Post-Reclamation

Water Quality Monitoring

of Cabin Branch Pyrite Mine

In fulfillment of Cooperative Agreement CA-3706-7-0001
between George Mason University and USDI, National Park Service,
Prince William Forest Park, Triangle, VA 22172

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Final Report

Submitted to

Prince William Forest Park
Resource Management

In fulfillment of Cooperative Agreement CA-3706-7-0001
between George Mason University and USDI, National Park Service,
Prince William Forest Park, Triangle, VA 22172

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Executive Summary

Abandoned mines provide dangers to human health and the ecosystem. Unfilled, exposed shafts are a constant draw to hikers but are hazardous to above and below ground trespassers due to the potential of collapse. From an environmental perspective, abandoned mines are a frequent source of acid mine drainage. Acid mine drainage occurs when sulfur (and other metals) in the mineral pyrite (FeS_2) is uncovered and exposed to the oxidizing action of air, water and certain chemical-loving bacteria which utilize the energy obtained from the conversion of sulfur to sulfate and sulfuric acid. (Letterman and Mitsch, 1978; Boccardy and Spaulding, 1968; Gray,1997; Frank, 1983).

When such metals are introduced to a waterway, they can upset the delicate ecosystem by placing added pressure on the community of organisms, which inhabit the stream or waterway. Fish and other stream life ingest the metals, are poisoned, and die (Frank, 1983). The spoils piles left from abandoned mining activities not only contain high levels of acidity but are also deficient in plant nutrients making it difficult for vegetation to grow (Pichtel, *et al.*, 1994). Unreclaimed mine areas thus contribute to water and soil pollution through acid drainage and sediment loading resulting from severe erosion. Removing topsoil from an un-mined site near the mined area and burying the toxic spoil is a commonly accepted reclamation practice (Pichtel, *et al.*, 1994).

While there seem to be ready solutions to both human and ecosystem health problems, a major stumbling block to reclamation efforts is accountability: who is responsible for payment of the reclamation effort? The mines are long abandoned and the property may have gone through many owners. One such mine exists within the boundaries of Prince William Forest Park (PRWI), a unit of the National Parks Service (NPS) in Triangle, Virginia. In 1994, seeking to reclaim the Cabin Branch Pyrite Mine and environs, the NPS entered into a memorandum of agreement with the Virginia Department of Mines, Minerals, and Energy, Division of Mineral Mining (VA DMME). Virginia DMME sought and obtained a grant from the Environmental Protection Agency (EPA) and together, the NPS and VA DMME sought and obtained matching funds. In the summer of 1995, the abandoned Cabin Branch Pyrite Mine was reclaimed. Approximately seven acres of highly acidic pyrite mine tailings were removed, treated with lime to neutralize them and buried under one foot of clean topsoil.

The reclamation of Cabin Branch Mine Site is now several years in the past. This two-year study, funded by the NPS Water Resources Division (WRD), aims to assess whether water quality and aquatic habitat improvement objectives of the reclamation and restoration program were obtained and sustained in Quantico Creek.

Although this study cannot definitively answer the question of whether or not the abandoned mine reclamation was successful, it has provided promising evidence of recovery. Comparisons of pre and post-reclamation data generally suggest decreases in the levels of sulfates and specific conductance as well as copper, iron and zinc. However, sites 3, 4, and 5 continue to have elevated levels of the above, indicative of the residual effects of acid mine drainage contributions. All sites maintained a pH level sufficient to support biotic life. Though the pattern of diversity and abundance at sites 3, 4, and 5 do not match that of 1 and 2, invertebrate assemblages fluctuated between non-impaired and moderately impaired with only one episode of severe impairment at site 4. The fish data suggests that there are now more individuals and greater diversity of fishes inhabiting the mine-impacted area. Groundwater sources as well as overland flow should be investigated to enhance the rate and extent of reclamation. If possible, appropriate supplementary reclamation efforts that will reduce the effects of the acid drainage to site 4 should be explored. Water quality monitoring, invertebrate monitoring, as well as fish data collection should logically follow any additional reclamation efforts. This study provides excellent baseline data from which further actions and/or progress can be measured.

Acknowledgments

This work could not have been accomplished without the excellent help of the following graduate students from George Mason University: Ann Sartori-Brazinski (fish), Don Morgan (fish), Amy Maher (invertebrate field work), Mike Komelaski (metals chemistry), LeAnn Astin (invertebrate lab work), Shannon Junior (jack of all trades), Gary Long, Kevin Brittingham, Ryan Hansen, and Sandra Byrd-Hughes (invertebrate and fish field work). The Park also supplied seasonal help which were trained and educated by the graduate students. It was a remarkably shared effort where all benefitted.

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INTRODUCTION

Abandoned mines occur in more than 140 of the 368 units of the National Park System (National Park Service, 1997). National Park Service (NPS) units include national parks, national monuments, national preserves and reserves, national seashores, national rivers and wild and scenic riverways, national scenic trails, national historic sites, national battlefields and military parks, national recreation areas, and national parkways. (U.S. Department of Interior, 1995) As of March 3, 1997, an ongoing inventory has revealed more than 2400 sites with approximately 10,000 mine openings, tailings piles, and overall hazardous site conditions. In 1983, the NPS established its Abandoned Mineral Land Program in an effort to inventory all abandoned mineral land sites in the NPS, to eliminate public safety hazards at such sites (through abandoned mine reclamation), to eliminate or reduce adverse effects on park resources from such sites (through abandoned mine reclamation), to increase awareness and educate the public through preservation and interpretation of historic and cultural artifacts, and to maintain abandoned mineral lands for critical wildlife habitat, particularly for threatened and endangered species (through abandoned mine reclamation and restoration) (National Park Service, 1997).

Reclamation is the process by which health and safety and environmental concerns are corrected on previously mined sites (Prince William Forest Park, 1995). Reclamation is very costly, and unfortunately, the NPS program does not have special funding associated with it for achieving its goals. However, since its implementation, the commitment by the NPS to designate resources and find funds through creative partnerships with other federal agencies, states, and private organizations for this important land management issue is evidenced by their numerous accomplishments. Since the implementation of its Abandoned Mineral Land Program, the NPS has completed a service-wide inventory of abandoned mines and set priorities for mitigation; restored 85 abandoned mineral land sites; closed 766 abandoned mine openings and plugged 34 oil and gas wells at a cost of approximately $7.5 million; entered into Memoranda of Agreement (MOA) with eight states and Memoranda of Understanding (MOU) with two, to direct $7.5 million toward reclamation of abandoned mine lands; published a brochure on abandoned mineral lands entitled "Abandoned Mineral Lands in the National Parks;" published a handbook entitled *Abandoned Mineral Land* and designed and posted several signs about the dangers of abandoned mineral lands (National Park Service, 1997).

One of the specific outcomes of this program occurred in Prince William Forest Park (PRWI), a unit of the NPS in Triangle, Virginia. In 1994 the park entered into a MOA with the Virginia

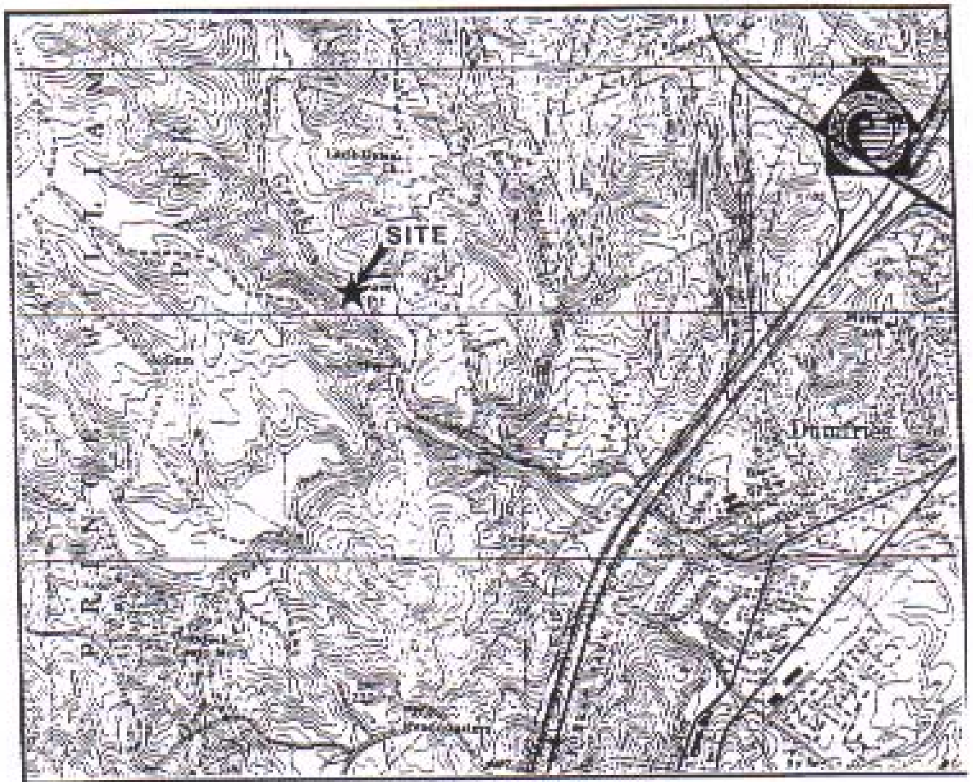
Department of Mines, Minerals, and Energy, Division of Mineral Mining (VA DMME) to reclaim the Cabin Branch Pyrite Mine, an abandoned mine located within boundaries of the park. VA DMME sought and obtained a grant from the Environmental Protection Agency (EPA) and together, the NPS and VA DMME sought and obtained matching funds. In the summer of 1995, the abandoned Cabin Branch Pyrite Mine was reclaimed. Approximately seven acres of highly acidic pyrite mine tailings were removed, treated with lime to neutralize them and buried under one foot of clean topsoil. *Mine tailings*, as defined by the Dictionary of Geological Terms, (Bates and Jackson 1984), are those portions of washed or milled ore that are regarded as too poor to be treated further, as distinguished from the *concentrates*, or material of value. Tailing piles are also often referred to as spoils which is defined as overburden or other waste material removed in mining, quarrying, dredging or excavating. (Bates and Jackson, 1984.)

A chronic problem associated with past and current mining activity is what is known as acid mine drainage. Acid mine drainage occurs when sulfur (and metals) in the mineral pyrite (FeS_2) is uncovered and exposed to the oxidizing action of air, water and certain "chemical-loving" bacteria which utilize the energy obtained from the conversion of sulfur to sulfate and sulfuric acid (Letterman and Mitsch, 1978; Boccardy and Spaulding, 1968; Gray,1997; Frank, 1983).

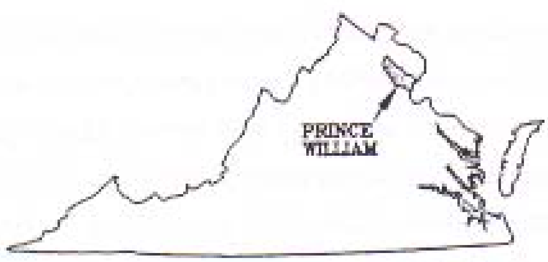
When metals are introduced to a waterway, the delicate ecosystem is disturbedby placing added pressure on the community of organisms, which inhabit the stream or waterway. Fish and other stream life ingest the metals, are poisoned, and die (Frank, 1983). The spoils piles left from abandoned mining activities not only contain high levels of acidity but are also deficient in plant nutrients making it difficult for vegetation to grow (Pichtel *et al.*, 1994). Unreclaimed mine areas thus contribute to water and soil pollution through acid drainage and sediment loading resulting from severe erosion. Removing topsoil from an un-mined site near the mined area and using it to cover the toxic spoil, as was done at the Cabin Branch Pyrite Mine Site, is a commonly accepted reclamation practice (Pichtel *et al.*, 1994).

The Cabin Branch Mine Site is now undergoing recovery. Lush green vegetation covers the once highly disturbed, barren landscape. Sealed and marked vertical mine shafts which were once a danger to visitors and park staff are readily seen and utilized to help tell the story of the mine. One post-reclamation water quality sample (PWFP, 1996) was collected below the mine site and its results are encouraging in that iron, copper and zinc concentrations in Quantico Creek are below pre-reclamation levels. Uncertainties remain, however, about the status of aquatic biological communities in this stream. This two-year study, funded by the NPS Water Resources

Division (WRD) aims to assess whether water quality and aquatic habitat improvement objectives of the reclamation and restoration program were obtained and sustained in Quantico Creek.



U.S.G.S. QUANTICO QUADRANGLE
7.5 MINUTE SERIES
SCALE: 1" = 2000'



NOTE: ALL LOCATIONS ARE APPROXIMATE.

Figure 1. Research Site, Prince William Forest Park, Triangle, Virginia (Resource International, LTD. 1993)

Site History

The Cabin Branch Pyrite Mine began its operation in 1889 and was open and active until 1920. Iron pyrite, also known as "fools gold" was mined and valued for its high sulfur content. During World War I, sulfur was in such great demand that the 200-300 men employed in the 24-hour-a-day operation of the mine were exempted from military service. From 1908 until 1920, the mine produced a total of more than 200,000 long tons (*a long ton is approximately 400 pounds more than a standard ton*) of pyrite for a value in excess of $1,160,000. This represents approximately 37% of all U.S.. Production of pyrite during that time (U.S. Bureau of Mines, 1993). The mine area consisted of approximately 70 buildings and was apparently owned by the Cabin Branch Mining Company from 1889-1916 and then by the American Agricultural Chemical Company from 1917-1920. The mine closed first because miners went on strike and demanded higher wages, which management refused to pay; and second, it was discovered that a higher grade of pyrite could be obtained at a lower cost from Spain. In the 1930s, the area in and around the mine was condemned and set aside as a conservation area under President Franklin D. Roosevelt's New Deal. The Civilian Conservation Corps (CCC), who was tasked to make the area into a park, dismantled the remaining structures, leaving just the foundations, and used the materials to construct the park's 5 cabin camps, which are still used by park visitors today. Some of the spoils were used as roadbed material beneath what is now the park's Scenic Drive. In 1937, the area was transferred to the U.S. Department of the Interior and in 1940 became a unit of the National Park System. Today this area is known as Prince William Forest Park.

Since its closure in 1920, the Cabin Branch Pyrite Mine has been considered an abandoned mine site. In 1920 when all mining operations ceased, reclamation was not required, even though the activities resulted in highly acidic, barren lands and diminished water quality (Prince William Forest Park, 1995). More recent efforts to mitigate the environmental impact of this historical mine site have had little effect. Prior to the 1995 reclamation, the site consisted of approximately 20-acres of historic foundations and surface features, underground workings, and approximately 5-7 acres of unvegetated pyrite tailings piles. According to a site conditions report by the VA DMME, these conditions were causing severe stream degradation due to acid runoff and heavy metal contamination. Deposition of heavy metals and acid mine drainage into Quantico Creek, a tributary of the Potomac River, can be attributed largely to the unvegetated mine tailings, acid producing pyritic material on the stream banks, sediments in the stream and improperly sealed mine shafts.

STUDY SITES

Five in-stream sampling sites were chosen with several considerations in mind. Water quality and metals sampling had been conducted in 1990 (an Abandoned Mineral Lands Investigation), 1993 (Resource International Investigation) and 1996 (another Abandoned Mineral Lands Investigation). These efforts were each single event investigations. While they captured the overall water quality of the stream at a point in time, they were not representative of seasonal or internal restorative changes within the stream. The scope of this investigation was broader. Though effort was made to duplicate some site specific sampling to facilitate comparisons of before and after water quality, this study does not seek specifically to provide these types of comparisons. It will, however, provide comparisons between the unimpacted and the impacted sites for the purposes of evaluating the effectiveness of the reclamation effort. Another consideration was that the fish investigation methodology used required a minimum of 200 m between sites. With these constraints in mind it was determined that all sites should be within Quantico Creek North Branch and consist of:

Site (1) up-stream non-impacted habitat (SS-7 from Resource International study): this will serve as the "reference" site.

Site (2) up-stream approximately 150m below the confluence of the two meandering branches (generally south of the milling operation yet upstream from the major impact of the mine): this will serve as a site to evaluate effects of the milling operation influence and may also serve as a reference site,

Site (3) site of pre-reclamation major impact (at the confluence with the drainage channel): this serves to evaluate the effects of the drainage channel,

Site (4) down-stream mixing habitat approximately 50 m upstream from the bridge (closely related to SS-4 from Resource International study though downstream approximately 60 m),

Site (5) down-stream mixing habitat approximately 200 m downstream of the bridge and downstream of the confluence to determine the effects of dilution from South Fork of Quantico Creek (downstream from SS-2 from Resource International study approximately 100 m).

Figure 1 outlines the study sites and their relation to the geography of the area. Figure 2 shows the historical use of the property and orients the reader to the sites in relation to the reclamation effort.

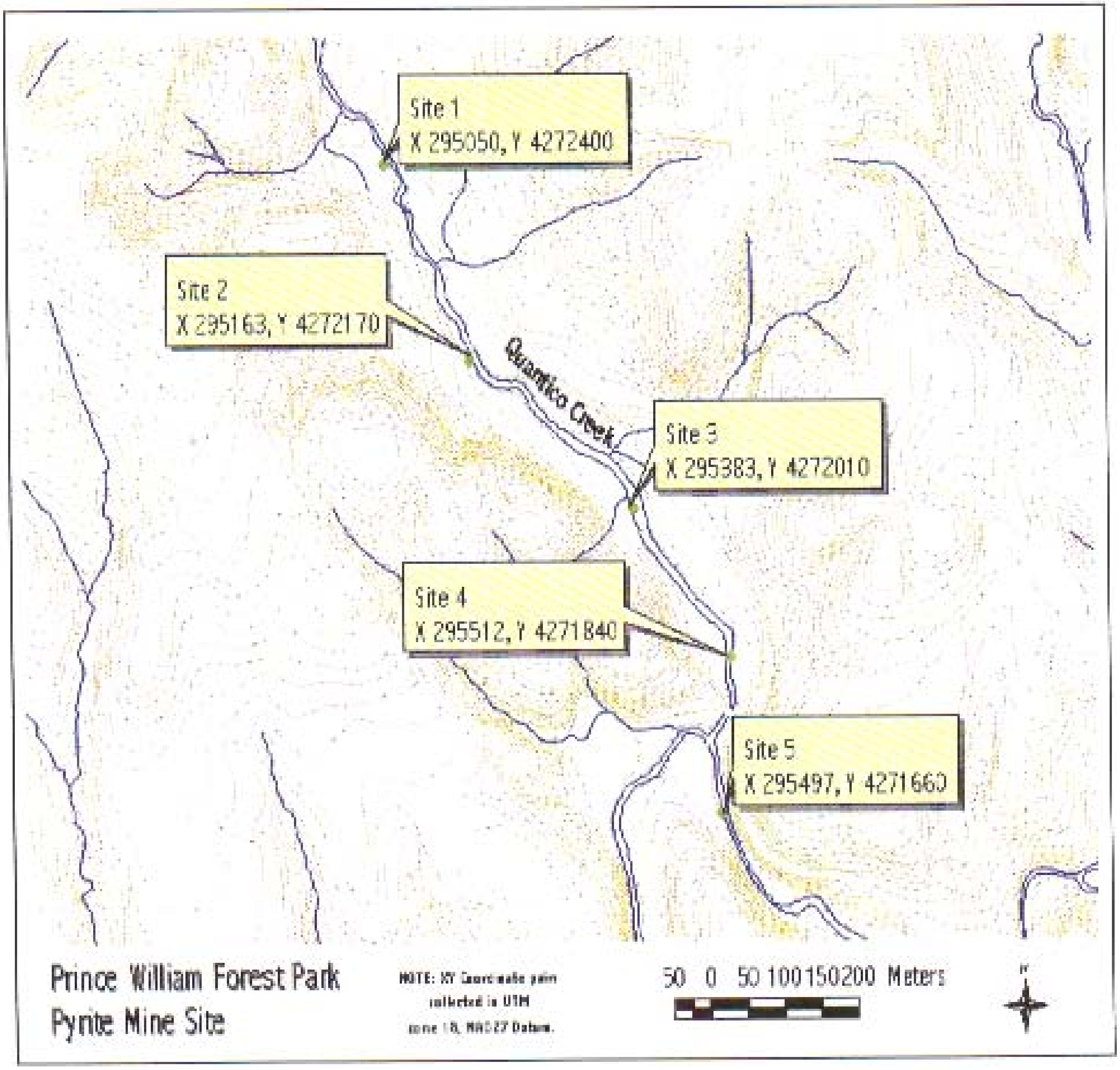
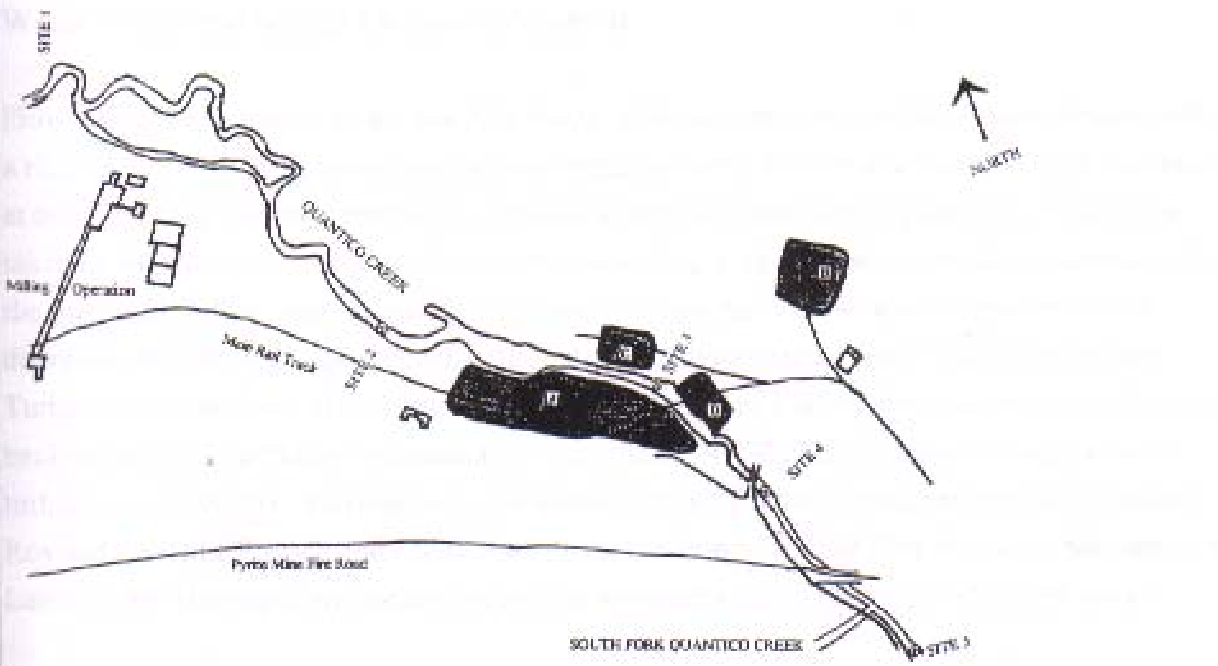


Figure 2. Location map of the sampling sites



A, B, C, and D are tailing sites where reclamation efforts have been focused.

Figure 3. Five stream sampling sites in relation to reclamation area.(Resource International, LTD. 1993)

METHODS

Sampling Schedule Strategy

Regular sampling of water profile and metals chemistry was scheduled for mid-month, every month. Invertebrate and fish sampling were planned for Spring, Summer and Fall (March, June, and September). The invertebrate sampling occurred generally after, or in conjunction with, the monthly water profile and metals sampling. Fish sampling occurred generally after the invertebrate sampling was completed. Wet weather sampling had no schedule other than it be three times a year and methods used were identical to dry weather sampling. The idea was to sample during a significant wet event which had been preceded by a dry period. While the aim was to get first flush results, the flashiness of the events and the researchers distance from the site made this extremely difficult, dangerous, and unlikely. Therefore, while each of these events are definately wet-weather grabs, they are not representative of first flush readings.

Water Profile and Metals Chemistry Methods

Flow velocity was gaged with a Swoffer Model 2100 current meter within a meter downstream of a riffle at each site. The same location was employed over the two year study. Depth was taken at the same time as flow immediately adjacent to the flowmeter with a yard stick. Width was taken as wetted substrate by two field crew suspending a tape measure over the stream bisecting the point where flow was measured. Conductivity, specific conductance, temperature and dissolved oxygen (mg/l and percent saturation) were determined using a YSI 85 DO meter. Turbidity, sulfates, and pH levels were performed on samples taken from the stream and brought back to the lab. Turbidity was measured by a HACH 2100P turbidity meter in nephelometric turbidity units (NTU). Sulfates were completed with a SpectroKit Reagent System by Milton Roy and read in a Bausch and Lomb Spec 20 at the Prince William Park Resource Management Laboratory. Hydrogen ion concentration was recorded using a Hanna HI 90-23 pH meter.

Metals analysis followed Method 200.9, Determination of Trace Elements by Stabilized Temperature Graphite Furnace Atomic Absorption, listed in Methods for the Determination of Metals in Environmental Samples., Supplement 1 (USEPA 1994). Sample bottles (250 ml nalgene wide-mouth and 150 ml nalgene narrow mouth) were prepared by washing with warm soapy water, rinsed in tap water, then rinsed in deionized water three times. Bottles were then placed in a 20% nitric acid bath and allowed to sit for four hours. After four hours the bottles were removed and rinsed three times with deionized water. They were then placed upside down on clean paper towels to air dry. Once dry they were sealed and labelled for sampling.

Each sample was an aggregate of the stream transect - right, middle, and left side. Sampling was accomplished by immersing a prepared 150 ml bottle to mid depth and filling with liquid. Approximately 2/3 of this liquid was transferred to a prepared 250 ml bottle. This procedure was repeated for all three locations across the stream. The 150 ml bottle was then filled for same day laboratory analysis of pH, sulfates, and turbidity.

Once back in the laboratory at Prince William Forest Park Resource Management Building (PWPRM) the metal samples were acidified to pH 2 with metals grade nitric acid.

The analysis of the water samples from the Pyrite Mine Project were performed on either a Perkin – Elmer, HGA-600, Graphite Furnace Atomic Absorption Spectrometer (AAS), and a Perkin – Elmer model 5100 Flame AAS. These were located in the Shared Research Instrumentation Facility (SRIF) in David King Hall on the campus of George Mason University. With the furnace AAS, the Perkin – Elmer model AS-60 Furnace Auto-sampler was used to obtain sample measurements.

In the laboratory the following equipment was used. 1) Several 250 ml Fluorinated Ethylene Propylene (FEP) bottles were used to store standards and modifier solutions. 2) 100 ml Pyrex volumetric flasks used to dilute solutions. 3) 10 ml Pyrex test tubes held the samples for the flame tests. 4) 2 ml Auto-sampler cups held the samples in the automatic sampling procedure. 5) 1 ml disposable tip micro-pipette (capable of a minimum measurement of 0.2 ml) was used in preparing diluted solutions.

The standard and matrix modifier solutions were purchased from Perkin – Elmer. The standard solutions were 1000 ppm of arsenic in nitric acid solution, and the others were aluminum, Copper, iron, lead, and zinc. The matrix modifier used a mixture of Palladium nitrate and Magnesium nitrate solutions. The water used was double distilled and de-ionized, and provided by SRIF. The nitric acid used in all solutions was research grade at a concentration of 1000 ppm.

The test solutions were prepared from the standard solutions. The nitric acid was mixed with the double distilled water to make a 0.2% nitric acid solution. This, in turn, was used to make all standards, make the matrix modifier, and make a final wash of all glassware. The standards of lead, copper and arsenic were diluted to 10 ppm. and stored in the FEP bottles for no more than six months. When furnace measurement runs for these three elements were performed, the standards were diluted further to 5, 10 and 20 ppb. (μg/l) using the 100 ml Pyrex volumetric flasks and the micro-pipette. For the aluminum, iron, and zinc standards, the solutions were diluted to 2.5, 5.0, and 10.0 ppm. (mg/l). The matrix modifier was a mixture of 0.1% Magnesium nitrate and 0.15% palladium nitrate.

The test tubes and auto-sampler cups were washed after each set of samples and the Pyrex 100 ml volumetric flasks were washed after each set of standards were prepared. The washing procedure involved three steps. 1) A hot soap and water solution cleaned the glassware. 2) The glassware was rinsed with distilled water to remove the soap. 3) A 0.2% nitric acid solution was used as a final rinse. The glassware was then allowed to dry insuring that nothing settled into the glassware.

The samples were retrieved from the storage refrigerator and pH tested to insure the pH reading was < 2. The AAS measurements were conducted within one week of removal from the refrigerator. The water from each sample bottle was used to make another rinse of the test tube or auto-sampler cup which would be holding that sample.

The flame procedure involved getting a low background reading using the 0.2% acid solution. The three standards were run until a good calibration curve was obtained. All the samples for two data collection days were then assayed for one element. The number of samples was between 20 and 30. Dispersed throughout the measurement run for each element, were concentration measurements of blanks and standards to insure no change in system characteristics had occurred. If a system change was detected, the measurement run was repeated. If an abnormally large concentration was measured for a sample beyond the calibration curve limits, a 1/40th dilution of that sample was made and tested.

The furnace procedure utilized an auto-sampler, but the method was similar to the flame. With a low background reading and an accurate calibration curve, the auto-sampler was allowed to continue to measure the concentrations of the sample set automatically. If an abnormality occurred during a measurement run, the run was stopped and the problem corrected. If the run was conducted over night, the results of the automatic measurement run were reviewed, and if an abnormality in the data was detected, the run was repeated. If a sample was found to exceed the limits of the calibration curve, a 1/40th dilution of the sample was added at the end of the measurement run. Blanks and standards were also used to check the stability of the system.

All the data was recorded and reports of the concentration measurement results were generated and submitted to the program manager approximately every month.

Benthic Macroinvertebrate Methods

A modification of EPA Rapid Bioassessment Protocol (RBP) II was used as the basic tool for macroinvertebrate bioassessment (Plafkin et al. 1989). RBP-II utilizes semiquantitative field collections in riffle/run and leaf litter habitats to determine the values of six metrics which characterize the status of the benthic macroinvertebrate community. The protocol allows for the modification of metrics and the use of alternative metrics depending on regional conditions.

Macroinvertebrate communities were sampled at each station using a 44 cm x 22 cm kick net. The 0.5 mm mesh net was held to the bottom facing upstream and the substrate was disturbed for 1 m directly upstream from the net for one minute. Larger stones were also wiped clean manually when deemed necessary. Contents of the net were placed in a shallow pan. The net was inspected to remove adhering animals. Large stones and leaves were rinsed and discarded. Obvious animals were picked directly into the sample jar. The remaining sample was collected by pouring the contents of the pan through a 0.5 mm sieve. This material was also transferred to the sample jar. The sample was preserved by adding formalin to about 10%. Two samples were collected at each site: one from a rapidly flowing riffle and second from a less rapid run. The two samples were pooled for identification and analysis.

In the lab, samples were rinsed with tap water through a 500 µm sieve to remove formalin and placed into a 35 cm x 40 cm pan marked with 5 cm x 5 cm squares. The pan was then gently agitated to distribute the sample evenly over the entire surface of the pan. Using a random number table, squares were selected for organism removal until a target number of organisms was achieved. The target number was generally 200, with the contents of the entire square containing the 200th organism identified. The remaining sample was returned to the sample jar and represerved with alcohol/glycerine. In some cases, the entire sample was less than 100 animals. The selected organisms were sorted into ethanol-glycerine, identified to family and enumerated. Taxonomic references included Merrit and Cummins (1978), Pennak (1978), and Clifford (1991).

Macroinvertebrate rating was calculated following the guidance of the EPA bioassessment manual (Plafkin *et al.* 1989). In order to determine the values of certain metrics, it was necessary to assign trophic strategies and biotic index values to each family. The trophic strategy information was obtained from Merrit and Cummins (1978): the biotic index values were obtained from Hilsenhoff (1982). Metrics, upon which this RBP-II was determined, were Taxa Richness, Family Biotic Index, Ratio of EPT/Chironomid Abundances, % Contribution of Dominant Family, EPT Index and Sorenson's Similarity Index (replaced Community Similarity Index as described in Plafkin). The derivation of these metrics, except Sorenson's, is available within Plafkin *et al.*(1989). Sorenson's is a binary measure of similarity between two quadrats. It is said to be "one of the best known and most widely used of the similarity indices available to ecologists." (Pielou 1984). The formula for Sorenson's: $2a/(2a+b+c)$ where a=the number of species present in BOTH quadrats, b=the number of species present in quadrat 1 but not quadrat 2, and c=the number of species present in quadrat 2 but not quadrat 1. Sorenson's values were calculated using MVSP Shareware. Two metrics - Ratio of Scrapers/Filtering Collectors and Ratio of Shredders/Total - were not used as they have been found to be less sensitive to changes within this ecoregion. No CPOM samples were taken.

Metric scoring criteria used were those cited for RBP II (Fig. 6.2-3, Plafkin *et al.* 1989). For Sorenson's, the metric scoring criteria was >0.5 = 6, 0.35-0.5 = 3, and <0.35 = 0. Bioassessment was determined according to RBP II (Fig. 6/2-3, Plafkin *et al.* 1989), a portion of which is reproduced here.

Table 1. Bioassessment Approach

Percent Compared to Reference Site[a]	Biological Condition Category	Attributes
> 79%	Non-Impaired	Comparable to the best situation to be expected within an ecoregion. Balanced trophic structure. Optimum community structure (composition and dominance) for stream size and habitat quality
29-72%	Moderately Impaired	Fewer species due to loss of most intolerant forms. Reduction in EPT index
< 21%	Severely Impaired	Fewer species present. If high densities of organisms, then dominated by one or two taxa. Only tolerant organisms present

(a) Percentage values obtained that are intermediate to the above ranges will require subjective judgment as to the correct placement. Use of the habitat assessment and physiochemical data may be necessary to aid in the decision process.

There were seven sampling events per site over a two year period. Site 1, which was considered a reference site, had only 4 individuals in the September 1999 sampling event. Though all sites were under considerable stress due to drought, these results were considered anomalous and the results not used in any analysis. To determine how similar the biotic communities were in the impacted sites as compared to the reference sites several analyses were completed. First, it was determined that there were no significant differences in populations between sites 1 and 2. Thus, sites 1 and 2 could both be considered reference sites. For thoroughness sites 3, 4, and 5 were compared to both sites 1 and 2 as references. To obtain the Percent Compared to Reference Score the six metric index of either site 1 or site 2 *on the comparable date* was used due to the great seasonal influences even among individual sites. Both comparison are included.

Relationships among sites were also explored using Analysis of Variance and Tukeys HSD post hoc test for multiple comparisons. This was accomplished using SYSTAT.

Fish Methods

Fish data collection began in the fall, 1997 and occurred three times a year (fall, spring and summer) at all five sites for two years (1997-1999). Fall data were collected in September, spring data were collected in March and summer data were collected in June of each year. Therefore, data collection provides 3 replicate samplings for fall (1997-1999), 2 replicate samplings for spring (1998-1999) and 2 replicate samplings for summer (1998-1999).

Fish collection was conducted using EPA Rapid Bioassessment Protocol V (Plafkin et al. 1989). This method involved a standardized field collection, species identification and enumeration and recommended the use of the Index of Biotic Integrity (IBI), a fish assemblage assessment developed by Karr (1981) for analyzing the data.

The method of fish collection was pulsed direct current electrofishing. All field sampling team members were required to wear chest waders and rubber gloves to insulate themselves from the water and electrodes. All field sampling team members were briefed on electrofishing safety precautions and unit operation in the field.

The electrofisher was a backpack model with 2 hand-held electrodes mounted on poles, one positive (anode) and one negative (cathode). The electrofisher operator carried the backpack unit and was able to control the current. The remaining field sampling team members netted fish with

The electrofisher was a backpack model with 2 hand-held electrodes mounted on poles, one positive (anode) and one negative (cathode). The electrofisher operator carried the backpack unit and was able to control the current. The remaining field sampling team members netted fish with dip-nets and were responsible for transporting specimens to the end of each sampling reach in buckets filled with water. In an effort to maximize efficiency and minimize time fish had to spend in the buckets (thereby attempting to minimize fish mortality), each 200-meter sampling site was broken into four 50-meter sub-sampling reaches. Boundary nets were set at the base and end of each 50-meter sub-sampling reach unless there was a natural break such as a riffle or a rock outcrop that would block the fish from escaping the electroshock and dip-nets.

Fish that were 2 cm or greater were collected and kept alive in water-filled buckets until they were identified, measured to the nearest 0.5 mm and then released back to the stream. Fish were released far enough down stream from each successive sampling reach to avoid re-capture.

Fish that could not be readily identified in the field were preserved in 10% formalin, labeled with site location, date and sampling station and were taken back to the lab for positive identification.

The IBI is based on 12 metrics, which reflect attributes of fish associations. The protocol allows for modification of metrics and recommends alternative metrics depending on regional conditions. With this in mind the following four substitutions were made:

1) %Generalists for %Omnivores (Metric 7)

2) % Specialists for %Insectivores (Metric 8) as recommended in Jones and Kelso (1994) for this region presumably because Generalists and Specialists incorporate a slightly wider range of species than just Omnivores or just Insectivores

3) %Tolerant species for %Green Sunfish (Metric 6) - since green sunfish were found only one time at one location during the entire 2 year study, it was determined that this metric may be limited in scope and should therefore be modified

4) %Natives for %Hybrids (Metric 11) - since hybrids were difficult to positively determine it was recommended that this metric be modified.

The 12 metrics used are depicted in Table 2.

Table 2: Metrics used in IBI	
Metric	Description
1	Total number of species (native and exotic)*
2	Number of darter species*
3	Number of sunfish species*
4	Number of sucker species*
5	Number of intolerant species*
6	Proportion of tolerant species
7	Proportion generalists
8	Proportion specialists
9	Proportion top carnivores
10	Total number individuals*
11	Proportion of natives
12	Proportion with disease or anomalies

**Scores for metrics 1-5 and 10 in this table are determined based on a species/watershed size relationship.*

Abundance data were utilized to calculate the 12 metrics. Six of the metrics in Table 2 are dependent on watershed size as noted (Plafkin *et al.* 1989; Karr 1999). Although there is very little difference in watershed size among the sites sampled in this study, metric vs. watershed area were plotted to calculate these six metrics. Reference points were plotted for each metric vs. watershed size (log Km^2). A maximum species richness line was then plotted such that 95% of the reference data points fell below the line. Two reference data points multiplied by 7 sampling times equals 14 data points. Ninety-five percent of 14 is 13.3 or 13. Maximum species richness lines were drawn through the top point such that 13 points fell below the line. The angle of this line was measured and divided into thirds according to the protocol. Data points less than 33% received a score of 1; data points between 33-67% received a score of 3 and data points greater than 67% received a score of 5. Sample points for each of the watershed dependent metrics were plotted on graphs using the reference plots as a template. These metric scores and those of the other 6 metrics were summed to determine the overall IBI values found in Table 31. Note that metrics not identified as watershed size dependent, were calculated according to the protocol (Plafkin *et al.* 1989).

RESULTS

Water Profile and Metals Chemistry Results

Graphical depiction of characteristic data by site are shown. Box plots are utilized to show the significant differences between sites. Analysis of variance using the Tukey-Kramer HSD method (SYSTAT 6.0) was performed on logrithmic transformed data. Sites which are significantly different from one another are noted.

pH

Levels of pH did not fluctuate greatly (Figure 4). The largest changes occurred generally between August and September of both years when water level was low and storms to replenish flow were sparse due to the drought. The largest single month variation occurred at Site 3 between August and September when pH fell from 7.2 to 5.4 then rose again to 7.21 in October. There was a significant difference in pH between site 1 and site 4 ($p<0.017$) and also a significant difference between sites 4 and 5 ($p<0.007$). Ionic concentration by site over time are shown in Figure 4. Figure 5 depicts a box plot of the data.. Raw data for pH is shown in Table 4.

Conductivity

Conductivity varied little throughout the study at sites 1,2, and 5 (between 26.6 and 110 µS/cm). Site 3 had peaks of 539 µS/cm on September 14, 1998 and 602 µS/cm on August 18, 1999. Site 4 varied considerably with peaks at 185µS/cm on October 14, 1997, 785 µS/cm on September 14, 1998, 290 µS/cm on October 15, 1998 and 571 µS/cm on August 18, 1999. Raw data for conductivity are shown in Table 5. Graphical depiction of conductivity data by site are shown in Figure 6. Figure 7, Box Plot of Conductivity, shows the differences between sites. Both site 1 and 2 are significantly different from site 3 ($p<0.023$ and $p<0.029$ respectively) and site 1 and 2 are significantly different from site 4 ($p<0.000$ and $p<0.000$ respectively). Site 4 is significantly different from site 5 ($p<0.001$).

Specific Conductance

Specific Conductivity (conductance corrected to 25°C) mirrored the conductivity data with little variation at sites 1, 2, and 5 throughout the study. Site 3 varied with peaks of 395 µS/cm on

September 14, 1998 and 583 µS/cm on August 18, 1999. Site 4 had peaks on September 14, 1998 and August 18, 1999. There were significant differences between sites 1 and 3 ($p<0.010$), sites 1 and 4 ($p<0.000$), sites 2 and 3 ($p<0.012$), sites 2 and 4 ($p<0.000$) and sites 4 and 5 ($p<0.000$) (Figure 8 and Figure 9). Raw data are presented in Table 6.

Sulfate

The method used for sulfate analysis was accurate between 10 and 80 mg/l. Levels less than 10 mg/l were listed on the graph as 10 mg/l and those greater than 80 mg/l are shown as 80 mg/l (Figure 10). Sites 1 and 2 were generally low throughout the study period and varied little (between 10 and 25 mg/l). Sites 3 exceeded 80 mg/l twice (9/14/98 and 8/14/99) and site 4 exceeded 80 mg/l three times (9/14/98, 10/15/98, and 9/18/99). Site 5 generally had varying levels of sulfates with an upper bound below 40 mg/l. Site 1 and 2 (Figure 11) were not significantly different. Sites 3 and 5 were not significantly different. Site 1 was significantly different from sites 3, 4 and 5 ($p<0.000$, 0.000, 0.002 respectively). Site 2 was significantly different from sites 3, 4, and 5 ($p<0.000$, 0.000, 0.007 respectively). Site 3 was significantly different from site 4 ($p<0.008$). Site 4 was significantly different from site 5 ($p<0.000$). Raw data are presented in Table 7.

Temperature

Temperature varied seasonally and as expected given the habitat surrounding the stream (Figure 12). Site 3, which had less canopy cover, was warmer during the summer. Site 5 reflected the input of the waters from South Fork of Quantico Creek. Regardless, there were no significant differences (Figure 13) between sites when temperature was considered. Raw data are presented in Table 8.

Dissolved Oxygen, percent saturation

Percent saturation varied seasonally (Figure 14). Due to the influence of the influx of waters from South Fork of Quantico Creek, site 5 appeared to generally have greater saturation. Regardless, there were no significant differences between sites when percent saturation was considered (Figure 15). Raw data are presented in Table 9.

Turbidity

Turbidity for this stream is very low (Figure 16). Sites 3 and 4 show some evidence of effects from the disturbed ground around the site with higher peaks during September of 1998 and 1999 and October in 1999. Site 5 shows the dilution effects (lower turbidity) of the South Fork of Quantico Creek during those same months, though less so in September of 1999. Regardless, there were no significant differences in turbidity between sites (Figure 17). Raw data are presented in Table 10.

Dissolved Oxygen

Dissolved oxygen varied from a low of 1.12 mg/l to a high of 14.5 mg/l (Figure 18). Sites 1, 2, and 3 experienced levels below 4.0 mg/l twice (September of 98 and August of 99) and site 4 once (August of 99) during the study period. Site 5, due to the influence of South Fork of Quantico Creek, never had readings this low. These low readings were due to low baseflow and extended high temperatures. There were no significant differences in dissolved oxygen between sites (Figure 19). Raw data are presented in Table 11.

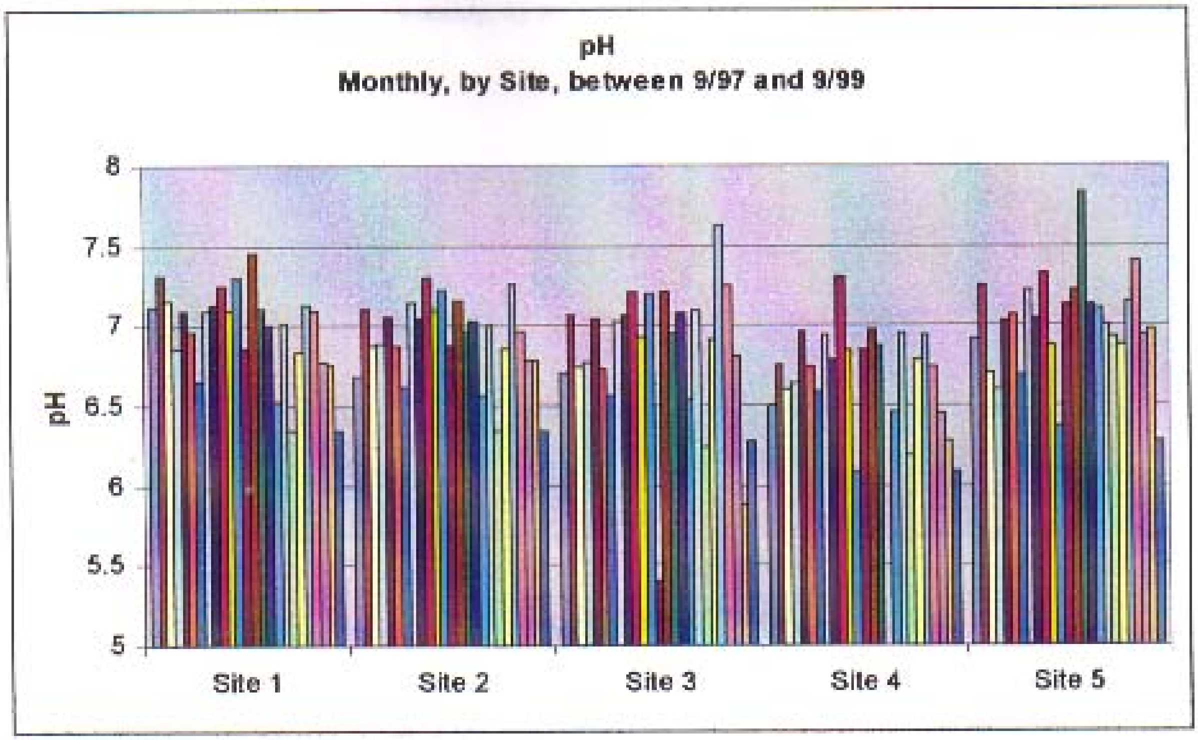


Figure 4. pH by Site

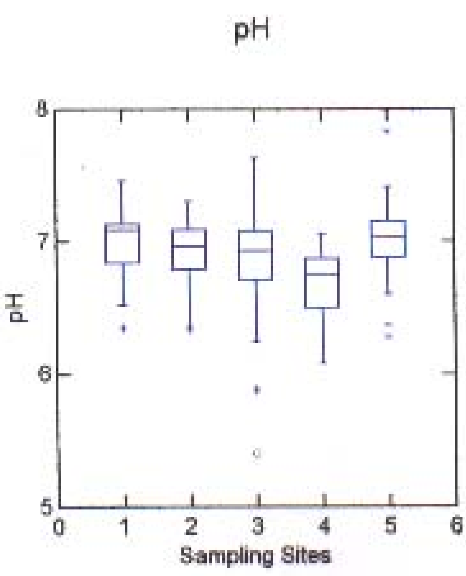


Figure 5. Box Plot of pH

ANOVA

1 vs 4 $p<0.017$

4 vs 5 $p<0.007$

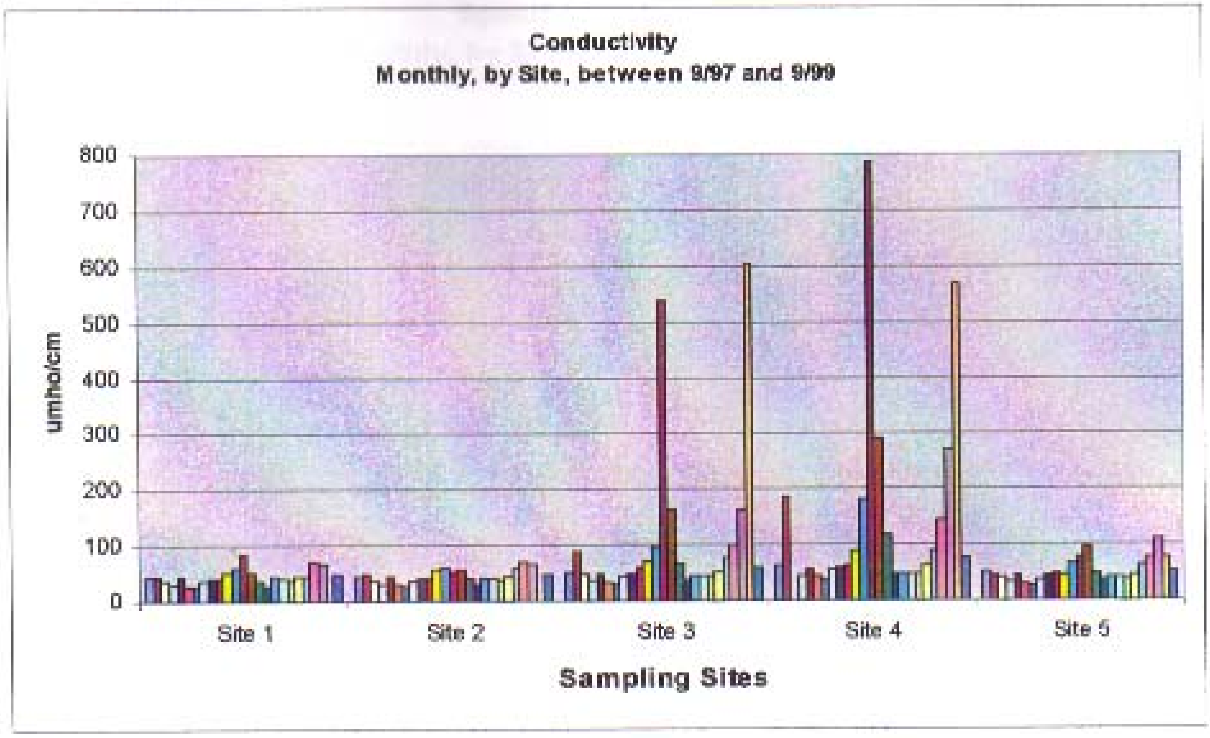


Figure 6. Conductivity

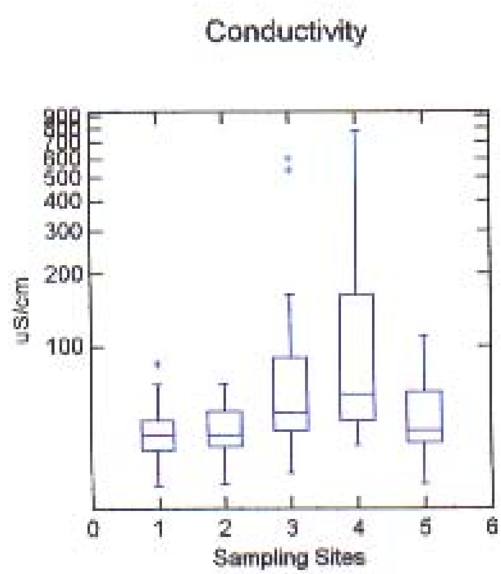


Figure 7. Box Plot of Conductivity

ANOVA

1 vs. 3 $p<0.023$

2 vs. 3 $p<0.029$

1 vs. 4 $p<0.000$

2 vs. 4 $p<0.000$

4 vs. 5 $p<0.001$

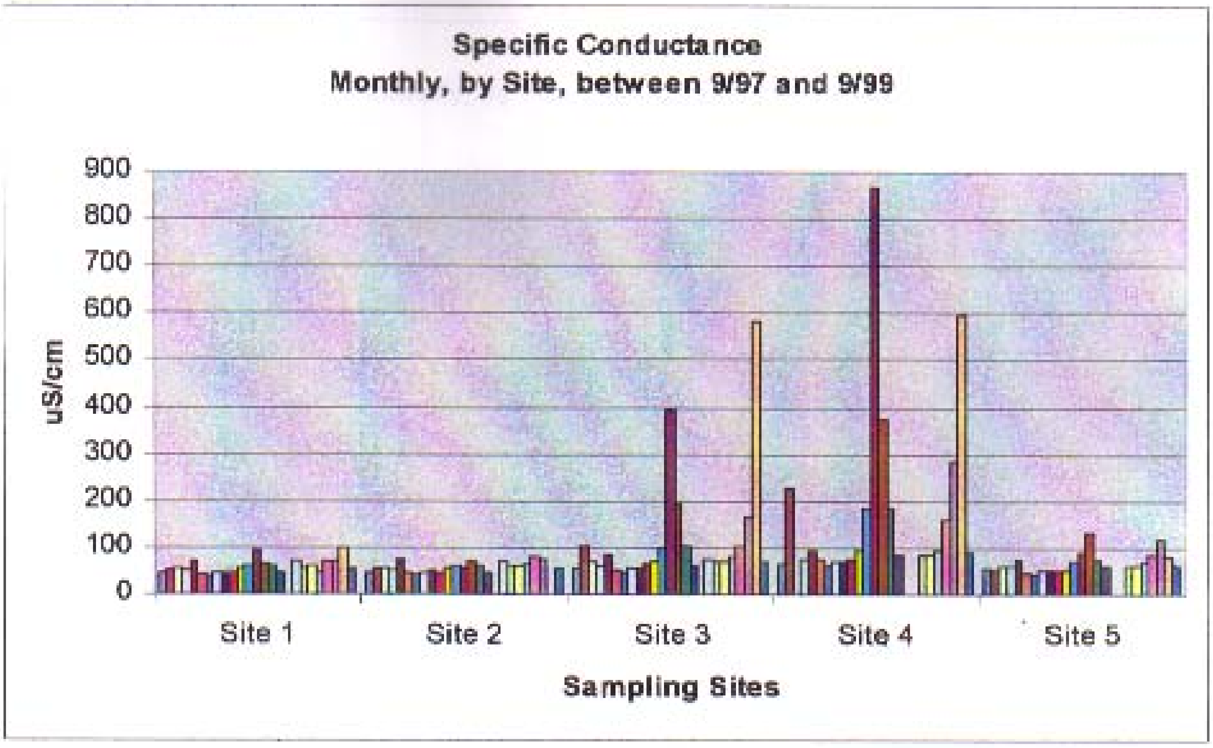


Figure 8. Specific Conductance

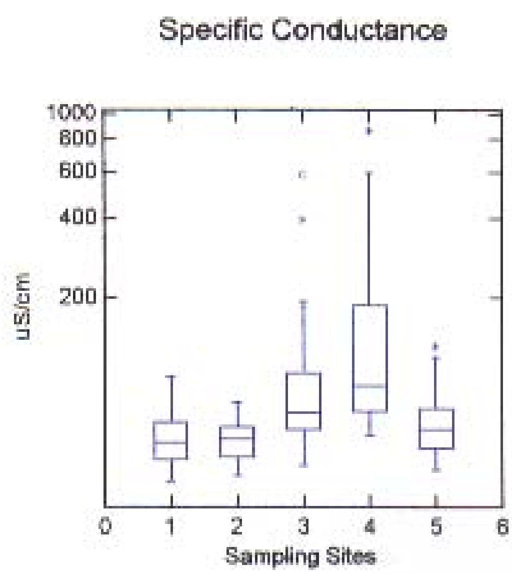


Figure 9. Box Plot of Specific Conductance

ANOVA

1 vs. 3 $p<0.010$

1 vs. 4 $p<0.000$

2 vs. 3 $p<0.012$

2 vs. 4 $p<0.000$

4 vs. 5 $p<0.000$

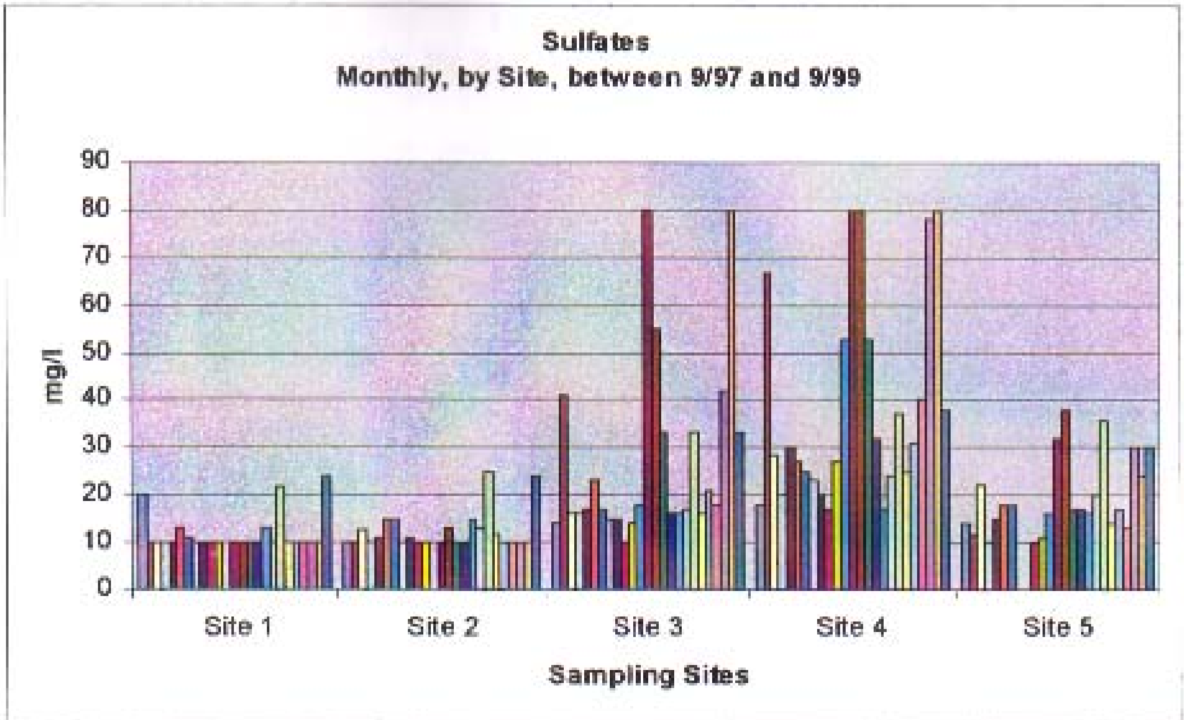


Figure 10. Sulfates

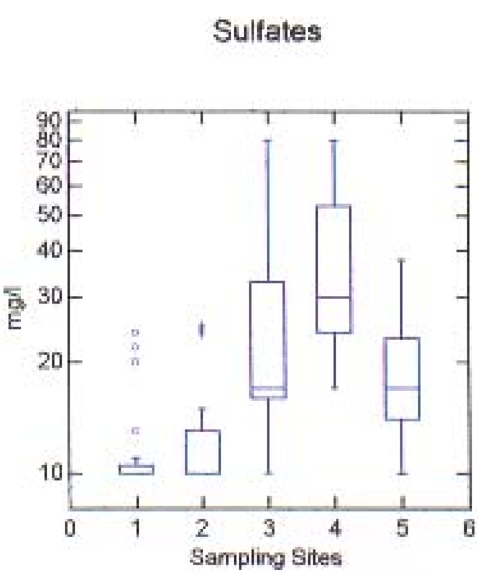


Figure 11. Box Plots of Sulfates

ANOVA

1 vs. 3 $p<0.000$

2 vs. 3 $p<0.000$

1 vs. 4 $p<0.000$

2 vs. 4 $p<0.000$

3 vs. 4 $p<0.008$

1 vs. 5 $p<0.002$

2 vs. 5 $p<0.007$

4 vs. 5 $p<0.000$

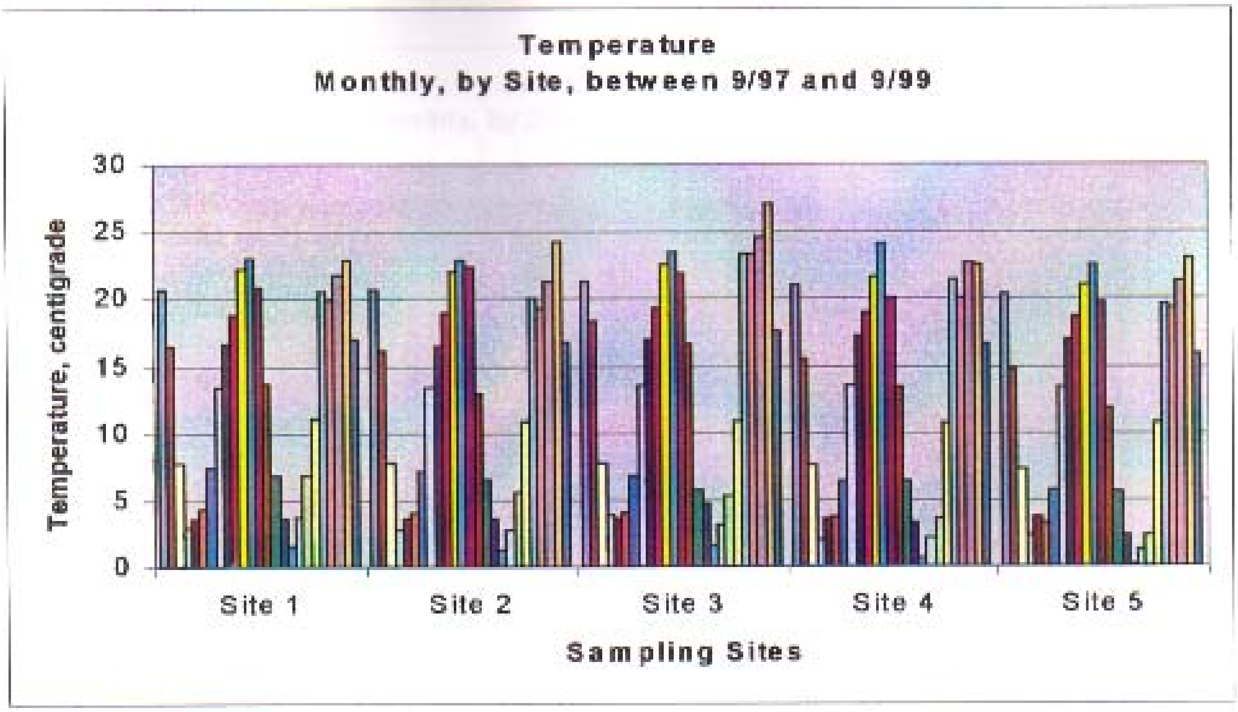


Figure 12. Temperature

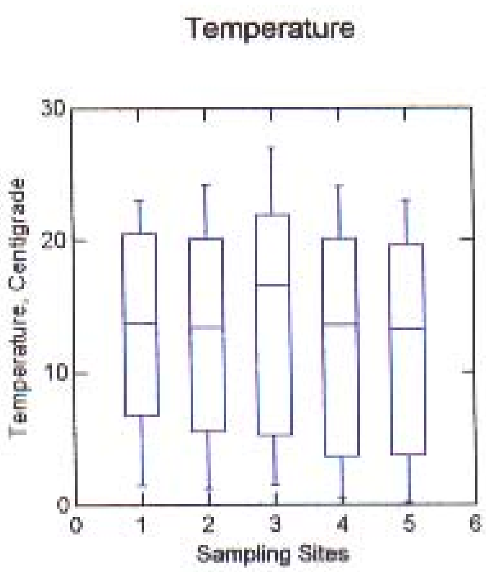


Figure 13. Box Plot of Temperature

ANOVA

There is no significant difference between sites.

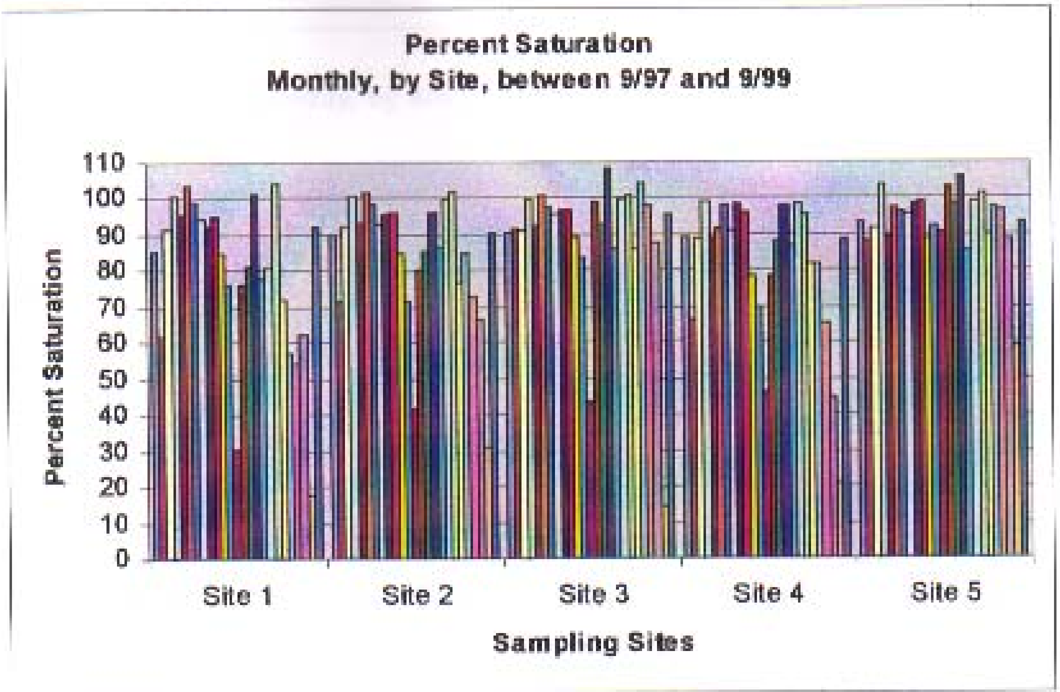


Figure 14. Percent Saturation

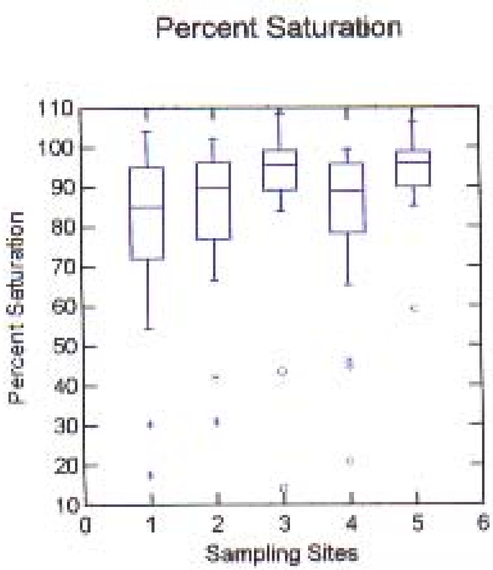


Figure 15. Box Plot of Percent Saturation

ANOVA

There are no significant differences between sites.

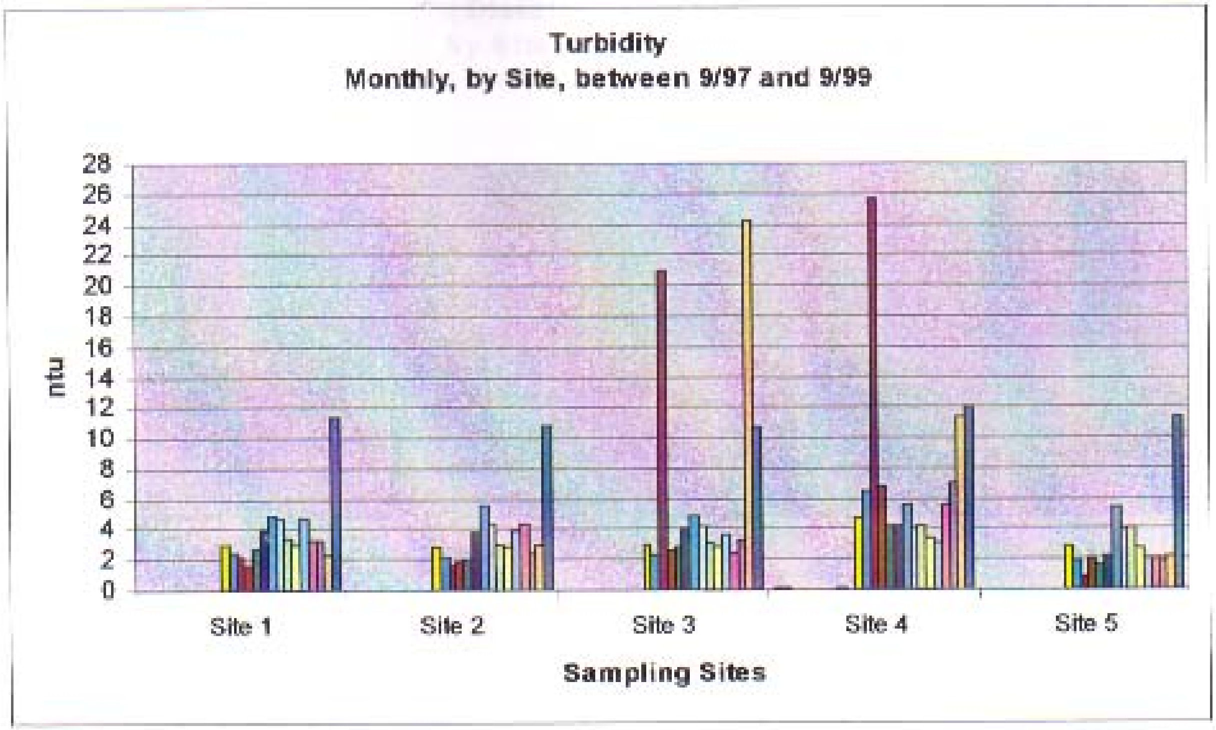


Figure 16. Turbidity

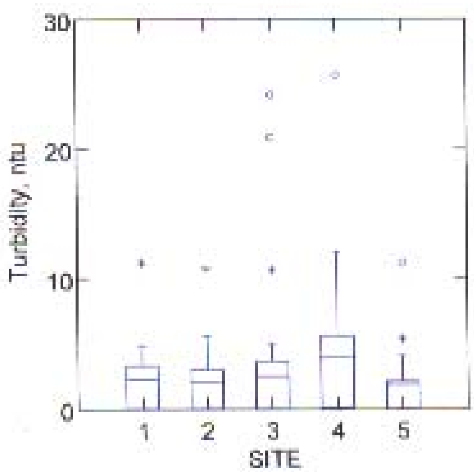


Figure 17. Box Plot of Turbidity

ANOVA

There are no significant differences between sites

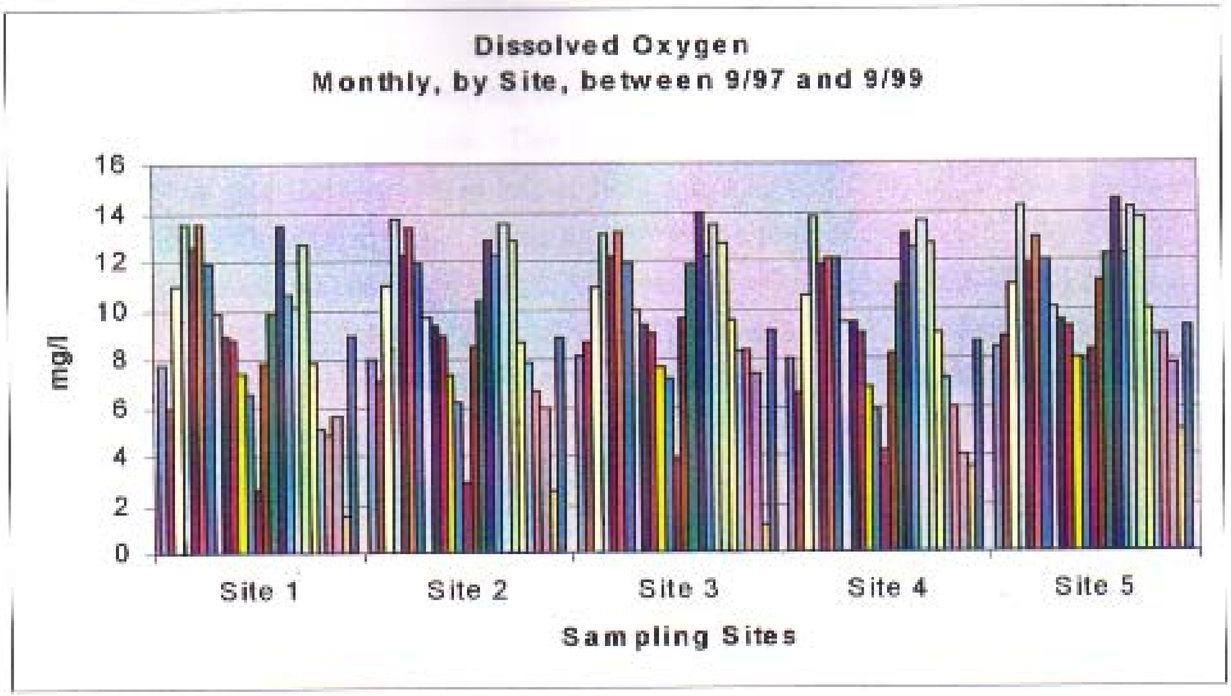


Figure 18. Dissolved Oxygen

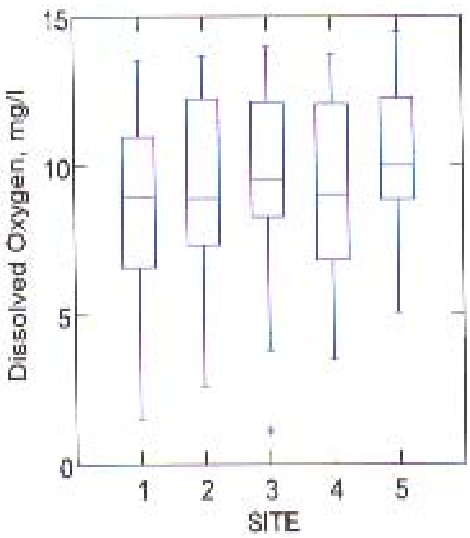


Figure 19. Box Plot of Dissolved Oxygen

ANOVA

There are no significant differences between sites.

Filtered Copper

The copper graph (Figure 20) is deceiving because the extremely high reading in October of 1997 (1.036 mg/l) skews the necessary scale. This is an outlier, probably due to excessively heavy rains near the sampling date. Site 1 peaks in July of 1999 with a high of 0.099 mg/l. Site 2 peaks in October of 1998 with 0.019 mg/l and in July of 1999 with a peak of 0.060 mg/l. Site 3 has highs (other than the outlier) of 0.065 mg/l in both September and October of 1998. Site 4 peaks in September of 1999 with a high of 0.055 mg/l. Site 5 peaks in May of 1999 with 0.025 mg/l. When multiple comparisons are made (Figure 21), sites 3 and 4 (both impacted sites) have copper content significantly different from sites 1, 2, and 5. Sites 3 and 4 act most like each other. Raw data are included as Table 12.

Filtered Aluminum

Again, due to unusually high readings in October of 1997 (4.88 mg/l Al) the graph (Figure 22) appears skewed. Site 1 peaks in February of 1998 with 1.28 mg/l. Site 2 peaks on the same date with a high of 1.18 mg/l. Site 3 peaks in October of 1997 as mentioned and then in September of 1999 with a high of 1.41 mg/l. Site 4 peaks in February of 1998 at 1.48 mg/l. Site 5 also has it's high in February of 1998 at 1.35 mg/l. When this outlier is removed there are no significant differences (Figure 23) between sites. Raw data is included as Table 13.

Filtered Arsenic

Arsenic remained fairly low with the highest reading at site 3 (0.009 mg/l) in March of 1999 (Figure 24). Other higher readings were seen at site 1 (0.006 mg/l) in December of 1997 and at site 4 (0.005 mg/l) in February of 1998. There are no significant differences (Figure 25) between sites. Raw data is included as Table 14.

Filtered Iron

Sites 1 and 2 consistently had reading less than 1.7 mg/l Fe (Figure 26). Site 5 consistently had readings less than 1.3 mg/l. Site 3 had the highest reading of 7.37 mg/l Fe in September of 1998. Site 4 had a mean concentration higher than any of the rest. Site 1 ($p<0.020$) and 2 ($p<0.005$) are significantly different from site 3 (Figure 27). Site 3 is significantly different from site 5 ($p<0.001$).

The behavior of sites 1, 2, and 5 seem to group together, site 3 standing alone but with some similarity to site 4. Raw data is included as Table 15.

Filtered Lead

The highest lead reading throughout the study occurred at Site 1 on June 24, 1998 (0.013 mg/l) (Figure 28). There are no significant differences (Figure 29) between sites for lead. Raw data is included as Table 16.

Filtered Zinc

Site 3 has the highest peaks of 4.62 mg/l in October of 1997 and 3.77 mg/l in September of 1998 (Figure 30). Site 4 had a high of 1.01 mg/l in September of 1998. Sites 1 and 2 group together with a pairwise comparison probability of 0.904 (Figure 31). Sites 3 and 4 group together with a pairwise comparison probability of 0.996. Site 5 is different from either group with readings generally slightly above sites 1 and 2 and generally below sites 3 and 4.
Raw data is included as Table 17.

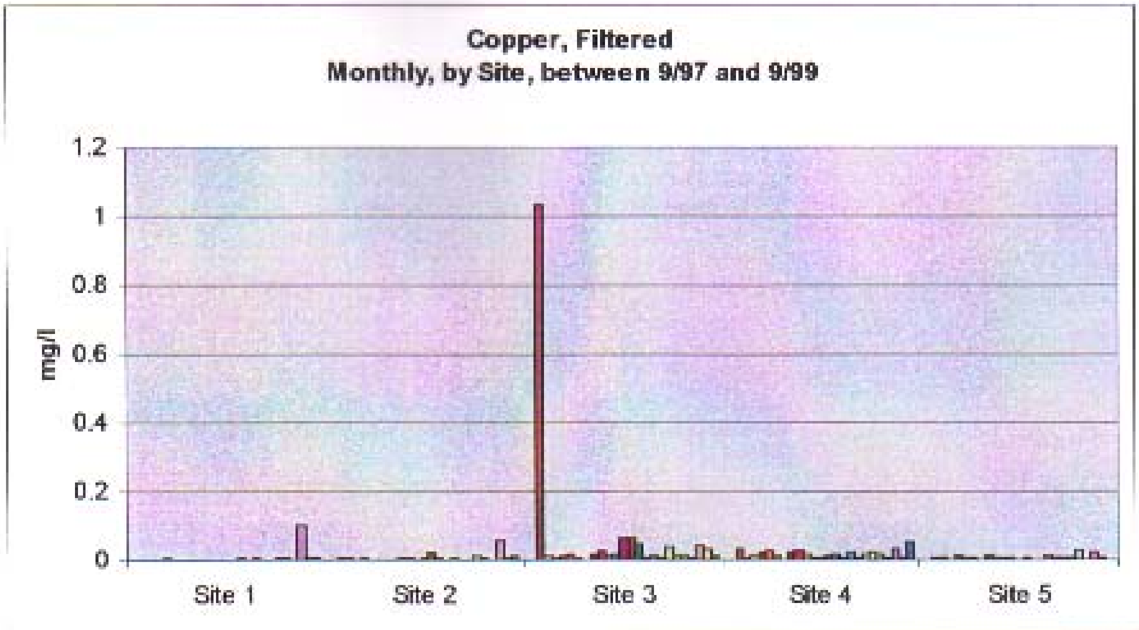


Figure 20. Copper, Filtered

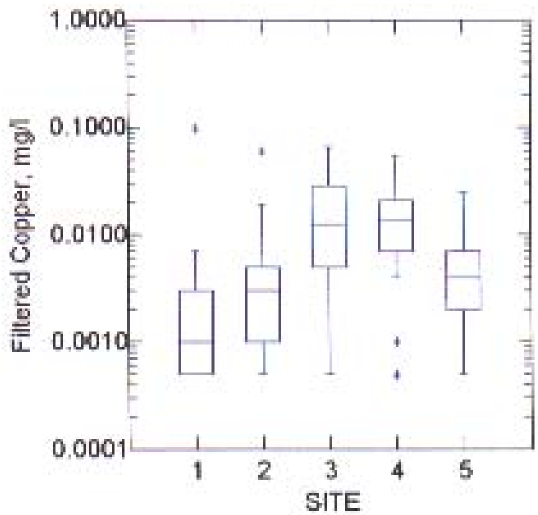


Figure 21. Box Plot of Filtered Copper

ANOVA

1 vs. 3 $p<0.000$
1 vs. 4 $p<0.000$
2 vs. 3 $p<0.000$
2 vs. 4 $p<0.001$
3 vs. 5 $p<0.005$
4 vs. 5 $p<0.030$

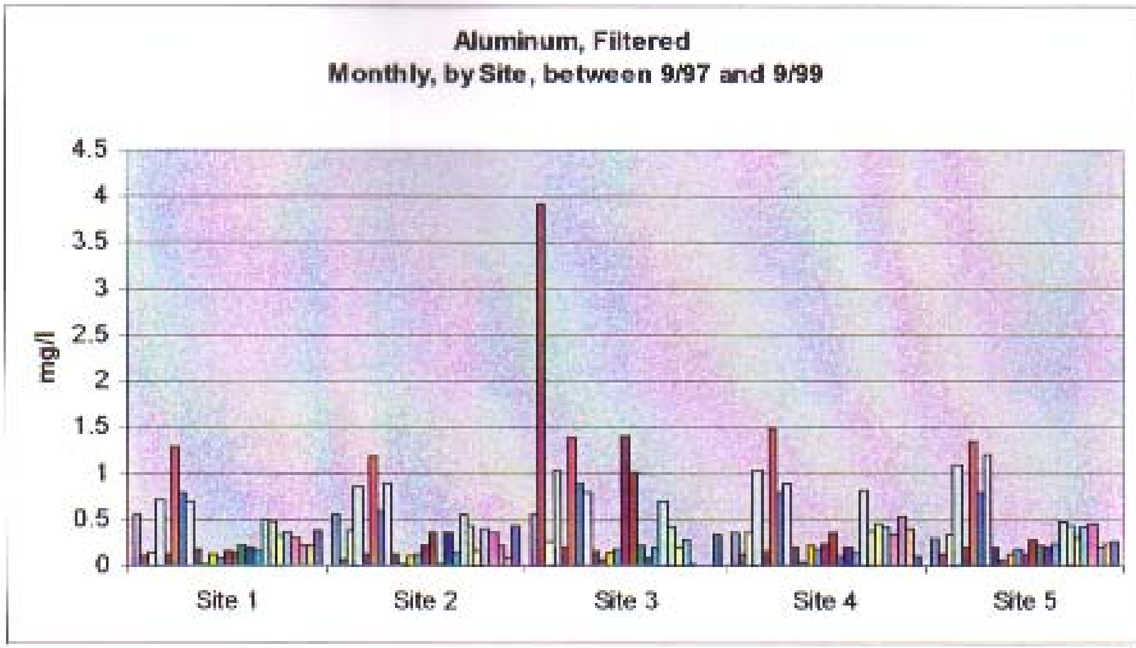


Figure 22. Aluminum, Filtered

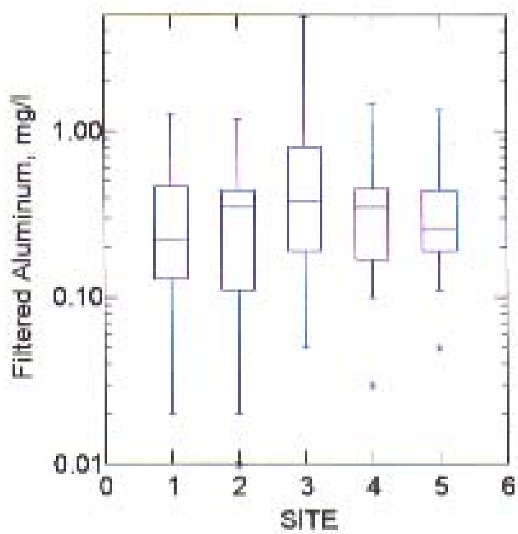


Figure 23. Box Plot of Filtered Aluminum

ANOVA

There are no significant differences between sites.

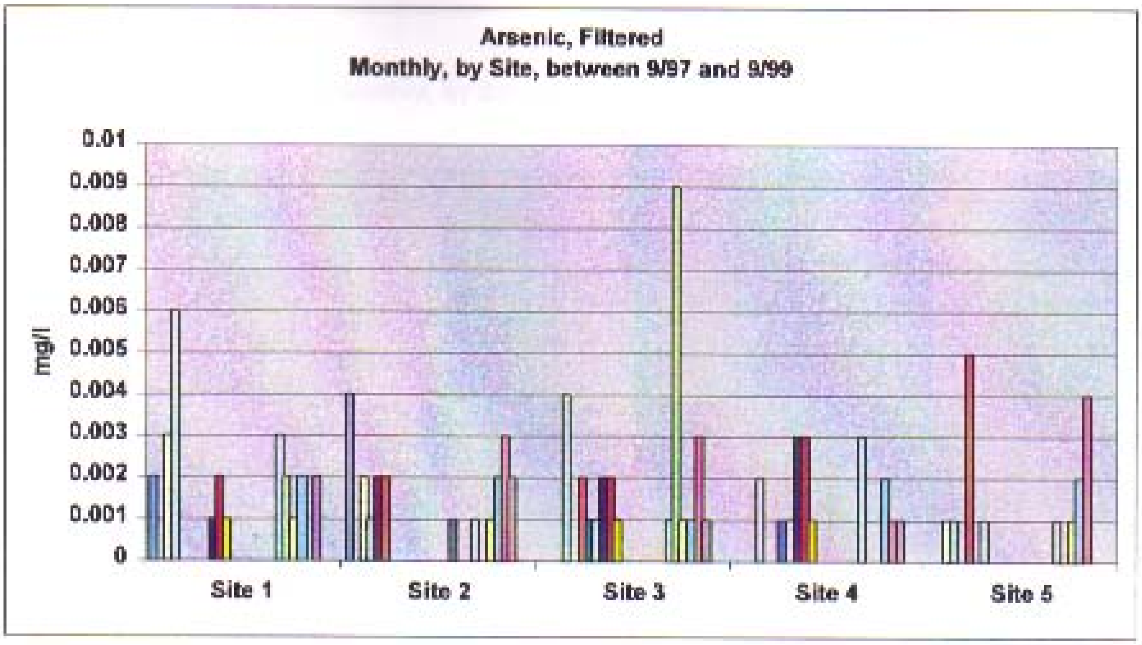


Figure 24. Arsenic, Filtered

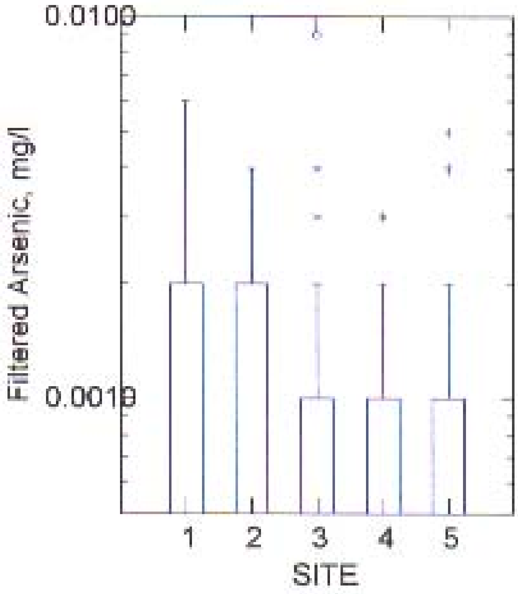


Figure 25. Box Plot of Filtered Arsenic

ANOVA

There are no significant differences between sites.

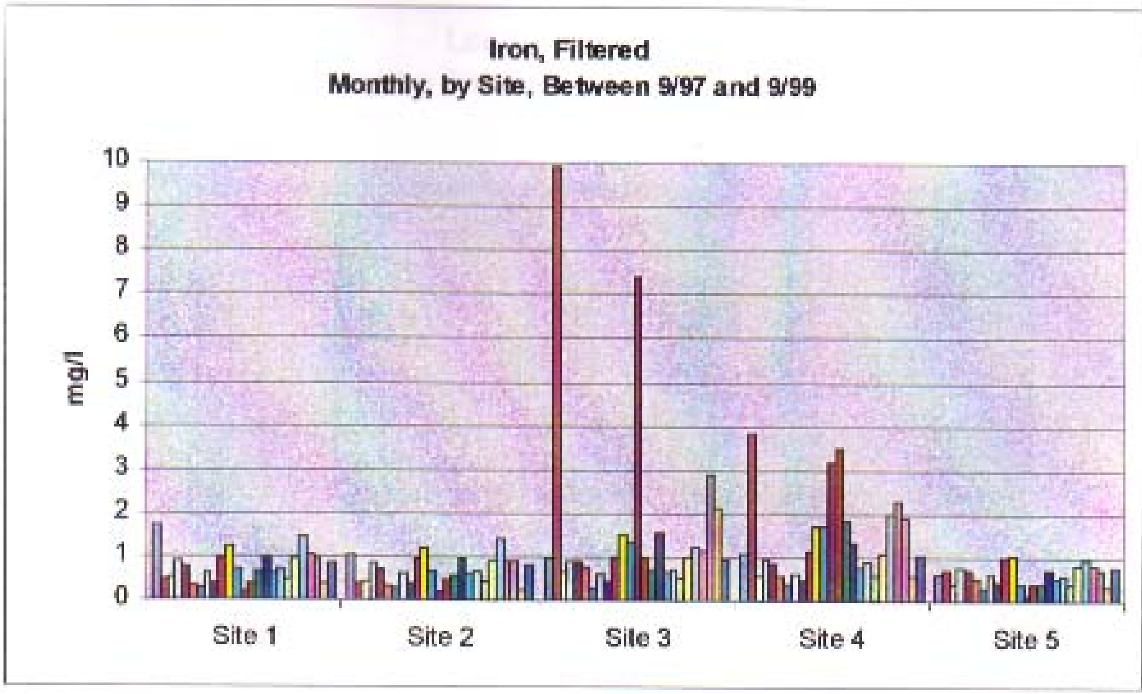


Figure 26. Iron, Filtered

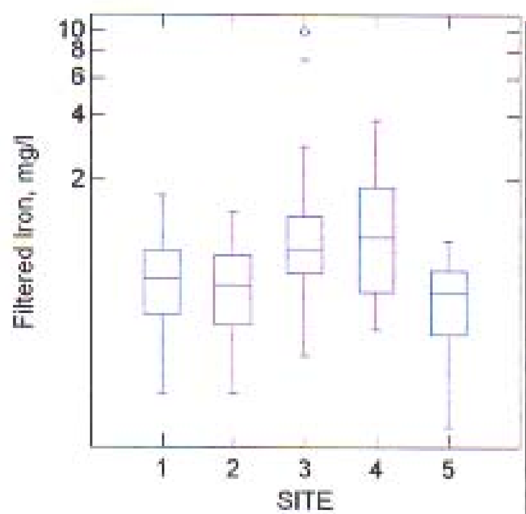


Figure 27. Box Plot for Filtered Iron

ANOVA

1 vs. 3 p<0.020
1 vs. 4 p<0.012
2 vs. 3 p<0.005
2 vs. 4 p<0.003
3 vs. 5 p<0.001
4 vs. 5 p<0.000

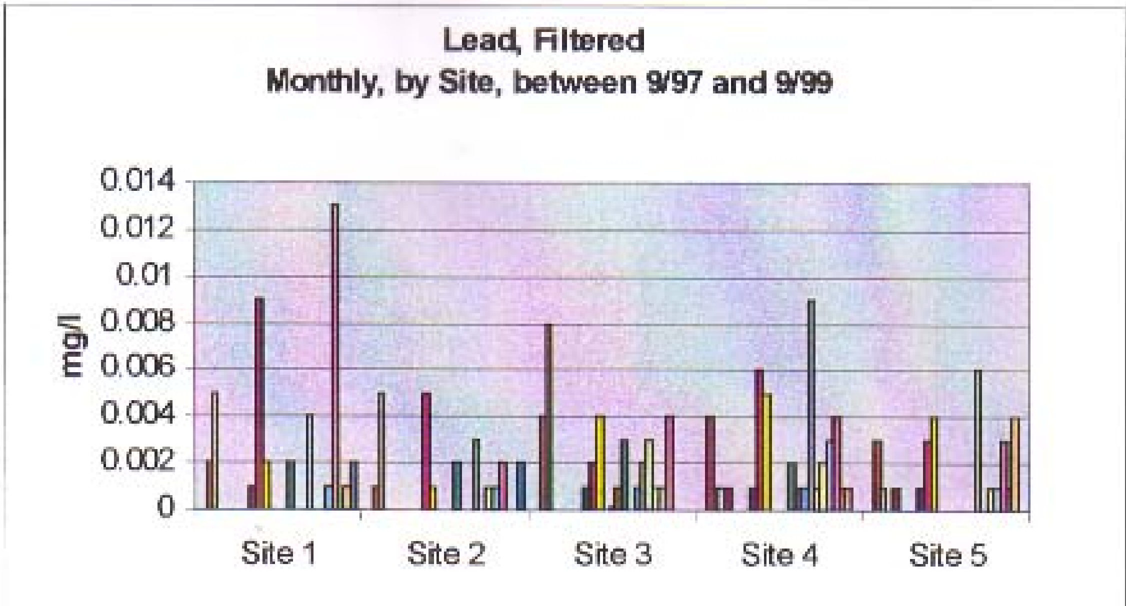


Figure 28. Lead, Filtered

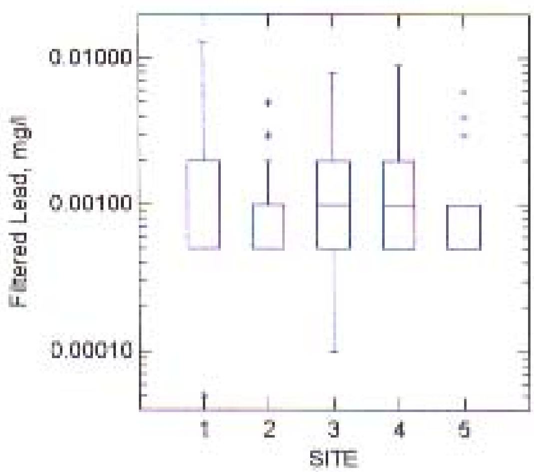


Figure 29. Box Plot of Filtered Lead

ANOVA

There are no significant differences between sites.

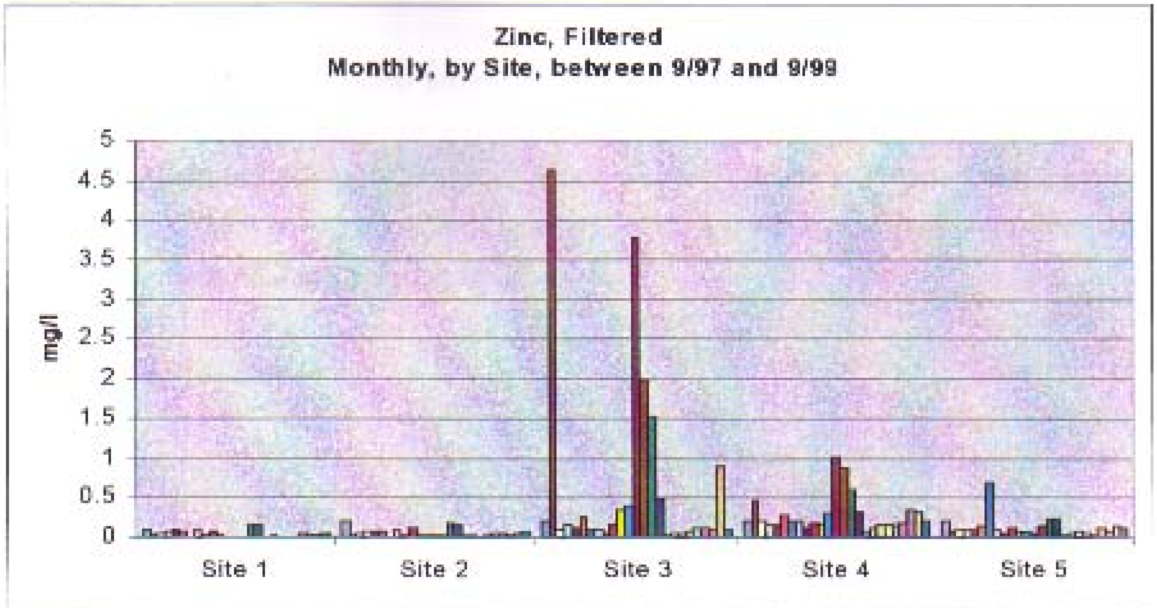


Figure 30. Zinc, Filtered

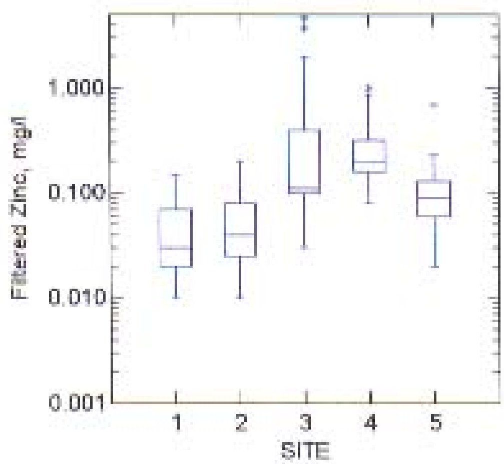


Figure 31. Box Plot of Filtered Zinc

ANOVA

1 vs. 3 $p<0.000$
1 vs. 4 $p<0.000$
1 vs. 5 $p<0.004$
2 vs. 3 $p<0.000$
2 vs. 4 $p<0.000$
2 vs. 5 $p<0.050$
3 vs. 5 $p<0.012$
4 vs. 5 $p<0.004$

Unfiltered Copper

Site 1 (Figure 32) had the highest peak in September of 1997 at 0.98 mg/l. Site 2 peaked at 0.071 mg/l in July of 1999. Site 3 peaked in October of 1997 at 0.80 mg/l. Site 4 peaked in September 1999 at 0.065 mg/l. Site 5 was consistently low. Site 1 and 2 group together, and 3 and 4 group together (Figure 33). Site 4 is significantly different from site 5 ($p<0.045$). Raw data are included at Table 18.

Unfiltered Aluminum

Site 3 (Figure 34) had two high peaks in October of 1997 (3.93 mg/l) and September of 1998 (4.0 mg/l). While site 3 had three peaks about 2.0 mg/l, the rest of the sites were always below 2.0 mg/l. There are no significant differences between sites (Figure 35). Raw data are included at Table 19.

Unfiltered Arsenic

Site 3 (Figure 36) had the two highest peaks in September of 1997 (0.006 mg/l) and February of 1998 (0.006 mg/l). All other readings were below 0.003 mg/l. There are no significant differences between sites (Figure 37). Raw data are included at Table 20.

Unfiltered Iron

Iron peaks (Figure 38) in August of 1999 at site 3 at 15.71 mg/l. The high at site 4 is 10.97 mg/l in September of 1998. Site 1 and 2 group together, sites 3 and 4 group together, and site 5 stands alone with readings slightly lower than the 1-2 group (Figure 39). Raw data are included at Table 21.

Unfiltered Lead

Lead peaks (Figure 40) at site 1 in June of 1999 at 0.015 mg/l. The peak at site 2 occurs in September of 1999 at 0.009 mg/l. Site 3 peaks in February of 1999 at 0.014 mg/l. Site 4 also peaks in February of 1999 at 0.011 mg/l. Site 5 peaks in November of 1997 at 0.011 mg/l. There are no significant differences between sites (Figure 41). Raw data are included at Table 22.

Unfiltered Zinc

Zinc (Figure 42) has two high peaks at site 3 in October of 1997 (3.72 mg/l) and in September of 1998 (4.0 mg/l). Site 4's highest reading was in September of 1998 (1.17 mg/l). Sites 1 and 2 group together at the lower readings, sites 3 and 4 group together at the higher readings, and site 5 stands along between the two groups (Figure 43). Raw data are included at Table 23.

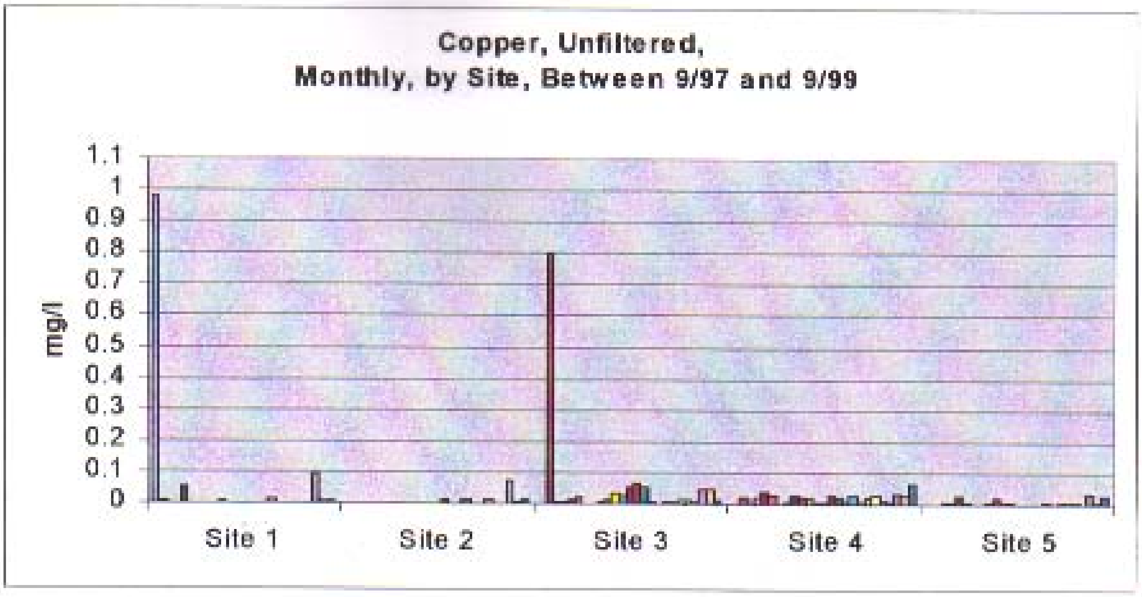


Figure 32. Copper, Unfiltered

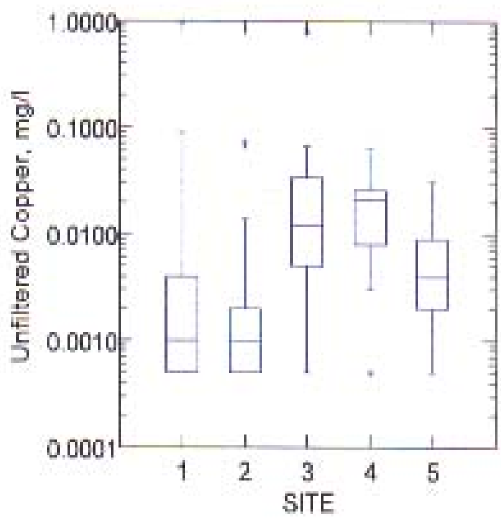


Figure 33. Box Plot of Unfiltered Copper

ANOVA

1 vs. 3	$p<0.006$
1 vs. 4	$p<0.001$
2 vs. 3	$p<0.000$
2 vs. 4	$p<0.000$
4 vs. 5	$p<0.045$

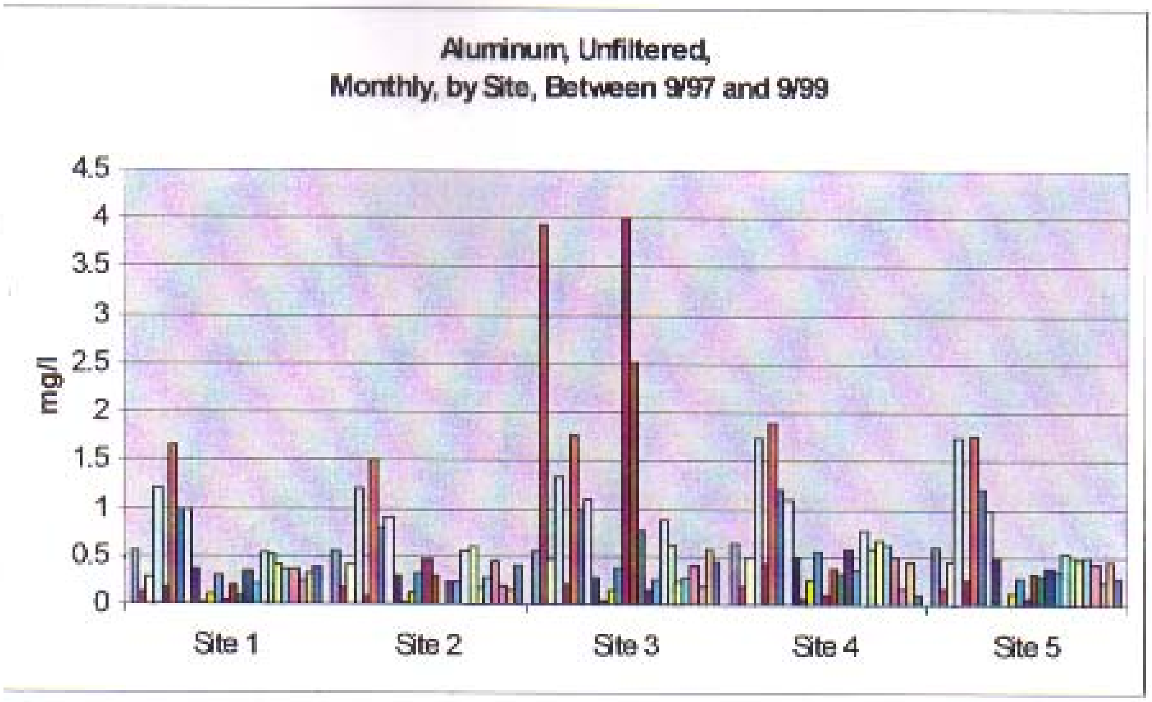


Figure 34. Aluminum, Unfiltered

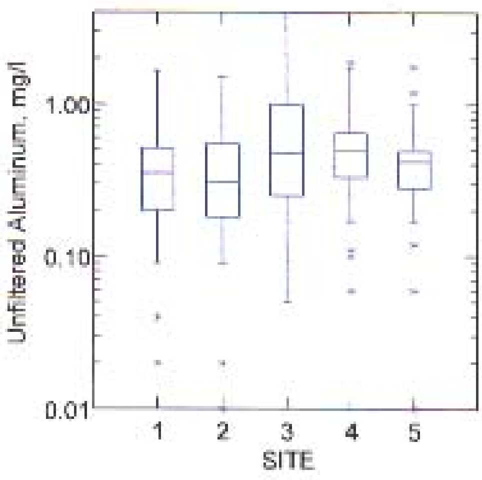


Figure 35. Box Plot of Unfiltered Aluminum

ANOVA

There are no significant differences between sites

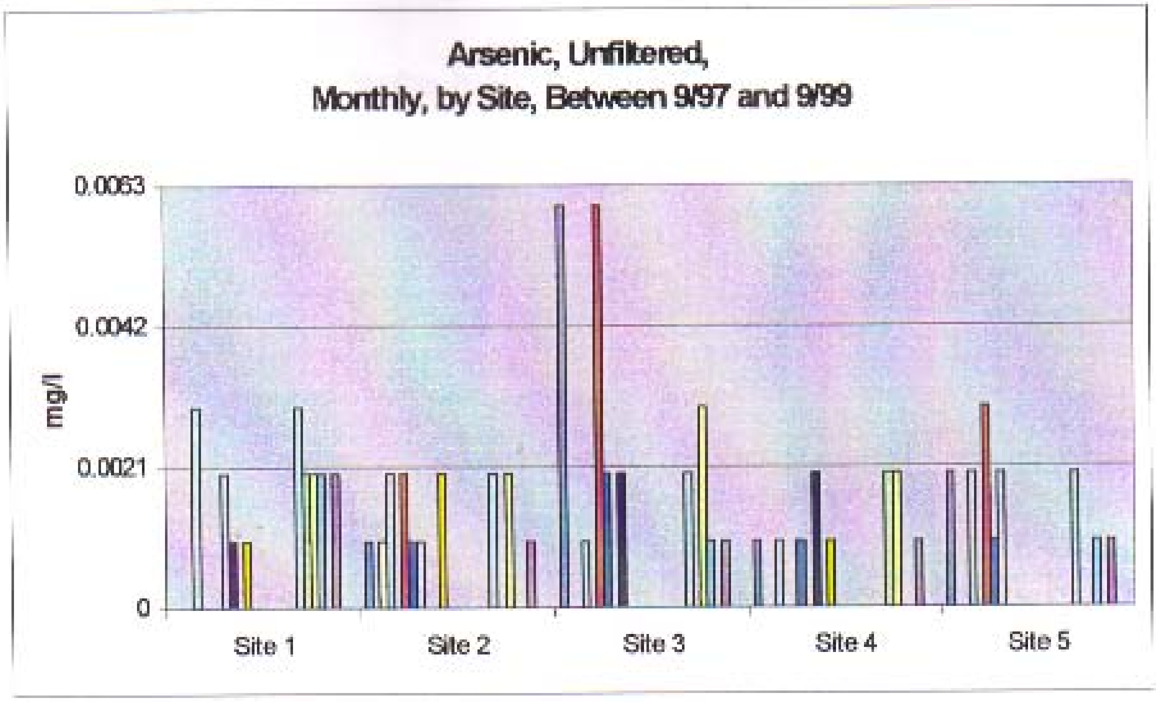


Figure 36. Arsenic, Unfiltered

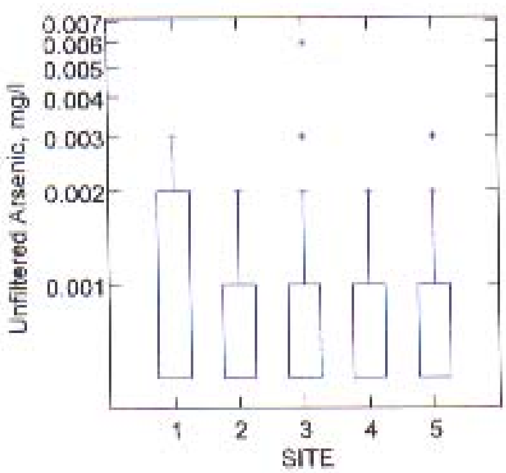


Figure 37. Box Plot for Unfiltered Arsenic

ANOVA

There are no significant differences between sites

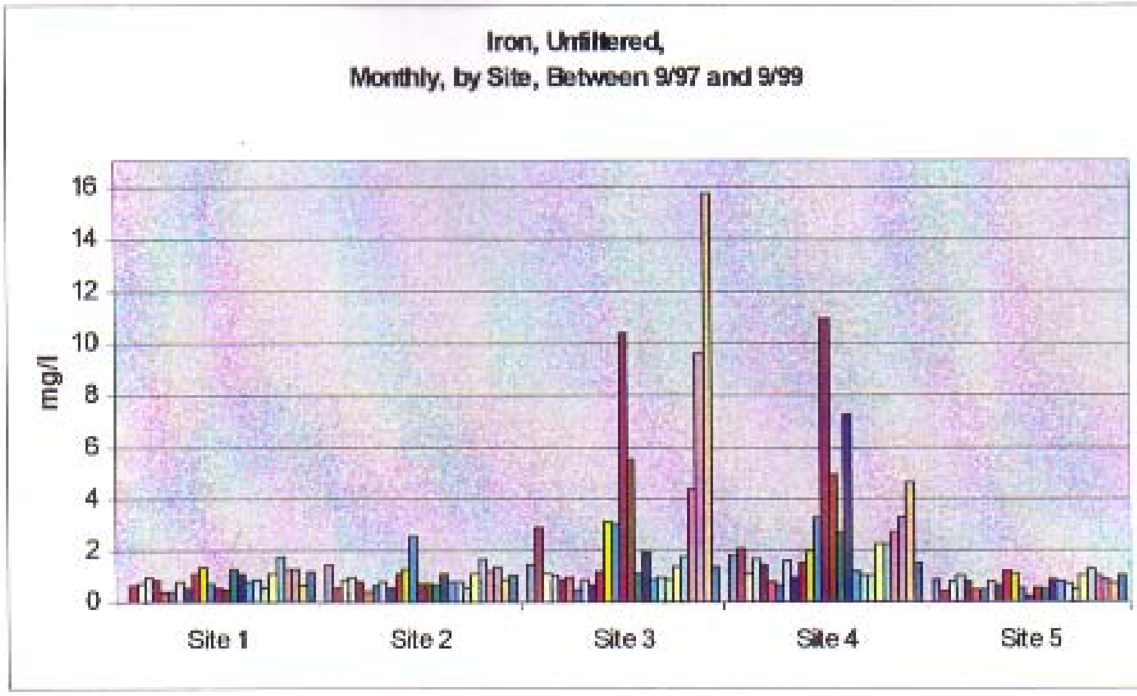


Figure 38. Iron, Unfiltered

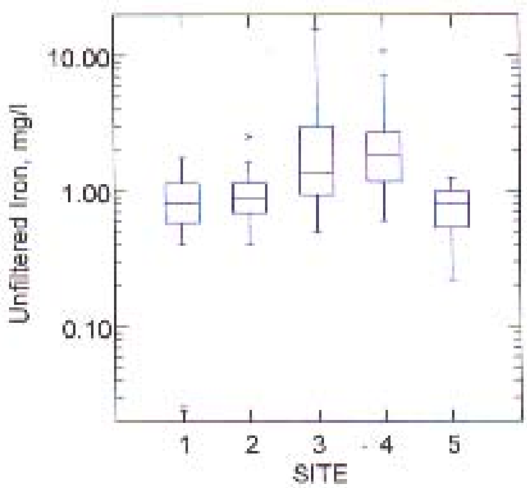


Figure 39. Box Plot for Unfiltered Iron

ANOVA

1 vs. 3 p<0.000
1 vs. 4 p<0.000
2 vs. 3 p<0.004
2 vs. 4 p<0.001
3 vs. 5 p<0.000
4 vs. 5 p<0.000

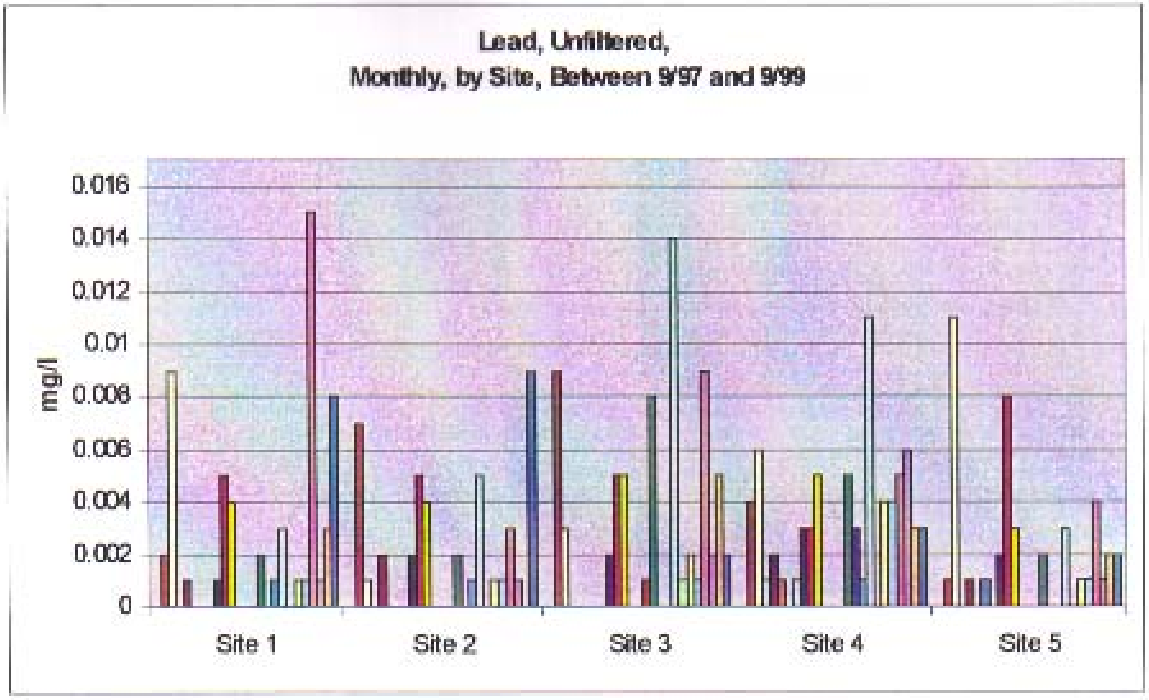


Figure 40. Lead, Unfiltered

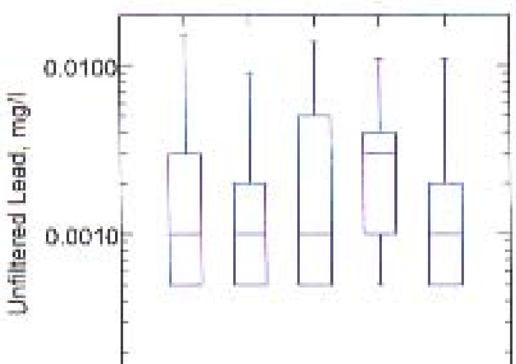


Figure 41. Box Plot for Unfiltered Lead

ANOVA

There are no significant differences between sites

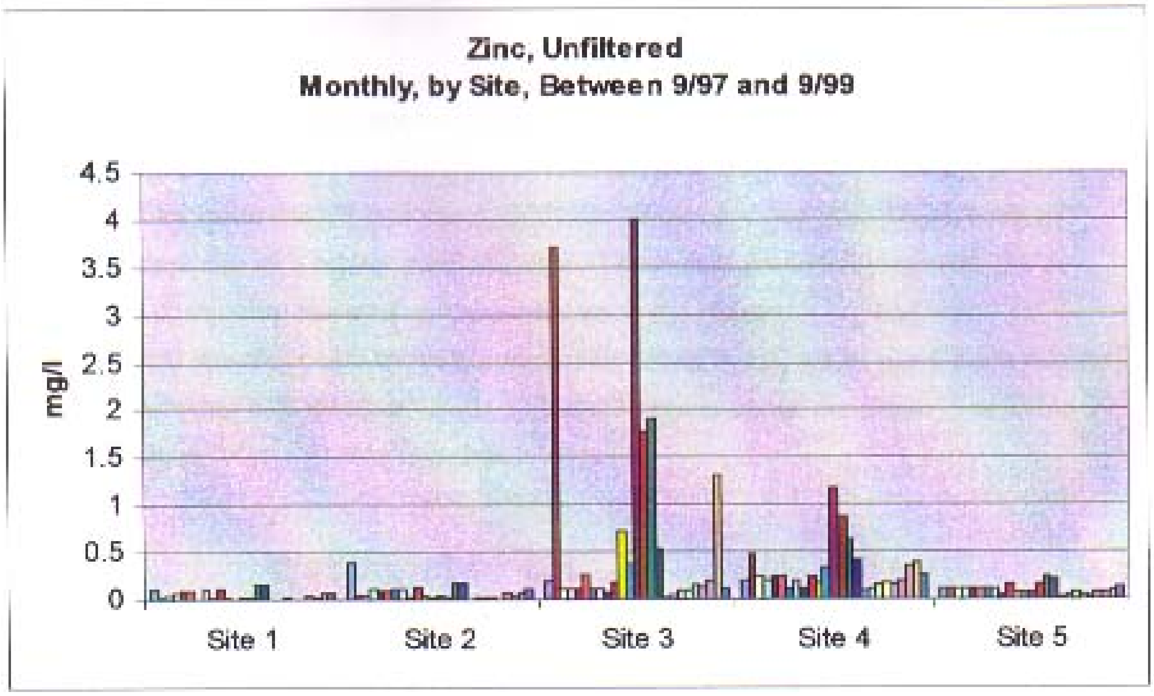


Figure 42. Zinc, Unfiltered

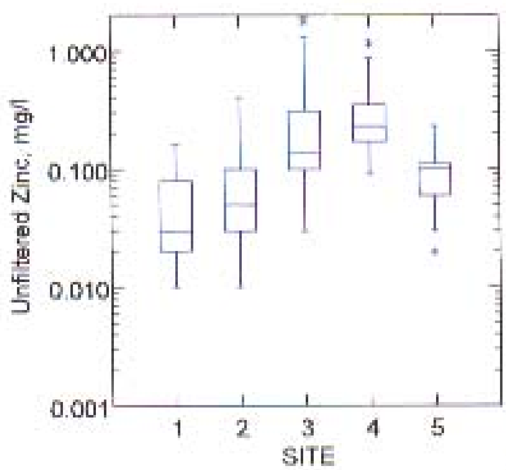


Figure 43. Box Plot of Unfiltered Zinc

ANOVA

1 vs. 3	p<0.000
1 vs. 4	p<0.000
1 vs. 5	p<0.033
2 vs. 3	p<0.000
2 vs. 4	p<0.000
3 vs. 5	p<0.000
4 vs. 5	p<0.000

Wet Weather Results

There are no significant differences between sites during wet weather conditions when considering pH. However, consultation of the Box Plot, Figure 45., shows that site 4 has a lower median value for pH and site 5, with it's influx of water from South Fork of Quantico Creek shows a higher median value. These data are in keeping with the dry data. When comparing the median values for each site (between dry and wet measurements) site 4 appears to have a minimally lower value, while site 5 has a minimally higher value during wet weather. Sites 1, 2 and 3 appear about the same. See Table 24 for Wet Weather Water Profile raw data.

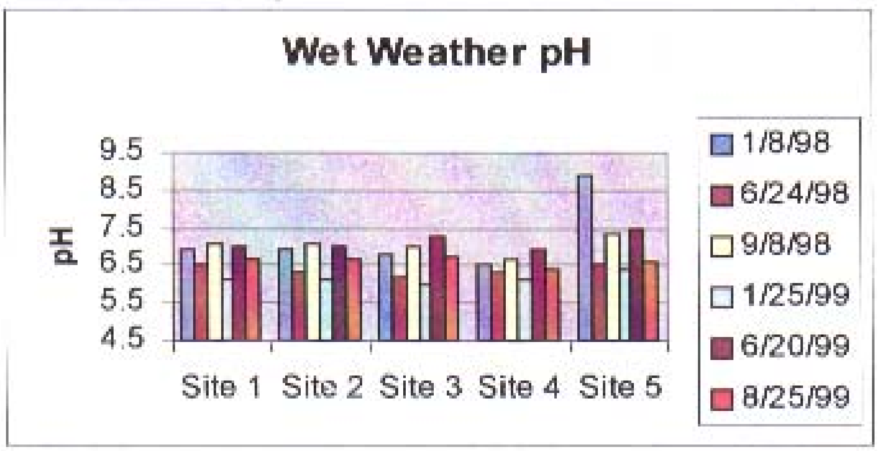


Figure 44. Wet Weather pH

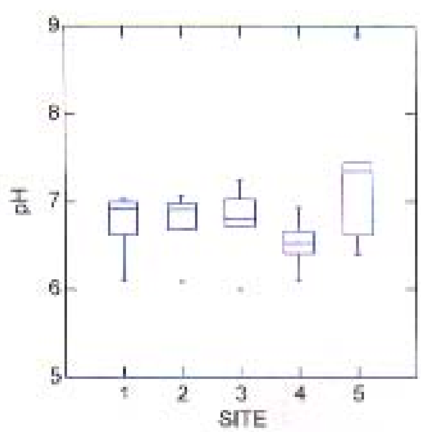


Figure 45. Box Plot of Wet Weather pH

ANOVA

There are no significant differences between sites.

There are no significant differences between sites during wet weather conditions when considering dissolved oxygen (Figure 47). This is as expected during a wet weather event. These data are in keeping with the dry data. When comparing the median values for each site (between dry and wet measurements) the dry values are somewhat lower than the wet values, but they generally follow the same pattern.

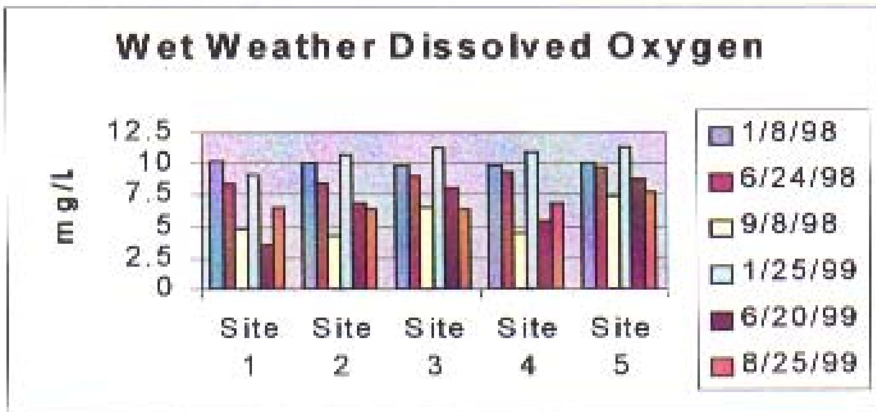


Figure 46. Wet Weather Dissolved Oxygen

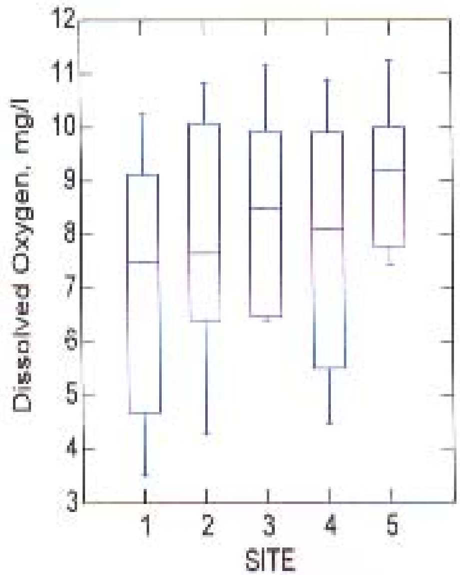


Figure 47. Box Plot of Wet Weather Dissolved Oxygen

ANOVA

There are no significant differences between sites.

Site 4 is significantly different from site 1 during wet weather conditions when considering conductivity (Figure 49). When comparing the median values for each site (between dry and wet measurements) sites 1 and 2 appear similar, site 3 has a higher mean during wet weather, site 4 has a considerably higher mean in wet weather, and site 5 has a slightly higher median value in wet weather.

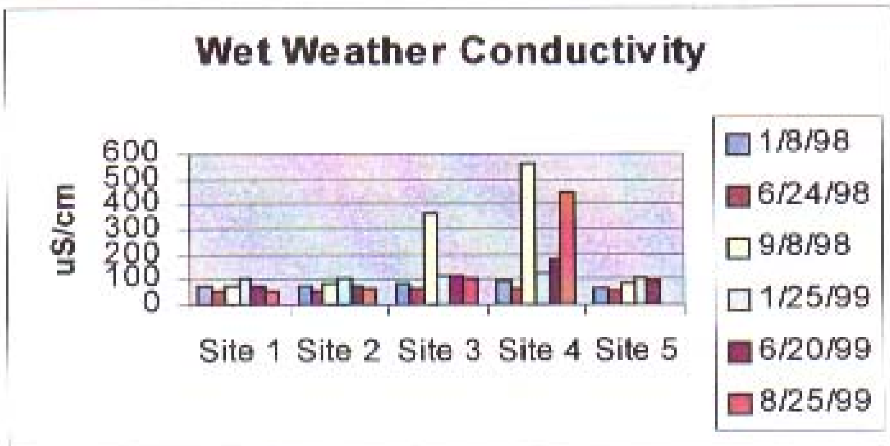


Figure 48. Wet Weather Conductivity

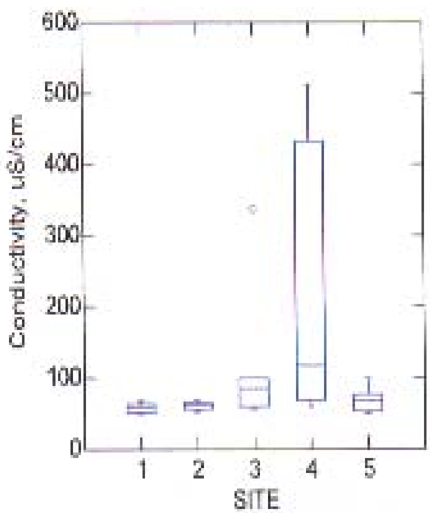


Figure 49. Box Plot of Wet Weather Conductivity

ANOVA

1 vs. 4 $p<0.0385$

2 vs. 4 $p<0.0565$ (near significance)

Site 4 is significantly different from site 2 during wet weather conditions when considering sulfates (Figure 51). When comparing the median values for each site (between dry and wet measurements) sites 1 and 2 appear similar, site 3 has a higher mean during wet weather, site 4 has a considerably higher mean in wet weather, and site 5 has a slightly lower median value in wet weather.

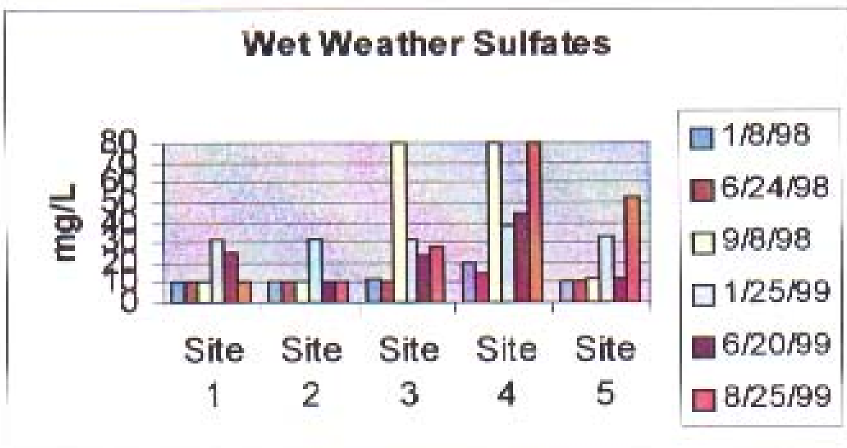


Figure 50. Wet Weather Sulfates

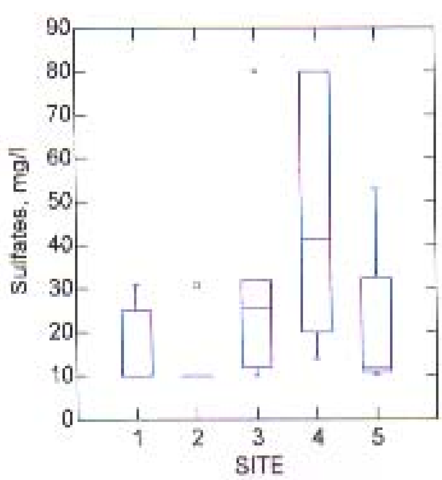


Figure 51. Box Plot of Wet Weather Sulfates

ANOVA

2 vs. 4 $p<0.0344$

There are no significant differences between sites during wet weather conditions when considering turbidity. However, consultation of the Box Plot, Figure 53., shows that site 4 has a higher median value for turbidity than any of the other sites. When comparing the median values for each site (between dry and wet measurements) all values are somewhat higher during wet weather compared to dry, with site 4 having a considerably higher median turbidity value during wet weather than during dry.

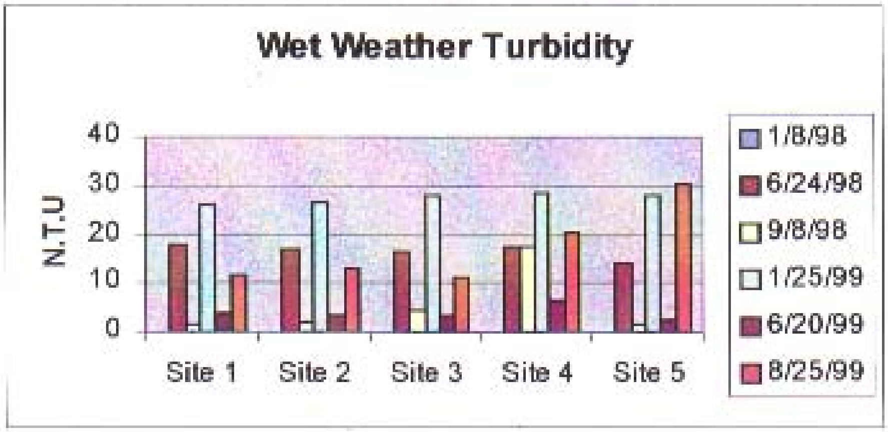


Figure 52. Wet Weather Turbidity

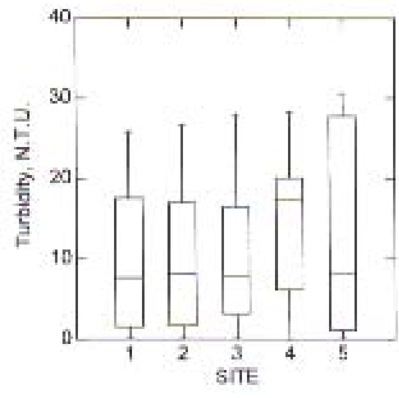


Figure 53. Box Plot of Wet Weather Turbidity

ANOVA

There are no significant differences between sites.

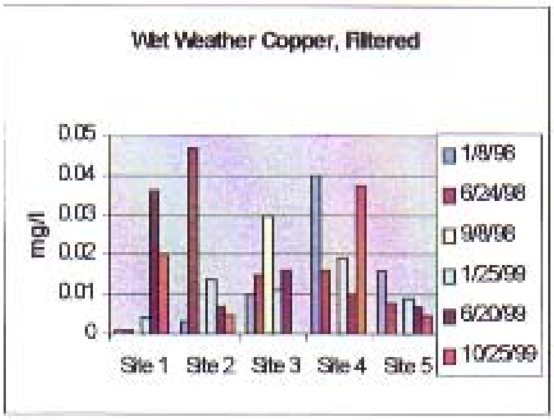


Figure 54. Wet Weather Filtered Copper

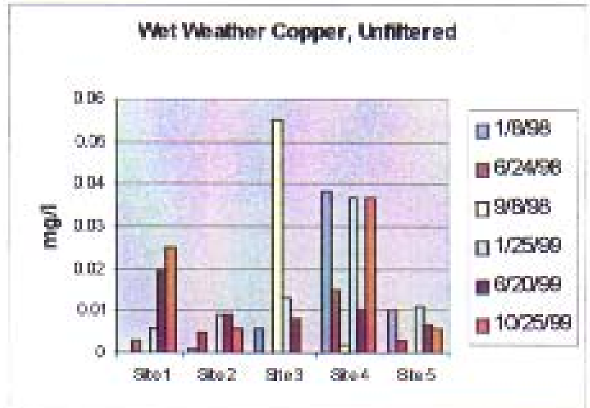


Figure 56. Wet Weather Unfiltered Copper

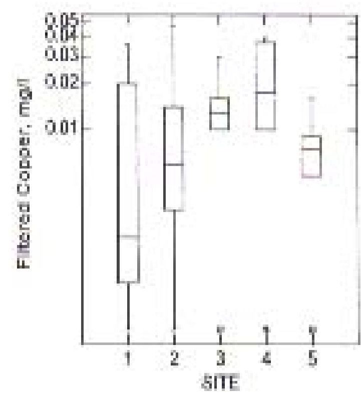


Figure 55. Box Plot Wet Weather Filtered Copper

ANOVA

There are no significant differences between sites.

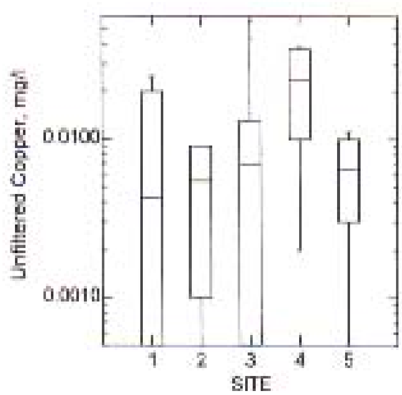


Figure 57. Box Plot Wet Weather Unfiltered Copper

ANOVA

There are no significant differences between sites.

Median values for filtered wet weather copper are somewhat higher for sites 1, 2, 3, and 4 than during dry weather. Site 5 appears about the same. Median values for unfiltered wet weather copper are slightly higher at sites 1, 2, and 5, and about the same at sites 3 and 4. See Table 25 for Wet Weather Metals raw data.

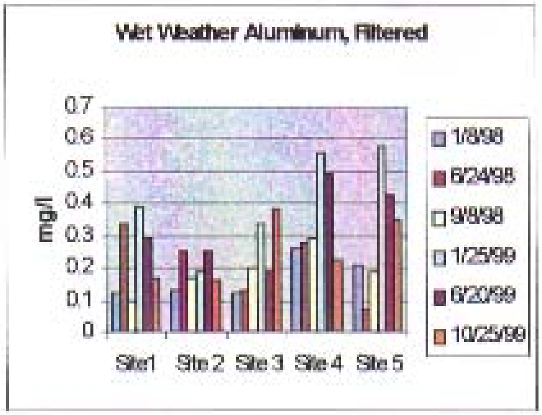


Figure 58. Wet Weather Filtered Aluminum

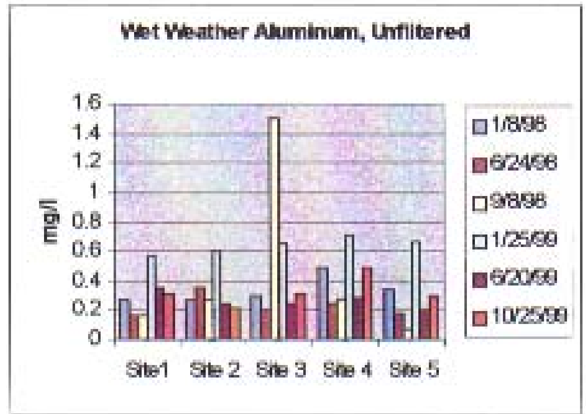


Figure 60. Wet Weather Unfiltered Aluminum

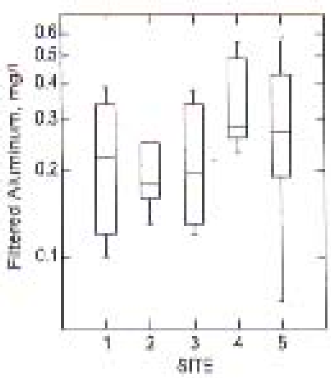


Figure 59. Box Plot of Wet Weather Filtered Aluminum

ANOVA

There are no significant differences between sites.

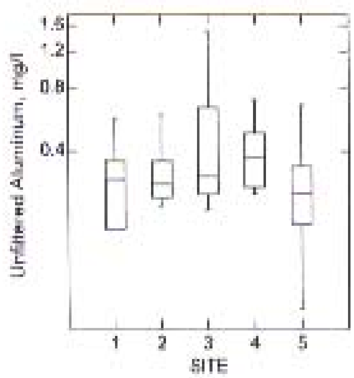


Figure 61. Box Plot of Wet Weather Unfiltered Aluminum

ANOVA

There are no significant differences between sites.

Median values for filtered wet weather aluminum are somewhat lower for sites 2, 3, and 4 than during dry weather. Median values for sites 1 and 5 appears about the same. Median values for unfiltered wet weather aluminum are about the same for sites 1, 2, and 5, and slightly lower at sites 3 and 4.

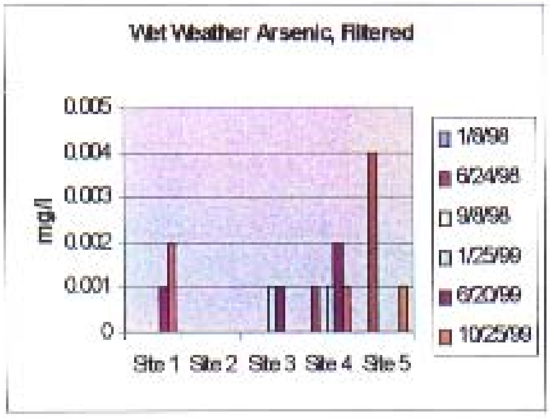


Figure 62. Wet Weather Filtered Arsenic

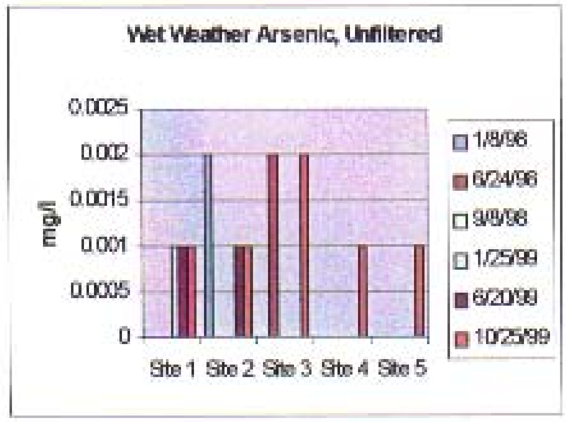


Figure 64. Wet Weather Unfiltered Arsenic

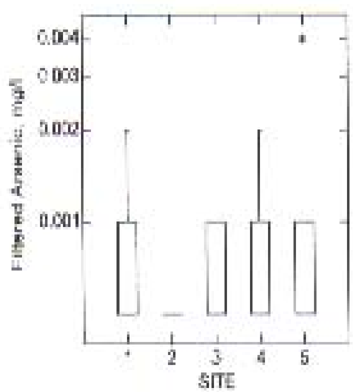


Figure 63. Box Plot of Wet Weather Filtered Arsenic

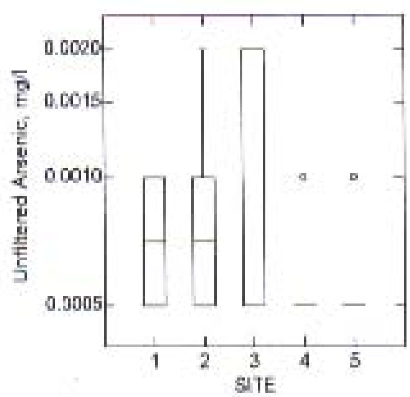


Figure 65. Box Plot of Wet Weather Unfiltered Arsenic

ANOVA

There are no significant differences between sites.

ANOVA

There are no significant differences between sites.

Median values for filtered wet weather arsenic are very similar for all sites when compared to dry values. Median values for unfiltered wet weather arsenic are slightly lower for all sites when compared to dry values.

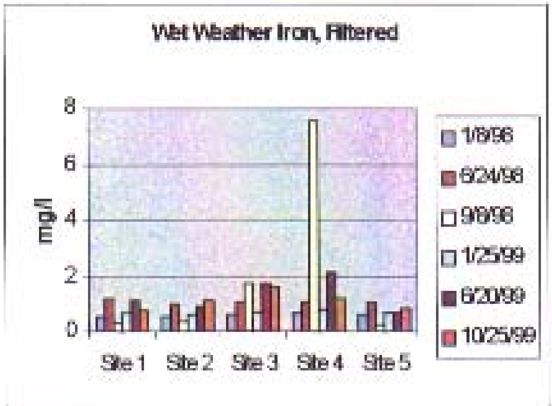


Figure 66. Wet Weather Filtered Iron

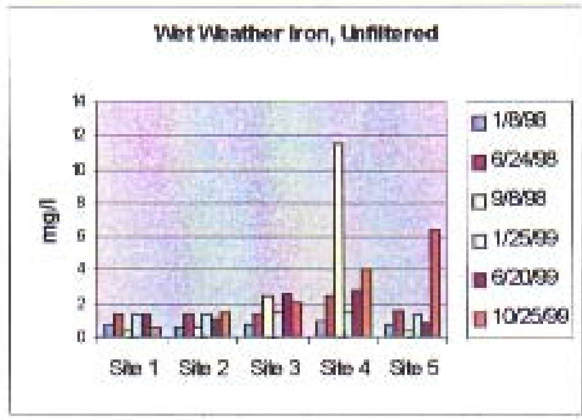


Figure 68. Wet Weather Unfiltered Iron

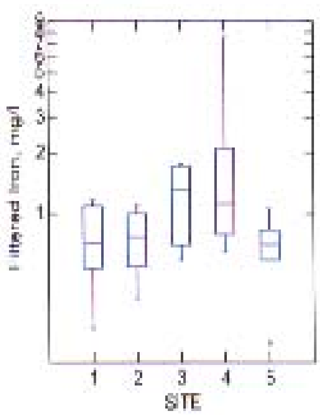


Figure 67. Box Plot of Wet Weather Filtered Iron.

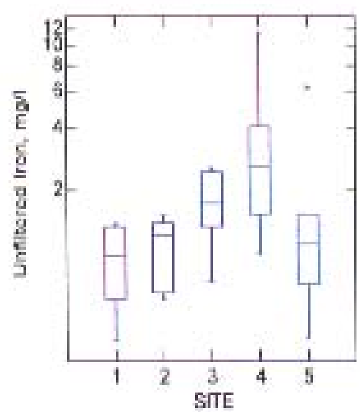


Figure 69. Box Plot of Wet Weather Unfiltered Iron.

ANOVA

There are no significant differences between sites.

ANOVA

There are no significant differences between sites.

Median values for filtered wet weather iron are very similar for all sites when compared to dry values. Median values for unfiltered wet weather arsenic are slightly higher for all sites when compared to dry values.

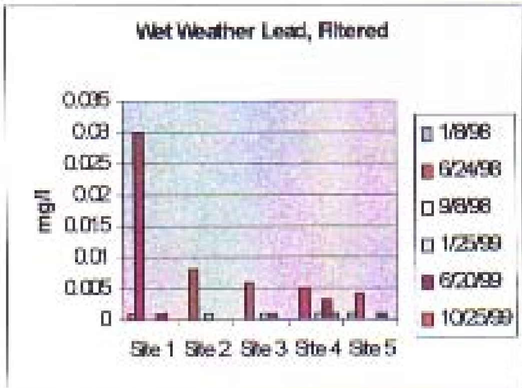


Figure 70. Wet Weather Filtered Lead

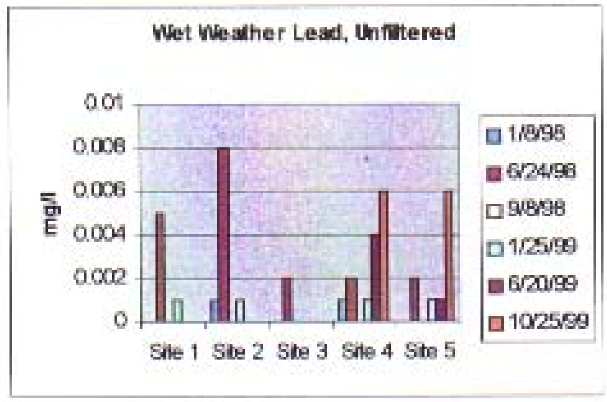


Figure 72. Wet Weather Unfiltered Lead

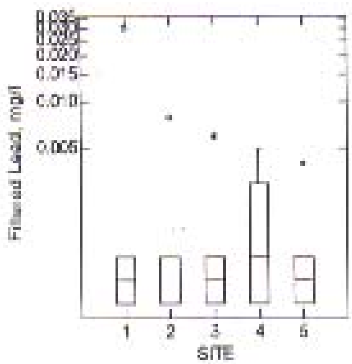


Figure 71. Box Plot of Wet Weather Filtered Lead

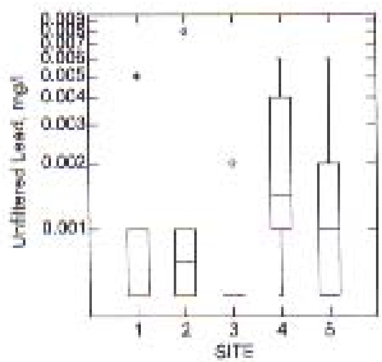


Figure 73. Box Plot of Wet Weather Unfiltered Lead

ANOVA

There were no significant differences between sites.

ANOVA

There were no significant differences between sites.

Median values for filtered wet weather lead are very similar for all sites when compared to dry values. Median values for unfiltered wet weather arsenic are similar if not slightly lower for all sites when compared to dry values.

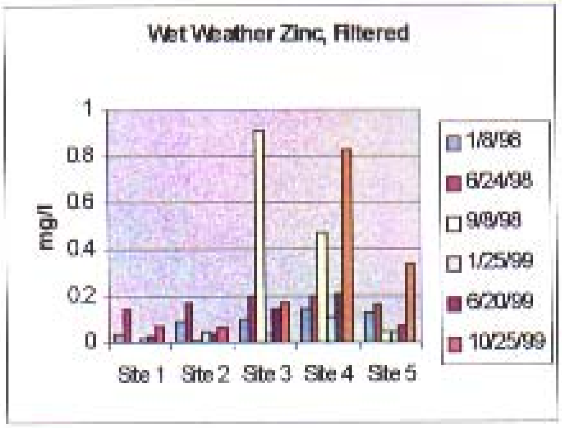


Figure 74. Wet Weather Filtered Zinc

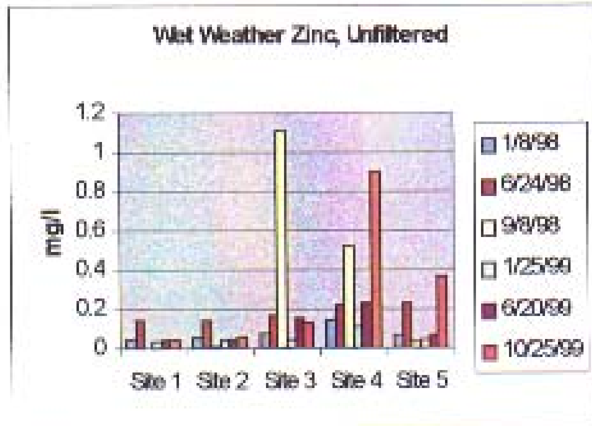


Figure 76. Wet Weather Unfiltered Zinc

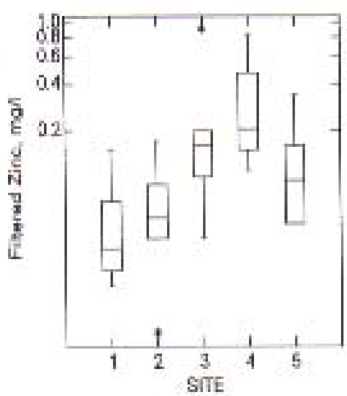


Figure 75. Box Plot of Wet Weather Filtered Zinc.

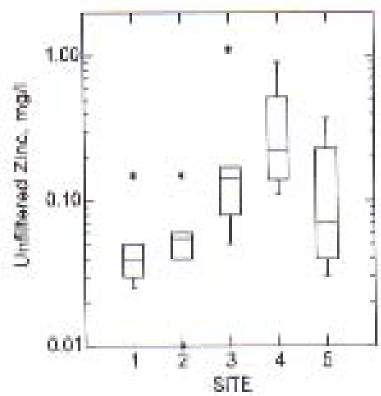


Figure 77. Box Plot of Wet Weather Unfiltered Zinc

ANOVA

1 vs. 4 $p<0.0152$

2 vs. 4 $p<0.0338$

ANOVA

1 vs. 4 $p<0.00199$

2 vs. 4 $p<0.0228$

Median values for filtered wet weather zinc are higher at sites 1,2, and 3 and about the same at sites 3 and 4 when compared to dry values. Median values for unfiltered wet weather arsenic are similar for all sites when compared to dry values.

In order to understand the repercussions of some of these data it is necessary to understand the rainfall data. Therefore we are presenting rainfall data as gathered at Quantico Marine Base adjacent to Prince William Forest Park.

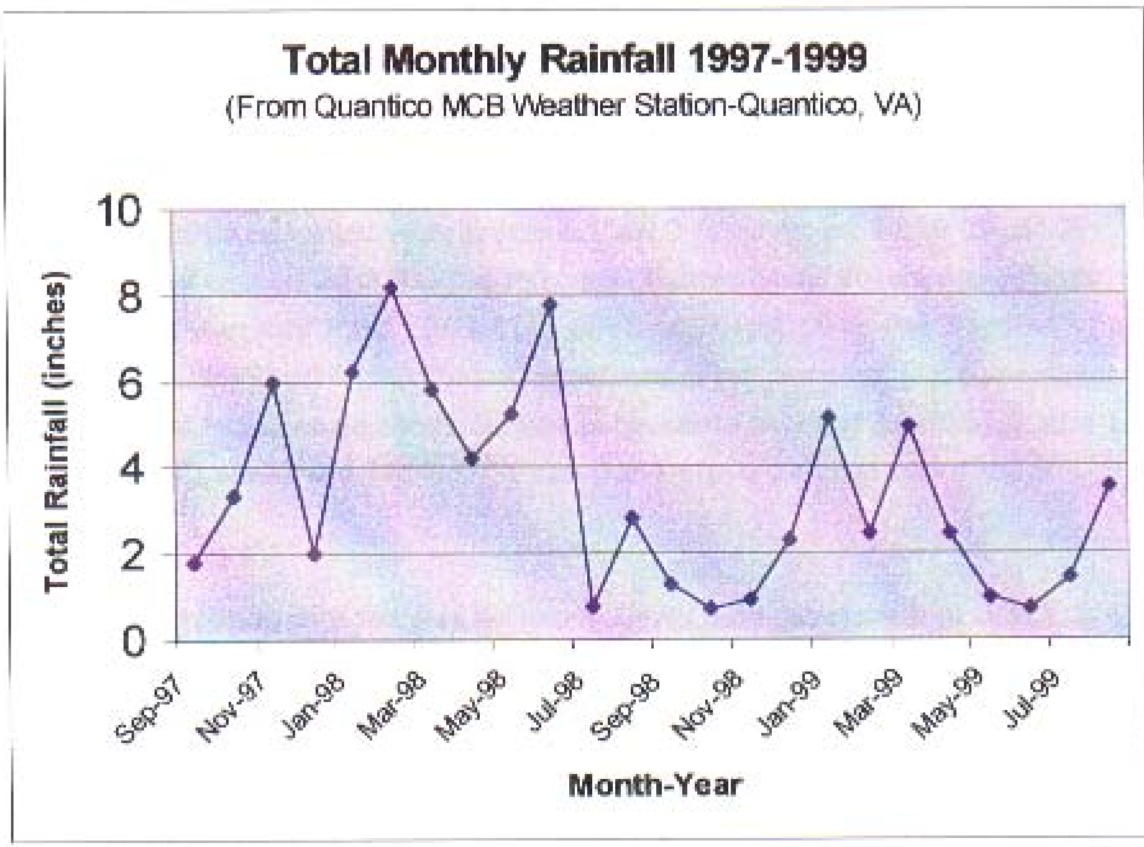


Figure 78. Total Monthly Rainfall 1997-1999

Note that July of 1998 started a drought period that remained throughout the study.

Benthic MacroInvertebrate Results

A total of 6,107 invertebrates were identified from the 35 samples collected between 1997 and 1999. The number of organisms identified in a sample ranged from 4 to 271. Table 27 contains the number of animals found in each of the samples by family.

An ANOVA determined that there were no significant differences between Sites 1 and 2 during any season (Site 1, 9/19/99 was not used). The RBP guidelines suggest omitting data from sampling events which do not generate 100 organisms. Since the lack of abundance was often an indication of habitat health, these data were included in this study. Metric scores were calculated using both sites 1 and 2 as reference (Tables 28 and 29). Comparisons of samples using Site 1 as reference (Figures 79 and 80) show significant differences between sites 1 and 3 ($p<0.014$), sites 1 and 4 ($p<0.004$), sites 2 and 3 ($p<0.014$) and sites 2 and 4 ($p<0.003$). Comparisons of samples using Site 2 as reference (Figures 81 and 82) show significant differences between sites 1 and 3 ($p<0.035$), sites 1 and 4 ($p<0.008$), sites 2 and 3 ($p<0.001$), sites 2 and 4 ($p<0.000$) and sites 4 and 5 ($p<0.028$).

Figure 79, Impairment with Site 1 as Reference, shows the bioassessment of sites 2, 3, 4, and 5 in comparison with the bioassessment of site 1 for each sampling date. According to these data, in comparison to site 1, site 3 was not impaired on March and June of 1998 and June of 1999. Site 3 was moderately impaired on October of 1997 and 1998, and March of 1999. Site 3 was never severely impaired. In comparison to site 1, site 4 was not impaired in March of 1998. Site 4 was moderately compared in October of 1997, June of 1998, March and June of 1999. Site 4 was severely impaired in October of 1998. In comparison to site 1, site 5 was not impaired in March and June in 1998 and in March in 1999. Site 5 was moderately impaired in October of 1997, October of 1998, and June of 1999. Site 5 was never severely impaired.

Figure 80 shows a box plot of the percent matrix comparison to reference number 1. Site 1 is significantly different from sites 3 and 4, as is site 2.

Figure 81, Impairment with Site 2 as Reference, shows the bioassessment of sites 1, 3,4, and 5 in comparison with the bioassessment of site 2 for each sampling date. According to these data, in comparison to site 2, site 1 was not impaired in October of 1997, October

of 1998, and March of 1999. Site 1 was on the borderline of being moderately impaired in June of 1998 and June of 1999. In comparison to site 2, site 3 was not impaired in March of 1998. Site 3 was moderately impaired in October of 1997,
June and October of 1998, and March, June and September of 1999. In comparison to site 2, site 4 was on the borderline of being non-impaired and moderately impaired in March of 1998. Site 4 was moderately impaired in October of 1997, June of 1998, and March, June and September of 1999. Site 4 was severely impaired in October of 1998. In comparison to site 2, site 5 was not impaired in March and June of 1998, and March and September of 1999. Site 5 was on the borderline of being non-impaired and moderately impaired in June of 1999. Site 5 was moderately impaired in October of 1997 and October of 1998.

Figure 82 shows a box plot of the percent matrix comparison to reference number 2. Site 1 is significantly different from sites 3 and 4, as is site 2. Site 4 is significantly different from site 5.

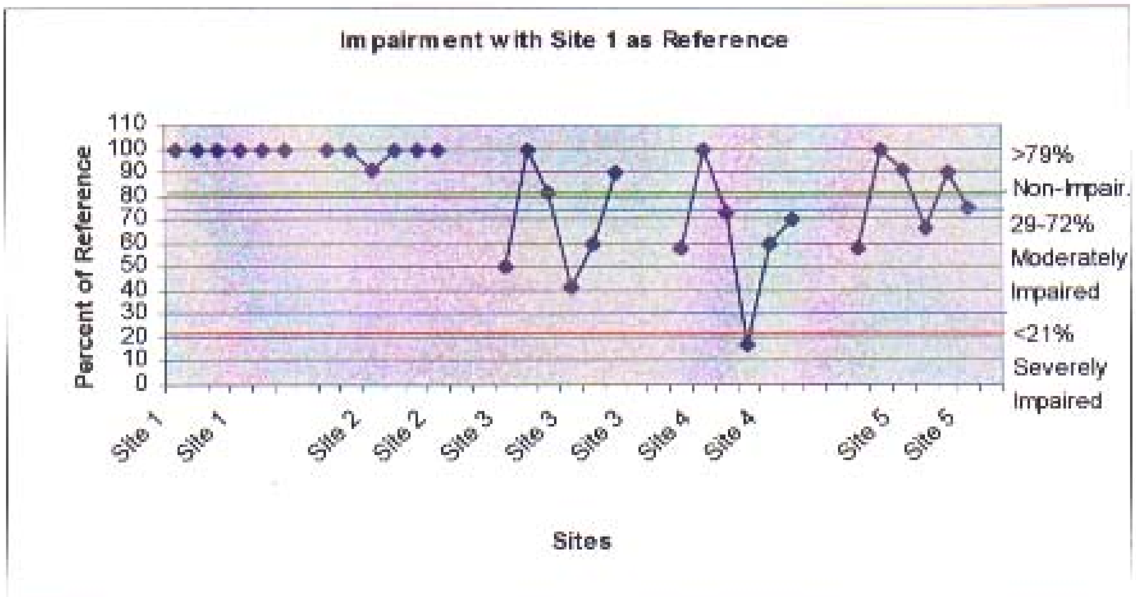


Figure 79. Impairment with Site 1 as Reference

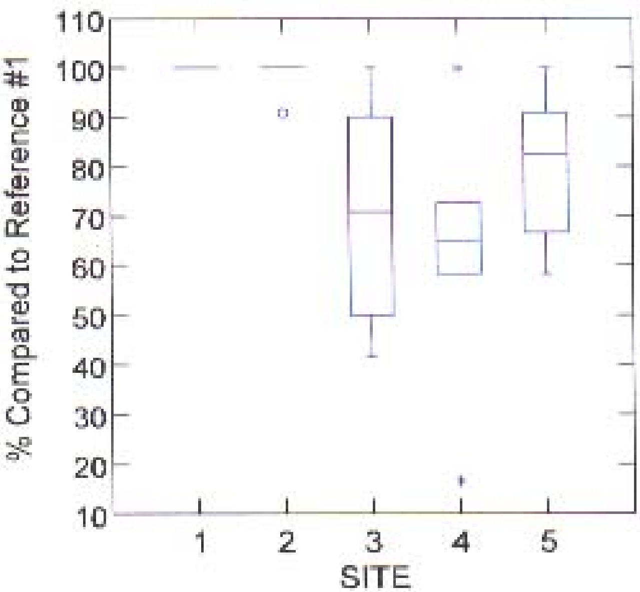


Figure 80. Box Plot of Percent Comparison to Reference Site #1

ANOVA

1 vs. 3 $p<0.014$
1 vs. 4 $p<0.004$
2 vs. 3 $p<0.014$
2 vs. 4 $p<0.003$

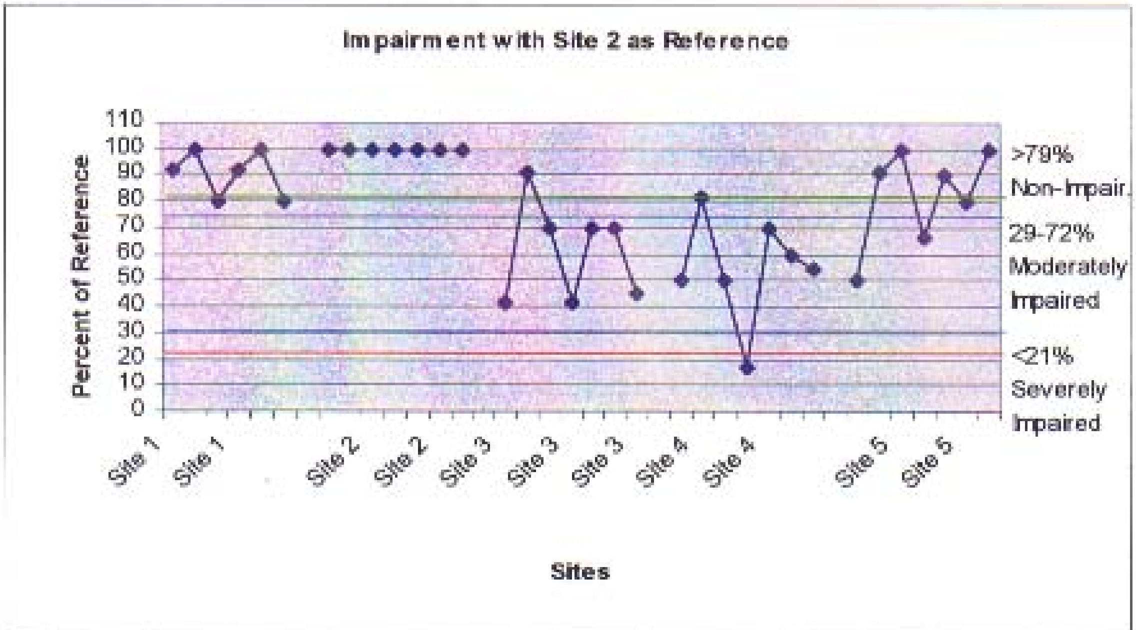


Figure 81. Impairment with Site 2 as Reference

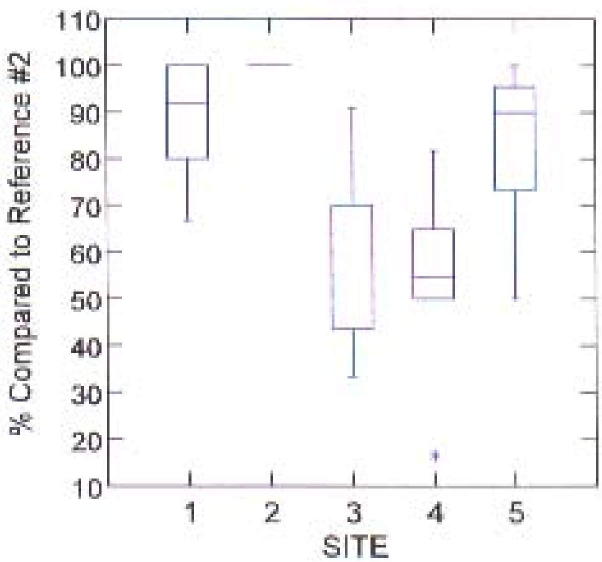


Figure 82. Box Plot of Percent Comparison to Reference Site #2

ANOVA

1 vs. 3 p<0.035
1 vs. 4 p<0.008
2 vs. 3 p<0.001
3 vs. 4 p<0.000
4 vs. 5 p<0.028

Fish Results

Index of Biotic Integrity

The Index of Biotic Integrity (IBI) was calculated according to the RBP V (Plafkin et al. 1989) protocol using scoring criteria derived from data collected at reference sites above the mining area.

Since all of the sample sites in this study were within 1,000 meters of each other, watershed size differed little among the sites. Nevertheless, Metrics 1-5 and Metric 10, which are identified as watershed dependent were calculated based on their watershed size and are plotted in Figure 90. Reference data were plotted first to determine the scoring criteria (1, 3 and 5), then all sample points from Sites 3, 4 and 5 were superimposed into the plots illustrated in Figure 90 to determine scores for all points. Scores were summed to obtain a total score for each site. According to the Plafkin et al. (1989) protocol, scores are classified into six different categories as illustrated in Table 3.

Table 3. Index Score Interpretation

IBI Score	Integrity Class	Characteristics
55-60	Excellent	Comparable to pristine conditions, exceptional assemblage of species
47-54	Good	Decreased species richness, intolerant species in particular; sensitive species present
37-46	Fair	Intolerant and sensitive species absent; skewed trophic structure
25-36	Poor	Top carnivores and many expected species absent or rare; omnivores and tolerant species dominant
12-24	Very Poor	Few species and individuals present; tolerant species dominant; diseased fish frequent

As shown in Figures 83 and 84, of the total 35 sampling points, most were considered "Fair" (57%), or "Poor" (37%). As shown in Figure 83, the control sites over the two-year period are typically characterized as "Fair" with two occasions at Site 1 that scored "Poor" (spring and summer 1998) and one occasion at Site 2 that scored "Poor" (spring 1999) according to this IBI scoring criteria. Likewise, the impacted area at Site 3 is also characterized as "Fair" with one occasion that scored "Good" over the two-year period. None of the sites ever scored "Excellent".

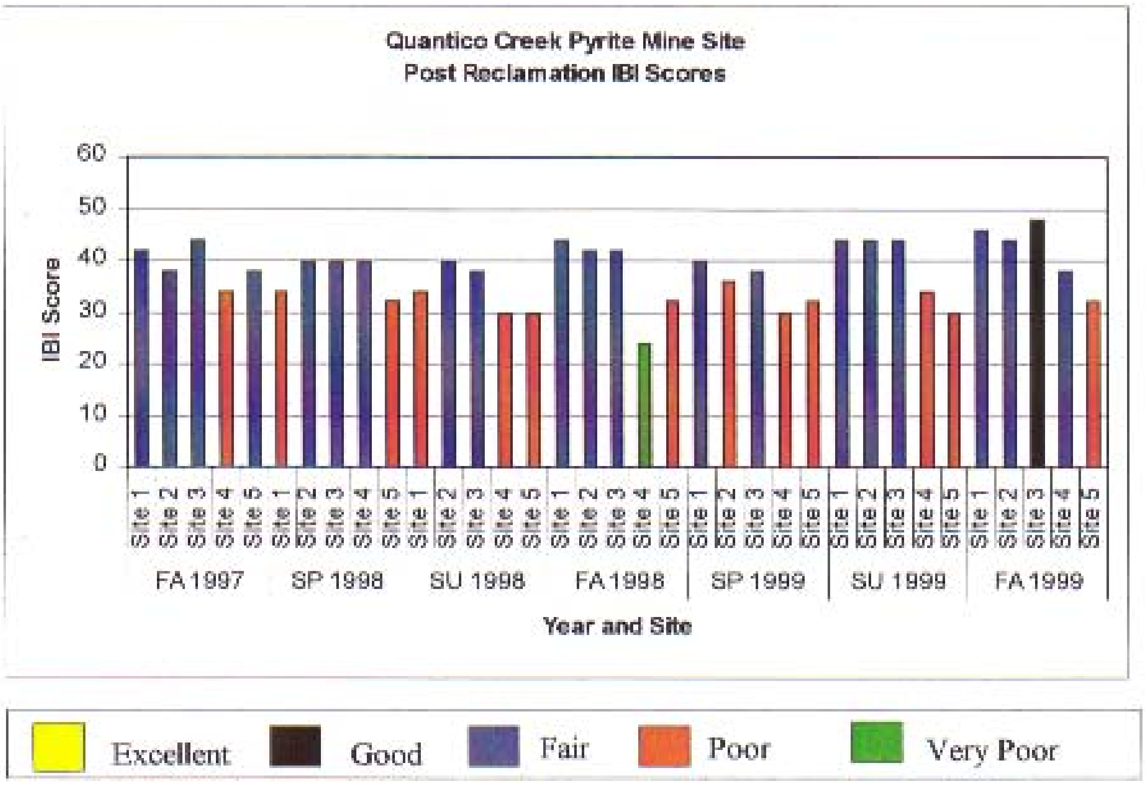


Figure 83: Post Reclamation IBI Scores

The impacted area at Site 4 and below the impacted area at Site 5 are typically characterized as "Fair" or "Poor" with only two occasions at Site 4 that scored "Fair" (spring 1998 and fall 1999) and only one occasion at Site 5 that scored "Fair" (fall 1997) according to this IBI scoring criteria. At one point over the two-year period, Site 4 scored "Very Poor" (fall 1998).

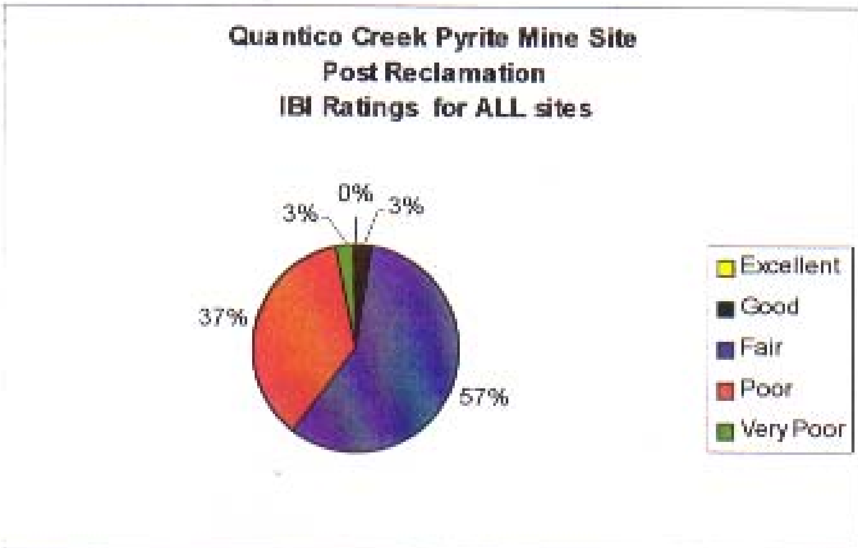


Figure 84. Post Reclamation IBI Ratings for ALL Sites

Figure 85 illustrates the IBI Ratings for Sites 1 & 2 and further exemplifies that the control sites tended to score "Fair" (79%) the majority of the time, "Poor" only 21% of the time and "Excellent", "Good" and "Very Poor" 0% of the time.

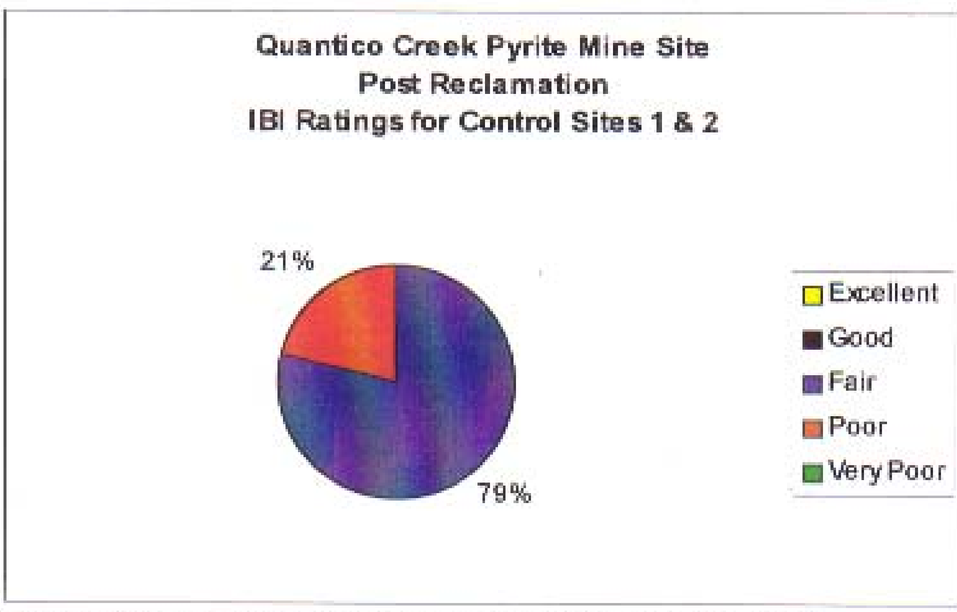


Figure 85: Post Reclamation IBI Ratings for Control Sites 1 & 2

Figure 86 illustrates the IBI Ratings for Site3. This site scored "Fair" (86%) the majority of the time, and "Good" 14% of the time.

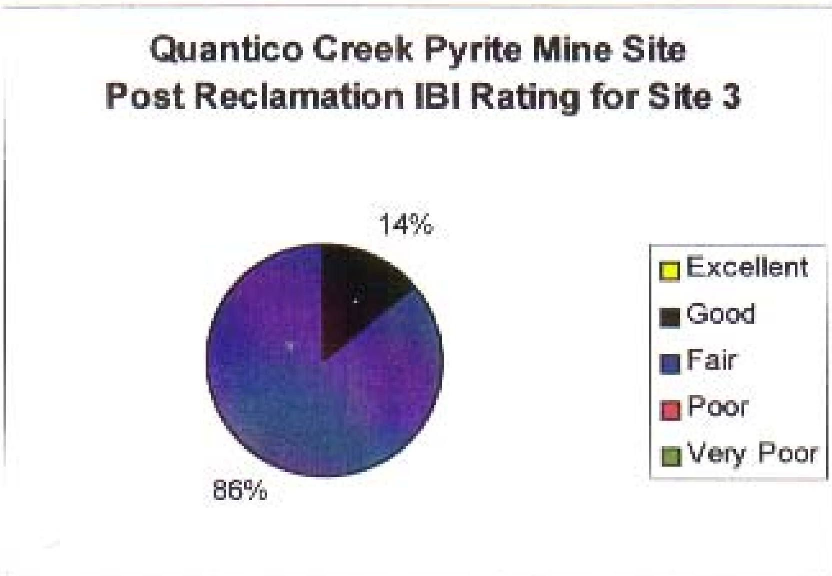


Figure 86. Post Reclamation IBI Ratings For Impacted Site 3

Figure 87. illustrates the IB Ratings for Site 4. This site scored "Fair" 29% of the time, "Poor" 57% of the time, and "Very Poor" 14% of the time. This site fares worst among all sites.

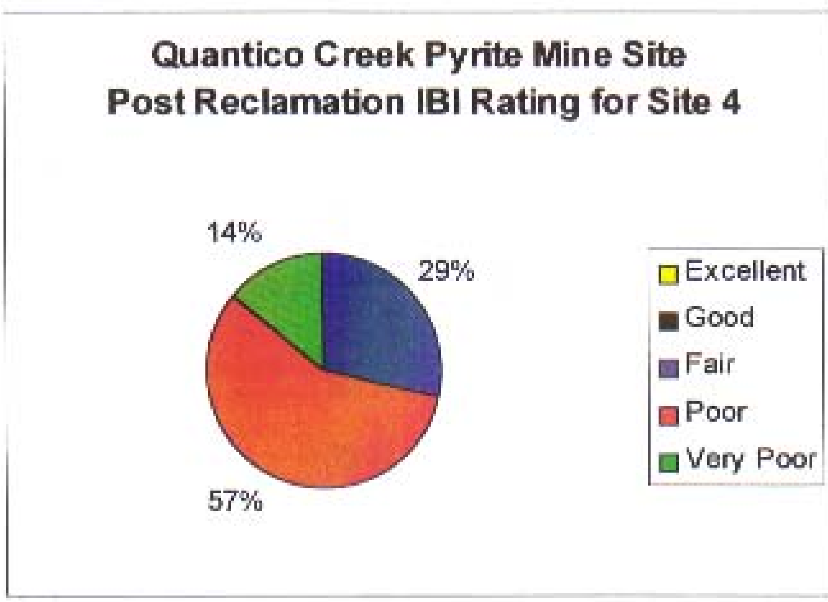


Figure 87. Post Reclamation IBI Ratings For Impacted Site 4

Figure 88. illustrates the IB Ratings for Site 5. This site scored "Fair" 14% of the time and "Poor" 86% of the time.

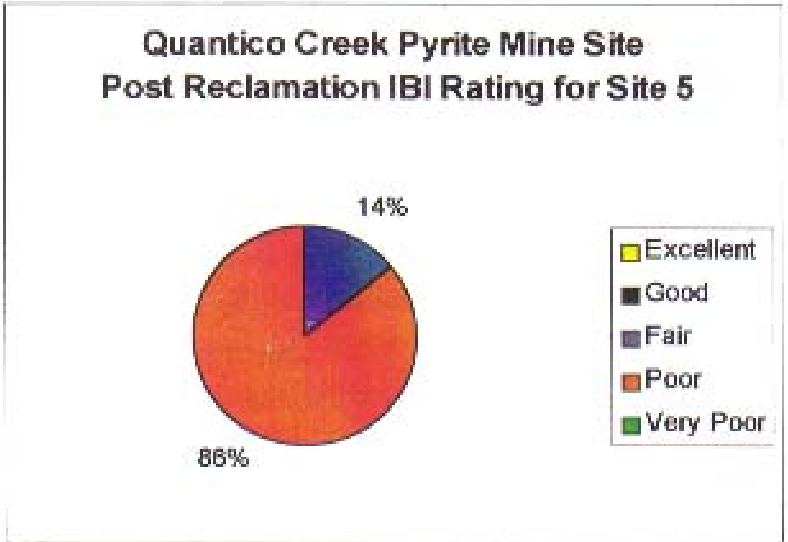


Figure 88. Post Reclamation IBI Rating For Impacted Site 5

Figure 89. shows the total ratings per catagory for each site. These data suggest that, in coparative order, site 3 is most healthy, followed by sites 2, 1, 5 then 4.

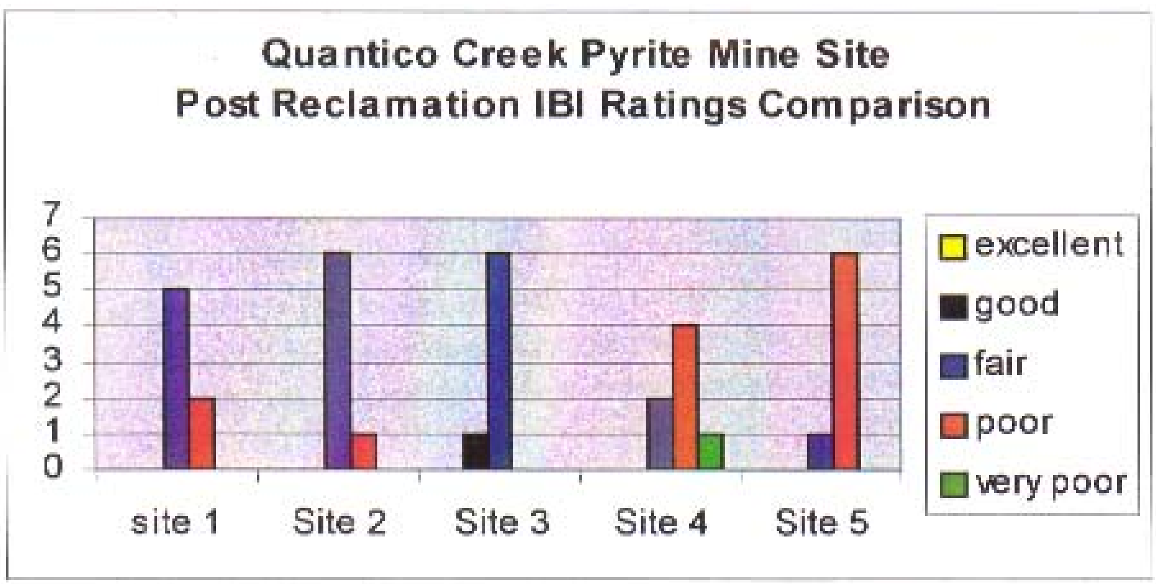


Figure 89. Comparison of IBI Ratings Among Sites

DISCUSSION

Water Profile Discussion

A discussion of water profile results must be preceeded by a discussion of the rainfall patterns (Figure 78) during the two years of this study. 1997 was a normal rainfall year. 1998 began normally but by July there were drought conditions which persisted and worsened into and through 1999. This drought could have several repercussions. First, it led to lower spring flows and very low baseflow conditions during the latter part of the study. This lack of baseflow tended to increase the temperature and decrease the dissolved oxygen. The lack of flow limited the available habitat for both fish and invertebrates, particularly invertebrates. Second, there was a decrease in the amount of acidic input (overflow) into the stream from July 1998 onward. While the lack of baseflow might seem to work against the biota, a decreased input of acidic water might have a positive effect on recovery (higher pH, fewer pulses and amounts of metals). Given these rather extreme weather conditions it is not known whether these data are representative of this stream's pattern of recovery under normal or wet conditions.

Hydrogen ion concentration was of considerable interest in this study. In general pH remained in the range conducive to sustain biotic life. There were times in August of 1999 and September of 1998 when pH levels at site 3 dropped to 5.5 and 5.4 respectively. While site 3 had the lowest singular reading, site 4 had consistently lower readings and was significantly different from site 1 ($p<0.017$) and site 5 ($p<0.007$). It would seem that site 4, while capable of maintaining a pH level of over 6.0, has not recovered as completely as site 3. Probably due to the influence of the diluting water of South Fork of Quantico Creek, site 5 is significantly different from site 4. It should be noted that there was very little run-off contribution from the "ditch" which gathers overland waters and feeds into the stream at site 3. This would be positive in the sense that the ditch could have brought in less waters of lower pH. This might contribute to a greater invertebrate population. However, the lack of flow also had the tendency not to dilute the rather low pH, high conductance baseflow. It is difficult to determine if the drought contributed to recovery.

Between sites there were no significant differences when temperature, percent saturation, dissolved oxygen and turbidity were considered. This means that the openness of the canopy at site 3 was counterbalanced by velocity of flow (rather amazing considering the lack of flow during the latter part of the study). The fact that turbidity was not significantly different among sites could attest to the lack of overland flow from the drought or the improved vegetation provided through the reclamation. The author was unable to locate any pre-reclamation turbidity readings for comparison. Regardless, even these higher turbidity readings are considered low.

Conductance and specific conductance are important as higher readings are indicators of higher ionic activity, and thus indicators (in the absence of other ion sources) that elevated levels of metals may be present. No conductivity or specific conductance readings were taken by the EPA during the Abandoned Mineral Lands Investigation (PWFP 1990). The Baseline Water Quality Data Inventory and Analysis of Prince William Forest Park (1994) cites a specific conductance reading of 1150 µS/cm taken on 5/25/83 at the bridge just downstream of our site 4 and above the confluence with South Fork Quantico Creek. In-stream pre-reclamation conductivity readings cited in Resource International (1993) were generally below 100 µS/cm. Their site 6 (our site 2 - control) had a reading of 232 µS/cm. Post-reclamation conductivity readings varied from a low of 26.6 µS/cm at site 1 in March of 1998 to a high of 785 µS/cm at site 4 in September of 1998. Specific conductivity readings (conductivity corrected to 25°C.) varied from a low of 39.9 µS/cm at site 1 in March of 1998 to a high of 866 µS/cm in September of 1998 at site 4. Field notes characterize the stream on both dates as having exceedingly low to no visible flow and the weather as clear and sunny. It is encouraging that site 5, with the influx of dilutant water from South Fork Quantico Creek, maintains a level similar to that of the control sites. However, the pulses of ions, as evidenced at site 3 and 4 suggest stress for the aquatic biota.

Sulfates are of interest because acid mine drainage occurs when sulfur in the mineral pyrite (FeS_2) is uncovered and exposed. The oxidizing action of air, water, is catalyzed by *Thiobacillus ferroxidans* (iron-loving bacteria) which utilizes the energy obtained from the conversion of sulfur to sulfate and sulfuric acid. (Letterman and Mitsch, 1978; Boccardy and Spaulding, 1968; Gray, 1997; Frank, 1983). Therefore, the measurement of sulfates is an in-stream measure of possible acid mine drainage activity. The Baseline Water Quality Data Inventory and Analysis of Prince William Forest Park (1994) cites a sulfate reading of 590 mg/l taken on 5/25/83 at the bridge just downstream of our site 4 and above the confluence with South Fork Quantico Creek. The method used in this study had a detection limit of 80 mg/l, and that was reached only 5 times throughout the study. much higher than any of our findings. No other pre-reclamation sulfate data were found. Sulfate levels at sites 1 and 2 remain low - generally below 10 mg/l and infrequently as high as 25 mg/l. Sites 3 and 4 have considerably greater sulfate levels than do sites 1 and 2. Site 4 has more frequent high levels than site 3. Site 5, again, has lower sulfate levels probably due to the dilution of the waters from South Fork Quantico Creek. These higher sulfate levels occur during extremely low flow periods and may be the result of baseflow concentrations rather than surface water input.

Metals Chemistry Discussion

On a gross level we see sites 1 and 2 grouping together and sites 3 and 4 grouping together. The two groups are significantly different when considering the groupings of copper, iron, and zinc. (There are no significant differences between sites when considering aluminum, arsenic, and lead.) Site 5 is significantly different from both groups only for zinc. Site 5 is significantly different from the 3-4 groupings for both copper and iron. This does not give us any indication that water quality had improved since the reclamation, only that conditions in the impaired area remain significantly different from the reference sites.

In terms of copper, sites 1 and 2 clearly have lower levels than sites 3 and 4. Site 5 has lower levels than the 3-4 group but higher levels than the reference group. The pre-reclamation copper levels from PWFP (1990) for our reference site 2 is 0.015 mg/l. It is not specified if these readings are total recoverable copper or dissolved copper. Since the criteria at that time was based on total recoverable levels it seems most plausible to assume that these levels were total recoverable. The readings taken between our sites 3 and 4 are listed as 0.061 mg/l. The reading for our site 5 was 0.046 mg/l. The PWFP Baseline data taken in 1983 from a site between our sites 3 and 4 was 0.060 mg/l (total recoverable). The Resource International report (1993) simply states that the copper reading between our sites 3 and 4 was below .100 mg/l (it is assumed these measurements are of the dissolved fraction because the standards against which they were compared are all soluble). All current results mentioned in this section are from the filtered metals results. If 0.015 mg/l were considered a historical reference point, then site 1 exceeded this level one time, site 2 exceeded this level two times, site 3 exceeded this level 11 times, site 4 exceeded this level 11 times and site 5 exceeded this level three times. If we use 0.060 mg/l copper as a historic level for sites 3 and 4, then site 3 exceeded this level only three times and sites 4 and 5 never exceeded this level. This would suggest an improvement in water quality attributable to the reclamation effort, at least in relation to the metal copper.

In terms of aluminum, there are no significant differences between sites. The pre-reclamation aluminum levels from PWFP (1990) for our reference site 2 is 0.096 mg/l. The readings taken between our site 3 and 4 are listed as 0.0055 mg/l, however just downstream just below our site 4 the level was 0.425 mg/l. The reading for our site 5 was 0.256 mg/l The PWFP Baseline data did not include aluminum., nor did the Resource International report. If 0.096 mg/l were considered a historical reference point, then the great majority of readings at all sites would exceed this level, indicating that it may be an anomaly. If we explore the historic 0.425 mg/l reading at our site 4 we find that site 1 exceeds this level seven times, site 2 exceeds this level eight times, site three exceeds this level 10 times, sites 4 and 5 exceed this level seven times each. Given the uniformity with which each site exceeds the historic level one might conclude that the sites continue to act uniformly. It is questionable whether there has been improvement in aluminum levels provided by the reclamation.

In terms of arsenic, there are no significant differences between sites. There are no pre-reclamation data for arsenic. For this reason it is difficult to determine if the reclamation had any affect on arsenic levels.

In terms of iron, sites 1 and 2 clearly have lower levels than sites 3 and 4. Site 5 has lower levels than the 3-4 group but is not significantly different from the reference group. The pre-reclamation iron level from PWFP (1990) for our reference site 2 is 0.490 mg/l. The readings taken between our site 3 and 4 are listed as 0.722 mg/l. The reading for our site 5 was 0.714 mg/l The PWFP Baseline data taken in 1983 from a site between our sites 3 and 4 was 1.4 mg/l (keep in mind this is a total recoverable measurement). The Resource International report (1993) simply states that the iron reading between our sites 3 and 4 was 3.9 mg/l. If 0.490 mg/l were considered a historical reference point, then site 1 would exceed this level 19 times, site 2 would exceed this level 17 times, site 3 would exceed this level 24 times, site 4 would exceed this level 24 times and site 5 would exceed this level 18 times. If we use 1.4 mg/l iron as a historic level for sites 3 and 4, then site 3 exceeded this level six times and site 4 exceeded the level nine times. Site 5 never exceeded this level. If we use 3.9 mg/l iron as a historic level for sites 3 and 4, then site 3 exceeds this level twice and site 4 never exceeds it. While the range of historical iron levels is rather wide, it would appear that iron levels may have improved since the reclamation.

In terms of lead, there are no significant differences between sites. The pre-reclamation lead level from PWFP (1990) for our reference site 2 (and all other in-stream sites) is below 0.050 mg/l . It is not specified if these readings are total recoverable lead or dissolved lead. The PWFP Baseline data taken in 1983 from a site between our sites 3 and 4 was 0.050 mg/ l (which was the level of detection). The Resource International report (1993) simply states that the lead reading between our sites 3 and 4 was below 0.050 mg/l (it is assumed these measurements are of the dissolved fraction because the standards they compare them to are all soluble). All the current measurements mentioned in this section are from the filtered metals results. If 0.050 mg/l were considered a historical reference point, then all readings at all sites would be below this level. Thus the historical data gives us little clue as to whether or not site conditions have improved, but is a remarkable benchmark from which to measure how detection levels have improved.

In terms of zinc, sites 1 and 2 clearly have lower levels than sites 3 and 4. Site 5 has lower levels than the 3-4 group but higher levels than the reference group. Each group is significantly different from the others. Zinc was not measured in the PWFP (1990). The PWFP Baseline data taken in 1983 from a site between our sites 3 and 4 was 0.280 mg/ l (total recoverable). The Resource International report (1993) simply states that the zinc reading between our sites 3 and 4 was below 0.320 mg/l (it is assumed these measurements are of the dissolved fraction because the standards they compare them to are all soluble). All the current measurements mentioned in this section are from the filtered metals results. If 0.280 mg/l were considered a historical reference point, then sites 1 and 2 would exceed this level zero times, sites 3 and 4 would exceed this level eight times each, site 5 would exceed this level one time. If we use 0.390 mg/l copper as a historic level for sites 3 and 4, then site 3 exceeded this level seven times and site 4 exceeded this level four times and site 5 never exceeded this level. These comparisons seem to imply an improvement in water quality attributable to the reclamation effort, at least in relation to the metal zinc.

The Virginia State Surface Water Standards for intake supply criteria are what Resource International (1993, 1994) used to evaluate Quantico Creek data.. They are: iron, 0.3 mg/l, lead, 0.05 mg/l, copper, 1.0 mg/l,zinc, 5.0 mg/l. They did not sample arsenic or aluminum. The Baseline Water Quality Data Inventory and Analysis for Prince William Forest Park (National Parks Service 1994) used freshwater acute criteria for the protection of aquatic life (with those metals that are hardness dependent, 100 mg/l $CaCO_3$) and drinking water standards. The acute criteria for copper was 18µg/l and the drinking water standard was 400µg/l. The acute criteria for lead was 82 µg/l and the drinking water standard was 5µg/l. They used only the acute criteria of zinc (120µg/l) for comparison. Since that time there have been some changes in the criteria. And, there is a "stay" of certain criteria (which includes arsenic, copper, lead, and zinc) which remains in effect. Regardless, the present acute water quality criteria for copper (all the hardness dependent criteria have been corrected using 20 mg/l $CaCO_3$ as it is more appropriate for this stream than 100 mg/l $CaCO_3$ - see Table 26) is 2.9 µg/l. The acute criteria for arsenic is 340 µg/l. The acute criteria for lead is 10 µg/l. The acute criteria for zinc is 30 µg/l. Aluminum is pH dependent. However, between the pH of 6.5 to 9 the criteria is 750 µg/l. EPA does not have an acute criteria for iron, but the continuous chronic criteria is 1,000 µg/l. This gives the reader a feel for the different criteria that can be used to compare the health of this stream. Since this investigation is interested in the biotic integrity of the water, the author chose to use the acute criteria (a dissolved measurement equating to our filtered samples) for comparison for compliance with the Clean Water Act.

The criteria maximum concentration (acute criteria) is the highest concentration of a pollutant to which aquatic life can be exposed for a short period of time (1-hour average) without deleterious effects (Federal Register, 1999). While the measurements taken were instantaneous, for the purposes of this comparison it is assumed that they persist for at least one hour.

In milligrams/liter, the acute copper criteria is 0.0029. Site 1 exceeded this criteria eight times, site 2 exceeded the criteria 14 times, site 3 exceeded the criteria 23 times, site 4 exceeded the criteria 23 times and site 5 exceeded the criteria 18 times. The acute criteria for arsenic is 0.340 mg/l. This site is in total compliance concerning arsenic. The acute criteria for lead is 0.010 mg/l. The only violation of this criteria occurred in June of 1999 when the reading at site 1 was 0.013 mg/l. The acute criteria for aluminum is 0.750 mg/l. Readings at site 1 exceeded the criteria twice, site 2 exceeded the criteria three times, site 3 exceeded the criteria seven times, site 4 exceeded the criteria five times and site 5 exceeded the criteria four times. The criteria of interest for iron is 1.0 mg/l. Site 1 exceeded this criteria four times, site 2 exceeded the criteria three times, site 3 exceeded the criteria ten times, site 4 exceeded the criteria 14 times, and site 5 exceeded the criteria one time. The acute criteria for zinc is 0.030 mg/l. Site 1 exceeded the criteria 16 times, site 2 exceeded the criteria 12 times, site 3 exceeded the criteria 24 times, site 4 consistently (25 times) exceeded the criteria and site 5 exceeded the criteria 23 times.

In summary, the historical data suggests that levels of copper in the stream have improved, though the waters continue to exceed the water quality criteria for copper. No conclusions can be made from the historical data concerning the improvement of aluminum levels in the stream and the waters continue to exceed the water quality criteria for aluminum. No conclusions can be made from the historical data concerning the improvement of arsenic levels in the stream but arsenic is in total compliance with the water quality criteria. The historical data suggests that levels of iron in the stream have improved, though the waters continue to exceed the water quality criteria for iron. No conclusions can be made from the historical data concerning the improvement of lead levels in the stream, but the waters continue to exceed the water quality criteria for lead. The historical data suggests that the levels of zinc in the stream have improved, thought the waters continue to exceed the water quality criteria for zinc.

Wet weather data suggests that, in general, wet weather pulses are no greater threat to biotic life than the water quality within the stream during dry periods. Site 4 continues to be problematic in that it exhibits significantly greater peaks of conductivity, sulfates, and zinc than the reference sites during wet weather events. This pattern suggests that this site continues to receive input of acid mine drainage, particularly during wet weather events.

Benthic Macroinvertebrate Discussion

While the RBP-II is not an exact measurement, it is extremely useful in this instance as we compare the assemblages of organisms at the non-impacted and recovering sites. Clearly the sites adjacent to reclaimed areas do not equal the reference sites. While there is some pre-reclamation invertebrate data available, none is comparable with these data so direct comparisons are impossible.

However, Resource International (1993) in their Phase I document, page 23, states:

> "The minor differences in faunal composition and density shown between stations are likely due to differences in substrate composition, which was visually controlled for but not actually measured. There is some depression of macroinvertebrate density and diversity, measured as number of taxa, at the lower end of the mine and in particular near the tailing piles. Benthic Station 3 [between our site 3 and 4], which is actually below the point of entry of the most acidic surface drainage, as indicated by the water quality results from Station 4, does show fewer individuals and taxa than the other stations sampled. However, this depression seems to be fairly localized as downstream Station 2 [between the confluence of South Fork Quantico Creek and our site 5] shows a modest recovery in types of species present, if not their density. In addition, Station, which serves as a background station on South Fork Quantico Creek, had similar densities and number of individuals to

Station 2.

Based on the above analysis, Resource International (1994) in their Phase II document (page 6) state:

> "Based upon the limited sampling of the benthic macroinvertebrate community in the vicinity of the abandoned mine, it does not appear that increased sediment load or low pH runoff have pervasively impacted the stream's ability to support macroinvertebrates."

It would appear that the more thorough investigation and analysis was able to illuminate the differences only hinted at in the pre-reclamation data.

This researcher was surprised and pleased at the positive invertebrate health exhibited at site 3, mainly because the pre-reclamation chemical and profile data painted a very grim picture. It was not known how quickly the invertebrate community would be able to rebound. The reclamation was designed to reduce overland flow of acid mine drainage and mitigate the effects of that which actually reached the stream. The non-impaired to moderately impaired status of site 3 over time suggests that the design has been effective. A contributor to the health of this community might be the drought and lack of acid mine drainage input as a result (see precipitation data Figure 78). However, the drought provided other stresses. Another explanation for its extent of recovery might be that the riffle and run sampled was approximately 0.5 and three meters respectively above the confluence with the "ditch" that drains the reclaimed area on the far side of the creek. Thus, the run may not get the full impact of any overland flow of remaining acid mine drainage.

Prince William Forest Park has completed invertebrate monitoring using the "SOS" method developed by the Issac Walton League (PWFP, 1992, 1993, 1995, 1996, 1997, 1998, 1999, 2000). The 1992 and 1993 results for the area immediately adjacent to the hill slope range from poor to good with one excellent in 1993. Direct comparisons with the RBP data presented here and with subsequent post-reclamation SOS data may not be possible. However, SOS data taken at our site 3 (B-2 in the PWFPa 1995, 1996, 1997, 1998, 1999, and 2000 reports) shows continuous improvement in ratings until the drought in 1999. Populations have still not reached the good range that existed in 1998.

Continued visual observation alone, of site 4, would have led this researcher to conclude that it was severely impaired. All substrate is covered with orange/yellow flocculate, at some places several centimeters deep. This is absent at sites 1, 2, 3, and 5. The invertebrate results show that while this site has RPR values slightly lower than site 3, it is still only moderately impaired, with only one instance of severe impairment. When compared to reference site 1 there is no significant difference between the communities of sites 3 and 4. When compared to reference site 2 there are significant differences between sites 3 and 4. Park rangers report that orange flocculate is commonly found throughout the park, including South Fork Quantico Creek, which supports healthy biotic communities. While the water quality profile and metals analyses point to its debilitated state, the biotic community appears only slightly less robust than that at site 3. Therefore, it appears that visual observance of yellow-boy is not a valid indication of community health.

The contribution that reclamation has made to the invertebrate community is not measurable because we have inadequate pre-reclamation data. What is known is that the communities at sites 3 and 4 are moderately impaired with site 3 fairing somewhat better than site 4. Site 5, with the influence of the input of South Fork Quantico Creek is also moderately impaired but fairing better than either site 3 or 4.

Fish Discussion

Index of Biotic Integrity

The IBI is valued by biologists primarily because of its ability to combine measures of fish health in individuals, populations, communities, ecosystems and landscapes. It is more than just a community-based analysis and is therefore very useful in revealing important biological patterns. Furthermore, the IBI standardizes fish data collection methods and allows for comparisons to be made not only within watersheds, but also between watersheds based on reference conditions specific to each sampling effort. These methods are manageable and fairly easy to employ in a wide variety of circumstances. For example, park areas, which may not have the funds or staff to employ a highly technical, sophisticated research program, can fairly easily employ the standardized field methods required for the IBI for use as an inventorying and monitoring tool. Although IBI scores are not intended to be diagnostic, they do serve as a sort of environmental screening to aid land managers in determining general stream health and may therefore be very useful in helping decision makers to prioritize areas that may require more in-depth research to determine the source and treatment of the problem.

In order to use the IBI most effectively, it is important to acknowledge its limitations. As is the case with any index, some valuable distinctions may be difficult to tease out in an overall score without a more thorough analysis of the data that make up each metric. This may be due, in part to the fact that some specific information may be lost in the process of assigning scores. For example, when calculating scores for watershed dependent metrics (Figure 90), points that are clearly "1", "3" or "5" get the same score as those that are borderline "1", "3" or "5". One investigator may score a high borderline "3" as a "3", while another investigator may score the same borderline "3" as a "5". This introduces additional variability to the scoring that could influence the overall IBI scores and obscure subtle difference between data points. Furthermore, when scores for each metric are summed and assigned to one of the five ratings (i.e. "Excellent", "Good", "Fair", "Poor", "Very Poor"), distinctive differences between two sites may exist even though each may be assigned the same rating. In other words, if two sites are assigned a rating of "Fair", it is assumed with the IBI that "Fair" equals "Fair" even though distinctive differences between may exist. However, it is not necessarily the intent of the IBI to be absolutely precise. Rather, it is intended to provide a ballpark approximation of overall stream health and provide clues about sites that may require more thorough investigation. Therefore, the IBI is a widely accepted method of analysis for fish and was helpful in this study in targeting general stream health patterns.

The IBI was used in this study to calculate scores for each of the five sampling sites by season. The 12 metrics considered included attributes of species richness and composition (6 metrics), trophic composition (3 metrics) and fish abundance and condition (3 metrics). The results indicated that 57% of the sites ranked "Fair" and 37% of the sites ranked "Poor" with a single ranking of "Good" (Site 3, fall 1999) and a single ranking of "Very Poor" (Site 4, fall 1998). Comparisons of these IBI scores revealed a pattern that was observed throughout the data analysis in this study. This pattern showed that Impacted Site 3 resembled the Control Sites 1 and 2 with the majority of scores being "Fair" and that Impacted Site 4 is still showing signs of degradation with the majority of scores being "Poor".

These results raise the question as to why the control sites only scored "Fair" and not "Good" or "Excellent". It is important to emphasize that although all stream reaches in the park have been afforded protection by the NPS for some 70 years, they are still recovering from a wide range of historical impacts. Although the control sites in this study (Sites 1 and 2) were selected as the 'least modified ecosystem' primarily because they were not impacted by the mining activity, clearly, they too, are still recovering from other historical uses of the land. Therefore, scores of "Fair" for the control sites, in this case are not surprising; scores of "Good", as was seen at impacted Site 3 in the fall 1999, is truly remarkable; and scores of "Excellent" are highly unlikely. Scores of "Excellent" are comparable to pristine conditions, which in a highly populated, densely developed area like Northern Virginia would be very difficult to achieve.

Pre- vs. Post Post Reclamation Fish Data Analysis

The Pyrite Mine Site pre-reclamation fish data collected by Kelso and Lawson (1995) in the impacted area showed low species richness (6 species in 5 families) and low fish abundance (56 individuals). The majority (92%) of the individual fish collected in this sample were generalist omnivores and fairly tolerant to disturbance (*Rhinichthys atratulus* (30%), *Semotilus corporalis* (16%) and *Anguilla rostrata* (46%)). The success of these species surely reflects their ability to tolerate degraded habitat and water quality conditions and to make the most of whatever food items are available.

By comparison, post-reclamation data collected in the impacted area showed a greater species richness in 1998, with representatives of 13 species in 6 families and even greater in 1999 with representatives of 16 species in 8 families. The majority (75%) of the total number of individual fish collected in 1998 were specialists and either Insectivores or Invertivores that were fairly intolerant of disturbance (*Notropis species* (24%), *Lepomis auritus* (21%), *Erimyson oblongus* (13%), *Lepomis gibbosus* (9%) and *Clinostomus funduloides* (8%)). As post reclamation species richness in the impacted area increases, this data suggests that tolerant generalist species are being replaced by more intolerant specialist species.

The total number of individual fish collected in 1999 represented both specialists and generalists; insectivores, invertivores and omnivores; and tolerant, intermediate and intolerant to disturbance with the majority (76%) *Notropis species* (22%), *Luxilus cornutus* (12%) *Lepomis auritus* (11%), *Anguilla rostrata* (9%), *Lepomis gibbosus* (8%), *Semotilus corporalis* (8%) and *Clinostomus funduloides* (6%). Assuming the Pyrite Mine Site pre-reclamation data point is representative of the pre-reclamation conditions, these 1999 data are promising in that habitat conditions in the mine-impacted area post reclamation seem more able to support a wider diversity of fish at various trophic guilds and tolerance levels. It is important to further note that in 1999 both Piscivore species (*Esox niger* and

Micropterus salmoides) were observed in the mine-impacted area. The presence of top predators in an ecosystem is evidence of robust and complex energy flow in the lower trophic levels (Alan 1995).

Post Reclamation Fish Data Analysis

These data indicate that larger numbers of fishes occur in the fall (53% of annual total) with smaller differences between spring (20%) and summer (27%). The high number of individual fish occurring in the fall may be due, in part, to the presence of young of the year. Although only fish 2cm in length and greater were counted to minimize young of the year effects, it is likely that a percentage of the fall counts can be attributed to young of the year.

Studies show that in temperate warm-water streams (such as Quantico Creek), fishes that feed on a wide range of invertebrate species (Invertivores) and fishes that feed primarily on benthic macroinvertebrates (Insectivores) tend to be numerous. Omnivores and Detritivores may also be common, depending on the habitat (Alan, 1995; Jenkins and Burkhead, 1993). Similar patterns are evident across all sites as indicated by fish samples collected from the post reclamation Pyrite Mine Site. Insectivores tended to numerically dominate the control Sites 1 and 2 (46% and 46% respectively) while Invertivores tended to dominate the impacted Sites 3 and 4 (44% and 51% respectively). Insectivores and Omnivores tended to co-dominate Site 5 (40% and 41% respectively) below the impacted area. The presence of top carnivores such as largemouth bass (*Micropterus salmoides*) and chain pickerel (*Esox niger*) is indicative of a relatively healthy, trophically diverse community (Karr 1981). The presence of these species in the post reclamation impacted sites is a hopeful sign of recovery.

Of the four disturbance-Intolerant species observed throughout this study, three were Insectivore species (*Clinostomus funduloides, Lepomis auritus* and *Etheostoma olmstedi*) and one was an Invertivore species (*Noturus insignis*). Since the control Sites 1 and 2 were not impacted by the mining operations, it would stand to reason that these sites would contain more habitat specialist, intolerant species.

A mine-impacted area, on the other hand, would tend to be dominated by habitat generalist, omnivore species, as was observed in the pre-reclamation data. Post reclamation data on the other hand, had a mix of generalist and specialist and intermediate and tolerant species represented by the Invertivore species. Six of the nine Invertivore species observed in this study were disturbance-tolerant, generalist species (*Notemigonus crysoleucas, Catostomus commersoni, Ameiurus melas, A. natalis, A. nebulosus* and *Lepomis cyanellus*) while two were disturbance-intermediate, specialists (*Notropis* species and *Erimyzon oblongus*) and as already mentioned, one species was a disturbance-intolerant, specialist (*Noturus insignis*). Considering tolerance alone, intermediate species dominated Sites 2, 3, and 4 (40%, 55% and 55% respectively) while tolerant species dominated Sites 1 and 5 (38% and 41% respectively). Considering generalists/specialists alone, specialists dominated all five sites (Site 1=57%, Site 2=68%, Site 3=77%, Site 4=65%, Site 5=54%). This mix of more specialized feeders and habitat generalist/specialist and intermediate/tolerant species in the mine-impacted area is encouraging, as it tends to support the notion that the site is recovering.

Although mine impacted Sites 3 and 4 show similar patterns in terms of trophic guild representatives, generalists/specialists and tolerance levels, comparisons of species richness and fish abundance between these two sites are significant. Site 3 tended to resemble the control Sites 1 and 2 in terms of total number of species, each ranging between 15 and 18 species over the two-year study period. Species richness for Site 4, on the other hand, ranged between 5 and 15 species over the two-year study period. Impacted Site 3 resembled the control Sites 1 and 2 while Site 4 showed an obvious decrease and Site 5 increased again, but not quite to the levels of the control sites.

Fish abundance at Site 3 again resembled the control Sites 1 and 2 with a total of nearly 4,000 fish over the two-year study period (Site 1 = 4,009 total fish, Site 2 = 3,492 total fish, Site 3 = 3,912 total fish). Fish abundance at Site 4 was nearly six-fold lower with a total of 706 total fish over the two-year study period.

These patterns seem to indicate that although conditions at impacted Sites 3 and 4 appear to be improving, conditions at Site 3 seem to be doing so at a faster rate. These data raise questions about how effective the reclamation was at Site 4. Perhaps the mine-impacted area around Site 4 is still experiencing effects from the abandoned mine. During the mine reclamation, the National Park Service learned of a mineshaft located on private property above Site 4. Because of its location on private property, this shaft was not included in the reclamation project and was initially thought to be contributing to results observed at Site 4. It is now not thought to be the case because there is no evidence that there is surface water runoff from this unreclaimed shaft. However, the area above the "ditch" was the "hottest" area when tested, pre-reclamation, for heavy metals and low pH. It would follow that this area would continue to be problematic, since the stormwater channel did not pick up the seeps entering park property as had been hoped. Park personnel believe that it is the seeps that account for the post-reclamation input of metals and acid at the "ditch" site.

It is unknown at this point and beyond the scope of this study whether or not Site 4 or any of the impacted sites are receiving acid mine drainage from groundwater. However, a separate post reclamation groundwater study conducted by the United States Geological Survey (USGS) was initiated at the same time as this surface water quality study. The results from the groundwater study are yet to be published but may contribute to an even better understanding of the fish, and also invertebrate, results observed at Site 4.

It should be noted that Resource International (1994) determined that 80% of the impact to the site was from surface water, with 20% groundwater contribution. The primary objective of the reclamation project was to reduce or eliminate the surface water contribution. It is a fact that there were seldom flows from the "ditch" at site 3 and this researcher never observed flows from the ditch near site 4.

The fact that species richness and fish abundance tend to increase again at Site 5 may be largely the result of the fact that the lower half of Site 5 is below the confluence with South Fork Quantico Creek, which is valued for its excellent water quality and is used as a reference stream in other water quality studies in Prince William County (Jones and Kelso, 1994). The graphs in Figure 90 illustrate that the majority of the values contributing to the species richness and fish abundance at Site 5 came from the 100-meter reach of Site 5 below the confluence with South Fork Quantico Creek. This lower 100-meter reach is approaching the fall line. It is wider in stream width and has a more varied substrate including large boulders and deeper pool areas than any other area sampled in this study. The 100-meter reach above the confluence is more similar, by comparison, to the sites upstream as it is narrower in stream width with a less varied substrate including smaller cobbles and stones. The lower numbers of species and lower numbers of individual fish in the 100-meter reach above the confluence are likely due to acid mine drainage impacts that are still apparently impacting this reach. It is important to note that a boundary net was not set up at the mouth of the confluence, which may have allowed some fish to escape into South Fork Quantico Creek. This may have had an effect on the fish data collected below the confluence.

CONCLUSIONS

Although this two-year study cannot definitively answer the question of whether or not the abandoned mine reclamation was successful, it has provided promising evidence of recovery. Comparisons of pre and post-reclamation data at and below site 4 suggest post-reclamation decreases in the levels of both sulfates and specific conductance. Water profile data suggests that, in terms of sulfates and specific conductance, sites 3 and 4 continue to have elevated levels, indicative of the residual effects of acid mine drainage contributions. Site 4 continues to have significantly lower pH than the reference sites, but all sites maintained a pH level sufficient to support biotic life. While copper, iron, and zinc contributions to sites 3 and 4 continue to be greater than those at sites 1 and 2, post-reclamation levels of these metals appears to be lower than the pre-reclamation levels. Invertebrate assemblages at sites 3 and 4 are generally moderately impaired, with site 4 being the most tenuous. The fish data suggests that there are now more individuals and greater diversity of fishes inhabiting the mine-impacted area. The fact that more intermediate and intolerant species and habitat specialists including Insectivores, Invertivores and Piscivores, are moving into the site is a promising sign of recovery. Further investigation of sources of acid drainage inputs at Site 4 is recommended. Groundwater sources as well as overland flow should be investigated. If possible, appropriate supplementary reclamation efforts that will reduce the effects of the acid drainage to site 4 should be explored. Water quality monitoring, invertebrate monitoring, as well as fish data collection should logically follow any additional reclamation efforts. This study provides excellent baseline data from which further actions and/or progress can be measured.

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