWR-USGS Internship**	**Supplemental Awards**	**Total**
Undergraduate	6	0	0	4	10
Masters	3	0	0	3	6
Ph.D.	0	0	0	0	0
Post-Doc.	0	0	0	0	0
Total	9	0	0	7	16

Notable Awards and Achievements

Publications from Prior Projects

None