Columbia Environmental Research Center

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For the
Missouri Department of Natural Resources

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science for a changing world

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Executive Summary

The Missouri Department of Natural Resources recently reclaimed an abandoned mine-land (AML) site located on the Upper Cedar Creek in Northern Boone County, MO. A study was conducted to determine the success of land reclamation activities at the site. The four-year study monitored physical habitat quality, water quality, dissolved metal concentrations, leaf decomposition rates, and fish and benthic invertebrate communities to assess the extent and rate of recovery. Ten sites in the Cedar Creek watershed were studied. Eight sites were located on the main stem of Cedar Creek; two of the sites were located on tributaries (Renfro and Manacle Creeks).

Water quality improved during the course of the study. There was a significant increase in pH and alkalinity. There were no excursions below the TMDL water quality criteria for either pH or sulfate after the reclamation was completed. Metal concentrations, such as aluminum and nickel increased in 2001 during the period of reclamation; however, acute and chronic water quality criteria were not exceeded after the reclamation was completed. Water quality in Manacle Creek still appears to be affected by several acid seeps due to unreclaimed abandoned mine lands in its watershed.

There was a significant difference in leaf decomposition between years and sites. Stepwise regression analysis indicated that decomposition was best explained by magnesium, turbidity, total number of Ephemeroptera, Plecoptera and Tricoptera, total number of scrapers, temperature and copper (R^2 = 0.817). The number of macroinvertebrates was significantly different between year, sites, and year*site interaction. Macroinvertebrate taxa richness and Simpson's Dominance were also significantly different by year, site and year*site interaction. Stepwise regression analysis of taxa richness indicated that taxa richness was best explained by

the total number of individuals, total number of filter feeders, cadmium, hardness, potassium, and manganese (R^2 = 0.932). Stepwise regression analysis of the total number of crayfish indicated that it was best explained by metals (e.g., aluminum, manganese, nickel), nutrients (e.g., TP, TN, TN/TP, NO_2/NO_3, ammonia), pH, potassium, magnesium, and sodium (R^2 = 0.881).

There was a significant difference in the total number of fish before and after the reclamation. There was also a significant difference in the total number of fish between sites. The apparent lack of concordance with the correlation data and the before/ after comparisons is in part due to the experimental design (i.e., the study ended soon after reclamation was completed) and the possible mobility of fish over such a small (10 km) study distance. Stepwise regression analysis suggests that fish taxa richness was best explained by a combination of variables including temperature, turbidity, hardness, SRP, pH, and conductivity (R^2 = 0.853).

Collectively, these results indicated that water quality was improved after the reclamation was completed at the Cedar Creek AML site. Results also indicate that fish and invertebrate communities show improvement following reclamation activities. To some extent, recovery of the biological communities was limited by other factors such as physical habitat quality and rainfall patterns. Although it is difficult to assess recovery in small headwater streams, biological assessments are a critical component to characterizing stream health after reclamation activities.

Introduction

Acid drainage from abandoned coal mines represents a significant threat to aquatic resources due to the affects of low pH, high sulfates and increased metals such as aluminum, manganese and iron. In 1977, the Surface Mining Control and Reclamation Act (SMCRA) created the U.S. Office of Surface Mining Reclamation and Enforcement (OSM) and initiated the Abandoned Mine Land (AML) Reclamation Fund. The Fund was established to permit recovery of abandoned coal mines in the United States.

Upper Cedar Creek, Boone County, Missouri, drains approximately 800 hectares of abandoned coal mines located on private lands approximately eight kilometers northeast of Columbia, Missouri. Cedar Creek lies within the proposed purchase boundaries of the Mark Twain National Forest and is a significant aquatic resource in Central Missouri. Cedar Creek is one of the few streams north of the Missouri River that contains populations of smallmouth bass (*Micropterus dolomieu*) (Pfleiger 1997). The Upper Cedar Creek watershed was a significant abandoned mine land problem (MDNR 2004). Periodic discharges of acid mine drainage and acidic sediments severely impacted water quality and resulted in numerous fish kills from 1948 until 1980. The 71-km segment of stream was declared lifeless several times during that period.

In the 1980's, the Missouri Department of Natural Resources' (MDNR) Land Reclamation Program (LRP) Section reclaimed over 280 hectares in the Upper Cedar Creek watershed. Acid mine drainage was reduced, although the main reclamation objective was to remove health and public safety hazards as required by the national AML Program. The overburden remained extremely acid-forming with high concentrations of pyrite. Acid-forming mine spoil and coal waste continued to generate enormous water quality problems in the form of large acid seeps. Flooding in the 1990's damaged significant portions of stream banks in Upper Cedar Creek (MDNR 2003). Additional acid-forming materials were exposed and more tailings and sediment entered Cedar Creek. In 1999, the Missouri Department of Natural Resources' LRP Section initiated the Upper Cedar Creek Clean Streams Project to repair the damage, remediate acid seeps, minimize future flooding impacts and improve Cedar Creek's water quality to meet state water quality standards with funds from the AML Program Clean Streams Initiative and a U.S. Environmental Protection Agency (USEPA) 319 grant.

Current Reclamation Project

Six acid-mine drainage treatment wetlands (four were completed in 2001; two additional wetlands were completed in 2002) were constructed to add alkalinity, increase pH and remove dissolved sulfates and metals from the mine drainage. Two wetlands were constructed using a process known as Successive Alkalinity Producing Systems (SAPS), which consisted of a "layer cake" of limestone rock, compost and standing water. Water is forced through layers of perforated PVC pipes on the bottom of the wetland. Impounded water in the wetland creates the hydraulic head necessary to push the water into the pipes. As water moves through the compost, dissolved oxygen is removed by the decomposition of organic compost, and ferric (Fe^{3+}) ion is reduced to ferrous (Fe^{2+}) iron in the compost layer. Sulfates and additional dissolved metals such as aluminum are also removed in this process. A portion of the limestone rock immediately neutralizes acidity in the mine drainage. More importantly, the calcium carbonate in the limestone is readily solubilized in the oxygen-poor water. Excess alkalinity in the treated drainage flows downstream neutralizing additional inputs of acidity that may enter the stream along the way. This process buffers the stream from periodic, rapid water quality changes that could harm aquatic organism and ecosystem stability. Anaerobic, compost-filled wetlands enclose the SAPS cells. These are very similar to the SAPS cells except water is not pulled through a piping system. Mine drainage slowly moves through the layer cake of limestone and compost as horizontal flow as opposed to the vertical flow created by the SAPS' hydraulic head.

The compost provides a rich substrate for sulfate-consuming bacteria. Sulfates and metals are removed, and alkalinity is increased in a similar fashion as in the SAPS cells, but at a slower rate.

Four anaerobic, compost wetlands called OLA (organic matter, limestone rock and agricultural lime) cells were also constructed. Two are free standing and not connected to the SAPS. These OLA cells were located in areas where the water quality was not as poor as that near the SAPS. All OLA cells were excavated 0.75 m below the proposed water elevation of each cell. Standing water (0.3 m) was placed over approximately 1-cm thick layer of limestone rock and a 2-cm thick layer of a mixture of compost and agricultural lime in the OLA cells.

Additional reclamation to the site included amending and re-vegetating barren spoil and mine land, as well as repairing 823 linear meters of streambank. This work was completed in 2002. Additional native grass seeding and tree planting were completed to promote long-term stream bank and wetland stability. A complete description of the Upper Cedar Creek Reclamation Project can be found in MDNR's final report (2003).

Need for Biological Assessments

Water quality criteria are the primary regulatory authority used in the United States to protect aquatic ecosystems; however, water quality criteria are not always protective of aquatic life (LaPoint et al. 1989). Water quality criteria are established for single chemicals, yet biological communities are often exposed to mixtures of chemicals and to chemicals for which no criteria exist. Therefore, biological impairment can occur due to contaminants even though regulatory criteria are not exceeded. Community-level biological assessments are frequently used to measure the impacts of contaminants on aquatic resources (USEPA 1994). Biological assessments can integrate the combined effects of other physical (e.g., substrate degradation, temperature alteration, low dissolved oxygen) and biological (e.g., disease, predation, species displacement due to competition) stressors. These measures provide direct assessments of aquatic resources and thus can be very cost-effective tools for measuring biological recovery.

The influence of physical habitat alteration can often lead to biological effects that could be incorrectly attributed to contaminant exposure. For example, in many Midwestern streams, substrate is highly embedded due to sedimentation which can alter physical habitat available for aquatic invertebrates. Substrate quality can also vary spatially in aquatic systems which can increase the variation in benthic invertebrate distributions and can decrease the statistical power of an assessment design. Therefore, artificial substrates are frequently used as an effective technique for sampling benthic invertebrates in aquatic systems (Rosenberg and Resh 1982). Artificial substrates can be used to estimate abundance and distribution of herpobenthos (sediment-dwelling) and haptobenthos (interface-dwelling) in aquatic systems and have been shown to be less variable than other sampling methods (Voshell and Simmons 1984). They can be used in a wide variety of aquatic habitats to provide benthic community information for many types of field studies, including contaminant exposures, multiple stressor effects, and biomonitoring.

Several types of artificial substrates are presently in use, and can be categorized as either totally artificial or artificially manipulated enclosures with natural materials, such as leaves. The latter are known to collect significantly more species than grab samples (Voshell and Simmons 1977). Dobson (1991) found that leaf-retaining mesh bags collected a fauna highly similar to that of natural leaf litter accumulations in streams, while King et al. (1987) found mesh bags collected benthic invertebrate densities higher than that of natural accumulations. Artificial Leaf

Retaining Devices (ALRDs or leaf packs) are intended to quantitatively sample benthic invertebrates from lentic or lotic aquatic systems. Leaf packs can yield samples that require shorter sample processing and sorting time, and allow more replicates to be included in the sample design.

Decomposition of leaves is used as an indicator of ecosystem health and recovery because it integrates the combined influence of physical (e.g., temperature, current velocity, and physical abrasion), chemical (e.g., pH, temperature, and metals), and biological (e.g., microbial activity, macroinvertebrate shredding/scraping activity) factors on leaf decomposition that is important to the metabolism of small streams (Petersen and Cummins 1974). Leaf decomposition rates have been shown under controlled experimental conditions to be sensitive to both contaminants (Fairchild et al. 1983, 1984) and nutrients (Fairchild et al. 1984).

Study Objective

The objective of the study was to determine the success of the wetland construction reclamation activities conducted at the Cedar Creek AML site during 2000-2002. We monitored habitat quality, water quality, dissolved metal concentrations, fish and benthic invertebrate community structures, and leaf decomposition rates over a four-year period to assess the rates of recovery of stream communities. We studied a number of physical, chemical and biological indicators in order to determine which methods offered the most sensitive indicators of the health of the aquatic system.

Methods

Site Description

We selected ten sites on Cedar Creek and several of its tributaries (Table 1, Figure 1). Cedar Creek is defined as a Class C stream (may cease to flow in dry periods, but maintains permanent pools that support aquatic life) (MDNR 2004). Bimonthly samples for water quality were taken at all sites to characterize the temporal and spatial response to the site restoration. Seven of the ten sites were studied using biological assessments.

Sites were identified using a global positioning system receiver (GPS). Watershed area was developed with data from the Missouri Spatial Data Information Service (MSDIS) (http://msdis.missouri.edu/msdis/html) (MDNR 1991). Watershed size was mapped using 30-m digital elevation model (DEM) in Arc Map 8.0 hydro utility. Watershed areas were developed based on GPS locations; by filling in sinks, and calculating flow direction and accumulation using a threshold of 10,000. Maps are formatted in UTM Nad83 meters. Stream order was based on the Strahler stream order procedure using a threshold of 10,000. Stream order and stream size is known to be a strong factor controlling aquatic community structure.

Water Quality

Water quality measurements (e.g., temperature, pH, conductivity, dissolved oxygen) were measured in situ bimonthly using a Hydrolab® DataSonde 3 Multi-parameter Water Quality Instrument and Surveyor 4 Data Display or a Quanta Multi-parameter Water Quality Monitoring Device (Hydrolab Instruments, Loveland, CO). Subsurface grab samples were also taken bimonthly for analysis of turbidity, alkalinity, and hardness. Samples were stored at 4 °C until analyses. Alkalinity and hardness were determined by titration (APHA 1998) within 24-hr of collection. Precision and accuracy were determined based on independent, certified standards on each day samples were analyzed. Well water at CERC is extremely consistent for pH, alkalinity and hardness; therefore it was used as a secondary reference sample. Yearly recoveries of alkalinity and hardness were compared to the overall study means to determine percent recovery.

Nutrients [e.g., total dissolved nitrogen (TN), total dissolved phosphorous (TP), soluble reactive phosphorous (SRP), dissolved nitrite/ nitrate (NO_2/NO_3), dissolved ammonia (NH_3)] were measured during leafpack deployment. Subsurface grab samples were filtered through a 0.4 μm-polycarbonate filter. Samples were kept at 4 °C (e.g., SRP, NO_2/NO_3, NH_3) or frozen (e.g., TN, TP) until analysis. Samples were analyzed with a Technicon® Autoanalyzer using colorimetric detection (Tarrytown, NY) (2000-2002). All samples were analyzed within the 30-d regulatory period (APHA 1998). Ammonia was analyzed as total ammonia using a salicylate/ nitroprusside colorimetric reaction (detection limit 0.1 mg/L total ammonia-N). Nitrite/ nitrate was measured by cadmium reduction (method adapted from Technicon® Industrial Method No. 158-71W). Soluble reactive phosphorus was determined using the automated ascorbic acid method (APHA 1998). Total phosphorus and total nitrogen samples were digested using the sodium hydroxide and potassium persulfate digestion, and subsequently analyzed using the automated ascorbic acid method and the automated cadmium reduction methods, respectively (APHA 1998). Concentrations were calculated based on a five-point standard curve. Precision and accuracy were determined based on triplicate analysis of independent, certified standards on each day samples were analyzed.

Water samples were collected for sulfate analysis by MDNR and provided to CERC for review and inclusion in this report (MDNR 2004; MDNR, personal communication). Water samples were taken at several study sites (e.g., Sites 2, 3, 5, 6, 9 and 10), as well as several sites in the reclamation area (i.e., wetlands, wells, lakes).

Elemental Analysis

Elemental analyses were conducted on water samples annually. Subsurface grab samples were filtered on-site through a 0.4-µm polycarbonate filter into a pre-cleaned polyethelene bottle. Samples were transported to CERC on ice and acidified using Ultrex® ultrapure nitric acid to 1% within six hours of collection. Filter blanks were also prepared using the same protocol. The samples were stored at 4 °C for no more than six months before analysis.

No additional chemical preparation was conducted on the samples prior to instrumental analysis. To perform a "scan" of elements, samples were analyzed by inductively-coupled plasma-mass spectrometry (ICP-MS) using the semi-quantitative scan mode (TotalQuant®). The scanning mode has a manufacturer's reported accuracy of ± 30-50%. All samples were diluted 10X by a CETAC ASD-500 autodiluter as part of the analytical sequence. Internal standards were germanium (50 ppb), rhodium (10 ppb), and thallium (10 ppb), which were metered into the sample line via peristaltic pump. The external standard consisted of a NIST traceable reference solution (Trace Metals in Drinking Water; High Purity Standard, Charleston, SC) to which five elements (praseodymium, terbium, thulium, tantalum, and gold) were added for improved calibration in the rare earth region of the mass spectral range.

Quality control included calibration check standards (Spex CertiPrep Inc., Metuchen, NJ), and a laboratory control sample ran repeatedly for a with-in run precision measurement (Trace Metals in Drinking Water; High Purity Standard, Charleston, SC), and monitoring of internal standards at the beginning and end of the run to determine instrumental drift. Most quality control results were tabulated to provide an overview of the quality assurance and to facilitate interpretation. Procedures for calculating QC statistics are as follows:

Percent Relative Standard Deviation (%RSD) = SD/Mean x 100;

Relative Percent Difference or %RPD = (D1-D2)/Mean x 100;

Percent Spike Recovery = (Total Measured – Background)/Spike Amount x 100;

Method Limit of Detection = $3 \times (SD_b^2 + SD_s^2)^{1/2}$ where

SD_b = standard deviation of a blank or low level standard and
SD_s = standard deviation of a low level sample.

Habitat

Habitat quality was assessed in the fall of 1999 using the MDNR Stream Habitat Assessment Protocol (1995). The protocol was developed to support community-level macroinvertebrate surveys in wadeable streams of Missouri. Quantitative and qualitative features of riffle/run or glide/pool habitats were scored at each site. Habitat variables were categorized as primary, which have the greatest influence on the structure of indigenous communities (e.g., bottom substrate or instream cover, embeddedness, stream depth or velocity, canopy cover, pool variability); secondary, which characterize channel morphology (e.g., island and point bar growth, bottom scouring and deposition, riffle-to-riffle width ratio, lower bank channel capacity), and tertiary, which characterize riparian and bank structure in the upstream section of the watershed (e.g., upper bank stability, bank vegetative stability, streamside cover, riparian vegetative zone width). Variables were summed and scored for each site. Assessment categories were defined as 1) comparable to reference (≥ 90%); 2) supporting of aquatic resources (75-89%); 3) partially supporting of aquatic resources (60-74%), and 4) non-supporting of aquatic resources (< 59%). Reference values used to place sites into these habitat categories were derived from Site 3 in Cedar Creek that was above the reclaimed area.

Substrate for particle size analysis (PSA) was collected using a 1.1-L cylindrical grab sampler in 1999 near location of leaf packs. Five substrate samples were wet-sieved (e.g., 38.1-, 19.0-, 9.5-, 2.0-mm sieves) and weighed in the field. Materials passing through the 2.0-mm sieve were retained for further particle size by gravimetric analysis. The percentages of sand-, silt- and clay-sized particles were determined by the Buoyocous density gradient method (ASTM 1963).

Leaf packs

Leaf packs were fabricated of ½”-mesh black aquaculture netting (polymesh) (Memphis Net and Twine, Memphis, TN) designed to contain leaf substrate and reduce substrate loss due to leaf fragmentation. Polymesh was cut into 15 x 21-cm squares, folded in half, and closed on three sides with nylon Zipties®. Cottonwood (*Populus deltoids*) leaves were collected from the riparian zone of Hinkson Creek (Boone County, Missouri) after leaf fall. Prior to insertion into leaf packs, leaves were soaked in distilled water for 24 hr, air-dried and weighed. Approximately 20 individual leaves were placed in the polymesh, which was closed using Zipties® and placed in a Ziplock® bag. A small amount of CERC well water was placed in each bag to keep the leaves moist. Leaf packs were stored at 4 °C until deployment. Leaf packs were prepared immediately prior to deployment.

Five leaf packs were deployed at each site. Leaf packs were attached to individual bricks using Zipties®. A plastic-coated stainless steel cable was strung through each brick and anchored to a tree located on the streambank, and instream by three bricks placed downstream of the leaf packs. Bricks were placed on the stream substrate parallel to the current at a water depth sufficient to maintain immersion for approximately 28 d. The distance between samplers was standardized at each site. Although the number of days the leaf packs were deployed varied between years (23-44 days), all leaf packs were deployed and retrieved on the same day in each year. Temperature was also measured at each site hourly during leafpack deployment using Onset® Tidbits (Bourne, MA).

Leaf packs were retrieved starting at the most downstream leaf pack moving upstream to minimize disturbance. Leaf packs were carefully lifted off the stream bottom. A D-net was immediately placed under the leaf pack to catch any organisms that fell off the leaf pack. Leaf packs were cut from the brick and placed in Ziplock® bags with a small amount of stream water. Bricks and the D-net were examined for invertebrates. If any organisms were found, they were placed in the Ziplock® bag. Leaf packs were stored on ice until they were processed.

Leaves and fragments larger than one centimeter were removed from the polymesh and washed through a 400-µm sieve to remove organisms. Organisms were placed into a labeled sample bottle with 80% ethanol. Leaf material was air-dried for seven days and weighed to compare the difference in pre-deployment and final leaf weight.

Organisms were sorted from debris using a dissecting microscope under 10X magnification. A total count of organisms was made. During sorting, organisms were removed from debris and placed into two separate vials: 1) species such as midge larvae (Diptera: Chironomidae) that require mounting on glass slides for identification, and 2) those that can be identified with a dissecting microscope and do not require slide mounting techniques. Permanent mounts of midge larvae and their head capsules were made with CMCP-10 mounting media (Masters Chemical Company, Des Plaines, IL), and were allowed to dry for 4-6 weeks before taxonomic identification. Organisms were identified and enumerated to the lowest taxonomic level, usually genus or species, except Oligochaeta that was identified to family. Benthic invertebrates were identified according to criteria presented by Brown (1972), Lewis (1974), Schuster and Etnier (1978), Bedmarik and McCafferty (1979), Morihara and McCafferty (1979), Widerholm (1983), Merritt and Cummins (1996), Schefter and Wiggins (1986), Pennak (1989), Poulton and Stewart (1991), and Thorp and Covitch (1991).

Fish

Fish were collected annually at each site after leaf packs were retrieved. Fish were collected in reaches that contained a full complement of riffles, runs and pools using 3-mm (1/8") mesh seines, except where indicated in Table 2. The width of seines varied (9.1, 12.2 or 15.2 m) depending on the width of stream sampled. Seines were 1.6 m (6') deep. Approximately 100-m sections were blocked off (with seines) at the upstream and downstream end of each section. In some cases, two segments of stream were sampled at each site to obtain 100 m because of low water. These segments were separated by a sand or gravel bar which was less than 2 m in width. Two successive passes were made in each segment of stream. Fish collected in multiple passes were combined to represent the fish assemblage present at that place and time. Fishes were identified on-site according to the criteria presented by Pfleiger (1997). Fish that could not be identified on site and voucher specimens were placed in 10% formalin for subsequent laboratory identification and confirmation. Fish were transferred to 80% ethanol after two weeks. Matt Winston (formerly Missouri Department of Conservation State Ichthyologist) verified fish identifications. All crayfish collected during seining were counted and released. Area sampled was calculated for each site for all years and used to standardized normalize total number of fish and the total number of crayfish.

Statistical Analysis

Data were tested for normality prior to statistical comparisons using the Proc Univariate procedure and the Shapiro-Wilk's statistic (SAS 1990). Water quality parameters were evaluated using two-way analysis of variance using year, site and year*site interaction. Water quality measurements analyzed were restricted to those taken during leafpack deployment.

Leaf decomposition rates were calculated by dividing total weight loss by the number of days the leaf packs were deployed. Data were tested for normality using Proc Univariate and the Shapiro-Wilk's Statistic (SAS 1990), and were found to be normally distributed. However, we evaluated leaf decomposition with two-way analysis of variance on ranked data using year, site, and the year*site interaction. Bivariate correlation analysis and multivariate stepwise regression with a Bonferroni correction ($\alpha = 0.05$) on ranked data were also conducted to further evaluate leaf decomposition. All data were pooled by all sites and years. All significance levels were maintained at the $p \leq 0.05$ level.

Fish and invertebrate data were not normality distributed, so all data was ranked and all analyses were done on the ranked data. Three community measures were used to statistically compare fish and invertebrate data between the sites and years. These analyses were performed using 1) total number of organisms (i.e., fish or invertebrates); 2) taxa richness, and 3) Simpson's Dominance (d'). A two-way analysis of variance was applied to the ranked data using year, site and year*site (invertebrates), and time, site and time*site (fish). Time was designated as "before" (1999 and 2000) and "after" (2001 and 2002) reclamation. To further evaluate factors affecting the fish taxa richness, we conducted a bivariate correlation analysis with a Bonferroni correction ($\alpha = 0.05$), as well as multivariate stepwise regression on ranked data. Ranked invertebrate data were also analyzed with the GLM procedure (SAS 1990) by year and by site. Tukey's Multiple Range Test was used for pair-wise comparisons between sites to identify significant differences between all site comparisons for each year. All significance levels were maintained at the $p \leq 0.05$ level.

Community data derived from colonization of leaf packs was used to evaluate the relative condition or biotic quality of the sites. This was accomplished by calculating attributes ("metrics") that are known to be indicators of overall water and habitat quality conditions in streams and rivers based on USEPA (1994) and Barbour et al. (1999). The choice of metrics was based on their appropriateness for application to leafpack data, and included 1) species richness measures (total taxa richness, and taxa richness of EPT, the Ephemeroptera, Plecoptera and Trichoptera), 2) species abundance and dominance measures (EPT abundance relative to total, density reported as number of organisms per gm leaf pack weight, abundance of Chironomidae, and abundance of Oligochaeta), and 3) functional feeding group measures (abundance of shredders, abundance of scrapers, and the ratio of scrapers to filtering collectors).

Each site was also scored independently for each of the seven metrics. Two different scoring assignment methods were applied to the mean metric values: 1) percentiles, and 2) proportional scaling. The percentile (%-tile) scoring included three categories; the two sites with the best values were given a score of 5, the sites with metric values in the middle 43% of the distribution (three sites out of seven) were given a score of 3, and the two sites with the worst values were given a score of 1. This three-category scoring system is similar to the one used by MDNR for evaluation of aquatic life use support in Missouri streams (MDNR 2001a; 2001b).

Metric values were also standardized across the seven sites using proportional scaling (Kreis 1988), where the sites were assigned proportional values from 1 (worst) to 100 (best) for each metric. Among the metrics calculated, the ones that appeared to demonstrate response patterns were included in multi-metric scoring, and a total site score was calculated by adding scores for each of the individual metrics included (Barbour et al. 1995). The scores resulting from these methods were used as the basis for ranking the relative quality or biotic condition of the sites.

Results and Discussion

Habitat

Stream order ranged from 1 to 4 for the water quality assessment sites (10 sites) and from 3 to 4 for the biological assessment sites (7 sites) (Table 1). Watershed size at the Cedar Creek sites progressively increased downstream (Figure 1). Watershed size in Renfro (Site 5) and Manacle Creek (Site 9) was approximately 50-65% smaller than Site 3 (our reference site).

Physical habitat (e.g., substrate, depth, current velocity, bank stability) represents the basic template for the assessment of fish and invertebrate community structure. Change in the quality and quantity of physical habitat is frequently the cause of altered community structure, and must be assessed in conjunction with water quality in order to properly diagnose the cause of biological impairment. We assessed physical habitat on both the local scale (i.e., substrate particle size) and the reach scale (using the MDNR multi-metric assessment protocol).

Substrate from Sites 4, 7 and 9 were predominately sand (Table 3). Site 4 had a greater proportion of gravel substrates than Sites 7 and 9, which had very little gravel-size or larger particles. Approximately 6% of the substrate at Sites 4, 7 and 9 were clay and silt. Site 5 had the greatest percentage of silt (7%). Substrates at Sites 5, 8 and 9 were predominately composed of large particle sizes. We did not collect large cobble and boulder substrate in our substrate sample at Site 8 because of the limitations of our sampling technique (i.e., the larger particles could not fit into our sampling container). Although we only collected substrate for analysis in the first year of the study, substrate and bank condition did not seem to vary greatly between years. The sites remained predominately sand and gravel, except at Site 8 which contained cobble and boulders. Riparian vegetation remained relatively stable, and we observed no increase in siltation in the sediment at our sites.

Habitat assessment scores are listed in Table 4. Sites 4, 7 and 9 had the lowest assessment scores for both riffle and pool habitats. The overall low scores can be attributed poor bank and substrate stability. No sites were classified as not supporting of aquatic life (Table 5). Sites 8 and 10 were comparable to Site 3 (reference site) for both pool and riffle habitats. Site 5 was comparable to Site 3 for pool habitats; however, it could only be classified as supporting for riffle habitats. Site 9 was supporting for pool habitats, however only partially supporting for riffle habitats. Sites 4 and 7 had the poorest habitat quality and were only partially supporting for both pool and riffle habitats. We expect that the reclamation completed in 2002 which included repairing stream banks, as well as the seeding and planting of trees, will increase the quality of habitat in Cedar Creek, especially at Site 4, which was directly downstream of the AML site.

Quality Assurance for Water Quality

Percent recoveries of all standards for field water quality parameters were close to 100% (Table 6). Standards for laboratory analyses ranged from 86-116% (Table 7). In addition to water quality standards, CERC well water was analyzed and data were very consistent throughout the study (Table 8).

Quality Assurance for Metals Analysis

Filter blanks were taken in each year (Table 9) and were within acceptable limits as specified by CERC. Independent calibration-check standards were analyzed as laboratory control samples to verify the accuracy of the external standard for certain elements. Recoveries of elements from the SPEX ClariasPPT solution ranged from 76% to 137% in 1999 (Table 10a); 96% to 126% in 2000 for all elements except potassium and strontium (Table 11a); 96% to 123% in 2001 for all elements except potassium, iron and strontium (Table 12a), and 94% to 134% in 2002 (Table 13a). To check the accuracy of the five elements that were added to the external standard, a separate SPEC Multi-element Standard was analyzed. Recoveries of the five elements added to the external varied from 98% to 142% in 1999 (Table 10b); 92% to 96% in 2000 (Table 11b); 101% to 135% in 2001 (Table 12b), and 94% to 125% in 2002 (Table 13b). An NIST traceable solution was analyzed at the beginning, middle and end of the run as a check on accuracy and within-run precision. Percent relative standard deviations were < 12% in 1999 (Table 14); < 16% in 2000 (Table 15); < 10% in 2001 (Table 16), and < 11% in 2002 for all elements except iron (22%) and Sr (24%) (Table 17). Internal standard intensities from the beginning to the end of a run increased 12% to 15% in 1999; < 18% in 2000; < 10% in 2001, and < 8% in 2002 (Table 18). Overall, the quality control was within acceptable limits as specified by CERC.

Water Quality

Water quality was examined on an annual cycle (Table 19); during leafpack deployment in May and June (Table 20), and during the winter (Table 21). In general, water quality improved over time.

Average annual temperature was similar between years and sites (Figure 2), and ranged between 2 °C and 33 °C. Although there was no significant difference between temperature between sites ($p = 0.9751$), years ($p = 0.9036$) or site*year ($p = 1.00$) during leafpack deployment, there appeared to be a difference in winter temperatures. Temperatures during the winter of 2000-2001 did not go above 5 °C throughout most of the winter. Colder temperatures may have slowed invertebrate development resulting in delayed emergence and more invertebrates on the leaf packs. Heavy rainfall in May 2002 (Table 23; Figure 3) may also have reduced water temperatures at the time of deployment by 3-5 °C compared to previous years.

Comparison of pH data indicates a significant recovery of water quality conditions over the course of the 4-yr restoration project. There was a significant difference in pH between sites ($p < 0.0001$) and year ($p = 0.0037$). Average pH at Site 4 generally increased and was less variable over time (Figure 4). Average pH was generally lower during the winter, when water levels were lowest and mine seepage had the greatest impact on water quality, but did increase after reclamation was completed. Average pH in Manacle Creek (Site 9) was consistently lower than all sites. No excursions below the criterion for pH of 6 (MDNR 2004) occurred in Cedar Creek after 2000.

There were significant differences in conductivity between sites ($p < 0.0001$) and years ($p < 0.0001$). Sites 1, 2 and 3 had the lowest conductivities and were all located upstream of the AML site. Conductivities in Cedar Creek and Renfro Creek were within the range (50-1500 μs/cm) of potable waters in the United States (MDNR 1995), except during 2000. Reclamation done in 2000 may have resulted in the increased conductivity at Sites 4, 6, and 7, which were directly downstream of the AML reclamation site (Figure 5). Renfro and Manacle Creeks (Sites 5 and 9) both contain abandoned mine land in their watersheds, which may contribute to high conductivities. Conductivity was one of the most cost effective and sensitive physical indicators of mine drainage in this study.

There was no significant difference in dissolved oxygen concentrations between sites ($p = 0.1244$), however there was a significant difference between years ($p < 0.0001$) (Figure 6). Average dissolved oxygen concentrations were generally highest during the winter and lowest in the summer. Dissolved oxygen concentrations did fall below 5.0 mg/L, the recommended concentration for warmwater streams (MDNR 1995) during all four years of the study. Dissolved oxygen concentrations improved overtime with fewer excursions below 5 mg/L in 2001 and 2002.

There was a significant difference in turbidity between years ($p < 0.0001$), but not between sites (Figure 7). Turbidities in Renfro Creek (Site 5) and Manacle Creek were similar to those in Cedar Creek except for two early peaks in the spring of 2000 (Site 5) and 2001 (Site 9). These sites scored lowest in our habitat assessment with poor riparian and bank stability. Turbidity was greatest in the spring; however, turbidities did not seem to be correlated well with rainfall (Table 22) (Figure 3). Turbidity at all sites in 1999 and 2002 were similar despite a three-fold difference in rainfall between those years. The highest turbidities occurred during 2000 and 2001, while peak rainfall occurred in 2002. Reclamation activities in 2000 and 2001 may have resulted in the higher observed turbidities. Watershed size may also affect turbidities. Sites 1, 2, 3, 5 and 9 had the smallest watershed size and the greatest changes in turbidity.

High flow events increase herbicides, pesticides, turbidity and nutrients in streams with agriculture in its watershed (Richards and Baker 1993). Acute and chronic exposure to herbicides and pesticides may impact fish and invertebrate communities directly or indirectly by killing algae and macrophytes, which are used by these communities as food and shelter. Increases in flow also resulted in higher pH, lower hardness and conductivities which reflected the decrease in the influence of mine drainage into Cedar Creek and its tributaries.

There were significant differences in alkalinity between sites ($p < 0.0001$) and years ($p = 0.0121$). Alkalinity generally was lowest during the winter (Figure 8). Alkalinity showed the greatest increase at Sites 4, 6 and 7, which were downstream of the AML site, suggesting that the constructed wetlands are neutralizing the acid seeps. Alkalinity remained low (< 50 mg/L $CaCO_3$) at Site 9 (Manacle Creek). This watershed contains additional acid seeps which have not been reclaimed due to landowner resistance. Alkalinity was a sensitive indicator of recovery of the Cedar Creek system. It is easily measured, and provides a useful assessment of the buffering capacity for hydrogen ions in the system.

There also were significant differences in hardness between sites ($p < 0.0001$) and years ($p < 0.0001$). Hardness values were greatest during the winter (Figure 9), but significantly declined after reclamation. Hardness remained high in Manacle Creek (Site 9), again influenced by additional acid seeps located within the watershed. Hardness is a functional measurement of the total divalent cations present in water. Further information regarding the chemical constituents contributing to hardness is provided below under the Elemental Analysis Section.

Average concentrations of NH_3 NO_2/NO_3, TN, SRP, and TP collected during leafpack deployment are listed in Table 23. Concentrations of all nutrients were high and are reflective of the agricultural activities (i.e., row crops and cattle) in the watershed. Nutrient concentrations generally declined during the 4-yr study.

Sulfate data collected at several of the study sites from the early 1980's through 2003 showed improvement in Cedar Creek (Table 24; Figure 10) (MDNR 2004; MDNR, personal communication); however sulfate levels continue to remain high in Renfro and Manacle Creeks. Sulfate concentrations at all of the study sites except Site 9 were below 960 mg/L, which was the water quality criterion set for sulfates (MDNR 2004). Sulfate concentrations at Site 5 (Renfro Creek) remain high and contribute to the high sulfate concentrations at Site 6, which is located just below the confluence of Cedar and Renfro Creek. Numerous acid seeps at the southeast corner of the Cedar Creek AML site and within the Manacle Creek watershed could not be reclaimed because of landowner resistance. Unreclaimed abandoned mine land in the watershed is the probable source of the high sulfate concentrations.

Sulfate data collected from the AML site (Table 25; Figure 11) indicate that there are still acid-forming materials on the site which have not been completely neutralized by the reclamation activities, but are not impacting the water quality in Cedar Creek. Sulfate concentrations on the reclamation area also peaked during the period of construction, but should continue to drop in wells and constructed wetlands as they come on-line.

Sulfate criteria are primarily based on human health issues such as odor and taste; however, they can have effects on aquatic communities. Sulfates, which are formed when pyrite (iron sulfide) weathers and oxidizes in water, are much less toxic than sulfides. Sulfates do have the ability to form strong acids and are involved with complexing and precipitation reactions, which can affect the solubility of metals such as aluminum and iron. At low pH, metals stay in solution, but at increased pH, metals such as iron, can precipitate and clog gills of fish and invertebrates. The reclamation activities (e.g., construction of the SAPs) should continue to increase pH and reduce the amount of sulfates in the water being discharged from the reclamation site. There was a significant increase in pH in Cedar Creek during this study, resulting in no excursions below water criterion for pH, which should be not impair the fish community.

Elemental Analysis

Concentrations of elements for all four years are listed in Table 26. Concentrations of major ions, including calcium, magnesium, iron, potassium, and sodium were similar to other prairie-border streams in North Central Missouri (Hauck, et al. 1997). Calcium concentrations did not show an increase during the study at any sites, however concentrations of calcium did increase one-to-two fold in 2000. Magnesium concentrations generally declined at all sites during the study, however concentrations also increased during 2000. Concentrations of metals generally increased in 2000 and 2001 during the period of most of the construction at the reclamation site. Aluminum (Figures 12) concentrations at all sites were generally elevated in 2000, with the highest concentration was at Site 4; however, concentrations in the two tributaries (Sites 5 and 9) were also elevated and remained so in 2001. Lead concentrations were low at all sites, except at Sites 5 and 7 in 2000. Concentrations of manganese (Figure 13) were also elevated in 2000, and were highest at Sites 4 and 7, which were located directly downstream of the AML site. Concentrations of zinc were highest at the site directly below the AML site (e.g., Site 4) and in the two tributaries (e.g., Sites 7 and 9).

Water quality criteria for selected metals (e.g., aluminum, cadmium, copper, lead, nickel, zinc) were only exceeded at two sites during 2000 (Table 26) (USEPA 2002). The concentration of aluminum at Site 4 (1600 µg/L) exceeded the acute (750 µg/L) and chronic (87 µg/L) criteria. The concentration of zinc at Site 9 (400 µg/L) exceeded both the acute (360 µg/L) and chronic (330 µg/L) criteria. The concentration of lead at Site 7 approached the chronic criteria for lead (17µg/L).

Leaf Decomposition

Leaf weight loss is listed in Table 27 and Figure 14. Average leaf weight loss ranged from 20-80% among sites and years. A two-way analysis of variance indicated that there were significant differences in leaf decomposition by year (< 0.0001) and by site (< 0.0001); however, the year*site interaction was also significant ($p = 0.0007$) (Table 28). There were no consistent trends of changes in leaf decomposition rates at sites considered to be “impacted” by mine drainage (e.g., Sites 4, 5, or 9) or those considered as non-impacted (e.g., Site 3 or 10).

This significant statistical interaction between year and site indicates that there were a large number of variables that may have affected decomposition rates. Therefore, we conducted bivariate correlation analysis of leaf decomposition to explore relationships among variables. Results of the bivariate correlations are presented in Table 29. Leaf decomposition was not significantly related to any water quality variable, nutrients, or benthic invertebrate metric. Nutrients have been shown to significantly increase decomposition of leaves in laboratory studies (Fairchild et al. 1984). However, Fairchild et al. (1987) found no effects of sediment and associated nutrients in experiments conducted in outdoor experimental streams where current velocity of riffles appeared to be a large factor controlling leaf decomposition.

A stepwise regression analysis indicated that leaf weight loss was best explained by a combination of magnesium ($r^2 = 0.328$; $p = 0.0004$), turbidity ($r^2 = 0.630$; $p < 0.0001$), number of EPT taxa (r^2 = 0.689; p = 0.0084), total number of scrapers (r^2 = 0.739; p = 0.0213), temperature (r^2 = 0.771; p = 0.0213) and copper (r^2 = 0.817; p = 0.0317), which explained 82% total variance in decomposition rates (Table 30).

Macroinvertebrates

The list of distinct macroinvertebrate taxa collected during the study is given in Table 31. Macroinvertebrates data collected during the study are listed in Table 32. The two-way analysis of variance (ANOVA) showed significant differences in the total number of macroinvertebrates, taxa richness and Simpson's Dominance by year ($p < 0.0001$), site ($p < 0.0001$) and year*site ($p < 0.0001$) (Table 33).

Results based on least square means and Duncan's Multiple Range tests are shown in Table 34. When all sites and years were pooled for all comparisons, the total number of macroinvertebrates was significantly greater at Sites 3, 4, 7, and 10 in 1999, and Site 3 in 2000 (Table 34a). Site 5 in 2000 and Site 4 in 2002 had statistically fewer numbers of macroinvertebrates than all other sites or years. All other comparisons were indistinguishable. There were similar trends for macroinvertebrate taxa richness (Table 34b). Sites 3, 4, 7, and 10 in 1999, and Site 3 in 2000 had the greatest taxa richness, while Site 5 in 1999 and Site 4 in 2002 had the least taxa richness. Multiple comparisons for macroinvertebrate Simpson's Dominance resulted in fewer groupings, but showed results (Table 34c). Macroinvertebrate Simpson's Dominance at Site 4 in 2002 was significantly higher than all other sites in all years. Sites 3, 4, 7, and 10 in 1999; Site 3 in 2000, and Site 10 in 2001 had the lowest mean Simpson's Dominance when compared by all sites and years.

The significant year*site interaction of the two-way ANOVA indicated that differences were not due to simply site or year alone. Therefore, we examined the relationship between benthic invertebrates and other physical, chemical, and biological variables using bivariate correlation analysis. Results are presented in Table 29. Taxa richness was positively correlated with total number of filter-collectors ($r^2 = 0.717$; $p < 0.0001$), scrapers ($r^2 = 0.825$; $p < 0.0001$), and the total number of EPT taxa ($r^2 = 0.794$; $p < 0.0001$). The total number of macroinvertebrates was positively correlated with taxa richness ($r^2 = 0.904$; $p < 0.0001$), scrapers ($r^2 = 0.829$; $p < 0.0001$), and the total number of EPT taxa ($r^2 = 0.753$; $p < 0.0001$). In addition to being correlated with the total number of invertebrates and taxa richness, total number of EPT taxa was positively correlated with scrapers ($r^2 = 0.908$; $p < 0.0001$). The ratio of scraper to filtering collector was positively correlated with scrapers ($r^2 = 0.673$; $p < 0.0001$).

Although the number of invertebrates, taxa richness or any functional group were not correlated to water quality, nutrients or dissolved metal concentrations, there were correlations between those variables. Salinity ($r^2 = -0.799$; $p = 0.0301$), calcium ($r^2 = -0.783$; $p < 0.0001$), manganese ($r^2 = 0.981$; $p < 0.0001$), and nickel ($r^2 = -0.740$; $p < 0.0001$) were all negatively correlated with pH. Magnesium was positively correlated with calcium ($r^2 = 0.711$; $p < 0.0001$), manganese ($r^2 = 0.759$; $p < 0.0001$), and nickel ($r^2 = 0.849$; $p < 0.0001$). Hardness was positively correlated with conductivity ($r^2 = 0.958$; $p < 0.0001$) and salinity ($r^2 = 0.906$; $p < 0.0001$), but negatively correlated with SRP ($r^2 = -0.755$; $p < 0.0001$). Aluminum was positively correlated with ammonia ($r^2 = 0.735$; $p < 0.0001$) and SRP ($r^2 = 0.747$; $p < 0.0001$). Iron was also positively correlated with SRP ($r^2 = 0.747$; $p < 0.0001$). Conductivity was positively correlated with salinity ($r^2 = 0.981$; $p < 0.0001$), but negativity correlated with turbidity ($r^2 = -0.689$; $p < 0.0001$) and SRP ($r^2 = -0.761$; $p < 0.0001$). Turbidity was positively correlated with

TN (r^2 = 0.756; p < 0.0001). Total nitrogen was also positively correlated with NO_2/NO_3 (r^2 = 0.920; p < 0.0001), and SRP (r^2 = 0.787; p < 0.0001). Total phosphorous was positively correlated with ammonia (r^2 = 0.871; p < 0.0001).

Taxa richness is generally accepted as one of the best indicators of water quality (Barbour et al. 1995). We conducted stepwise regression analysis to determine those factors impacting macroinvertebrate taxa richness. Data was pooled by site and year. Taxa richness was best explained by the total number of individuals (r^2 = 0.773; p < 0.0001), total number of filter feeders (r^2 = 0.841; p < 0.0001), cadmium (r^2 = 0.880; p = 0.0013), hardness (r^2 = 0.895; p = 0.0571), potassium (r^2 = 0.919; p = 0.0028), and manganese (r^2 = 0.932; p = 0.0611) which combined to explain a total of 93% of variation (Table 35). Overall, the results of the bivariate and multiple regression analyses indicate that the invertebrate community was positively associated with individual variables such as pH, and negatively associated with variables such as calcium and hardness. There was no influence of metals such as copper, zinc or manganese. When the relationship was examined by multiple regression, macroinvertebrate taxa richness was affected by both biological inter-relationships and water quality. Thus, there were many factors that influenced invertebrate community structure.

To assess the biotic condition and invertebrate colonization potential of the sites, a total of seven metrics were included in combination to provide a relative multi-metric score for the sites in each of the four study years (Tables 36-38) (Figures 15-24). A list of metric values calculated for the sites is given in Table 36. Percent (%) Oligochaeta did not show any pattern, and because the high variability in this metric is often due to the abundance of asexually-reproducing Naididae, it was not included in multi-metric scoring. Similarly, relative abundance

(%) of shredders was also omitted because it was highest at the upstream reference site in only one of the years (2002) and no discernable pattern was evident.

Leafpack colonization data varied considerably between years at many of the sites. All of the sites downstream of previously mined areas were ranked among the lowest in at least one of the study years (Table 37). In contrast, Site 3, upstream of the reclamation area, consistently scored among the highest of the sites, and had the best value for at least three of the seven metrics each year except for 2001 (Tables 36 and 37). Both Renfro Creek (Site 5) and Manacle Creek (Site 9) scored among the lowest in 1999, and had higher scores in 2001 and 2002. Site 4 directly below the reclaimed area, had the lowest rank in 2002 and the highest rank in 2001 based on total scores of scaled metric values.

In general, upstream-downstream patterns in the total multi-metric site scores suggested that 1999 and 2002 were similar to each other, as were 2000 and 2001 (Figure 22). Cedar Creek Sites 6, 8, and 10 had higher values for several metrics during years when the tributary sites (Sites 5 and 9) were in better condition. This was evident in EPT taxa richness (Figure 16), EPT abundance (Figure 17), and abundance of scrapers (Figure 20), which were all higher in 2001 and 2002 at both Manacle and Renfro Creek sites. This is possibly due to increased amounts of rainfall before and during leafpack deployment, which might have resulted in better conditions for invertebrate colonization in these intermittent tributary streams. Invertebrate site scores for Manacle and Renfro Creeks were positively correlated with May rainfall totals across years, and these correlations generated r-values above 0.65 (Figure 23). However, correlations between May rainfall and invertebrate scores for Cedar Creek sites were all negative (Figure 24), and were relatively weak except for the two most downstream (Sites 8 and 10).

The higher abundance and diversity of EPT organisms observed in leaf packs at Site 5 and 9 during the last two years of the study appeared to have a positive influence on colonization at lower Cedar Creek sites that are below their respective confluences. Although Site 4 (upstream of these tributaries) had the best scores in 2001, when EPT abundance was highest, this site had the lowest rank in 2002 with a mean EPT abundance of less than 1%, and the highest mean Chironomidae abundance (80%) observed during the study (Figure 19). In contrast, other Cedar Creek sites below the intermittent tributaries (Sites 6, 8 and 10) had similar invertebrate scores across years (Table 36). Even though Sites 8 and 10 both had higher values for several indicator metrics in the last two years of the study, they still ranked among the lowest relative to other sites (Table 37). In 2000, the sampling period immediately following the greatest pH depressions measured during the study (Figure 3), both mean EPT taxa richness and mean EPT abundance were the lowest at two or more of the lower Cedar Creek sites (Sites 6, 8, and 10). Site 4 also had lower values for these metrics in 2000, but this site did not demonstrate any improvement by 2002 and had the greatest year-to-year fluctuations in multi-metric invertebrate scores. Because the higher scores observed at the two tributary sites and lower Cedar Creek sites (8 and 10) in 2002 were not observed at Site 4, this suggests that the improvement was not due to factors related to the reclamation activities.

Total habitat scores suggest that Sites 4, 5, and 9 have the poorest overall habitat. The differences are mainly due to parameters related to substrate and riparian condition. Correlations between habitat scores and multi-metric invertebrate scores were weak and were all positive except in 2001 (Table 39). Correlations between size of watershed and the number of invertebrates collected ($r = 0.180$; $p = 0.0503$) or number of invertebrate species ($r = 0.252$; $p = 0.0040$) were also weak. Substrate composition affects the overall abundance of macroinvertebrates (Bourassa and Morin 1995). Overall density of invertebrates is greatest on fine and coarse gravel and lower on sand and boulders. Sediments in Cedar Creek may become highly mobile when discharge increases, resulting in a decline of benthic invertebrates (Lugthart and Wallace 1992; Dole-Oliver et al. 1997). High rainfall in 2002 and the presumed increase in stream discharge may have contributed to lower abundances of macroinvertebrates and lower metric scores.

Artificially-constructed leaf packs have been used successfully for assessing the effects of perturbations in stream systems (Scheiring 1993), and may be especially valuable for studies where comparable substrates are not available (Poulton et al. 1998). One of the primary goals of this study was to document the effects of low pH on headwater reaches of Cedar Creek, and to measure any recovery that might have occurred after the reclamation project was completed. The actual values for the metrics calculated in this study could only be used to provide relative comparisons of biotic condition rather than true site quality, because no reference values are available for leaf pack studies conducted in Missouri. Although taxa richness and the total number of macroinvertebrates increased with increasing pH, our data did not show any recovery of Cedar Creek sites in 2002 that could be solely attributed to the current reclamation activities alone, which was not entirely completed until 2002. The data suggests that the amount and timing of rainfall, together with pH depressions and the biotic condition of tributary streams, is having some influence on the invertebrate colonization of leaf packs in Cedar Creek. Based on several invertebrate metrics, year-to-year fluctuations were much greater at all of the sites affected by previously mined areas as compared to the upstream reference site. This is a common occurrence in stream perturbation sources such as mine drainage, where declines in water quality conditions can often occur in pulses (Dills and Rogers 1974). As a result, the relative condition of the invertebrate community fluctuated considerably between years, particularly at Sites 4 and 5. In contrast, the upstream reference site consistently ranked as one of the best two sites during each of the four study years, and was the only site not influenced by previously mined areas.

This study also shows that higher biotic condition at the tributary sites during the last two years of the study had a positive influence on leafpack colonization at Cedar Creek sites that are below their confluences (Sites 6, 8 and 10). It is possible that the higher rainfall amounts during these two years reduced the possibility that pH would be low enough to inhibit invertebrate colonization by sensitive taxa. The sensitivity of both Ephemeroptera and Trichoptera species to low pH levels has been documented in other studies (Feldman and Connor 1992; Rosemond et al. 1992). In our study, the effects of increased rainfall in 2001 and 2002 is most evident in EPT species richness and abundance, suggesting that rehabilitation efforts may be needed at other non-reclaimed locations, including on Renfro and Manacle Creeks, before improvement in biotic condition could be detected by any future evaluations conducted during lower rainfall years in Cedar Creek. Leafpack colonization data also suggests that recovery of benthic invertebrates may be enhanced if conditions related to timing of rainfall and pH depressions are favorable, as they were in the year 2001. It is also possible that the seven-month period between the end of the bulk of the reclamation activities and the 2002 sampling event, may not have been long enough to detect an improvement in invertebrate colonization potential. Even though pH values measured in this study suggest that partial recovery has occurred at the site directly downstream of the reclaimed area, all of the lower Cedar Creek sites may need at least a year or more of favorable water quality conditions for full recovery of aquatic invertebrate communities.

Crayfish

The number of crayfish collected during seining generally increased at all sites during the study (Figure 25). The number of crayfish declined at most sites in 2002 when compared to 2001, possibly due to the high rainfall. Although we did not identify most crayfish collected, we did collect and identify the northern crayfish (*Orconectes virilis*) and the papershell crayfish (*O. immunis*). These species are commonly found in Missouri prairie streams (Pflieger 1996).

A two-way analysis of variance indicated that there was a not significant increase in the total number of crayfish after the reclamation ($p = 0.4418$) (Table 40). Crayfish are tolerant of acute depressions in pH (DiStefano et al. 1991), and we did not measure any pH values (e.g., pH ≤ 3) at any of our sites, which are known to impair crayfish populations. However, during the winter of 1999, which was prior to reclamation, pH did fall to 5.5 at Sites 4, 5, and 6. Stepwise regression analysis of the total number of crayfish indicated that it was best explained by metals (e.g., aluminum, manganese, nickel), nutrients (e.g., TP, TN, TN/TP, NO_2/NO_3, ammonia), pH, potassium, magnesium, and sodium ($R^2 = 0.881$), factors which would reflect the overall productivity of the stream and impact from mining.

Fish

The list of fish species collected during the study is listed in Table 42, and is typical of a Missouri Prairie stream (Pflieger 1997). The total number of fish collected and species codes are listed in Tables 43 and 44, respectively. We collected 43 of the 60 species that were previously collected in Cedar Creek (MDC fish database, Matt Winston, personal communication). Four additional species, black redhorse (*Moxostoma duquesnei*), stonecat (*Noturus flavus*), starhead topminnow (*Fundulus dispari*) and warmouth (*Lepomis gulosus*), were collected. The most frequently collected fish species were bluegill (*L. macrochirus*), creek chub (*Semotilus atromaculatus*), johnny darter (*Etheostoma nigrum*), white sucker (*Catostomus commersoni*) and spotted bass (*M. punctulatus*) (Table 45).

Generally, the number of fish (when standardized by the area sampled) increased after the reclamation was completed (Figure 26), although Sites 8, 9, and 10 showed very little increase from the start of the project. The number of fish at Sites 4 and 7 increased proportionally more than at Site 3 from the first year of the study. The number of fish species at all sites generally increased overtime (Figure 27). Only Site 7 had fewer species caught in 2002 than in 1999. Correlations between size of watershed and the number of fish species collected ($r = 0.352$; $p = 0.0294$) or density of fish collected ($r = -0.048$; $p = 0.1416$) were weak.

A two-way analysis of variance indicated that the increase in the number of fish after the reclamation was completed was not significant ($p \leq 0.05$), however it was nearly so ($p = 0.0816$) (Table 46). There was a significant difference in the fish taxa richness after the reclamation ($p = 0.024$). Taxa richness was significantly different between sites ($p = 0.0031$), but not overtime ($p = 0.1927$) or the time*site interaction ($p = 0.8624$). There was also a significant difference in Simpson's Dominance ($p = 0.0073$). It was significantly different between sites ($p = 0.0018$), but not overtime ($p = 0.6725$) or the time*site interaction ($p = 0.1242$).

Bivariate correlations of fish and water quality and selected metal concentrations are presented in Table 47. The total number of fish was positively correlated with fish taxa richness ($r^2 = 0.717$; $p < 0.0001$). Fish taxa richness (e.g., the number of fish species) was also negatively correlated with Simpson's Dominance ($r^2 = -0.648$; $p = 0.0002$). The only water quality variable significantly correlated with the total number of fish species was temperature ($r^2 = 0.674$; $p < 0.0001$). All other correlations between water quality variables were discussed in the

Macroinvertebrate Section. Although most water quality variables were not significantly correlated with increasing number of fish species, there was an increase in pH in Cedar Creek which reflects improvements in water quality and over time may result in increased number of fish species.

Stepwise regression analysis of fish species richness was significant ($R^2 = 0.853$; $p < 0.0001$). Fish species richness was best explained by the temperature ($r^2 = 0.360$; $p = 0.2282$), turbidity ($r^2 = 0.543$; $p = 0.0004$), hardness ($r^2 = 0.611$; $p = 0.0002$), SRP ($r^2 = 0.697$; $p = 0.0024$), pH ($r^2 = 0.815$; $p = 0.0390$), and conductivity ($r^2 = 0.853$; $p = 0.0801$) which combined to explain a total of 85% of variation (Table 48).

Bank stabilization at the reclamation site should also improve turbidity within Cedar Creek, particularly at sites directly below the reclamation area. Although high turbidity reduces predation of crayfish by fish (Pflieger 1996), it may reduce the number of fish species (e.g., creek chubs) present in the stream because of the lack of clean gravel for spawning and foraging.

Sites 3, 4, and 7 generally had the greatest number of fish and species. We caught the fewest number of fish at Site 8, which had the largest substrate, which probably decreased our seining efficiency. Sites 3, 4 and 10 also had the greatest occurrence of rare fish species (i.e., collected at two or fewer sites). Species that were collected only at one or two sites included black crappie (*Pomoxis nigromaculatus*) (Site 7); bluegill/green sunfish (*Lepomis cyanellus*) hybrid (Site 3 and 4); black redhorse (Site 10); common carp (*Cyprinus carpio*) (Sites 4 and 7); fantail darter (*E. flabellare*) (Sites 3 and 8); golden redhorse (*Moxostoma erythrurum*) (Sites 3 and 10); northern hogsucker (*Hypentelium nigricans*) (Sites 3 and 10); quillback (*Carpiodes cyprinus*) (Site 10); river carpsucker (*Carpiodes carpio*) (Site 4); redfin shiner (*Lythrurus umratilis*) (Sites 3 and 4); rosyface shiner (*Notropis rubellus*) (Sites 3 and 4); slender madtom

(*Noturus exilis*) (Sites 3 and 4); starhead minnow (Site 9); smallmouth buffalo (*Ictiobus bubalus*) (Sites 3 and 4); smallmouth bass (Site 8); shortnose gar (*Lepisosteus platostomus*) (Site 8); shorthead redhorse (*Moxostoma macrolepidotum*) (Site 10), and white crappie (*Pomoxis annularis*) (Site 3 and 10). Many of these species are not typical stream fishes and likely reflect upstream movement in this Missouri River tributary.

Sucker species are commonly found in deeper pools, which are most prevalent at Sites 3, 8 and 10. These sites also had the highest scores for pool habitats. Fantail darters prefer gravel substrates, which were prevalent at Sites 3 and 8. The starhead minnow is an introduced species that mostly likely escaped from a farm pond during the floods of the early 1990's.

Several minnow species such as bigmouth shiner (*N. dorsalis*) and suckermouth minnow (*Phenacobius mirabilis*) were absent from our fish collections. Bigmouth shiners are commonly found in prairie streams, and are associated with sand and red shiners (Pflieger 1997). Although they are abundant over unstable, sand bottoms, they prefer permanent flow, which only occurred at Sites 8 and 10 during the study. Substrates at these sites were typically larger than sand. Suckermouth minnows are primarily riffle species (Pflieger 1997), which prefer silt-free sand to cobble substrates. The effect of turbidity and siltation may limit the distribution of these species as well as such species as the central stoneroller (*Campostoma pullum*) and orangethroat darter (*E. spectabile*) due to impacts on reproductive and feeding behavior (Berkman and Rabeni 1987).

Relative fish species tolerance to an array of stressors is listed in USEPA (1994). Of the 43 species collected, 29 are considered intermediate in their ability to tolerate stress; 7 are tolerant, and 6 are considered intolerant. Two species, bluegill/ green sunfish hybrid and starhead minnow, were not classified; however, hybridization and introduced species are generally considered indicators of degraded streams (Karr 1981). Those species which are considered intolerant primarily included benthic fish species, which have been shown to be good indicators of environmental disturbance (Scott and Hall 1997; Wildhaber et al. 2000). The stonecat (*Noturus flavus*), longear sunfish (*L. megalotis*), and northern hogsucker were primarily found at our reference site (Site 3); however, the northern hogsucker were also found at Site 10, and longear sunfish were found at Sites 8 and 10. The slender madtom was found at both Site 3 and Site 4. The only non-benthic fish species which was considered intolerant was the rosyface shiner. It was found at all sites except Sites 4 and 9, however it was most common at Sites 3, 8 and 10.

Species that were considered tolerant included golden shiner (*Notemigonus crysoleucas*), green sunfish (*L. cyanellus*), bluntnose minnow (*Pimephales notatus*), creek chub, common carp, white sucker and yellow bullhead (*Ameiurus natalis*). Creek chubs are common to smaller, headwater streams where few other fish species are present (Pflieger 1997). They prefer streams without a strong continuous current. Creek chubs can live in isolated pools, repopulating during high flows. The bluntnose minnow, creek chub, green sunfish and white suckers were commonly collected throughout the study. White suckers (n = 229) were the predominate fish collected at Site 7 in 2000. Common carp were only collected once at Sites 4 and 7. Golden shiners were collected at Sites 3, 5, 7 and 10 in relatively numbers. Yellow bullhead were only collected at Sites 3, 4, 10.

Overall, the results of the fish community analysis indicated that the fish community responded positively to the reclamation activities, with total numbers and fish taxa richness increasing over time. Furthermore, fish taxa richness was more sensitive that either total numbers or Simpson’s Dominance, which is supported by the basic theory of bioassessment of small streams (USEPA 1994). Fish community assessment was also a more sensitive indicator of stream recovery than benthic invertebrate community analysis or leaf decomposition rates. However, in this study, basic water quality indicators of simple variables like pH, alkalinity, and conductivity were not only more sensitive statistical indicators but more cost effective, as well. However, the assessment and findings of the fish community response were valuable due to the ecological and natural resource values associated with human perceptions and current regulatory directions.

Conclusions

The Missouri Dept. of Natural Resources reclaimed an abandoned mine-land site on the Upper Cedar Creek, Boone County, MO during the period from 1999 to 2002. Water quality was improved after the reclamation. Water quality criteria for pH, sulfates and metals were not exceeded at any of the study sites after the reclamation was completed. Results also indicated that fish and invertebrate community metrics improved following reclamation activities. Water quality measurements such as pH, alkalinity, hardness, conductivity, and sulfates were useful indicators of water quality status and improvement; in addition, they are relatively easy to monitor. However, simple water quality measurements should be continuously monitored in order to capture episodic events that might limit biological communities. However, biological impairment can occur due to the combined effects of pH and other water quality factors even though no single chemical criterion is exceeded. Fish and invertebrate community assessments can integrate water quality, physical habitat quality, and climatic factors such as rainfall, and thus can be sensitive, cost effective measures of reclamation success. In addition, they provide direct assessments of the resources that the Clean Water Act seeks to protect. Therefore, annual biological assessments, combined with strategic seasonal assessments of a small suite of chemical variables (e.g. pH, hardness, alkalinity, and conductivity) are recommended in small watersheds such as Cedar Creek that are suspected of having AML concerns.

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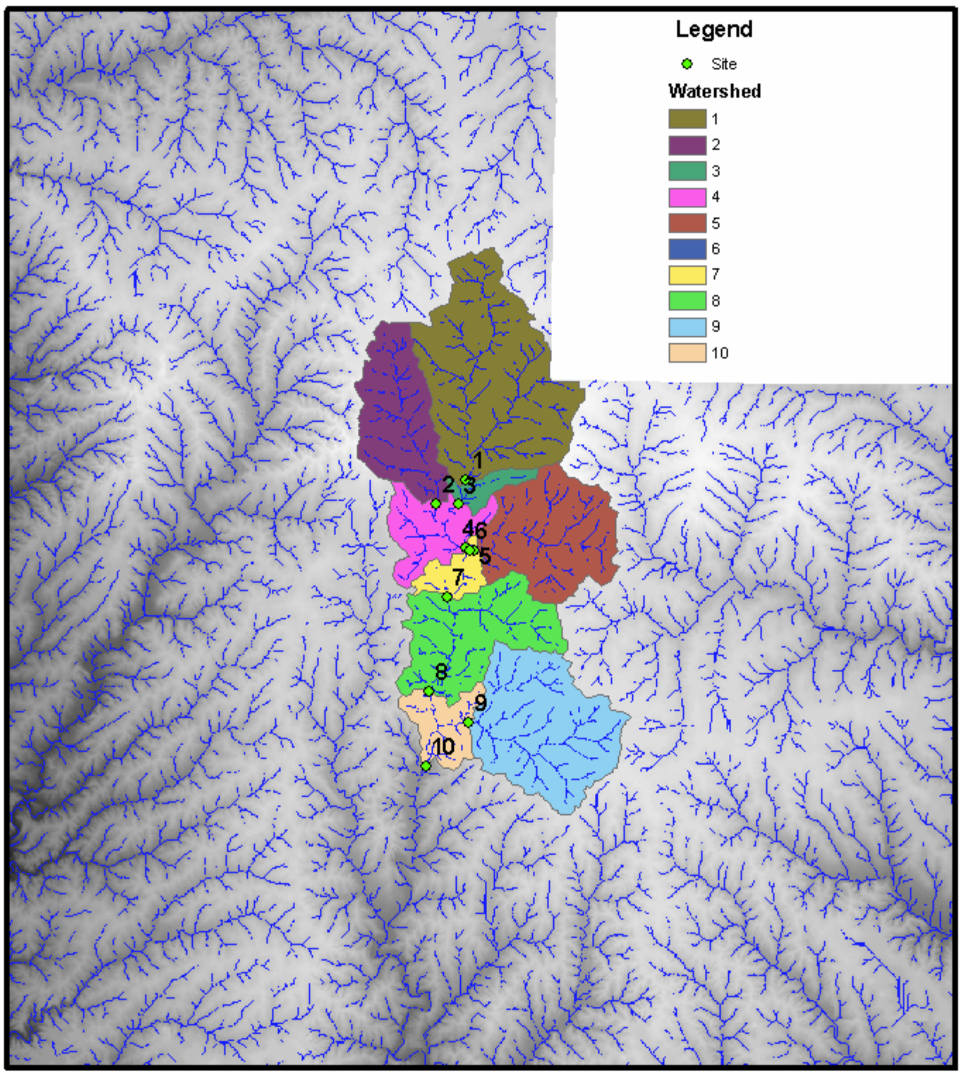
Assessment of the Biological Recovery of the Upper Cedar Creek, Boone County, Missouri, Following an Abandoned Mine Land Reclamation

Figures



Site	Watershed	Area km^2
1	1	29
2	2	13
3	3 + 1	31
4	1 + 2 + 3 + 4	51
5	5	16
6	1 + 2 + 3 + 4 + 5 + 6	66
7	1 + 2 + 3 + 4 + 5 + 6 + 7	69
8	1 + 2 + 3 + 4 + 5 + 6 + 7 + 8	84
9	9	20
10	1 + 2 + 3 + 4 + 5 + 6 + 7 + 8 + 9 + 10	109

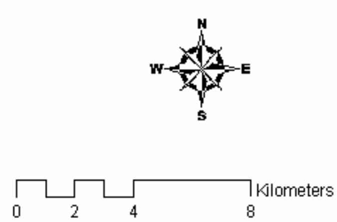


Figure 1. Site locations and watershed size.

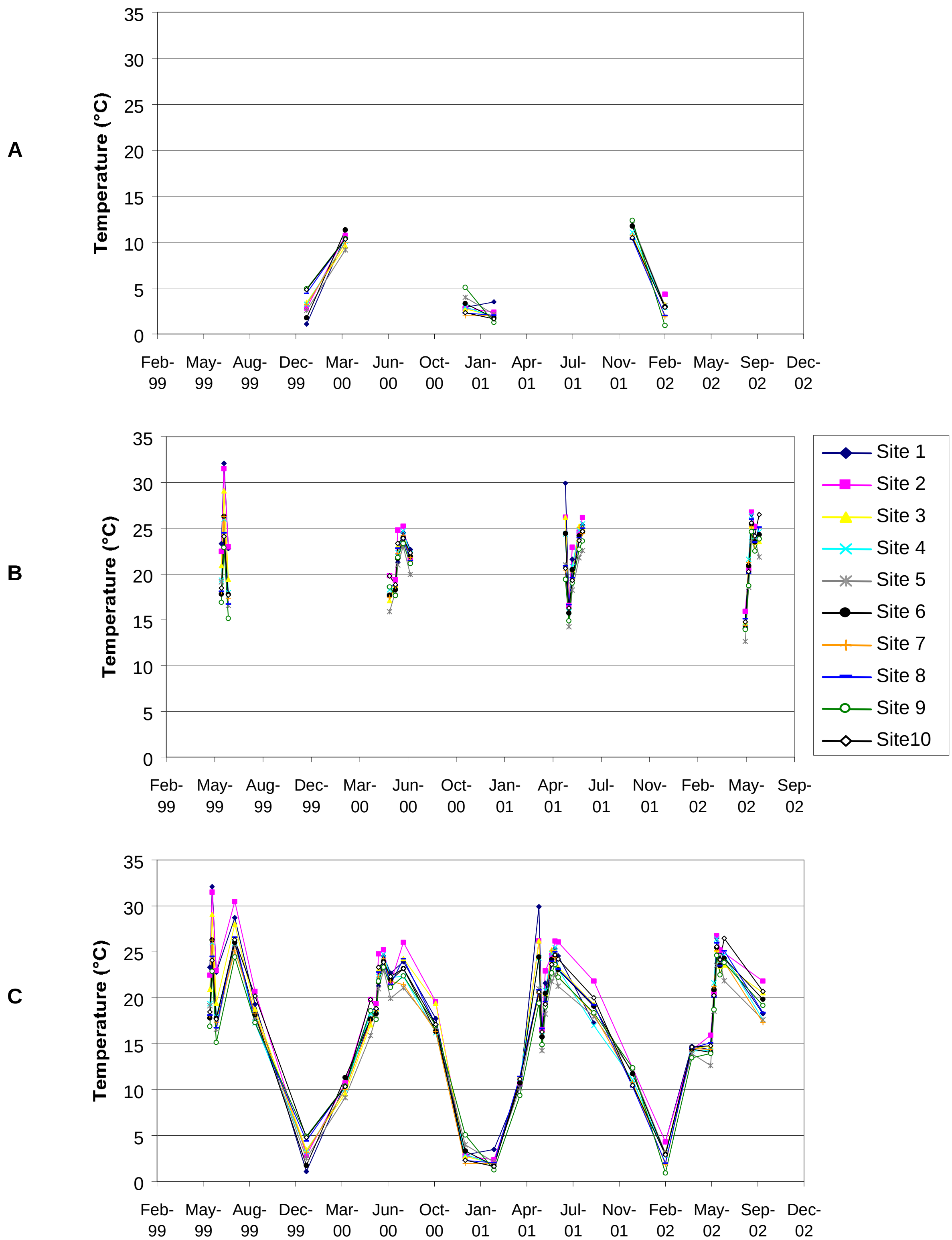


Figure 2. Temperature (°C) measured during winter (A), leafpack deployment (B), and duration of study (C).

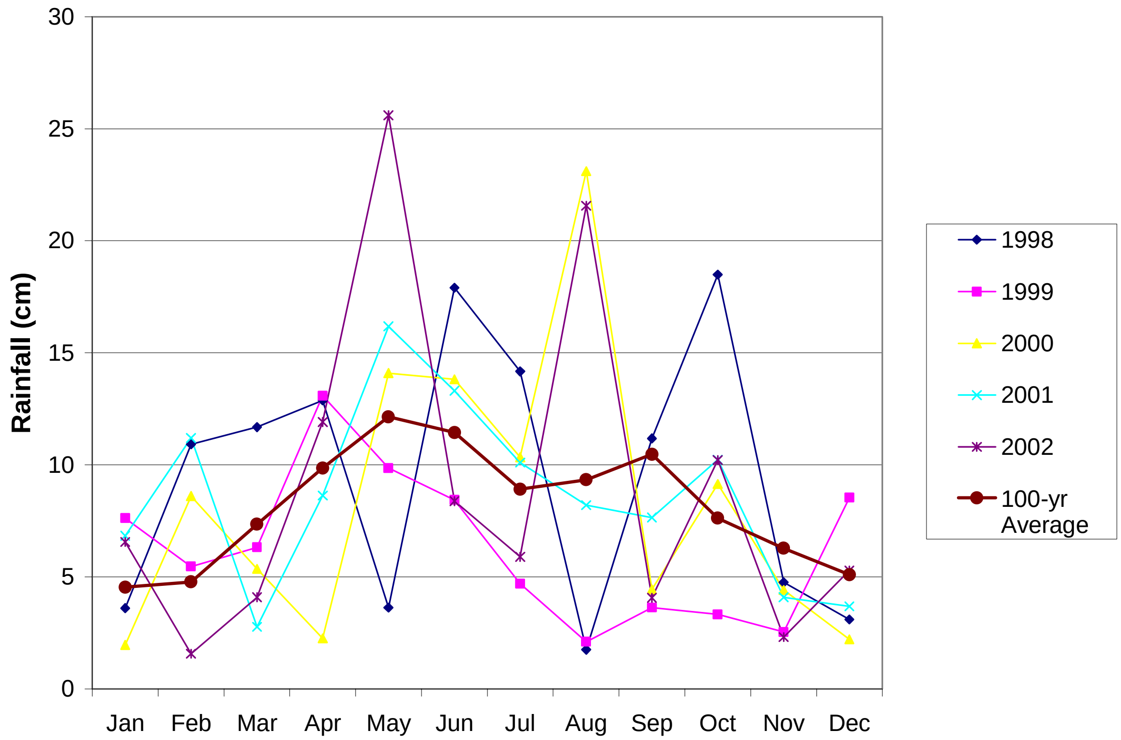


Figure 3. Monthly rainfall (cm) in Boone County during 1998-2002.

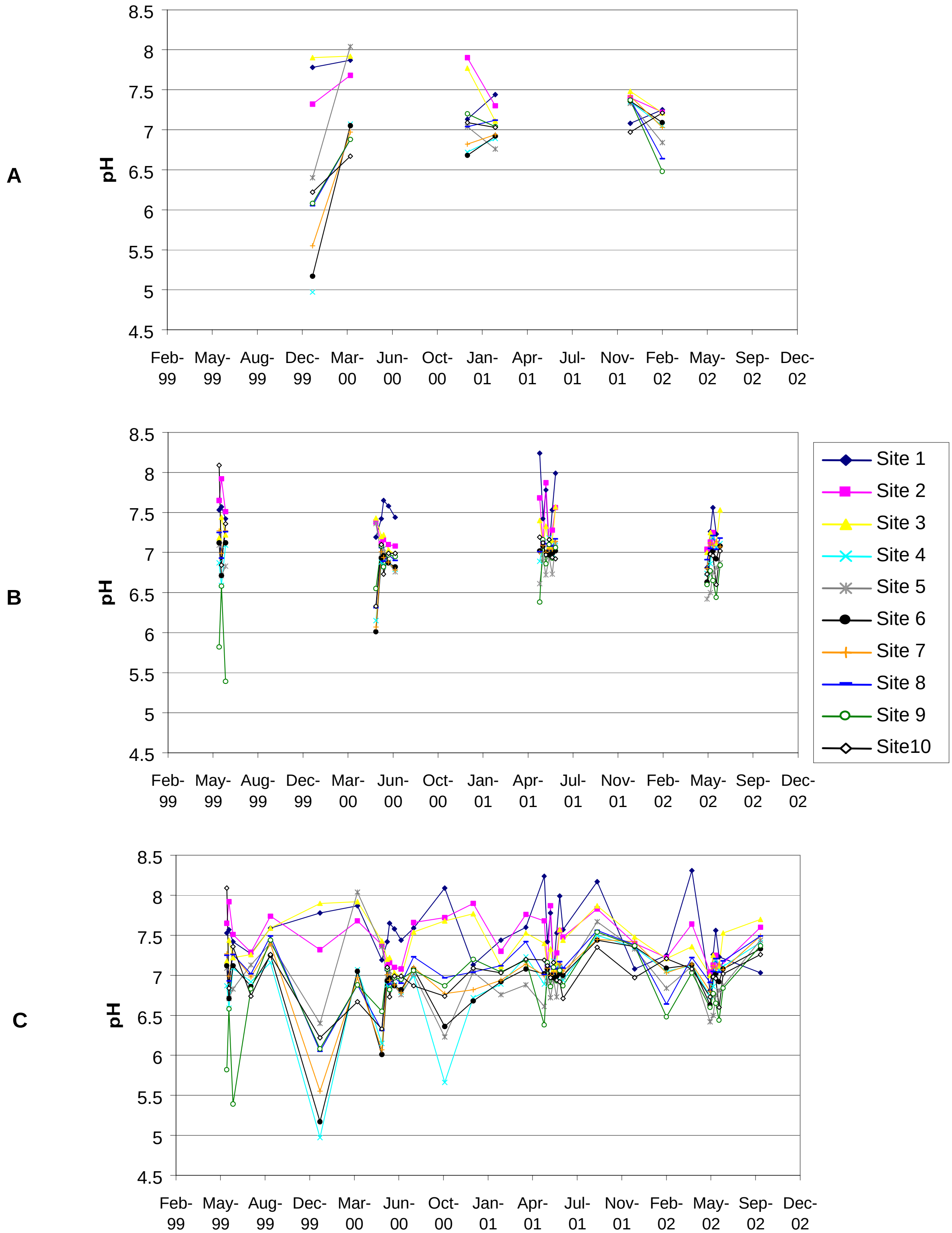


Figure 4. Measurement of pH during winter (A), leafpack deployment (B), and total duration of study (C).

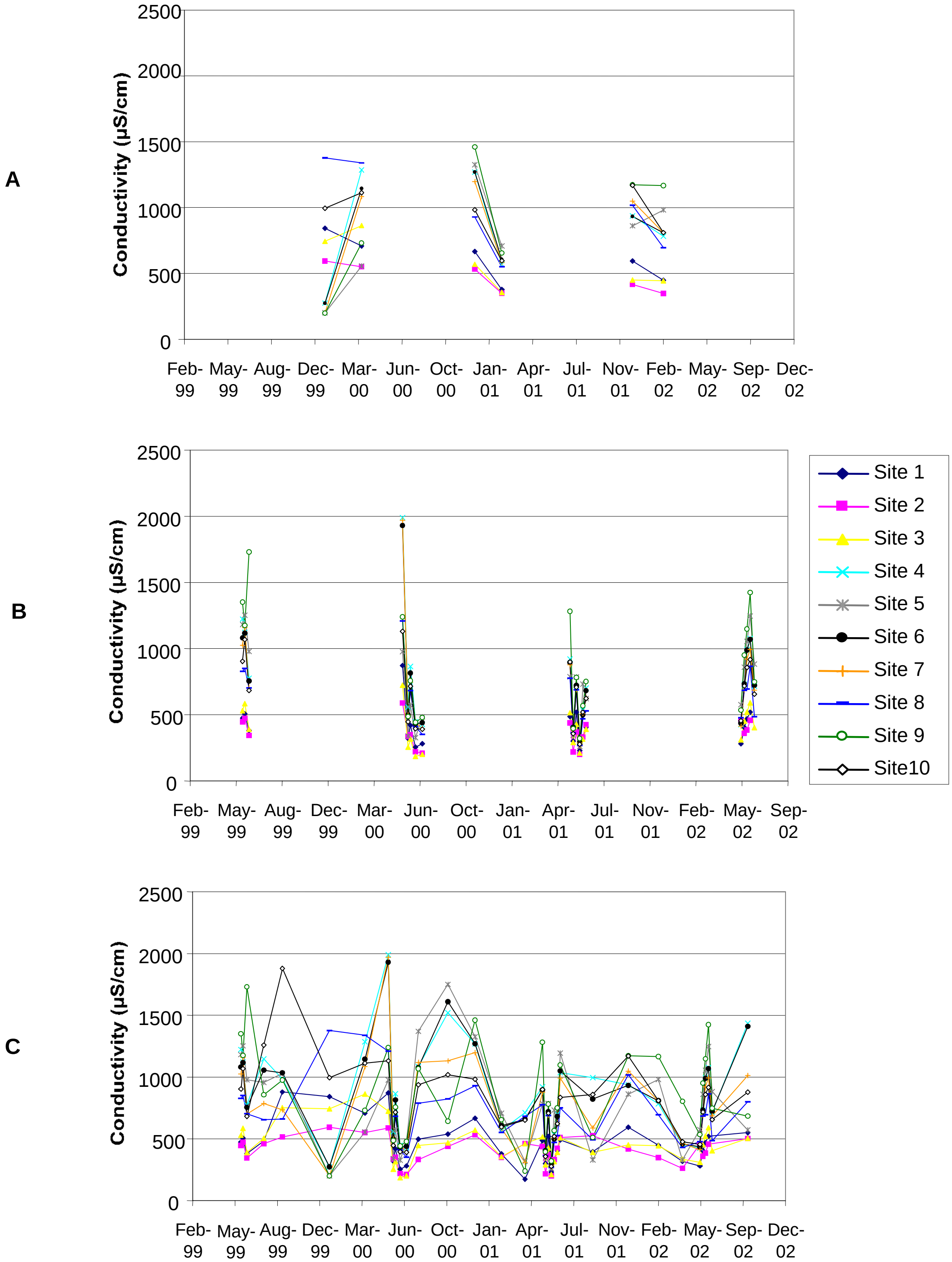


Figure 5. Conductivity (µS/cm) measured during winter (A), leafpack deployment (B), and duration of study (C).

A

B

C

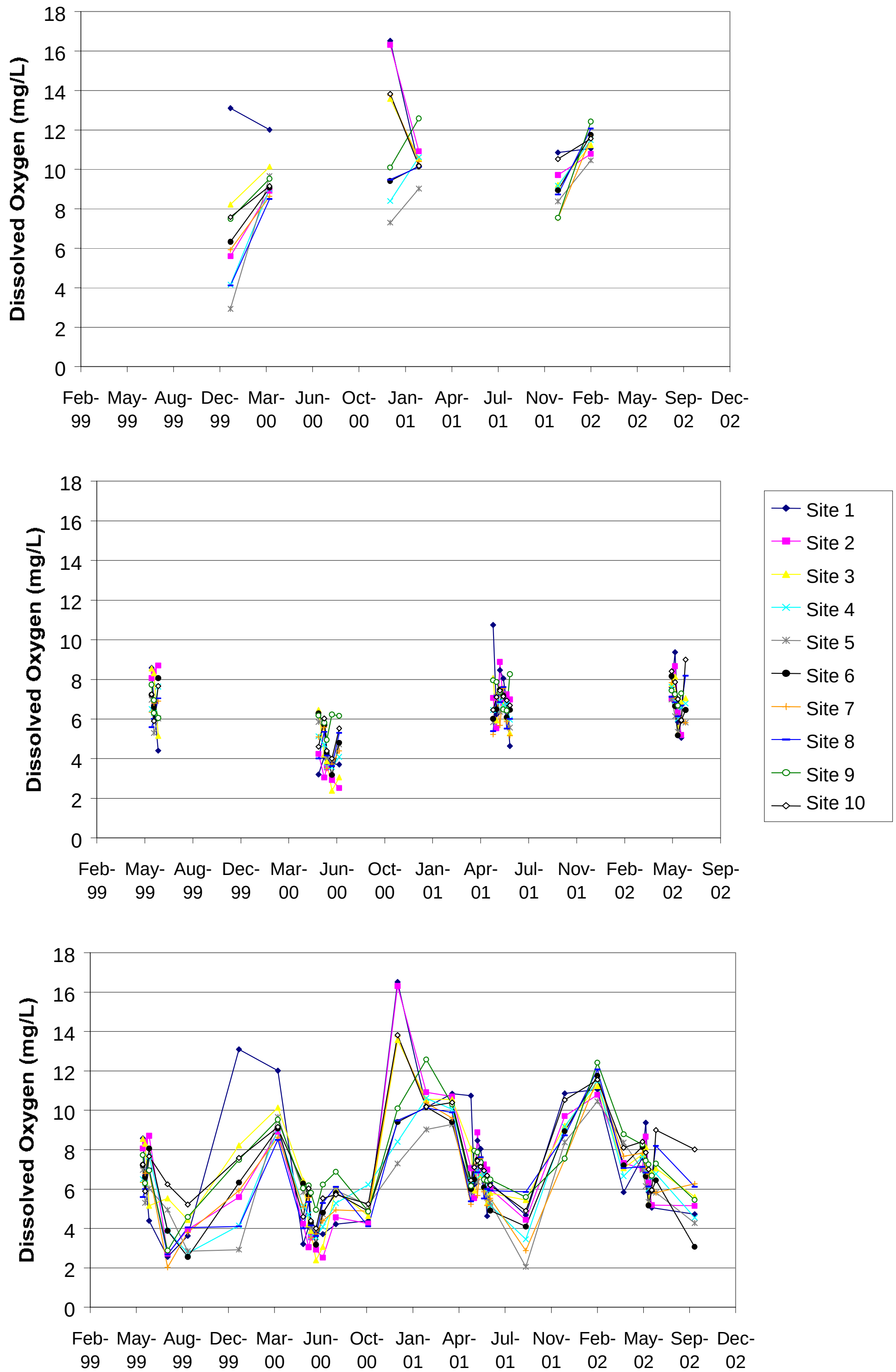


Figure 6. Dissolved oxygen (mg/L) measured during winter (A), leafpack deployment (B), and duration of study (C).

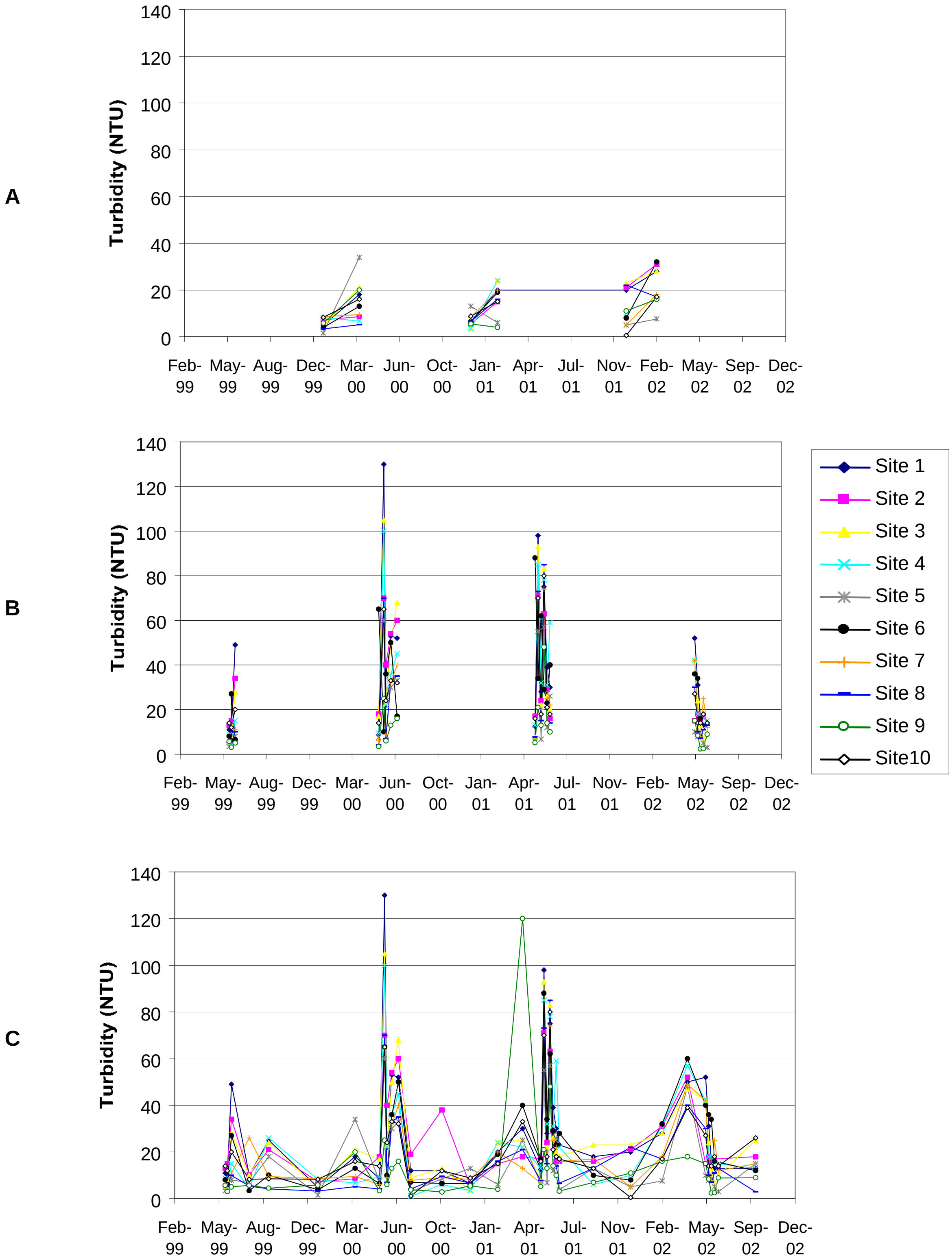


Figure 7. Turbidity (NTU) measured during winter (A), leafpack deployment (B), and duration of study (C).

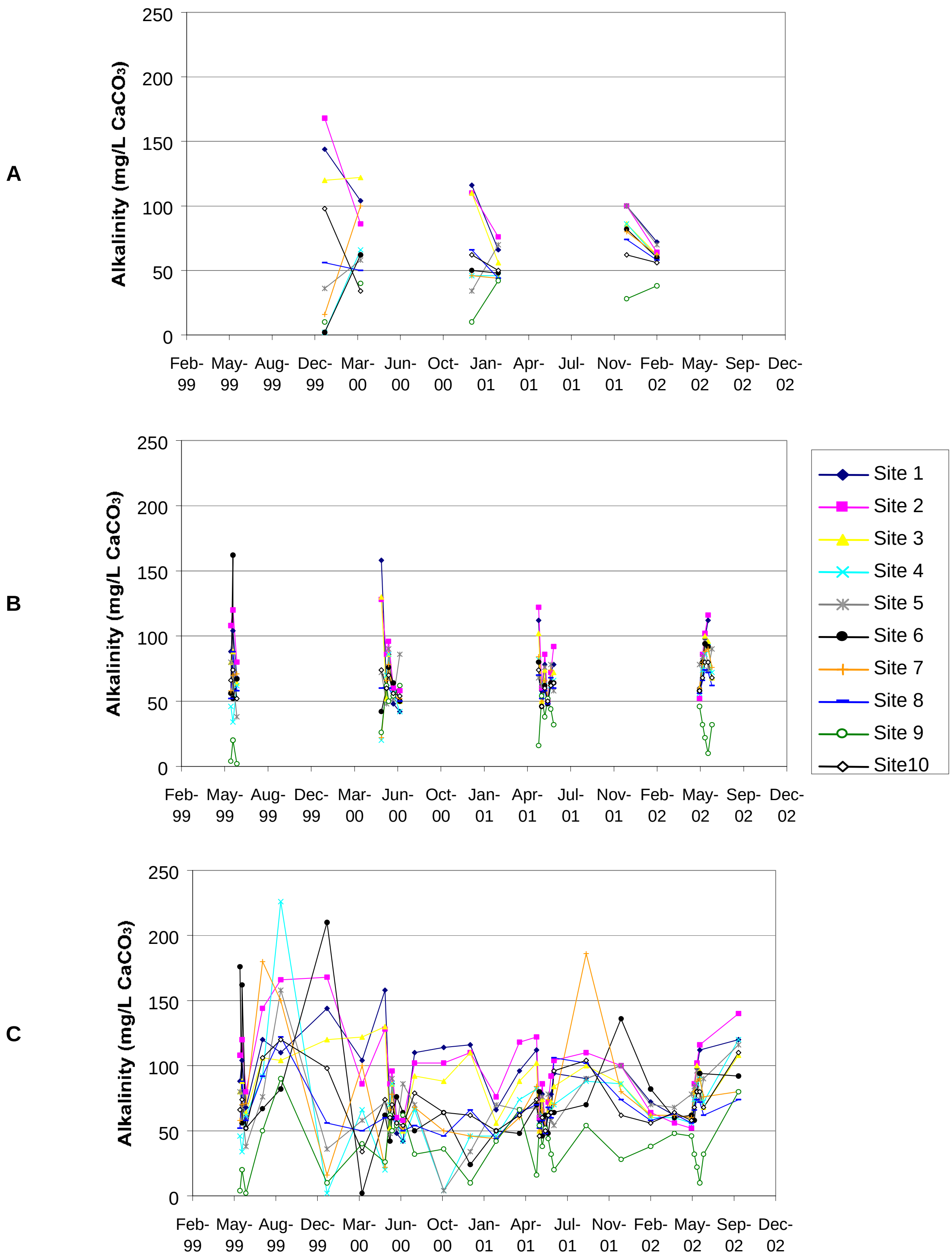


Figure 8. Alkalinity (mg/L as $CaCo_3$) measured during winter (A), leafpack deployment (B), and duration of study (C).

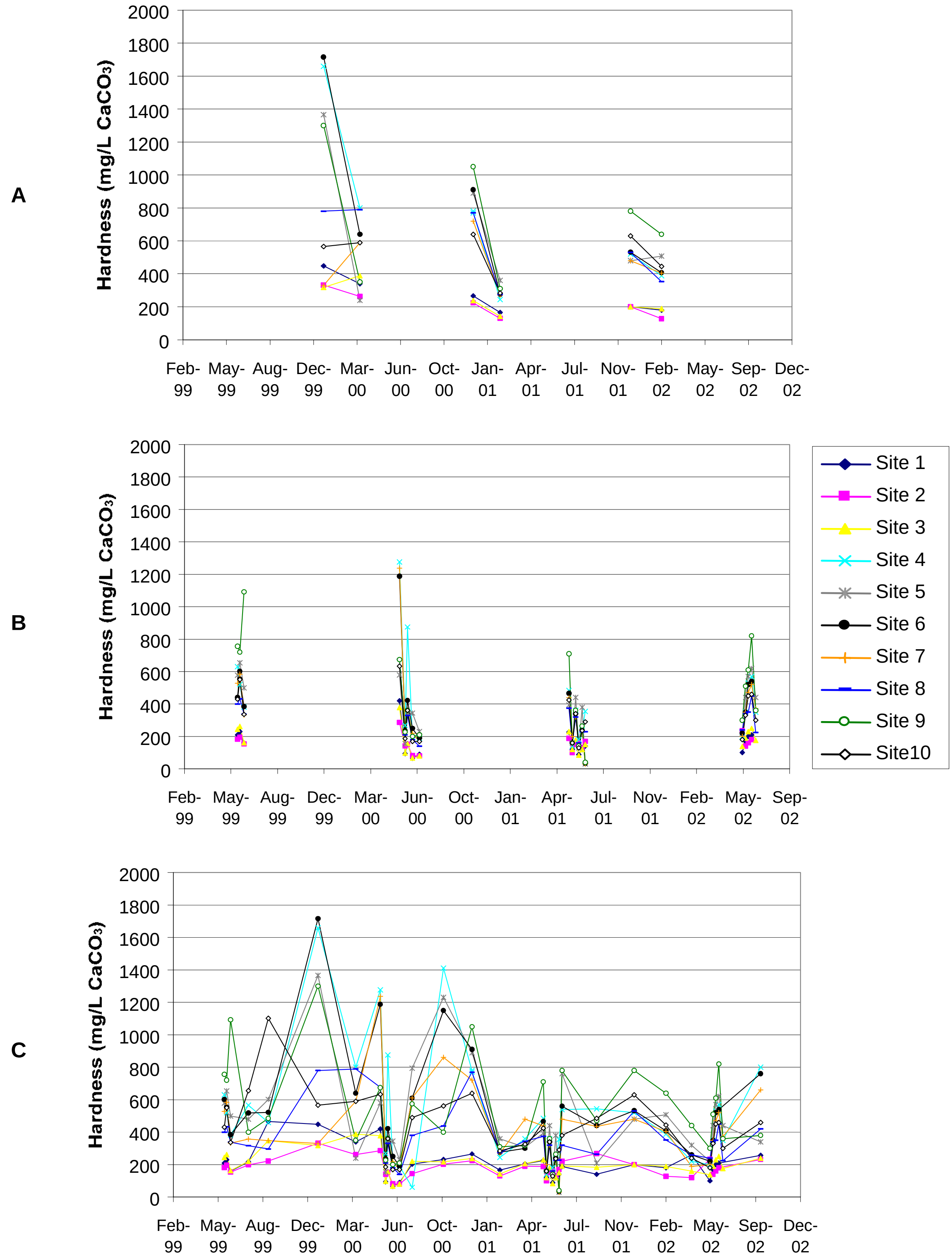


Figure 9. Hardness (mg/L as $CaCo_3$) measured during winter (A), leafpack deployment (B), and duration of study (C).

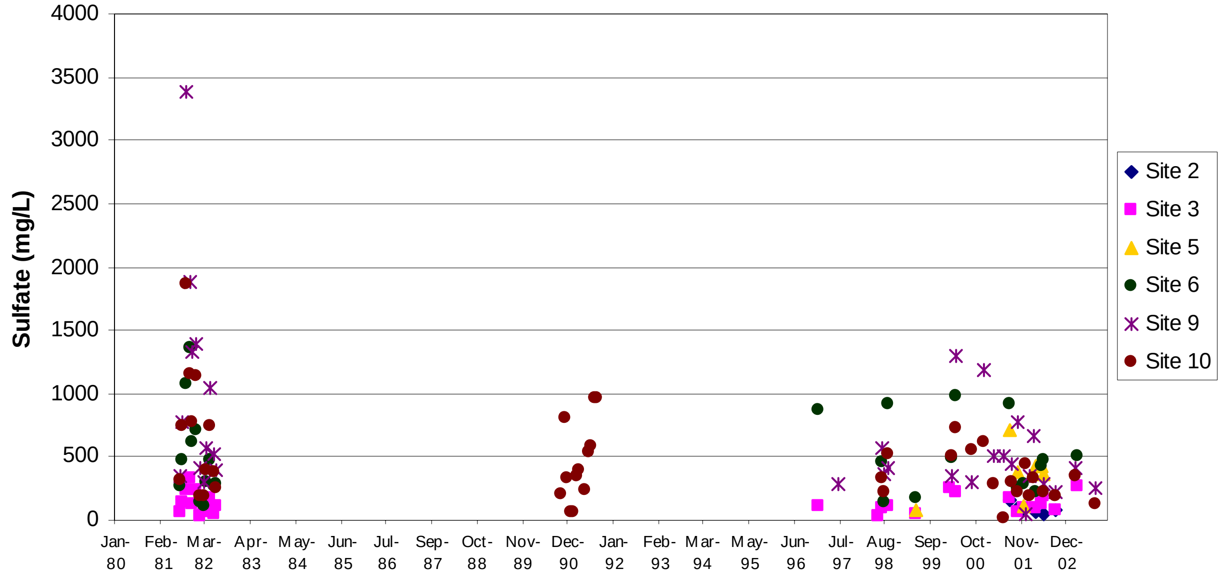


Figure 10. Sulfate (mg/L) measured at study sites (see Table 24 for data).

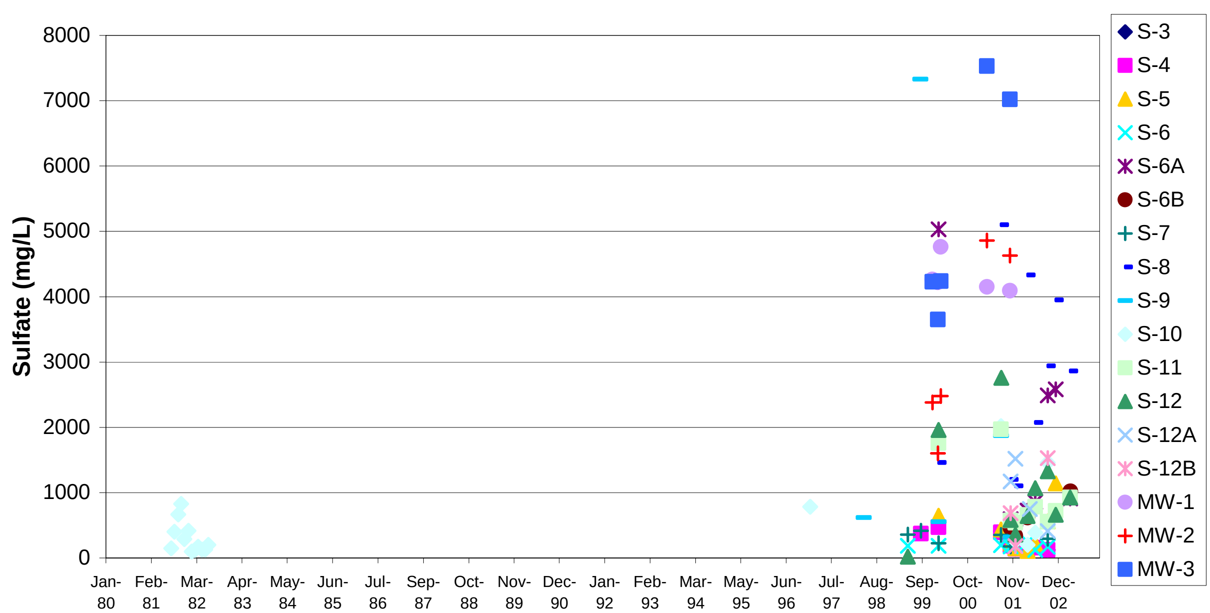


Figure 11. Sulfate (mg/L) measured at the reclamation site (see Table 25 for data).

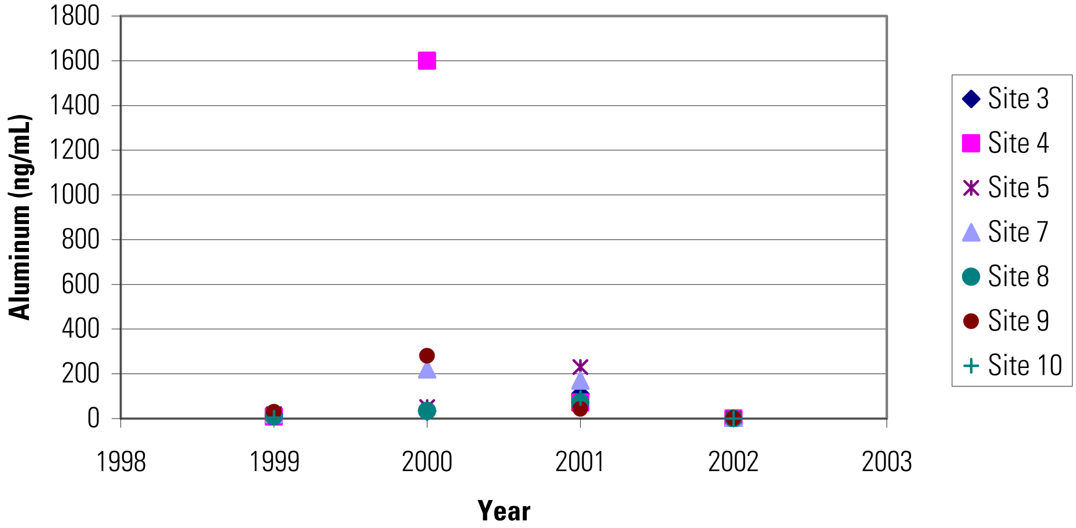


Figure 12. Concentrations of aluminum (ng/ml) in water samples, by year. Elemental analysis conducted using ICP-MS semi-quantitative scans.

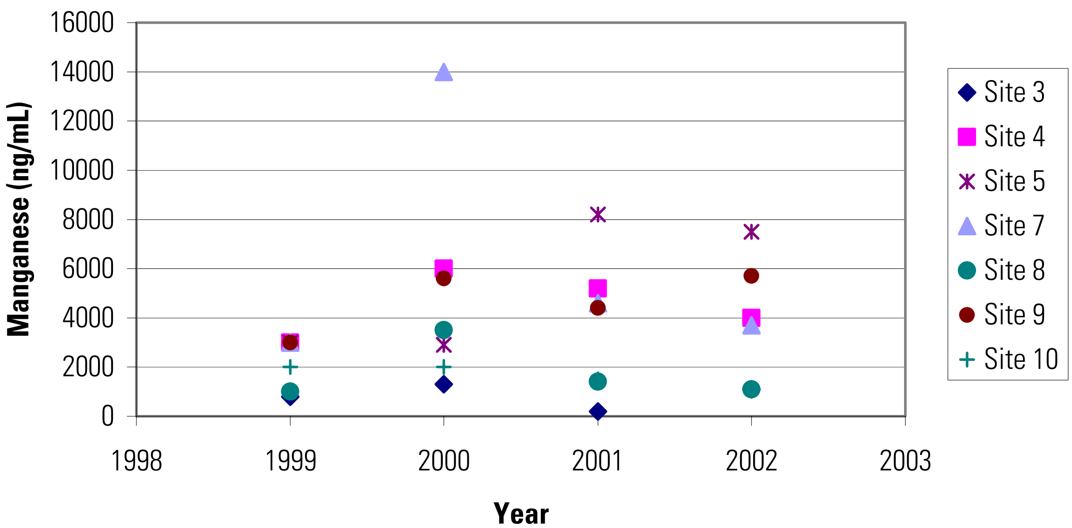


Figure 13. Concentrations of manganese (ng/ml) in water samples, by year. Elemental analysis conducted using ICP-MS semi-quantitative scans.

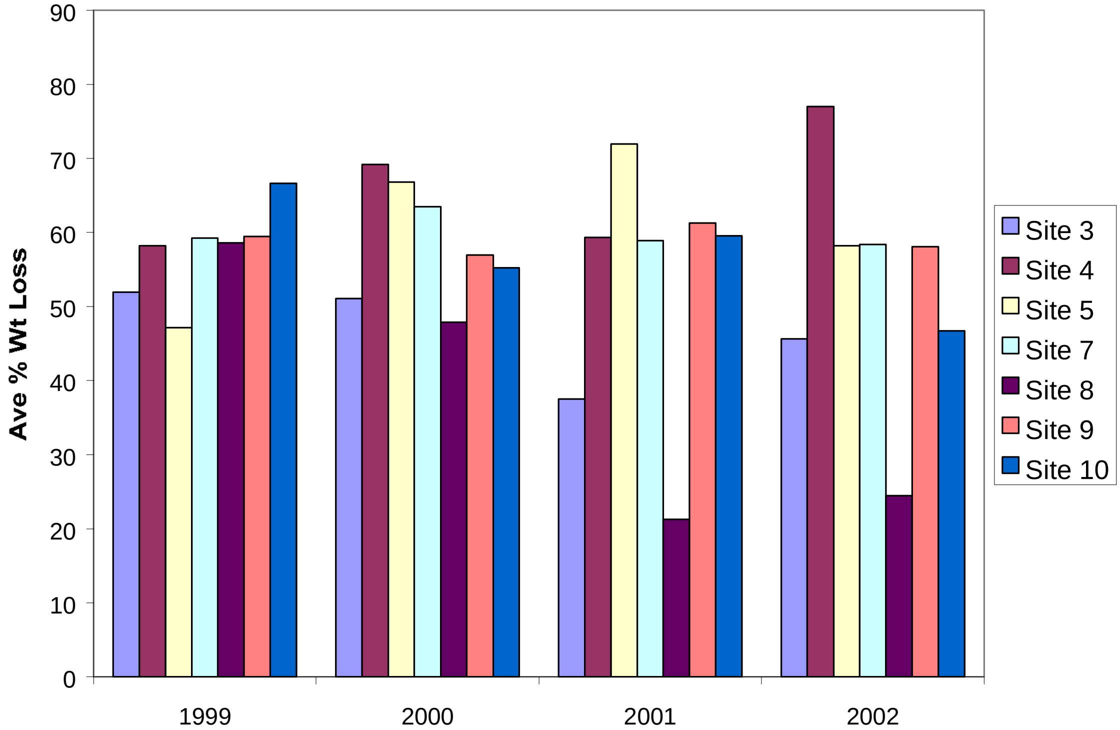


Figure 14. Leaf decomposition measured at each site, by year.

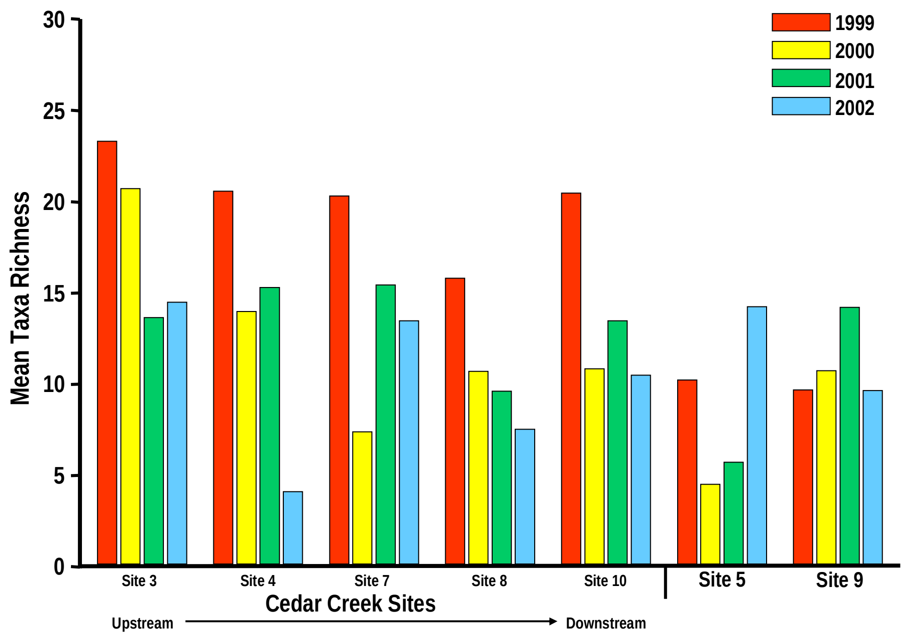


Figure 15. Mean taxa richness for leaf packs deployed at seven Cedar Creek sites, by year.

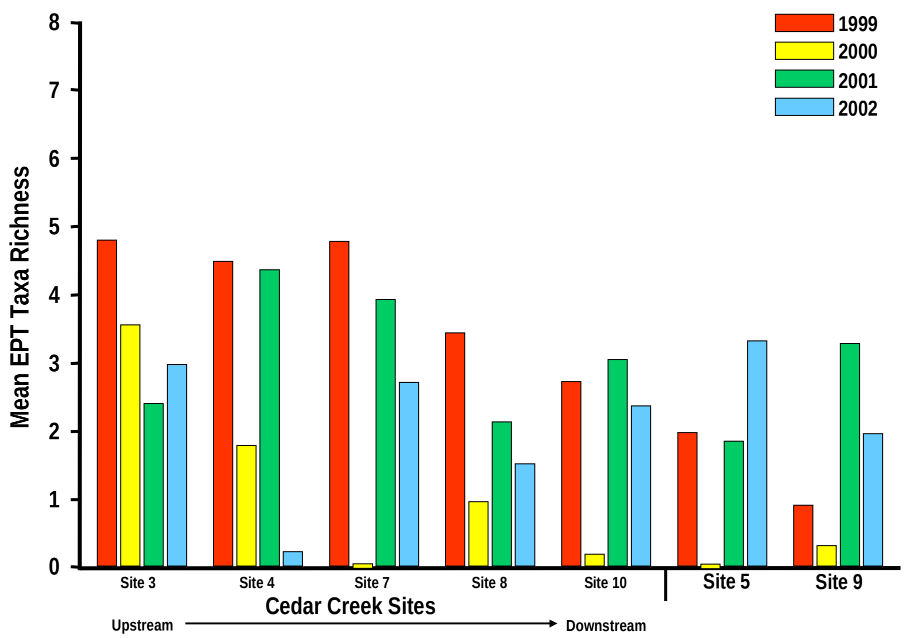


Figure 16. Mean EPT taxa richness for leaf packs deployed at seven Cedar Creek sites, by year.

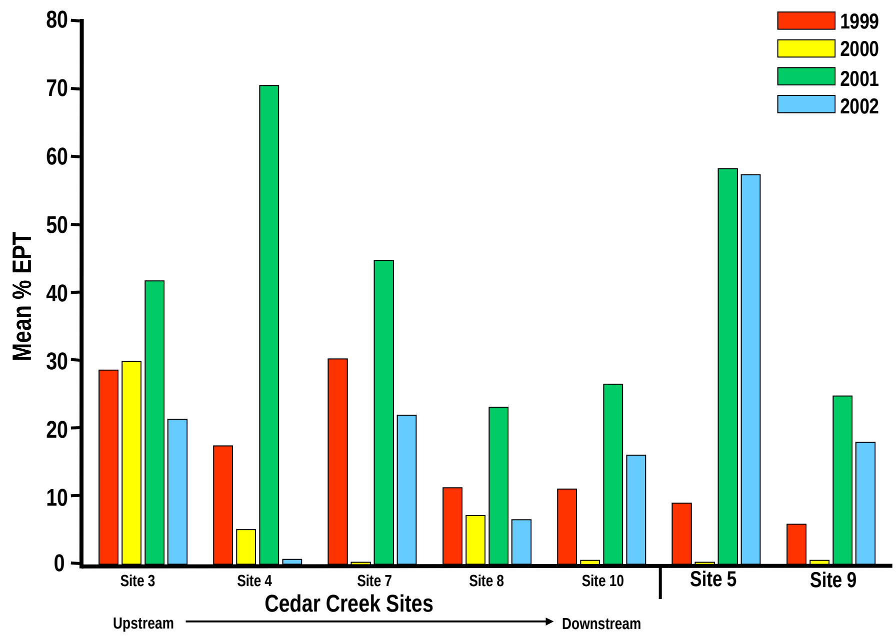


Figure 17. Mean EPT abundance (%) for leaf packs deployed at seven Cedar Creek sites, by year.

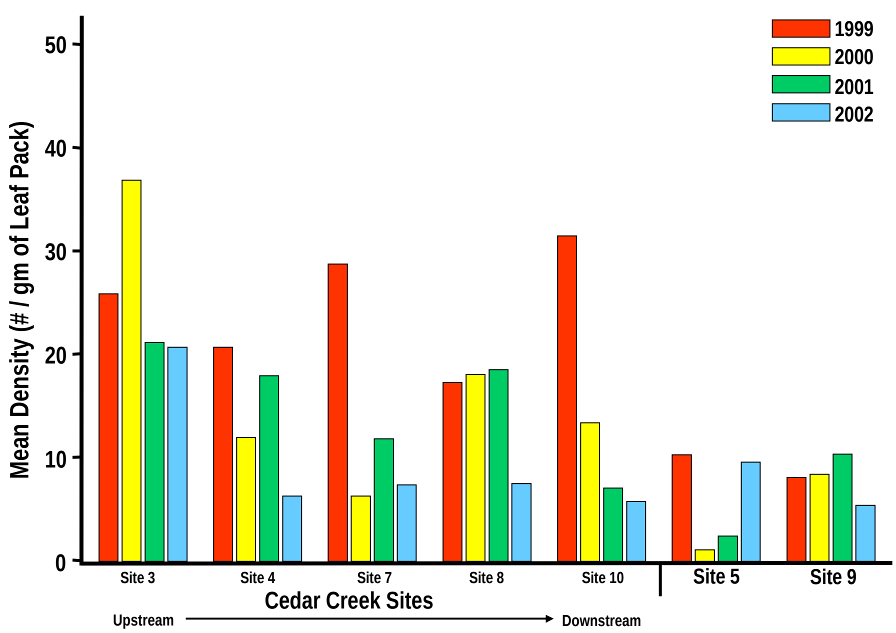


Figure 18. Mean density for leaf packs deployed at seven Cedar Creek sites, by year.

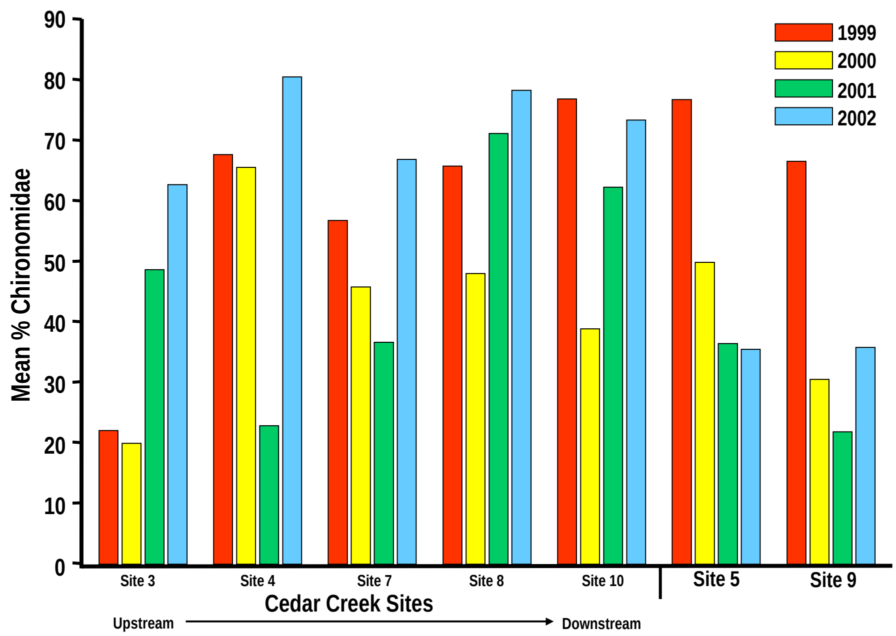


Figure 19. Mean Chironomidae abundance for leaf packs deployed at seven Cedar Creek sites, by year.

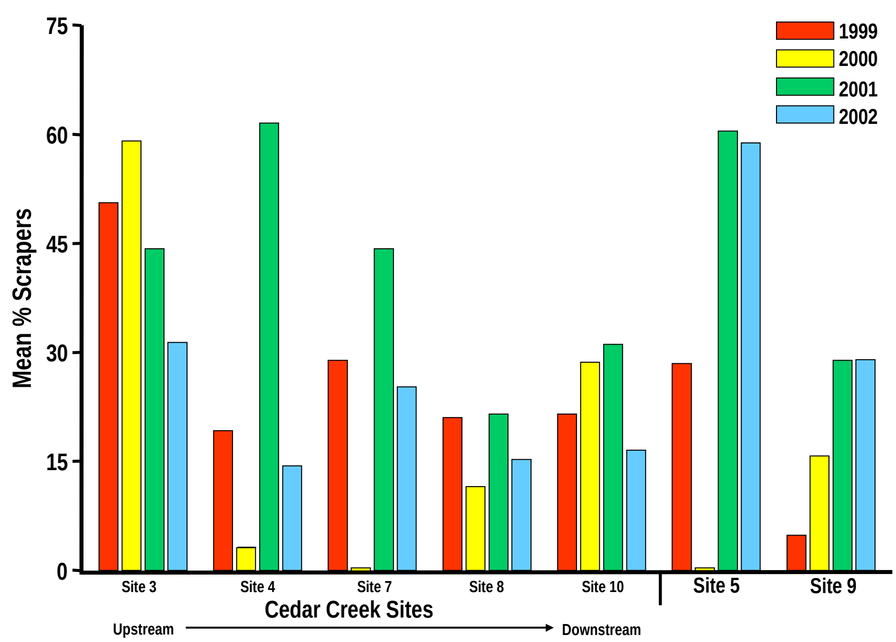


Figure 20. Mean scraper abundance for leaf packs deployed at seven Cedar Creek sites, by year.

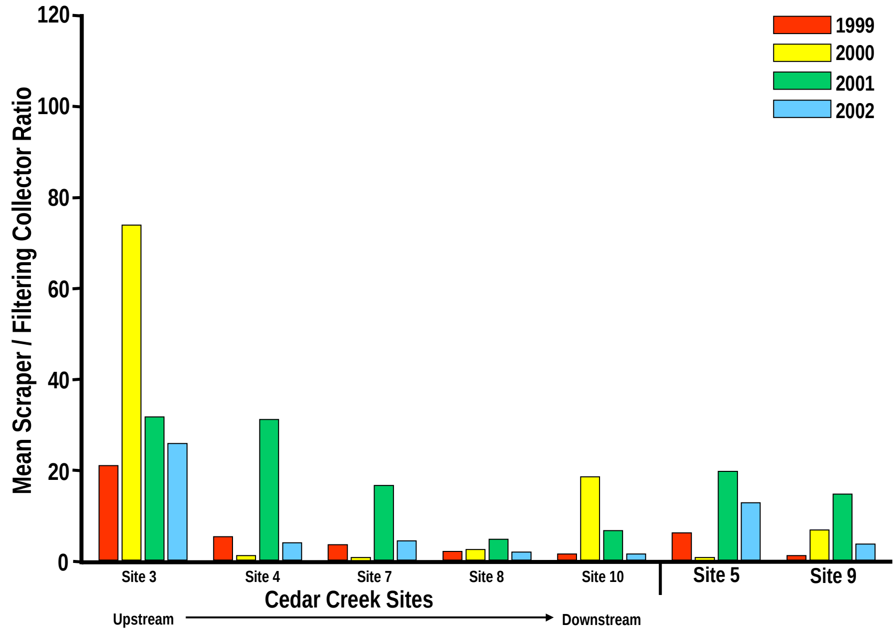


Figure 21. Mean scraper / filtering collector ratio for leaf packs deployed at seven Cedar Creek sites, by year.

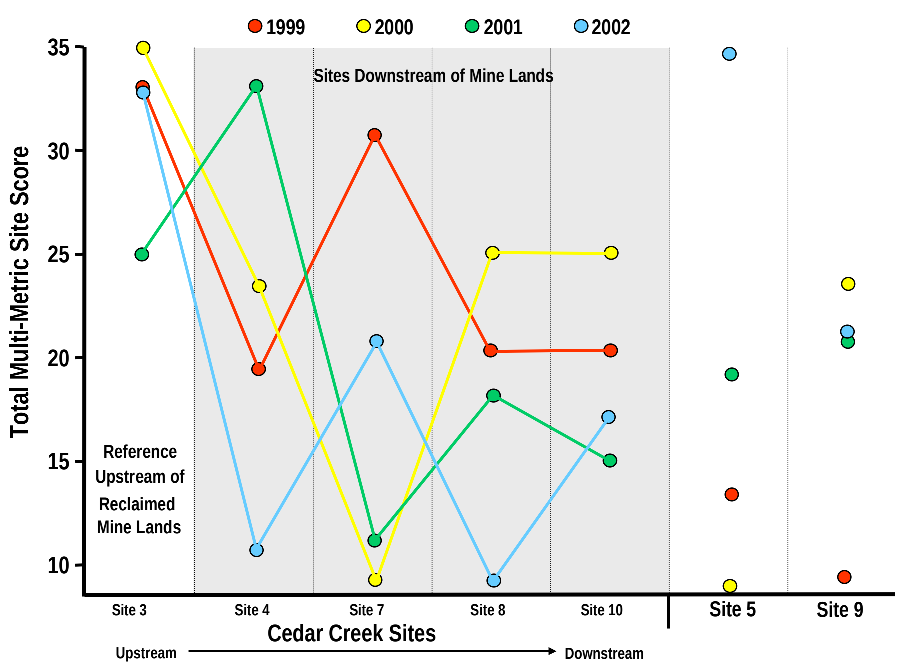


Figure 22. Total multi-metric site scores (7-metric) for invertebrates colonizing leaf packs at seven Cedar Creek sites, by year.

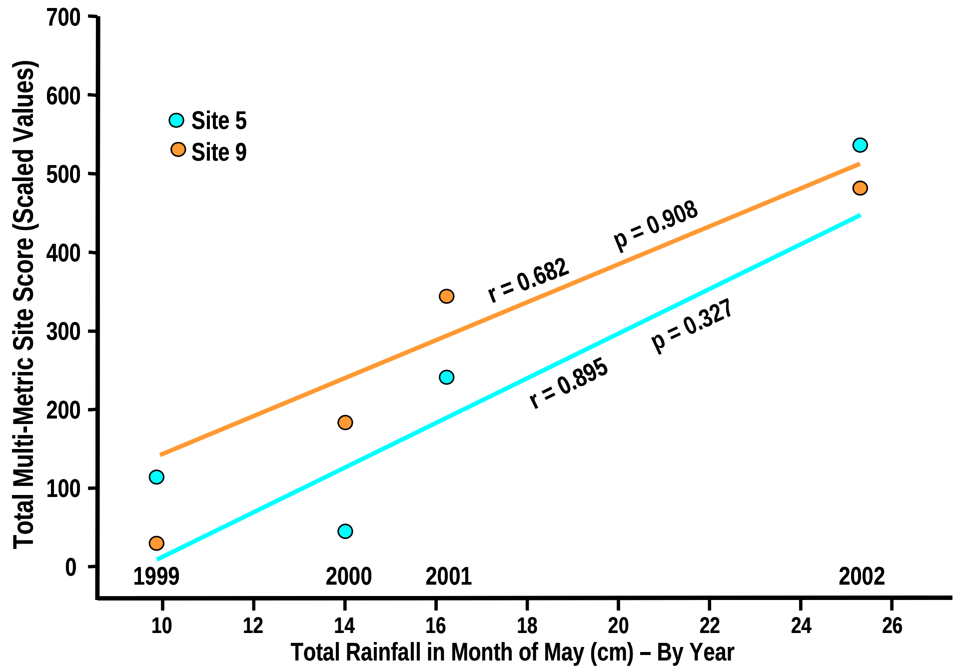


Figure 23. Correlations between May rainfall totals and multi-metric invertebrate score for two tributary sites in the Cedar Creek drainage, by year.

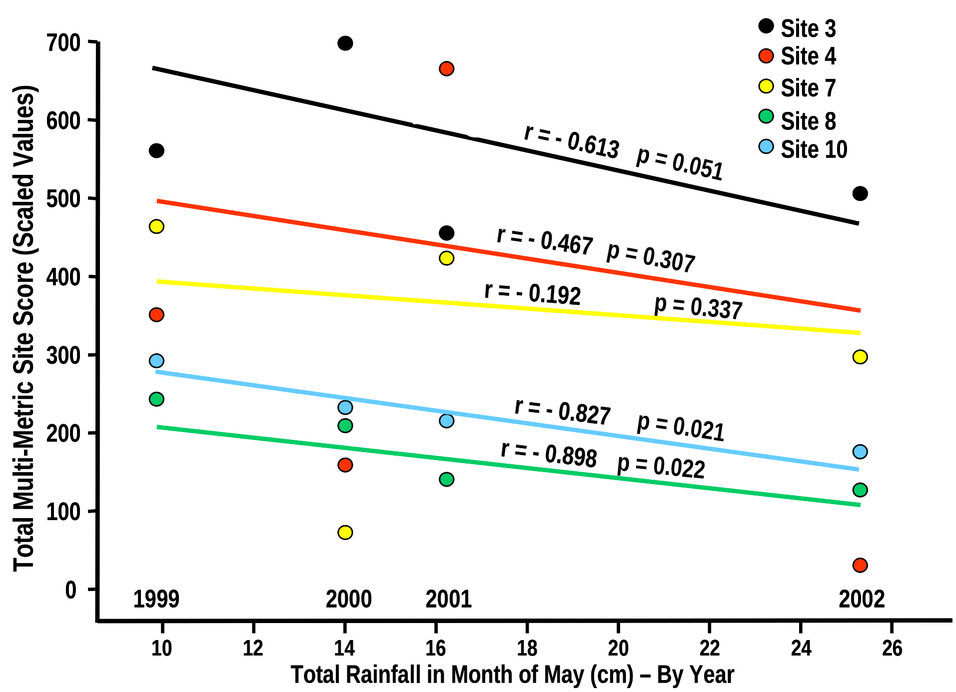


Figure 24. Correlations between May rainfall (cm) totals and multi-metric invertebrate score for five Cedar Creek sites, by year.

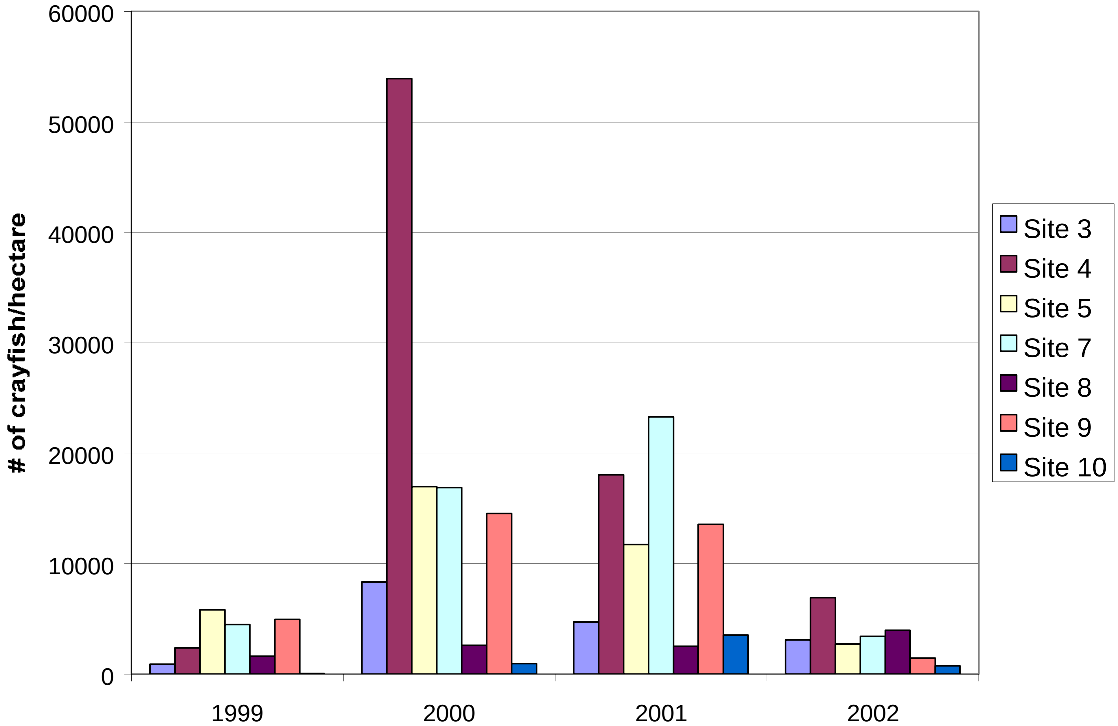


Figure 25. Number of crayfish per hectare found at each site, by year.

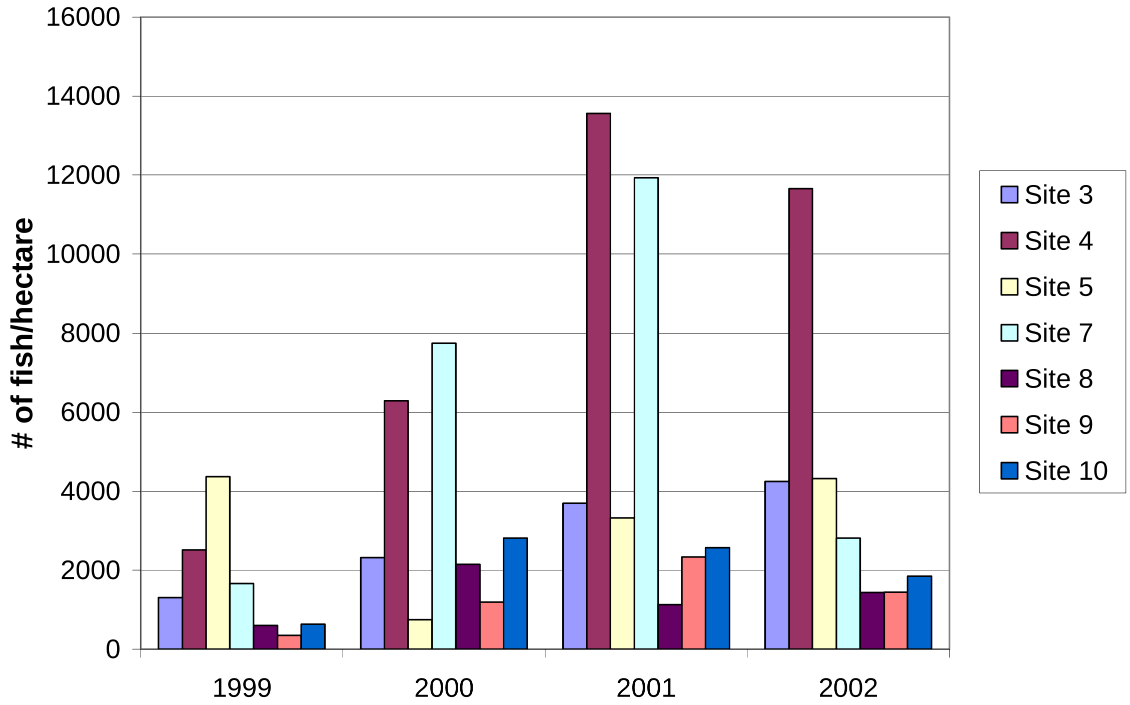


Figure 26. Total number of fish per hectare found at each site, by year.

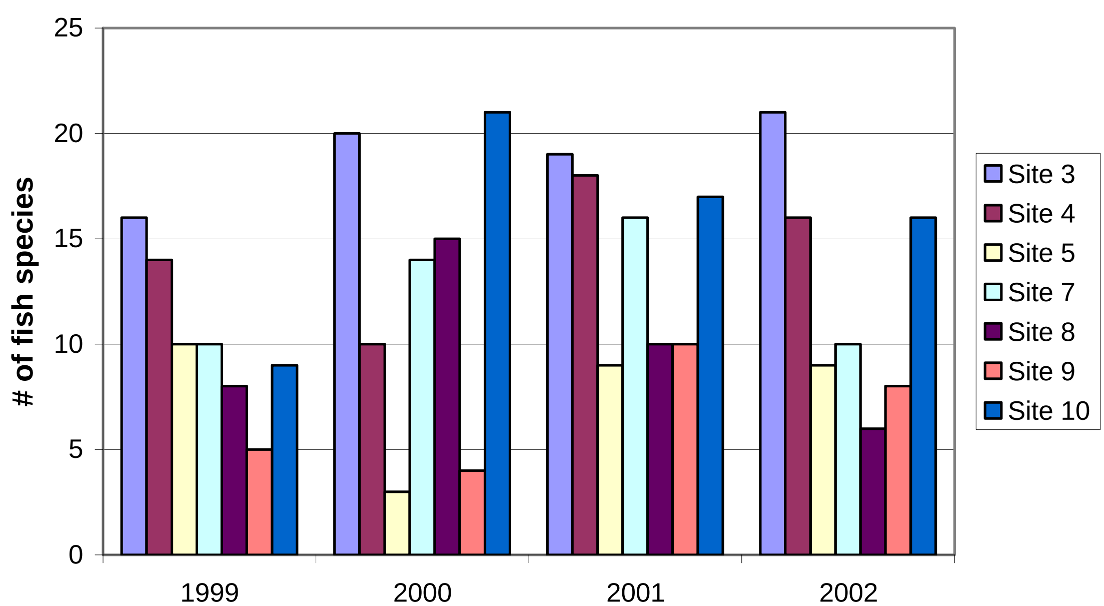


Figure 27. Number of fish species at each site, for each year.

Assessment of the Biological Recovery of the Upper Cedar Creek, Boone County, Missouri, Following an Abandoned Mine Land Reclamation

Tables

Table 1. Site numbers, description, GPS position, and stream order.

Site No.	Site name	Creek	Latitude North			Longitude West			Stream order
1	Dirk Road	Cedar	39°	02’	36.34”	92°	08’	00.54”	1
2	Zaring Road	Unknown tributary	39°	02’	10.91”	92°	08’	37.04”	3
3	Zaring Road	Cedar	39°	02’	10.62”	92°	08’	04.62”	4
4	Maupin Road	Cedar	39°	01’	17.50”	92°	07’	51.67”	4
5	Renfro	Renfro	39°	01’	18.01”	92°	07’	45.73”	3
6	Confluence of Renfro & Cedar Cr.	Cedar	39°	01’	19.00”	92°	07’	52.00”	4
7	Judy School Road	Cedar	39°	00’	25.42”	92°	08’	25.61”	4
8	St. Charles Road	Cedar	38°	58’	40.52”	92°	08’	49.49”	4
9	Manacle	Manacle	38°	58’	05.69”	92°	07’	52.81”	4
10	I-70	Cedar	38°	57’	16.24”	92°	08’	57.56”	4

Table 2. Sampling effort for fish collected during the entire study.

Site	Year	Segment	Sweep No.	Segment Length (m)	Segment Width (m)	Segment Area (m^2)	Sweep Duration (min)	Seine Height (m)	Mesh Size (in)	Seine Length (ft)	Seine Length (m)
3	1999	downstream	1	50	11.8	864	10	1.8	1/8"	30	9.1
		downstream	2	50	11.8		10	1.8	1/8"	30	9.1
		upstream	1	36	7.6		7	1.8	1/8"	30	9.1
		upstream	2	36	7.6		5	1.8	1/8"	30	9.1
4	1999	downstream	1	44	5.7	788	8	1.8	1/8"	30	9.1
		downstream	2	44	5.7		8	1.8	1/8"	30	9.1
		upstream	1	79	6.8		8	1.8	1/8"	30	9.1
		upstream	2	79	6.8		6	1.8	1/8"	30	9.1
5	1999	whole	1	90.5	6.6	597	8	1.8	1/8"	30	9.1
		whole	2	90.5	6.6		10	1.8	1/8"	30	9.1
7	1999	whole	1	96	6.4	614	12	1.8	1/8"	30	9.1
		whole	2	96	6.4		10	1.8	1/8"	30	9.1
8	1999	upstream	1	100	9.6	317	17	1.8	1/4"	50	15.2
		downstream	1	33	9.6		5	1.8	1/4"	50	15.2
9	1999	whole	1	100	7.2	665	8	1.8	1/8"	30	9.1
		whole	2	100	7.2		10	1.8	1/8"	30	9.1
10	1999	whole	1	100	11.8	1180	12	1.8	1/4"	50	15.2
		whole	2	100	11.8		10	1.8	1/4"	50	15.2
3	2000	whole	1	108	19.4	1274	25	1.8	1/8"	30	9.1
		whole	2	108	19.4		30	1.8	1/8"	30	9.1
4	2000	downstream	1	31.4	5.7	520	5	1.8	1/8"	30	9.1
		downstream	2	31.4	5.7		5	1.8	1/8"	30	9.1
		upstream	1	50.2	6.8		5	1.8	1/8"	30	9.1
		upstream	2	50.2	6.8		5	1.8	1/8"	30	9.1
5	2000	whole	1	92.7	6.6	612	17	1.8	1/8"	30	9.1
		whole	2	92.7	6.6		12	1.8	1/8"	30	9.1
7	2000	whole	1	53	9.2	488	25	1.8	1/8"	30	9.1
		whole	2	53	9.2		11	1.8	1/8"	30	9.1
8	2000	whole	1	65	9.6	624	20	1.8	1/8"	30	9.1
		whole	2	65	9.6		18	1.8	1/8"	30	9.1
9	2000	whole	1	110	7.2	722	15	1.8	1/8"	30	9.1
		whole	2	110	7.2		10	1.8	1/8"	30	9.1
10	2000	whole	1	98	13.4	1313	25	1.8	1/8"	60	18.3
		whole	2	98	13.4		20	1.8	1/8"	60	18.3

Table 2. Sampling effort for fish collected during the entire study.—Continued

Site	Year	Segment	Sweep No.	Segment Length (m)	Segment Width (m)	Segment Area (m^2)	Sweep Duration (min)	Seine Height (m)	Mesh Size (in)	Seine length (ft)	Seine Length (m)
3	2001	downstream	1	38	5.7	891	9	1.8	1/8"	30	9.1
		downstream	2	38	5.7		8.5	1.8	1/8"	30	9.1
		upstream	1	58	6.8		10	1.8	1/8"	30	9.1
		upstream	2	58	6.8		9	1.8	1/8"	30	9.1
4	2001	downstream	1	32	6.8	694	4	1.8	1/8"	30	9.1
		downstream	2	32	6.8			1.8	1/8"	30	9.1
		upstream	1	75	6.1		10	1.8	1/8"	30	9.1
		upstream	2	75	6.1		7	1.8	1/8"	30	9.1
5	2001	whole	1	92	6.6	608	16	1.8	1/8"	30	9.1
		whole	2	92	6.6		10	1.8	1/8"	30	9.1
7	2001	whole	1	63	6.4	404	11	1.8	1/8"	30	9.1
		whole	2	63	6.4		9.5	1.8	1/8"	30	9.1
8	2001	whole	1	51	9.6	489	8	1.8	1/8"	30	9.1
		whole	2	51	9.6		9	1.8	1/8"	30	9.1
9	2001	whole	1	94	7.2	633	18	1.8	1/8"	30	9.1
		whole	2	94	7.2		9	1.8	1/8"	30	9.1
10	2001	whole	1	68	13.4	913	19	1.8	1/8"	60	18.3
		whole	2	68	13.4		14.5	1.8	1/8"	60	18.3
3	2002	downstream	1	59	8.2	898	9	1.8	1/8"	30	9.1
		downstream	2	59	8.2		10.5	1.8	1/8"	30	9.1
		upstream	1	37	11.4		11	1.8	1/8"	30	9.1
		upstream	2	37	11.4		8	1.8	1/8"	30	9.1
4	2002	downstream	1	38.5	4.4	554	4	1.8	1/8"	30	9.1
		downstream	2	38.5	4.4		8	1.8	1/8"	30	9.1
		upstream	1	63	6.1		8	1.8	1/8"	30	9.1
		upstream	2	63	6.1		10	1.8	1/8"	30	9.1
5	2002	whole	1	97.5	7.9	765	20	1.8	1/8"	30	9.1
		whole	2	97.5	7.9		14	1.8	1/8"	30	9.1
7	2002	whole	1	83	9	749	18	1.8	1/8"	30	9.1
		whole	2	83	9		13	1.8	1/8"	30	9.1
8	2002	whole	1	50	9.4	472	6.5	1.8	1/8"	30	9.1
		whole	2	50	9.4		8	1.8	1/8"	30	9.1
9	2002	whole	1	114	9	1026	11	1.8	1/8"	30	9.1
		whole	2	114	9		18	1.8	1/8"	30	9.1
10	2002	whole	1	79	14.2	1122	18	1.8	1/8"	60	18.3
		whole	2	79	14.2		19	1.8	1/8"	60	18.3

Table 3. Characterization of substrate. Samples were collected in 1999. N = 5 per site.

Site No.	% Very Coarse Gravel	% Coarse Gravel	% Medium Gravel	% Fine Gravel	% Sand	% Clay	% Silt
3	13.5	23.6	13.9	16.6	28.8	1.57	2.02
4	0	7.64	16.2	26.3	44.0	1.72	4.08
5	12.3	32.8	16.9	11.7	15.9	3.31	7.10
7	0	0	11.5	20.9	61.2	3.28	3.19
8	85.2	3.81	2.96	5.46	1.94	0.13	0.51
9	0	0	0	0	93.3	2.58	4.08
10	21.3	32.2	19.0	13.1	12.8	0.45	1.13

Table 4. Habitat assessment scores for both riffle and pool habitats. The assessment was conducted in 1999.

Site Number	**3**	**4**	**5**	**7**	**8**	**9**	**10**
Riffle							
Primary							
Bottom Substrate/Instream Cover	17	10	15	7	16	9	17
Embeddedness	13	13	10	7	13	13	13
Flow Conditions / Depth Regime	16	9	6	13	15	10	12
Canopy Cover	17	16	15	16	16	15	16
Secondary							
Bank Deposition	11	5	10	3	13	4	11
Bottom Scouring & Deposition	11	3	10	4	9	5	12
Riffle to Riffle	12	12	6	15	14	13	14
Lower Bank Channel Capacity	10	10	9	10	7	8	9
Tertiary							
Upper Bank Stability	7	3	8	3	8	4	6
Bank Vegetation Stability / Grazing	9	5	7	7	8	5	7
Streamside Cover	9	7	7	9	9	8	9
Riparian Vegetative Zone Width	10	9	9	9	8	9	10
TOTAL SCORE	**142**	**102**	**112**	**103**	**136**	**103**	**136**

Table 4. Habitat assessment scores for both riffle and pool habitats. The assessment was conducted in 1999.—Continued

Site Number	**3**	**4**	**5**	**7**	**8**	**9**	**10**
Pool							
Primary							
Bottom substrate or instream cover	15	6	16	6	16	9	16
Pool Substrate Characterization	16	7	16	9	17	12	16
Pool Variability	16	16	14	14	17	16	14
Canopy Cover /Shading	17	17	15	16	16	16	16
Secondary							
Above-Water Bank Deposition	9	5	9	3	12	3	11
Deposition	10	5	11	4	11	6	10
Channel Sinuosity	9	6	5	6	9	7	9
Lower Bank Channel Capacity	10	10	9	10	7	8	9
Tertiary							
Upper Bank Stability	7	4	8	3	8	5	6
Bank Vegetation / Grazing	9	7	8	7	9	7	7
Streamside Cover	9	6	8	9	9	8	9
Riparian Vegetative Zone Width	10	9	9	9	8	8	10
TOTAL SCORE	**137**	**98**	**128**	**96**	**139**	**105**	**133**

Table 5. Assessment categories for habitat characterization. Categories are 1) comparable to reference ($\geq$ 90%); 2) supporting of aquatic life (75-89%); 3) partially supporting of aquatic life (60-74%), and 4) non-supporting of aquatic life(< 59%).

	Riffle		Pool	
Site	**%**	**Category**	**%**	**Category**
3	100	1	100	1
4	71.8	3	71.5	3
5	78.9	2	93.4	1
7	72.5	3	70.1	3
8	95.8	1	101	1
9	72.5	3	76.6	2
10	95.8	1	97.1	1

Table 6. Average percent recovery, standard deviation (in parenthesis) and number of samples (in brackets) of in situ water quality measurements.

Time Period	pH 7	pH 10	Conductivity (µS/cm)	Dissolved Oxygen (mg/L)
Study Mean	100 (1) [31]	100 (1) [31]	100 (3) [31]	99 (5) [31]
1999	100 (1) [5]	99 (0.5) [5]	101 (6) [5]	97 (12) [5]
2000	100 (1) [9]	100 (0.4) [9]	99 (2) [9]	101 (1) [9]
2001	101 (1) [9]	100 (1) [9]	100 (2) [9]	97 (4) [9]
2002	100 (1) [8]	100 (1) [8]	101 (1) [8]	99 (2) [8]

Table 7. Average percent recovery, standard deviation (in parenthesis) and number of samples (in brackets) of laboratory measurements of certified standards.

Time Period	**Alk** (mg/L $CaCO_3$)	**Hard** (mg/L $CaCO_3$)	**NH_3** (mg/L as N)	**NO_2/NO_3** (mg/L as N)	**TN** (mg/L as N)	**SRP** (mg/L as P)	**TP** (mg/L as P)
Study Mean	100 (14) [36]	98 (4) [37]	105 (6) [48]	101 (17) [120]	112 (33) [99]	96 (16) [60]	102 (5) [73]
1999	86 [1]	93 [1]	109 (7) [20]	100 (13) [23]	---	---	---
2000	100 (2) [7]	100 (3) [6]	---	111 (28) [20]	103 (4) [10]	100 (7) [6]	107 (12) [8]
2001	103 (20) [17]	99 (4) [15]	104 (2) [17]	98 (13) [66]	116 (39) [57]	95 (18) [43]	101 (2) [36]
2002	99 (2) [11]	97 (3) [15]	101 (1) [11]	101 (1) [11]	106 (26) [32]	99 (2) [11]	103 (1) [29]

Table 8. Average percent recovery, standard deviation (in parenthesis) and number of samples (in brackets) of CERC well water measurements.

Time Period	**pH**	**Alk** (mg/L as $CaCO_3$)	**Hard** (mg/L as $CaCO_3$)
Study Mean	100 (3) [69]	100 (3) [69]	100 (21) [69]
1999	98 (3) [15]	100 (3) [15]	103 (3) [15]
2000	100 (2) [22]	100 (4) [22]	101 (16) [22]
2001	101 (2) [24]	99 (2) [24]	95 (25) [24]
2002	102 (4) [8]	101 (5) [8]	90 (36) [8]

Table 9. Elemental analysis of filter blanks taken during the study. Units are ng/ml, except for Na, Mg, K, and Ca which are expressed as µg/ml.

	1999			2000			2001			2002		
Element	**1**	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**
Li	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Be	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Na	0.2	0.2	<0.1	0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Mg	<0.1	0.5	0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Al	10	3	3	40	29	22	34	17	22	<0.1	<0.1	<0.1
K	0.2	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Ca	<0.1	1	0.3	<0.1	<0.1	<0.1	0.2	0.21	<0.1	<0.1	<0.1	<0.1
Ti	0.8	0.5	0.4	<0.1	<0.1	<0.1	0.66	0.39	0.57	0.16	<0.1	<0.1
V	<0.1	<0.1	<0.1	0.77	0.59	<0.1	<0.1	<0.1	<0.1	0.13	<0.1	<0.1
Cr	<1	<1	< 1	2.3	1.4	<1	<1	<1	<1	<1	<1	<1
Mn	80	40	10	0.63	0.34	<0.1	0.51	0.42	0.26	<0.1	0.15	<0.1
Fe	30	<1	<1	<10	110	120	44	29	20	62	31	<10
Co	<0.1	0.2	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Ni	3	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Cu	4	<1	<1	2.6	<1	<1	<1	<1	<1	<1	<1	<1
Zn	30	20	9	11	5.7	<1	<1	12	3.7	<1	<1	<1
Ga	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Ge	<0.1	<0.1	0.4	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
As	0.3	<0.1	7	0.2	0.13	<0.1	<0.1	<0.1	<0.1	<0.1	0.22	<0.1
Se	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Rb	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	0.13	<0.1	<0.1	<0.1	<0.1	<0.1
Sr	<1	4	2	1.1	2.5	<1	<1	<1	<1	<1	<1	<1
Y	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Zr	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Nb	<1	<1	<1	1	<1	<1	<1	<1	<1	<1	<1	<1

Table 9. Elemental analysis of filter blanks taken during the study. Units are ng/ml, except for Na, Mg, K, and Ca which are expressed as µg/ml.—Continued

Element	1999			2000			2001			2002		
	1	2	3	1	2	3	1	2	3	1	2	3
Mo	0.3	0.2	0.3	0.43	0.2	<0.1	<0.1	<0.1	<0.1	0.33	<0.1	<0.1
Ru	1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Pd	0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<1	<1	<1	<0.1	<0.1	<0.1
Ag	0.3	0.2	0.1	1.5	0.68	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Cd	2	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
In	1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Sn	8	2	2	3.1	1.3	0.37	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Sb	0.6	0.3	0.2	0.23	0.13	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Te	0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Cs	1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Ba	1	2	<1	1.6	1.1	<1	<1	<1	<1	<1	<1	<1
La	0.1	<0.1	0.1	0.1	<0.1	<0.1	<0.1	<0.1	0.1	<0.1	<0.1	<0.1
Ce	0.1	0.1	0.1	0.1	<0.1	<0.1	0.1	<0.1	0.1	<0.1	<0.1	<0.1
Pr	0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Nd	0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Sm	0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Eu	0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Gd	0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Tb	0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Dy	0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Ho	0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Er	0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Tm	0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Yb	0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Lu	0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1

Table 9. Elemental analysis of filter blanks taken during the study. Units are ng/ml, except for Na, Mg, K, and Ca which are expressed as µg/ml.—Continued

Element	1999			2000			2001			2002		
	1	2	3	1	2	3	1	2	3	1	2	3
Hf	0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Ta	0.3	0.1	0.1	0.23	0.15	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
W	0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Re	0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Os	0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Ir	0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	0.1	0.1	<0.1	<0.1
Pt	0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	0.1	0.1	<0.1	<0.1
Au	2	1	0.5	1.1	0.29	<0.1	<0.1	<0.1	0.1	0.5	0.12	<0.1
Tl	0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	0.1	0.1	<0.1	<0.1
Pb	2	<1	<1	<1	<1	<1	<1	<1	1	1	<1	<1
Bi	1	<1	<1	<1	<1	<1	<1	<1	1	1	<1	<1
U	1	<1	<1	<1	<1	<1	<1	<1	1	1	<1	<1

Table 10. Recovery of elements from laboratory control samples ran with semi-quantitative analysis of Cedar Creek surface water in 1999. Units are in ng/ml unless noted.

a. SPEX ClaritasPPT[a]

Element	Actual Conc	Meas Conc	% Rec
Be	100	114	114
Na	500	532	106
Mg	500	591	118
Al	100	108	108
K	500	404	81
Ca	500	620	124
Ti	100	114	114
V	100	103	103
Cr	100	99	99
Mn	100	78	78
Fe	500	304	61
Co	100	106	106
Ni	100	117	117
Cu	100	109	109
Zn	100	125	125
As	100	115	115
Se	100	137	137
Sr	100	105	105
Mo	100	101	101
Ag	100	101	101
Cd	100	106	106
Sn	100	130	130
Sb	100	105	105
Ba	100	102	102
Tl	100	76	76
Pb	100	79	79

[a] a mixture of SPEX Claritas PPT Instrument Check Standards 1 (CL-ICS-1), 3 (CL-ICS-3), and 5 (CL-ICS-5); SPEX CertiPrep, Inc., Metuchen, NJ.

b. SPEX Custom Multi-element Standards[b]

Element	Actual Conc	Meas Conc	% Rec
Pr	10	10	98
Tb	10	10	101
Tm	10	10	101
Ta	10	14	142
Au	10	12	120

[b] a mixture of SPEX Custom Multi-element Standards XCERCMO-1 and XCERCMO-2; SPEX CertiPrep, Inc., Metuchen, NJ.

Table 11. Recovery of elements from laboratory control samples ran with semi-quantitative analysis of Cedar Creek surface water in 2000. Units are in ng/ml.

a. SPEX ClaritasPPT[a]

Element	Actual Conc	Meas Conc	% Rec
Be	50	56	113
Na	500	573	115
Mg	500	555	111
Al	50	54	109
K	500	350	70
Ca	500	566	113
Ti	50	53	107
V	50	50	99
Cr	50	49	97
Mn	50	52	104
Fe	500	288	58
Co	50	51	101
Ni	50	55	110
Cu	50	52	105
Zn	50	60	120
As	50	58	115
Se	50	60	121
Sr	50	74	149
Mo	50	51	101
Ag	50	57	113
Cd	50	53	105
Sn	50	63	126
Sb	50	53	106
Ba	50	52	103
Tl	50	49	97
Pb	50	48	96

[a] a mixture of SPEX Claritas PPT Instrument Check Standards 1 (CL-ICS-1), 3 (CL-ICS-3), and 5 (CL-ICS-5); SPEX CertiPrep, Inc., Metuchen, NJ.

b. SPEX Custom Multi-element Standards[b]

Element	Actual Conc	Meas Conc	% Rec
Pr	10	10	96
Tb	10	9.2	92
Tm	10	9.2	92
Ta	10	9.4	94
Au	10	9.4	94

[b] a mixture of SPEX Custom Multi-element Standards XCERCMO-1 and XCERCMO-2; SPEX CertiPrep, Inc., Metuchen, NJ.

Table 12. Recovery of elements from laboratory control samples ran with semi-quantitative analysis of Cedar Creek surface water in 2001. Units are in ng/ml.

a. SPEX ClaritasPPT[a]

Element	Actual Conc	Meas Conc	% Rec
Be	50	58	117
Na	500	528	106
Mg	500	509	102
Al	50	59	119
K	500	706	141
Ca	500	616	123
Ti	50	54	108
V	50	51	102
Cr	50	51	101
Mn	50	51	103
Fe	500	493	99
Co	50	51	102
Ni	50	53	107
Cu	50	55	111
Zn	50	62	123
As	50	57	114
Se	50	61	121
Sr	50	39	77
Mo	50	48	96
Ag	50	51	102
Cd	50	54	107
Sn	50	59	117
Sb	50	54	107
Ba	50	53	107
Tl	50	52	104
Pb	50	54	108

[a] a mixture of SPEX Claritas PPT Instrument Check Standards 1 (CL-ICS-1), 3 (CL-ICS-3), and 5 (CL-ICS-5); SPEX CertiPrep, Inc., Metuchen, NJ.

b. SPEX Custom Multi-element Standards[b]

Element	Actual Conc	Meas Conc	% Rec
Pr	10	10.4	104
Tb	10	10.3	103
Tm	10	10.1	101
Ta	10	12.9	129
Au	10	13.5	135

[b] a mixture of SPEX Custom Multi-element Standards XCERCMO-1 and XCERCMO-2; SPEX CertiPrep, Inc., Metuchen, NJ.

Table 13. Recovery of elements from laboratory control samples ran with semi-quantitative analysis of Cedar Creek surface water in 2002. Units are in ng/ml.

a. SPEX ClaritasPPT[a]

Element	Actual Conc	Meas Conc	% Rec
Be	50	57	113
Na	500	583	117
Mg	500	530	106
Al	50	58	116
K	500	646	129
Ca	500	610	122
Ti	50	54	109
V	50	50	101
Cr	50	50	100
Mn	50	53	107
Fe	500	544	109
Co	50	53	105
Ni	50	55	111
Cu	50	54	108
Zn	50	61	122
As	50	62	124
Se	50	62	124
Sr	50	50	99
Mo	50	48	96
Ag	50	52	105
Cd	50	55	109
Sn	50	67	134
Sb	50	54	108
Ba	50	53	105
Tl	50	49	99
Pb	50	53	106

[a] a mixture of SPEX Claritas PPT Instrument Check Standards 1 (CL-ICS-1), 3 (CL-ICS-3), and 5 (CL-ICS-5); SPEX CertiPrep, Inc., Metuchen, NJ.

b. SPEX Custom Multi-element Standards[b]

Element	Actual Conc	Meas Conc	% Rec
Pr	10	9.8	98
Tb	10	9.4	94
Tm	10	9.5	95
Ta	10	10.2	102
Au	10	12.5	125

[b] a mixture of SPEX Custom Multi-element Standards XCERCMO-1 and XCERCMO-2; SPEX CertiPrep, Inc., Metuchen, NJ.

Table 14. Percent relative standard deviation from repeated analysis of Trace Metals in Drinking Water Standard[a] during the semi-quantitative sample run of Cedar Creek surface water in 1999. Results expressed in ng/ml unless noted.

Element	Run #1	Run #2	Run #3	Actual Conc	Mean Conc	SD	% RSD
Li	19.9	19.0	21.0	20	19.9	1.0	5.0
Be	19.5	19.0	20.6	20	19.7	0.8	4.2
Na[b]	6.67	6.63	7.79	6	7.0	0.7	9.4
Mg[b]	9.81	9.85	11.4	9	10.4	0.9	9.0
Al	126	124	148	120	132.6	13.4	10.1
K[b]	1.94	2.06	2.41	2.5	2.1	0.2	11.3
Ca[b]	37.9	37.5	43.8	35	39.7	3.5	8.9
V	31.5	31.8	36.6	30	33.3	2.8	8.5
Cr	20.5	20.8	24.3	20	21.9	2.1	9.6
Mn	44.1	39.6	45.9	40	43.2	3.2	7.5
Fe	69.1	77.4	80.1	100	75.5	5.7	7.6
Co	26.3	26.2	31.5	25	28.0	3.0	10.7
Ni	63.9	63.2	73.9	60	67.0	6.0	9.0
Cu	20.0	20.7	24.4	20	21.7	2.4	10.9
Zn	72.6	72.6	85.4	70	76.9	7.4	9.7
As	79.2	79.7	92.6	80	83.8	7.6	9.1
Se	10.7	10.3	12.5	10	11.2	1.2	10.7
Rb	10.1	9.93	11.8	10	10.6	1.0	9.5
Sr	257	262	309	250	276	28.9	10.5
Mo	100	100	115	100	105	8.7	8.2
Ag	2.10	2.00	2.43	2.0	2.2	0.2	10.3
Cd	10.3	9.97	11.7	10	10.7	0.9	8.6
Sb	10.1	9.85	11.6	10	10.5	0.9	8.8
Te	2.94	3.05	3.55	3.0	3.2	0.3	10.2
Ba	51.5	50.6	62.2	50	54.8	6.5	11.8
Pr	10.2	9.79	11.8	10	10.6	1.1	10.0
Tb	10.4	9.85	12.3	10	10.8	1.3	11.7
Tm	10.2	10.1	12.1	10	10.8	1.1	10.3
Ta	10.5	10.1	12.0	10	10.9	1.0	8.8
Au	10.2	9.86	11.5	10	10.5	0.9	8.5
Tl	9.91	9.76	11.8	10	10.5	1.1	10.7
Pb	38.3	38.6	45.6	40	40.8	4.1	10.0
Bi	8.33	8.35	10.1	10	8.9	1.0	11.1
U	10.1	9.82	11.7	10	10.5	1.0	9.6

[a] High Purity Trace Metals in Drinking Water, Catalog # CRM-TMDW, Charleston, SC; Pr, Tb, Tm, Ta, and Au manually added to represent rare earth region of the mass spectral range.
[b] Concentrations are in µg/ml.

Table 15. Percent relative standard deviation from repeated analysis of Trace Metals in Drinking Water Standard[a] during the semi-quantitative sample run of Cedar Creek surface water in 2000. Results expressed in ng/ml unless noted.

Element	Run #1	Run #2	Run #3	Run #4	Actual Conc	Mean Conc	SD	% RSD
Li	18.9	20.6	18.7	21.0	20	19.8	1.2	5.9
Be	19.9	19.9	19.6	19.2	20	19.7	0.3	1.6
Na[b]	6.22	6.62	6.75	7.8	6	6.9	0.7	9.9
Mg[b]	9.60	10.21	9.97	11.8	9	10.4	1.0	9.3
Al	130	128.	136	145	120	135	7.9	5.9
K[b]	1.80	1.90	1.99	2.11	2.5	2	0.1	6.9
Ca[b]	35.5	38.7	37.8	42.5	35	38.6	2.9	7.6
V	30.0	30.5	30.0	32.9	30	30.8	1.4	4.4
Cr	20.9	22.4	21.4	21.9	20	21.7	0.7	3.0
Mn	40.6	44.1	40.4	46.4	40	42.9	2.9	6.8
Fe	63.3	84.2	72.5	76.4	100	74.1	8.7	11.7
Co	27.2	26.3	27.4	29.3	25	27.5	1.2	4.5
Ni	64.3	64.8	65.1	71.4	60	66.4	3.3	5.0
Cu	19.6	20.4	20.6	23.1	20	20.9	1.5	7.4
Zn	73.6	77.0	75.1	79.8	70	76.4	2.7	3.5
As	83.3	83.9	84.8	90.7	80	85.7	3.4	4.0
Se	10.8	10.5	10.4	11.9	10	10.9	0.7	6.0
Rb	10.2	10.48	10.3	11.9	10	10.7	0.8	7.6
Sr	276	274	278	310	250	284	17.0	6.0
Mo	104	104	101	115	100	106	6.3	6.0
Ag	2.24	2.28	2.17	2.66	2.0	2.3	0.2	9.4
Cd	10.5	10.71	10.4	11.2	10	10.7	0.3	3.2
Sb	0.05	0.07	0.07	0.07	10	0.07	0	15.4
Te	3.27	3.22	2.94	3.59	3.0	3.3	0.3	8.2
Ba	51.7	41.6	40.5	47.5	50	45.3	5.2	11.5
Pr	10.3	10.0	10.2	11.6	10	10.5	0.7	6.8
Tb	10.3	9.98	10.4	11.8	10	10.6	0.8	7.5
Tm	10.1	9.8	10.4	11.4	10	10.4	0.7	6.9
Ta	10.6	9.62	10.6	11.9	10	10.7	0.9	8.9
Au	10.2	9.79	10.2	11.7	10	10.5	0.8	7.9
Tl	10.1	10.1	10.5	11.8	10	10.6	0.8	7.9
Pb	38.6	38.4	38.2	45.1	40	40.1	3.4	8.4
Bi	8.47	8.20	8.77	9.88	10	8.8	0.7	8.4
U	9.92	9.67	9.88	11.4	10	10.2	0.8	7.7

[a] High Purity Trace Metals in Drinking Water, Catalog # CRM-TMDW, Charleston, SC; Pr, Tb, Tm, Ta, and Au manually added to represent rare earth region of the mass spectral range.
[b] Concentrations are in µg/ml.

Table 16. Percent relative standard deviation from repeated analysis of Trace Metals in Drinking Water Standard[a] during the semi-quantitative sample run of Cedar Creek surface water in 2001. Results expressed in ng/ml unless noted.

Element	Run #1	Run #2	Run #3	Actual Conc	Mean Conc	SD	% RSD
Li	20.4	21.1	19.3	20	20.3	0.9	4.4
Be	20.2	21.0	19.3	20	20.2	0.9	4.4
Na[b]	6.10	6.80	6.34	6	6.41	0.4	5.6
Mg[b]	9.38	10.4	9.62	9	9.81	0.6	5.6
Al	119	125	120	120	121	3.5	2.9
K[b]	3.32	3.6	3.37	2.5	3.42	0.1	3.8
Ca[b]	37.6	39.1	37.3	35	38.0	1.0	2.6
V	30.7	32.2	31.5	30	31.5	0.8	2.5
Cr	20.1	20.6	19.7	20	20.1	0.4	2.0
Mn	40.7	41.8	41.7	40	41.4	0.6	1.5
Fe	127.	141	133	100	134	7.3	5.4
Co	25.7	27.6	26.8	25	26.7	0.9	3.5
Ni	63.2	65.7	64.4	60	64.4	1.3	2.0
Cu	19.5	21.2	20.6	20	20.4	0.9	4.2
Zn	68.8	73.2	70.2	70	70.7	2.3	3.2
As	79.3	83.2	79.6	80	80.7	2.2	2.7
Se	9.01	10.9	10.5	10	10.1	1.0	9.8
Rb	10.34	10.7	10.8	10	10.6	0.2	2.3
Sr	245	262	268	250	258	12.2	4.7
Mo	99	105	101	100	101	3.4	3.3
Ag	1.99	2.23	2.17	2.0	2.13	0.1	5.9
Cd	9.83	10.4	10.5	10	10.2	0.4	3.4
Sb	9.41	10.4	10.4	10	10.1	0.6	5.6
Te	2.91	3.33	3.17	3.0	3.1	0.2	6.8
Ba	49.3	53.5	52.7	50	51.8	2.2	4.3
Pr	10.0	10.4	10.7	10	10.4	0.4	3.6
Tb	10.0	10.8	10.8	10	10.5	0.5	4.5
Tm	9.45	10.3	10.5	10	10.1	0.6	5.5
Ta	9.55	10.6	9.96	10	10.0	0.5	5.2
Au	9.78	10.0	9.98	10	9.92	0.1	1.3
Tl	10.1	10.5	10.3	10	10.3	0.2	1.8
Pb	41.2	43.0	42.8	40	42.3	1.0	2.4
Bi	8.97	9.14	9.12	10	9.08	0.1	1.0
U	9.64	10.2	10.0	10	9.94	0.3	2.7

[a] High Purity Trace Metals in Drinking Water, Catalog # CRM-TMDW, Charleston, SC; Pr, Tb, Tm, Ta, and Au manually added to represent rare earth region of the mass spectral range.
[b] Concentrations are in µg/ml.

Table 17. Percent relative standard deviation from repeated analysis of Trace Metals in Drinking Water Standard[a] during the semi-quantitative sample run of Cedar Creek surface water in 2002. Results expressed in ng/ml unless noted.

Element	Run #1	Run #2	Run #3	Run #4	Actual Conc.	Mean Conc.	SD	% RSD
Li	19.3	19.8	18.7	17.4	20	18.8	1.0	5.4
Be	18.8	19.7	19.3	18.2	20	19.0	0.7	3.4
Na[b]	6.05	6.38	5.70	5.50	6	5.9	0.4	6.6
Mg[b]	8.75	9.5	7.68	7.92	9	8.5	0.8	9.9
Al	119	121	103	100	120	111	10.8	9.8
K[b]	2.86	3.09	2.67	2.66	2.5	2.8	0.2	7.2
Ca[b]	34.9	36.5	30.6	29.4	35	32.9	3.4	10.3
V	29.1	29.8	26.4	26.6	30	28.0	1.7	6.2
Cr	19.0	19.3	17.2	16.6	20	18.0	1.3	7.2
Mn	39.0	41.0	34.9	34.3	40	37.3	3.2	8.6
Fe	116	125	100	164	100	126	27.2	21.6
Co	24.3	24.9	22.1	20.3	25	22.9	2.1	9.1
Ni	58.0	60.4	54.1	50.3	60	55.7	4.5	8.0
Cu	19.4	20.3	17.3	17.0	20	18.5	1.6	8.5
Zn	66.0	68.7	67.3	63.0	70	66.2	2.4	3.7
As	78.7	80.4	76.3	73.8	80	77.3	2.9	3.7
Se	9.41	10.1	9.8	8.8	10	9.5	0.6	5.8
Rb	12.0	10.6	11.0	10.7	10	11.1	0.7	5.9
Sr	244	251	357	213	250	266	62.9	23.6
Mo	97	97	90	89	100	93.0	4.6	4.9
Ag	1.96	2.06	1.82	1.74	2.0	1.9	0.1	7.5
Cd	9.87	9.5	9.3	9.0	10	9.4	0.4	3.9
Sb	9.78	10.0	9.3	9.0	10	9.5	0.5	5.0
Te	2.97	2.86	2.83	2.80	3.0	2.9	0.1	2.6
Ba	50.4	48.8	44.0	44.4	50	46.9	3.2	6.8
Pr	9.7	9.9	9.0	8.5	10	9.3	0.6	6.8
Tb	9.5	10.0	8.9	8.4	10	9.2	0.7	7.5
Tm	9.36	9.5	8.7	8.2	10	9.0	0.6	6.6
Ta	9.37	9.5	10.3	10.1	10	9.8	0.5	4.8
Au	9.87	9.6	9.62	9.26	10	9.6	0.3	2.6
Tl	9.52	9.4	8.8	8.5	10	9.1	0.5	5.2
Pb	40.2	38.3	36.6	35.8	40	37.7	1.9	5.1
Bi	8.41	7.99	7.72	7.46	10	7.9	0.4	5.1
U	10.1	9.4	9.1	8.8	10	9.3	0.6	6.2

[a] High Purity Trace Metals in Drinking Water, Catalog # CRM-TMDW, Charleston, SC; Pr, Tb, Tm, Ta, and Au manually added to represent rare earth region of the mass spectral range.
[b] Concentrations are in μg/ml.

Table 18. Percent change in internal standards from beginning to end of the ICP-MS semi-quantitative run.

BID	Run Date	IS	Conc (ppb)	Matrix	Initial Intensity	Middle Intensity	End Intensity	Mean Intensity	Intensity SD	%RSD
06/24/02	06/24/02	Sc	10	Filtered	93178	83513	80414	85702	6658	7.8
		Rh	10	Water	176172	159214	157598	164328	10289	6.3
		Th	10		282759	260750	253333	265614	15304	5.8

Table 19. Means, standard deviations (in parenthesis) and number of samples [in brackets] of Cedar Creek water quality during the entire study, by year.

Year	Site	Temperature (°C)	pH	Conductivity (µS/cm)	Dissolved Oxygen (mg/L)	Turbidity (NTU)	Alkalinity (mg/L as $CaCO_3$)	Hardness (mg/L as $CaCO_3$)
1999	1	21.2 (10.9) [6]	7.53 (0.2) [6]	0.59 (0.21) [6]	6.50 (3.9) [6]	18.4 (16.5) [6]	106 (26.2) [6]	289 (133) [6]
1999	2	21.8 (10.3) [6]	7.57 (0.2) [6]	0.47 (0.08) [6]	6.24 (2.5) [6]	16.8 (9.6) [6]	131 (34.7) [6]	214 (62.0) [6]
1999	3	19.9 (9.2) [6]	7.43 (0.3) [6]	0.58 (0.14) [6]	6.70 (1.9) [6]	13.2 (10.2) [6]	93.7 (20.3) [6]	259 (67.2) [6]
1999	4	18.3 (8.3) [6]	6.60 (0.8) [6]	0.92 (0.35) [6]	5.21 (1.9) [6]	11.2 (8.2) [6]	77.0 (78.8) [6]	703 (477) [6]
1999	5	17.7 (8.3) [6]	6.93 (0.4) [6]	0.93 (0.38) [6]	4.84 (1.7) [6]	7.3 (5.7) [6]	76.0 (44.4) [6]	696 (334) [6]
1999	6	18.0 (8.9) [6]	6.70 (0.8) [6]	0.89 (0.33) [6]	5.78 (2.1) [6]	9.75 (8.8) [6]	90.1 (71.3) [6]	756 (465) [6]
1999	7	18.1 (8.2) [6]	6.91 (0.7) [6]	0.77 (0.33) [6]	5.30 (2.0) [6]	11.0 (7.7) [6]	90.8 (61.6) [6]	413 (112) [6]
1999	8	17.9 (7.8) [6]	7.00 (0.5) [6]	0.85 (0.27) [6]	4.91 (1.6) [6]	5.6 (2.3) [6]	78.0 (27.5) [6]	427 (180) [6]
1999	9	16.9 (6.9) [6]	6.36 (0.7) [6]	1.05 (0.52) [6]	5.99 (1.9) [6]	5.0 (1.0) [6]	28.0 (31.7) [7]	792 (347) [6]
1999	10	18.6 (7.5) [6]	7.09 (0.6) [6]	1.13 (0.41) [6]	6.64 (1.0) [6]	11.9 (4.7) [6]	86.0 (26.1) [6]	607 (267) [6]
2000	1	17.8 (7.0) [9]	7.55 (0.3) [9]	0.51 (0.21) [9]	6.18 (4.7) [9]	34.9 (39.8) [9]	93.1 (37.7) [9]	207 (120) [9]
2000	2	18.9 (7.6) [9]	7.42 (0.3) [9]	0.40 (0.14) [9]	5.59 (4.4) [9]	34.8 (23.4) [9]	92.0 (22.6) [9]	174 (73.6) [9]
2000	3	17.8 (7.3) [9]	7.42 (0.3) [9]	0.45 (0.24) [9]	6.03 (3.6) [9]	34.4 (33.6) [9]	87.3 (30.0) [9]	204 (119) [9]
2000	4	17.5 (7.0) [9]	6.66 (0.5) [9]	1.05 (0.53) [9]	5.56 (2.0) [9]	25.5 (31.9) [9]	50.7 (25.8) [9]	662 (470) [9]
2000	5	16.5 (6.2) [9]	7.04 (0.5) [9]	0.86 (0.52) [9]	5.84 (1.8) [9]	23.7 (18.0) [9]	57.1 (26.9) [9]	534 (367) [9]
2000	6	17.5 (6.6) [9]	6.75 (0.4) [9]	1.02 (0.53) [9]	5.93 (2.1) [9]	22.3 (22.3) [9]	54.7 (15.2) [9]	622 (387) [9]
2000	7	17.1 (7.1) [9]	6.81 (0.3) [9]	0.95 (0.50) [9]	6.06 (3.2) [9]	20.7 (20.6) [9]	59.6 (22.0) [9]	554 (354) [9]
2000	8	17.7 (7.2) [9]	6.92 (0.3) [9]	0.78 (0.34) [9]	5.63 (2.1) [9]	19.4 (22.6) [9]	55.8 (6.59) [9]	435 (253) [9]
2000	9	17.5 (6.1) [9]	6.93 (0.2) [9]	0.81 (0.36) [9]	6.73 (1.9) [9]	10.6 (8.2) [9]	41.3 (17.4) [9]	450 (277) [9]
2000	10	17.9 (7.2) [9]	6.83 (0.2) [9]	0.79 (0.31) [9]	6.50 (3.1) [9]	22.9 (19.0) [9]	61.4 (13.2) [9]	422 (204) [9]

Table 19. Means, standard deviations (in parenthesis) and number of samples [in brackets] of Cedar Creek water quality during the entire study, by year.—Continued

Year	Site	Temperature (°C)	pH	Conductivity (µS/cm)	Dissolved Oxygen (mg/L)	Turbidity (NTU)	Alkalinity (mg/L as $CaCO_3$)	Hardness (mg/L as $CaCO_3$)
2001	1	19.3 (8.3) [9]	7.62 (0.4) [11]	0.39 (0.13) [11]	7.98 (2.4) [11]	35.8 (26.6) [11]	81.1 (13.3) [11]	160 (42.5) [11]
2001	2	19.7 (8.3) [9]	7.48 (0.3) [11]	0.39 (0.11) [11]	7.66 (2.1) [11]	27.8 (19.9) [11]	90.0 (23.5) [11]	174 (46.9) [11]
2001	3	17.9 (8.0) [10]	7.37 (0.2) [11]	0.39 (0.09) [11]	7.38 (2.0) [11]	33.1 (27.7) [11]	75.1 (18.6) [11]	164 (44.4) [11]
2001	4	17.6 (7.7) [10]	7.10 (0.2) [11]	0.71 (0.24) [11]	7.06 (2.1) [11]	34.7 (27.1) [11]	67.1 (14.5) [11]	360 (147) [11]
2001	5	16.1 (6.5) [10]	6.97 (0.3) [11]	0.63 (0.29) [11]	6.61 (2.0) [11]	19.6 (19.5) [11]	70.0 (15.4) [11]	332 (200) [11]
2001	6	17.6 (7.6) [10]	7.08 (0.2) [11]	0.69 (0.23) [11]	7.02 (1.9) [11]	32.5 (23.8) [11]	70.0 (25.1) [11]	317 (169) [11]
2001	7	17.0 (7.2) [10]	7.12 (0.2) [11]	0.63 (0.26) [11]	6.60 (2.1) [11]	26.2 (23.4) [11]	75.3 (38.8) [11]	319 (156) [11]
2001	8	17.2 (7.3) [10]	7.20 (0.2) [11]	0.60 (0.21) [11]	7.19 (1.7) [11]	26.8 (26.4) [11]	67.8 (20.1) [11]	291 (106) [11]
2001	9	16.3 (7.0) [10]	7.04 (0.3) [11]	0.71 (0.35) [11]	7.70 (2.1) [11]	23.3 (34.4) [11]	40.6 (15.5) [11]	394 (261) [11]
2001	10	18.0 (7.5) [9]	7.06 (0.2) [10]	0.63 (0.21) [10]	7.34 (1.7) [10]	30.1 (24.4) [10]	66.8 (19.4) [10]	305 (111) [10]
2002	1	17.7 (7.5) [7]	7.35 (0.5) [7]	0.43 (0.10) [7]	7.07 (2.4) [7]	29.0 (16.6) [7]	87.1 (23.9) [7]	196 (55.3) [7]
2002	2	18.4 (7.7) [7]	7.28 (0.2) [7]	0.40 (0.08) [7]	7.21 (2.0) [7]	23.7 (13.6) [7]	88.0 (33.1) [7]	171 (47.1) [7]
2002	3	18.3 (7.3) [8]	7.28 (0.2) [8]	0.45 (0.09) [8]	7.37 (1.8) [8]	24.4 (14.6) [8]	79.5 (19.4) [8]	197 (39.9) [8]
2002	4	18.2 (7.7) [8]	7.07 (0.2) [8]	0.83 (0.33) [8]	7.08 (2.0) [8]	26.2 (16.0) [8]	77.5 (21.4) [8]	426 (199) [8]
2002	5	16.9 (7.0) [8]	6.84 (0.3) [8]	0.81 (0.30) [8]	6.66 (1.9) [8]	14.2 (14.5) [8]	84.5 (16.0) [8]	432 (134) [8]
2002	6	18.2 (7.5) [8]	7.02 (0.2) [8]	0.83 (0.32) [8]	6.80 (2.5) [8]	32.9 (15.9) [7]	88.9 (41.3) [7]	437 (187) [7]
2002	7	17.6 (7.6) [8]	7.11 (0.2) [8]	0.75 (0.23) [8]	7.38 (1.9) [8]	22.8 (15.0) [8]	74.8 (12.0) [8]	395 (158) [8]
2002	8	18.1 (7.8) [8]	7.09 (0.3) [8]	0.64 (0.16) [8]	7.53 (1.9) [8]	16.4 (12.5) [8]	65.6 (7.1) [8]	330 (82.6) [8]
2002	9	17.2 (7.8) [8]	6.77 (0.3) [8]	0.93 (0.30) [8]	7.95 (2.1) [8]	10.0 (5.9) [8]	38.5 (20.8) [8]	508 (174) [8]
2002	10	17.8 (7.8) [9]	6.98 (0.2) [9]	0.77 (0.23) [9]	8.5 (1.7) [9]	18.8 (10.8) [9]	71.8 (16.7) [9]	388 (137) [9]

Table 20. Means, standard deviations (in parenthesis) and number of samples [in brackets] of Cedar Creek water quality during leafpack deployment.

Year	Site	Temperature (°C)	pH	Conductivity (µS/cm)	Dissolved Oxygen (mg/L)	Turbidity (NTU)	Alkalinity (mg/L as $CaCO_3$)	Hardness (mg/L as $CaCO_3$)
1999	2	25.6 (5.1) [3]	7.69 (0.2) [3]	0.42 (0.07) [3]	8.39 (0.32) [3]	20.7 (11.6) [3]	103 (20.5) [3]	177 (21.4) [3]
1999	3	23.1 (5.2) [3]	7.28 (0.1) [3]	0.50 (0.10) [3]	7.33 (1.89) [3]	13.5 (12.6) [3]	77.3 (12.2) [3]	223 (53.3) [3]
1999	4	21.1 (4.3) [3]	6.85 (0.3) [3]	1.04 (0.23) [3]	6.81 (0.72) [3]	9.6 (5.1) [3]	47.3 (14.0) [3]	511 (124) [3]
1999	5	20.0 (3.9) [3]	6.88 (0.2) [3]	1.14 (0.14) [3]	6.10 (0.84) [3]	5.8 (2.3) [3]	62.0 (21.6) [3]	577 (77.0) [3]
1999	6	20.6 (4.9) [3]	6.98 (0.2) [3]	0.98 (0.20) [3]	7.29 (0.73) [3]	13.7 (11.6) [3]	84.3 (52.2) [3]	635 (260) [3]
1999	7	20.6 (5.0) [3]	7.18 (0.2) [3]	0.96 (0.23) [3]	6.68 (0.30) [3]	7.3 (3.2) [3]	66.3 (7.2) [3]	481 (132) [3]
1999	8	19.8 (4.1) [3]	7.15 (0.2) [3]	0.79 (0.08) [3]	6.21 (0.75) [3]	7.0 (2.6) [3]	66.0 (19.3) [3]	390 (47.8) [3]
1999	9	18.3 (4.1) [3]	5.93 (0.6) [3]	1.42 (0.28) [3]	6.99 (0.72) [3]	4.6 (1.3) [3]	11.5 (9.8) [3]	856 (205) [3]
1999	10	20.1 (3.5) [3]	7.43 (0.6) [3]	0.89 (0.19) [3]	6.94 (0.92) [3]	15.3 (4.2) [3]	64.0 (11.1) [3]	439 (107) [3]
2000	1	21.0 (2.82) [5]	7.46 (0.2) [5]	0.43 (0.26) [5]	3.69 (0.31) [5]	53.1 (47.1) [5]	78.8 (47.4) [5]	165 (146) [5]
2000	2	22.2 (2.74) [5]	7.17 (0.1) [5]	0.34 (0.15) [5]	3.26 (0.66) [5]	48.4 (20.2) [5]	85.6 (28.8) [5]	148 (83.8) [5]
2000	3	20.9 (2.91) [5]	7.17 (0.2) [5]	0.34 (0.22) [5]	3.99 (1.55) [5]	52.6 (35.8) [5]	74.8 (34.1) [5]	156 (129) [5]
2000	4	21.2 (2.73) [5]	6.71 (0.3) [5]	0.86 (0.66) [5]	4.22 (0.69) [5]	42.5 (34.9) [5]	54.8 (25.4) [5]	561 (492) [5]
2000	5	19.6 (2.74) [5]	7.00 (0.2) [5]	0.54 (0.27) [5]	4.89 (0.93) [5]	31.0 (19.0) [5]	69.6 (19.2) [5]	330 (161) [5]
2000	6	20.7 (2.65) [5]	6.72 (0.4) [5]	0.82 (0.64) [5]	4.85 (1.21) [5]	33.5 (25.3) [5]	58.4 (13.1) [5]	457 (418) [5]
2000	7	21.0 (2.77) [5]	6.74 (0.4) [5]	0.81 (0.66) [5]	4.46 (0.88) [5]	30.4 (24.2) [5]	54.4 (20.9) [5]	442 (451) [5]
2000	8	21.1 (2.34) [5]	6.83 (0.3) [5]	0.63 (0.35) [5]	4.49 (0.79) [5]	29.8 (26.6) [5]	57.2 (5.0) [5]	307 (218) [5]
2000	9	20.5 (2.35) [5]	6.87 (0.2) [5]	0.68 (0.34) [5]	5.84 (0.53) [5]	12.7 (8.6) [5]	50.8 (14.8) [5]	335 (201) [5]
2000	10	21.6 (2.22) [5]	6.83 (0.3) [5]	0.62 (0.32) [5]	4.91 (0.84) [5]	33.6 (19.1) [5]	62.8 (8.8) [5]	304 (201) [5]

Table 20. Means, standard deviations (in parenthesis) and number of samples [in brackets] of Cedar Creek water quality during leafpack deployment. —Continued

Year	Site	Temperature (°C)	pH	Conductivity (µS/cm)	Dissolved Oxygen (mg/L)	Turbidity (NTU)	Alkalinity (mg/L as $CaCO_3$)	Hardness (mg/L as $CaCO_3$)
2001	1	23.5 (4.90) [5]	7.67 (0.4) [6]	0.38 (0.11) [6]	7.49 (2.10) [6]	47.1 (32.5) [6]	74.3 (22.0) [6]	143 (48.2) [6]
2001	2	23.3 (4.00) [6]	7.43 (0.3) [6]	0.33 (0.10) [6]	7.09 (1.07) [6]	36.7 (24.1) [6]	80.3 (25.7) [6]	150 (30.9) [6]
2001	3	22.6 (4.32) [5]	7.27 (0.2) [6]	0.36 (0.11) [6]	6.60 (1.05) [6]	41.9 (36.4) [6]	68.7 (19.3) [6]	147 (51.6) [6]
2001	4	22.3 (3.99) [5]	7.04 (0.1) [6]	0.60 (0.23) [6]	6.54 (0.33) [6]	49.7 (28.8) [6]	62.3 (11.6) [6]	293 (129) [6]
2001	5	19.6 (3.39) [5]	6.84 (0.2) [6]	0.60 (0.23) [6]	6.43 (0.67) [6]	27.2 (23.5) [6]	65.0 (11.4) [6]	256 (170) [6]
2001	6	21.9 (3.83) [5]	7.01 (0.04) [6]	0.58 (0.22) [6]	6.62 (0.59) [6]	42.2 (27.3) [6]	60.7 (12.4) [6]	230 (154) [6]
2001	7	21.1(3.68) [5]	7.05 (0.1) [6]	0.56 (0.21) [6]	6.12 (1.02) [6]	36.3 (28.4) [6]	64.7 (13.4) [6]	227 (142) [6]
2001	8	21.2 (3.37) [5]	7.10 (0.1) [6]	0.52 (0.19) [6]	6.42 (0.92) [6]	36.0 (33.8) [6]	59.3 (8.6) [6]	245 (86.4) [6]
2001	9	19.9 (3.45) [5]	6.92 (0.3) [6]	0.68 (0.35) [6]	7.04 (0.78) [6]	18.5 (15.3) [6]	39.3 (14.1) [6]	279 (238) [6]
2001	10	20.9 (3.37) [5]	7.05 (0.1) [6]	0.56 (0.23) [6]	6.96 (0.35) [6]	37.2 (29.5) [6]	59.3 (10.1) [6]	263 (111) [6]
2002	2	22.1 (4.89) [4]	7.13 (0.1) [4]	0.41 (0.05) [4]	6.80 (1.45) [4]	16.3 (1.5) [4]	89.0 (27.5) [4]	179 (40.4) [4]
2002	3	21.6 (4.11) [5]	7.19 (0.2) [5]	0.46 (0.11) [5]	7.02 (1.09) [5]	19.1 (14.4) [5]	80.8 (17.3) [5]	197 (44.4) [5]
2002	4	22.1 (4.72) [5]	6.99 (0.2) [5]	0.79 (0.26) [5]	6.78 (0.58) [5]	21.7 (11.4) [5]	76.0 (13.9) [5]	400 (151) [5]
2002	5	20.1 (4.68) [5]	6.67 (0.2) [5]	0.92 (0.25) [5]	6.04 (0.60) [5]	8.6 (5.4) [5]	84.4 (8.9) [5]	458 (155) [5]
2002	6	21.6 (4.57) [5]	6.93 (0.2) [5]	0.79 (0.25) [5]	6.47 (1.10) [5]	31.5 (10.6) [5]	81.0 (16.5) [4]	408 (151) [4]
2002	7	21.5 (4.22) [5]	7.04 (0.1) [5]	0.74 (0.23) [5]	6.69 (0.82) [5]	20.1 (13.8) [5]	78.8 (12.0) [5]	382 (123) [5]
2002	8	22.0 (4.44) [5]	7.08 (0.1) [5]	0.64 (0.16) [5]	6.99 (0.76) [5]	14.2 (9.1) [5]	66.0 (7.3) [5]	321 (91.9) [5]
2002	9	20.7 (4.42) [5]	6.66 (0.2) [5]	0.96 (0.35) [5]	7.38 (0.57) [5]	7.4 (5.2) [5]	28.4 (13.4) [5]	520 (207) [5]
2002	10	22.3 (4.81) [5]	6.86 (0.2) [5]	0.72 (0.18) [5]	7.64 (1.20) [5]	17.4 (5.6) [5]	70.8 (9.3) [5]	344 (116) [5]

Table 21. Means, standard deviation (in parenthesis) and number of samples [in brackets] of Cedar Creek water quality during winter months.

Year	Site	Temperature (°C)	pH	Conductivity (µS/cm)	Dissolved Oxygen (mg/L)	Turbidity (NTU)	Alkalinity (mg/L as $CaCO_3$)	Hardness (mg/L as $CaCO_3$)
1999-2000	1	5.88 (6.76) [2]	7.83 (0.06) [2]	0.78 (0.10) [2]	12.6 (0.7) [2]	11.4 (9.3) [2]	124 (28.3) [2]	394 (76.4) [2]
1999-2000	2	6.79 (5.59) [2]	7.50 (0.25) [2]	0.57 (0.03) [2]	7.26 (2.3) [2]	7.90 (0.8) [2]	127 (58.0) [2]	297 (49.5) [2]
1999-2000	3	6.51 (4.33) [2]	7.91 (0.01) [2]	0.80 (0.08) [2]	9.18 (1.4) [2]	12.7 (11.7) [2]	121 (1.4) [2]	353 (49.5) [2]
1999-2000	4	6.66 (4.84) [2]	6.02 (1.48) [2]	0.78 (0.72) [2]	6.58 (3.4) [2]	7.45 (1.1) [2]	34.0 (45.3) [2]	1230 (608) [2]
1999-2000	5	5.86 (4.66) [2]	7.22 (1.16) [2]	0.38 (0.25) [2]	6.30 (4.8) [2]	17.8 (22.9) [2]	47.0 (15.6) [2]	803 (796) [2]
1999-2000	6	6.55 (6.76) [2]	6.11 (1.33) [2]	0.71 (0.62) [2]	7.70 (1.9) [2]	8.45 (6.4) [2]	32.0 (42.4) [2]	1178 (761) [2]
1999-2000	7	6.60 (4.81) [2]	6.26 (1.00) [2]	0.64 (0.63) [2]	7.28 (1.9) [2]	9.00 (0.7) [2]	58.0 (59.4) [2]	460 (184) [2]
1999-2000	8	7.44 (4.25) [2]	6.47 (0.59) [2]	1.36 (0.03) [2]	6.31 (3.1) [2]	4.20 (1.3) [2]	53.0 (4.2) [2]	785 (7.1) [2]
1999-2000	9	7.66 (3.87) [2]	6.48 (0.57) [2]	0.47 (0.38) [2]	8.51 (1.4) [2]	12.9 (10.0) [2]	25.0 (21.2) [5]	825 (672) [2]
1999-2000	10	7.58 (3.90) [2]	6.45 (0.32) [2]	1.05 (0.08) [2]	8.37 (1.1) [2]	12.15 (5.4) [2]	66.0 (45.3) [2]	578 (17.0) [2]
2000-2001	1	3.21 (0.42) [2]	7.29 (0.22) [2]	0.52 (0.20) [2]	13.3 (4.5) [2]	13.2 (9.5) [2]	91.0 (35.4) [2]	216 (70.7) [2]
2000-2001	2	2.60 (0.28) [2]	7.60 (0.42) [2]	0.44 (0.13) [2]	13.6 (3.8) [2]	10.2 (6.7) [2]	93.0 (24.0) [2]	177 (66.5) [2]
2000-2001	3	2.35 (0.57) [2]	7.44 (0.47) [2]	0.46 (0.15) [2]	12.1 (2.1) [2]	13.9 (14.4) [2]	83.0 (38.2) [2]	190 (67.9) [2]
2000-2001	4	2.42 (0.78) [2]	6.81 (0.12) [2]	0.92 (0.50) [2]	9.51 (1.6) [2]	13.8 (14.5) [2]	46.0 (0.0) [2]	598 (307) [3]
2000-2001	5	3.08 (1.32) [2]	6.90 (0.20) [2]	1.02 (0.44) [2]	8.16 (1.2) [2]	9.50 (5.0) [2]	52.0 (25.5) [2]	625 (375) [2]
2000-2001	6	2.54 (1.12) [2]	6.80 (0.17) [2]	0.94 (0.47) [2]	9.79 (0.5) [2]	12.8 (8.8) [2]	49.0 (1.4) [2]	593 (448) [2]
2000-2001	7	1.99 (0.01) [2]	6.88 (0.08) [2]	0.89 (0.43) [2]	12.1 (2.4) [2]	14.1 (8.3) [2]	45.0 (1.4) [2]	495 (318) [2]
2000-2001	8	2.18 (0.18) [2]	7.08 (0.06) [2]	0.74 (0.27) [2]	9.80 (0.5) [2]	11.3 (6.6) [2]	55.0 (15.6) [2]	522 (351) [2]
2000-2001	9	3.18 (2.70) [2]	7.12 (0.11) [2]	1.06 (0.57) [2]	11.3 (1.8) [2]	4.75 (1.1) [2]	26.0 (22.6) [2]	680 (523) [2]
2000-2001	10	1.99 (0.48) [2]	7.06 (0.04) [2]	0.79 (0.27) [2]	12.0 (2.6) [2]	11.9 (4.4) [2]	56.0 (8.5) [2]	462 (252) [2]

Table 21. Means, standard deviation (in parenthesis) and number of samples [in brackets] of Cedar Creek water quality during winter months. —Continued

Year	Site	Temperature (°C)	pH	Conductivity (µS/cm)	Dissolved Oxygen (mg/L)	Turbidity (NTU)	Alkalinity (mg/L as $CaCO_3$)	Hardness (mg/L as $CaCO_3$)
2001-2002	1	4.34 [1]	7.17 (0.12) [2]	0.52 (0.10) [2]	11.0 (0.1) [2]	24.0 (5.7) [2]	86.0 (19.8) [2]	11.0 (0.1) [2]
2001-2002	2	4.33 [1]	7.31 (0.13) [2]	0.38 (0.05) [2]	10.2 (0.8) [2]	26.0 (7.1) [2]	82.0 (25.5) [2]	10.2 (0.8) [2]
2001-2002	3	6.88 (5.23) [2]	7.35 (0.19) [2]	0.45 (0.01) [2]	10.2 (1.4) [2]	25.5 (3.5) [2]	74.0 (17.0) [2]	10.2 (1.4) [2]
2001-2002	4	6.98 (5.81) [2]	7.20 (0.21) [2]	0.86 (0.11) [2]	10.3 (1.6) [2]	20.5 (14.8) [2]	73.0 (18.4) [2]	10.3 (1.6) [2]
2001-2002	5	7.53 (6.26) [2]	7.09 (0.35) [2]	0.92 (0.08) [2]	9.42 (1.5) [2]	6.30 (1.8) [2]	85.0 (21.2) [2]	9.42 (1.5) [2]
2001-2002	6	7.36 (6.20) [2]	7.23 (0.19) [2]	0.87 (0.09) [2]	10.3 (2.0) [2]	20.0 (17.0) [2]	71.0 (15.6) [2]	10.3 (2.0) [2]
2001-2002	7	6.32 (6.29) [2]	7.23 (0.28) [2]	0.93 (0.17) [2]	9.56 (2.9) [2]	11.5 (9.2) [2]	71.0 (12.7) [2]	9.56 (2.9) [2]
2001-2002	8	6.17 (5.88) [2]	7.01 (0.52) [2]	0.86 (0.23) [2]	10.4 (2.4) [2]	19.5 (3.5) [2]	66.0 (11.3) [2]	10.4 (2.4) [2]
2001-2002	9	6.66 (8.08) [2]	6.93 (0.63) [2]	1.17 (0.01) [2]	9.99 (3.4) [2]	13.5 (3.5) [2]	33.0 (7.1) [2]	9.99 (3.4) [2]
2001-2002	10	6.70 (5.35) [2]	7.09 (0.17) [2]	0.99 (0.26) [2]	11.0 (0.7) [2]	8.75 (11.7) [2]	59.0 (4.2) [2]	11.0 (0.7) [2]

Table 22. Monthly and seasonal rainfall (cm) in Columbia, Missouri during 1998-2002 (http://www.crh.noaa.gov/lsx/cli_record.php). Leaf packs were deployed in May and early June during 1999-2002.

Year	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**
1998	3.61	10.9	11.7	12.9	3.63	17.9
1999	7.62	5.46	6.32	13.1	9.86	8.43
2000	1.96	8.61	5.36	2.26	14.1	13.8
2001	6.83	11.2	2.77	8.64	16.2	13.3
2002	6.55	1.57	4.09	11.9	25.6	8.38
100-yr Ave.	4.54	4.78	7.35	9.86	12.1	11.4
	Jul	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
1998	14.2	1.75	11.2	18.5	4.75	3.10
1999	4.70	2.11	3.63	3.33	2.54	8.53
2000	10.3	23.1	4.45	9.14	4.42	2.21
2001	10.1	8.20	7.65	10.2	4.09	3.68
2002	5.89	21.6	4.06	10.2	2.31	5.28
100-yr Ave.	8.91	9.34	10.5	7.62	6.28	5.10

Table 23. Average nutrient concentrations, standard deviations (in parenthesis) and number of samples [in brackets] collected in Cedar Creek during leafpack deployment.

Year	Site	NH_3 (mg/L as N)	NO_2/NO_3 (mg/L as N)	TN (mg/L as N)	SRP (µg/L as P)	TP (µg/L as P)	TN/TP
1999	1	0.44 [1]	1.37 [1]	---	---	---	---
1999	2	0.04 [1]	0.24 [1]	---	---	---	---
1999	3	0.16 [1]	1.18 [1]	---	---	---	---
1999	4	0.02 [1]	0.48 [1]	---	---	---	---
1999	5	0.14 [1]	0.94 [1]	---	---	---	---
1999	6	0.03 [1]	0.49 [1]	---	---	---	---
1999	7	0.05 [1]	0.53 [1]	---	---	---	---
1999	8	0.30 [1]	0.62 [1]	---	---	---	---
1999	9	0.06 [1]	0.23 [1]	---	---	---	---
1999	10	0.17 [1]	0.62 [1]	---	---	---	---
2000	1	0.19 (0.1) [4]	2.17 (1.7) [4]	3.05 (1.9) [5]	92.4 (77.5) [4]	247 (162) [5]	0.16 (0.01) [5]
2000	2	2.85 (5.0) [4]	1.22 (1.6) [4]	2.63 (1.8) [5]	49.0 (58.1) [4]	228 (57.4) [5]	0.01 (0.01) [5]
2000	3	9.28 (18) [4]	1.64 (2.2) [4]	2.93 (2.2) [5]	83.7 (76.3) [4]	227 (141) [5]	0.02 (0.01) [5]
2000	4	0.20 (0.1) [4]	1.14 (1.2) [4]	1.74 (1.3) [5]	13.2 (13.9) [4]	121 (94) [5]	0.02 (0.02) [5]
2000	5	0.23 (0.2) [4]	3.90 (2.9) [4]	3.66 (2.7) [5]	64.4 (65.6) [4]	256 (159) [5]	0.02 (0.01) [5]
2000	6	0.19 (0.1) [4]	1.66 (1.6) [4]	2.20 (1.7) [5]	26.0 (25.9) [4]	186 (110) [5]	0.01 (0.01) [5]
2000	7	0.39 (0.2) [4]	1.42 (1.3) [4]	2.85 (2.4) [5]	25.8 (24.6) [4]	162 (102) [5]	0.02 (0.01) [5]
2000	8	0.20 (0.1) [4]	1.62 (1.4) [4]	2.25 (1.5) [5]	23.9 (21.0) [4]	145 (101) [5]	0.02 (0.01) [5]
2000	9	0.11 (0.02) [4]	1.92 (1.5) [4]	2.36 (1.8) [5]	26.6 (27.0) [4]]	133 (103) [5]	0.06 (0.09) [5]
2000	10	0.38 (0.2) [4]	1.84 (1.2) [4]	2.51 (1.3) [5]	27.4 (26.7) [4]	152 (85) [5]	0.02 (0.02) [5]

Table 23. Average nutrient concentrations, standard deviations (in parenthesis) and number of samples [in brackets] collected in Cedar Creek during leafpack deployment.—Continued

Year	Site	NH_3 (mg/L as N)	NO_2/NO_3 (mg/L as N)	TN (mg/L as N)	SRP (µg/L as P)	TP (µg/L as P)	TN/TP
2001	1	0.11 (0.1) [6]	2.84 (3.4) [2]	4.06 (3.6) [6]	108 (117) [6]	178 (100) [6]	0.02 (0.01) [6]
2001	2	0.11 (0.1) [6]	0.27 (0.3) [2]	1.17 (0.7) [6]	74.1 (41) [6]	106 (62) [6]	0.01 (0) [6]
2001	3	0.13 (0.1) [6]	4.45 (5.6) [2]	3.84 (3.6) [6]	96.3 (83) [6]	166 (107) [6]	0.02 (0.01) [6]
2001	4	0.17 (0.2) [6]	2.96 (3.6) [2]	2.71 (2.5) [6]	68.2 (46) [6]	116 (81) [6]	0.02 (0.01) [6]
2001	5	0.13 (0.1) [6]	0.67 (0.6) [4]	1.25 (0.5) [6]	113 (64) [6]	79.4 (90) [6]	0.05 (0.04) [6]
2001	6	0.19 (0.2) [6]	1.44 (1.1) [2]	2.84 (2.5) [6]	72.3 (39) [6]	127 (91) [6]	0.02 (0.01) [6]
2001	7	0.20 (0.1) [6]	1.29 (1.0) [2]	2.70 (2.5) [6]	86.9 (60) [6]	117 (85) [6]	0.03 (0.02) [6]
2001	8	0.12 (0.1) [6]	1.36 (1.1) [2]	2.43 (2.1) [6]	81.8 (22) [6]	99.1 (96) [6]	0.04 (0.03) [6]
2001	9	0.17 (0.1) [6]	0.78 (0.4) [2]	1.76 (1.1) [6]	57.4 (5.8) [6]	60.8 (75) [6]	0.07 (0.06) [6]
2001	10	0.16 (0.1) [6]	1.21 (0.5) [3]	2.62 (2.0) [5]	69.7 (17) [6]	116 (89) [5]	0.03 (0.01) [5]
2002	1	0.11 (0.10) [4]	0.39 (0.5) [4]	1.15 (0.6) [4]	12.4 (13) [4]	102 (46) [4]	0.01 (0) [4]
2002	2	0.06 (0.06) [4]	0.05 (0.04) [4]	0.63 (0.2) [4]	3.21 (1.5) [4]	48.8 (12) [4]	0.01 (0) [4]
2002	3	0.05 (0.03) [4]	0.35 (0.5) [4]	0.95 (0.6) [4]	5.07 (1.6) [4]	86.5 (44) [5]	0.01 (0) [4]
2002	4	0.06 (0.03) [4]	0.15 (0.2) [4]	0.67 (0.2) [4]	2.08 (1.3) [5]	50.0 (32) [5]	0.01 (0) [4]
2002	5	0.17 (0.02) [4]	0.34 (0.3) [4]	0.63 (0.3) [4]	1.61 (1.0) [4]	11.8 (6.7) [5]	0.05 (0.02) [4]
2002	6	0.08 (0.02) [4]	0.18 (0.2) [4]	0.70 (0.2) [4]	2.02 (2.2) [4]	57.3 (30) [4]	0.01 (0) [4]
2002	7	0.12 (0.03) [4]	0.25 (0.1) [4]	0.79 (0.2) [4]	4.60 (4.9) [4]	63.3 (32) [5]	0.01 (0.01) [4]
2002	8	0.05 (0.01) [4]	0.34 (0.2) [4]	0.81 (0.3) [4]	4.64 (1.4) [4]	55.1 (27) [5]	0.02 (0.01) [4]
2002	9	0.12 (0.03) [4]	0.33 (0.2) [4]	0.61 (0.2) [4]	1.71 (1.7) [4]	12.0 (13) [5]	0.11 (0.1) [4]
2002	10	0.19 (0.10) [4]	0.37 (0.3) [4]	0.93 (0.3) [4]	4.40 (3.1) [5]	38.8 (30) [5]	0.03 (0.01) [4]

Table 24. Sulfate data collected from the Cedar Creek study sites (MDNR 2004; MDNR, personal communication).

Site Location	CERC Site No.	Date Collected	Sulfate (mg/L)
Zaring Road	2	08/15/01	153
Zaring Road	2	11/06/01	95
Zaring Road	2	12/19/01	85
Zaring Road	2	04/05/02	67
Zaring Road	2	06/11/02	53
Zaring Road	2	09/30/02	86
Zaring Road	3	07/30/81	61
Zaring Road	3	08/27/81	136
Zaring Road	3	09/28/81	244
Zaring Road	3	10/26/81	332
Zaring Road	3	11/22/81	128
Zaring Road	3	12/28/81	240
Zaring Road	3	01/25/82	35
Zaring Road	3	02/24/82	63
Zaring Road	3	03/24/82	86
Zaring Road	3	04/27/82	170
Zaring Road	3	05/24/82	55
Zaring Road	3	06/21/82	105
Zaring Road	3	01/03/97	114
Zaring Road	3	07/21/98	98
Zaring Road	3	06/08/98	38
Zaring Road	3	09/09/98	112
Zaring Road	3	05/13/99	51
Zaring Road	3	03/03/00	256
Zaring Road	3	04/25/00	217
Zaring Road	3	08/15/01	174
Zaring Road	3	11/06/01	58
Zaring Road	3	12/19/01	89
Zaring Road	3	04/05/02	95
Zaring Road	3	06/04/02	131
Zaring Road	3	06/11/02	188
Zaring Road	3	09/30/02	86
Zaring Road	3	04/15/03	270
Renfro Creek	5	05/13/99	81
Renfro Creek	5	08/15/01	712
Renfro Creek	5	11/06/01	376
Renfro Creek	5	12/19/01	111
Renfro Creek	5	04/05/02	427
Renfro Creek	5	06/04/02	419
Renfro Creek	5	06/11/02	357
Confluence of Renfro and Cedar Cr	6	07/30/81	275
Confluence of Renfro and Cedar Cr	6	08/27/81	482
Confluence of Renfro and Cedar Cr	6	09/28/81	1083
Confluence of Renfro and Cedar Cr	6	10/26/81	1353
Confluence of Renfro and Cedar Cr	6	11/22/81	615
Confluence of Renfro and Cedar Cr	6	12/28/81	710
Confluence of Renfro and Cedar Cr	6	01/25/82	146
Confluence of Renfro and Cedar Cr	6	02/24/82	105

Table 24. Sulfate data collected from the Cedar Creek study sites (MDNR 2004; MDNR, personal communication.—Continued

Site Location	CERC Site No.	Date Collected	Sulfate (mg/L)
Confluence of Renfro and Cedar Cr	6	03/24/82	293
Confluence of Renfro and Cedar Cr	6	04/27/82	475
Confluence of Renfro and Cedar Cr	6	05/24/82	274
Confluence of Renfro and Cedar Cr	6	06/21/82	290
Confluence of Renfro and Cedar Cr	6	01/03/97	877
Confluence of Renfro and Cedar Cr	6	07/21/98	457
Confluence of Renfro and Cedar Cr	6	08/06/98	149
Confluence of Renfro and Cedar Cr	6	09/09/98	911
Confluence of Renfro and Cedar Cr	6	05/13/99	170
Confluence of Renfro and Cedar Cr	6	03/30/00	486
Confluence of Renfro and Cedar Cr	6	04/25/00	976
Confluence of Renfro and Cedar Cr	6	08/15/01	922
Confluence of Renfro and Cedar Cr	6	11/06/01	259
Confluence of Renfro and Cedar Cr	6	12/19/01	278
Confluence of Renfro and Cedar Cr	6	04/05/02	227
Confluence of Renfro and Cedar Cr	6	06/04/02	419
Confluence of Renfro and Cedar Cr	6	06/11/02	471
Confluence of Renfro and Cedar Cr	6	04/15/03	507
Manacle Creek	9	07/30/81	340
Manacle Creek	9	08/27/81	779
Manacle Creek	9	09/28/81	3390
Manacle Creek	9	10/26/81	1882
Manacle Creek	9	11/22/81	1330
Manacle Creek	9	12/28/81	1394
Manacle Creek	9	01/25/82	412
Manacle Creek	9	02/24/82	305
Manacle Creek	9	03/24/82	562
Manacle Creek	9	04/27/82	1045
Manacle Creek	9	05/24/82	525
Manacle Creek	9	06/21/82	400
Manacle Creek	9	06/01/97	280
Manacle Creek	9	07/01/97	280
Manacle Creek	9	07/21/98	568
Manacle Creek	9	08/06/98	368
Manacle Creek	9	09/09/98	411
Manacle Creek	9	03/30/00	345
Manacle Creek	9	04/25/00	1300
Manacle Creek	9	09/28/00	305
Manacle Creek	9	12/27/00	1190
Manacle Creek	9	03/29/01	506
Manacle Creek	9	06/27/01	512
Manacle Creek	9	09/05/01	439
Manacle Creek	9	10/30/01	782
Manacle Creek	9	12/31/01	50
Manacle Creek	9	02/05/02	355
Manacle Creek	9	03/21/02	659
Manacle Creek	9	06/18/02	281
Manacle Creek	9	10/08/02	222

Table 24. Sulfate data collected from the Cedar Creek study sites (MDNR 2004; MDNR, personal communication.—Continued

Site Location	CERC Site No.	Date Collected	Sulfate (mg/L)
Manacle Creek	9	04/02/03	411
Manacle Creek	9	09/16/03	256
I-70	10	07/30/81	316
I-70	10	08/27/81	746
I-70	10	09/28/81	1867
I-70	10	10/26/81	1148
I-70	10	11/22/81	770
I-70	10	12/28/81	1140
I-70	10	01/25/82	193
I-70	10	02/24/82	194
I-70	10	03/24/82	389
I-70	10	04/27/82	740
I-70	10	05/24/82	375
I-70	10	06/21/82	250
I-70	10	10/11/00	210
I-70	10	11/13/90	810
I-70	10	12/11/00	330
I-70	10	01/09/91	59
I-70	10	02/05/91	59
I-70	10	03/11/91	340
I-70	10	04/02/91	400
I-70	10	05/15/91	230
I-70	10	06/13/91	530
I-70	10	07/16/91	590
I-70	10	08/14/91	970
I-70	10	09/05/91	970
I-70	10	07/21/98	329
I-70	10	08/06/98	221
I-70	10	09/09/98	529
I-70	10	03/30/00	501
I-70	10	04/25/00	722
I-70	10	09/28/00	549
I-70	10	12/27/00	622
I-70	10	03/29/01	290
I-70	10	06/27/01	23
I-70	10	09/05/01	307
I-70	10	10/30/01	218
I-70	10	12/31/01	442
I-70	10	02/05/02	194
I-70	10	03/21/02	338
I-70	10	06/18/02	229
I-70	10	10/08/02	184
I-70	10	04/02/03	347
I-70	10	09/16/03	122

Data from WPCP's TMDL (MDNR 2004)
Data from LRP (MDNR 2003, personal communication)

Table 25. Sulfate data collected from the Cedar Creek Abandoned Mine Land sites (MDNR 2004; MDNR, personal communication)

MDNR Site No.	Sample Location	Date Collected	Sulfate (mg/L)
S-3	Blue Lake N.	08/15/01	410
S-3	Blue Lake N.	11/06/01	188
S-3	Blue Lake N.	12/19/01	143
S-3	Blue Lake N.	09/30/02	122
S-3	Blue Lake N.	12/11/02	NT
S-4	Blue Lake S.	09/07/99	371
S-4	Blue Lake S.	02/08/00	468
S-4	Blue Lake S.	08/15/01	394
S-4	Blue Lake S.	11/06/01	188
S-4	Blue Lake S.	12/19/01	138
S-4	Blue Lake S.	04/05/02	139
S-4	Blue Lake S.	06/11/02	157
S-4	Blue Lake S.	09/30/02	122
S-4	Blue Lake S.	12/11/02	NT
S-5	CC N.Berm: Audubon	02/08/00	645
S-5	CC N.Berm: Audubon	08/15/01	436
S-5	CC N.Berm: Audubon	11/06/01	224
S-5	CC N.Berm: Audubon	12/19/01	146
S-5	CC N.Berm: Audubon	04/05/02	110
S-5	CC N.Berm: Audubon	06/11/02	214
S-5	CC N.Berm: Audubon	09/30/02	558
S-5	CC N.Berm: Audubon	12/11/02	1140
S-6	Marchesi Pit	05/13/99	185
S-6	Marchesi Pit	02/08/00	184
S-6	Marchesi Pit	08/15/01	195
S-6	Marchesi Pit	11/06/01	176
S-6	Marchesi Pit	12/19/01	197
S-6	Marchesi Pit	04/05/02	243
S-6	Marchesi Pit	06/11/02	121
S-6	Marchesi Pit	09/30/02	173
S-6a	Wetland 1	02/08/00	5030
S-6a	Wetland 1	11/06/01	595
S-6a	Wetland 1	12/19/01	394
S-6a	Wetland 1	04/05/02	724
S-6a	Wetland 1	04/26/02	NT
S-6a	Wetland 1	06/11/02	857
S-6a	Wetland 1	09/30/02	2490
S-6a	Wetland 1	12/11/02	2580
S-6a	Wetland 1	04/15/03	910
S-6b	Wetland 1 Outfall pipe	11/06/01	457
S-6b	Wetland 1 Outfall pipe	12/19/01	340
S-6b	Wetland 1 Outfall pipe	04/05/02	618
S-6b	Wetland 1 Outfall pipe	04/26/02	NT
S-6b	Wetland 1 Outfall pipe	06/11/02	785
S-6b	Wetland 1 Outfall pipe	09/30/02	NT
S-6b	Wetland 1 Outfall pipe	12/11/02	NT

Table 25. Sulfate data collected from the Cedar Creek Abandoned Mine Land sites (MDNR 2004; MDNR, personal communication).—Continued

MDNR Site No.	Sample Location	Date Collected	Sulfate (mg/L)
S-6b	Wetland 1 Outfall pipe	04/17/03	1020
S-6c	Seep btwn Wet 1 and S-8	09/30/02	4360
S-7	Maupin Pond	09/07/99	414
S-7	Maupin Pond	05/13/99	360
S-7	Maupin Pond	02/08/00	226
S-7	Maupin Pond	08/15/01	352
S-7	Maupin Pond	11/06/01	176
S-7	Maupin Pond	09/30/02	294
S-8	N. Swale Crossing	02/08/00	1460
S-8	N. Swale Crossing	08/15/01	5100
S-8	N. Swale Crossing	11/06/01	1200
S-8	N. Swale Crossing	12/19/01	1100
S-8	N. Swale Crossing	04/05/02	4330
S-8	N. Swale Crossing	06/11/02	2070
S-8	N. Swale Crossing	09/30/02	2940
S-8	N. Swale Crossing	12/11/02	3950
S-8	N. Swale Crossing	04/15/03	2860
S-9	CC S. Berm area 6	04/20/98	615
S-9	CC S. Berm area 6	08/31/99	7330
S-9	CC S. Berm area 6	02/08/00	553
S-9	CC S. Berm area 6	08/15/01	1870
S-9	CC S. Berm area 6	11/06/01	319
S-9	CC S. Berm area 6	12/19/01	250
S-10	CC 97 Repair Bank	07/30/81	148
S-10	CC 97 Repair Bank	08/27/81	403
S-10	CC 97 Repair Bank	09/28/81	668
S-10	CC 97 Repair Bank	10/26/81	830
S-10	CC 97 Repair Bank	11/22/81	290
S-10	CC 97 Repair Bank	12/28/81	417.3
S-10	CC 97 Repair Bank	01/25/82	97.1
S-10	CC 97 Repair Bank	02/24/82	124
S-10	CC 97 Repair Bank	03/24/82	172
S-10	CC 97 Repair Bank	04/27/82	127
S-10	CC 97 Repair Bank	05/24/82	125
S-10	CC 97 Repair Bank	06/21/82	200
S-10	CC 97 Repair Bank	01/03/97	782
S-10	CC 97 Repair Bank	08/15/01	2020
S-10	CC 97 Repair Bank	11/06/01	NT
S-10	CC 97 Repair Bank	12/19/01	258
S-10	CC 97 Repair Bank	04/05/02	200
S-10	CC 97 Repair Bank	06/11/02	385
S-10	CC 97 Repair Bank	09/30/02	1460
S-11	South Swale Crossing	02/08/00	1760
S-11	South Swale Crossing	08/15/01	1970
S-11	South Swale Crossing	11/06/01	574
S-11	South Swale Crossing	12/19/01	538
S-11	South Swale Crossing	04/05/02	655

Table 25. Sulfate data collected from the Cedar Creek Abandoned Mine Land sites (MDNR 2004; MDNR, personal communication).—Continued

MDNR Site No.	Sample Location	Date Collected	Sulfate (mg/L)
S-11	South Swale Crossing	06/11/02	785
S-11	South Swale Crossing	09/30/02	554
S-11	South Swale Crossing	12/11/02	722
S-11	South Swale Crossing	04/15/03	926
S-12	Wetland 2	05/13/99	19.0
S-12	Wetland 2	02/08/00	1960
S-12	Wetland 2	08/17/01	2760
S-12	Wetland 2	11/06/01	585
S-12	Wetland 2	12/19/01	356
S-12	Wetland 2	04/05/02	642
S-12	Wetland 2	04/26/02	NT
S-12	Wetland 2	06/11/02	1070
S-12	Wetland 2	09/30/02	1330
S-12	Wetland 2	12/11/02	660
S-12	Wetland 2	04/15/03	926
S-12a	Wetland 2 outfall pipe	11/06/01	NT
S-12a	Wetland 2 outfall pipe	12/19/01	1170
S-12a	Wetland 2 outfall pipe	04/05/02	1520
S-12a	Wetland 2 outfall pipe	04/26/02	NT
S-12a	Wetland 2 outfall pipe	06/11/02	750
S-12a	Wetland 2 outfall pipe	09/30/02	NT
S-12a	Wetland 2 outfall pipe	04/17/03	411
S-12b	Area 9	11/06/01	684
S-12b	Area 9	12/19/01	183
S-12b	Area 9	09/30/02	1530
?	CC, below swales	02/08/00	1540
?	Confl Swale #1 S CC	05/13/99	607
?	Confl Swale #2 N CC	05/13/99	847
SS-2	Acid Seep South Swale	11/14/02	172.0
MW-1	Well	12/16/99	4260
MW-1	Well	02/03/00	4220
MW-1	Well	02/29/00	4760
MW-1	Well	04/12/01	4150
MW-1	Well	11/01/01	4090
MW-2	Well	12/16/99	2380
MW-2	Well	02/03/00	1600
MW-2	Well	02/29/00	2480
MW-2	Well	04/12/01	4860
MW-2	Well	11/01/01	4630
MW-3	Well	12/16/99	4230
MW-3	Well	02/03/00	3650
MW-3	Well	02/29/00	4240
MW-3	Well	04/12/01	7530
MW-3	Well	11/01/01	7020

NT = not tested

Data from WPCP's TMDLs for Cedar Creek (MDNR 2004)   Data from LRP (MDNR 2003, personal communication)

Table 26. Concentrations of metals (ng/ml) in water samples. Elemental analysis conducted using ICP-MS semi-quantitative scans.

		Site											
Date	**Element**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**7 dup**	**8**	**9**	**9 dup**	**10**
1999	Li	8	7	10	40	60	40	40	---	20	40	---	30
1999	Be	<1	<1	<1	<1	<1	<1	<1	---	<1	<1	---	<1
1999	Na	10	20	20	20	10	20	20	---	20	10	---	20
1999	Mg	20	20	20	70	60	60	70	---	40	60	---	50
1999	Al	70	10	20	8	20	6	20	---	10	30	---	4
1999	K	4	3	3	3	3	3	4	---	4	5	---	5
1999	Ca	70	60	80	100	200	100	100	---	100	200	---	100
1999	Ti	2	1	1	1	2	1	1	---	2	2	---	1
1999	V	0.8	0.5	0.3	<0.1	<0.1	<0.1	<0.1	---	0.2	<0.1	---	<0.1
1999	Cr	<1	<1	<1	<1	<1	<1	<1	---	<1	<1	---	<1
1999	Mn	1000	900	800	3000	3000	3000	3000	---	1000	3000	---	2000
1999	Fe	20	60	70	40	600	60	100	---	60	100	---	200
1999	Co	1	0.9	1	30	30	20	10	---	2	20	---	8
1999	Ni	7	4	8	70	100	60	40	---	10	80	---	20
1999	Cu	1	1	1	2	<1	<1	1	---	1	1	---	<1
1999	Zn	9	1	10	20	200	20	<1	---	<1	200	---	50
1999	Ga	<0.1	<0.1	<0.1	0.1	<0.1	<0.1	<0.1	---	<0.1	0.1	---	<0.1
1999	Ge	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	---	<0.1	0	---	<0.1
1999	As	2	3	1	0.7	0.5	1	0.8	---	1	0.5	---	0.6
1999	Se	<1	<1	<1	<1	<1	<1	<1	---	<1	<1	---	<1
1999	Rb	2	2	2	3	3	3	3	---	3	3	---	4
1999	Sr	300	200	300	500	500	400	500	---	400	400	---	500
1999	Y	<1	<1	<1	<1	<1	<1	<1	---	<1	3	---	<1
1999	Zr	20	<1	<1	<1	<1	<1	<1	---	<1	<1	---	<1
1999	Nb	<1	<1	<1	<1	<1	<1	<1	---	<1	<1	---	<1
1999	Mo	1	1	1	0.6	0.3	1	0.6	---	0.7	0.1	---	0.3
1999	Ru	<1	<1	<1	<1	<1	<1	<1	---	<1	<1	---	<1
1999	Pd	0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	---	<0.1	<0.1	---	<0.1
1999	Ag	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	---	<0.1	<0.1	---	<0.1
1999	Cd	1	<0.1	<0.1	<0.1	0.3	<0.1	<0.1	---	<0.1	0.8	---	0.1
1999	In	<1	<1	<1	<1	<1	<1	<1	---	<1	<1	---	<1
1999	Sn	1	1	1	2	2	0.5	0.6	---	0.3	0.2	---	0.1
1999	Sb	0.4	0.3	0.2	0.2	0.1	0.1	0.1	---	<0.1	<0.1	---	<0.1
1999	Te	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	---	<0.1	<0.1	---	<0.1
1999	Cs	<1	<1	<1	<1	<1	<1	<1	---	<1	<1	---	<1
1999	Ba	100	100	100	90	100	100	200	---	200	100	---	100
1999	La	0.1	<0.1	<0.1	0.8	0.7	0.5	<0.1	---	<0.1	2	---	<0.1
1999	Ce	0.2	0.1	0.1	0.8	0.5	0.4	0.1	---	0.1	4	---	0.1
1999	Pr	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	---	<0.1	0.4	---	<0.1
1999	Nd	<0.1	<0.1	<0.1	0.3	<0.1	<0.1	<0.1	---	<0.1	2	---	<0.1
1999	Sm	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	---	<0.1	0.3	---	<0.1
1999	Eu	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	---	<0.1	<0.1	---	<0.1
1999	Gd	<0.1	<0.1	<0.1	0.1	<0.1	<0.1	<0.1	---	<0.1	0.5	---	<0.1
1999	Tb	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	---	<0.1	<0.1	---	<0.1
1999	Dy	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	---	<0.1	0.3	---	<0.1
1999	Ho	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	---	<0.1	<0.1	---	<0.1
1999	Er	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	---	<0.1	0.1	---	<0.1
1999	Tm	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	---	<0.1	<0.1	---	<0.1
1999	Yb	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	---	<0.1	<0.1	---	<0.1
1999	Lu	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	---	<0.1	<0.1	---	<0.1
1999	Hf	0.6	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	---	<0.1	<0.1	---	<0.1

Table 26. Concentrations of metals (ng/ml) in water samples. Elemental analysis conducted using ICP-MS semi-quantitative scans.—Continued

		Site											
Date	**Element**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**7 dup**	**8**	**9**	**9 dup**	**10**
1999	Ta	<0.1	<0.1	<0.1	<0.1	<0.1	0.1	<0.1	---	<0.1	<0.1	---	<0.1
1999	W	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	---	<0.1	<0.1	---	<0.1
1999	Re	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	---	<0.1	<0.1	---	<0.1
1999	Os	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	---	<0.1	<0.1	---	<0.1
1999	Ir	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	---	<0.1	<0.1	---	<0.1
1999	Pt	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	---	<0.1	<0.1	---	<0.1
1999	Au	0.4	0.3	0.3	0.2	0.1	1	0.4	---	0.3	0.2	---	0.1
1999	Tl	<0.1	0.1	<0.1	<0.1	<0.1	0.1	<0.1	---	<0.1	<0.1	---	<0.1
1999	Pb	<1	<1	<1	<1	<1	<1	<1	---	<1	<1	---	<1
1999	Bi	<1	<1	<1	<1	<1	<1	<1	---	<1	<1	---	<1
1999	U	2	2	<1	<1	<1	<1	<1	---	<1	<1	---	<1
2000	Li	---	---	10	48	47	---	63	---	24	46	---	19
2000	Be	---	---	<1	1.4	<1	---	<1	---	<1	<1	---	<1
2000	Na	---	---	22	22	14	---	33	---	23	19	---	17
2000	Mg	---	---	30	93	54	---	140	---	65	80	---	47
2000	Al	---	---	33	1600	52	---	220	---	35	280	---	25
2000	K	---	---	5.5	4.1	4.6	---	7.3	---	7.4	5.9	---	5.6
2000	Ca	---	---	130	190	150	---	300	---	200	170	---	140
2000	Ti	---	---	0.67	0.89	1.1	---	0.91	---	0.63	1.1	---	0.59
2000	V	---	---	0.44	<0.1	<0.1	---	0.27	---	<0.1	<0.1	---	<0.1
2000	Cr	---	---	1.8	2.7	<1	---	1.1	---	1.6	1	---	2.9
2000	Mn	---	---	1300	6000	2900	---	14000	---	3500	5600	---	2000
2000	Fe	---	---	39	61	18	---	67	---	42	32	---	53
2000	Co	---	---	1.3	94	21	---	64	---	4.1	37	---	7.6
2000	Ni	---	---	7.3	200	79	---	150	---	27	130	---	14
2000	Cu	---	---	<1	1.2	1.4	---	1.4	---	<1	1.2	---	<1
2000	Zn	---	---	<1	160	25	---	63	---	<1	400	---	8.2
2000	Ga	---	---	0.22	1	0.33	---	0.55	---	0.18	0.41	---	0.13
2000	Ge	---	---	0.1	<0.1	<0.1	---	<0.1	---	<0.1	<0.1	---	<0.1
2000	As	---	---	1.7	<0.1	<0.1	---	<0.1	---	0.47	0.44	---	0.49
2000	Se	---	---	1.7	3.1	1	---	<1	---	1.8	<1	---	<1
2000	Rb	---	---	2.2	3.7	3.4	---	6.6	---	6.5	4.4	---	4.5
2000	Sr	---	---	560	610	370	---	690	---	650	470	---	440
2000	Y	---	---	<1	62	1.5	---	5.2	---	<1	12	---	<1
2000	Zr	---	---	<1	<1	<1	---	<1	---	<1	<1	---	<1
2000	Nb	---	---	<1	<1	<1	---	<1	---	<1	<1	---	<1
2000	Mo	---	---	2.2	<0.1	<0.1	---	<0.1	---	0.15	0.1	---	0.38
2000	Ru	---	---	<1	<1	<1	---	<1	---	<1	<1	---	<1
2000	Pd	---	---	<0.1	<0.1	<0.1	---	<0.1	---	<0.1	0.1	---	<0.1
2000	Ag	---	---	<0.1	<0.1	<0.1	---	<0.1	---	<0.1	0.1	---	<0.1
2000	Cd	---	---	<0.1	0.81	0.1	---	0.87	---	<0.1	1.9	---	<0.1
2000	In	---	---	<1	<1	<1	---	<1	---	<1	<1	---	<1
2000	Sn	---	---	0.83	0.83	0.87	---	0.8	---	0.76	0.13	---	0.58
2000	Sb	---	---	<0.1	<0.1	<0.1	---	<0.1	---	<0.1	<0.1	---	<0.1
2000	Te	---	---	<0.1	<0.1	<0.1	---	<0.1	---	<0.1	<0.1	---	<0.1
2000	Cs	---	---	<1	<1	<1	---	<1	---	<1	<1	---	<1
2000	Ba	---	---	82	24	56	---	73	---	53	56	---	59
2000	La	---	---	<0.1	16	1.2	---	3.6	---	0.13	4.5	---	<0.1
2000	Ce	---	---	<0.1	31	0.75	---	2.2	---	0.16	8.3	---	<0.1
2000	Pr	---	---	<0.1	3.6	<0.1	---	0.22	---	<0.1	0.78	---	<0.1

Table 26. Concentrations of metals (ng/ml) in water samples. Elemental analysis conducted using ICP-MS semi-quantitative scans.—Continued

		Site											
Date	**Element**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**7 dup**	**8**	**9**	**9 dup**	**10**
2000	Nd	---	---	<0.1	14	0.32	---	0.69	---	<0.1	2.8	---	<0.1
2000	Sm	---	---	<0.1	3.4	<0.1	---	0.12	---	<0.1	0.59	---	<0.1
2000	Eu	---	---	<0.1	1.1	<0.1	---	<0.1	---	<0.1	0.18	---	<0.1
2000	Gd	---	---	<0.1	6.5	0.12	---	0.31	---	<0.1	1	---	<0.1
2000	Tb	---	---	<0.1	0.9	<0.1	---	<0.1	---	<0.1	0.12	---	<0.1
2000	Dy	---	---	<0.1	4.8	<0.1	---	0.22	---	<0.1	0.69	---	<0.1
2000	Ho	---	---	<0.1	0.84	<0.1	---	<0.1	---	<0.1	0.14	---	<0.1
2000	Er	---	---	<0.1	1.9	<0.1	---	<0.1	---	<0.1	0.27	---	<0.1
2000	Tm	---	---	<0.1	0.21	<0.1	---	<0.1	---	<0.1	<0.1	---	<0.1
2000	Yb	---	---	<0.1	1	<0.1	---	<0.1	---	<0.1	0.14	---	<0.1
2000	Lu	---	---	<0.1	0.14	<0.1	---	<0.1	---	<0.1	<0.1	---	<0.1
2000	Hf	---	---	<0.1	<0.1	<0.1	---	<0.1	---	<0.1	<0.1	---	<0.1
2000	Ta	---	---	<0.1	<0.1	<0.1	---	<0.1	---	<0.1	<0.1	---	<0.1
2000	W	---	---	<0.1	<0.1	<0.1	---	<0.1	---	<0.1	<0.1	---	<0.1
2000	Re	---	---	<0.1	<0.1	<0.1	---	<0.1	---	<0.1	<0.1	---	<0.1
2000	Os	---	---	<0.1	<0.1	<0.1	---	<0.1	---	<0.1	<0.1	---	<0.1
2000	Ir	---	---	<0.1	<0.1	<0.1	---	<0.1	---	<0.1	<0.1	---	<0.1
2000	Pt	---	---	<0.1	<0.1	<0.1	---	<0.1	---	<0.1	<0.1	---	<0.1
2000	Au	---	---	<0.1	<0.1	<0.1	---	<0.1	---	<0.1	<0.1	---	<0.1
2000	Tl	---	---	<0.1	<0.1	<0.1	---	<0.1	---	<0.1	<0.1	---	<0.1
2000	Pb	---	---	<1	<1	15	---	11	---	<1	<1	---	<1
2000	Bi	---	---	<1	<1	<1	---	<1	---	<1	<1	---	<1
2000	U	---	---	2.2	<1	<1	---	<1	---	<1	<1	---	<1
2001	Li	---	---	7.5	31	71	---	27	---	16	38	38	20
2001	Be	---	---	<1	<1	<1	---	<1	---	<1	<1	<1	<1
2001	Na	---	---	12	17	14	---	17	---	13	15	15	14
2001	Mg	---	---	14	63	60	---	53	---	32	63	63	38
2001	Al	---	---	110	71	230	---	170	---	71	43	2.6	92
2001	K	---	---	8.8	8.9	6.7	---	9.5	---	8.9	9.1	8.4	10
2001	Ca	---	---	70	140	190	---	130	---	100	160	160	120
2001	Ti	---	---	3	2	6.4	---	4.3	---	2.8	2.7	1.5	3
2001	V	---	---	0.13	<0.1	<0.1	---	<0.1	---	<0.1	<0.1	<0.1	<0.1
2001	Cr	---	---	<1	<1	<1	---	<1	---	<1	<1	<1	<1
2001	Mn	---	---	200	5200	8200	---	4600	---	1400	4400	4600	1500
2001	Fe	---	---	210	120	210	---	290	---	99	130	150	260
2001	Co	---	---	0.55	21	54	---	9.2	---	1.7	17	17	4.8
2001	Ni	---	---	8.1	42	140	---	29	---	9.7	59	61	13
2001	Cu	---	---	1.6	<1	1.2	---	3.5	---	<1	<1	<1	1.6
2001	Zn	---	---	<1	<1	180	---	<1	---	<1	150	150	1
2001	Ga	---	---	<0.1	0.28	0.57	---	0.48	---	0.25	0.28	0.29	0.22
2001	Ge	---	---	<0.1	<0.1	<0.1	---	<0.1	---	<0.1	<0.1	<1	<0.1
2001	As	---	---	1.6	1	0.42	---	0.58	---	0.86	0.23	0.26	0.56
2001	Se	---	---	<1	<1	<1	---	<1	---	<1	<1	<1	<1
2001	Rb	---	---	2.4	3.3	3.8	---	3.9	---	3.7	2.9	3	4.3
2001	Sr	---	---	170	260	280	---	250	---	200	270	270	210
2001	Y	---	---	<1	<1	2.9	---	<1	---	<1	<1	<1	<1
2001	Zr	---	---	<1	<1	<1	---	<1	---	<1	<1	<1	<1
2001	Nb	---	---	<1	<1	<1	---	<1	---	<1	<1	<1	<1
2001	Mo	---	---	1.5	1.1	0.3	---	1	---	0.76	0.1	<0.1	0.63
2001	Ru	---	---	<1	<1	<1	---	<1	---	<1	<1	<1	<1
2001	Pd	---	---	<1	<1	<1	---	<1	---	<1	<1	<1	<1

Table 26. Concentrations of metals (ng/ml) in water samples. Elemental analysis conducted using ICP-MS semi-quantitative scans.—Continued

		Site											
Date	**Element**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**7 dup**	**8**	**9**	**9 dup**	**10**
2001	Ag	---	---	<0.1	<0.1	<0.1	---	<0.1	---	<0.1	<0.1	<0.1	<0.1
2001	Cd	---	---	<0.1	<0.1	0.5	---	<0.1	---	<0.1	0.65	0.71	0.1
2001	In	---	---	<1	<1	<1	---	<1	---	<1	<1	<1	<1
2001	Sn	---	---	<0.1	<0.1	<0.1	---	<0.1	---	<0.1	<0.1	<0.1	<0.1
2001	Sb	---	---	0.25	<0.1	<0.1	---	<0.1	---	<0.1	<0.1	<0.1	<0.1
2001	Te	---	---	<0.1	<0.1	<0.1	---	<0.1	---	<0.1	<0.1	<0.1	<0.1
2001	Cs	---	---	<1	<1	<1	---	<1	---	<1	<1	<1	<1
2001	Ba	---	---	100	100	130	---	130	---	120	120	130	100
2001	La	---	---	<0.1	0.13	3.1	---	0.11	---	<0.1	0.76	0.77	0.1
2001	Ce	---	---	0.18	0.21	3.9	---	0.17	---	<0.1	1.1	1.1	0.17
2001	Pr	---	---	<0.1	<0.1	0.41	---	<0.1	---	<0.1	<0.1	0.1	<0.1
2001	Nd	---	---	<0.1	<0.1	1.4	---	<0.1	---	<0.1	0.36	0.37	<0.1
2001	Sm	---	---	<0.1	<0.1	0.18	---	<0.1	---	<0.1	<0.1	<0.1	<0.1
2001	Eu	---	---	<0.1	<0.1	<0.1	---	<0.1	---	<0.1	<0.1	<0.1	<0.1
2001	Gd	---	---	<0.1	<0.1	0.38	---	<0.1	---	<0.1	0.11	0.13	<0.1
2001	Tb	---	---	<0.1	<0.1	<0.1	---	<0.1	---	<0.1	<0.1	<0.1	<0.1
2001	Dy	---	---	<0.1	<0.1	0.22	---	<0.1	---	<0.1	<0.1	<0.1	<0.1
2001	Ho	---	---	<0.1	<0.1	<0.1	---	<0.1	---	<0.1	<0.1	<0.1	<0.1
2001	Er	---	---	<0.1	<0.1	<0.1	---	<0.1	---	<0.1	<0.1	<0.1	<0.1
2001	Tm	---	---	<0.1	<0.1	<0.1	---	<0.1	---	<0.1	<0.1	<0.1	<0.1
2001	Yb	---	---	<0.1	<0.1	<0.1	---	<0.1	---	<0.1	<0.1	<0.1	<0.1
2001	Lu	---	---	<0.1	<0.1	<0.1	---	<0.1	---	<0.1	<0.1	<0.1	<0.1
2001	Hf	---	---	<0.1	<0.1	<0.1	---	<0.1	---	<0.1	<0.1	<0.1	<0.1
2001	Ta	---	---	<0.1	<0.1	<0.1	---	<0.1	---	<0.1	<0.1	<0.1	<0.1
2001	W	---	---	<0.1	<0.1	<0.1	---	<0.1	---	<0.1	<0.1	<0.1	<0.1
2001	Re	---	---	<0.1	<0.1	<0.1	---	<0.1	---	<0.1	<0.1	<0.1	<0.1
2001	Os	---	---	<0.1	<0.1	<0.1	---	<0.1	---	<0.1	<0.1	<0.1	<0.1
2001	Ir	---	---	<0.1	<0.1	<0.1	---	<0.1	---	<0.1	<0.1	<0.1	<0.1
2001	Pt	---	---	<0.1	<0.1	<0.1	---	<0.1	---	<0.1	<0.1	<0.1	<0.1
2001	Au	---	---	<0.1	<0.1	<0.1	---	<0.1	---	<0.1	<0.1	<0.1	<0.1
2001	Tl	---	---	<0.1	<0.1	<0.1	---	<0.1	---	<0.1	<0.1	<0.1	<0.1
2001	Pb	---	---	<1	<1	<1	---	<1	---	<1	<1	<1	<1
2001	Bi	---	---	<1	<1	<1	---	<1	---	<1	<1	<1	<1
2001	U	---	---	<1	1.2	<1	---	<1	---	<1	<1	<1	<1
2002	Li	---	---	11	28	55	---	25	---	17	48	---	21
2002	Be	---	---	<1	<1	<1	---	<1	<1	<1	<1	---	<1
2002	Na	---	---	13	16	12	---	15	15	11	15	---	14
2002	Mg	---	---	14	49	42	---	40	42	23	54	---	30
2002	Al	---	---	<0.1	<0.1	<0.1	---	<0.1	<0.1	<0.1	1.3	---	<0.1
2002	K	---	---	5.7	5.9	5	---	5.9	6.4	6.3	7.5	---	7.5
2002	Ca	---	---	69	120	140	---	110	110	87	150	---	110
2002	Ti	---	---	0.31	0.42	1.2	---	0.81	0.63	0.94	0.92	---	0.68
2002	V	---	---	0.25	<0.1	<0.1	---	<0.1	<0.1	<0.1	<0.1	---	<0.1
2002	Cr	---	---	<1	<1	1.3	---	<1	<1	<1	<1	---	<1
2002	Mn	---	---	1100	4000	7500	---	3700	3800	1100	5700	---	1100
2002	Fe	---	---	89	32	<1	---	31	48	54	10	---	10
2002	Co	---	---	1.9	9.8	44	---	6.1	6.3	2.1	24	---	4.1
2002	Ni	---	---	9.2	24	100	---	21	22	11	66	---	12
2002	Cu	---	---	1.1	<1	1.7	---	1.2	1	1.2	1.3	---	1.4
2002	Zn	---	---	<1	<1	150	---	<1	<1	<1	200	---	5.6
2002	Ga	---	---	0.12	0.39	0.8	---	0.47	0.43	0.29	0.75	---	0.3

Table 26. Concentrations of metals (ng/ml) in water samples. Elemental analysis conducted using ICP-MS semi-quantitative scans.—Continued

		Site											
Date	**Element**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**7 dup**	**8**	**9**	**9 dup**	**10**
2002	Ge	---	---	<0.1	<0.1	<0.1	---	<0.1	<0.1	<0.1	<0.1	---	<0.1
2002	As	---	---	1.2	0.83	0.52	---	0.97	0.89	1	0.34	---	0.43
2002	Se	---	---	<1	<1	<1	---	<1	<1	<1	<1	---	<1
2002	Rb	---	---	2.2	3.4	3.8	---	3.8	3.9	3.7	4.1	---	4.4
2002	Sr	---	---	210	300	290	---	280	280	210	300	---	260
2002	Y	---	---	<1	<1	2.3	---	<1	<1	<1	3.7	---	<1
2002	Zr	---	---	<1	<1	<1	---	<1	<1	<1	<1	---	<1
2002	Nb	---	---	<1	<1	<1	---	<1	<1	<1	<1	---	<1
2002	Mo	---	---	1.3	0.98	0.28	---	0.89	0.92	0.64	<0.1	---	0.51
2002	Ru	---	---	<1	<1	<1	---	<1	<1	<1	<1	---	1
2002	Pd	---	---	<0.1	<0.1	<0.1	---	<0.1	<0.1	<0.1	<0.1	---	<0.1
2002	Ag	---	---	<0.1	<0.1	<0.1	---	<0.1	<0.1	<0.1	<0.1	---	<0.1
2002	Cd	---	---	<0.1	<0.1	0.28	---	<0.1	<0.1	<0.1	0.83	---	0.13
2002	In	---	---	<1	<1	<1	---	<1	<1	<1	<1	---	<1
2002	Sn	---	---	<0.1	<0.1	<0.1	---	<0.1	<0.1	<0.1	<0.1	---	<0.1
2002	Sb	---	---	<0.1	<0.1	<0.1	---	<0.1	<0.1	<0.1	<0.1	---	<0.1
2002	Te	---	---	0.1	0.18	<0.1	---	<0.1	<0.1	<0.1	<0.1	---	<0.1
2002	Cs	---	---	<1	<1	<1	---	<1	<1	<1	<1	---	<1
2002	Ba	---	---	110	97	120	---	110	110	94	100	---	93
2002	La	---	---	<0.1	<0.1	1.4	---	<0.1	<0.1	<0.1	1.8	---	<0.1
2002	Ce	---	---	<0.1	<0.1	1.4	---	<0.1	<0.1	<0.1	2.6	---	<0.1
2002	Pr	---	---	<0.1	<0.1	0.13	---	<0.1	<0.1	<0.1	0.22	---	<0.1
2002	Nd	---	---	<0.1	<0.1	0.4	---	<0.1	<0.1	<0.1	0.83	---	<0.1
2002	Sm	---	---	<0.1	<0.1	<0.1	---	<0.1	<0.1	<0.1	0.17	---	<0.1
2002	Eu	---	---	<0.1	<0.1	<0.1	---	<0.1	<0.1	<0.1	<0.1	---	<0.1
2002	Gd	---	---	<0.1	<0.1	0.13	---	<0.1	<0.1	<0.1	0.31	---	<0.1
2002	Tb	---	---	<0.1	<0.1	<0.1	---	<0.1	<0.1	<0.1	<0.1	---	<0.1
2002	Dy	---	---	<0.1	<0.1	0.1	---	<0.1	<0.1	<0.1	0.2	---	<0.1
2002	Ho	---	---	<0.1	<0.1	<0.1	---	<0.1	<0.1	<0.1	<0.1	---	<0.1
2002	Er	---	---	<0.1	<0.1	<0.1	---	<0.1	<0.1	<0.1	<0.1	---	<0.1
2002	Tm	---	---	<0.1	<0.1	<0.1	---	<0.1	<0.1	<0.1	<0.1	---	<0.1
2002	Yb	---	---	<0.1	<0.1	<0.1	---	<0.1	<0.1	<0.1	<0.1	---	<0.1
2002	Lu	---	---	<0.1	<0.1	<0.1	---	<0.1	<0.1	<0.1	<0.1	---	<0.1
2002	Hf	---	---	<0.1	<0.1	<0.1	---	<0.1	<0.1	<0.1	<0.1	---	<0.1
2002	Ta	---	---	<0.1	<0.1	<0.1	---	<0.1	<0.1	<0.1	<0.1	---	<0.1
2002	W	---	---	<0.1	<0.1	<0.1	---	<0.1	<0.1	<0.1	<0.1	---	<0.1
2002	Re	---	---	<0.1	<0.1	<0.1	---	<0.1	<0.1	<0.1	<0.1	---	<0.1
2002	Os	---	---	<0.1	<0.1	<0.1	---	<0.1	<0.1	<0.1	<0.1	---	<0.1
2002	Ir	---	---	<0.1	<0.1	<0.1	---	<0.1	<0.1	<0.1	<0.1	---	<0.1
2002	Pt	---	---	<0.1	<0.1	<0.1	---	<0.1	<0.1	<0.1	<0.1	---	<0.1
2002	Au	---	---	<0.1	<0.1	<0.1	---	<0.1	<0.1	<0.1	<0.1	---	<0.1
2002	Tl	---	---	<0.1	<0.1	<0.1	---	<0.1	<0.1	<0.1	<0.1	---	<0.1
2002	Pb	---	---	<1	<1	<1	---	<1	<1	<1	<1	---	<1
2002	Bi	---	---	<1	<1	<1	---	<1	<1	<1	<1	---	<1
2002	U	---	---	1	1.4	<1	---	1	1.1	<1	<1	---	<1

Table 27. Number of days leaf packs were deployed and weight loss of leaves during the study.

Site	Year	Date Deployed	Date Retrieved	No. of Days Deploy	Tag No.	No. of Leaves	Pre-deployment Wt (mg)	Post-deployment Wt (mg)	Wt Loss (mg)	% Loss
3	1999	05/25/99	06/17/99	23	2581	24	11820	5645	6175	47.8
3	1999	05/25/99	06/17/99	23	2586	25	12670	5402	7268	42.6
3	1999	05/25/99	06/17/99	23	2591	25	13045	4908	8137	37.6
3	1999	05/25/99	06/17/99	23	2673	24	10320	6866	3454	66.5
3	1999	05/25/99	06/17/99	23	2676	24	10170	6635	3535	65.2
4	1999	05/25/99	06/17/99	23	2580	24	11620	6872	4748	59.1
4	1999	05/25/99	06/17/99	23	2583	24	11710	6761	4949	57.7
4	1999	05/25/99	06/17/99	23	2592	25	13530	7107	6423	52.5
4	1999	05/25/99	06/17/99	23	2595	25	11860	6687	5173	56.4
5	1999	05/25/99	06/17/99	23	2578	25	11610	4691	6919	40.4
5	1999	05/25/99	06/17/99	23	2590	25	10506	4267	6239	40.6
5	1999	05/25/99	06/17/99	23	2674	24	11560	3134	8426	27.1
5	1999	05/25/99	06/17/99	23	2675	24	10470	7269	3201	69.4
5	1999	05/25/99	06/17/99	23	2678	24	10960	6371	4589	58.1
7	1999	05/25/99	06/17/99	23	2577	25	10610	6717	3893	63.3
7	1999	05/25/99	06/17/99	23	2582	24	10939	5802	5137	53.0
7	1999	05/25/99	06/17/99	23	2584	24	11080	5649	5431	51.0
7	1999	05/25/99	06/17/99	23	2597	24	11650	7225	4425	62.0
7	1999	05/25/99	06/17/99	23	2680	24	10030	6707	3323	66.9
8	1999	05/25/99	06/17/99	23	2574	24	12300	7203	5097	58.6
8	1999	05/25/99	06/17/99	23	2589	25	12425	5308	7117	42.7
8	1999	05/25/99	06/17/99	23	2594	25	12090	9295	2795	76.9
8	1999	05/25/99	06/17/99	23	2600	24	12640	6467	6173	51.2
8	1999	05/25/99	06/17/99	23	2677	24	10710	6803	3907	63.5
9	1999	05/25/99	06/17/99	23	2576	25	12126	9538	2588	78.7
9	1999	05/25/99	06/17/99	23	2579	24	11730	6261	5469	53.4
9	1999	05/25/99	06/17/99	23	2593	25	10210	6470	3740	63.4
9	1999	05/25/99	06/17/99	23	2596	24	13885	4994	8891	36.0
9	1999	05/25/99	06/17/99	23	2598	24	11100	7322	3778	66.0
10	1999	05/25/99	06/17/99	23	2573	24	11880	7449	4431	62.7
10	1999	05/25/99	06/17/99	23	2585	24	9450	6842	2608	72.4
10	1999	05/25/99	06/17/99	23	2587	25	12970	7830	5140	60.4
10	1999	05/25/99	06/17/99	23	2599	24	11460	7623	3837	66.5
10	1999	05/25/99	06/17/99	23	2679	24	8850	6288	2562	71.1
3	2000	05/16/00	06/29/00	44	116	24	10270	4814	5456	46.9
3	2000	05/16/00	06/29/00	44	117	24	10460	5194	5266	49.7
3	2000	05/16/00	06/29/00	44	118	24	10420	5507	4913	52.9
3	2000	05/16/00	06/29/00	44	2681	24	10350	6121	4229	59.1
3	2000	05/16/00	06/29/00	44	2682	24	10330	4830	5500	46.8

Table 27. Number of days leaf packs were deployed and weight loss of leaves during the study.—Continued

Site	Year	Date Deployed	Date Retrieved	No. of Days Deploy	Tag No.	No. of Leaves	Pre-deployment Wt (mg)	Post-deployment Wt (mg)	Wt Loss (mg)	% Loss
4	2000	05/16/00	06/29/00	44	106	24	10210	7360	2850	72.1
4	2000	05/16/00	06/29/00	44	107	24	10410	6907	3503	66.3
4	2000	05/16/00	06/29/00	44	108	24	10430	7126	3304	68.3
4	2000	05/16/00	06/29/00	44	109	24	10290	7190	3100	69.9
4	2000	05/16/00	06/29/00	44	110	24	10360	7184	3176	69.3
5	2000	05/16/00	06/29/00	44	2693	24	10120	6784	3336	67.0
5	2000	05/16/00	06/29/00	44	2695	24	10170	6660	3510	65.5
5	2000	05/16/00	06/29/00	44	2696	24	10420	6835	3585	65.6
5	2000	05/16/00	06/29/00	44	2697	24	10320	7471	2849	72.4
5	2000	05/16/00	06/29/00	44	2699	24	10380	6582	3798	63.4
7	2000	05/16/00	06/29/00	44	101	24	10350	7143	3207	69.0
7	2000	05/16/00	06/29/00	44	102	24	10430	6614	3816	63.4
7	2000	05/16/00	06/29/00	44	103	24	10240	6446	3794	62.9
7	2000	05/16/00	06/29/00	44	104	24	10470	5999	4471	57.3
7	2000	05/16/00	06/29/00	44	105	24	10270	6650	3620	64.8
8	2000	05/16/00	06/29/00	44	111	24	10490	3325	7165	31.7
8	2000	05/16/00	06/29/00	44	112	24	10340	3868	6472	37.4
8	2000	05/16/00	06/29/00	44	113	24	10290	5684	4606	55.2
8	2000	05/16/00	06/29/00	44	114	24	10180	5114	5066	50.2
9	2000	05/16/00	06/29/00	44	2688	24	10240	5232	5008	51.1
9	2000	05/16/00	06/29/00	44	2689	24	10460	6807	3653	65.1
9	2000	05/16/00	06/29/00	44	2690	24	10310	6754	3556	65.5
9	2000	05/16/00	06/29/00	44	2692	24	10070	4654	5416	46.2
10	2000	05/16/00	06/29/00	44	2683	24	10260	5418	4842	52.8
10	2000	05/16/00	06/29/00	44	2684	24	10160	3981	6179	39.2
10	2000	05/16/00	06/29/00	44	2685	24	10430	5032	5398	48.2
10	2000	05/16/00	06/29/00	44	2686	24	10440	5621	4819	53.8
10	2000	05/16/00	06/29/00	44	2687	24	10000	8202	1798	82.0
3	2001	05/15/01	06/19/01	35	119	23	10440	3794	6646	36.3
3	2001	05/15/01	06/19/01	35	120	23	10420	4780	5640	45.9
3	2001	05/15/01	06/19/01	35	121	23	10408	5263	5145	50.6
3	2001	05/15/01	06/19/01	35	122	23	10423	2218	8205	21.3
3	2001	05/15/01	06/19/01	35	123	23	10444	3500	6944	33.5
4	2001	05/15/01	06/19/01	35	124	23	10429	5007	5422	48.0
4	2001	05/15/01	06/19/01	35	126	23	10404	4912	5492	47.2
4	2001	05/15/01	06/19/01	35	127	23	10454	6087	4367	58.2
4	2001	05/15/01	06/19/01	35	128	23	10425	5691	4734	54.6
4	2001	05/15/01	06/19/01	35	154	23	10499	9316	1183	88.7

Table 27. Number of days leaf packs were deployed and weight loss of leaves during the study.—Continued

Site	Year	Date Deployed	Date Retrieved	No. of Days Deploy	Tag No.	No. of Leaves	Pre-deployment Wt (mg)	Post-deployment Wt (mg)	Wt Loss (mg)	% Loss
5	2001	05/15/01	06/19/01	35	129	23	10456	7427	3029	71.0
5	2001	05/15/01	06/19/01	35	130	23	10434	7178	3256	68.8
5	2001	05/15/01	06/19/01	35	131	23	10519	7891	2628	75.0
5	2001	05/15/01	06/19/01	35	132	23	10453	7670	2783	73.4
5	2001	05/15/01	06/19/01	35	133	23	10407	7433	2974	71.4
7	2001	05/15/01	06/19/01	35	134	23	10445	5821	4624	55.7
7	2001	05/15/01	06/19/01	35	135	23	10403	6009	4394	57.8
7	2001	05/15/01	06/19/01	35	136	23	10445	6591	3854	63.1
7	2001	05/15/01	06/19/01	35	137	23	10449	5798	4651	55.5
7	2001	05/15/01	06/19/01	35	138	23	10459	6527	3932	62.4
8	2001	05/15/01	06/19/01	35	139	23	10410	2209	8201	21.2
8	2001	05/15/01	06/19/01	35	140	23	10467	1891	8576	18.1
8	2001	05/15/01	06/19/01	35	141	23	10463	2216	8247	21.2
8	2001	05/15/01	06/19/01	35	142	23	10421	1201	9220	11.5
8	2001	05/15/01	06/19/01	35	143	23	10404	3573	6831	34.3
9	2001	05/15/01	06/19/01	35	144	23	10415	5952	4463	57.1
9	2001	05/15/01	06/19/01	35	145	23	10434	5226	5208	50.1
9	2001	05/15/01	06/19/01	35	146	23	10445	6388	4057	61.2
9	2001	05/15/01	06/19/01	35	147	23	10481	6931	3550	66.1
9	2001	05/15/01	06/19/01	35	148	23	10416	7493	2923	71.9
10	2001	05/15/01	06/19/01	35	149	23	10408	6233	4175	59.9
10	2001	05/15/01	06/19/01	35	150	23	10485	5979	4506	57.0
10	2001	05/15/01	06/19/01	35	151	23	10474	6408	4066	61.2
10	2001	05/15/01	06/19/01	35	152	23	10449	6324	4125	60.5
10	2001	05/15/01	06/19/01	35	153	23	10433	6165	4268	59.1
3	2002	05/21/02	06/20/02	30	155	24	10030	1864	8166	18.6
3	2002	05/21/02	06/20/02	30	156	24	10070	2986	7084	29.7
3	2002	05/21/02	06/20/02	30	157	24	10090	6025	4065	59.7
3	2002	05/21/02	06/20/02	30	158	24	10040	5901	4139	58.8
3	2002	05/21/02	06/20/02	30	159	24	10070	6184	3886	61.4
4	2002	05/21/02	06/20/02	30	160	24	10070	7523	2547	74.7
4	2002	05/21/02	06/20/02	30	161	24	10000	7553	2447	75.5
4	2002	05/21/02	06/20/02	30	162	24	10080	7700	2380	76.4
4	2002	05/21/02	06/20/02	30	163	24	10040	7949	2091	79.2
4	2002	05/21/02	06/20/02	30	164	24	10060	7959	2101	79.1
5	2002	05/21/02	06/20/02	30	165	24	10030	6226	3804	62.1
5	2002	05/21/02	06/20/02	30	166	24	10050	5633	4417	56.0
5	2002	05/21/02	06/20/02	30	167	24	10020	5943	4077	59.3
5	2002	05/21/02	06/20/02	30	168	24	10080	5793	4287	57.5
5	2002	05/21/02	06/20/02	30	169	24	10060	5659	4401	56.3

Table 27. Number of days leaf packs were deployed and weight loss of leaves during the study. —Continued

Site	Year	Date Deployed	Date Retrieved	No. of Days Deploy	Tag No.	No. of Leaves	Pre-deployment Wt (mg)	Post-deployment Wt (mg)	Wt Loss (mg)	% Loss
5	2002	05/21/02	06/20/02	30	169	24	10060	5659	4401	56.3
7	2002	05/21/02	06/20/02	30	170	24	10020	5518	4502	55.1
7	2002	05/21/02	06/20/02	30	171	24	10090	5637	4453	55.9
7	2002	05/21/02	06/20/02	30	172	24	10070	5928	4142	58.9
7	2002	05/21/02	06/20/02	30	173	24	10040	6006	4034	59.8
7	2002	05/21/02	06/20/02	30	174	24	10000	6217	3783	62.2
8	2002	05/21/02	06/20/02	30	175	24	10000	1276	8724	12.8
8	2002	05/21/02	06/20/02	30	176	24	10020	3441	6579	34.3
8	2002	05/21/02	06/20/02	30	177	24	10030	3501	6529	34.9
8	2002	05/21/02	06/20/02	30	179	24	10090	1603	8487	15.9
9	2002	05/21/02	06/20/02	30	180	24	10020	5592	4428	55.8
9	2002	05/21/02	06/20/02	30	181	24	10070	6284	3786	62.4
9	2002	05/21/02	06/20/02	30	182	24	10080	5788	4292	57.4
9	2002	05/21/02	06/20/02	30	183	24	10010	5499	4511	54.9
9	2002	05/21/02	06/20/02	30	184	24	10080	6016	4064	59.7
10	2002	05/21/02	06/20/02	30	185	23	10090	5448	4642	54.0
10	2002	05/21/02	06/20/02	30	186	23	10030	4217	5813	42.0
10	2002	05/21/02	06/20/02	30	187	23	10070	4685	5385	46.5
10	2002	05/21/02	06/20/02	30	188	23	10050	3607	6443	35.9
10	2002	05/21/02	06/20/02	30	189	23	10060	5547	4513	55.1

Table 28. Ranked analysis of variance of leaf decomposition.

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	27	164882	6107	14.75	<0.0001
Error	108	44728	414		
Corrected total	135	209610			

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Year	3	86124	28708	69.3	<0.0001
Site	6	36523	6087	14.7	<0.0001
Year*Site	18	39722	2207	5.33	<0.0001

Table 29. Ranked bivariate analysis with a Bonferroni correction ($\alpha = 0.05$) of leafpack weight, macroinvertebrates, crayfish and water quality.

		R Square															
		Total no. of individuals (totsum)	Total no. of species (nsptot)	Simpson's dominance (simpdom)	Total no. of crayfish (cray)	Leafpack weight loss/day (wtlp)	Total shredders (shred)	Total filter feeders (filt)	Total scrapers (scrap)	Scrapers/ filters ratio (sprfr)	Total no. EPT[1] (ept)	Temp	Field pH (f_ph)	Hardness (hard)	Alkalinity (alk)	Conductivity (cond)	Turbidity (turb)
	totsum	1	0.90389	-0.18829	-0.11002	0.24959	0.62871	0.60208	0.82907	0.31997	0.75281	0.16587	0.47838	-0.13027	0.15686	-0.02901	0.02737
	nsptot	<.0001	1	-0.40608	-0.14403	0.27382	0.6066	0.71744	0.82459	0.33876	0.79417	0.13693	0.50958	-0.19469	0.16228	-0.08215	0.01177
	simpdom	0.3373	0.032	1	0.44992	-0.26382	-0.1801	-0.53659	-0.24607	0.14534	-0.19381	-0.04461	-0.27094	0.01149	-0.21215	-0.01149	0.08593
	cray	0.5773	0.4646	0.0163	1	-0.61576	0.02764	-0.40532	-0.10155	0.20775	-0.07364	-0.11852	-0.16639	-0.11604	-0.13906	-0.19157	0.47564
	wtlp	0.2002	0.1585	0.1749	0.0005	1	0.10538	0.4108	0.27207	0.00547	0.34164	0.10264	0.3514	0.07937	0.06488	0.17625	-0.55884
	shred	0.0003	0.0006	0.3591	0.8889	0.5936	1	0.30369	0.41445	0.18122	0.42108	0.35218	0.27426	-0.18558	-0.02327	-0.16423	0.40071
	filt	0.0007	<.0001	0.0032	0.0324	0.0299	0.1162	1	0.51802	-0.05783	0.53043	0.06359	0.26747	0.18306	0.02248	0.26692	-0.22691
	scrap	<.0001	<.0001	0.2069	0.6071	0.1613	0.0283	0.0047	1	0.6726	0.90815	0.14509	0.55727	-0.38456	0.32663	-0.23375	0.03805
	sprfr	0.0969	0.0778	0.4606	0.2888	0.9779	0.3561	0.77	<.0001	1	0.5796	0.32904	0.30656	-0.67743	0.28145	-0.57041	0.30738
	ept	<.0001	<.0001	0.323	0.7096	0.0752	0.0256	0.0037	<.0001	0.0012	1	0.1243	0.53025	-0.36956	0.30463	-0.21845	0.06105
	temp	0.3989	0.4872	0.8216	0.5481	0.6032	0.0661	0.7479	0.4613	0.0873	0.5286	1	0.2915	-0.40318	0.35044	-0.42288	0.43109
	f_ph	0.01	0.0056	0.1632	0.3974	0.0667	0.1579	0.1688	0.0021	0.1126	0.0037	0.1323	1	-0.56596	0.50999	-0.51724	0.16147
	hard	0.5088	0.3208	0.9537	0.5565	0.6881	0.3444	0.3511	0.0433	<.0001	0.0529	0.0334	0.0017	1	-0.36162	0.95785	-0.60591
	alk	0.4254	0.4093	0.2784	0.4803	0.7429	0.9064	0.9096	0.0898	0.1468	0.115	0.0675	0.0056	0.0586	1	-0.39064	0.09554
Prob > |r|	cond	0.8835	0.6777	0.9537	0.3288	0.3696	0.4037	0.1697	0.2312	0.0015	0.2641	0.025	0.0048	<.0001	0.0399	1	-0.68911
	turb	0.8901	0.9526	0.6637	0.0105	0.002	0.0346	0.2456	0.8476	0.1116	0.7576	0.022	0.4117	0.0006	0.6287	<.0001	1
	sal	0.2789	0.3496	0.6981	0.6265	0.2204	0.1503	0.5427	0.0623	0.0366	0.078	0.703	<.0001	<.0001	0.1527	<.0001	0.02
	amm	0.8227	0.9427	0.4615	0.1511	0.0031	0.7503	0.7395	0.9163	0.8769	0.6237	0.9196	0.3176	0.3014	0.9768	0.1536	0.0013
	no_2/no_3	0.5907	0.5742	0.9218	0.0402	0.1126	0.234	0.9113	0.3613	0.151	0.7418	0.5887	0.3719	0.0067	0.4557	0.0014	0.0004
	srp	0.3	0.2851	0.8963	0.0468	0.5854	0.245	0.6303	0.0749	0.048	0.09	0.4686	0.0357	<.0001	0.4408	<.0001	0.0004
	tn	0.2077	0.264	0.5586	0.0235	0.3614	0.0847	0.869	0.2397	0.4912	0.4504	0.9292	0.0815	0.0113	0.4718	0.0013	<.0001
	tp	0.2335	0.4488	0.6066	0.0345	0.1122	0.0659	0.5647	0.6632	0.9717	0.7925	0.8038	0.3201	0.1026	0.5012	0.0101	0.0007
	tn/tp	0.3847	0.9577	0.7785	0.5292	0.8835	0.1798	0.2503	0.7405	0.5006	0.5659	0.0383	0.0297	0.5517	0.0059	0.1733	0.1188
	Mg	0.7648	0.5713	0.2335	0.0324	0.0419	0.6572	0.7576	0.2024	0.0471	0.2038	0.0178	0.0014	0.0017	0.0001	0.0021	0.5383
	Ca	0.0405	0.0151	0.0997	0.0109	0.0045	0.0722	0.1735	0.0174	0.2129	0.0115	0.0064	<.0001	0.0369	0.0024	0.0792	0.9138
	Fe	0.1564	0.2294	0.5131	0.3523	0.3285	0.1471	0.6921	0.0911	0.2087	0.0697	0.6011	0.0607	0.1728	0.2589	0.4621	0.4131
	Mn	0.1409	0.1351	0.0808	0.0104	0.0014	0.255	0.2937	0.1721	0.5803	0.2718	0.0753	<.0001	0.0268	0.0431	0.0279	0.9338
	Al	0.6519	0.7473	0.1771	0.0005	0.0133	0.4693	0.299	0.6348	0.614	0.7331	0.3776	0.5246	0.1857	0.0106	0.1129	0.0038
	Ni	0.0633	0.0635	0.0819	0.016	0.0304	0.167	0.3525	0.0286	0.0692	0.0473	0.0034	<.0001	0.0003	0.0073	0.0009	0.2894
	Na	0.0153	0.018	0.1598	0.8315	0.0699	0.2336	0.0475	0.2921	0.4473	0.5415	0.7331	0.8544	0.8174	0.4392	0.8533	0.2783
	Cu	0.0715	0.5707	0.1339	0.6942	0.9517	0.6978	0.3729	0.3066	0.6744	0.8179	0.9187	0.3864	0.8936	0.819	0.9349	0.8803
	K	0.063	0.1453	0.5124	0.3264	0.1815	0.9757	0.1437	0.4691	0.1791	0.9244	0.2018	0.8712	0.0098	0.2995	0.0288	0.0053

Table 29. Ranked bivariate analysis with a Bonferroni correction (α = 0.05) of leafpack weight, macroinvertebrates, crayfish and water quality. —Continued. 116

		R Square															
		Salinity (sal)	Ammonia (amm)	Nitrite/ nitrate (no_2/no_3)	Soluble reactive phosphorus (srp)	Total nitrogen (tn)	Total phosphorus (tp)	TN/TP ratio (tn/tp)	Mg	Ca	Fe	Mn	Al	Ni	Na	Cu	K
	totsum	-0.24777	-0.04433	0.1062	0.23745	0.28665	0.27167	-0.20001	-0.05919	-0.38956	0.27519	-0.28548	-0.08916	-0.35555	0.4539	-0.34579	-0.35596
	nsptot	-0.21486	-0.01424	0.11091	0.24467	0.25531	0.17468	0.01232	-0.11174	-0.45441	0.23466	-0.28948	-0.06374	-0.35533	0.44369	-0.11193	-0.28248
	simpdom	0.08997	-0.14505	0.01943	0.03029	-0.13534	-0.11925	0.06531	0.23267	0.31753	0.12897	0.33567	0.26252	0.33447	-0.27306	-0.29034	0.12917
	cray	-0.11278	0.2786	0.39004	0.43852	0.4918	0.46311	-0.14549	0.40532	0.47368	0.18264	0.47607	0.61393	0.45107	0.04211	0.07774	0.19251
	wtlp	-0.27915	-0.53859	-0.30656	-0.1263	-0.20977	-0.35694	0.03405	-0.38696	-0.52124	0.19168	-0.57288	-0.46203	-0.40974	-0.34765	-0.01198	-0.25998
	shred	-0.32523	0.06295	0.23241	0.26537	0.38514	0.40862	-0.30435	-0.08771	-0.34493	0.28125	-0.22257	0.14256	-0.26855	0.23263	0.07677	-0.00603
	filt	0.14079	-0.06577	-0.02206	-0.11153	-0.03832	-0.13326	0.26253	0.06106	-0.2647	0.07828	-0.20568	-0.2035	-0.18254	0.37776	-0.17508	-0.28354
	scrap	-0.41372	-0.0208	0.1793	0.39688	0.26827	0.10098	0.07686	-0.24846	-0.44584	0.32535	-0.2655	-0.09385	-0.41391	0.20634	-0.20037	-0.14262
	sprfr	-0.45837	0.03066	0.27868	0.43626	0.15899	0.00824	0.1556	-0.37837	-0.24292	0.2451	-0.10916	0.09963	-0.34848	-0.14962	-0.08304	0.26138
	ept	-0.39303	-0.09691	0.06516	0.3792	0.17408	-0.0611	0.13287	-0.24767	-0.47037	0.34785	-0.21506	-0.06744	-0.3781	0.12046	-0.04557	-0.01879
	temp	-0.08847	0.01998	0.10676	-0.16729	-0.02065	-0.0577	-0.45476	-0.44457	-0.50275	-0.10325	-0.34147	-0.17339	-0.53463	0.06745	0.0202	0.24877
	f_ph	-0.79979	-0.19595	0.17545	0.46045	0.38877	0.22805	-0.47456	-0.57386	-0.78296	0.35898	-0.68038	-0.12548	-0.74039	0.03633	-0.17025	-0.03209
	hard	0.90553	-0.20252	-0.50062	-0.75521	-0.541	-0.36613	0.13771	0.56673	0.39616	-0.26506	0.41821	-0.25757	0.63473	0.04569	0.02647	-0.47991
	alk	-0.32339	-0.00575	-0.14689	-0.17774	-0.16608	-0.1554	-0.57983	-0.6594	-0.55122	-0.22076	-0.38486	-0.47537	-0.4961	-0.15226	0.04529	-0.20326
	cond	0.98077	-0.27696	-0.57479	-0.76063	-0.65499	-0.54817	0.30871	0.55687	0.33732	-0.14485	0.41547	-0.30628	0.59012	0.03661	-0.01616	-0.41327
Prob > |r|	turb	-0.50331	0.5769	0.62515	0.69716	0.75565	0.68079	-0.35092	-0.1214	0.02144	0.16101	0.01645	0.52945	-0.20747	0.21222	0.02981	0.51255
	sal	1	0.05879	-0.46644	-0.72255	-0.5848	-0.48083	0.30929	0.5441	0.5092	-0.4542	0.66675	-0.21273	0.61908	0.28732	0.04268	-0.13596
	amm	0.8002	1	0.55344	0.25894	0.52203	0.52307	0.09671	0.11373	0.45471	-0.02245	0.21637	0.38168	0.11523	0.30857	-0.04207	0.22624
	no_2/no_3	0.0331	0.0023	1	0.7295	0.91997	0.87121	0.06242	0.12252	0.17625	0.25236	-0.07213	0.73484	-0.05078	0.28562	-0.05183	0.21585
	srp	0.0002	0.257	0.0002	1	0.78701	0.61688	0.08571	-0.00431	0.00421	0.74705	-0.17765	0.74716	-0.15515	0.05244	-0.02268	0.35742
	tn	0.0054	0.0152	<.0001	<.0001	1	0.88442	-0.14416	0.08711	0.08262	0.46951	-0.24797	0.6938	-0.13935	0.28635	0.00394	0.16341
	tp	0.0273	0.015	<.0001	0.0029	<.0001	1	-0.31818	0.19385	0.2126	0.23783	-0.18469	0.65542	-0.04501	0.48616	-0.06953	-0.17014
	tn/tp	0.1725	0.6767	0.7881	0.7118	0.533	0.1598	1	0.3341	0.40046	0.08416	0.40593	0.2717	0.3759	-0.05874	0.143	0.43086
	Mg	0.0108	0.5645	0.5345	0.9852	0.7073	0.3998	0.1388	1	0.71067	0.04127	0.75903	0.44586	0.84884	0.43261	-0.05943	-0.12097
	Ca	0.0184	0.0151	0.3696	0.9856	0.7218	0.3548	0.072	<.0001	1	-0.02654	0.7281	0.46399	0.78005	0.10922	-0.11798	0.07521
	Fe	0.0386	0.9097	0.1951	<.0001	0.0318	0.2992	0.7168	0.8348	0.8933	1	-0.09988	0.4499	-0.03656	-0.1501	-0.15445	0.19701
	Mn	0.001	0.2688	0.7153	0.441	0.2785	0.4229	0.0679	<.0001	<.0001	0.6131	1	0.32373	0.85861	0.19666	0.12495	0.15293
	Al	0.3545	0.0451	<.0001	<.0001	0.0005	0.0013	0.2335	0.0174	0.0129	0.0163	0.0929	1	0.35407	0.24495	0.11571	0.30374
	Ni	0.0028	0.5593	0.7975	0.5019	0.5469	0.8464	0.0931	<.0001	<.0001	0.8535	<.0001	0.0645	1	0.05093	0.19883	-0.13549
	Na	0.2066	0.1101	0.1407	0.8214	0.2082	0.0254	0.8003	0.0215	0.5801	0.4458	0.3158	0.209	0.7969	1	-0.19449	-0.18342
	Cu	0.8542	0.8317	0.7934	0.9223	0.9865	0.7646	0.5363	0.7639	0.5499	0.4326	0.5264	0.5576	0.3104	0.3213	1	0.16627
	K	0.5568	0.247	0.2699	0.1117	0.4791	0.4609	0.0512	0.5398	0.7037	0.315	0.4372	0.1161	0.4918	0.3501	0.3978	1

Table 30. Ranked stepwise regression of leafpack decomposition (n = 28).

Source	**DF**	**Sum of Squares**	**Mean Square**	**F Value**	**Pr > F**
Model	6	1493	249	167	<0.0001
Error	21	334	16		
Corrected Total	27	1827			

Variable	**Parameter Estimate**	**Standard Error**	**Type III SS**	**F Value**	**Pr > F**	**Total R^2**
Intercept	22.01	3.269	720.7	45.3	<0.001	
Magnesium (µg/ml)	-0.438	0.105	276.0	17.4	0.0004	0.328
Turbidity (NTU)	-0.736	0.110	716.4	45.1	<0.0001	0.630
EPT Taxa	0.656	0.226	134.5	8.46	0.0084	0.698
Total Scrappers	-0.533	0.227	87.7	5.52	0.0287	0.739
Temperature (^oC)	0.291	0.117	98.46	6.19	0.0213	0.771
Copper (ng/ml)	0.242	0.105	84.3	5.3	0.0317	0.817

Leafpack weight loss per day = 22.01 - 0.438 * magnesium - 0.736 * turbidity
+ 0.656 * EPT taxa - 0.533 total scrappers
+ 0.291 * temperature + 0.242 * copper

Table 31. List of invertebrate species collected during the study.

Main Group (Phylum, Class, or Order)	Family or Subfamily	Genus
Turbellaria	Planaridae	*Dugesia*
Hydrozoa		*Hydra*
Nematomorpha	Gordiidae	*Gordius*
Nematoda		
Oligochaeta	Tubificidae	
	Naididae	
Hirudinea	Glossiphoniidae	*Helobdella*
	Erpodellidae	*Erpobdella*
Gastropoda	Physidae	*Physella*
	Planorbidae	*Helosoma*
	Ancylidae	*Ferrissia*
	Lymnaeidae	*Lymnaea*
Bivalvia	Spaeriidae	*Sphaerium*
Decapoda	Cambaridae	*Orconectes*
Amphipoda	Hyalellidae	*Hyalella*
Acarina		
Ephemeroptera	Caenidae	*Caenis*
	Heptageniidae	*Stenonema*
		Leucrocuta
	Ephemeridae	*Hexagenia*
Plecoptera	Perlidae	*Neoperia*
Odonata	Coenagrionidae	*Ischnura*
		Enallagma
		Argia
	Aeshnidae	*Boyeria*
	Libellulidae	*Celithemis*
		Libellula
	Lestidae	*Lestes*
Megaloptera	Corydalidae	*Corydalus*
	Sialidae	*Sialis*
Trichoptera	Hydropsychidae	*Cheumatopsyche*
	Hydroptilidae	*Hydroptila*
	Glossosomatidae	*Glossosoma*
	Leptoceridae	*Oecetis*
	Polycentropodidae	*Nyctiophylax*
		Polycentropus
Coleoptera	Dryopidae	*Helichus*
	Gyrinidae	*Gyrinus*
		Dineutus
	Elmidae	*Dubiraphia*
	Dytiscidae	*Oreodytes*
	Haliplidae	*Peltodytes*

Table 31. Invertebrate species list.—Continued

Main Group (Phylum,Class, or Order)	Family or Subfamily	Genus
Diptera	Tipulidae	*Tipula*
	Tabanidae	*Chrysops*
	Ceratopogonidae	*Bezzia*
	Empididae	*Hemerodromia*
	Chironomidae	*pupae*
	Chironominae	*Dicrotendipes*
		Glyptotendipes
		Microtendipes
		Paratendipes
		Phaenopsectra
		Tribelos
		Polypedilum
		Stenochironomus
		Crptochironomus
		Tanytarsus
		Rheotanytarsus
		Paratanytarsus
	Chironominae	*Cladotanytarsus*
		Endochironomus
		Parachironomus
		Chironomus
		Saetheria
	Orthocladiinae	*Nanocladiums*
		Corynoneura
		Cricotopus
		Orthocladius
	Tanypodinae	*Ablabesmyia*
		Procladius
		Labrundinia
		Nilotanypus
		Tanypus
		Unidentifiable

Table 32. Total number of macroinvertebrates collected during the study.

Main Grouping		Turbellaria	Oligochaete		Hirundinea		Mollusca					Decapoda	Amphipoda	Ephemeroptera						Plecoptera	Odonata					
Species		Dugesia	Tubificidae	Naididae	Erpobdella	Helobdella	Physella	Helisoma	Ferrissia	Spaerium	Lymnaea	Orconectes	Hyallela	Caenis	Stenonema	Stenacron	Hexaenia	Centroptilium	Leucrocuta	Neoperla	Ischnura/Enallagma	Argia	Boyeria	Celithemis	Libellula	Lestes
Date	Site																									
06/17/99	3	1	2	32			48	24		20				1	10	69						1				
06/17/99	3			8			25	7		1	1	1		1		16					1	2				1
06/17/99	3	5		10		1	21	15				1		2	16	29						1				
06/17/99	3	1		19			11	9				1		1	2	28					2	1				
06/17/99	3			13			12	11		12	1	4			7	31										
06/29/00	3			12			17	54	4				29		5	18							2			
06/29/00	3			13	1		17	27	7				22		39	26					6		1	1		
06/29/00	3			12			5	17	2				10		35	20					2	1				
06/29/00	3			3			13	37	17			1	6		44	17					1					
06/29/00	3			4			14	77	2				29		20	28					5					
06/21/01	3			3		1										35						1				
06/21/01	3		1				1							1		32										
06/21/01	3			1		1		1	1			1		2	4	36	1				1					
06/21/01	3						5							5	3	25										
06/21/01	3			2			2						1		7	6					1					
06/17/02	3						3	1								5						1				
06/17/02	3			2			15					1		4	3	26										
06/17/02	3						3	1		4				7	2	10										
06/17/02	3		1	2			11	3				1		9	1	10										
06/17/02	3						7							4	2	8										
06/17/99	4		1	10			1							12		7										
06/17/99	4			8			1	1		6		1		10		30	2									
06/17/99	4		6											6	1	1										
06/17/99	4			7			2					2		12	1	11					2					
06/29/00	4		1	21																						
06/29/00	4		7	60										3							1					
06/29/00	4		4	19										1												
06/29/00	4		4	3		1								4												
06/29/00	4		2	6			1							1	1											
06/21/01	4											4		11	36	47							1			
06/21/01	4							1				1		12	31	47				1						
06/21/01	4		2									1		18	17	22										
06/21/01	4					2						1		42	8	52										
06/21/01	4											3		21	4	31				1						
06/17/02	4						3																			
06/17/02	4						6																			
06/17/02	4						5																			
06/17/02	4			2			8					1														
06/17/02	4						8								1											
06/17/99	5			2											1											
06/17/99	5			5								2		1	8											
06/17/99	5			4											4											
06/17/99	5			6											1											

Table 32. Total number of macroinvertebrates collected during the study.

Main Grouping		Turbellaria	Oligochaete		Hirundinea		Mollusca					Decapoda	Amphipoda	Ephemeroptera						Plecoptera	Odonata					
Species		Dugesia	Tubificidae	Naididae	Erpobdella	Helobdella	Physella	Helisoma	Ferrissia	Spaerium	Lymnaea	Orconectes	Hyallela	Caenis	Stenonema	Stenacron	Hexaenia	Centroptilium	Leucrocuta	Neoperla	Ischnura/Enallagma	Argia	Boyeria	Celithemis	Libellula	Lestes
Date	Site																									
06/17/99	5			4								1		1	6											
06/29/00	5		1									1														
06/29/00	5																								2	
06/29/00	5			3								3														
06/29/00	5		1	7								1														
06/29/00	5			4																	1					
06/21/01	5			1										10	2											
06/21/01	5						1							18	1											
06/21/01	5													15	1											
06/21/01	5													2												
06/21/01	5						1							6	1											
06/17/02	5											2		24	2	10					1					
06/17/02	5											3		15	2	15		1								
06/17/02	5						1					1		12	1	19										
06/17/02	5			1			1					2		10	3	9										
06/17/99	7		2	27			1					1		1	3	27										
06/17/99	7		2				1					1		4	5	30										
06/17/99	7			8			4							1	2	30										
06/17/99	7		1	7										5	21	18										
06/17/99	7		2	11								3		1	5	29										
06/29/00	7			4								1									1					
06/29/00	7		2	2																						
06/29/00	7		1	1																						
06/29/00	7		1	24									1													
06/29/00	7		2	54																	1					
06/21/01	7		3				1					4		12	12	7							1			
06/21/01	7		41	1				1				3		7	3	10										
06/21/01	7											3		9	10	12										
06/21/01	7		3	5			4					1	2	13	11	14										
06/21/01	7		1									5		8	16	8										
06/17/02	7						1					2		14	6	13										
06/17/02	7						1					1		2	4	1										
06/17/02	7			2								1		3	3											
06/17/02	7						2								2	2										
06/17/02	7						1					2		4	1	1					1					
06/17/02	7													2	1	3										
06/17/99	8						15							1	2	6										
06/17/99	8			24								1		3	2	11										
06/17/99	8			25				1						4	1	15										
06/17/99	8			13			5							5	1	8										
06/17/99	8			1									1		1	3						1				
06/29/00	8		1	8					7				1	1												
06/29/00	8			36								1	7	9												
06/29/00	8		2	7			2						11	8							2					
06/29/00	8		2	41									12	9												

Table 32. Total number of macroinvertebrates collected during the study.

Main Grouping		Turbellaria	Oligochaete		Hirundinea		Mollusca					Decapoda	Amphipoda	Ephemeroptera						Plecoptera	Odonata					
Species		Dugesia	Tubificidae	Naididae	Erpobdella	Helobdella	Physella	Helisoma	Ferrissia	Spaerium	Lymnaea	Orconectes	Hyallela	Caenis	Stenonema	Stenacron	Hexaenia	Centroptilium	Leucrocuta	Neoperla	Ischnura/Enallagma	Argia	Boyeria	Celithemis	Libellula	Lestes
Date	**Site**																									
06/21/01	8													1	3	1										
06/21/01	8													2	8											
06/21/01	8											2				4										
06/21/01	8											1		1	6											
06/21/01	8			1									1	2	6											
06/17/02	8						1																			
06/17/02	8						3							1												
06/17/02	8						2							2											1	
06/17/02	8															2					1	1				
06/17/99	9			7			11					2														
06/17/99	9																									
06/17/99	9		4			1	1																			
06/17/99	9					1						1														
06/17/99	9			4	1							1														
06/29/00	9		1	13			9						2	1												
06/29/00	9		4	16			12																			
06/21/01	9			1									34		1	6									1	
06/21/01	9						5						24	8	11	1										
06/21/01	9						1					1	30	6	3	1										
06/21/01	9						12					2		2	16											
06/21/01	9			1								1	23	3	8	1										
06/17/02	9						3						8	2												
06/17/02	9						2					1	1	8	1										1	
06/17/02	9						1					1	16	6												
06/17/02	9						5						9	3					1		2					
06/17/02	9						4					1		1	1						1					
06/17/99	10			17						16		1		8	8	23										
06/17/99	10			5						5				8	6	24						1				
06/17/99	10			30			3					5		11		16										
06/17/99	10			5						1		1		5	1	8										
06/17/99	10			3			1							6	9	2					1	1				
06/29/00	10			10			28	5	14				10													
06/29/00	10			9			8	5	3				6								1	1				
06/29/00	10			16			14	4	24				10													
06/29/00	10			2			3		2				2								1					
06/29/00	10		1	22			4																			
06/21/01	10											4			6	1										
06/21/01	10						1							1	1	6										
06/21/01	10		3	2										1	5	2										
06/21/01	10								1				1	2	2	1										
06/21/01	10				1		2						2	9	11	4										
06/17/02	10													1	1											
06/17/02	10													2	1	1		1								
06/17/02	10														1											
06/17/02	10						1							2	2						1					
06/17/02	10									1				4	1	2					1					

Table 32. Total number of macroinvertebrates collected during the study.

Main Grouping		Megaloptera		Tricoptera							Coleoptera							Diptera Tipulidae	Tabaniae	Ceratopogonidae	Chironiminae								
Species		Corydalus	Sialis	Cheumatopsyche	Polycentropus	Hydroptila	Pychnopsyche	Glossosoma	Oecetis	Paranyctiophylax	Helichus	Gyrinus	Dineutus	Dubiraphia	Oreodytes	Peltodytes	Stenelmis	Tipula	Chrysops	Bezzia	Pupae	Dicrotendipes	Glyptotendipes	Micaratendipes	Paratendipes	Phaenopsectra	Tribelos	Polypedilum	Stenochironomus
Date	Site																												
06/17/99	3			5	1					2				2		1					9	5				2	8	4	
06/17/99	3			1	1																2		2				2		
06/17/99	3		1	1	2		1							3						2	5	2	2			3	15	4	
06/17/99	3				1		2					1		5						1	8	4			1		6	1	
06/17/99	3		1		1									3							1	1	2				8	2	
06/29/00	3				13									1						1	3	6	16				1		
06/29/00	3		1		4	1								1								4	8				3		
06/29/00	3				6	1								1								11	11					2	
06/29/00	3				3																5	3	1				4	2	
06/29/00	3		2		5	3								2							3	9	11						
06/21/01	3											2									1	4	27					3	
06/21/01	3											2									3	1	10				2	2	
06/21/01	3																				2	3	13			1	1	2	
06/21/01	3												1								1	3	31					2	
06/21/01	3																					5	7					1	
06/17/02	3																					2	17				3		
06/17/02	3				2									2						1	1		24				1		
06/17/02	3													2			1				2	4	59	1			1	1	
06/17/02	3		1																			6	45		2		15	1	
06/17/02	3						1							1								2	18				3		
06/17/99	4		2	5	1								1						1	1		3			1	3	21	18	
06/17/99	4		2		1									1						1	7	11				11	37	22	
06/17/99	4		5	1				1							1					3		1				3	26	18	
06/17/99	4		1	2		1								2				1		3	2	2	2			4	17	14	
06/29/00	4		1										1							2							2	7	
06/29/00	4												1		1					1		2	2					8	
06/29/00	4		1										1							1	4	4						4	1
06/29/00	4			1	1																2		1					4	
06/29/00	4		1	1	1								4							1	1	2	1					5	
06/21/01	4			8	1									1						1	2							3	
06/21/01	4			3																	2		3					2	
06/21/01	4													1							5		5	1				6	
06/21/01	4				1									1			1			2	4	1	2		1			2	
06/21/01	4			53													1			2	3	3	3					31	
06/17/02	4																				1								
06/17/02	4																				1								
06/17/02	4																				5							1	
06/17/02	4																				2								
06/17/02	4																						2						
06/17/99	5		1												1						1	2				22	2	1	
06/17/99	5				1																4	1					5	9	
06/17/99	5								1												5	1				14	3	2	
06/17/99	5																				3				1	9		3	

Table 32. Total number of macroinvertebrates collected during the study.

Main Grouping		Megaloptera		Tricoptera							Coleoptera							Diptera Tipulidae	Tabaniae	Ceratopogonidae	Chironiminae								
Species		Corydalus	Sialis	Cheumatopsyche	Polycentropus	Hydroptila	Pychnopsyche	Glossosoma	Oecetis	Paranyctiophylax	Helichus	Gyrinus	Dineutus	Dubiraphia	Oreodytes	Peltodytes	Stenelmis	Tipula	Chrysops	Bezzia	Pupae	Dicrotendipes	Glyptotendipes	Micarotendipes	Paratendipes	Phaenopsectra	Tribelos	Polypedilum	Stenochironomus
Date	Site																												
06/17/99	5				1																					9	3		
06/29/00	5																					1							
06/29/00	5													1							3	2						2	
06/29/00	5																												
06/29/00	5																						1					1	
06/29/00	5																												
06/21/01	5																				1		1		5		1		
06/21/01	5													1								1			6			1	
06/21/01	5													1							1	1						2	
06/21/01	5																												
06/21/01	5																												
06/17/02	5																1					1	1						
06/17/02	5													1									1				1	1	
06/17/02	5													1						1			2				2	2	
06/17/02	5																				1	1		1			4	2	
06/17/99	7		4	1	1										1					4	3		1			10	7	4	
06/17/99	7			84	1									1						1	9	1				8	2	2	
06/17/99	7		1	14	2						1										7	4	1		16	20	12	15	
06/17/99	7		1		1																8	1	3	1		28	16	5	
06/17/99	7		6	2	1									1						2			2	1	1	13	29	15	
06/29/00	7																				3								
06/29/00	7																				1	1							
06/29/00	7																				3	8	5		6			2	
06/29/00	7																					1	1						
06/29/00	7																			1	2	6	1					4	
06/21/01	7																				3	4	13	2	1			1	
06/21/01	7																				2	2	11	1	1		1	7	
06/21/01	7																				1	2	1			1			
06/21/01	7		1										1	1							3	2	8	1			1	3	
06/21/01	7																				1	1	9	2		1	1	2	
06/17/02	7													3								4		1			6	1	
06/17/02	7																				4	1	6	1			3		
06/17/02	7												1					1			1		2		4		3		
06/17/02	7																				2	2	3				2		
06/17/02	7																						3	1					
06/17/02	7												1								1	1	5	1				2	
06/17/99	8			3									1								6	3	1					3	1
06/17/99	8											1								3	10	19				9	2		
06/17/99	8			5					1												4	2	1	1		16	14	10	
06/17/99	8																1				9	23	6	1		21		8	
06/17/99	8													2							3	4							
06/29/00	8																					9	6						
06/29/00	8																			1	3	17	4				1	4	
06/29/00	8											3									1	31	13						
06/29/00	8																				2	11	5				2	4	

Table 32. Total number of macroinvertebrates collected during the study.

Main Grouping		Megaloptera		Tricoptera							Coleoptera							Diptera Tipulidae	Tabaniae	Ceratopogonidae	Chironiminae								
Species		Corydalus	Sialis	Cheumatopsyche	Polycentropus	Hydroptila	Pychnopsyche	Glossosoma	Oecetis	Paranyctiophylax	Helichus	Gyrinus	Dineutus	Dubiraphia	Oreodytes	Peltodytes	Stenelmis	Tipula	Chrysops	Bezzia	Pupae	Dicrotendipes	Glyptotendipes	Micarotendipes	Paratendipes	Phaenopsectra	Tribelos	Polypedilum	Stenochironomus
Date	**Site**																												
06/21/01	8																					2							
06/21/01	8																				2	3	2						
06/21/01	8			2													1				1	1	9					1	
06/21/01	8																				1	1	7					2	
06/21/01	8																				3	3	16	1	1	3		8	
06/17/02	8																						3	1		1			
06/17/02	8																				1		10						
06/17/02	8																				1		9						
06/17/02	8																				1		3						
06/17/99	9				2						4				3						1	1				2	10	10	
06/17/99	9	1			3						3				1												6	1	
06/17/99	9																			10							1	3	
06/17/99	9				1						2				1						1						13	15	
06/17/99	9			6	4						10				1											4	10	11	
06/29/00	9										1				1						1	3	3	1			1	2	
06/29/00	9	1									2				8						3		3		1	1		6	
06/21/01	9													2								1	1						
06/21/01	9			1							1				1						11	3	1		6		1	3	
06/21/01	9			2							1				1		1				1	1	1		1			1	
06/21/01	9			1							2						1					1	1		3		3	1	
06/21/01	9			1										1							3	2	5		2	1			
06/17/02	9																										3	2	
06/17/02	9																1					2	3	2					
06/17/02	9			2											1								1						
06/17/02	9			1							1										1								
06/17/02	9																								2		2	3	
06/17/99	10		3											1							13	2	19		6	27	41	8	
06/17/99	10		2											1							3	4	9		1	5	20	9	
06/17/99	10		1										1				1			1	10	4	16	1		46	12	6	
06/17/99	10																			2	6	4	3			36	11	1	
06/17/99	10		1																		10	13				2	10	7	
06/29/00	10																			1	4		29				9	2	
06/29/00	10																				2	2	21		1		1	1	
06/29/00	10				2									1						1	1	1	14				5		
06/29/00	10																				1		1						
06/29/00	10										3										3		7				1	6	
06/21/01	10			1																		1	17				1	2	
06/21/01	10																1					3	11			3	4		
06/21/01	10																						1	1				1	
06/21/01	10																				1	1	3			2	1	1	
06/21/01	10																				2	3	11	4			1	4	
06/17/02	10											1			1						1		2			2		1	
06/17/02	10																				1		5	1			2		
06/17/02	10																				4		3	6	1				
06/17/02	10																						2						
06/17/02	10																1				1		6	2	1	1	4		

Table 32. Total number of macroinvertebrates collected during the study.

Main Grouping		**Chironiminae**									**Orthocladinae**				**Tanypodinae**				**Diamesinae**	**Other Diptera**	**Other Taxa**			
Species		Cryptochironomuys	Tanytarsus	Rheotanytarsus	Paratanytarsus	Cladotanytarsus	Endochironomus	Parachironomus	Chironomus	Saetheria	Nanocladius	Corynoneura	Thienemanniella	Cricotopus / Orthocladius	Ababesmyia	Procladius	Labrundinia(incl. Nilotanypus)	Tanypus	Unidentifyable midges	Hemerodromia	Nematomorpha	Nematoda	Acarina	Hydra
Date	**Site**																							
06/17/99	3	1	18		1			2			1				12				5					
06/17/99	3		3		1				5						3	1								
06/17/99	3	1	4	1	1				5		2	1		1	8	1								
06/17/99	3	2	4						4		1				6	1								
06/17/99	3	1	1		1				1						3	1								
06/29/00	3		1		1		8	1	1		4				2				3					
06/29/00	3		1		1		1	6	1		3				2									
06/29/00	3		1		4		1	2	3		2				3				5					
06/29/00	3		2		3			2	2		1				2									
06/29/00	3		8		6		3	11	7		6				4	1								
06/21/01	3				7		2		6		3	1			3				7					
06/21/01	3				2				9						3				1					
06/21/01	3		1		1		1		4								1		5					
06/21/01	3		2		5				6		1				4						3			
06/21/01	3						2	2	2						1									
06/17/02	3		1				2							2	2						2			
06/17/02	3		1		3		5								2									
06/17/02	3						3		8						4									
06/17/02	3				1		3		5						1	2								
06/17/02	3		1		1		2		5						4									
06/17/99	4	2	6						4			1		1	20				4					
06/17/99	4	2	7		7				5		3				18				2					
06/17/99	4		1		1				5		2				18				1					
06/17/99	4		14	7					8		3	2		1	25	1	2		1					
06/29/00	4		3				50		1					2	4				5					
06/29/00	4	1	5		5		28	6			6	1			7	1								
06/29/00	4		2		2		45	1	8		3				8				7					
06/29/00	4		2		2		12	2	1		4				3				1					
06/29/00	4					1	23		3		2			1	3									
06/21/01	4						3								8				1					
06/21/01	4				2		2				2	1	3	1	7		1							
06/21/01	4	1	4		1				3		1				12									
06/21/01	4		1				6		1						8									
06/21/01	4							1			2		1		11		1							
06/17/02	4		1						19															
06/17/02	4								65						1									
06/17/02	4								49									1						
06/17/02	4								32					1										
06/17/02	4						1		19						1				1					
06/17/99	5		2						11						17									
06/17/99	5		4						15						5									
06/17/99	5	1	4		2				8		3	1			9									
06/17/99	5		2		2				7						3									

Table 32. Total number of macroinvertebrates collected during the study.

Main Grouping		Chironiminae									Orthocladinae				Tanypodinae				Diamesinae	Other Diptera	Other Taxa			
Species		Cryptochironomuys	Tanytarsus	Rheotanytarsus	Paratanytarsus	Cladotanytarsus	Endochironomus	Parachironomus	Chironomus	Saetheria	Nanocladius	Corynoneura	Thienemanniella	Cricotopus / Orthocladius	Ababesmyia	Procladius	Labrundinia(incl. Nilotanypus)	Tanypus	Unidentifyable midges	Hemerodromia	Nematomorpha	Nematoda	Acarina	Hydra
Date	Site																							
06/17/99	5		3		2				2		2				23									3
06/29/00	5		1						2						1									
06/29/00	5				1				8						5									
06/29/00	5								1						1									
06/29/00	5						1		1						4									
06/29/00	5				1				1															
06/21/01	5								1															
06/21/01	5		1					1	3						1									
06/21/01	5								6															
06/21/01	5														1									
06/21/01	5								1						3									
06/17/02	5		2		1		5	5	3															
06/17/02	5		3		3		2	3	1						4									
06/17/02	5		3		4		5		3						1				1					
06/17/02	5		3				1		2						1									
06/17/99	7		10		9						5				25									
06/17/99	7	2	16		3						4	3			22									
06/17/99	7	2	33								2	5	1		36	1	1		2					
06/17/99	7	1	11		13						16	4	1		21	2								
06/17/99	7	5	23		8	2					1	1			24							2		
06/29/00	7																							
06/29/00	7						1	2	6															
06/29/00	7		1				8		2		1			2	4	1								
06/29/00	7		1				3	1	5						2		1		2					
06/29/00	7						7	6	8		3				3									
06/21/01	7						1		4						8				1					
06/21/01	7		2		1		2	1	6						4				2					
06/21/01	7				3		1		2						3									
06/21/01	7				2		3		4		1				7									
06/21/01	7		2		1		3	1	2						5				1					
06/17/02	7		2		1		3		1						3									
06/17/02	7	1	3		12		1	1	11						5				1					
06/17/02	7		2		2		7		6						5									
06/17/02	7		1		1		2		4						1	2			2					
06/17/02	7		3		1		5		3						2									
06/17/02	7		2		3		5		12								6		1					
06/17/99	8		8		2						9	5	1	1	14				3					
06/17/99	8		29		1						7	18	1	3	29				4					
06/17/99	8		20		3						3	3			44				1					
06/17/99	8	1	17		3						1	1	2	1	30				1					
06/17/99	8		3								1	2		1	4		1							
06/29/00	8							1							1									
06/29/00	8		3		6			2	2		2	1		1	1		2							
06/29/00	8		5		6		2	1	1															
06/29/00	8		6		6			2			1				5									

Table 32. Total number of macroinvertebrates collected during the study.

Main Grouping		Chironiminae									Orthocladinae				Tanypodinae				Diamesinae	Other Diptera	Other Taxa			
Species		Cryptochironomuys	Tanytarsus	Rheotanytarsus	Paratanytarsus	Cladotanytarsus	Endochironomus	Parachironomus	Chironomus	Saetheria	Nanocladius	Corynoneura	Thienemanniella	Cricotopus / Orthocladius	Ababesmyia	Procladius	Labrundinia(incl. Nilotanypus)	Tanypus	Unidentifyable midges	Hemerodromia	Nematomorpha	Nematoda	Acarina	Hydra
Date	**Site**																							
06/21/01	8		2		1										11									
06/21/01	8		2		2										8									
06/21/01	8		1		1										7				1					
06/21/01	8		1		2										11									
06/21/01	8		1		2		1		2					1	10									
06/17/02	8				3				1															
06/17/02	8		1		1				2						1									
06/17/02	8		3		2		1		1						6									
06/17/02	8				4			1	2						1									
06/17/99	9								1						11				1					
06/17/99	9														8									
06/17/99	9								7						13									
06/17/99	9													1	7				1					
06/17/99	9								1	1					33				1					
06/29/00	9		4		2		2		2						5									
06/29/00	9		1						2						5	1								
06/21/01	9		1		1										2									
06/21/01	9		1		1										2									
06/21/01	9		1		1										4									
06/21/01	9				1				1						4				1					
06/21/01	9						3								4									
06/17/02	9								2						1									
06/17/02	9								15										2					
06/17/02	9								3						1									
06/17/02	9		1												2									
06/17/02	9								3															
06/17/99	10	6	57		16	1		4	5			3			39	1	1		9					
06/17/99	10	5	57		16			5	11		1	2	1	4	46	1			8					
06/17/99	10	2	62		25				13		1	4			51	1			10					
06/17/99	10	6	18		1				4		1	1			18									3
06/17/99	10	3	34					14	1		1				44									1
06/29/00	10		3		4										2				5					
06/29/00	10										1				2									
06/29/00	10		1		2				1		1				3									
06/29/00	10							1						1	2									
06/29/00	10		3		2			1	1			1		1	6				5					
06/21/01	10		1		1		2							1	3									
06/21/01	10		1				2		2						5								1	
06/21/01	10				1				2						2									
06/21/01	10		1						1						1									
06/21/01	10		7		9		2		2		1			1	11				1	1		1		
06/17/02	10		1						8					1										
06/17/02	10		3		4		2		4						7				1					
06/17/02	10		1				1		3						3									
06/17/02	10		2												3									
06/17/02	10		3		6		2		3						4									

Table 33. Ranked analysis of variance of macroinvertebrates: a) total number of organisms, b) taxa richness, and c) Simpson's Dominance.

33 (a) Total number of macroinvertebrate organisms.

Source	**DF**	**Sum of Squares**	**Mean Square**	**F Value**	**Pr > F**
Model	27	158644	5876	13.6	<0.0001
Error	107	46344	433		
Corrected total	134	204988			

Source	**DF**	**Type III SS**	**Mean Square**	**F Value**	**Pr > F**
Year	3	44020	15340	35.4	<0.0001
Site	6	55664	9277	21.4	<0.0001
Year*Site	18	54655	3036	7.01	<0.0001

33 (b) Macroinvertebrate taxa richness

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	27	163354	6050	15.8	<0.0001
Error	107	40975	383		
Corrected total	134	204329			

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Year	3	36209	12736	33.3	<0.0001
Site	6	50467	8411	22.0	<0.0001
Year*Site	18	71752	3986	10.4	<0.0001

33 (c) Macroinvertebrate Simpson's Dominance

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	27	105504	3908	4.20	<0.0001
Error	107	99515	930		
Corrected total	134	205019			

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Year	3	10287	3429	3.69	0.0143
Site	6	49771	8296	8.92	<0.0001
Year*Site	18	40919	2273	2.44	0.0024

Table 34. Statistical differences for multiple comparisons among invertebrates at seven Cedar Creek sites for a) total number of organisms, b) taxa richness, and c) Simpson's Dominance. Results are based on ranked least square means and Duncan's Multiple Range Test. Sites that share the same letter are not significantly different across sites, for each metric and year.

34 (a) Total number of macroinvertebrates

Year	Site	Mean Total Number Organisms	N	Duncan Grouping														
1999	3	133	5	A	B	C	D											
1999	4	132	4	A	B	C												
1999	5	50	5					E	F	G	H	I	J	K				
1999	7	171	5	A	B													
1999	8	104	5		B	C	D	E										
1999	9	48	5						F	G	H	I	J	K	L			
1999	10	220	5	A														
2000	3	185	5	A														
2000	4	65	5					E	F	G	H	I						
2000	5	9	5															O
2000	7	22	5													M	N	O
2000	8	60	4					E	F	G	H	I	J					
2000	9	33	3											K	L	M	N	
2000	10	59	5					E	F	G	H	I	J	K				
2001	3	74	5			C	D	E	F	G								
2001	4	128	5	A	B	C												
2001	5	19	5														N	O
2001	7	66	5				D	E	F	G	H							
2001	8	33	5										J	K	L	M	N	
2001	9	57	5					E	F	G	H	I	J	K				
2001	10	41	5									I	J	K	L	M	N	
2002	3	84	5			C	D	E	F									
2002	4	45	5							G	H	I	J	K	L	M		
2002	5	53	4					E	F	G	H	I	J	K				
2002	7	42	6									I	J	K	L	M		
2002	8	18	4														N	O
2002	9	27	5												L	M	N	O
2002	10	25	5												L	M	N	O

34 (b) Macroinvertebrate taxa richness

Year	Site	Mean Taxa Richness	N	Duncan Grouping									
1999	3	23	5	A									
1999	4	21	4	A									
1999	5	11	5					E	F	G			
1999	7	20	5	A									
1999	8	16	5		B								
1999	9	9	5						F	G	H	I	
1999	10	21	5	A									
2000	3	21	5	A									
2000	4	14	5		B	C	D						
2000	5	5	5								H	I	J
2000	7	7	5							G	H	I	J
2000	8	12	4			C	D	E	F				
2000	9	11	3				D	E	F	G			
2000	10	12	5			C	D	E	F				
2001	3	14	5		B	C	D	E					
2001	4	15	5		B	C							
2001	5	6	5								H	I	J
2001	7	15	5		B	C							
2001	8	10	5						F	G	H		
2001	9	14	5		B	C	D						
2001	10	14	5		B	C	D	E					
2002	3	15	5		B	C	D						
2002	4	4	5										J
2002	5	14	4		B	C	D						
2002	7	14	6		B	C	D	E					
2002	8	8	4							G	H	I	J
2002	9	9	5						F	G	H	I	J
2002	10	11	5					E	F	G			

34 (c) Macroinvertebrate Simpson's Dominance

Year	Site	Mean Simpson's Dominance	N	Duncan Grouping								
1999	3	0.131	5			C	D	E	F	G	H	I
1999	4	0.113	4							G	H	I
1999	5	0.180	5		B	C	D	E	F	G		
1999	7	0.134	5					E	F	G	H	I
1999	8	0.116	5						F	G	H	I
1999	9	0.201	5	A	B	C	D	E				
1999	10	0.127	5				D	E	F	G	H	I
2000	3	0.131	5			C	D	E	F	G	H	I
2000	4	0.258	5	A	B	C	D					
2000	5	0.146	5			C	D	E	F	G	H	I
2000	7	0.141	5				D	E	F	G	H	I
2000	8	0.157	4			C	D	E	F	G	H	I
2000	9	0.198	3			C	D	E	F	G	H	I
2000	10	0.139	5			C	D	E	F	G	H	I
2001	3	0.209	5	A	B	C	D	E				
2001	4	0.212	5	A	B	C	D					
2001	5	0.312	5	A	B							
2001	7	0.109	5								H	I
2001	8	0.189	5		B	C	D	E	F			
2001	9	0.257	5	A	B	C						
2001	10	0.106	5							G	H	I
2002	3	0.199	5	A	B	C	D	E				
2002	4	0.658	5	A								
2002	5	0.160	4			C	D	E	F	G	H	
2002	7	0.093	6									I
2002	8	0.172	4			C	D	E	F	G	H	I
2002	9	0.185	5		B	C	D	E	F	G	H	
2002	10	0.113	5							G	H	I

Table 35. Ranked stepwise regression of macroinvertebrate taxa richness (n = 28).

Source	**DF**	**Sum of Squares**	**Mean Square**	**F Value**	**Pr > F**
Model	1	541	541	86	<0. 0001
Error	26	159	6.11		
Corrected total	27	700			

Variable	**Parameter Estimate**	**Standard Error**	**Type III SS**	**F Value**	**Pr > F**	**Total R^2**
Intercept	1.423	1.27	2.95	1.30	0.2665	
Total # of Individuals	0.4436	0.0489	186.74	82.43	<0.0001	0.7731
Total # Filter Feeders	0.2458	0.0486	58.07	25.64	<0.0001	0.8414
Cadmium (ng/L)	0.1442	0.0389	31.01	13.73	0.0013	0.8800
Hardness (mg/L as $CaCO_3$)	-0.1027	0.0510	9.18	4.05	0.0571	0.8951
Potassium (µg/ml)	0.1883	0.557	25.87	11.42	0.0028	0.9194
Manganese (ng/L)	-0.1194	0.0604	8.87	3.92	0.0611	0.9321

Macroinvertebrate taxa richness = 1.423 - 0.4436 * total # individuals
+ 0.2458 * total # filter feeders
+ 0.1442 * cadmium
– 0.0127 * hardness
+ 0.1883 * potassium
– 0.1194 * manganese

Table 36. Means and scores for nine invertebrate metrics calculated from colonization of leaf packs deployed at seven Cedar Creek sites between 1999 and 2002. Seven of the nine metrics were included in the multi-metric site scoring given in Table 35. % Oligochaeta and % Shredders were omitted.

	Metric Means and Scoring								
	Taxa Richness			**EPT Richness**			**% EPT**		
Site & Year	**Mean**	**%Tile Score**	**Scaled Value**	**Mean**	**%Tile Score**	**Scaled Value**	**Mean**	**%Tile Score**	**Scaled Value**
1999									
3	23.2	5	100	4.8	5	100	29	5	95.5
4	21	3	84.4	4.5	3	92.2	17.6	3	48.6
5	10.6	1	10.9	2	1	27.0	8.6	1	11.7
6	20.2	3	78.8	4.8	5	100	30.1	5	100
8	16	3	49.1	3.4	3	63.5	12.4	3	27.3
9	9.2	1	1.00	1	1	1.00	6	1	1.00
10	21.2	5	85.9	2.8	3	47.9	11.3	3	22.8
2000									
3	21	5	100	3.6	5	100	30.7	5	100
4	14.2	5	58.4	1.8	5	50.5	4.5	3	15.5
5	4.8	1	1.00	0	1	1.00	0	1	1.00
6	7.2	1	15.7	0	1	1.00	0	1	1.00
8	11.8	3	43.5	1	3	28.5	7.1	5	23.9
9	11	3	38.9	0.3	3	9.25	0.6	3	2.93
10	11.8	3	43.8	0.2	3	6.50	0.4	3	2.29
2001									
3	13.8	3	83.1	2.4	3	23.9	41.2	3	39.1
4	15.2	5	97.9	4.4	5	100	71.1	5	100
5	6	1	1.00	1.8	1	1.00	58.6	5	74.5
6	15.4	5	100	3	3	46.7	42.3	3	41.3
8	9.6	1	38.9	2.2	1	16.2	22.5	1	1.00
9	14.2	3	87.4	3.4	5	61.9	23.9	1	3.85
10	13.8	3	83.1	3	3	46.7	26.2	3	8.54
2002									
3	14.6	5	100	3	5	90.4	21.9	5	38.3
4	4	1	1.00	0.2	1	1.00	0.6	1	1.00
5	14	5	94.4	3.3	5	100	57.1	5	100
6	13.7	3	91.2	2.7	3	80.8	21.7	3	38.0
8	7.5	1	33.7	1.5	1	42.5	6.2	1	10.8
9	9	3	47.7	2	3	58.5	17.8	3	31.1
10	10.6	3	62.6	2.4	3	71.3	15.2	3	26.6

Table 36. Means and scores for nine invertebrate metrics calculated from colonization of leaf packs deployed at seven Cedar Creek sites between 1999 and 2002. Seven of the nine metrics were included in the multi-metric site scoring given in Table 35. % Oligochaeta and % Shredders were omitted.—Continued

	Metric Means and Scoring								
	Density			Chironomidae			Oligocheate		
Site & Year	Per Gm	%Tile Score	Scaled Value	%	%Tile Score	Scaled Value	%	%Tile Score	Scaled Value
1999									
3	26.2	3	76.7	22.4	5	100	10.8	1	1.00
4	20.4	3	53.3	67.9	3	17.04	5.9	3	76.8
5	11.7	1	18.3	76.6	1	1.18	8.2	1	41.2
6	29	5	87.9	56.1	5	38.6	7.1	3	58.2
8	17.2	3	40.4	65	3	22.3	8	3	44.3
9	7.4	1	1.00	66.3	3	20.0	5.1	5	89.2
10	32	5	100	76.7	1	1.00	4.4	5	100
2000									
3	37.3	5	100	20.1	5	100	4.8	5	100
4	12.7	3	31.6	65.3	1	1.00	23.6	3	45.1
5	1.7	1	1.00	49.4	1	35.8	31.2	1	22.9
6	6.1	1	13.2	46.2	3	42.8	38.7	1	1.00
8	18.4	5	47.4	48.6	3	37.6	27.5	3	33.7
9	7.8	3	18.0	30.8	5	76.6	20.5	3	54.1
10	13.7	3	34.4	38.3	3	60.1	17.6	5	62.6
2001									
3	21.7	5	100	48.6	3	45.7	2.2	3	81.9
4	17.9	3	79.9	22.4	5	9.90	0.4	5	99.1
5	3	1	1.00	35.3	3	72.8	0.9	3	94.3
6	11.8	3	47.6	37.3	3	68.7	10.7	1	1.00
8	18.9	5	85.2	70.6	1	1.00	0.3	5	1000
9	10.6	3	41.2	21.9	5	100	0.7	3	96.2
10	6.5	1	19.5	61.3	1	19.9	4.8	1	57.2
2002									
3	20.2	5	100	62.7	3	39.1	0.9	1	1.00
4	5.9	3	9.83	80.2	1	1.00	0.9	1	1.00
5	9	5	29.4	34.7	5	100	0.6	3	34.0
6	7.3	3	18.7	66.9	3	29.9	0.8	3	12.0
8	7.6	3	20.5	78.1	1	5.57	0	3	100
9	4.5	1	1.00	36.1	5	97.0	0	5	100
10	5.3	1	6.04	72.8	3	17.1	0	5	100

Table 36. Means and scores for nine invertebrate metrics calculated from colonization of leaf packs deployed at seven Cedar Creek sites between 1999 and 2002. Seven of the nine metrics were included in the multi-metric site scoring given in Table 35. % Oligochaeta and % Shredders were omitted.—Continued

	Metric Means and Scoring								
	Shredders			Scrapers			Scrapers/Filtering Collectors		
Site & Year	%	%Tile Score	Scaled Value	%	%Tile Score	Scaled Value	SC/FC Ratio	%Tile Score	Scaled Value
1999									
3	4.1	1	1.00	52.6	5	100	21.9	5	1000
4	14.3	5	83.8	19.7	1	31.0	4.3	3	17.8
5	6.9	3	23.7	27.1	3	46.5	5.7	5	24.3
6	5.6	3	13.2	28.6	5	49.7	2.7	3	10.3
8	4.3	1	2.62	21	3	33.7	1.6	3	5.20
9	16.3	5	100	5.4	1	1.00	0.7	1	1.00
10	6.4	3	19.7	22.1	3	36.0	1.3	1	3.80
2000									
3	6.7	1	1.00	58.4	5	100	75.4	5	100
4	42.9	5	100	3.3	3	6.59	1.1	3	2.44
5	16.7	3	28.3	0	1	1.00	0	1	1.00
6	14.6	3	22.6	0	1	1.00	0	1	1.00
8	12.5	3	16.9	12.6	3	22.4	2.2	3	3.89
9	10.6	1	11.7	16.2	3	28.5	7.5	3	10.9
10	20.2	5	37.9	28.6	5	49.5	19.7	5	26.9
2001									
3	26.4	5	91.5	44.1	3	54.5	32	5	100
4	11.2	3	32.7	62.8	5	100	31.3	5	97.5
5	3	1	1.00	60.9	5	95.4	20	3	57.1
6	20.1	3	67.1	44.4	3	55.2	18.3	3	51.0
8	23.5	3	80.3	22.1	1	1.00	4.3	1	1.00
9	7	1	16.5	28.9	1	17.54	13.2	3	32.8
10	28.6	5	100	31.3	3	23.4	6.8	1	9.94
2002									
3	42.8	5	100	31.8	5	40.1	25.3	5	100
4	2.6	1	1.00	14.9	1	1.00	3	3	6.06
5	13.9	3	28.8	57.7	5	100	11.4	5	41.4
6	21.8	3	48.3	24.1	3	22.3	4.3	3	11.5
8	33.6	5	77.3	16.7	1	5.16	2.4	1	3.53
9	9.8	1	18.7	28.7	3	32.9	4.5	3	12.4
10	17.4	3	37.4	18.6	3	9.56	1.8	1	1.00

Table 37. Multi-metric scores for macroinvertebrates, and total habitat scores for seven Cedar Creek sites, by year. % Oligochaeta and % Shredders were omitted.

Site	Habitat Score	Year	Site Scoring (7-Metric) and Ranking (By Year): Percentile Score	Percentile Rank	Scaling Score	Scaling Rank
3	142	1999	33	1	672	1
		2000	35	1	700	1
		2001	25	2	446	2
		2002	33	2	508	2
4	102	1999	19	5	344	3
		2000	23	4 or 5	166	5
		2001	33	1	674	1
		2002	11	6	21	7
5	112	1999	13	6	140	6
		2000	7	7	42	7
		2001	19	5	303	5
		2002	35	1	565	1
6	103	1999	31	2	465	2
		2000	9	6	76	6
		2001	23	3	411	3
		2002	21	3 or 4	292	3
8	136	1999	21	3 or 4	242	5
		2000	25	2 or 3	207	3
		2001	11	7	144	7
		2002	9	7	122	6
9	103	1999	9	7	26	7
		2000	23	4 or 5	185	4
		2001	21	4	345	4
		2002	21	3 or 4	281	4
10	136	1999	21	3 or 4	297	4
		2000	25	2 or 3	223	2
		2001	15	6	211	6
		2002	17	5	194	5

Table 38. Summary of site ranks based on relative multi-metric scores from macroinvertebrate leafpack data at seven Cedar Creek sites. Ranks were based on seven macroinvertebrate metrics (% Oligochaeta and % Shredders were omitted) (Figures 13-22), and average rank represents a site mean among the years prior to reclamation (1999-2001).

Site Number	No. Of Years Ranked Among Best 2 Sites	No. Of Years Ranked Among Worst 2 Sites	Average Rank (1999-2001)	2002 Rank
3	4 (all)	0	1.3	2
4	1 (2001 only)	1 (2002 only)	3	7
5	1 (2002 only)	2 (1999 and 2000)	6	1
6	1 (1999 only)	1 (2000 only)	3.7	3
8	0	2 (2001 and 2002)	5	6
9	0	1 (1999 only)	5	4
10	1 (2000 only)	1 (2001 only)	4	5

Table 39. Coefficients of correlation (r values) between habitat scores and macroinvertebrate site scores, by year. Scores based on macroinvertebrate colonization of leaf packs were determined with percentiles and proportional scaling of metric values (7-metric combination). Habitat scores are given in Table 4.

	Correlations vs. Habitat Scores (r values)	
Year	**Percentiles**	**Scaling**
1999	0.421 (p = 0.8962)	0.418 (p = 0.6551)
2000	0.642 (p = 0.4010)	0.671 (p = 0.1859)
2001	-0.521 (p = 0.0537)	-0.517 (p = 0.0839)
2002	0.070 (p = 0.6054)	0.154 (p = 0.8919)

Table 40. Ranked analysis of variance of the total number of crayfish (per area sampled) (n = 28). Time is designated as before (1999 and 2000) and after (2001 and 2002) reclamation.

Source	**DF**	**Sum of squares**	**Mean square**	**F Value**	**Pr > F**
Model	13	915	70.4	1.08	0.4418
Error	14	912	65.1		
Corrected total	27	1827			

Source	**DF**	**Type III SS**	**Mean square**	**F Value**	**Pr > F**
Site	6	2.29	2.29	0.04	0.8541
Time	1	791	132	2.03	0.1298
Site*Time	6	121	20.2	0.31	0.9212

Table 41. Ranked stepwise regression of total number of crayfish (n = 28).

Source	DF	Sum of squares	Mean square	F Value	Pr > F
Model	1	452	452	10.95	0.0037
Error	19	785	41.3		
Corrected total	20	1237			

Variable	Paramete r estimate	Standard error	Type III SS	F Value	Pr > F	Total R^2
Intercept	-9.17	16.4	5.77	0.31	0.5915	
Aluminum (µg/L)	0.195	0.309	7.36	0.40	0.5454	0.3657
TN/TP	0.64	0.386	0.504	0.03	0.8729	0.4693
Manganese (µg/L)	-0.092	0.401	0.971	0.05	0.8244	0.5722
pH	1.08	0.481	93.0	5.04	0.0550	0.6801
Potassium (mg/L)	-0.561	0.390	38.1	2.06	0.1887	0.7414
Magnesium (mg/L)	-0.041	0.729	0.060	0	0.9561	0.7752
Ammonia (mg/L as N)	-0.047	0.321	0.392	0.02	0.8878	0.8024
TP (µg/L)	-1.22	0.793	43.8	2.37	0.1619	0.8258
TN (mg/L as N)	1.14	1.14	18.5	1.00	0.3457	0.8430
NO_2/NO_3 (mg/L as N)	-0.075	0.677	0.225	0.01	0.9149	0.8559
Sodium (mg/L)	0.663	0.517	30.4	1.64	0.236	0.8656
Nickel (µg/L)	0.883	0.881	18.5	1.00	0.3457	0.8806

Total number of crayfish = -9.17 + 0.195 * Al + 0.64 * TN/TP + 1.08 * pH – 0.561 * K – 0.041 Mg – 0.047 NH_3-N – 1.22 * TP + 1.14 * TN - 0.075 * NO_2/NO_3 + 0.663 Na + 0.883 * Ni.

Table 42. Complete list of fish species collected during the study.

Class	Order	Family	Genus Species	Common Name
Crustacea	Decapoda	Astacidae		crayfish
Osteichthyes	Lepisosteiformes	Lepisosteidae	*Lepisosteus platostomus*	shortnose gar
	Clupeiformes	Clupeidae	*Dorosoma cepediannum*	gizzard shad
	Cypriniformes	Cyprinidae	*Campostoma pullum*	central stoneroller
			Cyprinella lutrensis	red shiner
			Cyprinus carpio	common carp
			Luxilus cornutus	common shiner
			Lythrurus umratilis	redfin shiner
			Notemigonus crysoleucas	golden shiner
			Notropis ludibundus	sand shiner
			Notropis rubellus	rosyface shiner
			Pimephales notatus	bluntnose minnow
			Semotilus atromaculatus	creek chub
		Catostomidae	*Carpiodes carpio*	river carpsucker
			Carpiodes cyprinus	quillback
			Catostomus commersoni	white sucker
			Hypentelium nigricans	northern hogsucker
			Ictiobus bubalus	smallmouth buffalo
			Moxostoma duquesnei	black redhorse
			Moxostoma erythrurum	golden redhorse
			Moxostoma macrolepidotum	shorthead redhorse
	Siluriformes	Ictuluridae	*Ameiurus natalis*	yellow bullhead
			Noturus exilis	slender madtom
			Noturus flavus	stonecat
			Ameiurus melas	black bullhead
	Cyprinodontiformes	Fundulidae	*Fundulus dispari*	starhead topminnow
			Fundulus notatus	Blackstripe topminnow
			Gambusia affinis	western mosquitofish
	Atheriniformes	Atherinidae	*Labidesthes sicculus*	brook silverside
	Perciformes	Centrarchidae	*Lepomis cyanellus*	green sunfish
			Lepomis gulosus	warmouth
			Lepomis macrochirus	bluegill
			Lepomis megalotis	longear sunfish
			Lepomis microlophus	redear sunfish
			Micropterus dolomieu	smallmouth bass
			Micropterus punctulatus	spotted bass
			Micropterus salmoides	largemouth bass
			Pomoxis annularis	white crappie
			Pomoxis nigromaculatus	black crappie
				bluegill/ green sunfish hybrid
		Percidae	*Etheostoma flabellare*	fantail darter
			Etheostoma nigrum	johnny darter
			Etheostoma spectabile	orangethroat darter
			Percina caprodes	logperch

Table 43. Total number of fish and crayfish collected during the study, by site and year. See Table 44 for species code abbreviations.

Year	1999							2000						
Site	**3**	**4**	**5**	**7**	**8**	**9**	**10**	**3**	**4**	**5**	**7**	**8**	**9**	**10**
Crayfish	78	185	348	276	51	329	6	1062	2804	1039	824	163	1050	125
Total No. of Species	16	14	10	10	8	5	9	20	10	3	14	15	4	21
Total No. of Fish	113	198	261	102	19	23	75	295	327	46	378	134	86	370
Simpson's Dominance	0.129	0.215	0.343	0.303	0.275	0.403	0.161	0.137	0.301	0.873	0.4	0.158	0.544	0.233
BKCP	0	0	0	0	0	0	0	0	0	0	0	0	0	0
BKHD	0	6	0	1	0	0	0	0	0	0	3	0	0	0
BKSS	5	0	0	0	2	0	9	1	0	0	0	7	0	8
BLGL	26	59	74	46	10	2	20	35	1	2	29	36	0	83
BLGN	0	0	0	0	0	0	0	0	0	0	0	0	0	0
BLRH	0	0	0	0	0	0	0	0	0	0	0	0	0	2
BNMW	16	0	0	0	2	0	8	25	0	1	1	22	0	153
BTTM	7	0	0	2	1	0	7	6	2	0	0	4	0	11
CKCB	3	49	130	13	0	5	0	6	73	43	31	1	59	0
CLSR	0	0	6	0	0	0	0	0	75	0	23	0	0	0
CMCP	0	0	0	0	0	0	0	0	1	0	0	0	0	0
CMSN	0	0	6	0	0	0	0	1	0	0	0	0	0	0
FTDR	0	0	0	0	0	0	0	0	0	0	0	1	0	0
GAMB	0	0	0	0	0	0	0	13	21	0	2	0	0	1
GDRH	1	0	0	0	0	0	0	1	0	0	0	0	0	1
GDSN	0	0	0	0	0	0	0	0	0	0	0	0	0	0
GNSF	2	12	32	5	1	0	3	12	0	0	0	2	0	10
GZSH	0	0	0	0	0	0	0	0	2	0	17	0	0	0
JYDR	21	10	2	30	0	0	6	60	0	0	4	3	2	26
LESF	1	0	0	0	0	0	0	1	0	0	0	1	0	1
LGPH	1	1	0	0	0	0	0	0	0	0	0	0	0	1
LMBS	5	5	2	0	1	1	3	11	0	0	0	0	0	2
NHSK	1	0	0	0	0	0	0	1	0	0	0	0	0	1
OTDR	1	49	2	1	1	14	0	18	0	0	33	1	1	11
QLBK	0	0	0	0	0	0	0	0	0	0	0	0	0	0
RCSK	0	0	0	0	0	0	0	0	0	0	0	0	0	0
RDSN	0	1	0	0	0	0	1	4	0	0	2	10	0	4
RESF	0	1	0	0	0	0	0	0	0	0	0	0	0	0
RFSN	15	0	1	1	1	0	18	13	0	0	1	25	0	18
ROSN	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SDMT	0	2	0	0	0	0	0	1	0	0	0	0	0	0
SHTM	0	0	0	0	0	1	0	0	0	0	0	0	0	0
SMBF	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SMBS	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SNGR	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SNSN	0	1	0	1	0	0	0	7	0	0	0	0	0	0
SPBS	0	0	0	0	0	0	0	75	145	0	32	19	24	18
STCT	0	0	0	0	0	0	0	0	0	0	0	0	0	0
STRH	0	0	0	0	0	0	0	0	0	0	0	0	0	1
WARM	0	0	0	0	0	0	0	0	0	0	1	1	0	12
WTCP	3	0	0	0	0	0	0	4	0	0	0	0	0	1
WTSK	5	1	6	2	0	0	0	0	3	0	229	1	0	5
YLBH	0	1	0	0	0	0	0	0	4	0	0	0	0	0

Table 43. Total number of fish collected during the study, by site and year. See Table 44 for species code abbreviations.—Continued

Year	2001							2002						
Site	**3**	**4**	**5**	**7**	**8**	**9**	**10**	**3**	**4**	**5**	**7**	**8**	**9**	**10**
Crayfish	420	1252	713	941	122	858	322	278	383	207	255	187	148	85
Total No. of Species	19	18	9	16	10	10	17	21	16	9	10	6	8	16
Total No. of Fish	329	941	202	482	55	148	234	381	646	330	211	68	148	207
Simpson's Dominance	0.25	0.28	0.33	0.32	0.32	0.24	0.27	0.19	0.18	0.38	0.24	0.32	0.43	0.28
BKCP	0	0	0	1	0	0	0	0	0	0	0	0	0	0
BKHD	0	0	0	1	0	0	0	2	0	0	1	1	0	0
BKSS	3	1	0	0	0	0	0	10	5	0	0	0	0	3
BLGL	146	106	30	248	29	19	104	144	211	182	55	48	103	31
BLGN	1	1	0	0	0	0	0	1	0	0	0	0	0	0
BLRH	0	0	0	0	0	0	0	0	0	0	0	0	1	0
BNMW	8	8	0	22	2	0	17	12	9	0	0	0	14	0
BTTM	0	0	0	0	0	0	2	0	0	0	0	0	2	0
CKCB	17	104	102	45	1	63	0	32	57	86	11	2	0	0
CLSR	0	17	4	1	1	2	0	2	60	3	1	0	0	0
CMCP	0	0	0	1	0	0	0	0	0	0	0	0	0	0
CMSN	1	20	6	6	0	2	1	10	2	7	1	0	8	0
FTDR	2	0	0	0	0	0	0	0	0	0	0	0	0	0
GAMB	0	1	0	0	0	1	0	11	23	0	0	4	1	19
GDRH	2	0	0	0	0	0	2	1	0	0	0	0	1	0
GDSN	2	0	1	2	0	0	1	0	1	1	0	0	16	0
GNSF	17	17	1	19	1	4	7	23	37	26	24	0	3	0
GZSH	0	0	0	0	0	0	0	0	0	0	0	0	1	0
JYDR	55	256	0	102	4	16	58	54	116	0	20	4	10	0
LESF	3	0	0	0	0	0	2	4	0	0	0	0	0	0
LGPH	2	3	0	2	0	0	3	1	0	0	0	0	0	0
LMBS	50	44	5	23	12	23	20	48	71	16	81	84	23	13
NHSK	0	0	0	0	0	0	0	0	0	0	0	0	0	0
OTDR	5	24	7	3	1	3	4	3	48	8	16	4	2	1
QLBK	0	0	0	0	0	0	1	0	0	0	0	0	0	0
RCSK	0	1	0	0	0	0	0	0	0	0	0	0	0	0
RDSN	0	0	0	0	0	0	0	0	1	0	0	0	0	0
RESF	0	0	0	0	0	0	0	2	0	0	0	0	0	0
RFSN	15	0	0	0	3	0	4	5	0	0	0	0	0	0
ROSN	3	0	0	0	0	0	0	0	0	0	0	0	2	0
SDMT	0	1	0	0	0	0	0	4	1	0	0	0	0	0
SHTM	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SMBF	0	0	0	0	0	0	0	0	2	0	1	0	0	0
SMBS	0	0	0	0	1	0	0	0	0	0	0	0	0	0
SNGR	0	0	0	0	0	0	0	0	0	0	0	0	0	1
SNSN	1	23	0	1	0	13	0	0	0	0	0	1	0	0
SPBS	0	0	0	0	0	0	0	0	0	0	0	0	0	0
STCT	1	0	0	0	0	0	0	0	0	0	0	0	0	0
STRH	0	0	0	0	0	0	0	0	0	0	0	0	0	0
WARM	0	0	0	0	0	0	0	0	0	0	0	0	0	0
WTCP	0	0	0	0	0	0	2	0	0	0	0	0	6	0
WTSK	0	11	46	5	0	0	5	10	0	1	0	0	14	0
YLBH	1	3	0	0	0	0	1	2	2	0	0	0	0	0

Table 44. Abbreviation codes for fish listed in Tables 43, 45 and 47.

Fish Code	Fish Name	Scientific Name
BKCP	black crappie	*Pomoxis nigromaculatus*
BKHD	black bullhead	*Ameiurus melas*
BKSS	brook silverside	*Labidesthes sicculus*
BLGL	bluegill	*Lepomis macrochirus*
BLGN	bluegill/green sunfish hybrid	
BLRH	black redhorse	*Moxostoma duquesnei*
BNMW	bluntnose minnow	*Pimephales notatus*
BTTM	blackstripe topminnow	*Fundulus notatus*
CKCB	creek chub	*Semotilus atromaculatus*
CLSR	central stoneroller	*Campostoma pullum*
CMCP	common carp	*Cyprinus carpio*
CMSN	common shiner	*Luxilus cornutus*
Crayfish		Decapoda
FTDR	fantail darter	*Etheostoma flabellare*
GAMB	western mosquitofish	*Gambusia affinis*
GDRH	golden redhorse	*Moxostoma erythrurum*
GDSN	golden shiner	*Notemigonus crysoleucas*
GNSF	green sunfish	*Lepomis cyanellus*
GZSH	gizzard shad	*Dorosoma cepediannum*
JYDR	johnny darter	*Etheostoma nigrum*
LESF	longear sunfish	*Lepomis megalotis*
LGPH	logperch	*Percina caprodes*
LMBS	largemouth bass	*Micropterus salmoides*
NHSK	northern hogsucker	*Hypentelium nigricans*
OTDR	orangethroat darter	*Etheostoma spectabile*
QLBK	quillback	*Carpiodes cyprinus*
RCSK	river carpsucker	*Carpiodes carpio*
RDSN	red shiner	*Cyprinella lutrensis*
RESF	redear sunfish	*Lepomis microlophus*
RFSN	redfin shiner	*Lythrurus umratilis*
ROSN	rosyface shiner	*Notropis rubellus*
SDMT	slender madtom	*Noturus exilis*
SHTM	starhead topminnow	*Fundulus dispari*
SMBF	smallmouth buffalo	*Ictiobus bubalus*
SMBS	smallmouth bass	*Micropterus dolomieu*
SNGR	shortnose gar	*Lepisosteus platostomus*
SNSN	sand shiner	*Notropis ludibundus*
SPBS	spotted bass	*Micropterus punctulatus*
STCT	stonecat	*Noturus flavus*
STRH	shorthead redhorse	*Moxostoma macrolepidotum*
WARM	warmouth	*Lepomis gulosus*
WTCP	white crappie	*Pomoxis annularis*
WTSK	white sucker	*Catostomus commersoni*
YLBH	yellow bullhead	*Ameiurus natalis*

Table 45. Total number of fish collected during the study, by site. See Table 44 for species code abbreviations.

Site	3	4	5	7	8	9	10	Study Total
Total No. of Crayfish	1838	4624	2307	2296	523	2385	538	14511
Total No. of Fish	1118	2112	839	1173	276	405	886	6809
BKCP	0	0	0	1	0	0	0	1
BKHD	2	6	0	6	1	0	0	15
BKSS	19	6	0	0	9	0	20	54
BLGL	351	377	288	378	123	124	238	1879
BLGN	2	1	0	0	0	0	0	3
BLRH	0	0	0	0	0	1	2	3
BNMW	61	17	1	23	26	14	178	320
BTTM	13	2	0	2	5	2	20	44
CKCB	58	283	361	100	4	127	0	933
CLSR	2	152	13	25	1	2	0	195
CMCP	0	1	0	1	0	0	0	2
CMSN	12	22	19	7	0	10	1	71
FTDR	2	0	0	0	1	0	0	3
GAMB	24	45	0	2	4	2	20	97
GDRH	5	0	0	0	0	1	3	9
GDSN	2	1	2	2	0	16	1	24
GNSF	54	66	59	48	4	7	20	258
GZSH	0	2	0	17	0	1	0	20
JYDR	190	382	2	156	11	28	90	859
LESF	9	0	0	0	1	0	3	13
LGPH	4	4	0	2	0	0	4	14
LMBS	114	120	23	104	97	47	38	543
NHSK	2	0	0	0	0	0	1	3
OTDR	27	121	17	53	7	20	16	261
QLBK	0	0	0	0	0	0	1	1
RCSK	0	1	0	0	0	0	0	1
RDSN	4	2	0	2	10	0	5	23
RESF	2	1	0	0	0	0	0	3
RFSN	48	0	1	2	29	0	40	120
ROSN	3	0	0	0	0	2	0	5
SDMT	5	4	0	0	0	0	0	9
SHTM	0	0	0	0	0	1	0	1
SMBF	0	2	0	1	0	0	0	3
SMBS	0	0	0	0	1	0	0	1
SNGR	0	0	0	0	0	0	1	1
SNSN	8	24	0	2	1	13	0	48
SPBS	75	145	0	32	19	24	18	313
STCT	1	0	0	0	0	0	0	1
STRH	0	0	0	0	0	0	1	1
WARM	0	0	0	1	1	0	12	14
WTCP	7	0	0	0	0	6	3	16
WTSK	15	15	53	236	1	14	10	344
YLBH	3	10	0	0	0	0	1	14

Table 46. Ranked analysis of variance of fish a) total number of fish (per area sampled); b) taxa richness, and c) Simpson's Dominance. Time is designated as before (1999 and 2000) and after (2001 and 2002) reclamation.

42 (a) Number of fish per area sampled

Source	DF	Sum of squares	Mean square	F Value	Pr > F
Model	13	1221	93.9	2.17	0.0816
Error	14	605.5	43.2		
Corrected total	27	1826			

Source	DF	Type III SS	Mean square	F Value	Pr > F
Time	1	229	229	5.28	0.0374
Site	6	886	148	3.41	0.0274
Time*Site	6	107	17.8	0.41	0.8590

46 (b) Fish taxa richness

Source	**DF**	**Sum of squares**	**Mean square**	**F Value**	**Pr > F**
Model	13	1330	102	3.04	0.024
Error	14	471	33.6		
Corrected total	27	1801			

Source	**DF**	**Type III SS**	**Mean square**	**F Value**	**Pr > F**
Time	1	63	63	1.87	0.1927
Site	6	1185	197	5.87	0.0031
Site*Time	6	1330	102.3	0.41	0.8624

46 (c) Fish **-** Simpson's Dominance

Source	**DF**	**Sum of Squares**	**Mean Square**	**F Value**	**Pr > F**
Model	13	1440	110.8	4.02	0.0073
Error	14	386	27.6		
Corrected total	27	1827			

Source	**DF**	**Type III SS**	**Mean Square**	**F Value**	**Pr > F**
Time	1	5.14	5.14	0.19	0.6725
Site	6	1094	182	6.61	0.0018
Site*Time	6	341	56.9	2.06	0.1242

Table 47. Ranked bivariate correlation analysis with a Bonferroni correction (α = 0.05) of fish and selected water quality parameters. See Table 44 for fish species codes.

Prob > |r|	Total no. of fish (totfsh)	Total no. fish species (totspc)	Simpson's dominance (simp)	Temp	Field pH (f_ph)	Hardness (hard)	Alkalinity (alk)	Conductivity (cond)	Turbidity (turb)	Salinity (sal)	Ammonia (amm)	Nitrite/ nitrate (no_2/no_3)	Soluble reactive phosphorus (srp)
	R Square												
totfsh	1	0.71704	-0.2112	0.4703	-0.10593	-0.19926	0.24148	-0.18256	0.50089	0.11752	0.33037	0.11634	-0.0241
totspc	<.0001	1	-0.64785	0.67445	0.28363	-0.54136	0.2804	-0.49119	0.56865	-0.33081	0.27178	0.28753	0.24466
simp	0.2807	0.0002	1	-0.487	-0.47626	0.39852	-0.32635	0.30656	-0.24634	0.23797	-0.03038	0.00493	-0.03605
temp	0.0116	<.0001	0.0086	1	0.2915	-0.40318	0.35044	-0.42288	0.43109	-0.08847	0.01998	0.10676	-0.16729
f_ph	0.5916	0.1436	0.0104	0.1323	1	-0.56596	0.50999	-0.51724	0.16147	-0.79979	-0.19595	0.17545	0.46045
hard	0.3094	0.0029	0.0357	0.0334	0.0017	1	-0.36162	0.95785	-0.60591	0.90553	-0.20252	-0.50062	-0.75521
alk	0.2157	0.1484	0.0901	0.0675	0.0056	0.0586	1	-0.39064	0.09554	-0.32339	-0.00575	-0.14689	-0.17774
cond	0.3525	0.0079	0.1126	0.025	0.0048	<.0001	0.0399	1	-0.68911	0.98077	-0.27696	-0.57479	-0.76063
turb	0.0066	0.0016	0.2064	0.022	0.4117	0.0006	0.6287	<.0001	1	-0.50331	0.5769	0.62515	0.69716
sal	0.6119	0.143	0.2989	0.703	<.0001	<.0001	0.1527	<.0001	0.02	1	0.05879	-0.46644	-0.72255
amm	0.086	0.1618	0.878	0.9196	0.3176	0.3014	0.9768	0.1536	0.0013	0.8002	1	0.55344	0.25894
no_2/no_3	0.5555	0.1379	0.9801	0.5887	0.3719	0.0067	0.4557	0.0014	0.0004	0.0331	0.0023	1	0.7295
srp	0.9174	0.2851	0.8767	0.4686	0.0357	<.0001	0.4408	<.0001	0.0004	0.0002	0.257	0.0002	1
tn	0.7655	0.1409	0.9279	0.9292	0.0815	0.0113	0.4718	0.0013	<.0001	0.0054	0.0152	<.0001	<.0001
tp	0.993	0.288	0.7154	0.8038	0.3201	0.1026	0.5012	0.0101	0.0007	0.0273	0.015	<.0001	0.0029
tn/tp	0.2708	0.1544	0.0363	0.0383	0.0297	0.5517	0.0059	0.1733	0.1188	0.1725	0.6767	0.7881	0.7118
mg	0.9063	0.0777	0.0573	0.0178	0.0014	0.0017	0.0001	0.0021	0.5383	0.0108	0.5645	0.5345	0.9852
ca	0.678	0.1349	0.01	0.0064	<.0001	0.0369	0.0024	0.0792	0.9138	0.0184	0.0151	0.3696	0.9856
fe	0.6241	0.2789	0.7439	0.6011	0.0607	0.1728	0.2589	0.4621	0.4131	0.0386	0.9097	0.1951	<.0001
mn	0.1152	0.1383	0.015	0.0753	<.0001	0.0268	0.0431	0.0279	0.9338	0.001	0.2688	0.7153	0.441
al	0.7521	0.9281	0.1291	0.3776	0.5246	0.1857	0.0106	0.1129	0.0038	0.3545	0.0451	<.0001	<.0001
ni	0.7831	0.0064	0.0003	0.0034	<.0001	0.0003	0.0073	0.0009	0.2894	0.0028	0.5593	0.7975	0.5019
na	0.7595	0.3407	0.0389	0.7331	0.8544	0.8174	0.4392	0.8533	0.2783	0.2066	0.1101	0.1407	0.8214
cu	0.6554	0.5219	0.0229	0.9187	0.3864	0.8936	0.819	0.9349	0.8803	0.8542	0.8317	0.7934	0.9223
k	0.1483	0.172	0.6772	0.2018	0.8712	0.0098	0.2995	0.0288	0.0053	0.5568	0.247	0.2699	0.1117

Table 47. Ranked bivariate correlation analysis with a Bonferroni correction (α = 0.05) of fish and selected water quality parameters.—Continued. See Table 44 for fish species codes.

		R Square											
		Total nitrogen (tn)	Total phosphorus (tp)	TN/TP ratio (tn/tp)	Mg	Ca	Fe	Mn	Al	Ni	Na	Cu	K
Prob > |r|	totfsh	0.06923	0.00205	-0.25181	-0.0233	0.08207	0.09681	0.30444	0.06248	0.05448	0.06057	0.0882	0.28044
	totspc	0.33247	0.24325	-0.32214	-0.33895	-0.28963	0.21195	-0.28726	0.01788	-0.5027	0.187	-0.12629	0.26557
	simp	-0.02103	-0.08461	0.4591	0.36344	0.47856	-0.06463	0.45502	0.2938	0.63701	-0.3923	0.42846	0.08228
	temp	-0.02065	-0.0577	-0.45476	-0.44457	-0.50275	-0.10325	-0.34147	-0.17339	-0.53463	0.06745	0.0202	0.24877
	f_ph	0.38877	0.22805	-0.47456	-0.57386	-0.78296	0.35898	-0.68038	-0.12548	-0.74039	0.03633	-0.17025	-0.03209
	hard	-0.541	-0.36613	0.13771	0.56673	0.39616	-0.26506	0.41821	-0.25757	0.63473	0.04569	0.02647	-0.47991
	alk	-0.16608	-0.1554	-0.57983	-0.6594	-0.55122	-0.22076	-0.38486	-0.47537	-0.4961	-0.15226	0.04529	-0.20326
	cond	-0.65499	-0.54817	0.30871	0.55687	0.33732	-0.14485	0.41547	-0.30628	0.59012	0.03661	-0.01616	-0.41327
	turb	0.75565	0.68079	-0.35092	-0.1214	0.02144	0.16101	0.01645	0.52945	-0.20747	0.21222	0.02981	0.51255
	sal	-0.5848	-0.48083	0.30929	0.5441	0.5092	-0.4542	0.66675	-0.21273	0.61908	0.28732	0.04268	-0.13596
	amm	0.52203	0.52307	0.09671	0.11373	0.45471	-0.02245	0.21637	0.38168	0.11523	0.30857	-0.04207	0.22624
	no_2/no_3	0.91997	0.87121	0.06242	0.12252	0.17625	0.25236	-0.07213	0.73484	-0.05078	0.28562	-0.05183	0.21585
	srp	0.78701	0.61688	0.08571	-0.00431	0.00421	0.74705	-0.17765	0.74716	-0.15515	0.05244	-0.02268	0.35742
	tn	1	0.88442	-0.14416	0.08711	0.08262	0.46951	-0.24797	0.6938	-0.13935	0.28635	0.00394	0.16341
	tp	<.0001	1	-0.31818	0.19385	0.2126	0.23783	-0.18469	0.65542	-0.04501	0.48616	-0.06953	-0.17014
	tn/tp	0.533	0.1598	1	0.3341	0.40046	0.08416	0.40593	0.2717	0.3759	-0.05874	0.143	0.43086
	mg	0.7073	0.3998	0.1388	1	0.71067	0.04127	0.75903	0.44586	0.84884	0.43261	-0.05943	-0.12097
	ca	0.7218	0.3548	0.072	<.0001	1	-0.02654	0.7281	0.46399	0.78005	0.10922	-0.11798	0.07521
	fe	0.0318	0.2992	0.7168	0.8348	0.8933	1	-0.09988	0.4499	-0.03656	-0.1501	-0.15445	0.19701
	mn	0.2785	0.4229	0.0679	<.0001	<.0001	0.6131	1	0.32373	0.85861	0.19666	0.12495	0.15293
	al	0.0005	0.0013	0.2335	0.0174	0.0129	0.0163	0.0929	1	0.35407	0.24495	0.11571	0.30374
	ni	0.5469	0.8464	0.0931	<.0001	<.0001	0.8535	<.0001	0.0645	1	0.05093	0.19883	-0.13549
	na	0.2082	0.0254	0.8003	0.0215	0.5801	0.4458	0.3158	0.209	0.7969	1	-0.19449	-0.18342
	cu	0.9865	0.7646	0.5363	0.7639	0.5499	0.4326	0.5264	0.5576	0.3104	0.3213	1	0.16627
	k	0.4791	0.4609	0.0512	0.5398	0.7037	0.315	0.4372	0.1161	0.4918	0.3501	0.3978	1

Table 48. Ranked stepwise regression of fish taxa richness (n = 28).

Source	DF	Sum of squares	Mean square	F Value	Pr > F
Model	6	1255	209	13.5	<0.0001
Error	14	217	217		
Corrected total	20	1472			

Variable	Parameter estimate	Standard error	Type III SS	F Value	Pr > F	Total R^2
Intercept	29.38	9.145	160	10.3	0.0063	
Temperature (^oC)	0.227	0.180	24.6	1.59	0.2282	0.3598
Turbidity (NTU)	1.225	0.264	333	21.5	0.0004	0.5426
Hardness (mg/L as $CaCO_3$)	-2.101	0.424	380	24.5	0.0002	0.6108
SRP (µg/L)	-1.424	0.386	211	13.6	0.0024	0.6970
pH	-0.553	0.243	80.3	5.19	0.0390	0.8153
Conductivity (µs/cm)	0.856	0.454	55.1	3.56	0.0801	0.8527

Fish taxa richness = -29.38 + 0.227 * temperature + 1.225 * turbidity - 2.101 * hardness
- 1.424 * SRP - 0.553 * pH + 0.856 conductivity.

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