Acid Mine Drainage Abatement in the Lower Rock Creek Watershed

Rock Creek Clean Water Action Plan Project

Final Report

October, 1999 – June, 2002

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EXECUTIVE SUMMARY

Rock Creek above White Oak Junction is a beautiful boulder strewn stream designated as a Kentucky Wild River and is the premier mountain trout stream in Kentucky. Below White Oak Junction acid mine drainage from over 40 coal mine portals and eight pyrite-rich coal processing refuse dumps has decimated aquatic life and rendered segments of the stream virtually lifeless. The Rock Creek Task Force, a group of 12 state and federal agencies and conservation organizations was formed to find solutions to the degraded water quality in the lower Rock Creek watershed. Funding for reclamation in the watershed was provided by several Task Force partners and included an EPA 319 Clean Water Action Plan grant.

In 1999 a biological and water monitoring program began in the lower Rock Creek watershed. In the fall of 2000 construction began on a reclamation project targeting several of the worst acid mine drainage sites in the lower Rock Creek watershed. Pyrite-rich refuse was removed from the banks of Rock Creek. The refuse was hauled to a pre-existing refuse fill in Roberts Hollow. The refuse was mixed with agricultural limestone and placed in a compacted fill. Open limestone channels were installed treating acid water seeping from the pre-existing refuse. Areas with sparse vegetation were revegetated reducing sediment loading to the streams.

Removal of the pyrite-rich refuse and revegetation of the three acre Water Tank Hollow site has resulted in a reduction of 500 tons of sediment and over 80 tons of acidity entering Rock Creek annually from the site. Reclamation at the Roberts Hollow site has resulted in a 44% reduction in acid load entering Rock Creek from the tributary. Dissolved iron loading decreased by 46% and dissolved aluminum loading decreased by 56%.

The combination of reclamation of the above sites in conjunction with limestone sand dosing and acid mine drainage abatement reclamation at other sites in the lower Rock Creek watershed has reduced the acid load entering the Big South Fork of the Cumberland River from Rock Creek to near zero. Fish populations are rebounding with increases in numbers and diversity.

INTRODUCTION

The exposure and oxidation of certain sulfide minerals in rocks as a consequence of coal mining activities has resulted in acid mine drainage (AMD), a serious water pollution problem in the Appalachian coal field region. Acid mine drainage is a low pH, iron and sulfate rich water with high acidity that is formed under natural conditions when certain coal seams or other associated rocks containing pyrite, and/or other sulfide minerals are exposed to the atmosphere or oxidizing environments. When pyrite is exposed through natural weathering only small amounts of pyrite are oxidized and acid generation is minimal. When large volumes of pyritic material are exposed to oxidizing conditions through mining or other disturbances the pyrite reacts and water moves the reaction products, dissolved metals, sulfate, and acidity into groundwater and surface water sources.

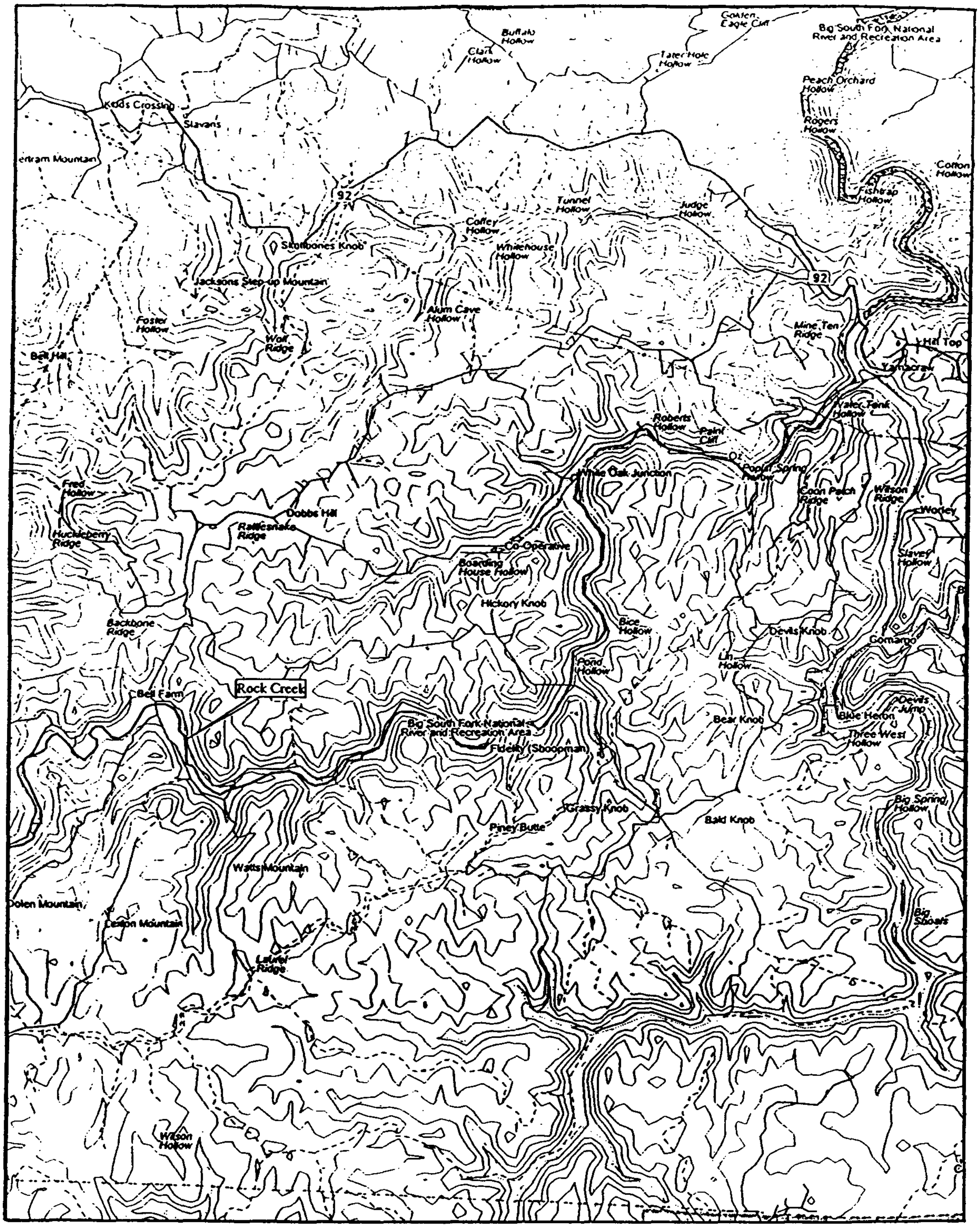
Acid mine drainage is formed by the oxidation of pyrite to release dissolved ferrous iron, sulfate, and free hydrogen ions. Further oxidation of the ferrous iron results in the formation of ferric iron and, at a pH greater than 3.5, the precipitation of iron as a hydroxide commonly referred to as "yellow boy". The ferrous iron to ferric iron reaction results in an increase of free hydrogen ions and a lowering of pH. Acid mine drainage neutralized by limestone or other bases can form neutral mine drainage high in sulfate and possibly elevated concentrations of iron and manganese. These neutral solutions can become acidic on oxidation and precipitation of the iron and manganese.

Acidity is a measurement of the amount of base needed to neutralize a volume of water. Acidity in AMD is comprised of hydrogen ion concentration acidity (low pH) and mineral acidity which arises from the presence of dissolved metals in the water. In coal mine drainage the major contributors to acidity are ferrous and ferric iron, aluminum, and manganese as well as free hydrogen ions.

Many factors control the rate and extent of AMD formation. Acidity of the drainage tends to increase with an increase in the amount of pyrite in the overburden, coal, floor rock, or mine spoil and a decrease in the grain size of the pyrite. Iron oxidizing bacteria and low pH values speed up the acid forming reactions. Rates of acid formation tend to be slower in the presence of limestone or other neutralizing agents. Access to oxygen is commonly the limiting factor in rate of acid generation. Because of the complex interactions of these and other factors, prediction and remediation of AMD is site specific.

Study Area Description

Rock Creek originates in Pickett State Park, Tennessee, traverses 21 miles in McCreary County, Kentucky and empties into the Big South Fork of the Cumberland River within the Big South Fork National River and Recreation Area, which is administered by the National Park Service. Rock Creek lies mostly within lands managed by the U.S. Department of Agriculture Forest Service (Fig. 1). Eighteen miles of the stream is a Kentucky Wild River and is proposed for inclusion in the National Wild and Scenic Rivers System. Rock Creek is a major recreational attraction and is recognized nationally as a Blue Ribbon trout stream. It is also state-designated outstanding resource water and is visited by thousands yearly. Acid mine drainage from



Scale 1 : 100,000

Figure 1. Location of the Study Area, McCreary County, Kentucky

numerous abandoned mine workings and coal refuse piles heavily impacts a stretch of Rock Creek downstream of the Wild River segment and approximately four miles upstream of the confluence with the Big South Fork. The Kentucky Division of Water has listed this portion of Rock Creek on its 303(d) list of impaired streams as a high priority nonpoint source impacted stream due to low pH from acid mine drainage (Wilson, 1998). The stream from mile point 0.0 to 4.1 is listed as first priority for total maximum daily load (TMDL) development in the Upper Cumberland Basin. The impaired uses include aquatic life and recreation (swimming). The impacts are from mining activities that took place prior to the Surface Mining Reclamation Act of 1977. These activities result in Rock Creek being the single largest source of acid mine discharge into the Big South Fork of the Cumberland. The impacted area of the Rock Creek watershed includes White Oak Creek from Cabin Branch downstream to the confluence with Rock Creek at White Oak Junction, as well as Rock Creek from White Oak Junction to the confluence with the Big South Fork. All tributaries to White Oak Creek and this portion of Rock Creek are included. The project is located within the impacted area specifically at the mouth of Water Tank Hollow and the area within Roberts Hollow on a portion of the Barthell 7 ½ minute quadrangle (Fig.2).

Location

The Water Tank Hollow refuse site is a three-acre coal processing refuse dump located on the north bank of Rock Creek adjacent to Kentucky highway 1363 in McCreary County Kentucky. The longitude and latitude of the Water Tank Hollow refuse site is 84°33'05" longitude by 36°42'41" latitude.

The Roberts Hollow refuse site is located on the northeast bank of the Roberts Hollow tributary to Rock Creek. The longitude and latitude of the Roberts Hollow refuse site is 84°35'00" longitude by 36°42'41" latitude.

Geologic Setting

The project area is located near the Cumberland Escarpment on the edge of the Cumberland Plateau. The topography is highly dissected with steep stream valleys having elevations ranging from 1400 feet above mean sea level on top of Rattlesnake Ridge to 740 feet above sea level at the mouth of Water Tank Hollow. Stratigraphy of the site includes the Lower Pennsylvanian Lee Formation on the upper slopes underlain by the Upper Mississippian Pennington Formation, which crops out on the lower slopes of the study area. Quaternary alluvium is found on the banks and underlying Rock Creek at several locations including the Water Tank Hollow refuse site. The Rockcastle Conglomerate Member of the Lee Formation forms conspicuous cliffs near the top of the ridges in the study area. The Beattyville Shale Member of the Lee Formation, located below the Rockcastle Conglomerate Member, consists of shale, siltstone, coal, and clay. The Stearns coal zone is located in the lower part of the Beattyville Shale Member. The coal beds in the Stearns coal zone are known locally as the Stearns No.1, No.1-1/2 and No. 2 and are commonly separated by only a few feet of sandstone, siltstone, or shale. Locally the coal beds may merge into one or two beds, or split into several very thin seams. The Pennington Formation consists of shale, sandstone, and limestone. The

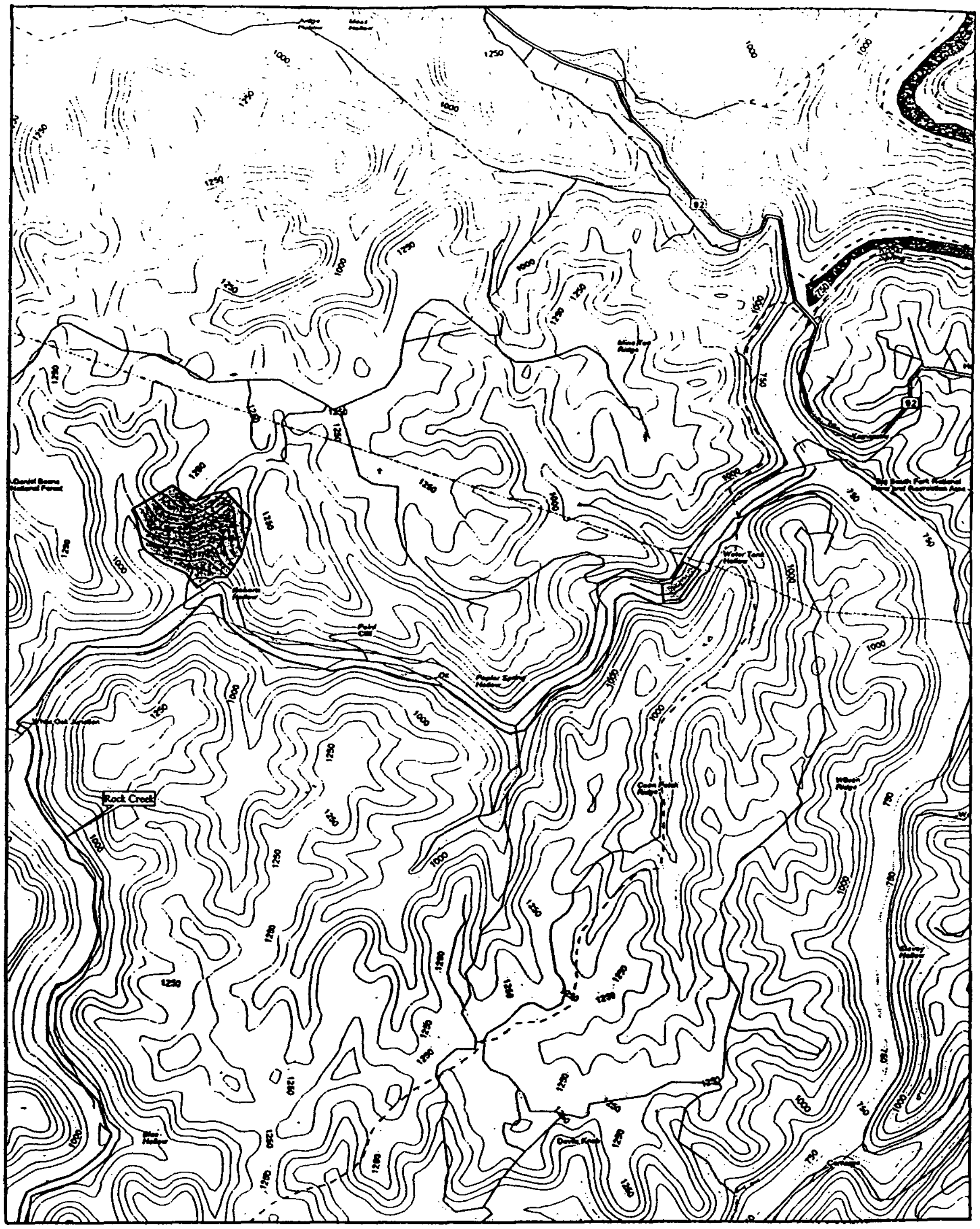


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Figure 2. Location of the project area.

Water Tank Hollow refuse is located on the Pennington Formation and on alluvium on the north bank of Rock Creek. The majority of the Roberts Hollow refuse is located on Pennington Formation strata with the upper slope of the refuse located on the Beattyville Shale Member below the Stearns coal zone. The regional dip is to the East-Southeast.

Hydrologic Regime

Roberts Hollow is a 420-acre watershed flowing into Rock Creek. The Roberts Hollow refuse site is located on the east bank of the tributary. Roberts Hollow receives discharges from several coal mine portals located within the watershed. In addition there are several seeps flowing from the coal processing refuse.

The Water Tank Hollow refuse site is a three-acre coal processing refuse dump located on the north bank of Rock Creek. Surface water above the refuse is diverted by ditch lines along Kentucky Highway 1363. Several seeps have been observed flowing from the refuse, one of which is flowing into the Water Tank Hollow tributary near the confluence with Rock Creek.

No sinks have been observed in the project area, however, two sinks have been observed in the stream bed of the Jones Branch tributary of Rock Creek which is located upstream and to the west of the project area. The uppermost sink was dye traced by Kentucky Abandoned Mine Land (AML) and United States Forest Service (USFS) personnel. The upper sink discharges at a spring located across Highway 1363 from the church driveway at the mouth of Jones Branch. The spring is about ten feet below the road elevation. The lower sink which is located about fifty feet upstream from the confluence of Jones Branch and White Oak Creek has not been dye traced yet. Flow conditions have to be exact with the lower sink receiving the entire flow of Jones Branch before a dye trace can be done to prevent dye from entering the stream. Rock Creek flows into a large sink located on its south bank just upstream from White Oak Junction. This sink has been dye traced by AML and USFS personnel and is discharging from a spring about 3000 feet downstream on the southern bank of Rock Creek.

Five aquifer types have been identified within or near the project area. The karst aquifer flow regime and coal bed aquifers were noted above. In addition, groundwater flow in the study area is controlled by granular aquifers within the sandstone units, alluvial aquifers composed of unconsolidated sediments located along Rock Creek, and near surface fracture aquifers formed by stress relief fractures and joints which may cut through and influence the other aquifer types. Recharge to the hillside aquifers occurs when precipitation soaks through the thin soils and colluvium, percolating down through the fractured units until a confining bed is reached. The groundwater then flows horizontally along bedding planes toward the hillside until the perched water is intercepted by vertical fractures in the confining bed or in the absence of vertical fractures in the confining bed is forced to the surface as wet weather springs. This results in a stair step pattern of groundwater movement from the ridge-tops to the valley floor.

Land-use Activities

Underground coal mining began in the project area in the first decade of the century and continued through the 1960's. Several small towns were built supporting the mining and lumber industries of the area. Several of the towns including Yamacraw, Fidelity, and Co-Operative no longer exist. With the exception of the railroad right of way, owned by the K & T Railroad Company, and a few small private in-holdings, the project area is managed by the United States Forest Service. Rock Creek is a major recreational attraction and is visited by thousands yearly. Fishing, hunting, hiking, backpacking, and camping are just a few of the interests pursued by visitors.

Project Description

This specific project is part of an overall larger project addressing several AMD sources in Rock Creek. The overall plan was developed by the Kentucky Division of Abandoned Mine Lands with the partnership and assistance of the following agencies and organizations: Kentucky Division of Water (DOW), federal Office of Surface Mining (OSM), Kentucky Department of Fish and Wildlife Resources (KDFWR), National Park Service (NPS), United States Forest Service, Trout Unlimited (TU), and the Kentucky Department for Surface Mining Reclamation and Enforcement (DSMRE).

The overall goal of the Rock Creek Project is to show a demonstrable reduction in sedimentation and acidity entering Rock Creek. Secondary goals are to return the land where the coal processing refuse dump was located to a revegetated state compatible with the surrounding land and to use the project for public education.

Construction activities to attain these goals include removal of the acid forming material from the banks of Rock Creek at the 3-acre Water Tank Hollow refuse site. The acid forming material was treated and placed in a compacted fill at the Roberts Hollow refuse site. Open limestone channels and a limestone sand application site were constructed in Roberts Hollow to treat AMD. All disturbed areas were revegetated.

Educational activities to achieve the project goals included a field day for local school children and preparation of a brochure for public dissemination. A segment of the Kentucky Afield television show produced by KDFWR highlighting AMD remediation efforts at Rock Creek was filmed and broadcast statewide on public television, and was shown by closed circuit television to Kentucky schools.

DATA COLLECTION AND METHODOLOGY

Data collection and methodology included a water monitoring program conducted by the United States Geological Survey (USGS), a biological monitoring program conducted by AML, USFS and KDFWR personnel, and soil and refuse analysis including computer modeling utilizing the Revised Universal Soil Loss Equation (RUSLE) conducted by AML. Best management practices were chosen after analysis of water chemistry, soil and refuse testing and site specific conditions.

Water Monitoring

Monitoring Objectives

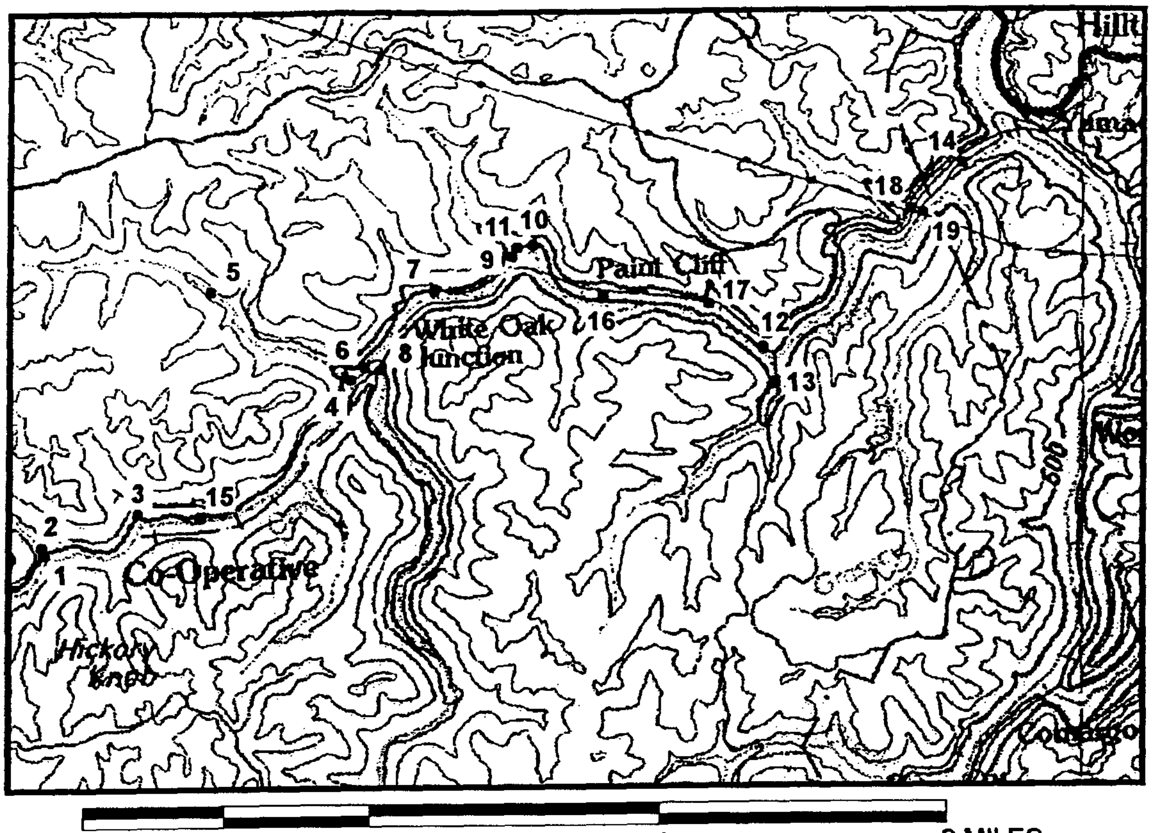
The water monitoring objectives were to collect acid and metal concentrations and loading data for the Water Tank Hollow tributary of Rock Creek, the Roberts Hollow tributary of Rock Creek, and the main stem of Rock Creek immediately above and downstream of Roberts Hollow.

The Water Tank Hollow tributary was being degraded by seeps flowing from the refuse located at the mouth of Water Tank Hollow. Monitoring before and after removal of the refuse indicates the efficacy of removal of the refuse.

The Roberts Hollow tributary is being degraded by refuse located in Roberts Hollow and by mine portals located above the refuse. Loading data was used to calculate the limestone sand treatment dosage and to measure the efficacy of the treatment.

Monitoring Program

Existing water quality data was available for portals and seeps in the study area but may not take into account all of the acid drainage sources or any natural buffering which may occur within the watershed. To address this, the mouths of the main tributaries and the main stem of Rock Creek were monitored (Fig. 3). The sites were monitored monthly, for a period of eighteen months before construction activities began, to collect background data. The sites were monitored monthly during construction of the project and then monthly thereafter at Roberts Hollow, Water Tank Hollow, and the main stem of Rock Creek to demonstrate project success. The Water Tank Hollow site was monitored above the coal processing refuse dump and at the mouth of the tributary adjacent to the refuse dump. After removal of the refuse at Water Tank Hollow monitoring of the Water Tank Hollow site above the refuse area ceased.



EXPLANATION

• Station

Station name	Site number	Station number
White Oak Creek above Cabin Branch at Co-Operative	1	3410540
Cabin Branch at Mouth at Co-Operative	2	3410542
Unnamed Tributary at Mouth below Boarding House Hollow	3	3410545
White Oak Creek above Jones Branch at White Oak Junction	4	3410552
Jones Branch above Unnamed Tributary at White Oak Junction	5	3410555
White Oak Creek at Mouth at White Oak Junction	6	3410557
Limestone Spring below Unnamed Tributary at White Oak Junction	7	3410565
Rock Creek above White Oak Creek at White Oak Junction	8	3410559
Rock Creek above Roberts Hollow at White Oak Junction	9	3410569
Unnamed Tributary at Culvert below Roberts Hollow	10	3410571
Roberts Hollow at Mouth at Paint Cliff	11	3410570
Rock Creek below Poplar Spring Hollow at Paint Cliff	12	3410580
Koger Fork above Mouth at Paint Cliff	13	3410585
Rock Creek below Grassey Fork at Yamacraw	14	3410597
Unnamed Tributary to White Oak Creek at Culvert	15	3410547
Paint Cliff Discharge at Paint Cliff	16	3410575
Poplar Spring Hollow at Mouth at Paint Cliff	17	3410578
Water Tank Hollow at Culvert above Mouth at Yamacraw	18	3410594
Water Tank Hollow at Mouth at Yamacraw	19	3410595

Figure 3. Water monitoring sites in the lower Rock Creek watershed.

The following sites are part of a larger monthly monitoring program but are specific to this project:

Monitoring Site (USGS designations)

Station Name	Site Number	Station Number	Lat./Long.
Rock Ck. above Roberts Hollow	9	3410569	36.70967/-84.58417
Unnamed trib. at culvert below Robts. Hol.	10	3410571	36.71045/-84.58243
Roberts Hollow at mouth	11	3410570	36.71026/-84.58376
Rock Creek below Poplar Spring	12	3410580	36.70309/-84.56370
Rock Creek below Grassy Fork	14	3410597	36.71508/-84.54687
Water Tank Hollow above refuse	18	3410594	36.71212/-84.55127
Water Tank Hollow at mouth	19	3410595	36.71184/-84.55034

The following parameters were tested monthly:

Parameter	Method
Discharge	Field
pH	Field
Specific Conductance	Field
Total Dissolved Solids	Lab
Acidity	Lab
Alkalinity	Lab
Sulfate	Lab
Fe (total)	Lab
Fe (dissolved)	Lab
Mn (total)	Lab
Mn (dissolved)	Lab
Al (total)	Lab
Al (dissolved)	Lab
Ca (total)	Lab

All sample collection, preservation, and analysis were conducted in accordance with Standard Methods for the Examination of Water and Wastewater. Discharge was measured by current velocity meter or by the "bucket and stopwatch" method where possible. The bucket and stopwatch method involves measuring how much time it takes a given source to fill a container of known volume. This time is then interpolated to volume per minute. Three measurements were taken and the results averaged. Conductivity and pH were measured using calibrated pH and conductivity meters.

Chain of Custody Procedures

All water sampling was conducted by the USGS. Procedures used by USGS personnel are outlined in "U.S. Geological Survey Protocol for the Collection and Processing of Surface-Water Samples for the Subsequent Determination of Inorganic Constituents in Filtered Water" – U.S. Geological Survey Open-File Report 94-539.

Quality Control Procedures

All water sampling was conducted by the USGS. Procedures used by USGS personnel are outlined in "U.S. Geological Survey Protocol for the Collection and Processing of Surface-Water Samples for the Subsequent Determination of Inorganic Constituents in Filtered Water" – U.S. Geological Survey Open-File Report 94-539.

Biological Monitoring

Monitoring Objectives

The biological monitoring objectives were to measure the effectiveness of the acid mine drainage mitigation project on water quality as measured by the aquatic communities of Rock Creek. Monitoring macroinvertebrates indicates the short-term effectiveness of the acid mine drainage mitigation project on water quality. Monitoring the fish populations indicates the long-term effectiveness of the acid mine drainage mitigation project on water quality.

Monitoring Program

Aquatic macroinvertebrates were collected spring and fall by a series of three surber samples per station, along with one triangular kick-net sweep to cover all habitat types in the sample area. All whole samples were picked in the field, stored in 70% ethanol, and returned to the DAML Frankfort office for sorting and identification to the lowest possible taxon. After sorting and identification, the data was evaluated using the modified Hilsenhoff Biotic Index (HBI) (Lenat, 1993) to determine the overall pollution tolerance of the macroinvertebrate community and the degree to which the habitat is impaired. Other metrics used include the Total Number of Individuals, Ephemeroptera/Plecoptera/Trichoptera Richness (EPT), and Percent Dominant Taxon. Fishes were collected in early summer by the use of a Smith-Root model 12A battery powered backpack electrofishing device. Fish collected were identified in the field when possible, with voucher specimens being returned to the lab for positive identification. Identification was to the lowest possible taxon. Type specimens were preserved in 10% buffered formalin for 1-2 weeks, then rinsed and transferred to 70% ethanol for long-term preservation and storage. After final identification the data was evaluated using the Index of Biotic Integrity (IBI) to determine the overall structure and health of the piscid community as an indicator of aquatic habitat health. Also, Catch Per Unit of Effort (CPUE) of shocking time was considered as a measure of relative abundance.

Biological monitoring stations (Fig. 4) are at the following sites on Rock Creek (RC) and White Oak Creek (WO):

Monitoring Site

Station Name	Site Number	Station Number	Lat/Long
Rock Creek			
Above White Oak Creek	RC-00	INT02002004	36.70277/-84.59540
Below White Oak Creek	RC-01	INT02008003	36.70320/-84.59634
Above Schoolhouse Branch	RC-02		36.70687/-84.57848
Below Koger Fork Bridge	RC-03	INT02008002	36.70323/-84.56210
Grassy Fork Mouth	RC-04		36.71360/-84.54832
White Oak Creek			
Above Cabin Branch	WO-01		36.69080/-84.62320
Below Cabin Branch	WO-02		36.69110/-84.62132

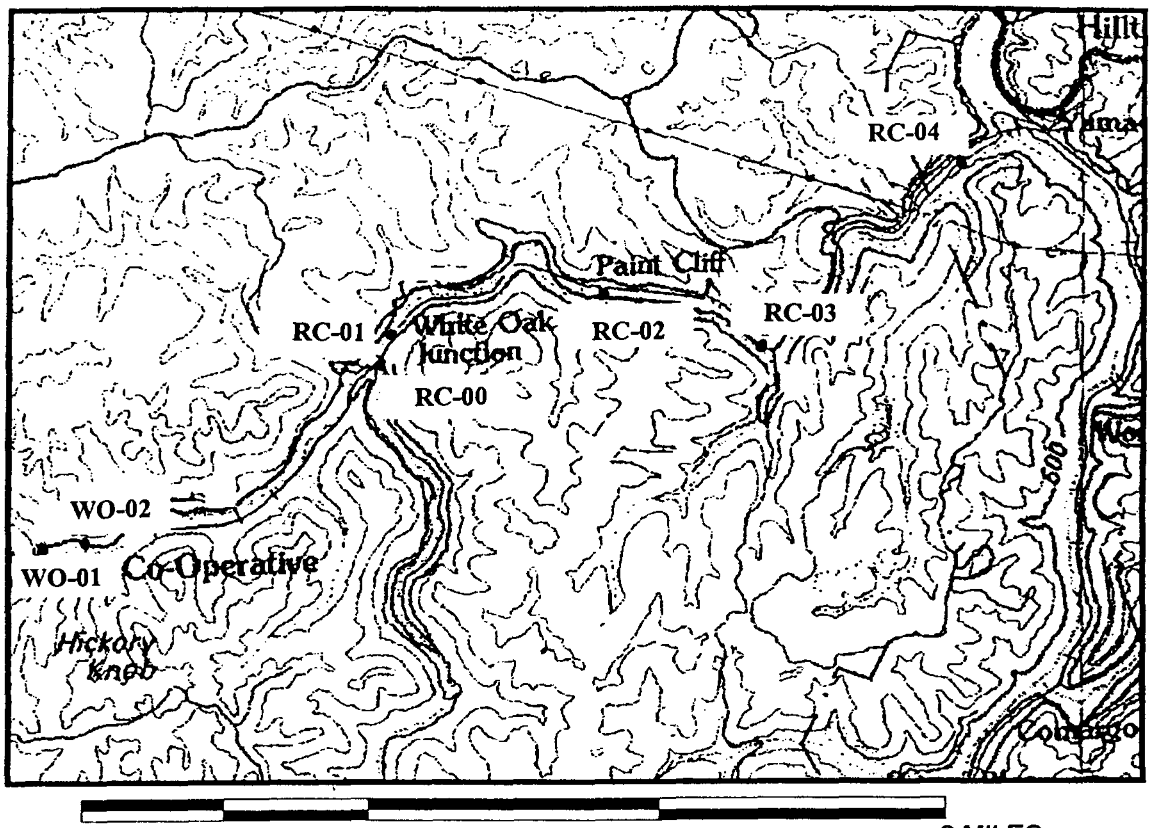
The stations were used for both fish and macroinvertebrate sampling. Site selection criteria included ease of repositioning, and the ability to determine the effects of AMD treatments within the project area on the main stem of Rock Creek. All sites except for the control sites RC-00 and WC-01 are downstream from the AMD impacted tributaries. The monitoring sites encompass a larger study area than this specific project and are part of a larger AMD mitigation project in the lower Rock Creek watershed. Sites RC-03 and RC-04 are downstream from this specific project. Site RC-03 is downstream from Roberts Hollow and site RC-04 is immediately downstream from Water Tank Hollow.

Chain of Custody Procedures

Samples taken in the field were labeled with the following information:

- Date the sample was taken.
- Station at which the sample was taken.
- Name of the person conducting the sampling.
- Gear and/or method used to obtain the sample.
- General stream conditions at the time of sampling (high or low flow, turbid or clear, etc).
- Water temperature.
- pH
- Conductivity.
- Weather.

Macroinvertebrate samples were collected, processed, and the resulting data analyzed by USFS personnel. Fish samples were collected, processed, and analyzed by KDFWR personnel. Volunteer biologists from DOW and AML assisted in collection, processing, and identification of both macroinvertebrates and fish.



EXPLANATION

• Station

Station Name	Site Number
Rock Creek	
Above White Oak Creek	RC-00
Below White Oak Creek	RC-01
Above Schoolhouse Branch	RC-02
Below Koger Fork Bridge	RC-03
Grassy Fork Mouth	RC-04
White Oak Creek	
Above Cabin Branch	WO-01
Below Cabin Branch	WO-02

Figure 4. Biological monitoring sites in the lower Rock Creek watershed.

Quality Control Procedures

Equipment used in biological monitoring was decontaminated by rinsing in clean water or, in the case of pH and conductivity meters, rinsing with distilled water. Electrofishing equipment was calibrated on site. Conductivity meters and pH meters were calibrated with known calibration solutions prior to each sampling session, and re-calibrated periodically. Organisms collected from each sample at each sampling station were collected in a new container. Quality control for biological samples was provided by replicate samples at each station, and by ensuring that all habitat types at each station were sampled. Variance in organisms and numbers of organisms between sampling stations and trips reflects improvement or degradation of water quality. In order to explain such variance, factors such as variations in flow from portals and coal waste, weather, and life cycles of aquatic insects were considered and investigated.

Soil and Refuse Analysis

Monitoring Objectives

The soil and refuse analysis objectives were to collect site specific data to populate the Revised Universal Soil Loss Equation (RUSLE) and to collect acidity data from representative samples of the pyritic coal processing refuse that was reclaimed by this project. RUSLE was used to calculate soil loss from the project area before, and after, the Best Management Practices (BMPs) were completed. This provided a means of estimating the reduction in sediment entering Rock Creek from the Water Tank Hollow site after completion of the project. The annual acid load reduction into Rock Creek from the Water Tank Hollow refuse site was calculated using the acidity data from the refuse analysis in combination with the reduction in quantity of refuse washing into Rock Creek annually from the Water Tank Hollow refuse site as calculated by RUSLE.

Monitoring Program

The RUSLE Model

The Revised Universal Soil Loss Equation (RUSLE, Renard et al., 1997) is a set of mathematical equations for estimating average annual soil loss and sediment yield due to overland flow from undisturbed lands, lands undergoing disturbance, and from newly or established reclaimed lands. RUSLE estimates soil loss from a slope caused by raindrop impact and overland flow, plus rill erosion. It does not estimate gully or stream-channel erosion. Soil loss is defined here as that material actually removed from a particular slope or slope segment. The sediment yield from a surface is the sum of the soil losses minus deposition in macro-topographic depressions, at the toe of the slope, along field boundaries, or in terraces and channels sculpted into the slope.

RUSLE is derived from the theory of erosion processes, more than 10,000 plot years of data from natural rainfall plots, and from numerous rainfall simulation plots. RUSLE was developed by a group of nationally recognized scientists and soil conservationists who had considerable experience with erosion processes (Soil and Water Conservation Society, 1993).

RUSLE retains the structure of its predecessor, the Universal Soil Loss Equation (USLE) (Wischmeier and Smith, 1978), namely:

$$A = R\ K\ LS\ C\ P$$

Where: A = Average annual soil loss in tons per acre per year
R = Rainfall/runoff erosivity
K = Soil erodibility
LS = Slope length and steepness
C = Cover management
P = Support practice

The R factor is an expression of the erosivity of rainfall and runoff at a particular location. The value of "R" increases as the amount and intensity of rainfall increases. The data for "R" for the project site was obtained from the Division of Water, Engineering Memorandum Number 2, (4-30-71) revised (6-1-79) for McCreary County, Kentucky.

The K factor is an expression of the inherent erodibility of the soil surface material at a particular site under standard experimental conditions. The value of "K" is a function of the particle size distribution, organic matter content, structure, and permeability of the soil or surface material. For disturbed soils such as those encountered at the project site the nomograph equations embedded within the RUSLE program are used to compute appropriate erodibility values.

The LS factor is an expression of the effect of topography, specifically slope length and steepness, on rates of soil loss at a particular site. The value of "LS" increases as slope length and steepness increase, under the assumption that runoff accumulates and accelerates in the downslope direction. This assumption is usually valid for lands experiencing overland flow, as is found in our project area, but may not be valid for forest and other densely vegetated areas. The LS factor for our project site was determined by actual before and after reclamation surveys of the project area.

The C factor is an expression of the effects of surface covers and roughness, soil biomass, and soil disturbing activities on rates of soil loss at a particular site. The value of "C" decreases as surface cover and soil biomass increase, thus protecting the soil from rainsplash and runoff. The RUSLE program uses a sub-factor method to compute the value of "C". The sub-factors that influence "C" change through time, resulting in concomitant changes in soil protection. A vegetation database is contained within the computer program that characterizes numerous plant types. RUSLE also contains an operations database file that characterizes the effects of various soil disturbing activities on soil loss rates. These operations alter the roughness, infiltration, distribution of biomass, and runoff properties of the surface. The operations include common tillage activities that may be used in the development of a seedbed at reclaimed sites. C values were calculated using the RUSLE equations that consider local conditions.

The P factor is an expression of the effects of supporting conservation practices, such as contouring, buffer strips of close growing vegetation, and terracing, on soil loss at a particular site. The value of "P" decreases with the installation of these practices because they reduce runoff volume and velocity and encourage the deposition of sediment on the slope surface. The effectiveness of certain erosion control practices varies due to local conditions, therefore P values were calculated through the RUSLE equations based on site specific conditions.

Soil / Refuse Sampling

The coal processing refuse was sampled by the project agronomist at various locations in the project area. Any areas that had noticeably different soil properties were sampled and analyzed as separate samples. The soil/refuse samples were analyzed for Soil Water pH, Buffer pH, Extractable Phosphorus, Extractable Potassium, and Potential Acidity.

Chain of Custody Procedures

Soil/refuse samples taken in the field were labeled with the following information:

- Date the sample was taken.
- Station at which the sample was taken.
- Name of the person conducting the sampling.
- Gear and/or method used to obtain the sample.

Soil/refuse samples were collected by AML personnel and taken to and analyzed by a qualified independent laboratory.

Quality Control Procedures

All soil/refuse sampling for this project was conducted by an AML agronomist. The samples were analyzed at a qualified independent laboratory using accepted analytical procedures. The results were forwarded to the AML agronomist for interpretation.

The RUSLE model relied on before and after site surveys conducted by an AML licensed surveyor. The resulting cross sections were used by an AML engineer for inclusion into the RUSLE model for the project area.

Best Management Practice Technologies Installed

Refuse Removal and Treatment

The Rock Creek Clean Water Action Plan Project involved the removal of 18,331 cubic yards of highly acidic coal mine refuse from the banks of Rock Creek near Water Tank Hollow (Fig 5). The refuse was a significant source of sedimentation and acid mine drainage (AMD) into Rock Creek, as well as a visual blight to the surrounding forested area. The refuse was loaded and hauled to an existing refuse area in Roberts Hollow (Fig. 6). The refuse was placed in six inch to eight-inch lifts near the toe of the existing refuse fill. Foundation benches were excavated and an agricultural limestone barrier was placed prior to placement of the refuse. Agricultural limestone was incorporated into each lift. The rate of 20 tons of agricultural limestone per 100 cubic yards of refuse was used. The rate of limestone mixed with the refuse was determined by soil tests. Suitable borrow material for soil cover on the refuse was found in the fill area and was placed two feet deep on top of the final lift of refuse. The area filled had sparse vegetation and revegetation efforts following placement of the fill has improved the vegetative cover on the site reducing the sediment load to the stream. The refuse fill area was seeded with a mix of acid tolerant warm and cool season grasses and legumes.

After removal of the refuse from the Water Tank Hollow site the slope was graded to a smooth uniform configuration. Agricultural limestone was added to the site and tracked in with a bulldozer. The site was fertilized, seeded, mulched, and netted. The site was revegetated with a mix of warm and cool season grasses, legumes, and trees compatible with the surrounding vegetation. The stream bank was restored and stabilized using bioengineering techniques and native vegetation to closely resemble its natural riparian state. Large rocks encountered during excavation of the refuse were placed at the toe of the slope to provide slope protection.

Acidity produced by acid mine drainage can be neutralized in the presence of sufficient carbonate minerals. Where neutralization is occurring the pH can remain at a near neutral value that inhibits bacterial catalysis of iron oxidation and where ferric iron is relatively insoluble. Thus the quality of drainage produced is largely dependent on the availability of calcium carbonate or other neutralizing agents in the overburden. A strong empirical relationship exists between the neutralization potential of coal mine overburden and whether or not the drainage will be alkaline (Brady et al., 1994). Brady et al., (1994) found that sites with more than 3% naturally occurring carbonates produced alkaline drainage. Sites with less than 1% carbonate generally produced acidic drainage.

The role of carbonate is so important in acid mine drainage formation that neutralization potential was found to be a better predictor of whether drainage would be alkaline or acidic than was the maximum potential acidity calculated from the sulfur content (Brady and Hornberger, 1990, Brady et al., 1994, Perry and Brady, 1995). Agricultural limestone was mixed with the refuse on this project in sufficient quantity, as determined by soil/refuse testing, to achieve greater than 3% calcium carbonate content in the refuse which should produce net alkaline drainage.

Construction BMPs including staking of silt control bales at the toe of the slopes at Water Tank Hollow and Roberts Hollow and installation of permanent water diversions were used during the construction activities.

Open Limestone Channels

Open limestone channels were installed at the Roberts Hollow refuse fill site and the Water Tank Hollow refuse removal site. A limestone channel 1000 feet in length was constructed immediately above the refuse fill area at the Roberts Hollow site. A limestone channel 800 feet in length was installed in the natural drain on the southeast side of the fill area. The limestone channels intercept acidic water from the upper slopes of the refuse fill area, diverting acidic water away from the new fill, and provide treatment to the water before discharging into the main tributary and Rock Creek.

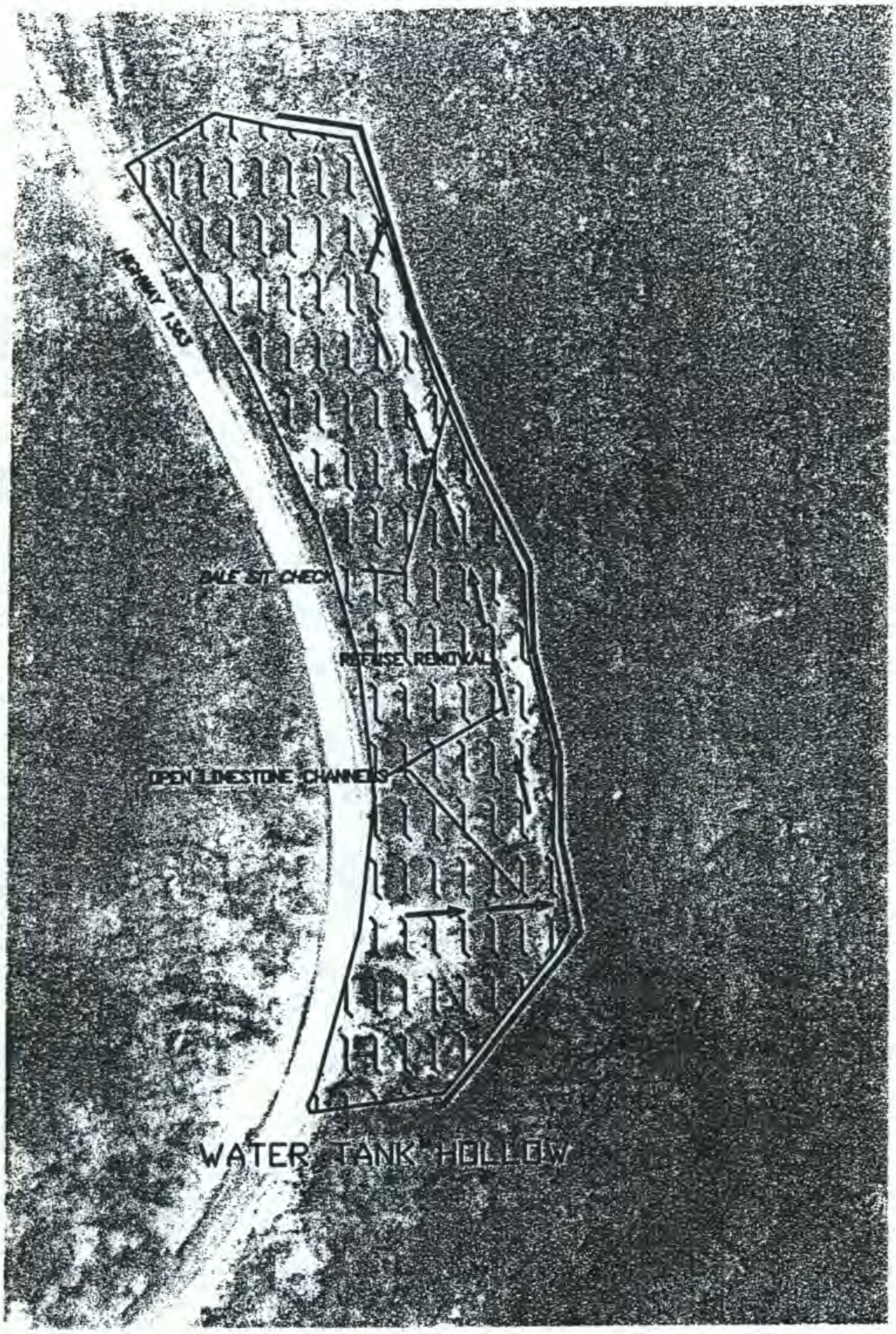


Figure 5. Water Tank Hollow BMP technologies installation site.

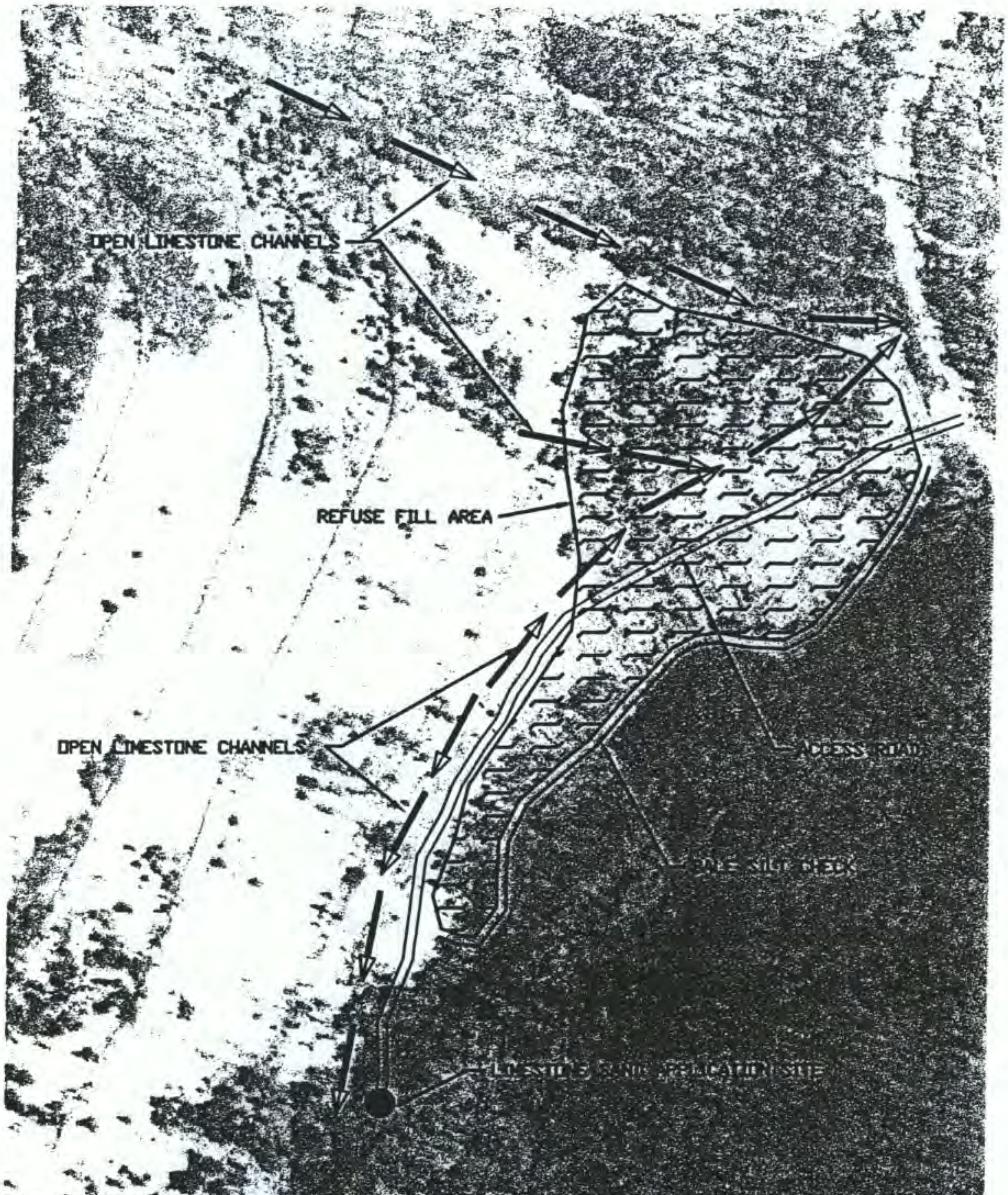


Figure 6. Roberts Hollow BMP technologies installation site.

A natural drainage feature was encountered during excavation of the coal mine refuse from the banks of Rock Creek at the Water Tank Hollow site. An open limestone channel was installed in the steep natural drain encountered during excavation of the refuse. Acid seeps were encountered near the toe of the slope after removal of the refuse from the Water Tank Hollow site. An open limestone channel was installed along the toe of the slope picking up the acid water and directing it through the limestone before discharging into Rock Creek.

Open limestone channels (OLCs) introduce alkalinity to acid water in open channels or ditches lined with limestone rock (Ziemkiewicz et al., 1994). Acid water is introduced to the channel and the acid mine drainage is treated by limestone dissolution. Past assumptions have held that armored limestone (limestone coated with Fe and/or Al hydroxides) ceased to dissolve, but experiments show that coated limestone continues to dissolve at about 20% the rates of unarmored limestone (Pearson and McDonnell 1975). Another problem is that hydroxides tend to settle into and plug the voids in limestone beds forcing water to move around rather than through the limestone. While both armoring and plugging are caused by the precipitation of metal hydroxides they are two different problems. Maintaining a high flushing rate through the limestone bed can minimize plugging of voids in limestone beds. Armoring, however, occurs regardless of the water velocity. Recent work has demonstrated that the rate of dissolution for armored limestone may be even higher than found in previous laboratory studies (Ziemkiewicz et al., 1997). Field experiments show considerable treatment by OLCs (Ziemkiewicz et al., 1994). The length of channel and the channel gradient are design factors that can be varied for optimum performance. Optimum performance is attained on slopes exceeding 20%, where flow velocities keep precipitates in suspension, and clean precipitates from limestone surfaces. Dissolved metals sorb onto the surfaces of the precipitates in suspension further reducing the amount of dissolved metals in the water. Open limestone channels may be designed and constructed for long term treatment. Utilizing OLCs with other passive systems can maximize treatment and metal removal.

Computer modeling of the open limestone channels was conducted before construction of the OLCs using water-monitoring data from 2/99 to 2/00. Flow in the unnamed tributary at Roberts Hollow is intermittent. No flow was recorded for the months of 6/99, and 8/99 to 11/99. No acidity data was available for 4/99 and 5/99. For the months having data the limestone channel as designed will reduce the acidity by 100% except for 2 months. Calculations using water-monitoring data for 2/99 indicates the net acidity in the unnamed tributary will be reduced by 98% after installation of the proposed OLC. Calculations using water-monitoring data for 3/99 indicates the net acidity in the unnamed tributary will be reduced by 67%. The two months that had less than 100% reduction were high flow conditions. The limestone channel near the toe of the existing refuse could not be modeled because it doesn't intercept the main stem of Roberts Hollow that is being monitored, so no data is available for the flow and acidity levels it will intercept.

Limestone Sand Treatment

During testing of a self-feeding rotary drum system that ground limestone aggregate into a slurry, Zurbuch (1989) found that undissolved sand-sized particles continued to be reactive in stream sediments and significantly reduced acidity. Further research into the use of quarry produced limestone fines as a method to treat streams acidified by acid deposition corroborated the rotary drum results (Ivahnenko et al., 1988).

Sand-sized limestone may be directly dumped into acid mine drainage impacted streams at various locations in watersheds. The sand is picked up by the stream flow and redistributed downstream, neutralizing the acid as the stream moves the limestone through the streambed. The limestone in the streambed reacts with acid in the stream, causing neutralization. Coating of limestone particles with Fe oxides can occur, but the agitation and scouring of the limestone in the streambed keep fresh surfaces available for reaction.

Water monitoring was conducted to determine the acid load being contributed by each tributary to the lower Rock Creek watershed. Limestone sand was placed in each tributary at rates determined by the acid loading calculations. Limestone sand was added at double the calculated rate for the first year and at the calculated rate thereafter so that after the first year there is one year worth of neutralization potential in the streambed. This project included the application of limestone sand to the Roberts Hollow tributary to Rock Creek at the acid loading rates calculated.

The use of the direct application of limestone sand to treat acidified streams is the least expensive method available based on the cost per ton of acid neutralized (Zurbuch, 1996; Zurbuch et al., 1996). This method does not require the large capital investment or the costs associated with the operation and maintenance of mechanical stream dosing systems.

The annual cost to treat the acid load in the lower Rock Creek watershed with limestone sand after construction of all application sites and after the first year of dosing when rates are doubled was calculated to be $15,000. The Division of Abandoned Mine Lands, as part of its annual grants from the Office of Surface Mining, budgets for the continued dosing of the lower Rock Creek watershed with limestone sand into the foreseeable future. It is anticipated that at some time in the future the United States Forest Service will assume the responsibility for dosing the lower Rock Creek watershed. If and when this occurs AML will relinquish responsibility for the dosing to the USFS.

Alternative Treatment Technologies

Active Treatment Technologies

Active treatment systems involve treating mine drainage with alkaline chemicals to neutralize acidity, raise water pH, and precipitate metals. Active treatment technologies are effective; however, when the cost of equipment, chemicals, and manpower are considered active treatment is expensive (Skousen et al. 1990). Chemical treatment is a long term never ending process. A variety of active treatment methods can be employed. Most active chemical treatment systems consist of an inflow pipe or ditch, a storage tank or bin to hold the chemical, a means of controlling the chemical application, a settling pond to capture precipitated metal oxyhydroxides, and a discharge point. Chemical compounds used in AMD treatment include:
Crushed limestone – rotating drum
Hydrated lime

Sodium carbonate (soda ash)
Sodium hydroxide (solid and liquid forms)
Ammonia
Pebble Quicklime (Calcium oxide).

None of the above treatment options are suitable for the Water Tank Hollow refuse site. The refuse on the site toes out into the stream therefore any structure built to intercept the flow from the site would be in the flood zone. The above treatment options could possibly have been used on the Roberts Hollow refuse site. The flow at the toe of the refuse areas would have to be intercepted and directed to a central application site. The treated water would then flow into a settling pond before being discharged into the stream. The costs for construction of an active treatment site and the continuous operation and maintenance of an active treatment site are prohibitive at current funding levels. In addition many of the active treatment options use chemicals that in their concentrated state are harmful to biota. The risk of release of these chemicals in concentrated form by vandalism or accident must be considered before deciding to use them, particularly on public lands.

Passive Treatment Options

Aerobic Wetland

An aerobic wetland consists of a large surface area pond with horizontal surface flow. The pond may be planted with cattails and other wetland species. Aerobic wetlands can only effectively treat water that is net alkaline. In aerobic wetland systems, metals are precipitated through oxidation reactions to form oxides and hydroxides.

Aerobic wetlands are not suitable for the Water Tank Hollow refuse site or the Roberts Hollow refuse site. The water discharging from both sites is net acidic.

Compost / Anaerobic Wetland

Compost wetlands, sometimes called anaerobic wetlands, consist of a large pond with a lower layer of organic substrate. The flow is horizontal through the substrate layer of the pond. The compost layer usually contains calcium carbonate either naturally as in spent mushroom compost, or added during construction of the wetland. A typical compost wetland will have 12 to 24 inches of organic substrate and be planted with cattails or other wetland vegetation. The vegetation helps stabilize the substrate and provides additional organic matter to perpetuate the sulfate reduction reactions. Compost wetlands can treat discharges that contain dissolved oxygen, ferric iron, aluminum, or acidity in the 500 ppm range.

The compost wetland acts as a reducing environment. The compost removes oxygen from the system. Microbial processes within the organic substrate reduce sulfates to water and hydrogen sulfide. The anoxic environment within the substrate increases the dissolution of limestone. Chemical and microbial processes generate alkalinity and increase the pH.

The Water Tank Hollow refuse site was not suitable for a compost wetland. The refuse toes out in the stream and there was not enough room to intercept the flow into a constructed wetland and be out of the flood zone. The Roberts Hollow site may have been suitable for a compost wetland. The flow from the refuse would have to be intercepted and directed to the wetland at the toe of the slope. This would have required relocation of the refuse on the lower slope.

Anaerobic wetlands are sized according to the U.S. Bureau of Mines criteria for AML sites. The formula for sizing anaerobic wetlands is:

Minimum wetland size (square meter) = acid loading (g/day) / 0.7

The acid load for the Roberts Hollow site for the period 9/98 to 12/99 ranged from a low of 2,563 g/day in September 1998 to 621,526 g/day in December 1999. Assuming an acid-loading rate of 500,000 g/day (which would handle the acid load 90% of the time) an anaerobic wetland would need to be 180 acres in size. Assuming an acid-loading rate of 25,000 g/day (which would handle the acid load 50% of the time) an anaerobic wetland would need to be 9 acres in size. Even at the lower acid loading rate the size of the anaerobic wetland needed exceeds the amount of land available for construction.

Anoxic Limestone Drains

An anoxic limestone drain (ALD) is a buried bed of limestone constructed to intercept subsurface mine water flows and prevent contact with atmospheric oxygen. Keeping the water anoxic prevents oxidation of metals and prevents armoring of the limestone. The process of limestone dissolution generates alkalinity. The purpose of an ALD is to provide alkalinity thereby changing net acidic water to net alkaline water. ALDs are limited to the amount of alkalinity they can generate based on solubility equilibrium reactions. An ALD is a pretreatment step to increase alkalinity and raise pH before the water is oxidized and the metals precipitated in an aerobic wetland.

This project involved acidic refuse material placed on a slope. The water leaving the site had already been oxidized so the use of an ALD on the refuse sites was not possible.

Water analysis of 41 portals in the lower Rock Creek area in the spring of 1995 indicated that none of the 41 portals were suitable for the installation of an ALD. In all instances ferric iron and/or aluminum, and/or dissolved oxygen levels were too high for long term successful treatment.

Vertical Flow Reactors

Vertical flow reactors were conceived as a way to overcome the alkalinity generation limitations of an anoxic limestone drain and the large area requirements for compost wetlands. The vertical flow reactor consists of a treatment cell with a limestone underdrain topped with an organic substrate and standing water. The water flows vertically through the organic substrate, which strips the oxygen from the water making it anoxic. The water then passes through the limestone, which dissolves increasing alkalinity. The water is discharged through a pipe with an air trap to prevent oxygen from entering the treatment cell. Water with high acidity levels can be treated by passing the water through a series of treatment cells. A settling pond and an aerobic wetland where metals are oxidized and precipitated typically follow the treatment cells.

Problems associated with vertical flow reactors include plugging of the pipes with aluminum which must be periodically flushed when aluminum loading is high, and precipitation of metals in the organic substrate which may clog, preventing flow into the limestone underdrain.

The Water Tank Hollow site was not suitable for a vertical flow reactor due to the refuse toeing out into the stream. There is no room for construction of the treatment cells, and interception of the acid water out of the flood zone. The Roberts Hollow refuse site may have been suitable for vertical flow reactors. It may have proven difficult to intercept all of the acid water flowing through the refuse and direct it to the treatment cells. Refuse would have needed to be moved from the lower slopes to provide room for construction of the treatment cells and polishing wetland. Moving the refuse and construction of the treatment cells, settling pond, and wetland would have exceeded the funding level.

Other Options

Other options included leaving the refuse in place at the Water Tank Hollow refuse site, applying agricultural limestone to the surface of the refuse, covering the refuse with hardwood bark mulch or a suitable borrow material, and revegetating the site. This treatment method would have reduced the amount of material washing into the stream by revegetation of the site and would therefore decrease the acid load to the stream. The pyrite material in the refuse would have continued to weather, however, by chemical and biological processes, generating acid drainage that would have entered the stream. The removal and mixing of the refuse with agricultural limestone as done on this project inhibits the formation of acid in the refuse by suppressing bacterial catalysis of the iron and neutralizes any acid formed.

Another option was to do nothing. The Water Tank Hollow refuse site would have continued to erode into the stream contributing about 300 cubic yards of sediment and more than 80 tons of acidity annually to the lower Rock Creek drainage.

Maintenance Agreement

The Division of Abandoned Mine Lands continues to monitor all project sites annually for a period of 5 years after the final inspection of the project. All project sites are inspected annually by AML's staff agronomist or his representative. In addition AML responds to any complaints received for maintenance on its project sites. Any maintenance required will be performed under a separate maintenance contract. The Division of Abandoned Mine Lands as part of its annual grants from the Office of Surface Mining budgets a portion of the annual grant for maintenance of reclamation projects completed by AML. Funds for any maintenance work required will be made available through AML's annual grant from OSM. This is standard operating procedure for all AML projects. After the 5 year monitoring period by AML maintenance of the project sites will be performed by mutual agreement with the landowner (United States Forest Service).

RESULTS

Water Tank Hollow Site

The Water Tank Hollow site was a 3-acre coal processing refuse disposal site on the north bank of Rock Creek. This project involved the removal of 18,331 cubic yards of highly acidic coal mine refuse from the site. The refuse was hauled to an existing fill area in Roberts Hollow, treated, and placed in compacted lifts. The computer programs SEDCAD4 and RUSLE were used to calculate the soil/refuse loss from the Water Tank Hollow refuse site each year. It was calculated that the annual soil/refuse loss was about 500 tons per year. The refuse was sampled and found to have a potential acidity of 165 tons per kiloton. Removal of the refuse from the Water Tank Hollow site resulted in a reduction of 82.5 tons of acidity per year from the direct washing of the refuse into the stream. The actual acid load reduction is higher due to the formation of sulfur salts in the refuse and subsequent dissolution and runoff of acid into the stream during precipitation events. It was not possible to directly monitor the acid runoff at this site due to the nonpoint source nature of the 3 acres of acidic refuse located on the north bank of Rock Creek.

A seep, flowing from the refuse, was observed draining into the Water Tank Hollow tributary near the mouth of the stream prior to reclamation. Water Monitoring was conducted above the seep to document background conditions and below the seep at the mouth of the tributary to document the impacts to water quality this small seep was having on the Water Tank Hollow tributary. Removal of the refuse from the Water Tank Hollow site eliminated the seep and the impacts the refuse was causing on water quality entering Rock Creek from the Water Tank Hollow tributary. Water monitoring upstream from the mouth of the tributary ceased after elimination of the acidic seep.

The pH values at the mouth of Water Tank Hollow were lower than above the seep on thirteen out of fifteen sampling dates prior to reclamation of the site (Figs. 7 and 8). The largest decline in pH occurred on September 5, 2000 with a reduction in pH value from 6.2 above the seep to 3.5 below the seep at the mouth of the tributary.

Acidity increased and alkalinity decreased on nine out of ten sampling dates below the seep prior to removal of the refuse. Water Tank Hollow was net acidic at the mouth all but one sampling date, January 4, 2000, prior to reclamation and was net alkaline all but two sampling dates, September 25, 2001 and December 18, 2001, post reclamation (Figs. 9 and 10).

Iron concentrations (Figs. 11 and 12) and iron loading (Figs. 13 and 14) were higher below the seep prior to reclamation with reductions close to background levels post reclamation. Total iron loading at the mouth of Water Tank Hollow was reduced by 85% dropping from an average of 45.4 kilograms per month before reclamation to 5.4 kilograms per month post reclamation. Dissolved iron loading was reduced by 88% dropping from an average of 25 kilograms per month before reclamation to an average of 3 kilograms per month after reclamation. Similar results were seen with aluminum concentrations and loading with an 85% reduction in total aluminum loading from an average of 35 kilograms per month before reclamation to an average of 5 kilograms per month after reclamation. Dissolved aluminum loading was reduced by 89% from an average of 27 kilograms per month before reclamation to an average of 2.5 kilograms per

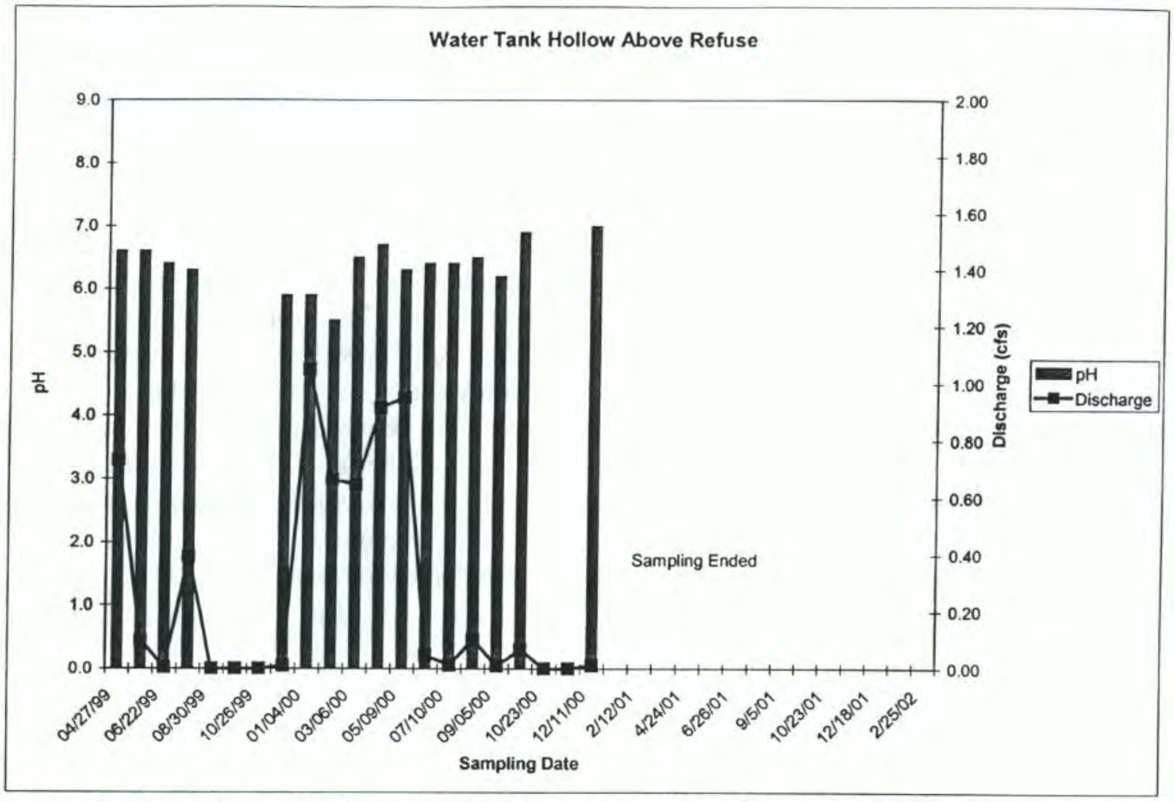


Figure 7. Discharge and pH values above the refuse at Water Tank Hollow.

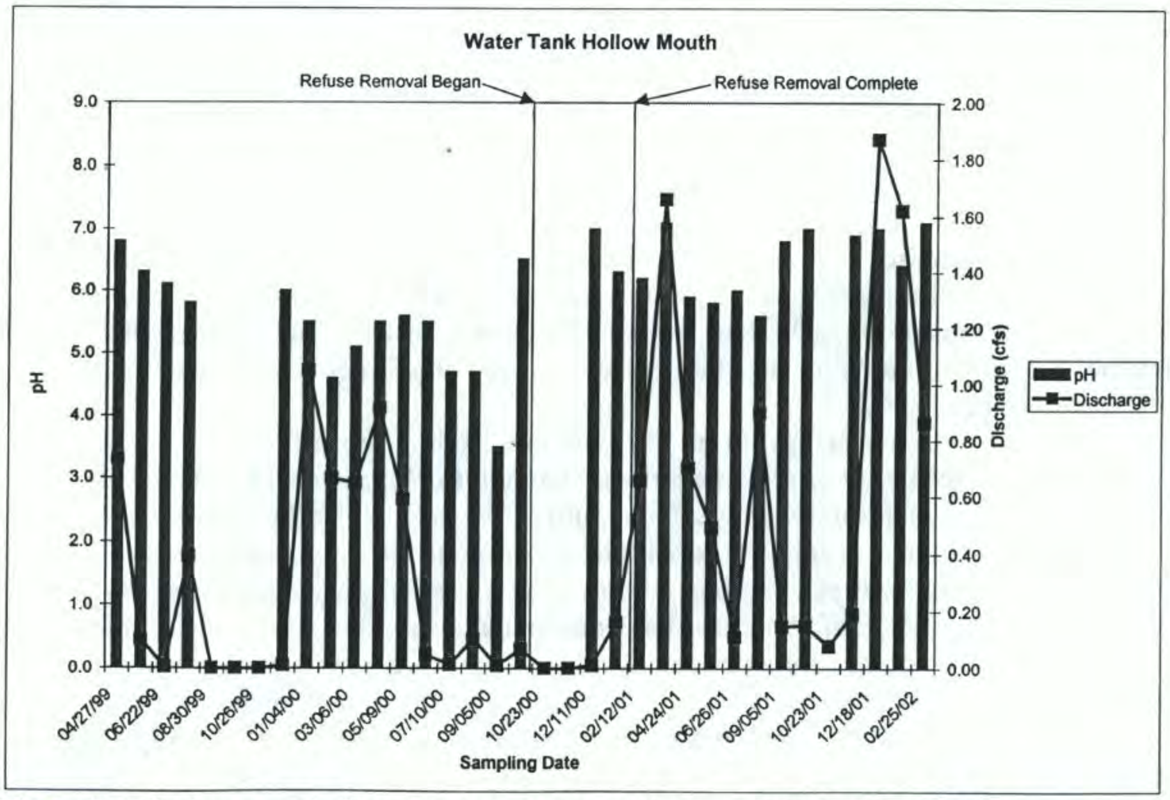


Figure 8. Discharge and pH values below the acidic seep at Water Tank Hollow.

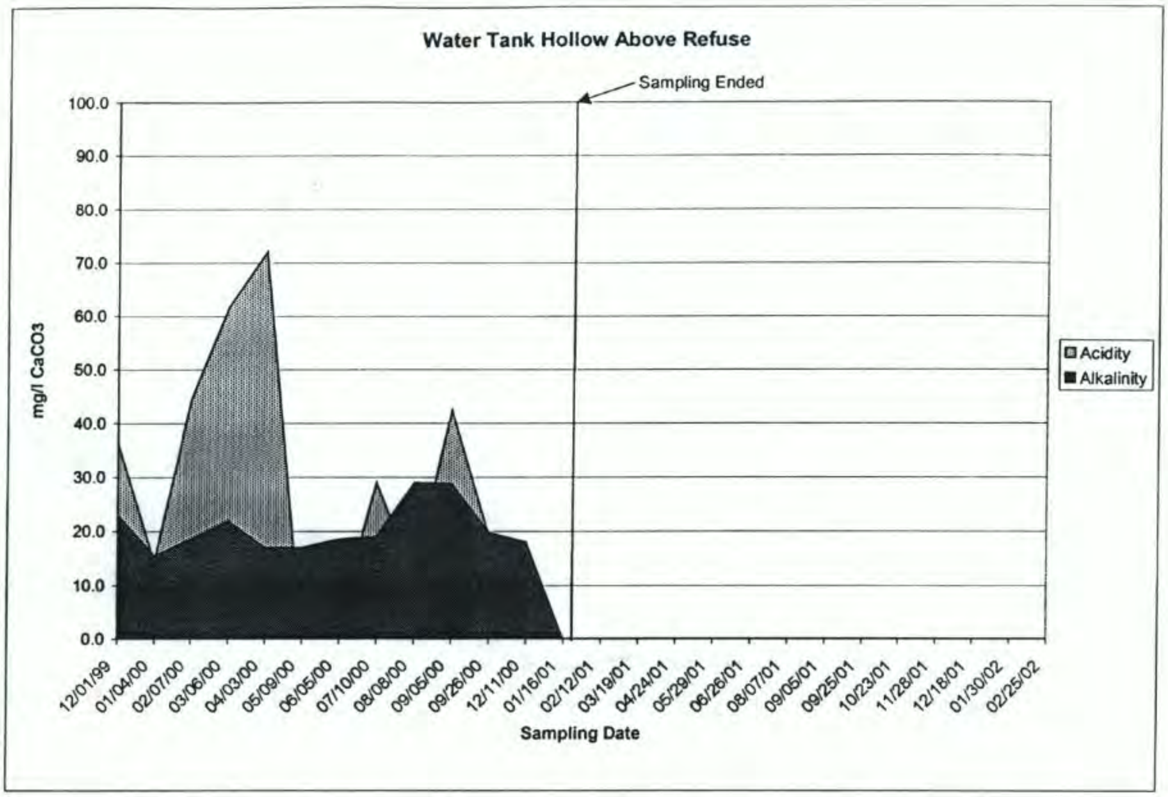


Figure 9. Acidity and Alkalinity above the refuse at Water Tank Hollow.

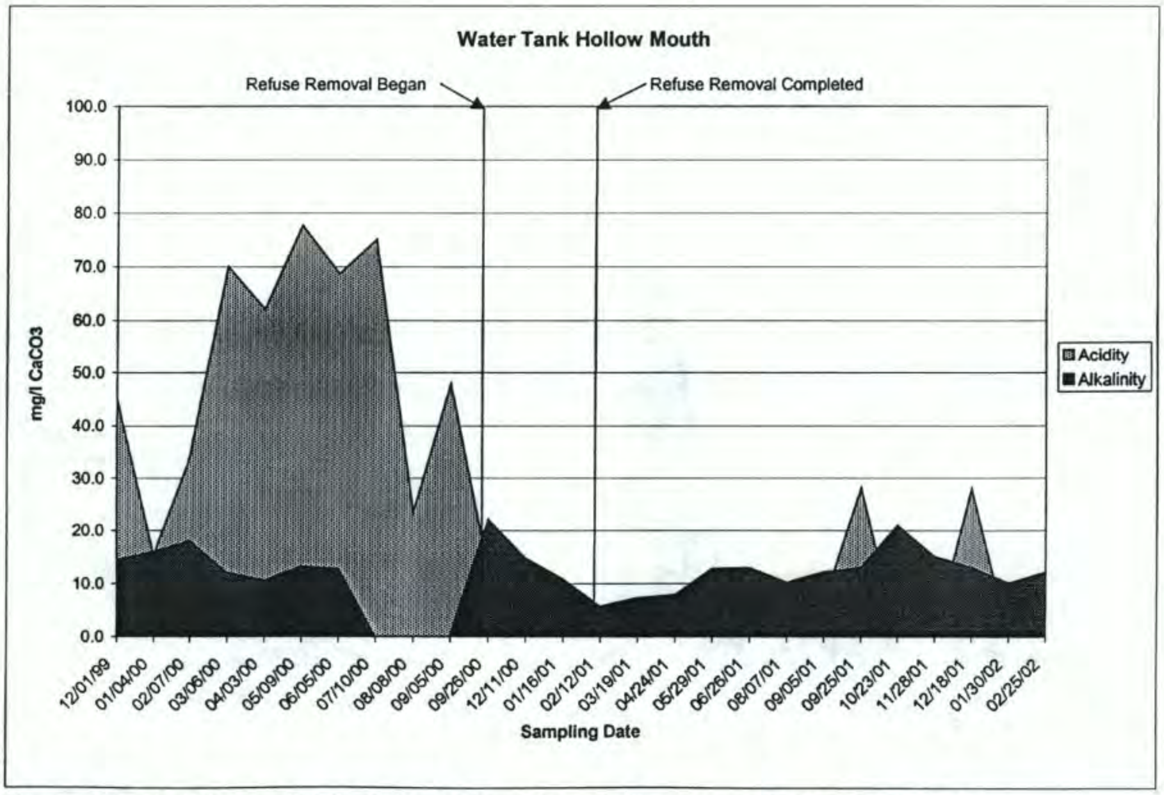


Figure 10. Acidity and Alkalinity below the acidic seep at Water Tank Hollow.

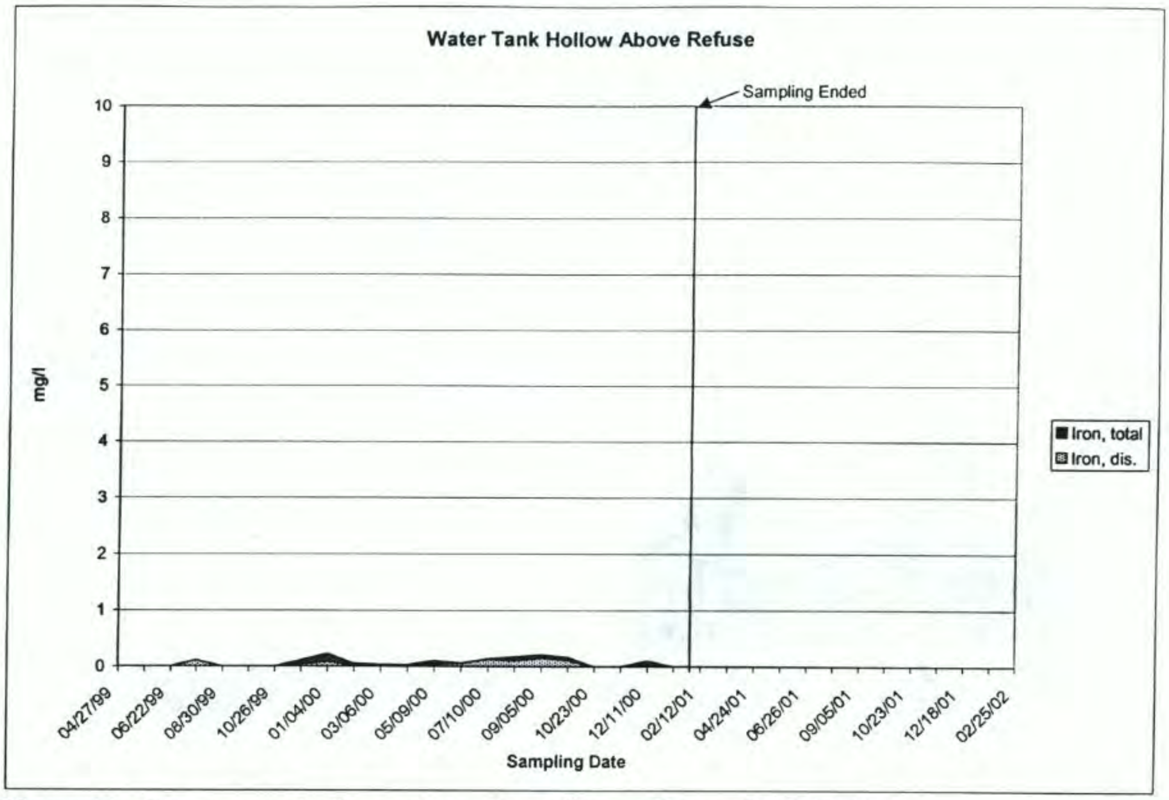


Figure 11. Iron concentrations above the refuse at Water Tank Hollow.

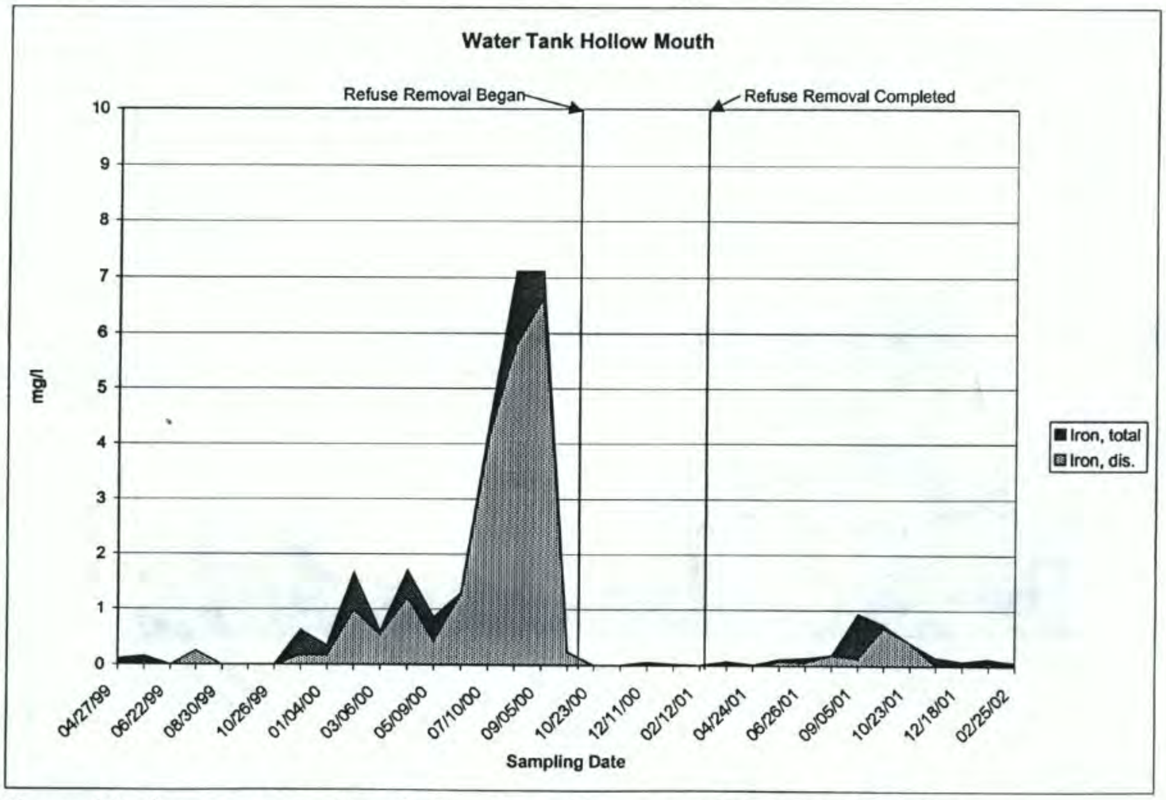


Figure 12. Iron concentrations below the acidic seep at Water Tank Hollow.

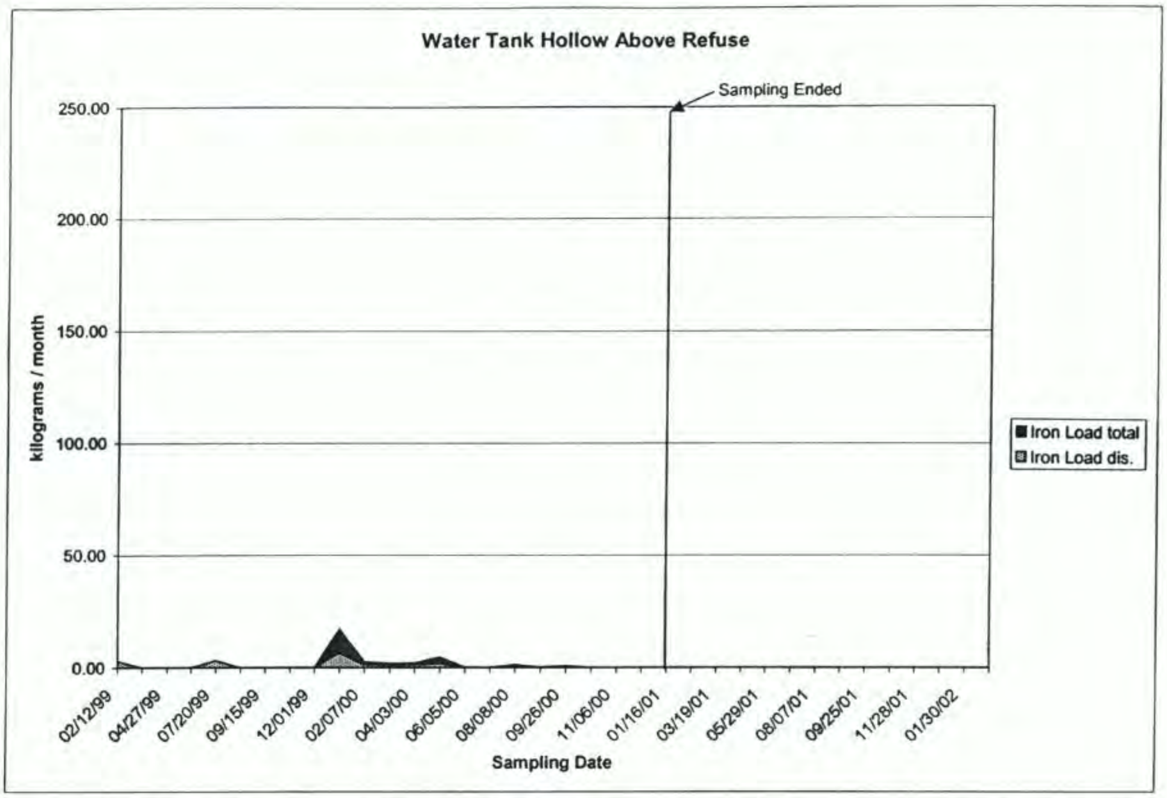


Figure 13. Iron loading above the refuse at Water Tank Hollow.

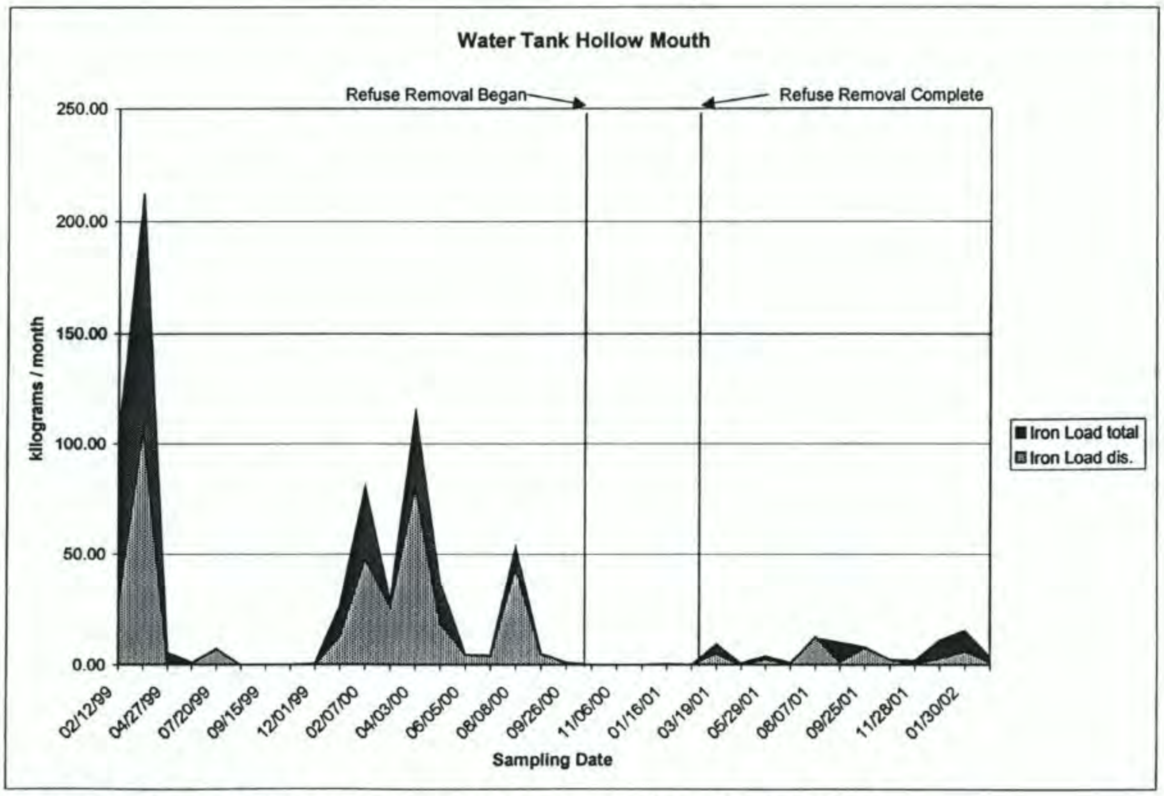


Figure 14. Iron loading below the acidic seep at Water Tank Hollow.

month after reclamation (Figs. 15, 16, 17, and 18).

The water monitoring at Water Tank Hollow shows what a significant impact a small acidic seep can have on a headwaters watershed with little natural buffering. Removal of the 3 acres of pyritic refuse and revegetation at Water Tank Hollow has resulted in dramatic reductions in sedimentation and acid and metal loads entering Rock Creek.

Unnamed Tributary below Roberts Hollow

The unnamed tributary below Roberts Hollow has a drainage area of 0.11 square miles. The tributary receives drainage from a coal processing refuse fill and deep mine portals located in Roberts Hollow. Flow in the tributary is intermittent with no flow during dry months. An open limestone channel (OLC) 800 feet in length was installed in the natural drain. Water monitoring was conducted near the mouth of the tributary before and after construction of the OLC.

The pH values ranged from 2.7 to 4.9 and averaged 3.4 for the 13 sampling dates that had flow prior to construction of the OLC. The pH values ranged from 4.9 to 7.9 and averaged 6.8 for the 10 sampling dates having flow after installation of the OLC (Fig.19).

For the 13 sampling dates having flow prior to construction of the OLC total calcium concentrations averaged 47 mg/l. Calcium concentrations averaged 127 mg/l for the 10 sampling dates having flow after installation of the OLC (Fig. 20).

Acidity decreased from an average of 182 mg/l CaCO3 to an average of 63 mg/l CaCO3 after installation of the OLC. Alkalinity increased from 0 to an average of 65 mg/l CaCO3 after installation of the OLC. Net acidity was reduced 92% from an average of 166 mg/l CaCO3 to an average of 14.3 mg/l CaCO3 post construction. The tributary was net acidic until installation of the OLC when it became net alkaline for six of the ten sampling periods post construction (Fig. 21). Net acid loading was near zero post construction with the exception of the December 18, 2001 sampling date when high flows increased the loading. Acid loading averaged 441 kilograms per month before construction and averaged 252 kilograms per month post construction, a 43% decrease. The single high flow event on December 18, 2001 contributed 98% of the post construction acid loading (Fig. 22).

Iron concentrations decreased post construction. As the pH increases dissolved iron precipitates and may either be deposited or remain in suspension. The decrease in dissolved iron versus total iron indicates that iron is precipitating as it passes through the OLC (Fig. 23). Iron loading also decreased with the exception of the December 18, 2001 sampling date when high flows increased the loading. The percentage of dissolved iron loading to total iron loading decreased with the installation of the OLC (Fig. 24).

Aluminum concentrations also decreased post construction. Dissolved aluminum concentrations also decreased versus total aluminum indicating the rise in pH in the OLC is causing dissolved aluminum to precipitate (Fig. 25). Aluminum loading also showed a general decline with a corresponding decrease in dissolved aluminum loading versus total aluminum loading (Fig. 26).

Installation of the OLC at the unnamed tributary below Roberts Hollow has resulted in an increase in pH, calcium concentrations, and alkalinity, and a corresponding decrease in acidity and dissolved metals.

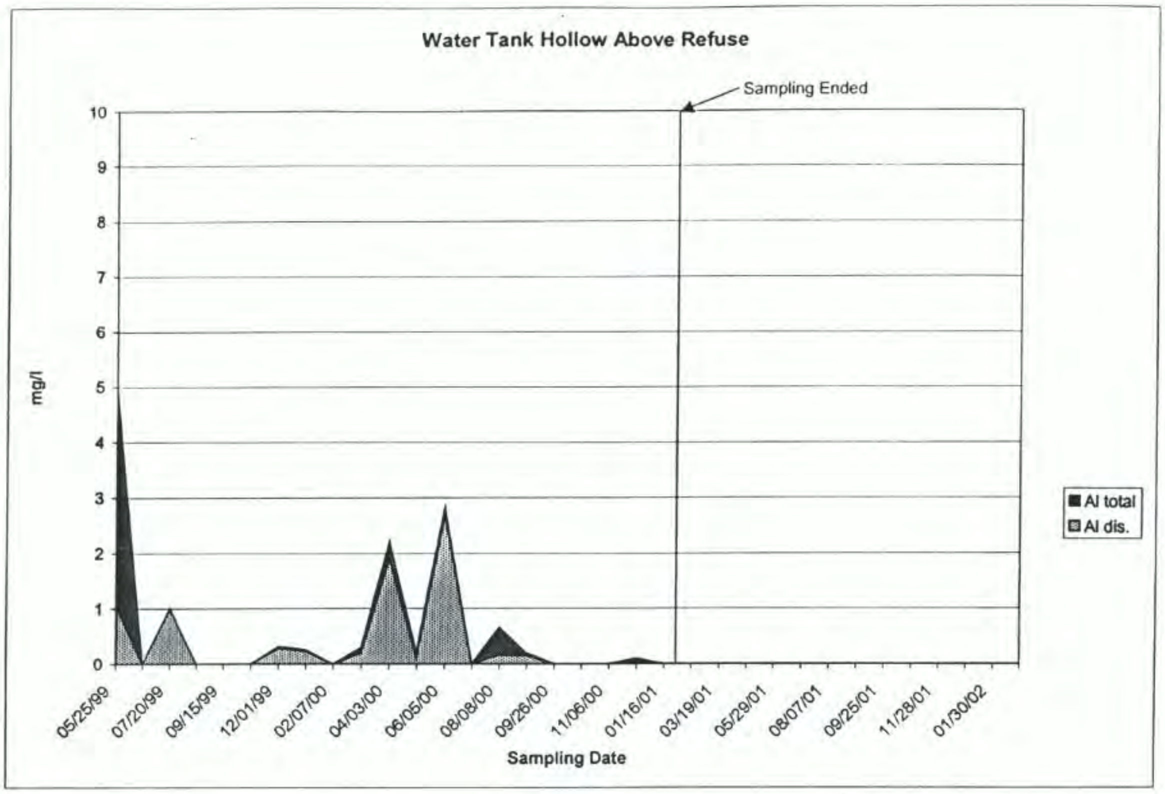


Figure 15. Aluminum concentrations above the refuse at Water Tank Hollow.

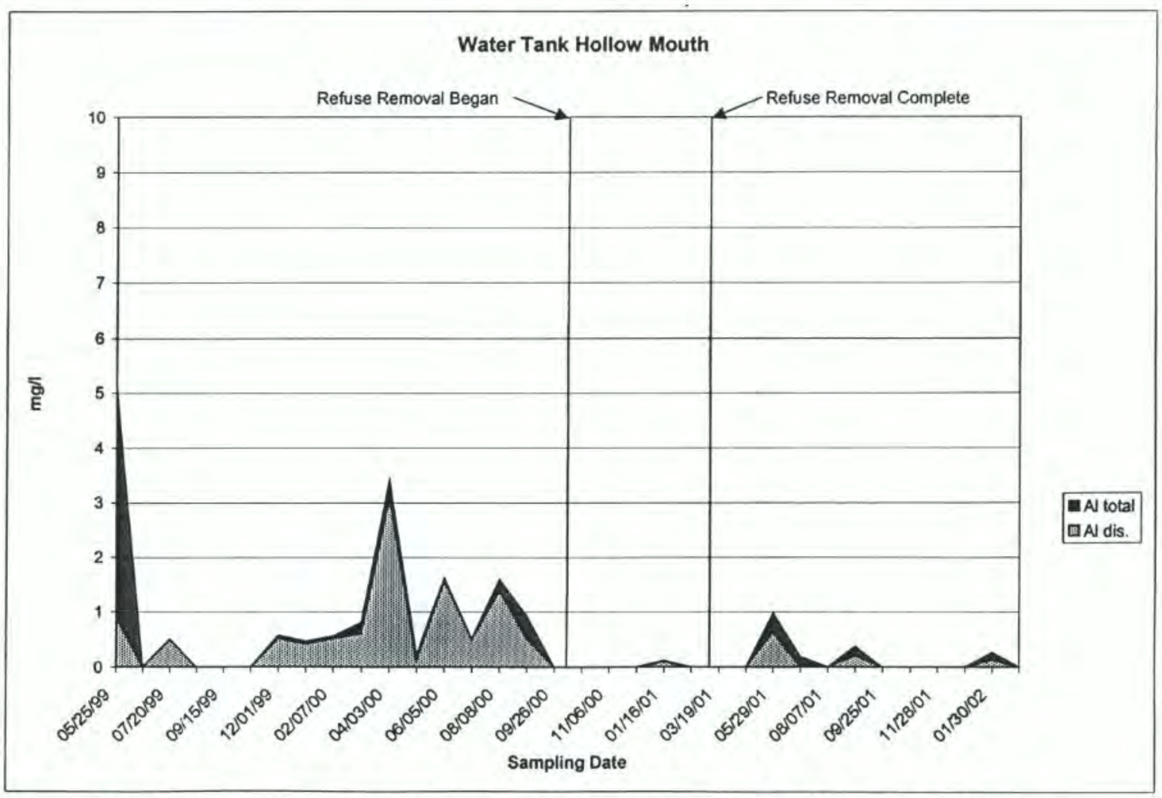


Figure 16. Aluminum concentrations below the acidic seep at Water Tank Hollow.

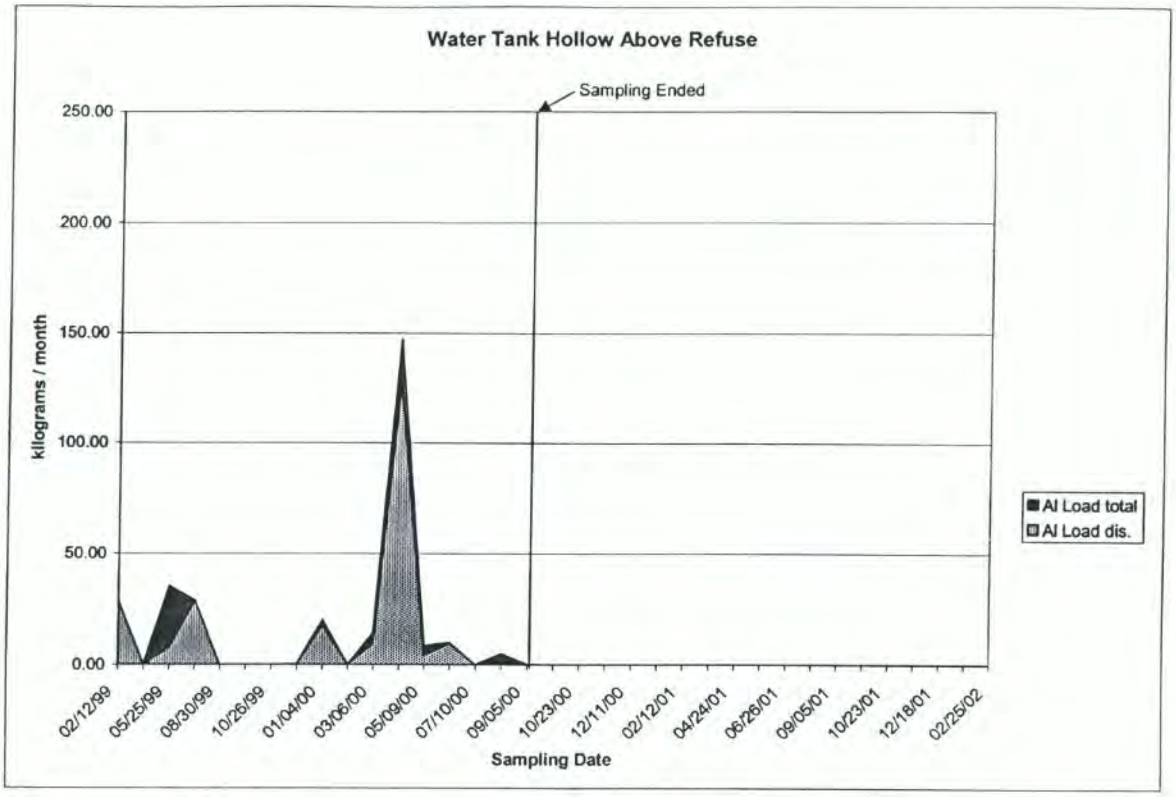


Figure 17. Aluminum loading above the refuse at Water Tank Hollow.

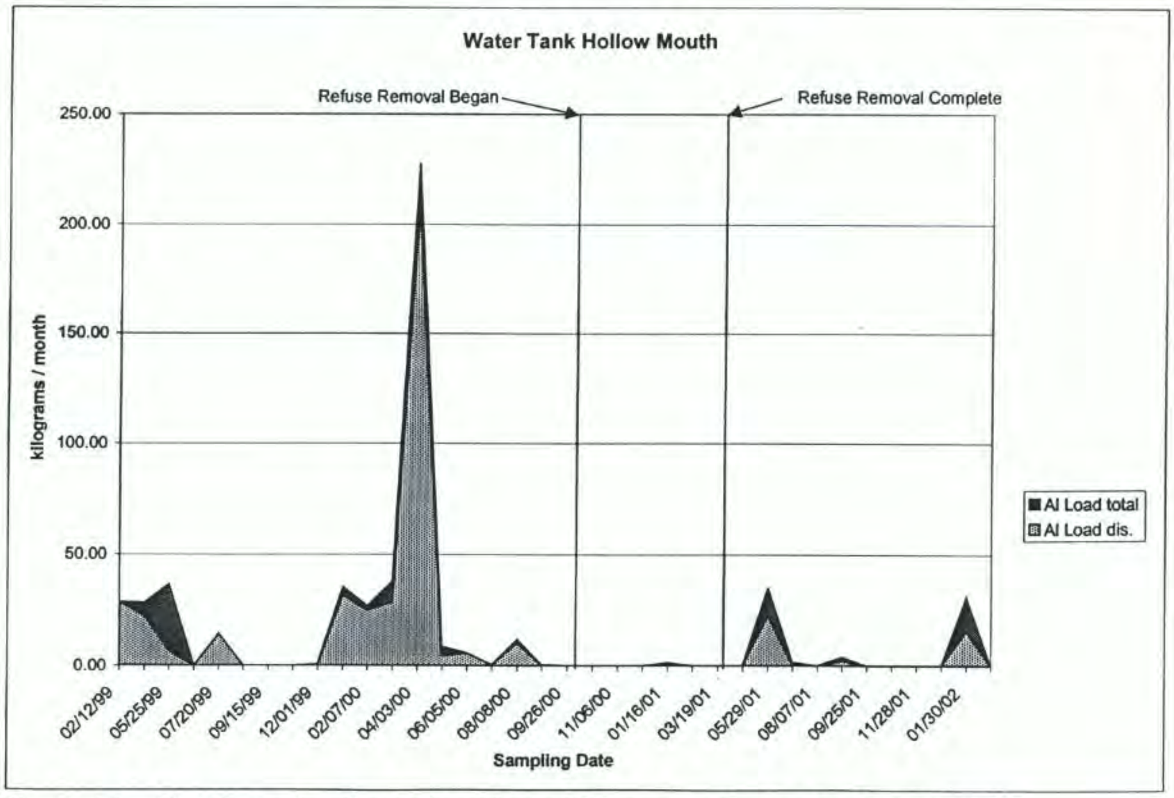


Figure 18. Aluminum loading below the acidic seep at Water Tank Hollow.

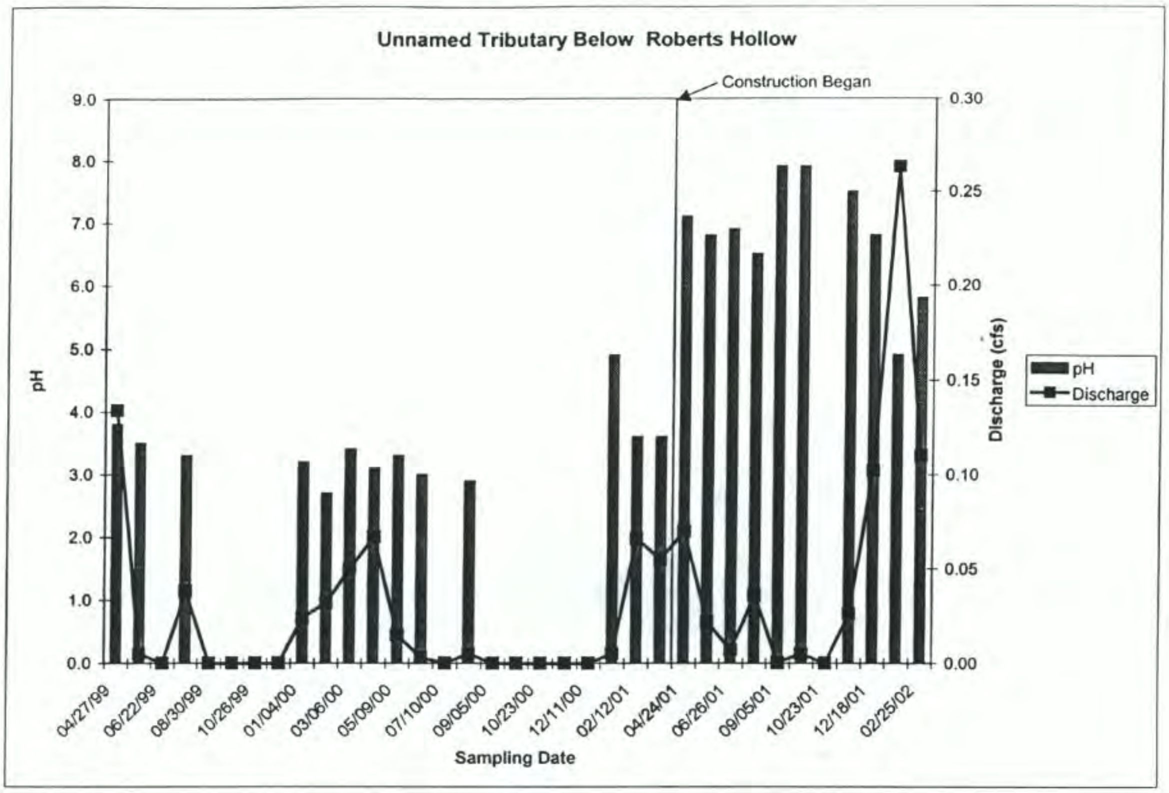


Figure 19. Discharge and pH at the unnamed tributary below Roberts Hollow.

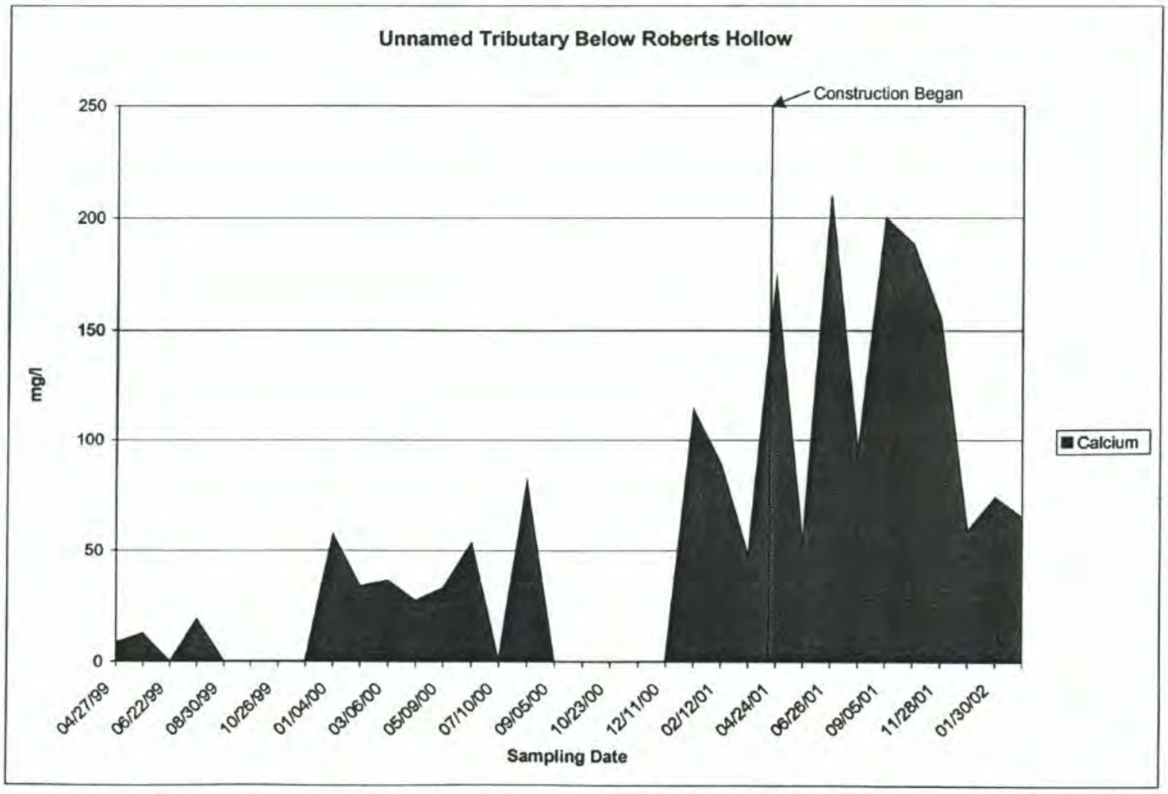


Figure 20. Calcium concentrations at the unnamed tributary below Roberts Hollow.

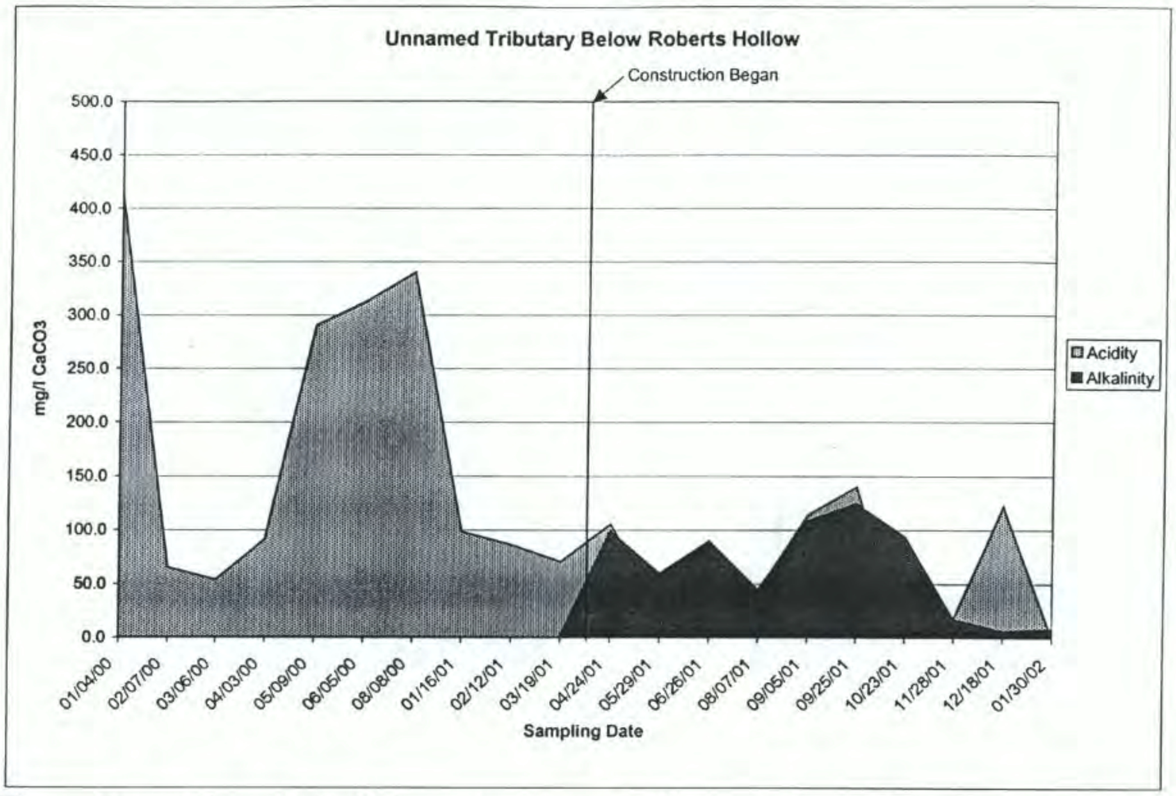


Figure 21. Acidity and alkalinity at the unnamed tributary below Roberts Hollow.

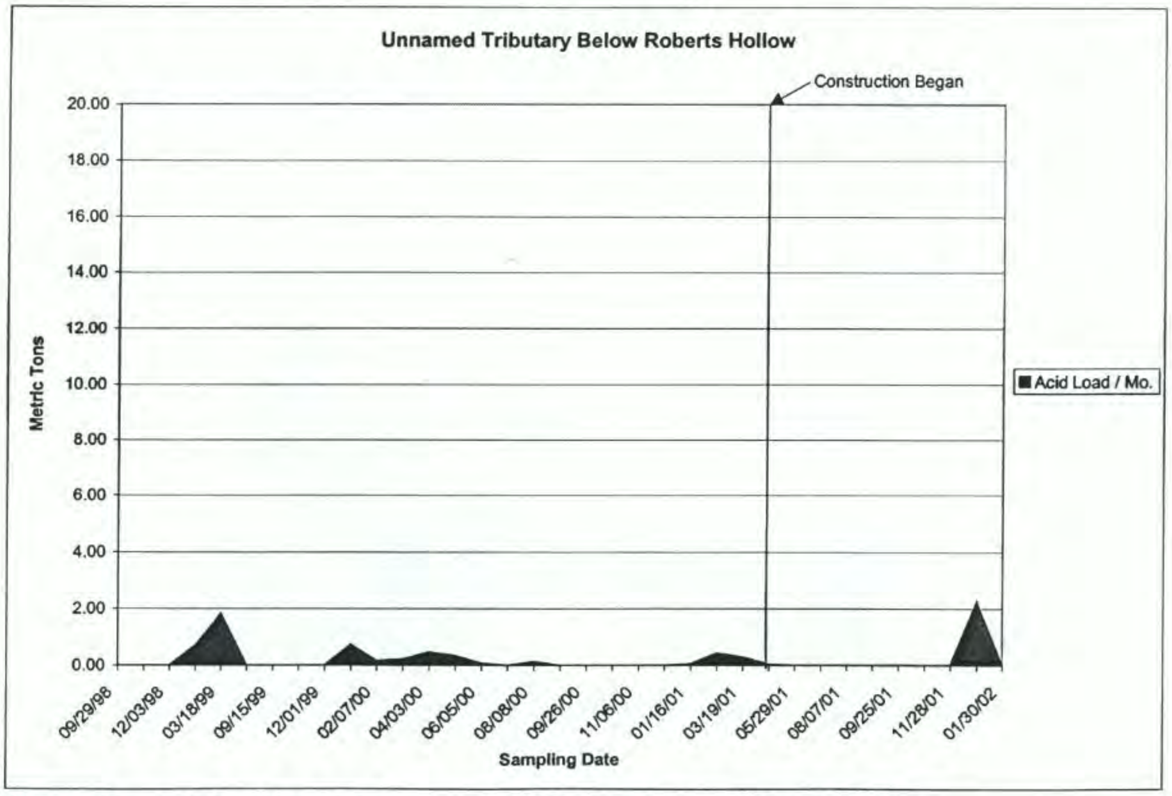


Figure 22. Acid loading at the unnamed tributary below Roberts Hollow.

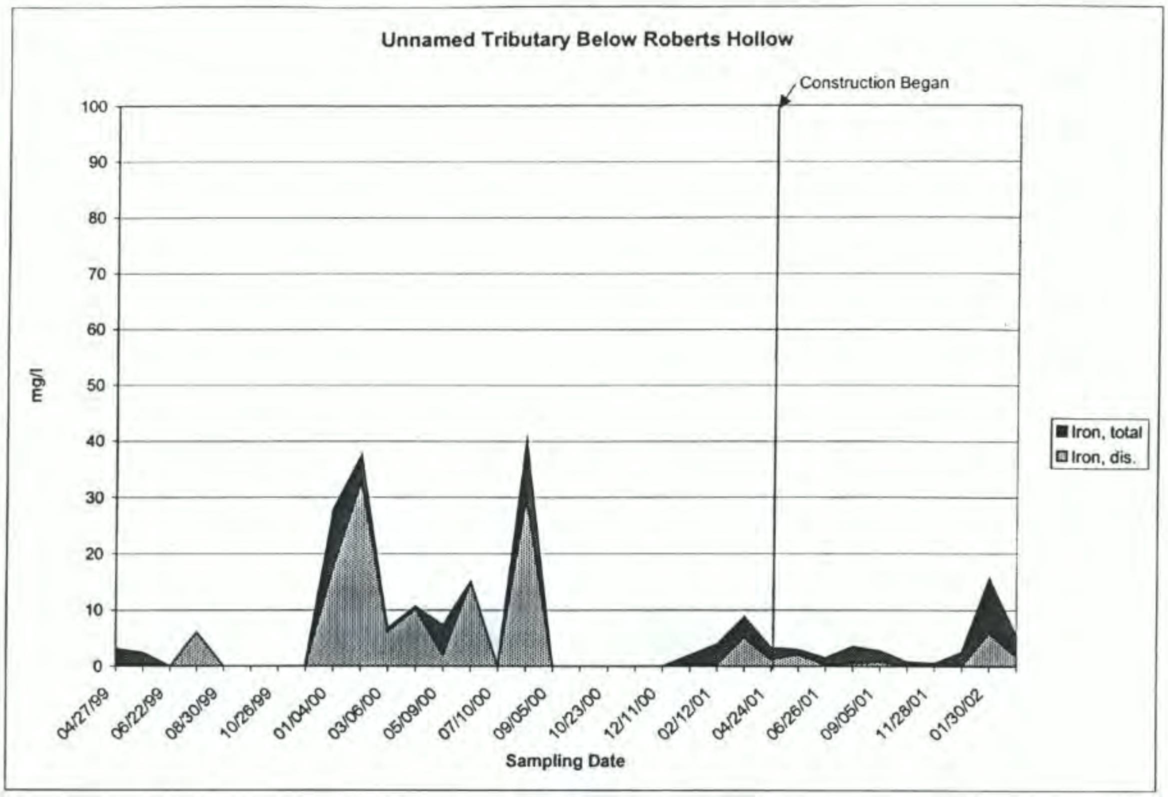


Figure 23. Iron concentrations at the unnamed tributary below Roberts Hollow.

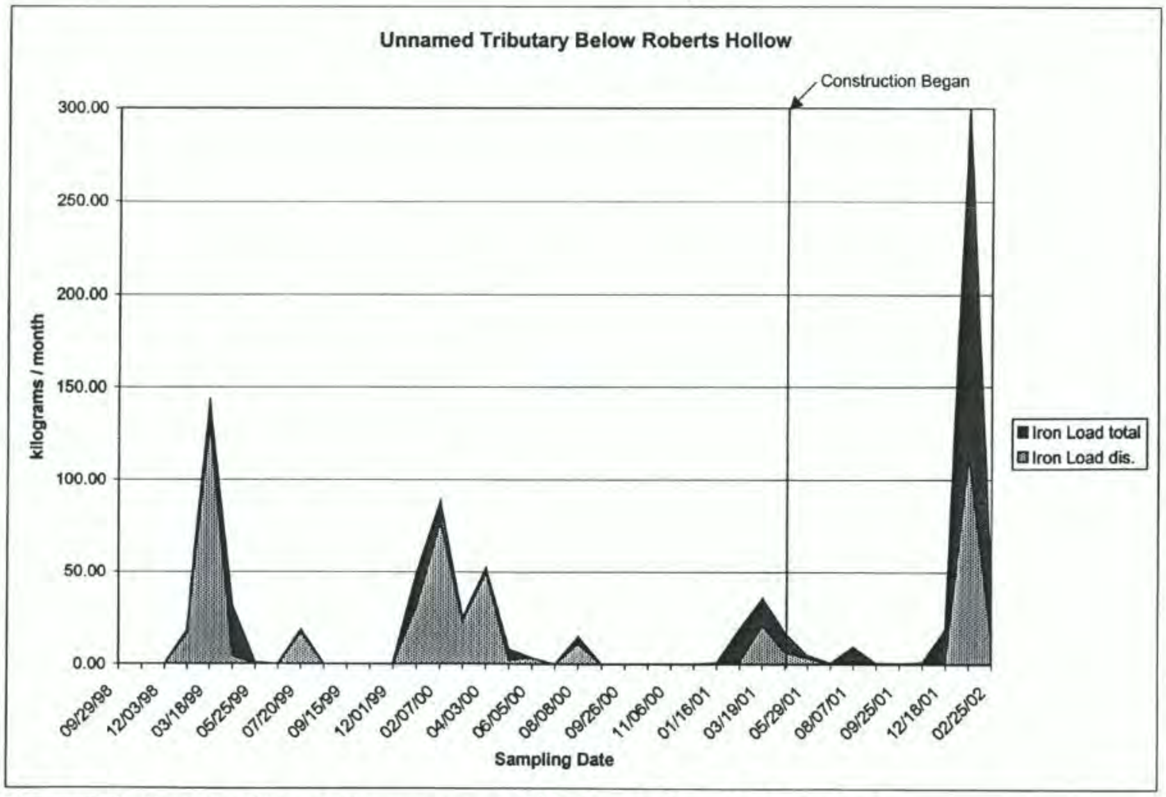


Figure 24. Iron loading at the unnamed tributary below Roberts Hollow.

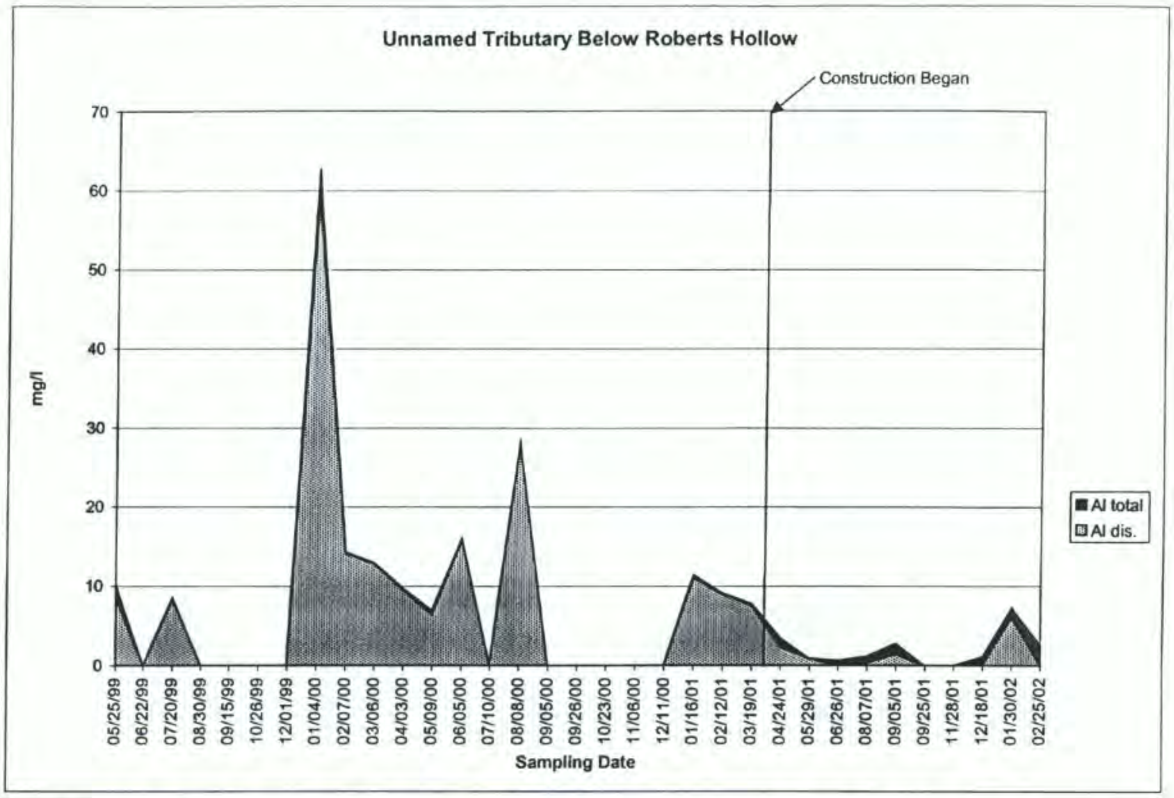


Figure 25. Aluminum concentrations at the unnamed tributary below Roberts Hollow.

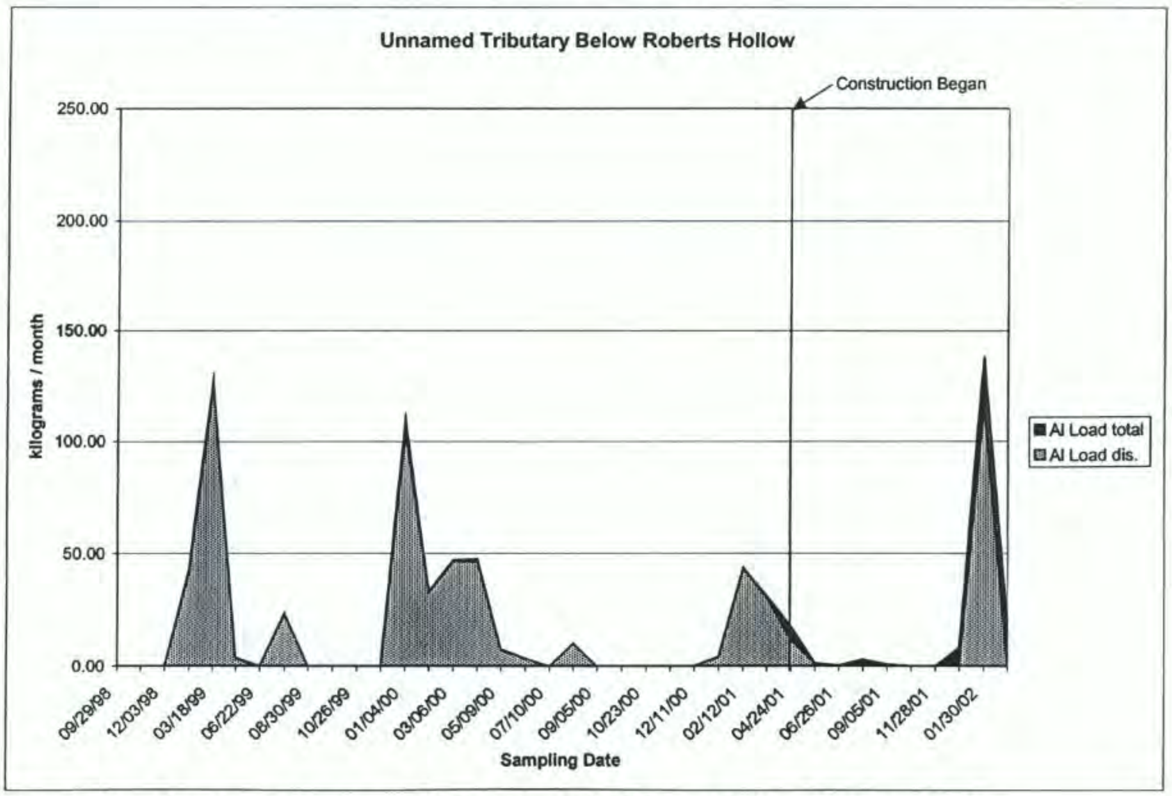


Figure 26. Aluminum loading at the unnamed tributary below Roberts Hollow.

Roberts Hollow Site

Roberts Hollow has a drainage area of 0.64 square miles. The tributary receives drainage from a coal processing refuse fill and several underground mine portals. The existing refuse fill had sparse vegetation on the lower third of the slope due to acidic groundwater seepage being generated by the pyritic refuse. The refuse from the Water Tank Hollow site was hauled to the existing refuse fill at Roberts Hollow. Foundation benches were excavated in the lower fill area and an agricultural limestone barrier was placed prior to placement of the refuse. Agricultural limestone was mixed with the refuse at a rate determined by soil tests and placed in six to eight inch lifts. The treated refuse fill was capped with two feet of soil material and revegetated. An open limestone channel 1000 feet in length was installed between the existing refuse fill and the treated refuse fill. The OLC intercepts the acidic groundwater and treats it before discharging into the tributary. A limestone sand dosing station was constructed 1000 feet upstream from the mouth of the tributary. The tributary was dosed with limestone sand monthly at a rate based on acid loading calculations.

The field pH of the Roberts Hollow tributary ranged from 2.8 to 3.4 prior to dosing the tributary with limestone sand. After limestone dosing began the field pH of the tributary ranged from 3.5 to 5.7 (Fig. 27).

Total calcium concentrations of the tributary averaged 46 mg/l prior to construction of the new fill and monthly dosing with limestone sand. Total calcium concentrations averaged 107 mg/l after construction of the new refuse fill began and monthly dosing with limestone sand.

Acidity decreased from an average of 254 mg/l $CaCO_3$ to an average of 164 mg/l $CaCO_3$ after construction of the new fill began and with monthly treatment of the tributary with limestone sand. Alkalinity was zero before treatment and remained at zero after treatment with the exception of one sampling date, October 23, 2001, when 5 mg/l $CaCO_3$ was recorded (Fig. 29). Acid loading was reduced by 44% with the calculated net acid loading averaging 4.1 metric tons per month prior to reclamation and averaging 2.3 metric tons per month after reclamation and limestone dosing began (Fig 30).

Total iron concentrations averaged 41 mg/l prior to reclamation. Dissolved iron concentrations averaged 34 mg/l prior to reclamation and was 84% of the total iron concentration. After reclamation and dosing began total iron concentrations averaged 28 mg/l, a reduction of 32% of the average total iron concentrations prior to reclamation. Dissolved iron concentrations averaged 14 mg/l after dosing and reclamation began and was 50% of the total iron concentration. Dissolved iron concentrations were reduced by 59% after dosing and reclamation began (Fig. 31). Total iron loading decreased by 31% after reclamation began. Total iron loading averaged 482 kilograms per month prior to reclamation versus 331 kilograms per month after reclamation began. Dissolved iron loading decreased by 46% after reclamation began. Dissolved iron loading averaged 299 kilograms per month prior to reclamation and 162 kilograms per month after reclamation began (Fig. 32).

Total aluminum concentrations averaged 18mg/l prior to reclamation. Dissolved aluminum concentrations averaged 13 mg/l prior to reclamation and was 72% of the total aluminum concentration. After reclamation began total aluminum concentrations averaged 12 mg/l, a reduction of 33% of the average total aluminum concentrations prior

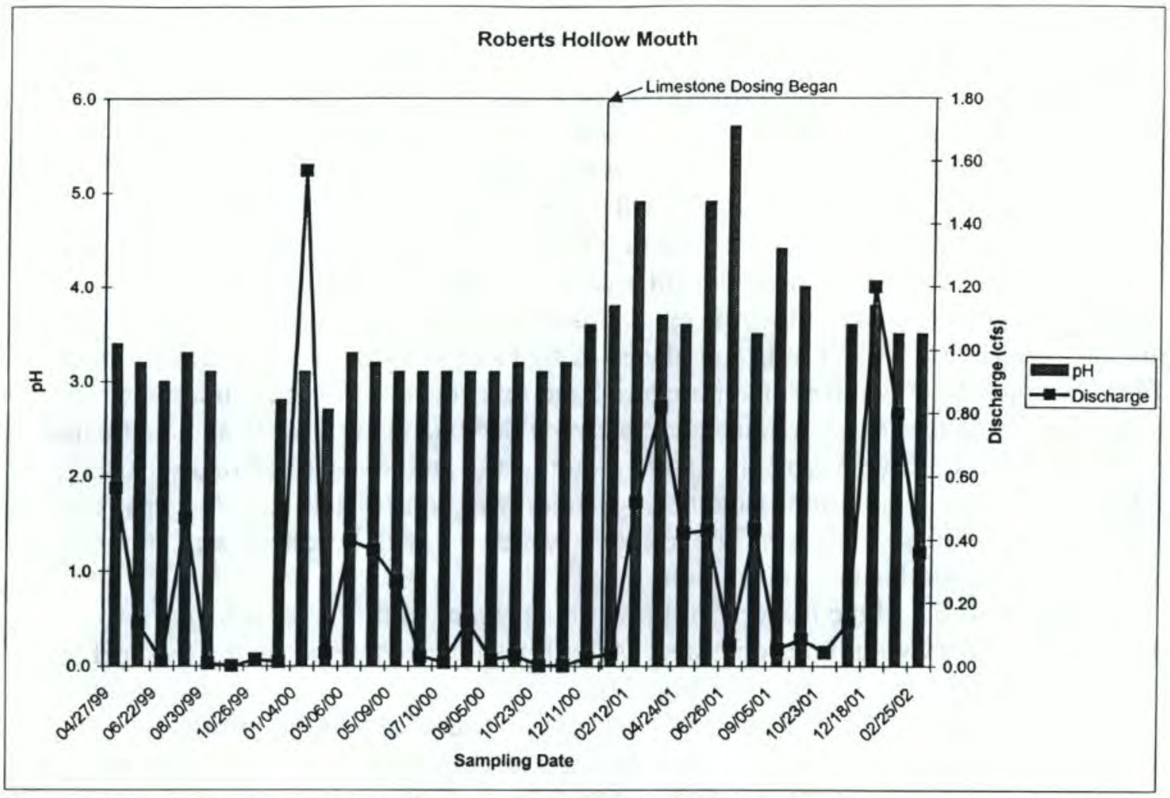


Figure 27. Discharge and pH values at the mouth of Roberts Hollow.

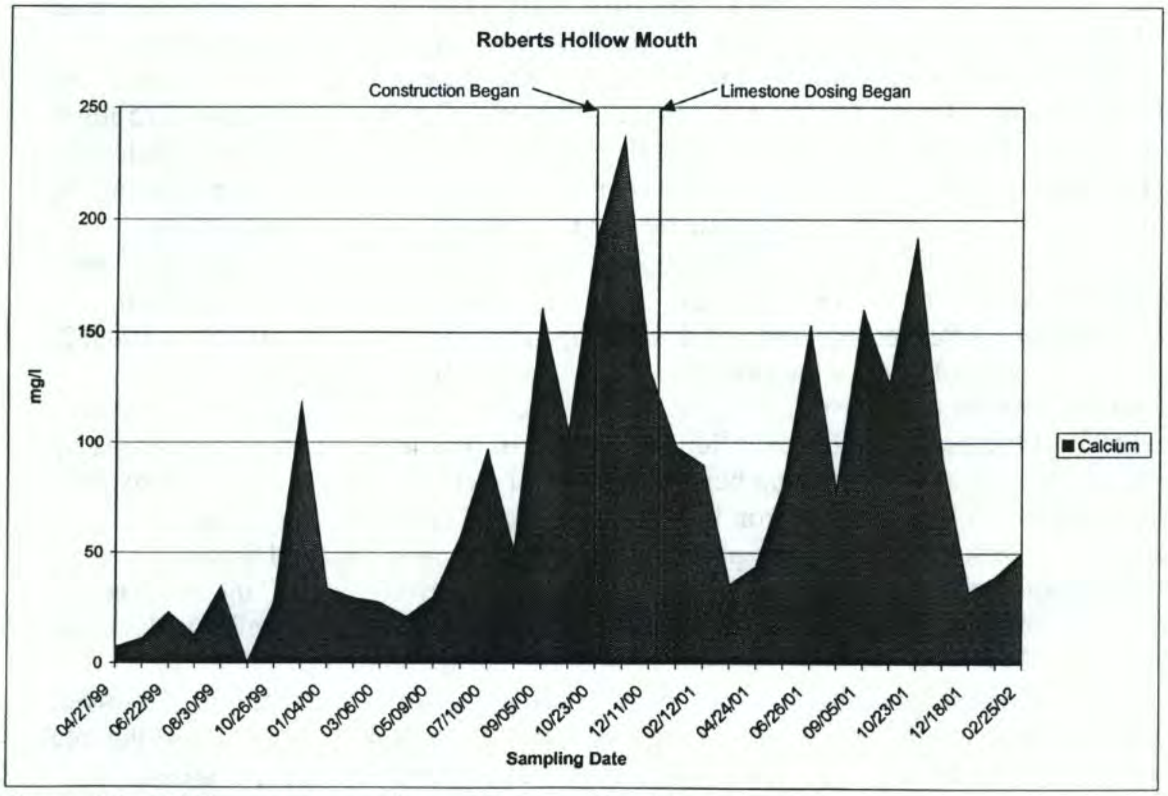


Figure 28. Calcium concentrations at the mouth of Roberts Hollow.

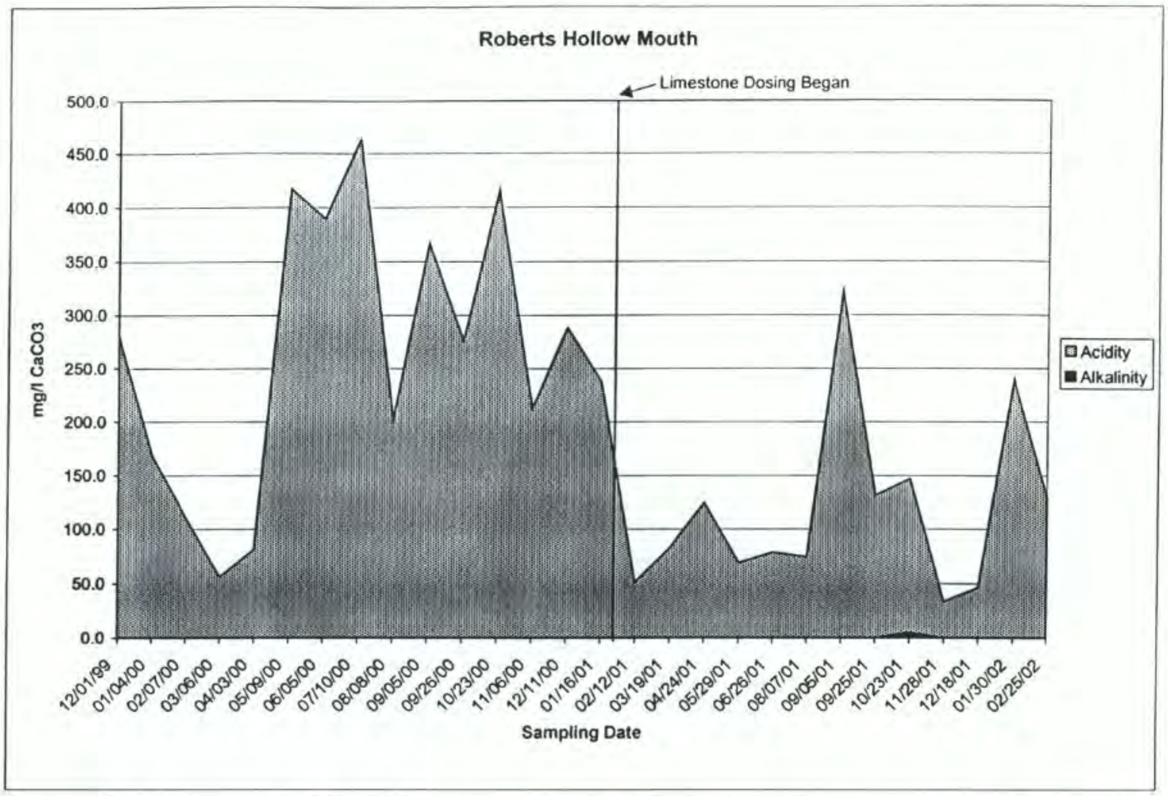


Figure 29. Acidity and Alkalinity at the mouth of Roberts Hollow.

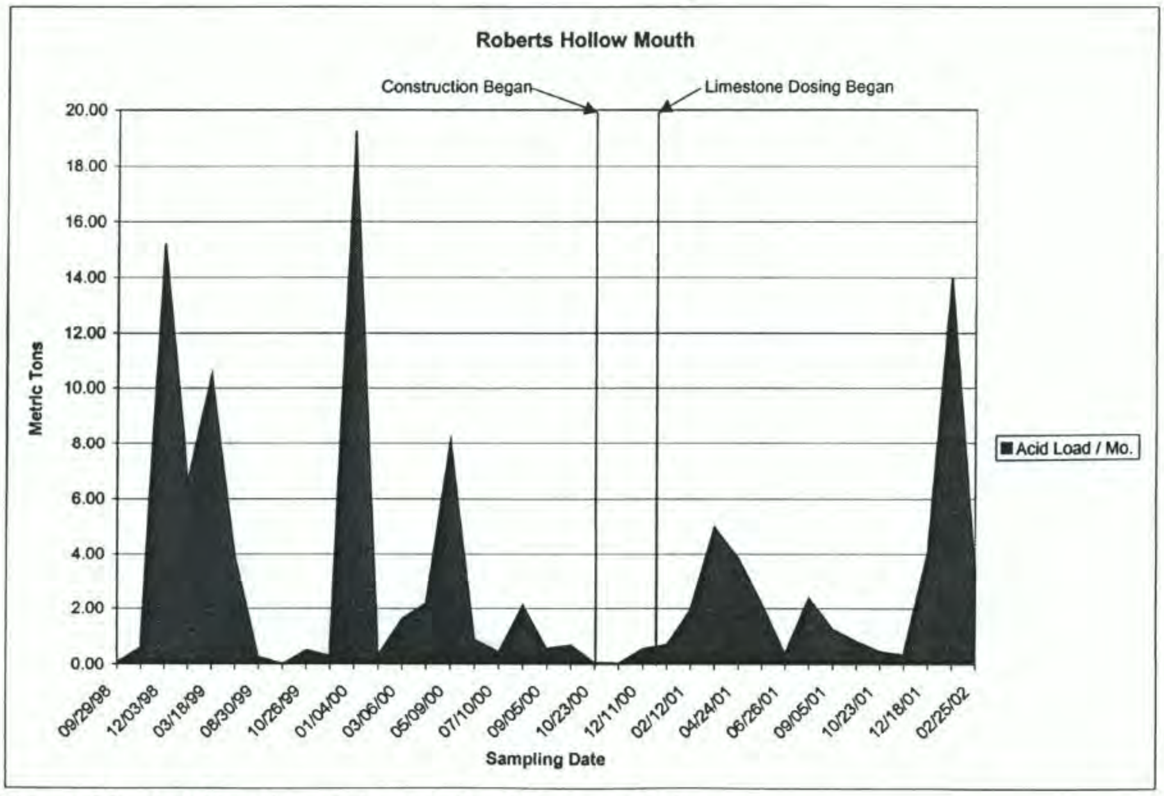


Figure 30. Acid loading at the mouth of Roberts Hollow.

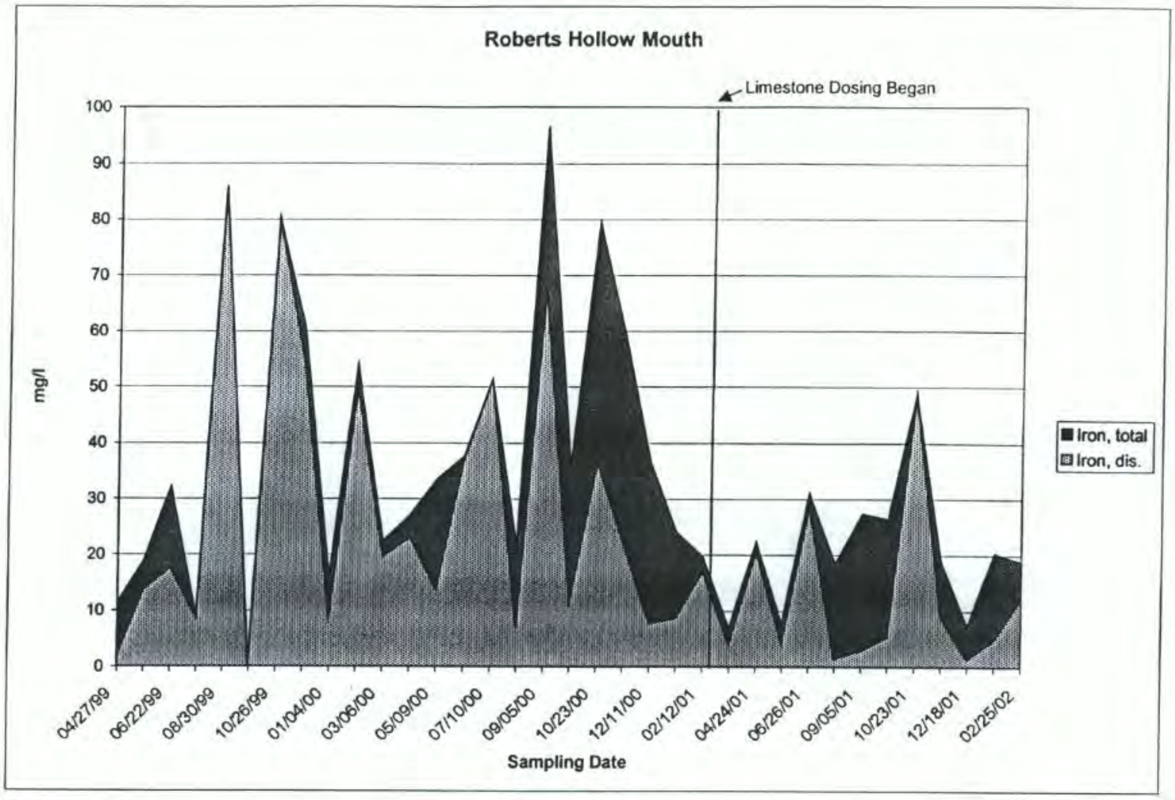


Figure 31. Iron concentrations at the mouth of Roberts Hollow.

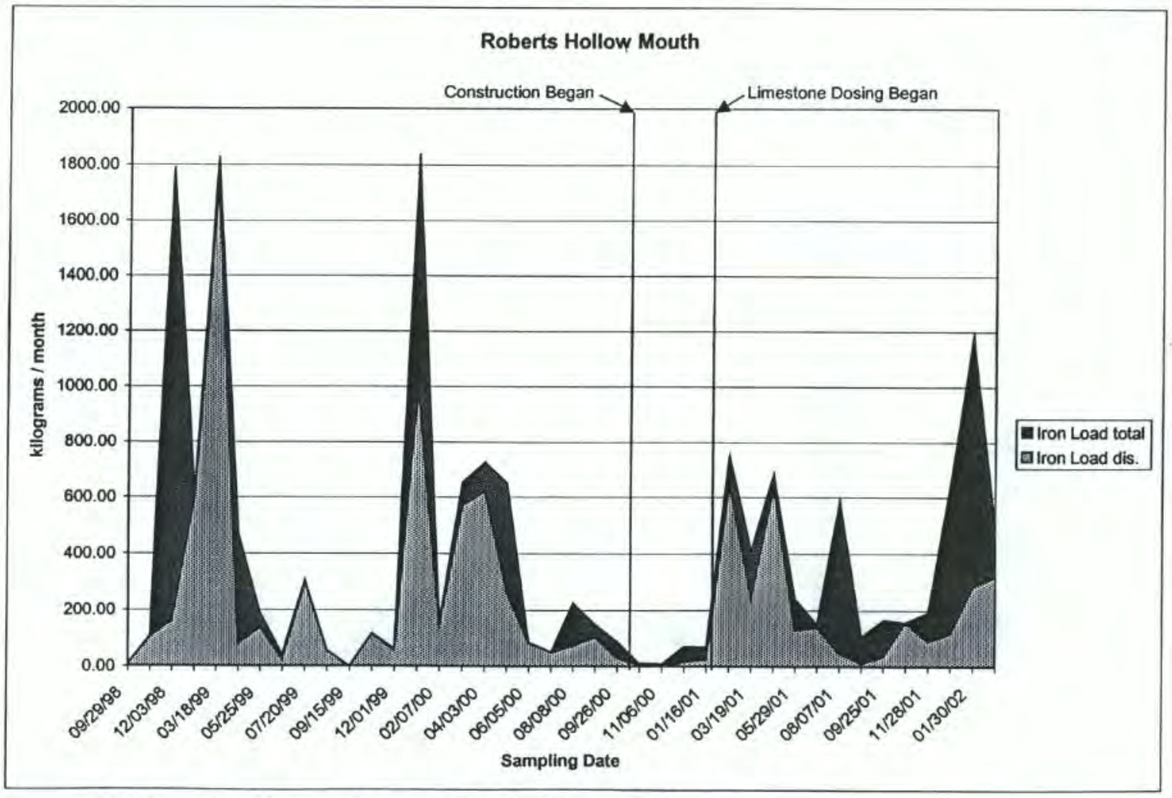


Figure 32. Iron loading at the mouth of Roberts Hollow.

to reclamation. Dissolved aluminum concentrations averaged 11 mg/l after dosing began and was 92% of the total aluminum concentration. Dissolved aluminum concentrations were reduced by 15% after reclamation began (Fig. 33). Total aluminum loading decreased by 58% after reclamation began. Total aluminum loading averaged 343 kilograms per month prior to reclamation and 145 kilograms per month after reclamation began. Dissolved aluminum loading decreased by 56% after reclamation began. Dissolved aluminum loading averaged 324 kilograms per month prior to reclamation and 142 kilograms per month after reclamation began (Fig. 34).

Although the Roberts Hollow tributary remained net acidic after installation of the open limestone channel, construction of the treated refuse fill, and monthly dosing with limestone sand, acid loading into Rock Creek from the tributary was reduced by 44%. Dissolved iron loading decreased by 46% and dissolved aluminum loading decreased by 56% after reclamation and dosing.

The limestone sand dosing station is located 1000 feet upstream from the mouth of the tributary. Current plans under a future contract are to relocate the dosing station one-mile upstream from the mouth of the tributary. Moving the dosing station upstream will allow the AMD more contact time and distance with the limestone before discharging at the mouth and will improve water quality discharging from Roberts Hollow into Rock Creek. Plans also include the installation of additional OLCs in Roberts Hollow. The OLCs will intercept AMD from portals and the pyritic refuse fill improving water quality before discharging into the tributary. As reclamation practices such as installation of OLCs and treatment of the pyritic refuse with limestone increases dosing the tributary with limestone sand will decrease. Inadequate funding is preventing the ultimate goal of complete reclamation of the Roberts Hollow site negating the need for dosing the tributary with limestone sand.

Rock Creek

A water monitoring program sampling the main stem of lower Rock Creek and the tributaries contributing acid mine drainage to Rock Creek was started in September 1998. Acid loading into Rock Creek from the impacted tributaries was calculated based on water monitoring results. In February 2000 a pilot project was started dosing lower Rock Creek and the impacted tributaries with sand-size limestone particles. The dosing rate was based on the acid loading calculations. Improvements in water quality were seen almost immediately. In addition to the water monitoring program a biological monitoring program was started in June 1999 sampling macroinvertebrate and fish populations in the main stem of Rock Creek and White Oak Creek. This specific project is part of a larger Rock Creek AMD abatement project. The changes in water quality and biological communities are a combination of this specific project and the larger Rock Creek AMD abatement project. Water quality analysis for the main stem of Rock Creek immediately above and downstream from the project sites is included in this report. Biological monitoring results are also included.

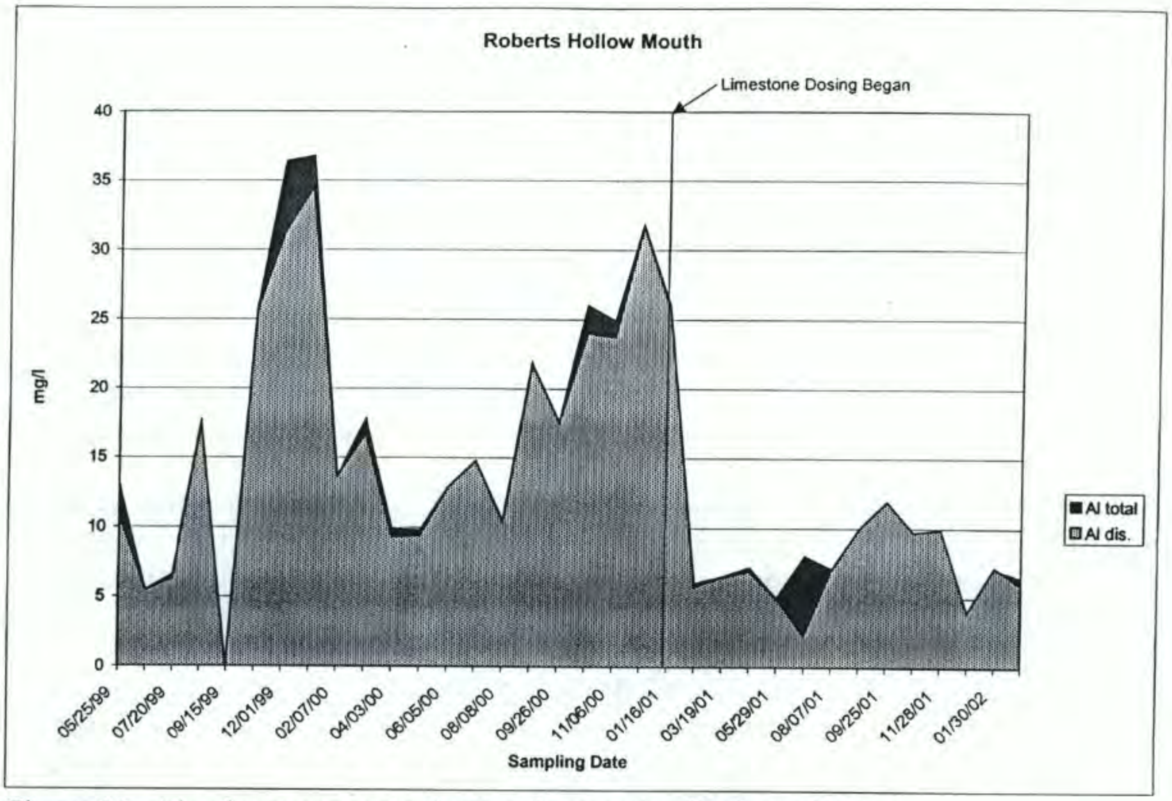


Figure 33. Aluminum concentrations at the mouth of Roberts Hollow.

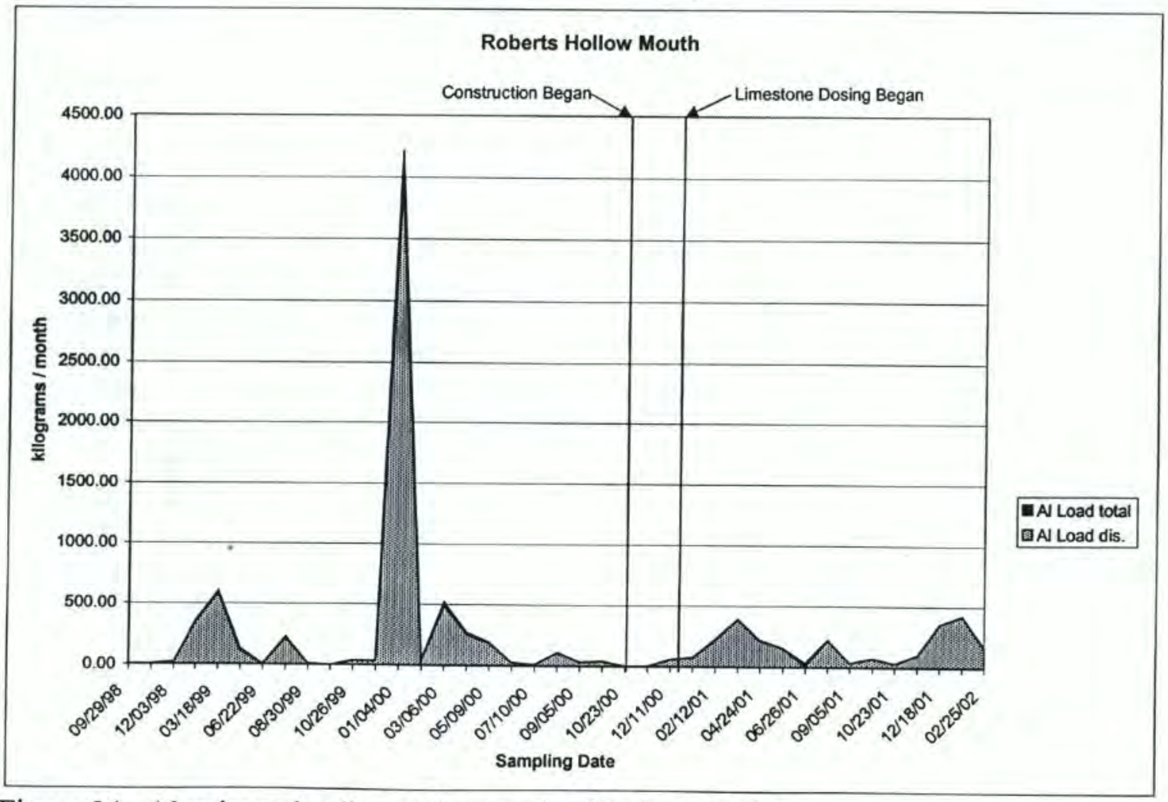


Figure 34. Aluminum loading at the mouth of Roberts Hollow.

Water Quality Monitoring Analysis of Rock Creek

The field pH values of the main stem of Rock Creek immediately upstream from the Roberts Hollow project site ranged from 5.1 to 7.0 prior to limestone dosing and ranged from 6.0 to 7.7 after limestone dosing started (Fig. 35). The field pH values for the main stem of Rock Creek downstream from the Roberts Hollow project site and upstream from the Water Tank Hollow project site ranged from 5.5 to 7.3 prior to limestone dosing and ranged from 6.7 to 7.8 after limestone dosing started (Fig. 36). At the mouth of Rock Creek, downstream from both project sites, the field pH values ranged from 5.9 to 6.9 prior to limestone dosing and ranged from 6.1 to 7.8 after limestone dosing started (Fig. 37).

Prior to limestone dosing the main stem of Rock Creek upstream from Roberts Hollow was net acidic on all but one sampling date. Four months after limestone dosing began Rock Creek upstream from Roberts Hollow was net alkaline 19 out of 21 sampling dates (Fig. 38). The monitoring site downstream from Roberts Hollow fluctuated between net acidity and net alkalinity prior to the start of limestone dosing. After limestone dosing began the monitoring site was net alkaline 17 out of 24 sampling dates (Fig. 39). Rock Creek was net acidic at its mouth all but one sampling date prior to limestone dosing. Two months after limestone dosing began Rock Creek was net alkaline on 20 of 22 sampling dates (Fig. 40).

With the exception of one sampling date the acid load at the monitoring station upstream from Roberts Hollow dropped to zero four months after limestone dosing began (Fig. 41). The monitoring station downstream from Roberts Hollow has shown some fluctuations in acid load prior to and after limestone dosing began (Fig. 42). Two months after limestone dosing began there is sufficient alkalinity downstream from the monitoring site that by the time the flow reaches the mouth of Rock Creek the acid load drops to zero on all but two sampling dates (Fig. 43).

Total calcium concentrations averaged 8 mg/l prior to limestone dosing and 13 mg/l after limestone dosing began at the monitoring station upstream from Roberts Hollow (Fig. 44). Total calcium concentrations averaged 9 mg/l prior to limestone dosing and 15 mg/ after limestone dosing began at the monitoring station downstream from Roberts Hollow (Fig. 45). At the mouth of Rock Creek total calcium concentrations averaged 9 mg/l prior to limestone dosing and 16 mg/l after limestone dosing began (Fig. 46).

The farther downstream the greater the iron concentrations and loading became with no significant differences between sampling dates prior to reclamation and sampling dates after reclamation (Figs. 47, 48, 49, 50, 51, and 52). Similar results were seen with aluminum concentrations and loading (Figs. 53, 54, 55, 56, 57, and 58).

Monthly dosing of the AMD impacted tributaries of Rock Creek has had a tremendous impact on water quality in the main stem of lower Rock Creek. Acid loading entering the Big South Fork of the Cumberland River from Rock Creek has nearly ceased. As funding permits, additional reclamation projects in the lower Rock Creek watershed will allow limestone dosing to be reduced.

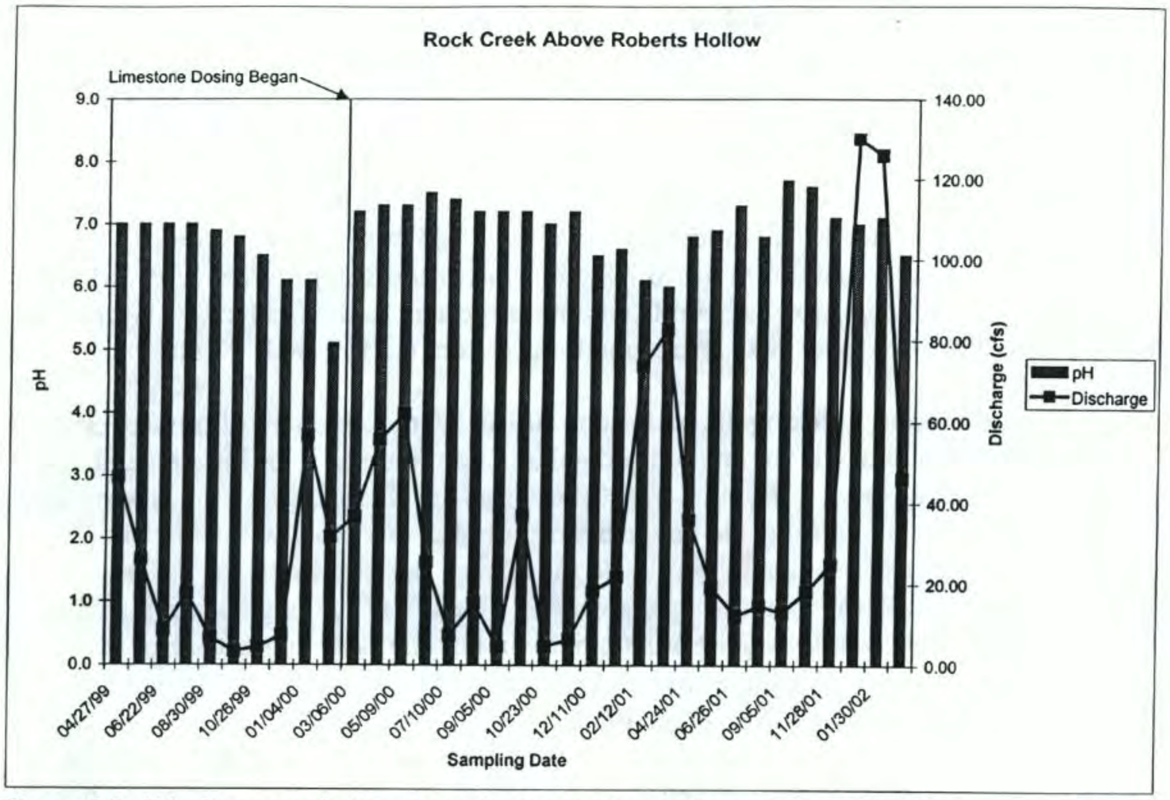


Figure 35. Discharge and pH values for Rock Creek above Roberts Hollow.

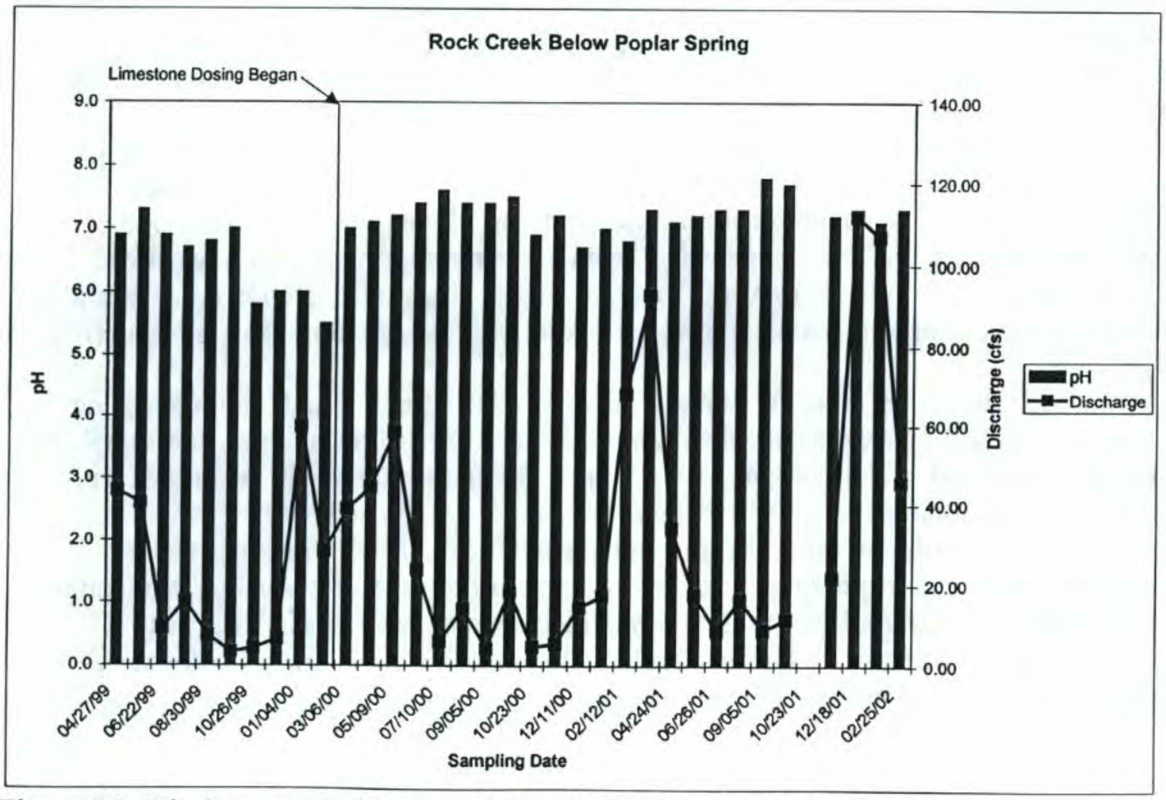


Figure 36. Discharge and pH values for Rock Creek below Poplar Spring.

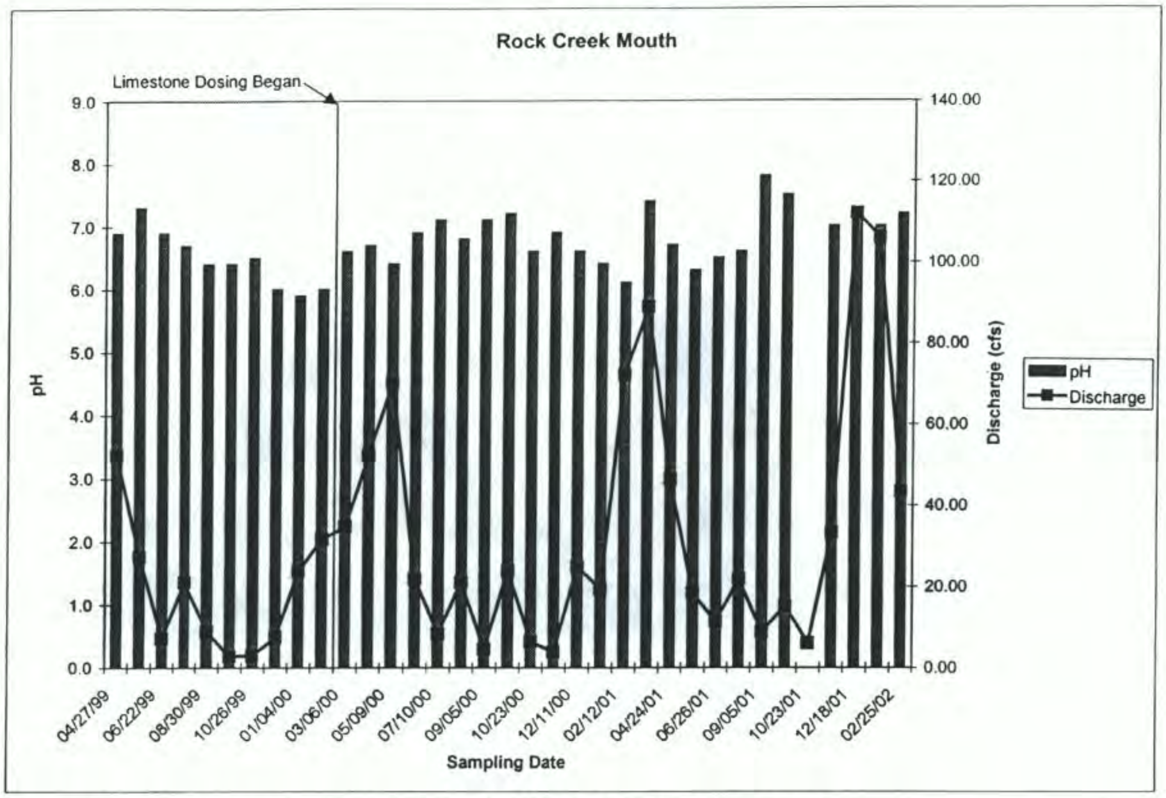


Figure 37. Discharge and pH values for Rock Creek at its mouth.

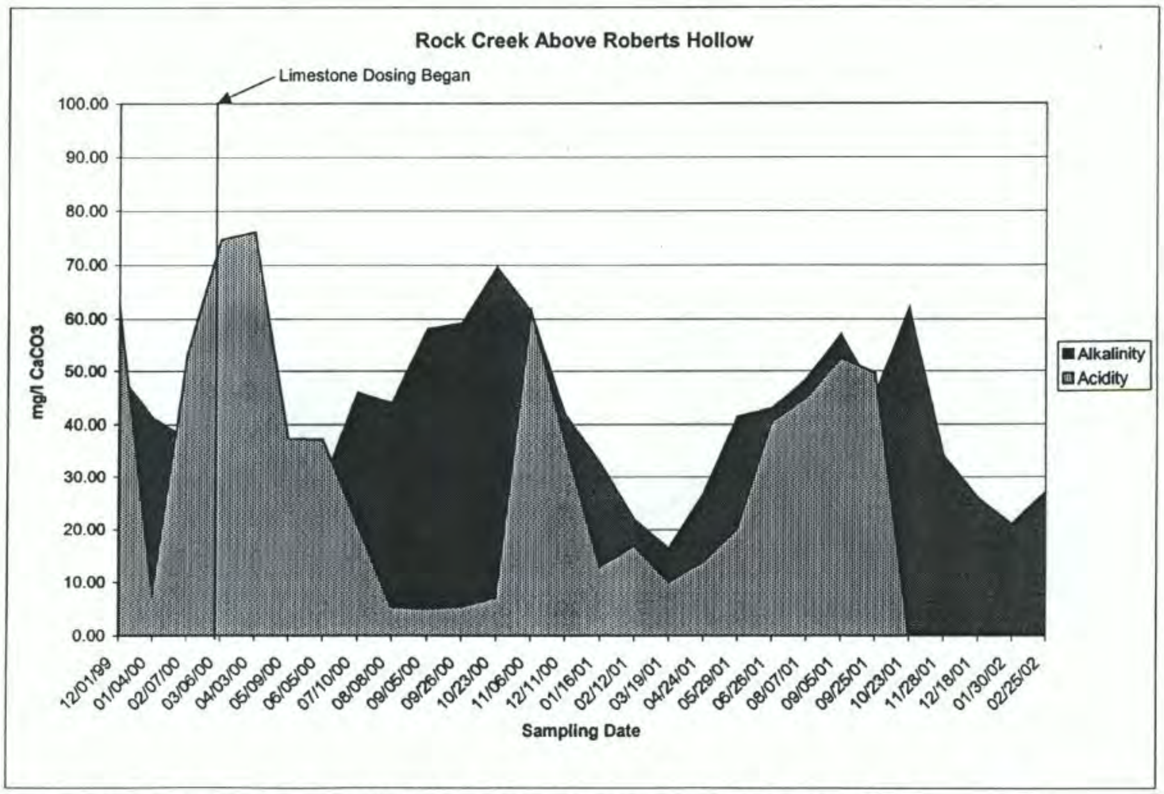


Figure 38. Acidity and Alkalinity for Rock Creek above Roberts Hollow.

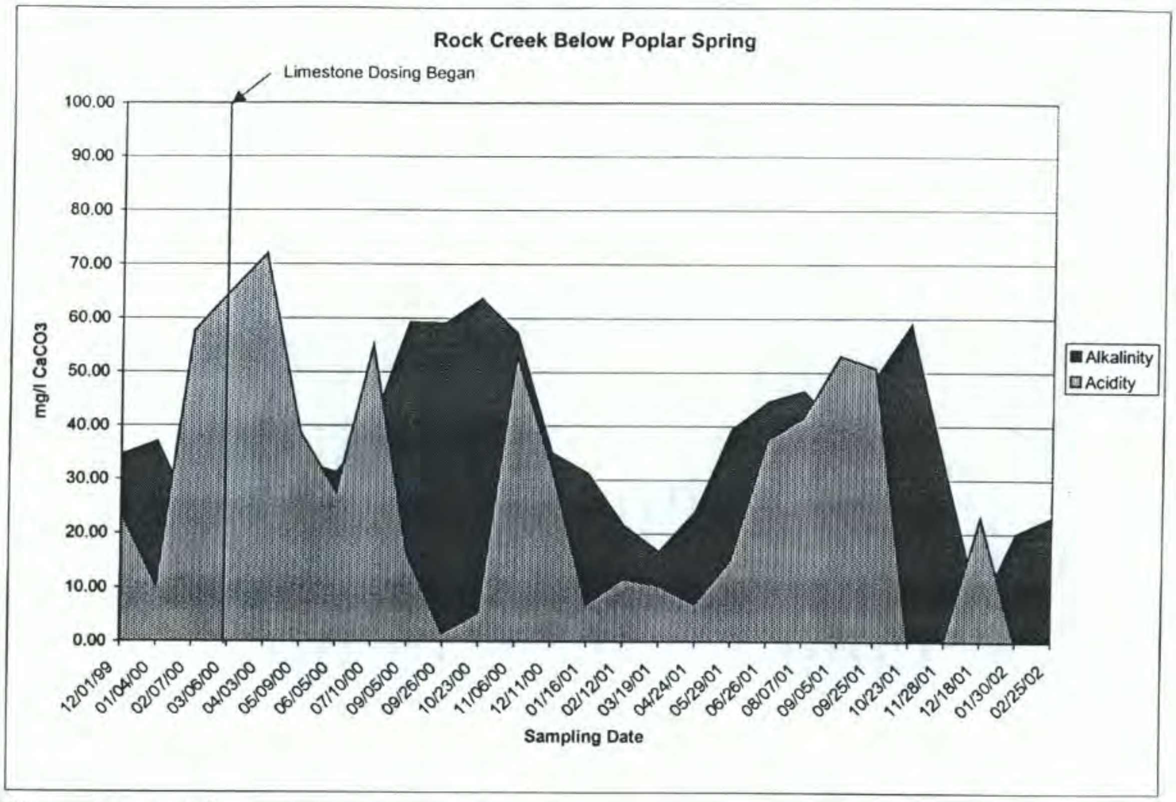


Figure 39. Acidity and Alkalinity for Rock Creek below Poplar Spring.

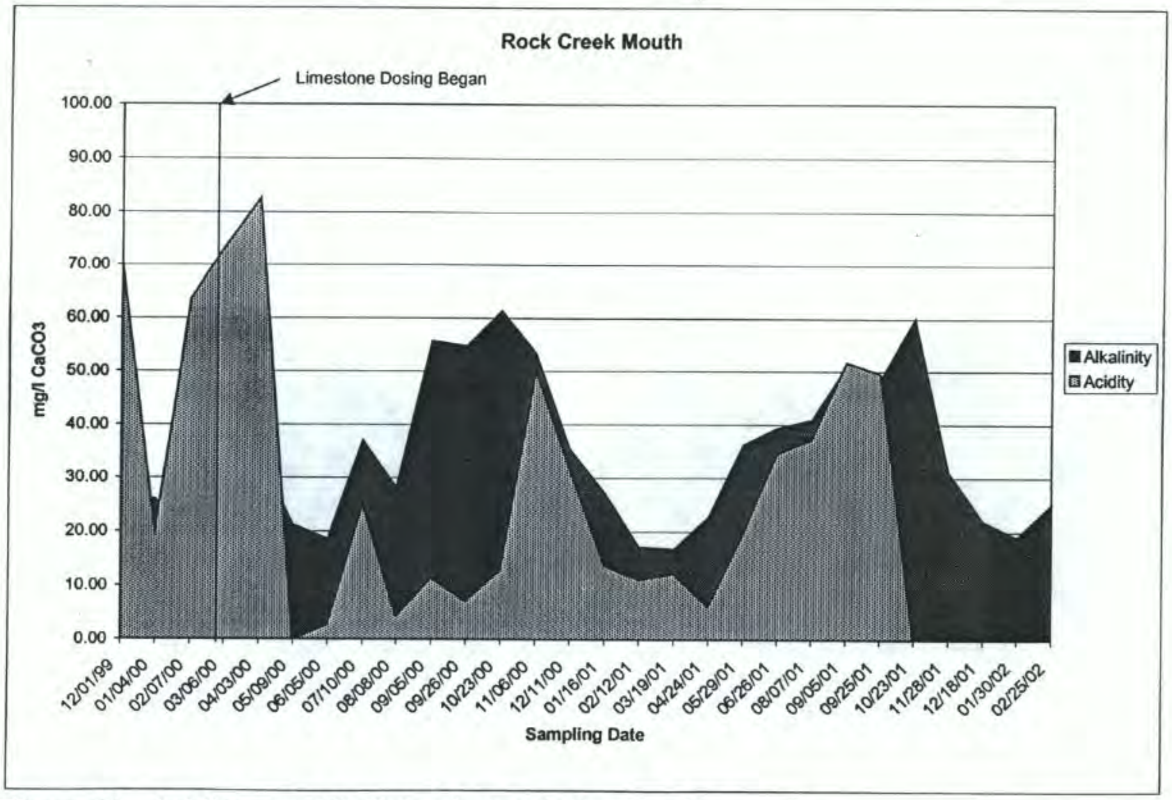


Figure 40. Acidity and Alkalinity for Rock Creek at its mouth.

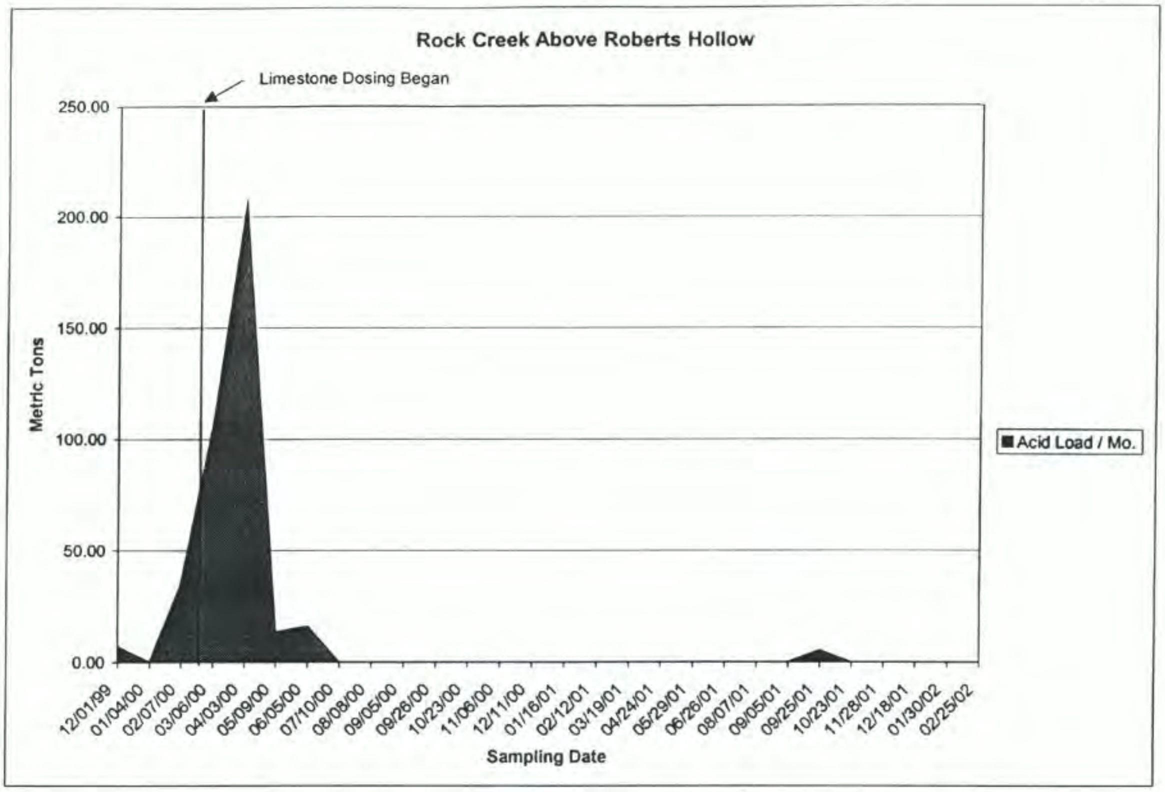


Figure 41. Acid loading for Rock Creek above Roberts Hollow.

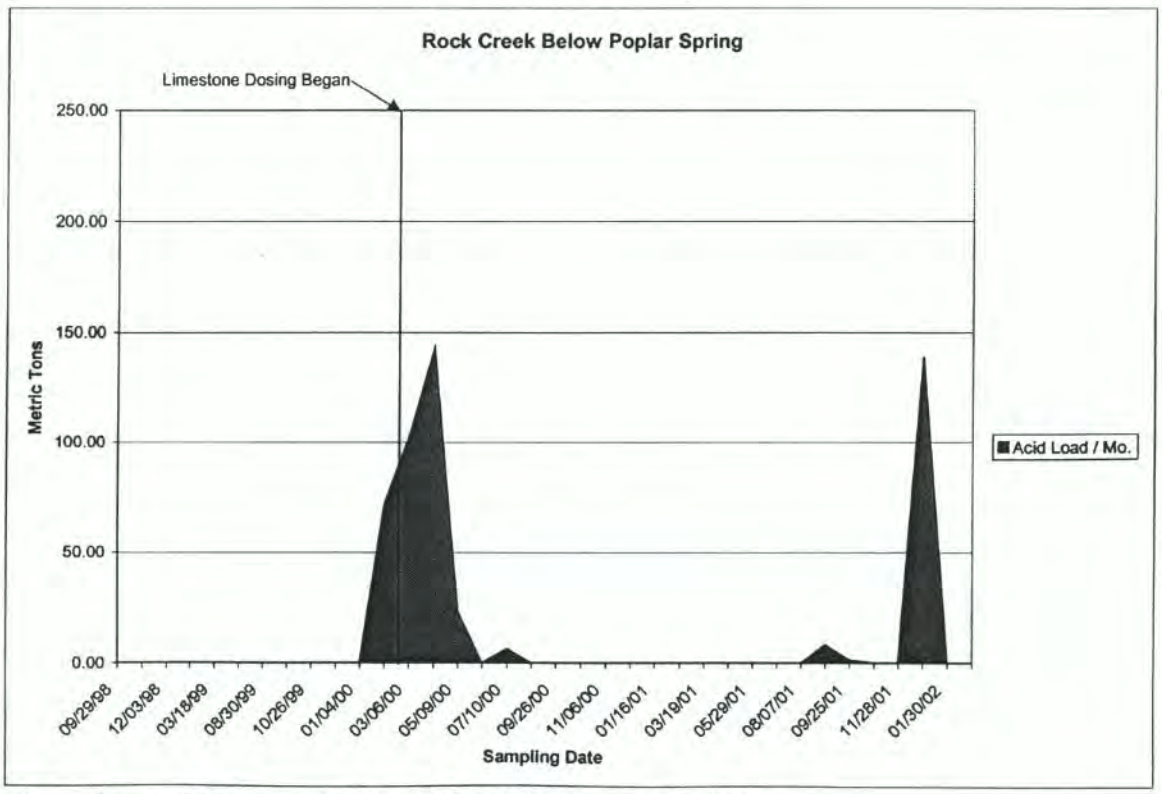


Figure 42. Acid loading for Rock Creek below Poplar Spring.

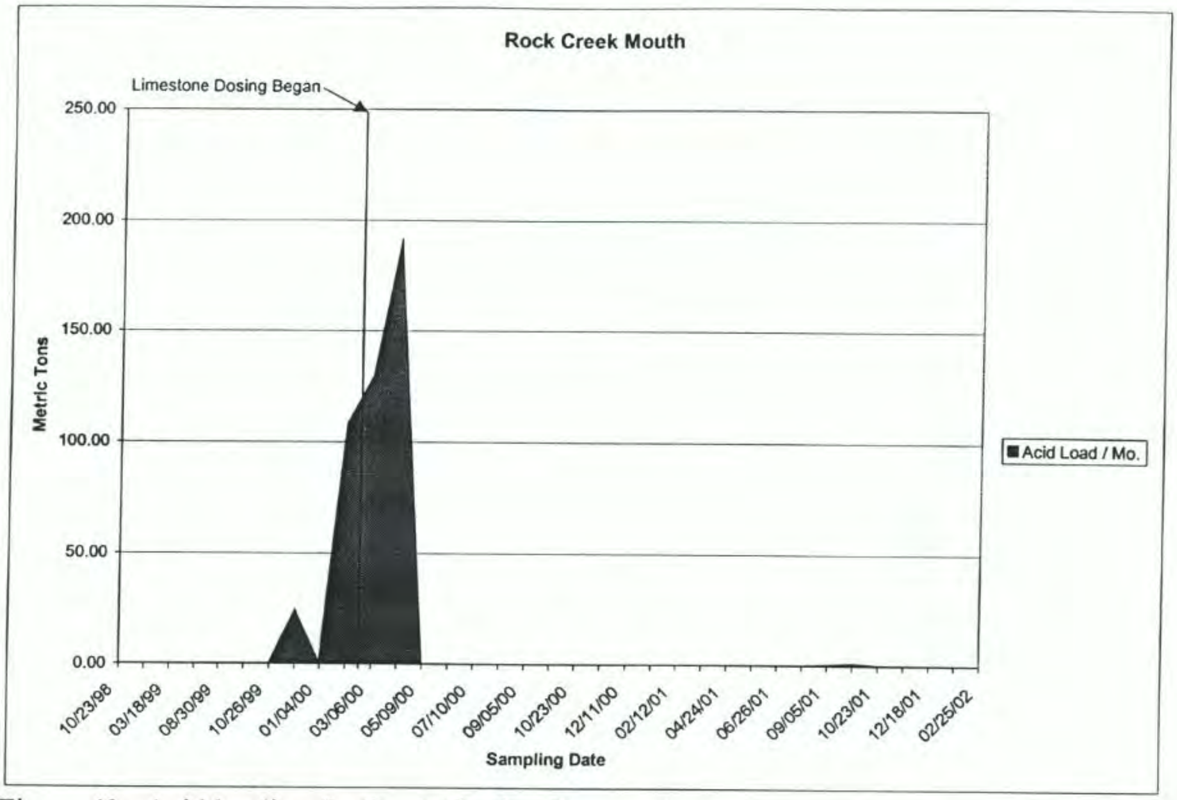


Figure 43. Acid loading for Rock Creek at its mouth.

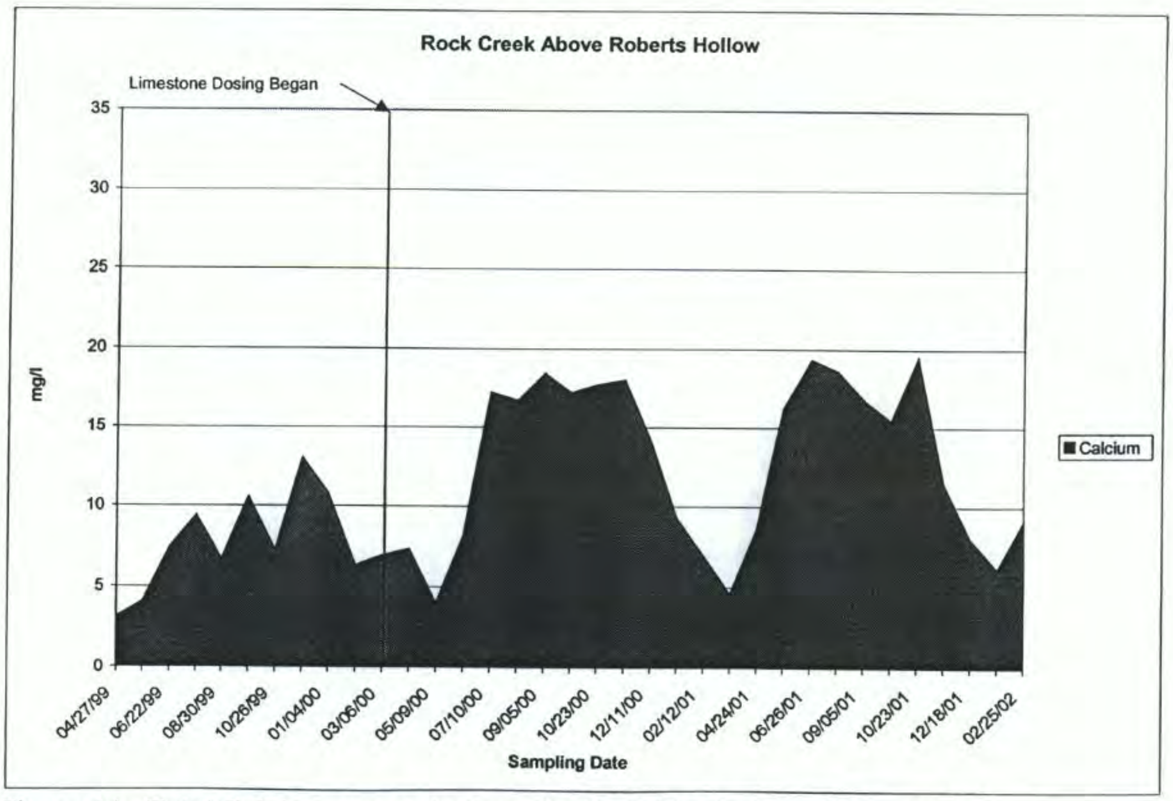


Figure 44. Total Calcium concentrations for Rock Creek above Roberts Hollow.

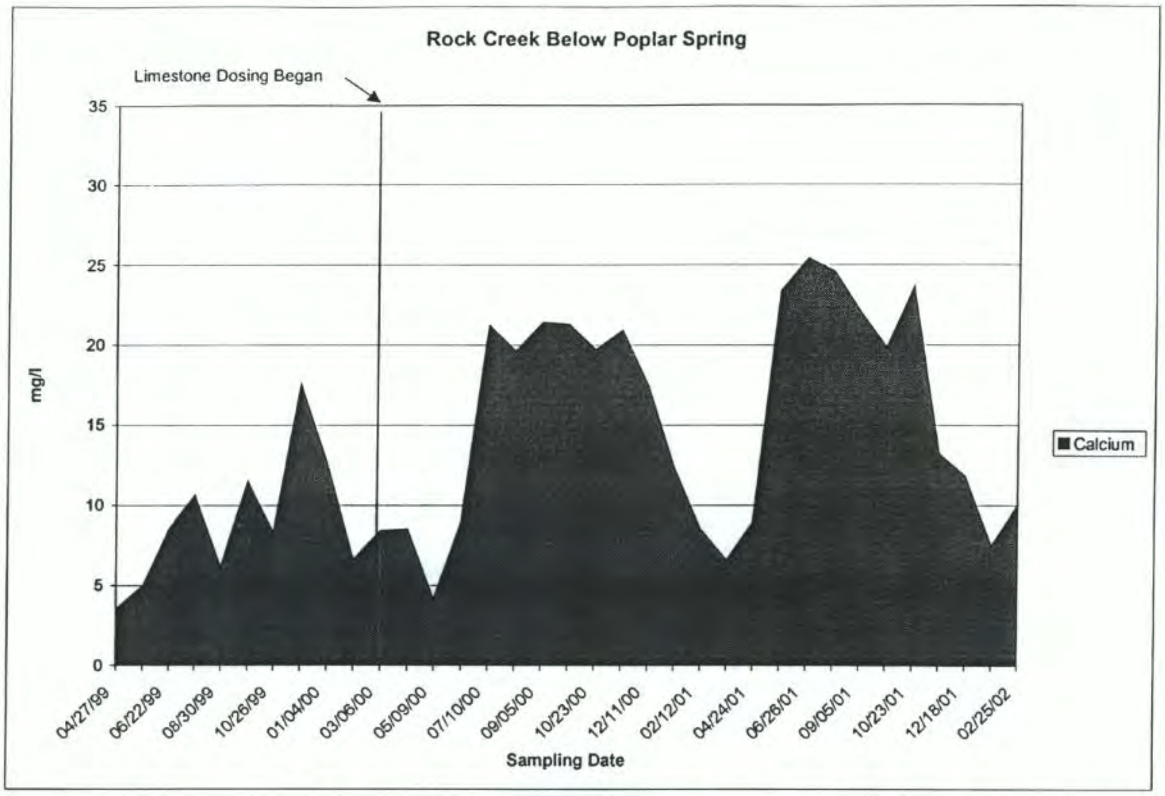


Figure 45. Total Calcium concentrations for Rock Creek below Poplar Spring.

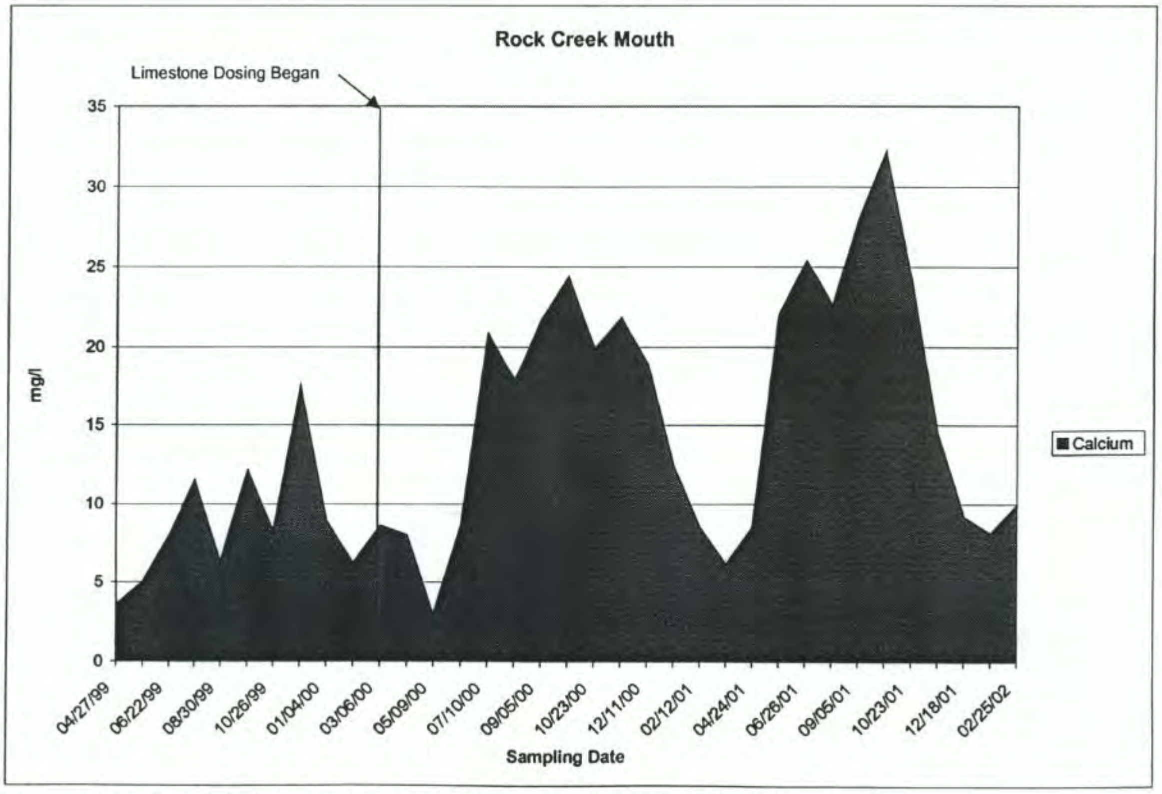


Figure 46. Total Calcium concentrations for Rock Creek at its mouth.

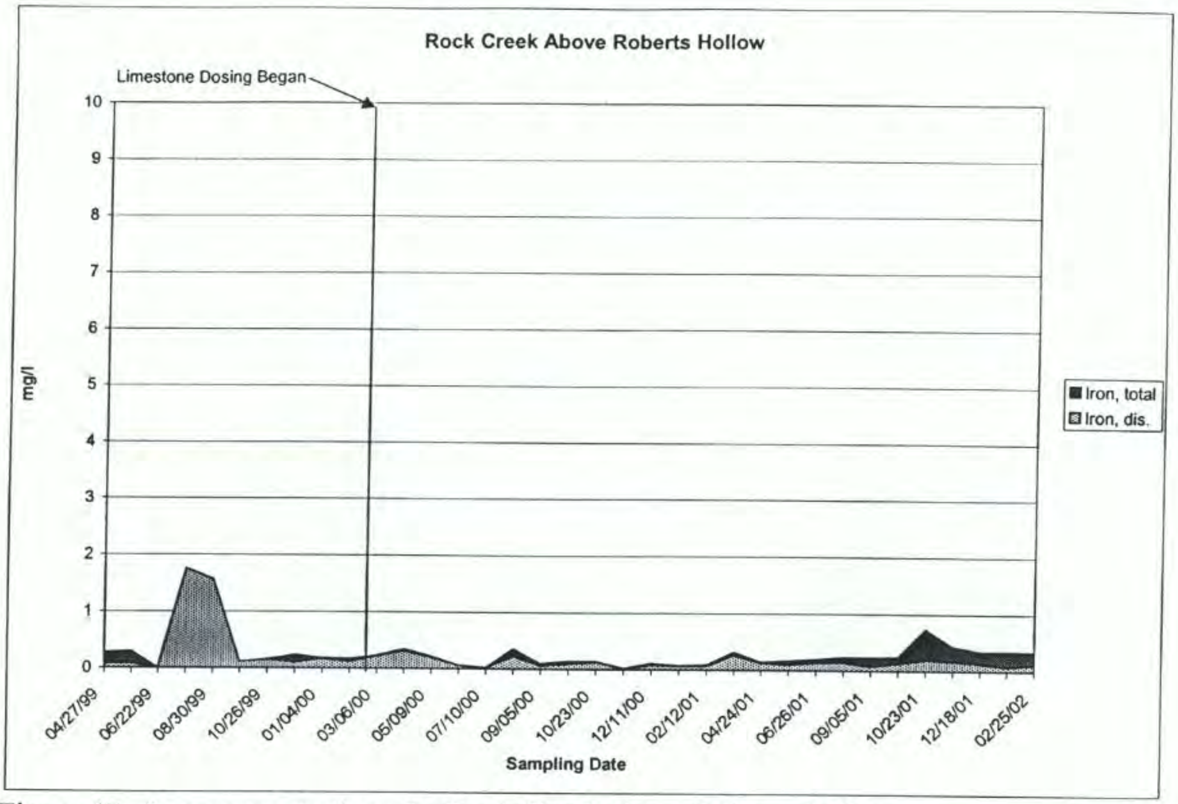


Figure 47. Iron concentrations for Rock Creek above Roberts Hollow.

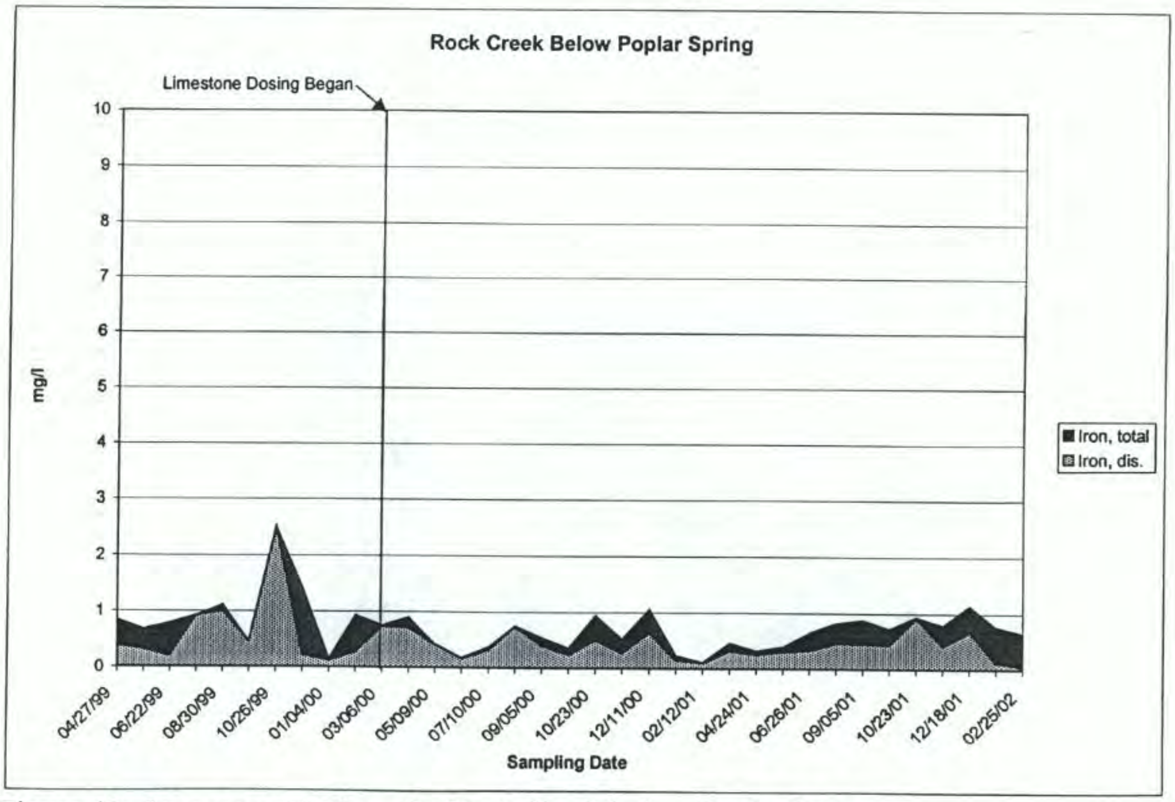


Figure 48. Iron concentrations for Rock Creek below Poplar Spring.

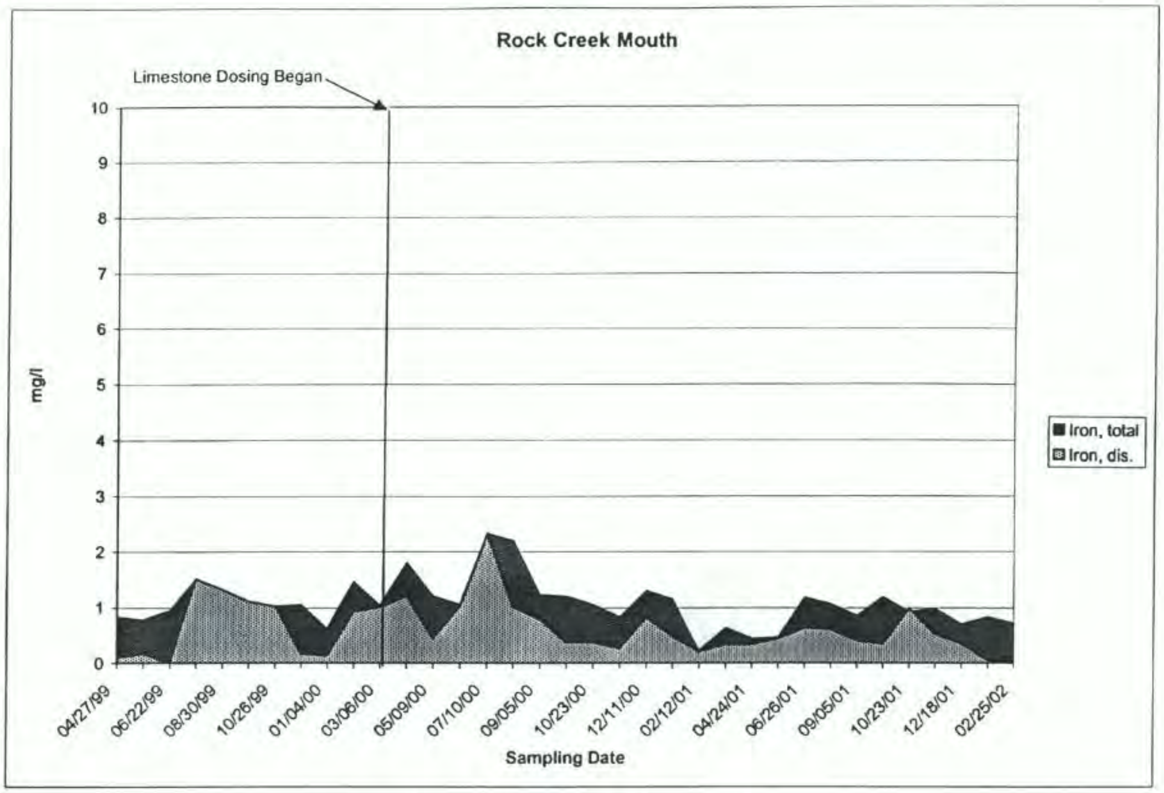


Figure 49. Iron concentrations for Rock Creek at its mouth.

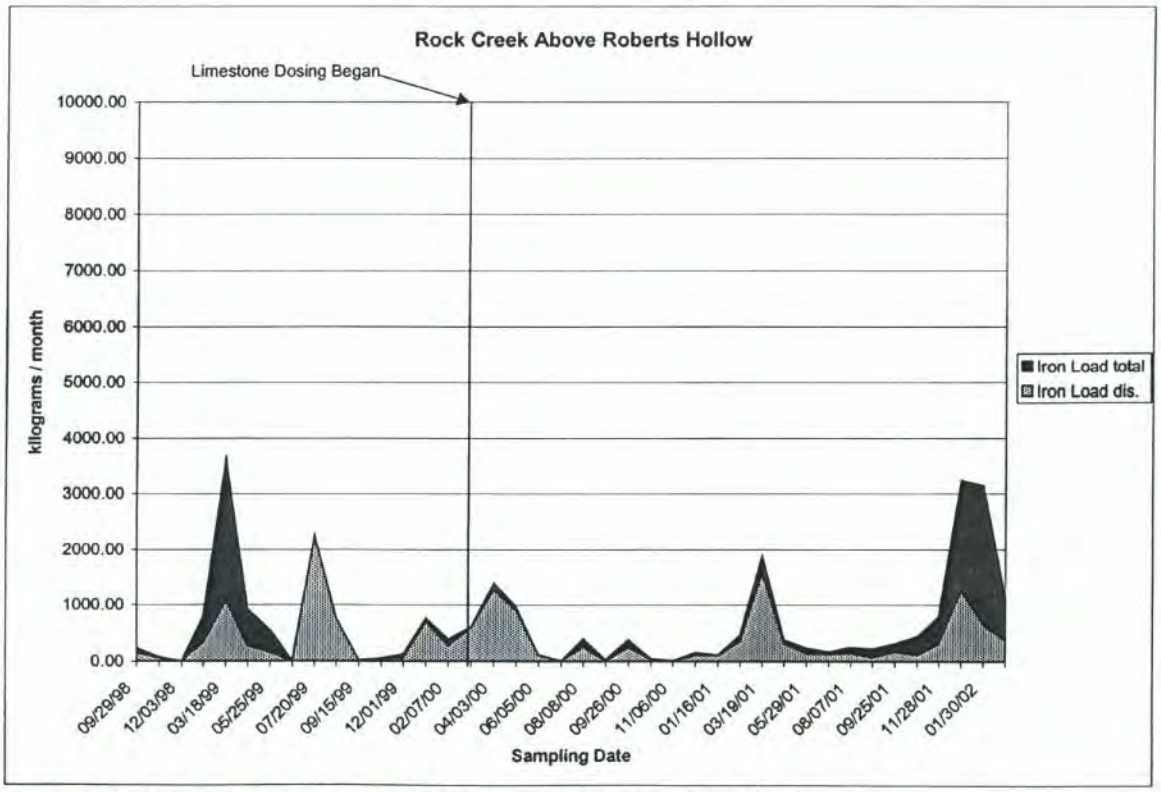


Figure 50. Iron loading for Rock Creek above Roberts Hollow.

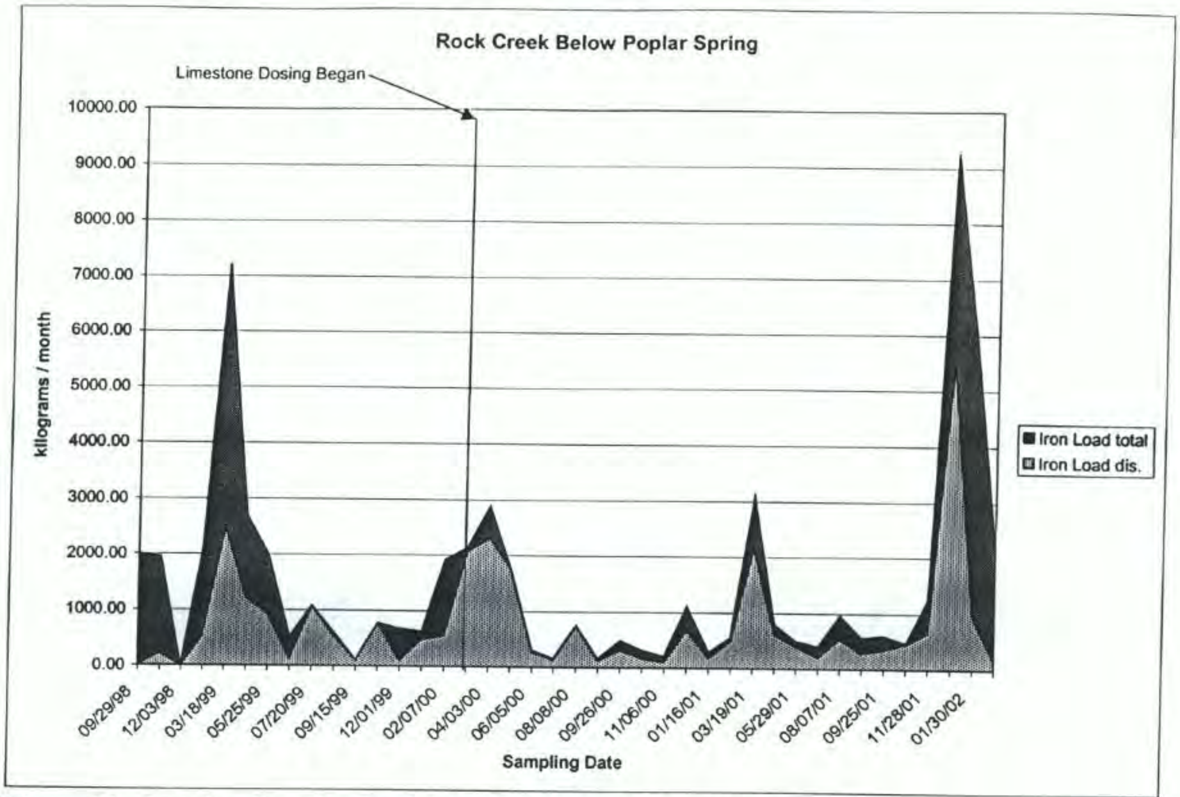


Figure 51. Iron loading for Rock Creek below Poplar Spring.

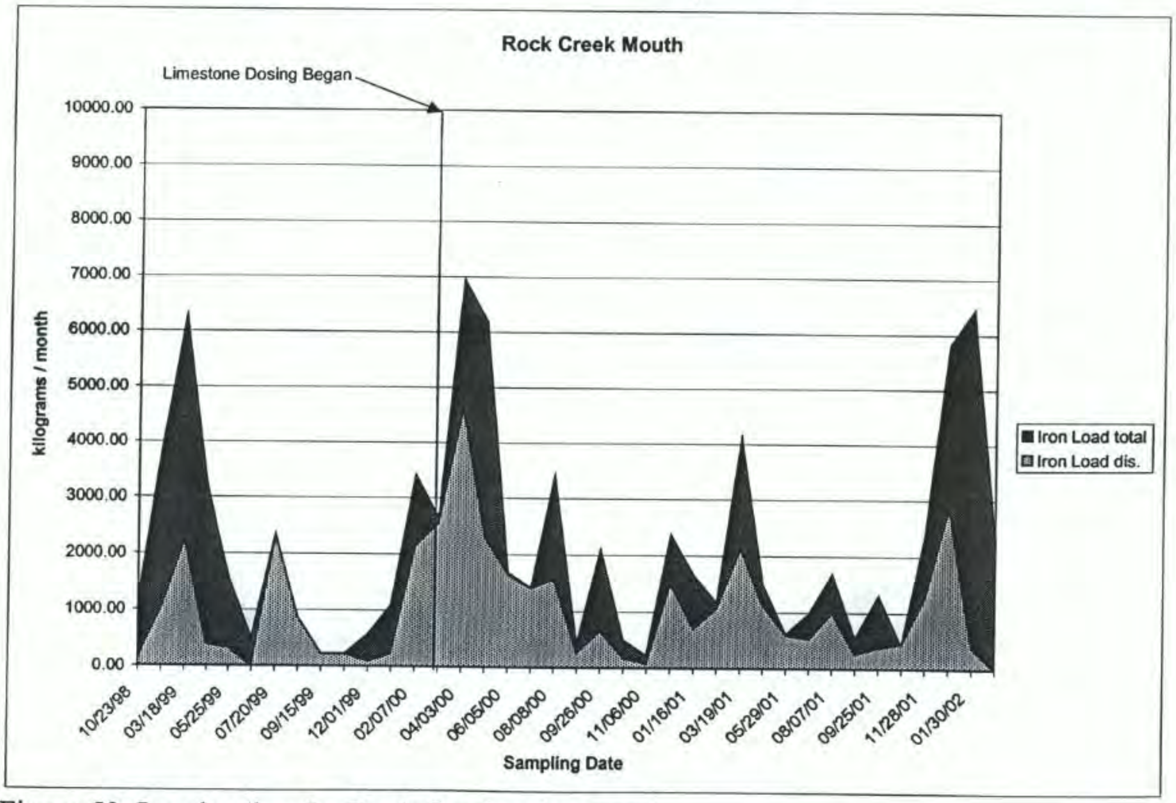


Figure 52 Iron loading for Rock Creek at its mouth.

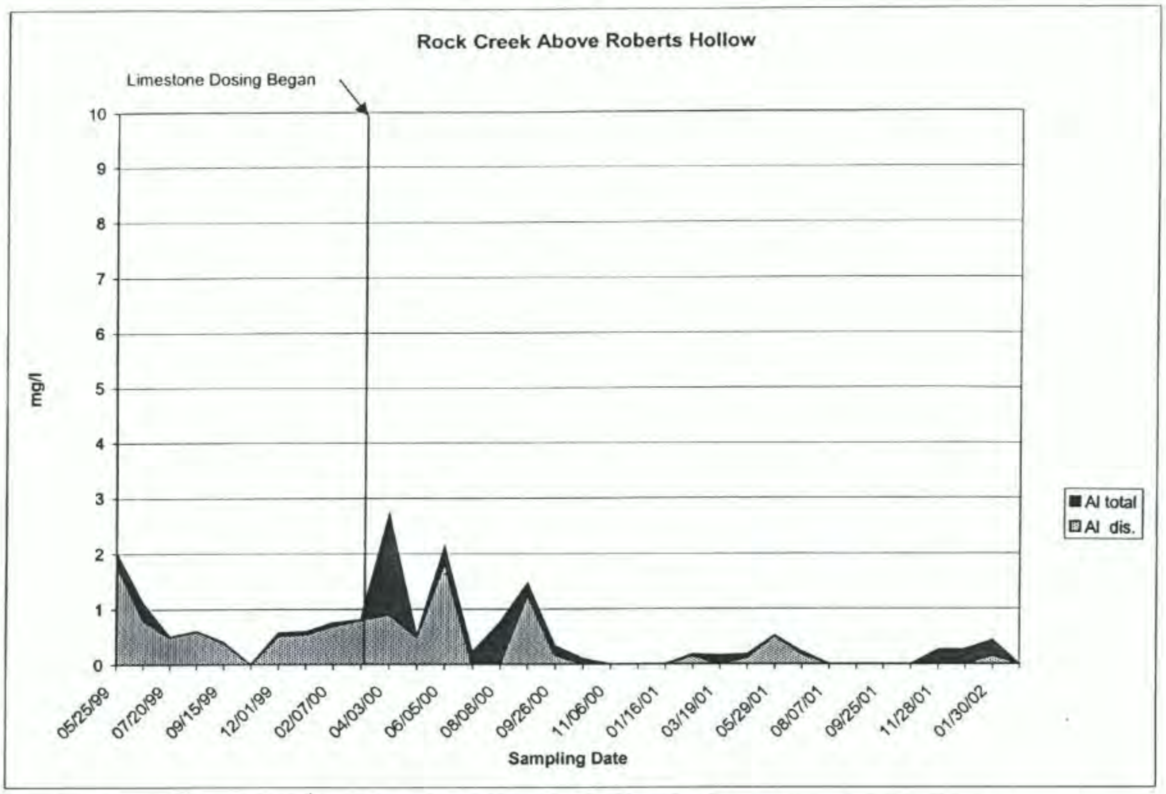


Figure 53. Aluminum concentrations for Rock Creek above Roberts Hollow.

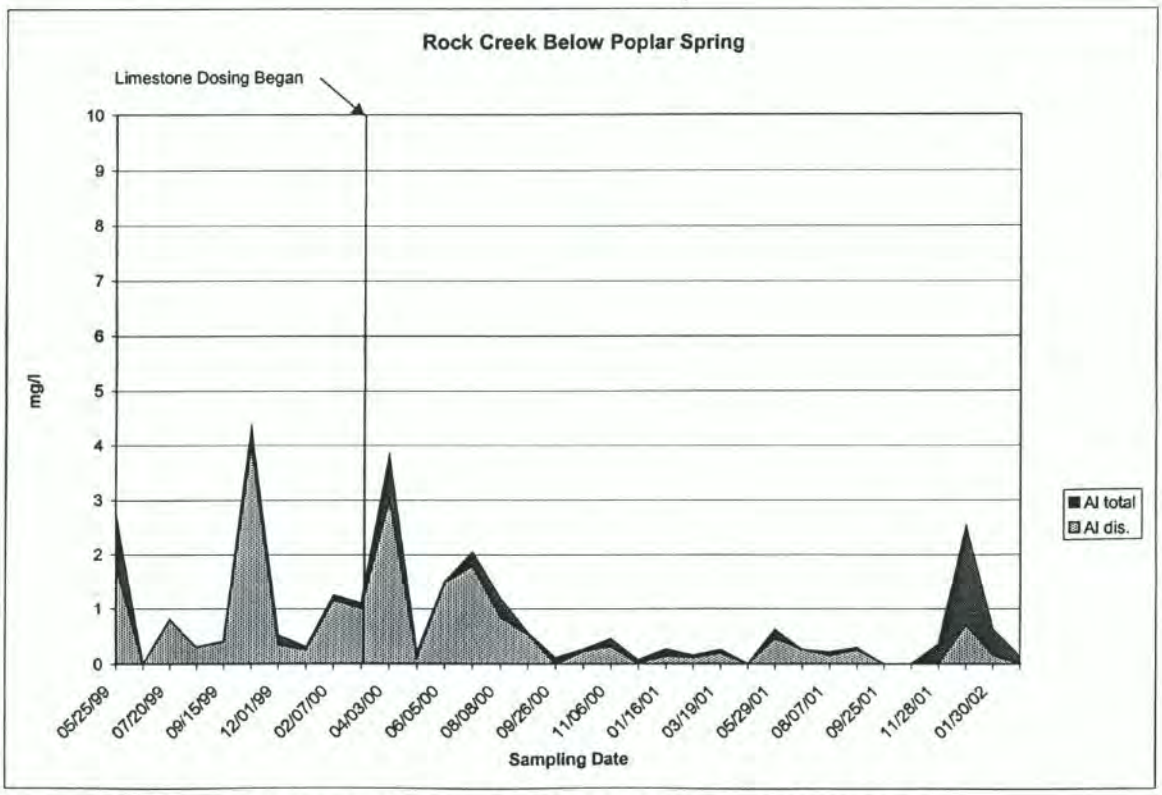


Figure 54. Aluminum concentrations for Rock Creek below Poplar Spring.

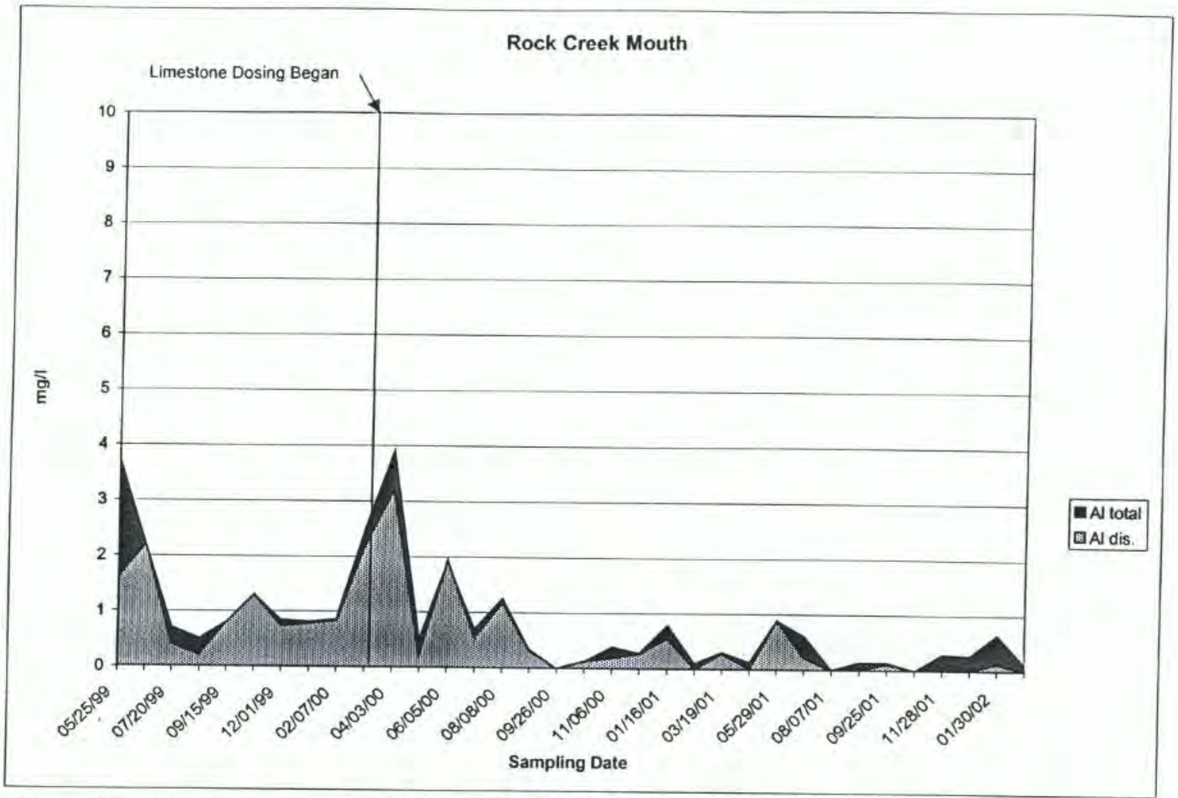


Figure 55. Aluminum concentrations for Rock Creek at its mouth.

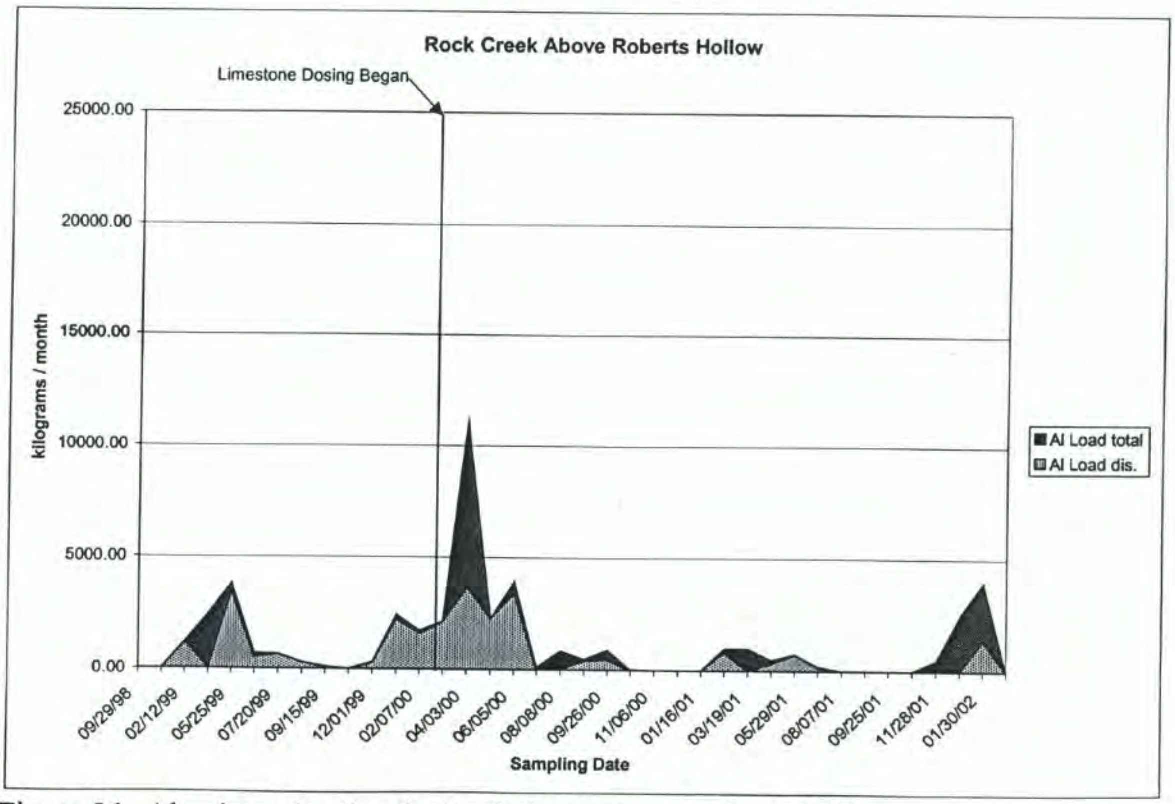


Figure 56. Aluminum loading for Rock Creek above Roberts Hollow.

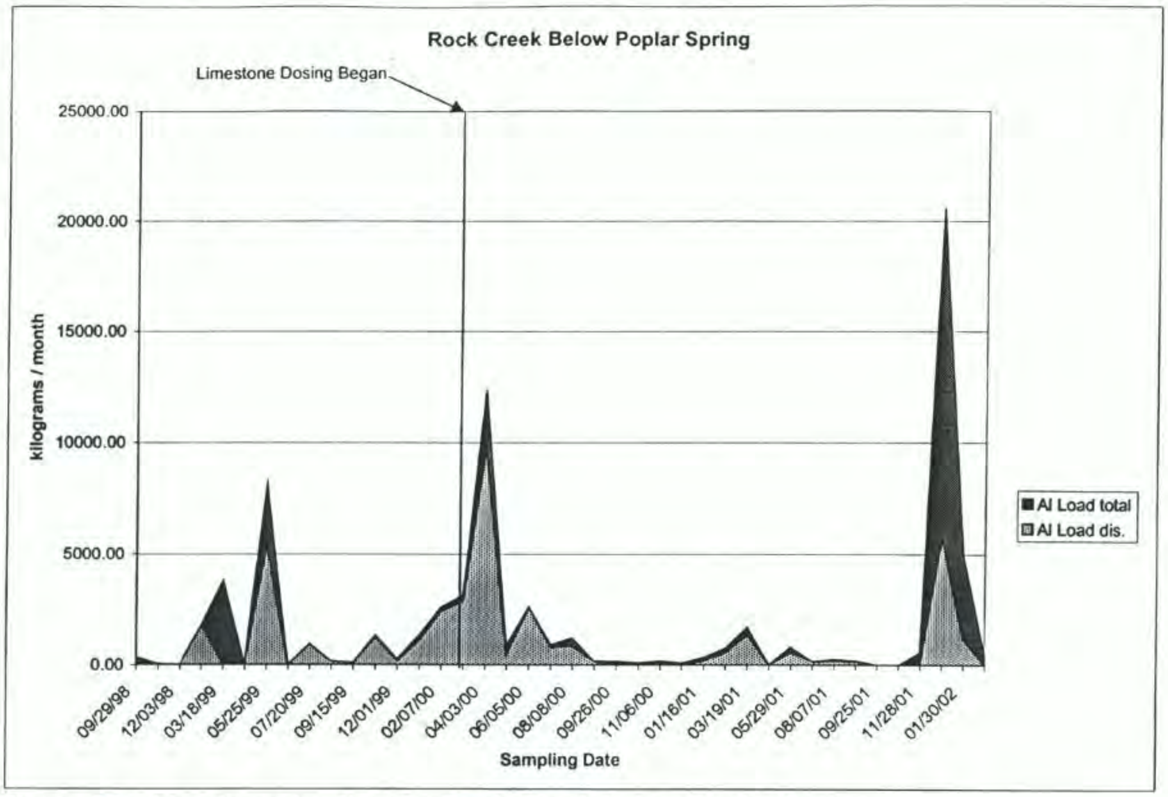


Figure 57. Aluminum loading for Rock Creek below Poplar Spring.

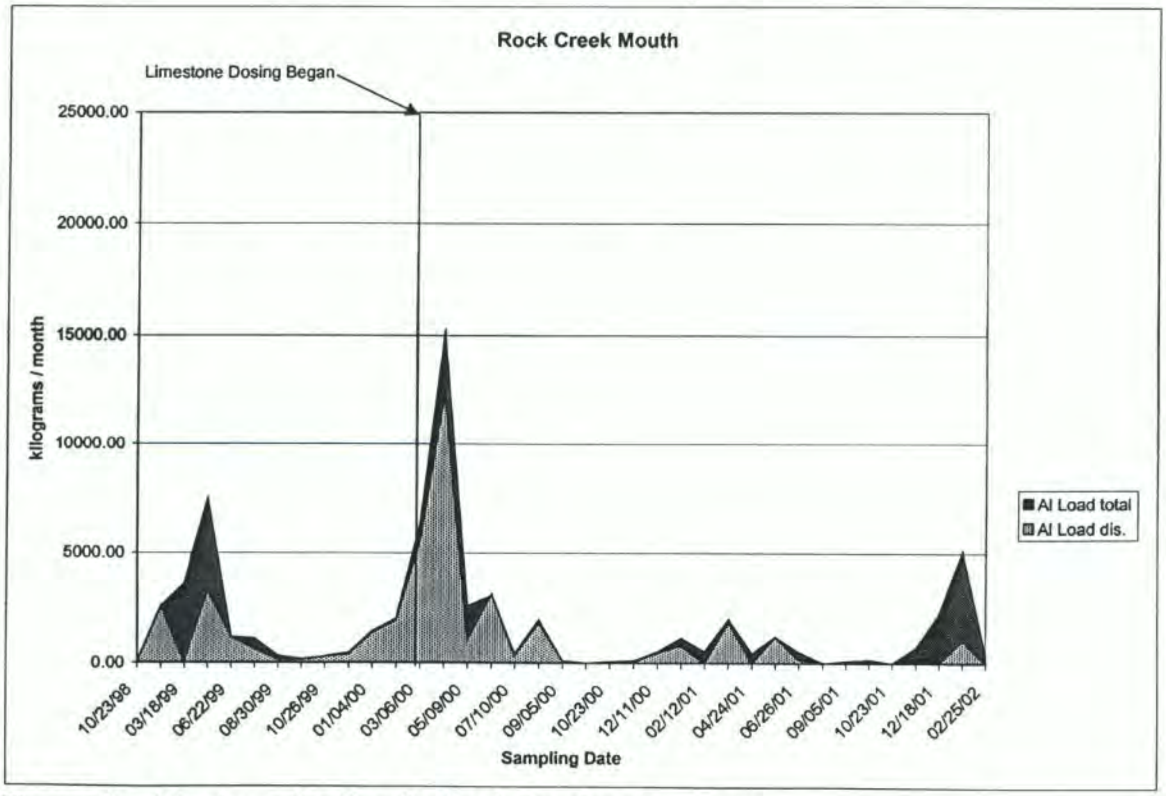


Figure 58. Aluminum loading for Rock Creek at its mouth.

Biological Monitoring Results

Aquatic macroinvertebrates were collected spring/summer and fall/winter beginning in 1999. USFS personnel are analyzing aquatic macroinvertebrate results. Results of the macroinvertebrate study are not available at this time. The results will be forwarded to Kentucky DOW personnel when they are made available by the USFS.

Fish were collected in early summer beginning in 1999. Monitoring station WO-01 is located upstream of the AMD impacted tributaries on White Oak Creek. Fish were sampled at this location on June 2, 1999. Only three species were collected. Blackside dace, a federally threatened species, was one of the three species collected. Blackside dace were previously unknown in this watershed. The total IBI on this sampling date was 32, a ranking of poor. Due to the presence of Blackside dace in this stream segment and this monitoring station's role as an upstream control the decision was made to suspend sampling at this site.

Monitoring station WO-02 is located immediately downstream from the mouth of Cabin Branch, the first AMD impacted tributary discharging into White Oak Creek. This site was sampled twice in 1999. On both of the sampling dates, June 2, 1999 and October 19, 1999, no fish were collected from this stream segment. In February 2000 dosing of the stream with sand-sized limestone particles began. On July 17, 2000, six months after limestone dosing began, one species of fish was collected from this previously dead section of stream. Ninety-one creek chubs, a tolerant species, were collected. The total IBI for this stream segment on this date was 26, a ranking of very poor to poor. On July 23, 2001 this stream segment was sampled again. Four species of fish were collected on this previously dead section of stream including barcheek darters and the federally endangered blackside dace, both intolerant species. The total IBI was 34 a ranking of poor.

Monitoring station RC-00 is located immediately upstream from the mouth of White Oak Creek on Rock Creek and is the upstream control site for Rock Creek. This site was sampled only once, August 5, 1999, due to its role as an upstream control site. There were 10 species of fish collected, six of which were intolerant species. The total IBI was 40, a ranking of fair.

Monitoring station RC-01 is located on Rock Creek immediately downstream from the confluence with White Oak Creek. The water quality in this section of stream is highly variable. During periods of low flow the entire flow of Rock Creek immediately upstream is diverted through a cave, discharging from a spring 3000 feet downstream from the monitoring site. This results in the water at this site during low flow being entirely from the White Oak Creek watershed. In addition, a spring discharges at this site whose source is the severely AMD impacted Jones Branch tributary. During high flow this section of stream receives water from Rock Creek upstream from the site. The highly variable nature of the water quality and the mobility of fish result in dramatic changes in fish populations on different sampling dates. This site was sampled on three separate dates in 1999. On June 2, 1999 nine species of fish were collected, five of which were intolerant species. The IBI was 44, a ranking of fair. Two months later on August 5, 1999 only three species of fish were collected, one of which was an intolerant species. The IBI on this date was 24, a ranking of very poor. Two months after the August sampling date on October 19, 1999 the stream segment was sampled again. Sixteen species of fish were collected, seven of which were intolerant species. The IBI on this date was 40, a ranking of fair. On July 17, 2000 the stream segment was again sampled. Limestone dosing began six months prior to this sampling date. The total number of species collected was six, three of which were intolerant species. The IBI on this date was 32, a ranking of poor. On July 23, 2001 the stream segment was sampled again. Eight species of fish were collected, four of which were intolerant species. The IBI on this date was 32, a ranking of poor.

Monitoring station RC-02 is located on Rock Creek immediately downstream from the mouth of Roberts Hollow. This stream segment was sampled three times in 1999. On June 2, 1999 no fish were found. On August 5, 1999 three species were collected, three of which were intolerant species. The IBI was 34, a ranking of poor. On October 19, 1999 this stream segment was sampled and again no fish were collected. On July 17, 2000, six months after limestone dosing began, 13 species, nine of which were intolerant species, were collected. The IBI on this date was 44, a ranking of fair. On July 23, 2001 sampling resulted in the collection of nine species, seven of which were intolerant species. On this date a brown trout was collected, the first trout to be collected on the AMD impacted section of Rock Creek. The IBI on this date was 42, a ranking of fair.

Monitoring station RC-O3 is located on Rock Creek at the mouth of Koger Fork. This site was sampled three times in 1999. On June 2, 1999 13 species of fish were collected, eight of which were intolerant species. The IBI for this date was 46, a ranking of fair to good. On August 26, 1999 only two species of fish were collected, one of which was an intolerant specie. The IBI for this date was 29, a ranking of poor. On October 19, 1999 12 species of fish were collected, eight of which were intolerant species. The IBI for this date was 48, a ranking of good. On July 17, 2000, six months after limestone dosing began, the number of species collected was 13, eight of which were intolerant species. The IBI was 37, ranking poor to fair on this date. The presence of green sunfish and the increase in largescale stonerollers lowered the IBI score. On July 23, 2001 the number of species collected increased to 15, with 11 species being classified as intolerant. The IBI on this date was 48, a ranking of good.

Monitoring station RC-04 is located on Rock Creek at the mouth of Grassy Fork, immediately downstream from the Water Tank Hollow site. This stream segment was sampled three times in 1999. On June 2, 1999 10 species were collected, five of which were intolerant species. The IBI on this date was 38, a ranking of poor to fair. On August 26, 1999 six species of fish were collected, with three species being classified as intolerant species. The IBI on this date was 34, a ranking of poor. On October 19, 1999 only two species were collected, none of which are classified as intolerant. The IBI for this date was 22, a ranking of very poor. On July 17, 2000, six months after limestone dosing began, 14 species were collected, and seven of which are classified as intolerant. The IBI for this date was 44, a ranking of fair. On July 23, 2001 10 species were collected, with eight species classified as intolerant. The IBI on this date was 46, a ranking of fair to good.

Fish populations have increased in both diversity and numbers in the White Oak Creek and lower Rock Creek watersheds since limestone dosing and AMD abatement reclamation in the watersheds began. Stream segments in both White Oak Creek and Rock Creek that were dead or severely stressed have improved. IBI scores have consistently increased after limestone dosing and AMD abatement reclamation practices were initiated. Additional AMD abatement reclamation projects in the lower Rock Creek watershed will further improve water quality in the watershed, positively impacting fish populations. As funding permits, additional AMD abatement projects such as the ones completed at the Water Tank Hollow site and the Roberts Hollow site will reduce the need for limestone dosing in the lower Rock Creek watershed.

Technology Demonstration

The Rock Creek project provided an opportunity for education and outreach. By developing brochures and conducting school field trips, issues such as the importance of clean water, acid mine drainage abatement techniques, and the availability of programs involved with environmental restoration were highlighted.

The Kentucky Department of Fish and Wildlife Resources (KDFWR) filmed and broadcast a segment about the project on its weekly television show "Kentucky Afield". The show aired twice statewide on the Kentucky Public Broadcasting Network (Appendix L). The video segment was also shown in Kentucky elementary schools via closed circuit television as part of the "Kentucky Afield for Kids" program on December 5, 2001 (Appendix J). In addition an article was written and published in the Spring 2002 edition of "Kentucky Afield" the magazine (Appendix I).

The United States Forest Service conducted a two day "Environmental Camp" on May 17 and 18, 2001. Acid Mine Water was one of the segments at the camp. Approximately 150 school children attended the camp each day. A list of activities and attendance is located in Appendix H. The Kentucky Division of Abandoned Mine Lands participated in a field trip on Rock Creek that was led by the McCreary County Agricultural Extension Agent, Greg Whitis, on June 12, 2002. The field trip was part of the "Exploring McCreary County" program. An AML biologist discussed stream ecology and an AML geologist discussed the impacts to the stream from acid mine drainage and the remediation efforts being conducted in Rock Creek. Approximately 20 students attended the field trip.

The United States Forest Service produced a brochure that described the Rock Creek project. The brochure is for public dissemination and highlights the improvements realized by the project (Appendix G).

The Kentucky Division of Abandoned Mine Lands photographed the project from beginning to end in digital format and the entire photo collection is on CD in Appendix K.

CONCLUSIONS

Removal of 18,331 cubic yards of pyritic coal mine refuse from the north bank of Rock Creek at the three acre Water Tank Hollow site has eliminated over 80 tons of acidity entering Rock Creek annually from direct washing of the refuse into the stream. Revegetation of the sparsely vegetated site has reduced the sediment load into Rock Creek by 500 tons annually. Iron loading and aluminum loading have also been significantly reduced.

Installation of the open limestone channel (OLC) at the unnamed tributary below Roberts Hollow has reduced net acidity by 92%. Acid loading has been reduced to near zero with the exception of a single high flow event. Similar results were seen with iron and aluminum loading. The OLC has resulted in an increase in pH, calcium concentrations, and alkalinity, and a corresponding decrease in acidity and dissolved metals. The documented changes in water chemistry illustrate the value of OLCs in treating acid mine drainage, particularly at low flows.

Treating the pyritic coal mine refuse from the Water Tank Hollow site by mixing it with agricultural limestone and placing it in compacted lifts at the pre-existing Roberts Hollow refuse fill reclaimed two acres of sparsely vegetated refuse. The combination of the treated refuse and the installation of OLCs reduced acid groundwater seepage entering the Roberts Hollow tributary. Revegetation of the site further reduced the sediment load entering the stream. Acid loading into Rock Creek from the tributary was reduced by 44%. Dissolved iron loading decreased by 46% and dissolved aluminum loading decreased by 56%.

The combination of the reclamation of the above sites in conjunction with limestone sand dosing and AMD abatement reclamation at other sites in the lower Rock Creek watershed has reduced the acid load entering the Big South Fork of the Cumberland River to near zero. Fish populations are rebounding with increases in numbers, diversity of species, and numbers of intolerant species. Sections of the streams that were once dead or severely impacted by AMD are being re-colonized by fish.

Additional reclamation work being planned for the severely impacted tributaries of Jones Branch and Roberts Hollow will continue to reduce acid and metal loading, improving water quality further in the lower Rock Creek watershed. As additional funding allows reclamation projects like the ones undertaken at Water Tank Hollow and Roberts Hollow to be completed the dependence on limestone dosing of the tributaries will be reduced.

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APPENDIX A. FINANCIAL AND ADMINISTRATIVE CLOSEOUT

Workplan Outputs

The Rock Creek Clean Water Action Plan Project listed several education activities that were to be performed as part of the project.

- The Kentucky Department of Fish and Wildlife was to produce a videotape for play on their television show "Kentucky Afield". The show was filmed and aired twice over the Kentucky Public Broadcasting System. In addition the segment was aired via closed circuit television in Kentucky schools as part of the "Kentucky Afield for Kids" program. In addition an article was written and published in the Spring 2002 edition of "Kentucky Afield the Magazine". Copies of the video segment and the magazine article are attached.

- The United States Forest Service committed to producing a brochure describing the Rock Creek project. The brochure has been designed and an initial printing of 1000 brochures will occur when final approval of the brochure design is received from the Kentucky Division of Water. Copies of the brochure are attached.

- The United States Fish and Wildlife Service and the United States Forest Service each committed to conducting a minimum of one (total of two) educational/informational field trips for school children while the project was underway. The United States Forest Service conducted a two day "Environmental Camp" on May 17 and 18, 2001. Acid Mine Water was one of the segments at the camp. Approximately 150 school children attended the camp each day. A list of activities and attendance is attached. The United States Fish and Wildlife Service backed out of their agreement to conduct a field trip. The Kentucky Division of Abandoned Mine Lands, however, participated in a field trip on Rock Creek that was led by the McCreary County Agricultural Extension Agent, Greg Whitis, on June 12, 2002. The field trip was part of the "Exploring McCreary County" program. An AML biologist discussed stream ecology and an AML geologist discussed the impacts to the stream from Acid Mine Drainage and the remediation efforts being conducted at Rock Creek. Approximately 20 students attended the field trip.

- Trout Unlimited committed to producing an educational/informational video and an explanatory brochure. The Kentucky Division of Abandoned Mine Lands has not received either. If and when AML receives the video and brochure they will be sent to the Kentucky Division of Water. AML has a digital photograph record of the AMD remediation activities on Rock Creek and copies of the photos on CD are attached.

Budget Summary

Detailed Budget Summary

Budget Categories	CWAP Funds	Non-Federal Match	Total	Final Expenditures
Personnel		$ 113,896.14	$ 113,896.14	$ 110,560.15
Supplies		$ 1,250.00	$ 1,250.00	$ 150.00
Equipment		$ 1,200.00	$ 1,200.00	$ 0.00
Travel		$ 15,881.00	$ 15,881.00	$ 31,283.48
Contractual	$ 200,000.00	$ 44,539.00	$ 244,539.00	$ 365,981.14
Operating Costs		$ 29,605.70	$ 29,605.70	$ 39,318.27
Other				
TOTAL	**$ 200,000.00** **49.2 %**	**$ 206,371.84** **50.8 %**	**$ 406,371.84** **100 %**	**$ 547,293.04**

The Kentucky Division of Abandoned Mine Lands was reimbursed $200,000.00. All dollars were spent; there were no excess project funds to reallocate. This project did generate overmatch provided by the Kentucky Division of Abandoned Mine Lands. This overmatch was not posted to the Grant.

Equipment Summary

There was no equipment purchased for this project.

Special Grant Conditions

There were no special grant conditions.

APPENDIX B. QA/QC FOR WATER MONITORING

QA/QC PLAN
for
THE ROCK CREEK WATERSHED
CLEAN WATER ACTION PLAN PROJECT

Prepared by
Mark Carew -- Project Geologist
Edwin Boone – Project Biologist
KENTUCKY DIVISION OF ABANDONED MINE LANDS

Updated – May 24, 2000

Nonpoint Source Acid Runoff Pollution at the
Water Tank Hollow Coal Processing Refuse Disposal Site

PART I -- QA/QC for Physiochemical Water Sampling

PART II – QA/QC for Biological Monitoring

PART I – QA/QC for Physiochemical Water Sampling

Project Organization

Water monitoring for this project will be conducted by the United States Geological Survey (USGS) in conjunction with the Kentucky Division of Abandoned Mine Lands (AML). The following people will be in charge of the major monitoring activities:

AML Project Geologist --	Mark Carew 2521 Lawrenceburg Rd. Frankfort, KY 40601 (502) 564-2141
USGS Project Officer --	Michael D. Unthank 9818 Bluegrass Parkway Louisville, KY 40299-1906 (502) 493-1900
USGS Field Supervisor --	F. Dave Byrd P.O. Box 1028, Jackson Mall Williamsburg, KY 40769 (606) 549-2406

The following laboratories may be used by AML for analysis:

J & M Monitoring, Inc.
P.O. Box 2486
Pikeville, KY 41502

Commonwealth Technology, Inc.
2520 Regency Road
Lexington, KY 40503-2921

McCoy and McCoy Laboratories, Inc.
P.O. Box 907
85 East Noel Avenue
Madisonville, KY 42431

The USGS will contract with a laboratory for analysis. The laboratory is unknown at this time.

Watershed Information

Rock Creek (05130104-007, GNIS-515024) originates in Pickett County Tennessee, flows into Scott County Tennessee and then into McCreary County Kentucky. The upper eighteen miles of the stream in Kentucky is designated as a Kentucky Wild River and is proposed for inclusion in the National Wild and Scenic Rivers System. It is also a state-designated outstanding resource water. In the study area Rock Creek is a fourth order stream which discharges into the Big South Fork of the Cumberland River.

Monitoring Objectives

A. To collect acid and metal loading data for the Water Tank Hollow tributary of Rock Creek. The Water Tank Hollow tributary is being degraded by seeps flowing from the refuse located at the mouth of Water Tank Hollow. Monitoring before and after removal of the refuse will indicate the efficacy of removal of the refuse.

B. To collect acid and metal loading data for the Roberts Hollow tributary of Rock Creek. The Roberts Hollow tributary is being degraded by refuse located in Roberts Hollow and by mine portals located above the refuse. Loading data will be used to calculate the limestone sand treatment dosage and to measure the efficacy of the treatment.

Study Area Description

Location

The Water Tank Hollow refuse site is a three acre coal processing refuse dump located on the north bank of Rock Creek adjacent to Kentucky highway 1363 in McCreary County Kentucky. The longitude and latitude of the Water Tank Hollow refuse site is 84°33'05" degrees longitude by 36°42'41" degrees latitude.

The Roberts Hollow refuse site is located on the northeast bank of the Roberts Hollow tributary to Rock Creek. The longitude and latitude of the Roberts Hollow refuse site is 84°35'00" longitude by 36°42'41" latitude.

Geologic Setting

The project area is located near the Cumberland Escarpment on the edge of the Cumberland Plateau. The topography is highly dissected with steep stream valleys having elevations ranging from 1400 feet above mean sea level on top of Rattlesnake Ridge to 740 feet above sea level at the mouth of Water Tank Hollow. Stratigraphy of the site includes the Lower Pennsylvanian Lee Formation on the upper slopes underlain by the Upper Mississippian Pennington Formation which crops out on the lower slopes of the study area. Quaternary alluvium is found on the banks and underlying Rock Creek at several locations including the Water Tank Hollow refuse site. The Rockcastle Conglomerate Member of the Lee Formation forms conspicuous cliffs near the top of the ridges in the study area. The Beattyville Shale Member of the Lee Formation, located below the Rockcastle Conglomerate Member, consists of shale, siltstone, coal, and clay. The Stearns coal zone is located in the lower part of the Beattyville Shale Member. The coal beds in the Stearns coal zone are known locally as the Stearns No. 1, No. 11/2, and No. 2 and are commonly separated by only a few feet of sandstone, siltstone, or shale. Locally the coal beds may merge into one or two beds, or split into several very thin seams. The Pennington Formation consists of shale, sandstone, and limestone. The Water Tank Hollow refuse is located on the Pennington Formation and on alluvium on the north bank of Rock Creek. The majority of the Roberts Hollow refuse is located on Pennington Formation strata with the upper slope of the refuse located on the Beattyville Shale Member below the Stearns coal zone. The regional dip is to the East-Southeast.

Hydrologic Regime

Roberts Hollow is a 420 acre watershed flowing into Rock Creek. The Roberts Hollow refuse site is located on the east side of the tributary. Roberts Hollow receives discharges from several coal mine portals located within the watershed. In addition there are several seeps flowing from the coal processing refuse.

The Water Tank Hollow refuse site is a three acre coal processing refuse dump located on the bank of Rock Creek. Flow from above the refuse is being diverted by ditch lines along Kentucky Highway 1363. Several seeps have been observed flowing from the refuse, one of which is flowing into the Water Tank Hollow tributary near the confluence with Rock Creek.

No sinks have been observed in the project area, however, two sinks have been observed in the stream bed of the Jones Branch tributary of Rock Creek which is located upstream and to the west of the project area. The uppermost sink was dye traced by Kentucky Abandoned Mine Land and United States Forest Service personnel. The upper sink discharges at a spring located across Highway 1363 from the church driveway at the mouth of Jones Branch. The spring is about ten feet below the road elevation. The lower sink which is located about fifty feet upstream from the confluence of Jones Branch and White Oak Creek has not been dye traced yet. Flow conditions have to be exact with the lower sink receiving the entire flow of Jones Branch before a dye trace can be done to prevent dye from entering the stream. Rock Creek flows into a large sink located on its south bank just upstream from White Oak Junction. This sink has been dye traced by AML and USFS personnel and is discharging from a spring about 3000 feet downstream on the southern bank of Rock Creek.

There are five types of aquifers located within or near the project area. In addition to the karst aquifer flow regime and the coal bed aquifers demonstrated by the mine portal discharges noted
above, groundwater flow in the study area is controlled by granular aquifers within the sandstone units, alluvial aquifers which are composed of unconsolidated sediments located along Rock Creek, and near surface fracture aquifers which are formed by stress relief fractures and joints and may cut through and influence the other aquifer types. Recharge to the hillside aquifers occurs when precipitation soaks through the thin soils and colluvium, percolates down through the fractured units until a confining bed is reached, flows horizontally along bedding planes toward the hillside until the perched water is intercepted by vertical fractures in the confining bed or in the absence of vertical fractures in the confining bed is forced to the surface as wet weather springs. This results in a stair step pattern of groundwater movement from the ridgetops to the valley floor.

Land-use Activities

Underground coal mining began in the project area in the first decade of the century and continued through the 1960's. Several small towns were built supporting the mining and lumber industries of the area. Several of the towns including Yamacraw, Fidelity, and Co-Operative no longer exist. With the exception of the railroad right of way which is owned by the K & T Railroad Company, and a few small private in-holdings the project area is managed by the United States Forest Service. Rock Creek is a major recreational attraction and is visited by thousands yearly. Fishing, hunting, hiking, backpacking, and camping are just a few of the interests pursued by visitors.

Monitoring Program

Existing water quality data has been collected at the point source (portals, seeps) and may not take into account all of the acid drainage sources or any natural buffering which may occur within the watershed. To address this the mouths of the main tributaries and the main stem of Rock Creek will be monitored. The sites will be monitored monthly for a period of one year before construction activities for background data. The sites will be monitored monthly during construction of the project and then monthly thereafter at Roberts Hollow to determine the acid loading which will be used to calculate the limestone sand dosage requirements. The Water Tank Hollow site will be monitored monthly after construction of the project todemonstrate project success. After that, monitoring of the Water Tank Hollow site will cease. The following sites which are part of a larger monthly monitoring program are specific to this project:

Monitoring Site

9 Lat/Long–N36°42.594'/W84°35.025
Rock Creek above Roberts Hollow

10 Lat/Long – N36°42.615/W84°35.025
Mouth of Roberts Hollow

11 Lat/Long – N36°42.635/W84°34.988
Culvert discharge below the mouth of Roberts Hollow

WTA Lat/Long – N36°42.724/W84°33.053
Water Tank Hollow above the refuse site

WTB Lat/Long – N36°42.717/W84°33.033
Mouth of Water Tank Hollow

The following parameters will be tested monthly:

Parameter	**Method**
Discharge	Field
pH	Field
Specific Conductance	Field
Total Dissolved Solids	Lab
Acidity	Lab
Alkalinity	Lab
Sulfate	Lab
Fe (total)	Lab
Fe (dissolved)	Lab
Mn (total)	Lab
Mn (dissolved)	Lab
Al (total)	Lab
Al (dissolved)	Lab
Ca (total)	Lab

The following samples for analysis will be prepared for each site:

500 ml unfiltered, unpreserved
500 ml unfiltered, acidified
250 ml filtered, unpreserved
250 ml filtered, acidified

All sample collection, preservation, and analysis will be conducted in accordance with Standard Methods For The Examination Of Water and Wastewater. Discharge will be measured with a Swoffer model 3000 current velocity meter or by the "bucket and stopwatch" method where possible. The bucket and stopwatch method involves the measuring of how much time it takes a given source to fill a container of known volume. This time is then interpolated to volume per minute. Three measurements will be taken and the results averaged. Conductivity and pH will be measured using pH and conductivity meters.

Chain of Custody Procedures

The attached chain of custody form or a similar form will be used for all samples collected. Samples will be collected from the exact same locations monthly. Sample bottles will be marked with the monitoring site number, whether the sample is filtered or raw, and whether the sample is acidified or unpreserved. Immediately upon acquisition the sample will be placed in a cooler on ice and the form will be filled out indicating the sample was taken. Samples will be delivered to the laboratory for analysis within 24 hours of acquisition. The chain of custody form will be filled out by the receiving party at the laboratory and a copy of the form will be given to the party relinquishing the sample.

Quality Control Procedures

All samples will be collected in new sample bottles. Conductivity and pH meters will be calibrated with known calibration solutions at the beginning of each sampling session and checked and re-calibrated periodically. Conductivity and pH probes will be rinsed in de-ionized distilled water between each reading. Filter apparatus will also be rinsed with de-ionized distilled water between each sample. All samples will be labeled clearly and recorded immediately upon acquisition to prevent contamination. Split samples will be taken periodically and sent to different labs to assure accuracy. Acceptable levels of variance for duplicate results will be those specified in Standard Methods. All results will be checked for anion-cation balance, measured TDS vs. calculated TDS, measured conductivity vs. calculated conductivity, the ratio of calculated TDS to conductivity, and the measured TDS to conductivity ratio. The criteria for acceptance will be determined by Standard Methods. Any sample falling out of the acceptable range will be reanalyzed. Procedures used by USGS personnel are outlined in "U.S. Geological Survey Protocol for the Collection and Processing of Surface-Water Samples for the Subsequent Determination of Inorganic Constituents in Filtered Water" -- U.S. Geological Survey Open-File Report 94-539, which is attached.

PART II – Biological Monitoring

Project Organization

DAML Project Biologist:	Ed Boone Kentucky Division of Abandoned Mine Lands 2521 Lawrenceburg Road Frankfort, KY 40601 (502) 564-2141
United States Forest Service Aquatic Biologist	Vicki Bishop, USFS Daniel Boone National Forest 1700 Bypass Road Winchester, KY 40391
Fish Sampling Coordinator:	Doug Stephens, KDFWR District Fisheries Biologist Southeastern District 2073 North Highway 25W Williamsburg, KY 40769

The following Laboratories may be used for sample processing:

Fish samples will be processed by personnel from KDFWR, USFS, and KDAML, while macroinvertebrate samples will be processed by personnel from USFS and KDAML, with aid and advice from cooperating outside sources as necessary. As such, no contracted services will be utilized for sample identification and data analysis.

Monitoring Objectives

A. To obtain data regarding short term impacts of acid mine drainage mitigation efforts upon the water quality as measured by the aquatic communities of Rock Creek by means of sampling the macroinvertebrate population. Monitoring macroinvertebrates before, during, and after reclamation efforts will indicate the short-term effectiveness of this acid mine drainage mitigation project.

B. To obtain data regarding long term impacts of acid mine drainage mitigation efforts upon the water quality as measured by the aquatic communities of Rock Creek by means of sampling the fish population. Monitoring fishes before, during, and after reclamation efforts will indicate the long-term effectiveness of this acid mine drainage mitigation project.

Monitoring Program

Biological monitoring is to be conducted by the following methods:

A. Aquatic macroinvertebrates are to be collected spring and fall by a series of three surber samples per station, along with one triangular kick-net sweep to cover all habitat types in the sample area. All whole samples are to be picked in the field, stored in 70% ethanol, and returned to the DAML Frankfort office for sorting and identification to the lowest possible taxon. After sorting and identification, the data will be evaluated using the modified Hilsenhoff Biotic Index (HBI) (Lenat, 1993) to determine the overall pollution tolerance of the macroinvertebrate community and the degree to which the habitat is impaired. Other metrics to be used include the Total Number of Individuals, Ephemeroptera/Plecoptera/Trichoptera Richness (EPT), and Percent Dominant Taxon. Also, comparison with background data from the 1999 pilot project may be used to estimate impacts to the aquatic habitat.

B. Fishes are to be collected spring and fall by the use of a Smith-Root model 12A battery powered backpack electrofishing device. Fish collected are to be identified in the field when possible, with voucher specimens being returned to the lab for positive identification. Identification will be to the lowest possible taxon. Type specimens are to be preserved in 10% buffered formalin for 1-2 weeks, then rinsed and transferred to 70% ethanol for long-term preservation and storage. After final identification has been completed, the data will be evaluated using the Index of Biotic Integrity (IBI) to determine the overall structure and health of the piscid community as an indicator of aquatic habitat health. Also, Catch Per Unit of Effort (CPUE) of shocking time will be considered as a measure of relative abundance.

Biological monitoring stations will be at the following sites on Rock Creek (RC) and White Oak Creek (WO). See attached map:

RC-00 (INT02002004) Lat/Long – N36°42.166'/W84°35.724'
Rock Creek – immediately upstream from the mouth of White Oak Creek

RC-01 (INT02008003) Lat/Long – N36°42.192'/W84°35.780'
Rock Creek – immediately downstream from the mouth of White Oak Creek

RC-02 ( ) Lat/Long – N36°42.412'/W84°34.709'
Rock Creek – immediately upstream from the mouth of Schoolhouse Branch

RC-03 (INT02008002) Lat/Long – N36°42.194'/W84°33.726'
Rock Creek – immediately downstream from Koger Fork bridge

RC-04 ( ) Lat/Long – N36°42.816'/W84°32.899'
Rock Creek – mouth of Grassy Fork

WO-01 ( ) Lat/Long – N36°41.448'/W84°37.392'

White Oak Creek – immediately upstream from the mouth of Cabin Branch

WO-02 ( ) Lat/Long – N36°41.466'/W84°37.279'
White Oak Creek – 75 yards downstream from the mouth of Cabin Branch

These stations will be used for both fish and macroinvertebrate sampling. Site selection criteria included ease of repositioning, ability to determine the effects of AMD treatments within the project area on the main stem of Rock Creek. All sites (except for the control sites RC-00 and WC-01) are downstream from each treated tributary. Data reporting for all collections will be conducted as per KDOW accepted methods (See later discussion for details).

Chain of Custody Procedures

Samples taken in the field shall be labeled with the following information:

- Date the sample was taken.
- Station at which the sample was taken.
- Name of the person conducting the sampling.
- Gear and/or method used to obtain the sample.
- General stream conditions at the time of sampling (high or low flow, turbid or clear, etc).
- Water temperature.
- pH
- Conductivity.
- Weather.

Macroinvertebrate samples are to be collected, processed, and the resulting data analyzed by USFS personnel. Fish samples are to be collected, processed, and analyzed by KDFWR personnel. Volunteer biologists from KDOW and DAML will assist in collection, processing, and identification of both macroinvertebrates and fish. Sample specimens will reside with the agency conducting the collection (USFS or KDFWR) until final data analysis is complete, at which time the agency will deliver the specimens to USFS.

Quality Control Procedures

Equipment used in biological monitoring will be decontaminated by rinsing in clean water or, in the case of pH and conductivity meters, rinsed with distilled water. Electrofishing equipment will be calibrated on site. Conductivity meters and pH meters will be calibrated with known calibration solutions prior to each sampling session, and be recalibrated periodically. Organisms collected from each sample at each sampling station will be collected in a new container. Quality control for biological samples will be provided by replicate samples at each station, and by ensuring that all habitat types at each station are sampled. Variance in organisms and numbers of organisms between sampling stations and trips will reflect improvement or degradation of water quality. In order to explain such variance, factors such as variations in flow from portals and coal waste, weather, and life cycles of aquatic insects will be considered and investigated. Species identification of collected organisms will be cross-checked and verified by outside experts such as KDOW and/or Kentucky State Nature Preserves Commission, as necessary.

Data Management and Data Reporting Standards

Forms used for reporting the results of data analysis for biological samples will contain the following information:

- The site of the sampling station, including:
  - Name of County.
  - Name of stream.
- A unique sample identifier, which will include:
  - Sampling station ID number.
  - Date the sample was taken.
- Name and agency of the individual who took the sample.
- The results of the analysis, including:
  - Taxonomy and number of individuals of each organism identified
  - Summary of HBI or IBI calculation
  - Results of HBI or IBI calculation
  - For macroinvertebrate samples, the HBI tolerance value of each organism identified.

DAML and KDFWR will report the results of data analysis to KDOW for entry into their database, including the raw data as well as the conclusions of all indices used. The data will be compiled and recorded in Microsoft Excel, and will be reported to KDOW in both software and hardcopy. Each sampling date at each site will be reported on a separate page. Each organism will be reported on a separate line, including order, family, genus, species and number encountered. The KDOW database will be the primary repository for this information.

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APPENDIX C. BMP IMPLEMENTATION PLAN

BMP IMPLEMENTATION PLAN
for
THE ROCK CREEK WATERSHED
CLEAN WATER ACTION PLAN PROJECT

Prepared by
Mark Carew – Project Geologist
KENTUCKY DIVISION OF ABANDONED MINE LANDS

June 23, 2000
Revised – August 7, 2000

Nonpoint Source Acid Runoff Pollution at the
Water Tank Hollow Coal Processing Refuse Disposal Site

BMP Technologies to be Installed

Refuse Removal and Treatment

The Rock Creek Clean Water Action Plan Project will involve the removal of an estimated 20,000 to 30,000 cubic yards of highly acidic coal mine refuse from the banks of Rock Creek near Water Tank Hollow. The refuse is a significant source of sedimentation and acid mine drainage (AMD) into Rock Creek, as well as a visual blight to the surrounding forested area. The refuse will be loaded and hauled to an existing refuse area in Roberts Hollow. The refuse will be placed in 6" to 8" lifts near the toe of the existing refuse fill. Foundation benches will be excavated and an agricultural limestone barrier will be placed prior to placement of the refuse. Agricultural limestone will be incorporated into each lift at the rate of 100 tons per acre per foot of lift. Suitable borrow material is not available so hardwood bark mulch, at the rate of 100 dry tons per acre will be used in the revegetation efforts. Hardwood bark mulch adds buffering capacity to the soil matrix, aids in the water holding capacity of the soil, improves the soil texture, stabilizes the soil temperature, provides a chelating effect which helps agricultural limestone work better by resisting iron coating, and is a more durable mulch than straw. The area to be filled currently has sparse vegetation and revegetation efforts following placement of the fill should improve the vegetation of the site reducing the sediment load to the stream. The refuse fill area will be seeded with a mix of acid tolerant warm and cool season grasses and legumes. Final determination of seed species planted will be made by the landowner (United States Forest Service).

After removal of the refuse from the Water Tank Hollow site the slope will be graded to a smooth uniform configuration. Agricultural limestone will be added to the site and either disked in or tracked in with a bulldozer depending on the slope angle. The site will be fertilized, seeded, mulched, and netted. The site will be revegetated with a mix of warm and cool season grasses, legumes, and trees compatible with the surrounding vegetation. Final determination of seed and tree species planted will made by the landowner (United States Forest Service). The stream bank will be restored and stabilized using bioengineering techniques and native vegetation to closely resemble its natural riparian state. Any large rocks encountered during excavation of the refuse, if found to have no potential acidity will be placed at the toe of the slope to provide slope protection.

Prior to existing surface mining laws coal mine refuse was often dumped on hillsides with no regard for existing drainage, oftentimes covering up natural drainage features. If natural drainage features are encountered during excavation of the coal mine refuse from the banks of Rock Creek they may be retained as natural drains. Based on the stream banks adjacent to the Water Tank Hollow coal mine refuse disposal site it is anticipated that the final grade after removal of the refuse from the bank of Rock Creek will be steep. Class III limestone channel lining may be installed in any natural drains encountered during excavation of the refuse. It is the intention of the Division of Abandoned Mine Lands to direct as much of the drainage in the lower Rock Creek watershed through alkaline materials as possible to provide buffering for any acidic drainage encountered. The Class III limestone that may be used on the Water Tank

Hollow refuse site to protect any natural drains or seeps encountered will add alkalinity to the water in addition to protecting the slope from erosion.

Acidity produced by acid mine drainage can be neutralized in the presence of sufficient carbonate minerals. Where neutralization is occurring the pH can remain at a near neutral value which inhibits bacterial catalysis of iron oxidation and where ferric iron is relatively insoluble. Thus the quality of drainage produced is largely dependent on the availability of calcium carbonate or other neutralizing agents in the overburden. A strong empirical relationship exists between the neutralization potential of coal mine overburden and whether or not the drainage will be alkaline (Brady et al., 1994). Brady et al., (1994) found that sites with more than 3% naturally occurring carbonates produced alkaline drainage. Sites with less than 1% carbonate generally produced acidic drainage.

The role of carbonate is so important in acid mine drainage formation that neutralization potential was found to be a better predictor of whether drainage would be alkaline or acidic than was the maximum potential acidity calculated from the sulfur content (Brady and Hornberger, 1990, Brady et al., 1994, Perry and Brady, 1995). Agricultural limestone will be mixed with the refuse on this project in sufficient quantity to achieve greater than 3% calcium carbonate content in the refuse which should produce net alkaline drainage.

The computer programs SEDCAD4 and RUSLE were used to calculate the soil/refuse loss from the Water Tank Hollow refuse site each year. It was calculated that the annual soil loss is about 500 tons per year. The refuse was sampled and found to have a potential acidity of 165 tons per kiloton. Removal of the refuse from the Water Tank Hollow site will result in a potential reduction of 82.5 tons of acidity per year from the direct washing of the refuse into the stream. The actual acid load is probably higher due to the formation and subsequent dissolution during precipitation events of sulfur salts forming in the refuse.

Construction BMPs including but not limited to staking of silt control bales at the toe of the slopes at Water Tank Hollow and Roberts Hollow, and temporary and/or permanent water diversions will be used during all construction activities.

The estimated construction cost for implementation of the refuse removal and treatment is $175,000.00.

Open Limestone Channels

Open limestone channels will be installed at the Roberts Hollow refuse fill site. A limestone channel 1000 feet in length will be constructed immediately above the proposed refuse disposal area. A limestone channel 800 feet in length will be installed in the natural drain on the southeast side of the fill area. The limestone channels will intercept acidic water from the upper slopes of the refuse fill area, diverting acidic water away from the new fill, and providing treatment to the water before discharging into the main tributary and Rock Creek.

Open limestone channels (OLCs) introduce alkalinity to acid water in open channels or ditches lined with limestone rock (Ziemkiewicz et al., 1994). Acid water is introduced to the channel and the acid mine drainage is treated by limestone dissolution. Past assumptions have held that armored limestone (limestone coated with Fe and/or Al hydroxides) ceased to dissolve, but experiments show that coated limestone continues to dissolve at about 20% the rates of unarmored limestone (Pearson and McDonnell 1975). Another problem is that hydroxides tend to settle into and plug the voids in limestone beds forcing water to move around rather than through the limestone. While both armoring and plugging are caused by the precipitation of metal hydroxides they are two different problems. Plugging of the voids in limestone beds can be minimized by maintaining a high flushing rate through the limestone bed. Armoring, however, occurs regardless of the water velocity. Recent work has demonstrated that the rate of dissolution for armored limestone may be even higher than previous laboratory studies (Ziemkiewicz et al., 1997). Field experiments show considerable treatment by OLCs (Ziemkiewicz et al., 1994). The length of channel and the channel gradient are design factors which can be varied for optimum performance. Optimum performance is attained on slopes exceeding 20%, where flow velocities keep precipitates in suspension, and clean precipitates from limestone surfaces. Dissolved metals sorb onto the surfaces of the precipitates in suspension further reducing the amount of dissolved metals in the water. Open limestone channels may be designed and constructed for long term treatment. Utilizing OLCs with other passive systems can maximize treatment and metal removal.

Computer modeling of the proposed open limestone channels was conducted using water monitoring data from 2/99 to 2/00. Flow in the unnamed tributary at Roberts Hollow is intermittent. No flow was recorded for the months of 6/99, and 8/99 to 11/99. No acidity data was available for 4/99 and 5/99. For the months having data the limestone channel as designed will reduce the acidity by 100 % except for 2 months. Data for 2/99 indicates the acidity would be reduced by 98%. Data for 3/99 indicates the acidity would be reduced by 67%. The two months that had less than 100% reduction were high flow conditions. The limestone channel proposed near the toe of the existing refuse could not be modeled because it won't intercept the main stem of Roberts Hollow that is being monitored, so no data is available for the flow and acidity levels it will intercept.

The estimated construction costs to install the open limestone channels in the Roberts Hollow refuse area is $44,800.

Limestone Sand Treatment

During testing of a self-feeding rotary drum system that ground limestone aggregate into a slurry, Zurbuch (1989) found that undissolved sand-sized particles continued to be reactive in stream sediments and significantly reduced acidity. Further research into the use of quarry produced limestone fines as a method to treat streams acidified by acid deposition corroborated the rotary drum results (Ivahnenko et al., 1988).

Sand-sized limestone may be directly dumped into acid mine drainage impacted streams at various locations in watersheds. The sand is picked up by the stream flow and redistributed downstream, neutralizing the acid as the stream moves the limestone through the stream bed. The limestone in the stream bed reacts with acid in the stream, causing neutralization. Coating of limestone particles with Fe oxides can occur, but the agitation and scouring of the limestone in the stream bed keep fresh surfaces available for reaction.

Water monitoring is being conducted to determine the acid load being contributed by each tributary to the lower Rock Creek watershed. Limestone sand will be placed in each tributary at rates determined by the acid loading calculations. Limestone sand will be added at double the calculated rate for the first year and at the calculated rate for every year after so that after the first year there will always be one years worth of neutralization potential in the stream bed. This project includes the application of limestone sand to the Roberts Hollow tributary to Rock Creek at the acid loading rates calculated.

The use of the direct application of limestone sand to treat acidified streams is the least expensive method available based on the cost per ton of acid neutralized (Zurbuch, 1996; Zurbuch et al., 1996). This method does not require the large capital investment nor the costs associated with the operation and maintenance of mechanical stream dosing systems.

The annual cost to treat the acid load in the lower Rock Creek watershed with limestone sand after construction of all application sites and after the first year of dosing when rates are doubled is calculated to be $15,000. The Division of Abandoned Mine Lands will, as part of its annual grants from the Office of Surface Mining, budget for the continued dosing of the lower Rock Creek watershed with limestone sand into the foreseeable future. It is anticipated that at some time in the future the United States Forest Service will assume the responsibility for dosing the lower Rock Creek watershed. If and when this occurs AML will relinquish responsibility for the dosing to the USFS.

The estimated construction cost for development of the Roberts Hollow limestone sand application site, road to the site, and limestone sand application for one year is $22,400.

Alternative Treatment Options

Active Treatment Technologies

Active treatment systems involve treating mine drainage with alkaline chemicals to neutralize acidity, raise water pH, and precipitate metals. Active treatment technologies are effective, however, when the cost of equipment, chemicals, and manpower are considered active treatment is expensive (Skousen et al. 1990). Chemical treatment is a long term never ending process. A variety of active treatment methods can be employed. Most active chemical treatment systems consist of an inflow pipe or ditch, a storage tank or bin to hold the chemical, a means of controlling the chemical application, a settling pond to capture precipitated metal oxyhydroxides, and a discharge point. Chemical compounds used in AMD treatment include:

Crushed limestone – rotating drum
Hydrated lime
Sodium carbonate (soda ash)
Sodium hydroxide (solid and liquid forms)
Ammonia
Pebble Quicklime (Calcium oxide).

None of the above treatment options are suitable for the Water Tank Hollow refuse site. The refuse on the site toes out into the stream therefore any structure built to intercept the flow from the site would be in the flood zone. The above treatment options could possibly be used on the Roberts Hollow refuse site. The flow at the toe of the refuse areas would have to be intercepted and directed to a central application site. The treated water would then flow into a settling pond before being discharged into the stream. The costs for construction of an active treatment site and the continuous operation and maintenance of an active treatment site are prohibitive at current funding levels. In addition many of the active treatment options use chemicals that are harmful to biota in their concentrated state. The risk of release of these chemicals in concentrated form by vandalism or accident must be considered before deciding to use them, particularly on public lands.

Passive Treatment Options

Aerobic Wetland

An aerobic wetland consists of a large surface area pond with horizontal surface flow. The pond may be planted with cattails and other wetland species. Aerobic wetlands can only effectively treat water that is net alkaline. In aerobic wetland systems, metals are precipitated through oxidation reactions to form oxides and hydroxides.

Aerobic wetlands are not suitable for the Water Tank Hollow refuse site or the Roberts Hollow refuse site. The water discharging from both sites is net acidic.

Compost / Anaerobic Wetland

Compost wetlands, sometimes called anaerobic wetlands, consist of a large pond with a lower layer of organic substrate. The flow is horizontal through the substrate layer of the pond. The compost layer usually contains calcium carbonate either naturally as in spent mushroom compost, or added during construction of the wetland. A typical compost wetland will have 12 to 24 inches of organic substrate and be planted with cattails or other wetland vegetation. The vegetation helps stabilize the substrate and provides additional organic matter to perpetuate the sulfate reduction reactions. Compost wetlands can treat discharges that contain dissolved oxygen, ferric iron, aluminum, or acidity in the 500 ppm range.

The compost wetland acts as a reducing environment. The compost removes oxygen from the system. Microbial processes within the organic substrate reduces sulfates to water and hydrogen sulfide. The anoxic environment within the substrate increases the dissolution of limestone. Chemical and microbial processes generate alkalinity and increase the pH.

The Water Tank Hollow refuse site is not suitable for a compost wetland. The refuse toes out in the stream and there is not enough room to intercept the flow into a constructed wetland and be out of the flood zone. The Roberts Hollow site may be suitable for a compost wetland. The flow from the refuse would need to be intercepted and directed to the wetland at the toe of the slope. This would require relocation of the refuse on the lower slope.

Anaerobic wetlands are sized according to the U.S. Bureau of Mines criteria for AML sites. The formula for sizing anaerobic wetlands is:

Minimum wetland size (square meter) = acid loading (g/day) / 0.7

The acid load for the Roberts Hollow site for the period 9/98 to 12/99 ranged from a low of 2,563 g/day in September 1998 to 621,526 g/day in December 1999. Assuming an acid loading rate of 500,000 g/day (which would handle the acid load 90% of the time) an anaerobic wetland would need to be 180 acres in size. Assuming an acid loading rate of 25,000 g/day (which would handle the acid load 50% of the time) an anaerobic wetland would need to be 9 acres in size. Even at the lower acid loading rate the size of the anaerobic wetland needed exceeds the amount of land available for construction.

Anoxic Limestone Drains

An anoxic limestone drain (ALD) is a buried bed of limestone constructed to intercept subsurface mine water flows and prevent contact with atmospheric oxygen. Keeping the water anoxic prevents oxidation of metals and prevents armoring of the limestone. The process of limestone dissolution generates alkalinity. The purpose of an ALD is to provide alkalinity thereby changing net acidic water to net alkaline water. ALDs are limited to the amount of alkalinity they can generate based on solubility equilibrium reactions. An ALD is a pretreatment step to increase alkalinity and raise pH before the water is oxidized and the metals precipitated in an aerobic wetland.

This project involves acidic refuse material placed on a slope. The water leaving the site has already been oxidized so the use of an ALD on the refuse sites is not possible. Water analysis of 41 portals in the lower Rock Creek area in the spring of 1995 indicated that none of the 41 portals were suitable for the installation of an ALD. In all instances either ferric iron, aluminum, and/or dissolved oxygen levels were too high for long term successful treatment.

Vertical Flow Reactors

Vertical flow reactors were conceived as a way to overcome the alkalinity generation limitations of an anoxic limestone drain and the large area requirements for compost wetlands. The vertical flow reactor consists of a treatment cell with a limestone underdrain topped with an organic substrate and standing water. The water flows vertically through the organic substrate which strips the oxygen from the water making it anoxic. The water then passes through the limestone which dissolves increasing alkalinity. The water is discharged through a pipe with an air trap to prevent oxygen from entering the treatment cell. Highly acidic water can be treated by passing the water through a series of treatment cells. A settling pond and an aerobic wetland where metals are oxidized and precipitated typically follow the treatment cells.

Problems associated with vertical flow reactors include plugging of the pipes with aluminum which must be periodically flushed when aluminum loading is high, and precipitation of metals in the organic substrate which may clog, preventing flow into the limestone underdrain.

The Water Tank Hollow site is not suitable for a vertical flow reactor due to the refuse toeing out into the stream. There is no room for construction of the treatment cells, and interception of the acidic water, out of the flood zone. The Roberts Hollow refuse site may be suitable for vertical flow reactors. It may prove difficult to intercept all of the acidic water flowing through the refuse and direct it to the treatment cells. Refuse would need to be moved from the lower slopes to provide room for construction of the treatment cells and polishing wetland. Moving the refuse and construction of the treatment cells, settling pond, and wetland would exceed the current funding level.

Other Options

Other options include leaving the refuse in place at the Water Tank Hollow refuse site, applying agricultural limestone to the surface of the refuse, covering the refuse with hardwood bark mulch or a suitable borrow material, and revegetating the site. This treatment method would reduce the amount of material washing into the stream by revegetation of the site and would therefore decrease the acid load to the stream. The pyrite material in the refuse would continue to weather, however, by chemical and biological processes, generating acid drainage that would enter the stream. The removal and mixing of the refuse with agricultural limestone as proposed inhibits the formation of acid in the refuse by suppressing bacterial catalysis of the iron oxidation and neutralization of any acid formed.

Another option is to do nothing. The Water Tank Hollow refuse site will continue to erode into the stream contributing about 300 cubic yards of sediment and more than 80 tons of acidity annually to the lower Rock Creek drainage.

DOW – NPS Notification

The Division of Water Non-Point Source Section will be contacted and kept informed of the BMP implementation by e-mail and Rock Creek Task Force meetings. DOW personnel will be invited to attend the pre-bid meeting and pre-construction conference. Anticipated start dates will be discussed at the pre-construction conference.

Technology Demonstration Financial Plan of Action

Educational Activities

The Rock Creek project will provide an opportunity for education and outreach. By developing videos and brochures and conducting school field trips, issues such as the importance of clean water, acid mine drainage abatement techniques, and the availability of programs involved with environmental restoration will be highlighted.

The Kentucky Department of Fish and Wildlife Resources (KDFWR) will include a 5 to 15 minute videotape segment about the project on its weekly television show "Kentucky Afield". The show is aired statewide on the Public Broadcasting Network. Funds expended by KDFWR for the video segment will be included in the non-federal match for the project.

The United States Fish and Wildlife Service and the United States Forest Service will conduct at least one educational field trip each accommodating approximately 50 participants in an effort to help with the educational component of the project. Funds expended by these agencies are not eligible for matching funds on this project.

Trout Unlimited will develop a professional quality video and brochure to serve as an educational tool and document the work conducted on the project. The video will target the general public and government agencies to increase environmental awareness and the existence of clean water projects. Initially, a dozen copies will be made available for distribution to local schools, citizen groups, and governmental agencies. If the demand for the video is greater than anticipated more copies will be produced. 500 brochures will be printed that include photos and text of the project to promote the video. Funds expended by Trout Unlimited are included in the non-federal match for the project.

The United States Forest Service will produce a brochure that describes the Rock Creek project. The brochure will be for public dissemination and will highlight the improvements realized by the project. Approximately 1000 brochures will be printed. Funds expended by the U.S. Forest Service are not eligible for matching funds on this project.

All final draft educational materials produced by this project will be submitted to the Division of Water for review and approval before production and distribution.

Budget Synopsis

The total budget for the Rock Creek Clean Water Action Plan Project is $406,371. Funds from non-federal matching sources amount to $206,371. This equates to a 49/51 cost share between federal and non-federal matching funds for the project.

Contractual expenses account for $244,539 of the budget. This includes project construction at $241,289, Trout Unlimited video editing at $3,000, and $250 for Kentucky Department of Fish and Wildlife Resources for airtime on public television. Of the $241,289 for construction, $200,000 comes from the Clean Water Action Plan funding and the remaining $41,289 will come from Appalachian Clean Streams Initiative (ACSI) funds. ASCI money is AML money made available through a grant from OSM to Kentucky AML. This money is allowed to be used as a non-federal match.

Personnel costs for the project total $113,896. Of this total $82,326 is budgeted for AML in-kind service costs. $31,170 is budgeted for Trout Unlimited in-kind services, and $400 is budgeted for Kentucky Department of Fish and Wildlife (KDFWR) in-kind personnel costs.

Supplies for public education on this project will total $1,250. Trout Unlimited will expend $1,100 on video materials and photo development. KDFWR will spend $50 on videotapes and batteries, and $100 on supplies for biological monitoring. All costs for supplies will be incurred by the participating partners.

KDFWR will expend $1,200 on equipment for the project. This includes camera use and equipment used for biological monitoring.

The total travel costs budgeted for the project is $15,881. The AML in-kind portion is $12,456. Trout Unlimited will incur $3,000 in travel costs and KDFWR will incur $425 in travel costs. All travel costs will be provided in-kind by the respective participating partners.

The operating budget for the Rock Creek project will be $29,606. Kentucky AML will incur $26,756 in operating costs, the Kentucky Finance Cabinet will incur $750 in costs for advertising and award of the contract, Trout Unlimited will incur $2,000 in operating costs and KDFWR will incur $100 in operating costs. All operating costs will be provided in-kind by the respective partners.

A complete breakdown of the cost share component of this project is provided in the Clean Water Action Plan Project work plan submitted February, 1999.

Maintenance Agreement

The Division of Abandoned Mine Lands continues to monitor all project sites annually for a period of 5 years after the final inspection of the project. All project sites are inspected annually by AML's staff agronomist or his representative. In addition AML responds to any complaints received for maintenance on its project sites. Any maintenance required will be performed under a separate maintenance contract. The Division of Abandoned Mine Lands as part of its annual grants from the Office of Surface Mining budgets a portion of the annual grant for maintenance of reclamation projects completed by AML. Funds for any maintenance work required will be made available through AML's annual grant from OSM. This is standard operating procedure for all AML projects. After the 5 year monitoring period by AML maintenance of the project sites will be performed by mutual agreement with the landowner (United States Forest Service).

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APPENDIX D. FIELD DATA

Site 9 - Rock Creek above Roberts Hollow
Station number: 3410569 Latitude: 36.70967 Longitude: -84.58417 Drainage area: 56.40 sq mi.

Field parameters

Sampling date	Discharge cfs	Temperature degrees C	pH	Sp. Cond. uS/cm
1999 - April 27	46.20	15.7	7.0	100
1999 - May 25	25.90	18.0	7.0	121
1999 - June 22	8.60	20.8	7.0	167
1999 - July 20	17.50	23.7	7.0	143
1999 - August 30	6.57	21.9	6.9	127
1999 - September 15	3.29	19.3	6.8	201
1999 - October 26	4.38	11.4	6.5	188
1999 - December 1	7.32	6.5	6.1	146
2000 - January 4	56.50	10.0	6.1	176
2000 - February 7	31.60	2.6	5.1	93
2000 - March 6	36.50	8.5	7.2	97
2000 - April 3	55.60	13.0	7.3	96
2000 - May 9	61.90	17.8	7.3	84
2000 - June 5	25.40	19.1	7.5	106
2000 - July 10	7.33	23.2	7.4	160
2000 - August 8	15.10	22.6	7.2	155
2000 - September 5	4.45	22.4	7.2	192
2000 - September 26	36.90	18.0	7.2	164
2000 - October 23	4.57	15.2	7.0	194
2000 - November 6	6.34	13.1	7.2	193
2000 - December 11	18.30	5.5	6.5	140
2001 - January 16	21.80	3.6	6.6	95
2001 - February 12	73.90	5.0	6.1	78
2001 - March 19	82.90	6.7	6.0	78
2001 - April 24	36.00	16.9	6.8	109
2001 - May 29	19.30	17.0	6.9	162
2001 - June 26	12.10	19.9	7.3	155
2001 - August 7	14.60	23.3	6.8	161
2001 - September 5	13.00	21.9	7.7	181
2001 - September 25	18.10	17.3	7.6	181
2001 - October 23	8.15	13.0		170
2001 - November 28	24.80	11.6	7.1	110
2001 - December 18	130.00	11.0	7.0	76
2002 - January 30	126.00	10.1	7.1	74
2002 - February 25	46.10	6.0	6.5	97

Site 10 - Unnamed tributary at culvert below Roberts Hollow
Station number: 3410571 Latitude 36.71045 Longitude: -84.58243 Drainage area: 0.11 sq. mi

Field parameters

Sampling date	Discharge cfs	Temperature degrees C	pH	Sp. Cond. uS/cm
1999 - April 27	0.13	14.9	3.8	600
1999 - May 25	0.01	14.7	3.5	908
1999 - June 22	0.00			
1999 - July 20	0.04	22.4	3.3	998
1999 - August 30	0.00			
1999 - September 15	0.00			
1999 - October 26	0.00			
1999 - December 1	0.00			
2000 - January 4	0.02	10.0	3.2	1500
2000 - February 7	0.03	3.6	2.7	786
2000 - March 6	0.05	8.4	3.4	741
2000 - April 3	0.07	13.1	3.1	856
2000 - May 9	0.02	15.5	3.3	728
2000 - June 5	0.00 est	16.6	3.0	1270
2000 - July 10	0.00			
2000 - August 8	0.01	21.2	2.9	1790
2000 - September 5	0.00			
2000 - September 26	0.00			
2000 - October 23	0.00			
2000 - November 6	0.00			
2000 - December 11	0.00			
2001 - January 16	0.01	3	4.9	1010
2001 - February 12	0.07	6.5	3.6	834
2001 - March 19	0.06	7.8	3.6	632
2001 - April 24	0.07	13.9	7.1	943
2001 - May 29	0.02	15.1	6.8	793
2001 - June 26	0.01	17.4	6.9	1390
2001 - August 7	0.04	20.9	6.5	697
2001 - September 5	0.00 est	20.8	7.9	1280
2001 - September 25	0.01	13.6	7.9	1410
2001 - October 23	0.00			
2001 - November 28	0.03	12.5	7.5	1040
2001 - December 18	0.10	11	6.8	457
2002 - January 30	0.26	11.5	4.9	640
2002 - February 25	0.11	6.5	5.8	610

Site 11 - Roberts Hollow at mouth at Paint Cliff
Station number. 3410570 Latitude. 36 71026 Longitude: -84.58376 Drainage area. 0.64 sq mi

Field parameters

Sampling date	Discharge cfs	Temperature degrees C	pH	Sp. Cond. uS/cm
1999 - April 27	0.56	14.7	3.4	672
1999 - May 25	0.14	15.3	3.2	1055
1999 - June 22	0.02	18.8	3.0	1720
1999 - July 20	0.47	22.2	3.3	735
1999 - August 30	0.01	18 7	3 1	1903
1999 - September 15	0.00			
1999 - October 26	0.02 est			
1999 - December 1	0.01	3.9	2.8	1805
2000 - January 4	1.57	10.0	3 1	896
2000 - February 7	0.04	4.3	2.7	814
2000 - March 6	0.40	9 4	3.3	771
2000 - April 3	0.37	13.2	3.2	768
2000 - May 9	0.27	16.3	3.1	715
2000 - June 5	0.03	16.2	3.1	1210
2000 - July 10	0.01	19.6	3.1	1560
2000 - August 8	0.14	20 8	3.1	1100
2000 - September 5	0.02	19.7	3.1	2000
2000 - September 26	0.03	14.4	3.2	1490
2000 - October 23	0.00 est	14.5	3.1	2430
2000 - November 6	0.00 est	8.5	3.2	2360
2000 - December 11	0.03	7.0	3 6	1750
2001 - January 16	0.04	3.5	3.8	1190
2001 - February 12	0.52	6.3	4.9	616
2001 - March 19	0.82	8 3	3.7	512
2001 - April 24	0.42	13.5	3.6	652
2001 - May 29	0.43	15.5	4.9	534
2001 - June 26	0.07	18.1	5.7	1110
2001 - August 7	0.43	21.4	3 5	720
2001 - September 5	0.05	20.4	4.4	1130
2001 - September 25	0.09	12.8	4.0	1150
2001 - October 23	0.04	11.6		1380
2001 - November 28	0.14	12.8	3.6	904
2001 - December 18	1.20	10.9	3.8	420
2002 - January 30	0.80	11.9	3.5	613
2002 - February 25	0.36	7.7	3.5	633

Site 12 - Rock Creek below Poplar Spring Hollow at Paint Cliff
Station number: 3410580 Latitude: 36 70309 Longitude: -84.56370 Drainage area: 58.53 sq. mi.

Field parameters

Sampling date	Discharge cfs	Temperature degrees C	pH	Sp. Cond. uS/cm
1999 - April 27	43.50	15.8	6.9	119
1999 - May 25	40.50	20.2	7.3	138
1999 - June 22	9.25	22.3	6 9	193
1999 - July 20	15.90	24 5	6.7	184
1999 - August 30	7.41	23.7	6.8	149
1999 - September 15	3.31	18.5	7.0	242
1999 - October 26	4.22	11.2	5.8	238
1999 - December 1	6.56	4.7	6.0	192
2000 - January 4	59.70	9.5	6.0	211
2000 - February 7	28.30	2.4	5 5	123
2000 - March 6	39.00	8.5	7.0	118
2000 - April 3	44.40	13.1	7.1	117
2000 - May 9	58.20	18.0	7.2	94
2000 - June 5	23.80	19.1	7.4	122
2000 - July 10	5.97	23.5	7.6	195
2000 - August 8	13.90	22.4	7.4	181
2000 - September 5	4.24	22.3	7.4	234
2000 - September 26	18.20	17.7	7.5	218
2000 - October 23	4.63	15.2	6.9	229
2000 - November 6	5.42	11.0	7.2	232
2000 - December 11	14.40	5.4	6.7	187
2001 - January 16	17.20	2.8	7.0	125
2001 - February 12	67.80	5.0	6.8	94
2001 - March 19	92.60	7.0	7.3	93
2001 - April 24	34.20	16 7	7.1	132
2001 - May 29	17.50	16.7	7.2	215
2001 - June 26	8.59	19.6	7.3	198
2001 - August 7	16.20	23.0	7.3	208
2001 - September 5	8.79	21.9	7.8	233
2001 - September 25	11.40	16.7	7.7	233
2001 - October 23		12.7		217
2001 - November 28	21.90	11.4	7.2	134
2001 - December 18	112.00	11.1	7.3	93
2002 - January 30	107.00	10.0	7.1	93
2002 - February 25	45.70	6.5	7.3	

Site 14 - Rock Creek below Grassy Fork at Yamacraw
Station number 3410597 Latitude. 36.71508 Longitude: -84.54687 Drainage area: 62.64 sq mi.

Field parameters

Sampling date	Discharge cfs	Temperature degrees C	pH	Sp. Cond. uS/cm
1999 - April 27	52.30	16.5	6.9	125
1999 - May 25	27.40	19.3	7.3	140
1999 - June 22	7.25	22.1	6.9	194
1999 - July 20	21.20	23.8	6.7	175
1999 - August 30	8.87	21.1	6.4	145
1999 - September 15	2.80	16.5	6.4	254
1999 - October 26	2.98	8.0	6.5	240
1999 - December 1	7.44	3.1	6.0	194
2000 - January 4	23.90	9.5	5.9	154
2000 - February 7	31.70	0.5	6.0	
2000 - March 6	34.80	17.4	6.6	123
2000 - April 3	52.60	12.7	6.7	124
2000 - May 9	70.20	17.6	6.4	98
2000 - June 5	21.90	18.8	6.9	125
2000 - July 10	8.32	23.8	7.1	205
2000 - August 8	21.10	22.5	6.8	186
2000 - September 5	4.58	22.5	7.1	242
2000 - September 26	23.90	17.3	7.2	240
2000 - October 23	6.45	15.4	6.6	236
2000 - November 6	3.84	10.3	6.9	241
2000 - December 11	24.90	5.5	6.6	203
2001 - January 16	19.50	2.4	6.4	131
2001 - February 12	72.20	5.0	6.1	101
2001 - March 19	88.90	6.6	7.4	108
2001 - April 24	46.40	16.3	6.7	130
2001 - May 29	18.40	16.6	6.3	211
2001 - June 26	11.40	19.6	6.5	196
2001 - August 7	21.80	22.7	6.6	193
2001 - September 5	8.85	22.0	7.8	251
2001 - September 25	15.10	16.2	7.5	240
2001 - October 23	6.09	12.4		221
2001 - November 28	33.20	11.3	7.0	133
2001 - December 18	112.00	11.0	7.2	118
2002 - January 30	106.00	10.0	7.0	98
2002 - February 25	43.40	5.5	7.2	126

Site 18 - Water Tank Hollow at culvert above mouth at Yamacraw
Station number 3410594 Latitude 36 71212 Longitude: -84 55127 Drainage area 1.05 sq. mi

Field parameters

Sampling date	Discharge cfs	Temperature degrees C	pH	Sp. Cond. uS/cm
1999 - April 27	0.73	13.5	6 6	50
1999 - May 25	0.10	14.8	6.6	61
1999 - June 22	0.01 est	17.1	6.4	96
1999 - July 20	0.39	20.8	6.3	58
1999 - August 30	0.00			
1999 - September 15	0.00			
1999 - October 26	0.00			
1999 - December 1	0.01	8.1	5.9	84
2000 - January 4	1.05	8.6	5 9	65
2000 - February 7	0.66	2.0	5.5	56
2000 - March 6	0.65	6.8	6.5	50
2000 - April 3	0.92	11.4	6 7	50
2000 - May 9	0.95	15.4	6.3	52
2000 - June 5	0.05	15.9	6.4	68
2000 - July 10	0.01	18.6	6.4	83
2000 - August 8	0.10	19.6	6.5	72
2000 - September 5	0.01 est	19.5	6.2	105
2000 - September 26	0.07	16.1	6.9	82
2000 - October 23	0.00			
2000 - November 6	0.00			
2000 - December 11	0.01	7.6	7.0	68

Site 19 - Water Tank Hollow at mouth at Yamacraw
Station number: 3410595 Latitude: 36.71184 Longitude: -84.55034 Drainage area: 0.92 sq. mi.

Field parameters

Sampling date	Discharge cfs	Temperature degrees C	pH	Sp. Cond. uS/cm
1999 - April 27	0.73	13.6	6.8	51
1999 - May 25	0.10	15.0	6.3	62
1999 - June 22	0.01 est	22.4	6.1	102
1999 - July 20	0.39	20.9	5.8	64
1999 - August 30	0.00			
1999 - September 15	0.00			
1999 - October 26	0.00			
1999 - December 1	0.01	5.2	6.0	97
2000 - January 4	1.05	8.6	5.5	66
2000 - February 7	0.66	2.0	4.6	64
2000 - March 6	0.65	6.8	5.1	86
2000 - April 3	0.92	11.4	5.5	58
2000 - May 9	0.59	15.4	5 6	58
2000 - June 5	0.05	15.9	5.5	79
2000 - July 10	0.01	19.0	4.7	129
2000 - August 8	0.10	19.6	4.7	153
2000 - September 5	0.01 est	20.5	3.5	220
2000 - September 26	0.07	15.9	6.5	87
2000 - October 23	0.00			
2000 - November 6	0.00			
2000 - December 11	0.01	7.6	7.0	70
2001 - January 16	0.16	2.1	6.3	50
2001 - February 12	0.66	4.6	6.2	58
2001 - March 19	1.66	5.7	7.1	48
2001 - April 24	0.70	13.3	5.9	52
2001 - May 29	0.49	14.3	5.8	53
2001 - June 26	0.11	16.4	6.0	66
2001 - August 7	0.90	19.9	5.6	53
2001 - September 5	0.15	19.5	6.8	72
2001 - September 25	0.15	15.0	7.0	70
2001 - October 23	0.08	12.5		71
2001 - November 28	0.19	10.9	6.9	56
2001 - December 18	1.87	10.6	7.0	46
2002 - January 30	1.62	10.2	6.4	44
2002 - February 25	0.87	5.4	7.1	29

APPENDIX E. LABORATORY DATA

Site 9 - Rock Creek above Roberts Hollow
Station number: 3410569 Drainage area: 56.40 sq. mi.

Laboratory results

Sampling date	Discharge cfs	pH	Conductivity uS 25C	Alkalinity mg/l CaCO3	Acidity mg/l CaCO3	TDS mg/l	Calcium, total, mg/l	Zinc, total mg/l
1999 - April 27	46.20	7.20	98	40.00		65	3.12	
1999 - May 25	25.90	7.40	119	63.30		66	4.05	
1999 - June 22	8.60	7.60	165	84.00		110	7.43	
1999 - July 20	17.50	7.50	143	83.30	<0.1	95	9.39	
1999 - August 30	6.57	7.50	131	77.40	<0.1	87	6.65	
1999 - September 15	3.29	7.70	210	113.00	<0.1	137	10.52	
1999 - October 26	4.38	7.40	188	42.00	<0.1	125	7.21	
1999 - December 1	7.32	6.74	152	49.50	62.3	183.5	13	0.07
2000 - January 4	56.50	5.94	132	41.25	7.9	10	10.7	0.01
2000 - February 7	31.60	6.29	90	37.50	52.8	16	6.3	0.088
2000 - March 6	36.50	6.64	95	34.50	74.6	114.15	6.9	<0.01
2000 - April 3	55.60	7.69	97	25.50	76.0	56	7.3	0.023
2000 - May 9	61.90	6.57	60	34.25	37.2	95.5	4	<0.020
2000 - June 5	25.40	6.58	59	28.50	37.1	60	8.1	0.085
2000 - July 10	7.33	6.58	119	46.00	21.0	71	17.2	<0.020
2000 - August 8	15.10	7.33	152	44.00	5.2	3	16.7	<0.020
2000 - September 5	4.45	6.55	33	58.08	4.9	133	18.4	<0.020
2000 - September 26	36.90	7.07	34	59.20	5.2	3	17.18	<0.020
2000 - October 23	4.57	6.62	151	69.50	7.0	94	17.7	<0.020
2000 - November 6	6.34	5.98	136	61.30	61.5	151	18	<0.020
2000 - December 11	18.30	6.07	106	41.90	36.7	102.5	14.1	<0.020
2001 - January 16	21.80	6.98	88	32.60	12.9	34.5	9.2	<0.020
2001 - February 12	73.99	7.11	70	22.00	16.8	92	6.9	<0.020
2001 - March 19	82.90	6.77	58	16.40	10.0	72.5	4.56	<0.020
2001 - April 24	36.00	6.98	74	26.67	13.8	61	8.58	<0.020
2001 - May 29	19.30	7.15	144	41.39	20.0	105.5	16.3	<0.020
2001 - June 26	12.10	7.09	150	42.98	40.5	113	19.3	<0.020
2001 - August 7	14.60	7.32	155	48.50	44.9	11.5	18.54	<0.020
2001 - September 5	13.00	7.09	160	57.13	52.4	121.5	16.72	<0.020
2001 - September 25	18.10	6.90	160	45.60	49.6	69	15.4	<0.020
2001- October 23	8.15	7.90	185	62.00	<8	122	19.4	<0.003
2001- November 28	24.80	7.29	115	34.00	<8	76	11.34	<0.003
2001- December 18	130.00	7.23	79	26.00		62	7.96	<0.003
2002- January 30	126.00	7.02	62	21.00	<8	56	6.1	<0.003
2002- February 25	46.10	6.88	44	27.00	<8	30	9.05	<0.003

Site 9 - Rock Creek above Roberts Hollow
Station number: 3410569

Drainage area: 56.40 sq. mi.

Laboratory results

Sampling date	Aluminum, total, mg/l	Aluminum, dis., mg/l	Iron, total mg/l	Iron, dis. mg/l	Manganese total, mg/l	Manganese, dis., mg/l	Sulfate, dis. mg/l
1999 - April 27			0.27	0.08	<0.01	<0.01	2
1999 - May 25	2.01	1.8	0.29	0.08	0.06	<0.01	12.5
1999 - June 22	1.1	0.8	<0.01	<0.01	<0.01	<0.01	10
1999 - July 20	0.5	0.5	1.75	1.75	0.05	0.05	12.5
1999 - August 30	0.6	0.6	1.56	1.56	<0.01	<0.01	65
1999 - September 15	0.4	0.4	0.11	0.11	0.05	0.05	5
1999 - October 26	<0.01	<0.01	0.15	0.15	<0.01	<0.01	15
1999 - December 1	0.57	0.52	0.23	0.1	0.11	0.11	21
2000 - January 4	0.59	0.54	0.182	0.167	0.214	0.182	36.8
2000 - February 7	0.75	0.69	0.168	0.118	0.084	0.078	17.5
2000 - March 6	0.8	0.8	0.226	0.221	0.076	0.073	21.9
2000 - April 3	2.7	0.9	0.34	0.31	0.116	0.077	23.5
2000 - May 9	0.5	0.5	0.212	0.196	0.055	0.029	20.17
2000 - June 5	2.11	1.83	0.062	0.061	0.065	0.062	11.11
2000 - July 10	0.23	<0.10	0.023	0.014	<0.10	<0.10	23.3
2000 - August 8	0.76	<0.1	0.356	0.227	<0.050	<0.050	1.02
2000 - September 5	1.46	1.25	0.097	0.059	<0.050	<0.050	16.5
2000 - September 26	0.33	0.17	0.14	0.09	0.084	<0.050	19.6
2000 - October 23	0.1	<0.01	0.14	0.13	<0.050	<0.050	25.7
2000 - November 6	<0.1	<0.1	0.019	0.018	<0.050	<0.050	38.27
2000 - December 11	<0.1	<0.1	0.112	0.08	<0.050	<0.050	2.5
2001 - January 16	<0.1	<0.1	0.069	0.066	<0.050	<0.050	13.6
2001 - February 12	0.18	0.15	0.086	0.065	<0.050	<0.050	11.31
2001 - March 19	0.16	<0.1	0.309	0.257	<0.050	<0.050	12.55
2001 - April 24	0.18	0.12	0.143	0.123	<0.050	<0.050	9.26
2001 - May 29	0.52	0.52	0.166	0.095	<0.050	<0.050	17.08
2001 - June 26	0.23	0.19	0.195	0.134	<0.050	<0.050	17.5
2001 - August 7	<0.10	<0.10	0.232	0.137	<0.050	<0.050	11.1
2001 - September 5	<0.10	<0.10	0.232	0.078	<0.050	<0.050	13.4
2001 - September 25	<0.01	<0.10	0.236	0.129	<0.050	<0.050	26.55
2001- October 23	<0.087	<0.087	0.73	0.19	0.014	0.013	26.7
2001- November 28	0.26	<0.087	0.43	0.17	0.02	<0.001	18.6
2001- December 18	0.26	<0.087	0.34	0.13	0.03	<0.001	12
2002- January 30	0.43	0.15	0.34	0.07	0.036	0.019	13.6
2002- February 25	<0.087	<0.087	0.33	0.11	0.04	0.04	19.5

Site 10 - Unnamed tributary at culvert below Roberts Hollow
Station number: 3410571 Drainage area: 0.11 sq. mi.

Laboratory results

Sampling date	Discharge cfs	pH	Conductivity uS 25C	Alkalinity mg/l CaCO3	Acidity mg/l CaCO3	TDS mg/l	Calcium, total, mg/l	Zinc, total mg/l
1999 - April 27	0.13	3.50	548	<0.01		366	8.49	
1999 - May 25	0.01	3.40	828	<0.01		562	12.43	
1999 - June 22	0.00							
1999 - July 20	0.04	3.20	986	<0.1	126.6	656	18.63	
1999 - August 30	0.00							
1999 - September 15	0.00							
1999 - October 26	0.00							
1999 - December 1	0.00							
2000 - January 4	0.02	2.94	835	<0.5	413.8	825	57	0.015
2000 - February 7	0.03	3.13	840	<0.5	65.2	529	33.6	0.139
2000 - March 6	0.05	3.31	700	<0.5	53.6	815.5	36.3	0.049
2000 - April 3	0.07	3.02	704	<0.5	91.7	720	27.1	0.088
2000 - May 9	0.02	3.22	430	<0.5	290.3	545	32.8	0.022
2000 - June 5	0.00	3.36	604	<0.5	312.5	523.25	53.4	0.088
2000 - July 10	0.00							
2000 - August 8	0.01	2.81	1520	<0.5	340.2	1475.5	80.6	0.198
2000 - September 5	0.00							
2000 - September 26	0.00							
2000 - October 23	0.00							
2000 - November 6	0.00							
2000 - December 11	0.00							
2001 - January 16	0.01	4.44	760	<0.5	98.3	42	113.2	0.042
2001 - February 12	0.07	3.46	572	<0.5	86.2	535.5	89.3	0.059
2001 - March 19	0.06	3.66	335	<0.5	70.6	660.5	47.2	0.03
2001 - April 24	0.07	7.12	627	99.3	105.4	670.5	171.6	0.045
2001 - May 29	0.02	7.11	759	59.7	29.4	609	52.8	<0.020
2001 - June 26	0.01	7.17	1353	90.35	62.7	1186	209.6	<0.020
2001 - August 7	0.04	7.08	690	44.5	42.6	475	93.8	<0.020
2001 - September 5	0.00	7.35	1100	108.45	113.9	1158.5	200	<0.020
2001 - September 25	0.01	7.28	1300	124.11	140.0	1317	188.4	<0.020
2001- November 28	0.03	7.78	1059	94	<8	86	155	<0.003
2001- December 18	0.10	6.81	466	17	17.0	330	58.8	0.02
2002- January 30	0.26	4.71	568	6	122.0	474	74.1	0.02
2002- February 25	0.11	5.81	621	8	<8	410	64.9	0.03

Site 10 - Unnamed tributary at culvert below Roberts Hollow
Station number: 3410571 Drainage area: 0.11 sq. mi.

Laboratory results

Sampling date	Aluminum, total, mg/l	Aluminum, dis., mg/l	Iron, total mg/l	Iron, dis. mg/l	Manganese total, mg/l	Manganese, dis., mg/l	Sulfate, dis. mg/l
1999 - April 27			3.14	0.45	2.05	2	200
1999 - May 25	10.21	8.63	2.42	0.41	4.1	3.85	412.5
1999 - June 22							
1999 - July 20	8.5	8.3	6.06	6.06	3.94	3.94	487.5
1999 - August 30							
1999 - September 15							
1999 - October 26							
1999 - December 1							
2000 - January 4	62.78	58.95	28.2	17.6	7.73	7.56	707.5
2000 - February 7	14.25	14.03	37.65	32.83	3.894	3.655	356
2000 - March 6	12.9	12.7	6.74	6.18	2.831	2.807	317.9
2000 - April 3	9.7	9.4	10.6	10.1	4.48	4.48	342.2
2000 - May 9	6.9	6.4	7.3	1.9	2.48	2.51	276.8
2000 - June 5	16	15.8	15.02	14.95	0.039	0.031	612.05
2000 - July 10							
2000 - August 8	28.01	28	40.1	29.9	6.95	7.04	890.7
2000 - September 5							
2000 - September 26							
2000 - October 23							
2000 - November 6							
2000 - December 11							
2001 - January 16	11.4	10.94	1.98	0.322	7.69	7.65	553.8
2001 - February 12	9.04	8.93	3.9	0.277	5.24	5.18	399.04
2001 - March 19	7.73	7.49	8.76	5.14	3.27	3.07	284
2001 - April 24	3.47	2.25	3.31	1.2	1.997	1.582	391.02
2001 - May 29	0.91	0.85	2.997	2.103	2.239	2.19	358.09
2001 - June 26	0.64	<0.1	1.509	0.286	2.52	2.09	712.1
2001 - August 7	1.15	0.29	3.493	0.55	2.52	1.512	308.5
2001 - September 5	2.75	1.41	2.75	0.757	1.961	1.627	605.5
2001 - September 25	<0.10	<0.10	0.821	0.11	1.995	1.571	762.28
2001- November 28	<0.087	<0.087	0.55	<0.014	2.01	1.67	473
2001- December 18	1.09	<0.087	2.49	<0.014	1.32	1.38	196
2002- January 30	7.19	5.98	15.55	5.84	1.33	1.43	328
2002- February 25	2.55	<0.087	5.38	1.8	1.53	1.74	309

Site 11 - Roberts Hollow at mouth at Paint Cliff
Station number: 3410570 Drainage area: 0.64 sq. mi.

Laboratory results

Sampling date	Discharge cfs	pH	Conductivity uS 25C	Alkalinity mg/l CaCO3	Acidity mg/l CaCO3	TDS mg/l	Calcium, total, mg/l	Zinc, total mg/l
1999 - April 27	0.56	3.30	718	<0.01		478	7.03	
1999 - May 25	0.14	3.10	1117	<0.01		563	10.7	
1999 - June 22	0.02	2.40	1684	<0.01		1119	22.54	
1999 - July 20	0.47	3.20	754	<0.1	113.3	502	12.34	
1999 - August 30	0.01	2.90	2280	<0.1	397.2	1507	34.26	
1999 - September 15	0.00							
1999 - October 26	0.02	2.80	2250	<0.1	338.0	1510	27.22	
1999 - December 1	0.01	3.61	1252	<0.5	279.9	1988	116.4	0.19
2000 - January 4	1.57	3.11	542	<0.5	167.5	549	33.4	0.057
2000 - February 7	0.04	3.09	800	<0.5	110.2	3499	29.1	0.136
2000 - March 6	0.40	3.24	800	<0.5	55.9	559.5	27	0.069
2000 - April 3	0.37	2.99	811	<0.5	81.5	409	20.6	0.102
2000 - May 9	0.27	2.87	600	<0.5	417.0	556	29.6	0.053
2000 - June 5	0.03	3.36	573	<0.5	389.5	552	57.1	0.093
2000 - July 10	0.01	2.81	1116	<0.5	464.0	1210.5	96.1	0.117
2000 - August 8	0.14	3.11	989	<0.5	202.4	881.5	50.2	0.13
2000 - September 5	0.02	2.74	173	<0.5	367.0	1741	159	0.101
2000 - September 26	0.03	3.10	98	<0.5	275.8	881.5	103.9	0.076
2000 - October 23	0.00	2.91	885	<0.5	415.9	2018	191	0.056
2000 - November 6	0.00	3.07	1233	<0.5	212.8	2101.5	236	0.125
2000 - December 11	0.03	3.23	1125	<0.5	288.0	985	132.2	0.13
2001 - January 16	0.04	3.55	875	<0.5	237.4	1169	97.8	0.157
2001 - February 12	0.52	3.82	455	<0.5	51.1	520	89.7	0.057
2001 - March 19	0.82	3.75	282	<0.5	82.6	503	35.4	0.031
2001 - April 24	0.42	3.16	435	<0.5	124.2	394	43.7	0.054
2001 - May 29	0.43	3.81	538	<0.5	69.0	465.5	80.2	<0.020
2001 - June 26	0.07	3.90	1077	<0.5	78.5	1005	151.6	0.061
2001 - August 7	0.43	3.22	775	<0.5	74.3	596.5	77.72	0.046
2001 - September 5	0.05	3.81	950	<0.5	322.1	1046.5	159.12	0.075
2001 - September 25	0.09	3.63	1030	<0.5	131.5	1011	126	0.136
2001- October 23	0.04	4.96	1496	5.00	147.0	1298	190.3	0.104
2001- November 28	0.14	3.65	925	<3	33.0	673	92.7	0.06
2001- December 18	1.20	3.79	435	<3	46.0	256	32.1	0.04
2002- January 30	0.80	3.42	644	<3	240.0	350	39.3	0.04
2002- february 25	0.36	3.47	663	<3	130.0	350	50.1	0 06

Site 11 - Roberts Hollow at mouth at Paint Cliff
Station number: 3410570 Drainage area: 0.64 sq. mi

Laboratory results

Sampling date	Aluminum, total, mg/l	Aluminum, dis., mg/l	Iron, total mg/l	Iron, dis. mg/l	Manganese total, mg/l	Manganese, dis., mg/l	Sulfate, dis. mg/l
1999 - April 27			11.38	1.9	2.1	2.06	225
1999 - May 25	13.03	10.91	19.02	13.71	3.04	2.97	500.5
1999 - June 22	5.5	5.5	32.15	17.57	3.45	3.45	1175
1999 - July 20	6.6	6.3	8.88	8.63	2.22	2.22	325
1999 - August 30	17.5	17.5	86.01	86.01	4.44	4.32	1200
1999 - September 15							
1999 - October 26	25.6	25.6	80.2	80.2	4.72	4.56	1650
1999 - December 1	36.35	31.3	60.8	54.3	2.73	2.71	1159
2000 - January 4	36.7	34.5	16	8.6	2.2	2.14	396.4
2000 - February 7	13.64	13.63	53.82	49.87	5.102	4.227	310.6
2000 - March 6	17.8	16.7	22.5	19.65	2.129	2.117	344
2000 - April 3	9.9	9.3	27	23	3.9	3.76	309.7
2000 - May 9	9.8	9.4	33.5	13.6	2.08	2.09	396.57
2000 - June 5	12.9	12.9	37.65	37.34	3.69	3.64	769.9
2000 - July 10	14.79	14.75	51.3	51.25	3.81	3.77	793.77
2000 - August 8	10.49	10.38	21.49	6.96	3.92	3.85	530.35
2000 - September 5	21.85	21.68	96.7	67.3	4.87	4.86	1148.2
2000 - September 26	17.58	17.53	35.5	11.4	5.58	5.37	790.2
2000 - October 23	26	24	79.4	36.5	4.67	4.53	1390.1
2000 - November 6	24.9	23.7	59.7	22.1	3.87	3.81	1398.2
2000 - December 11	31.8	31.7	36.5	7.7	7.4	7.4	1056.4
2001 - January 16	26.01	25.77	24.1	8.64	7.4	7.36	787.2
2001 - February 12	6.01	5.79	19.69	17.04	3.29	3.23	362.82
2001 - March 19	6.48	6.47	6.84	4.01	2.13	1.91	233.99
2001 - April 24	7.17	6.9	22.25	20.54	2.514	2.477	271.04
2001 - May 29	4.94	4.94	7.64	4.12	2.076	2.052	276.18
2001 - June 26	7.98	2.3	30.9	28.53	3.4	3.4	591.1
2001 - August 7	7.07	6.99	18.45	1.435	3.4	2.54	358.7
2001 - September 5	9.96	9.99	27.33	2.85	3.068	3.065	664.3
2001 - September 25	11.8	11.9	26.4	5.38	3.667	3.655	769.89
2001- October 23	9.38	9.7	48.5	48.6	3.48	3.47	803
2001- November 28	9.48	9.91	18.8	8.74	3.37	3.67	425
2001- December 18	3.94	3.96	7.32	1.32	1.44	1.56	165
2002- January 30	7.03	7.21	20.24	4.85	1.42	1.51	254
2002- february 25	6.44	5.96	18.8	12.13	1.78	1.73	285

Site 12 - Rock Creek below Poplar Spring Hollow at Paint Cliff
Station number: 3410580 Drainage area: 58.53 sq. mi.

Laboratory results

Sampling date	Discharge cfs	pH	Conductivity uS 25C	Alkalinity mg/l CaCO3	Acidity mg/l CaCO3	TDS mg/l	Calcium, total, mg/l	Zinc, total mg/l
1999 - April 27	43.50	7.10	131	36.60		87	3.51	
1999 - May 25	40.50	7.40	158	60.30		100	4.93	
1999 - June 22	9.25	7.50	1649	70.60		1098	8.5	
1999 - July 20	15.90	6.80	187	51.60	<0.1	123	10.6	
1999 - August 30	7.41	7.10	182	43.40	<0.1	121	6.11	
1999 - September 15	3.31	7.60	245	114.10	<0.1	164	11.45	
1999 - October 26	4.22	7.20	247	80.00	<0.1	162	8.24	
1999 - December 1	6.56	5.76	166	34.50	23.6	131.5	17.5	0.09
2000 - January 4	59.70	5.79	153	37.00	10.3	131	12.6	12.6
2000 - February 7	28.30	6.24	110	23.00	57.7	67	6.6	0.102
2000 - March 6	39.00	6.54	115	29.00	64.9	1575	8.4	0.015
2000 - April 3	44.40	6.31	113	28.00	72.0	118	8.5	<0.010
2000 - May 9	58.20	5.90	80	33.25	38.6	109	4.1	<0.020
2000 - June 5	23.80	6.70	65	31.25	27.5	34.75	8.9	0.024
2000 - July 10	5.97	5.93	193	40.00	55.0	157	21.2	<0.020
2000 - August 8	13.90	1.66	1103	<0.5	1542.0	725	19.6	<0.020
2000 - September 5	4.24	6.30	84	59.23	16.1	182.5	21.4	<0.020
2000 - September 26	18.20	6.35	121	59.10	1.4	725	21.26	<0.020
2000 - October 23	4.63	6.27	176	63.60	5.2	165.5	19.7	<0.020
2000 - November 6	5.42	5.71	167	57.30	53.1	199.5	20.9	<0.020
2000 - December 11	14.40	6.02	143	35.00	32.3	173.5	17.4	<0.020
2001 - January 16	17.20	6.20	118	31.20	6.9	134.5	12.3	<0.020
2001 - February 12	67.80	7.20	83	21.69	11.6	67	8.5	<0.020
2001 - March 19	92.60	6.62	63	16.70	10.4	224	6.55	<0.020
2001 - April 24	34.20	6.79	93	24.06	7.0	9	8.92	<0.020
2001 - May 29	17.50	6.65	209	39.40	15.2	32	23.4	<0.020
2001 - June 26	8.59	6.90	195	44.58	37.4	195	25.4	<0.020
2001 - August 7	16.20	7.24	210	46.50	41.7	153.5	24.57	<0.020
2001 - September 5	8.79	6.95	200	40.10	53.0	154.5	22.04	<0.020
2001 - September 25	11.40	6.65	205	49.06	50.8	147.5	19.8	<0.020
2001- October 23	6.84	7.40	234	59.00	<8	138	23.6	<0.003
2001- November 28	21.90	6.87	141	32.00	<8	69	13.2	<0.003
2001- December 18	112.00	5.02	165	6.00	23.0	90	11.8	0.02
2002- January 30	107.00	6.45	81	20.00	<8	58	7.44	<0.003
2002- February 25	45.70	6.33	126	23.00	<8	30	9.95	<0.003

Site 12 - Rock Creek below Poplar Spring Hollow at Paint Cliff
Station number: 3410580 Drainage area: 58.53 sq. mi.

Laboratory results

Sampling date	Aluminum, total, mg/l	Aluminum, dis., mg/l	Iron, total mg/l	Iron, dis. mg/l	Manganese total, mg/l	Manganese, dis., mg/l	Sulfate, dis. mg/l
1999 - April 27			0.84	0.38	0.67	0.65	250
1999 - May 25	2.73	1.81	0.67	0.31	0.1	0.1	25.2
1999 - June 22	<0.01	<0.01	0.78	0.19	0.11	0.11	65
1999 - July 20	0.8	0.8	0.92	0.92	0.25	0.25	25
1999 - August 30	0.3	0.3	1.11	0.99	0.08	0.08	45
1999 - September 15	0.4	0.4	0.45	0.45	0.16	0.16	100
1999 - October 26	4.3	4	2.5	2.5	0.18	0.18	80
1999 - December 1	0.52	0.34	1.41	0.22	0.37	0.36	49
2000 - January 4	0.3	0.25	0.143	0.11	0.307	0.265	41.8
2000 - February 7	1.25	1.16	0.926	0.267	0.219	0.213	53.5
2000 - March 6	1.1	1	0.749	0.722	0.16	0.162	76.5
2000 - April 3	3.8	3	0.89	0.71	0.167	0.156	36.4
2000 - May 9	0.2	0.1	0.414	0.408	0.138	0.093	25.52
2000 - June 5	1.5	1.48	0.174	0.159	0.1	0.098	31.49
2000 - July 10	2.04	1.78	0.366	0.312	0.179	0.174	49.6
2000 - August 8	1.18	0.84	0.74	0.74	0.198	0.178	10.49
2000 - September 5	0.57	0.54	0.539	0.395	0.126	0.12	46.5
2000 - September 26	0.12	<0.1	0.36	0.24	0.116	0.056	31.3
2000 - October 23	0.26	0.23	0.94	0.49	0.123	0.071	29
2000 - November 6	0.45	0.31	0.521	0.263	0.141	0.129	69.14
2000 - December 11	0.07	0.02	1.05	0.64	0.16	0.15	33.1
2001 - January 16	0.26	0.14	0.232	0.147	0.118	0.106	41.8
2001 - February 12	0.15	0.11	0.111	0.098	0.117	0.106	17.9
2001 - March 19	0.25	0.2	0.456	0.316	0.113	0.111	6.99
2001 - April 24	<0.1	<0.1	0.32	0.25	0.104	0.083	32.72
2001 - May 29	0.62	0.45	0.388	0.305	0.16	0.136	49.6
2001 - June 26	0.25	0.26	0.644	0.324	0.114	0.084	16.7
2001 - August 7	0.21	0.15	0.814	0.456	0.114	0.144	42.2
2001 - September 5	0.29	0.25	0.874	0.446	0.113	0.099	35.2
2001 - September 25	<0.10	<0.10	0.715	0.424	0.109	0.094	51.66
2001- October 23	<0.087	<0.087	0.93	0.91	0.102	0.103	54.5
2001- November 28	0.35	<0.087	0.78	0.41	0.094	0.002	31
2001- December 18	2.51	0.7	1.13	0.67	0.62	0.66	57.7
2002- January 30	0.63	0.15	0.76	0.12	0.088	0.077	22.5
2002- February 25	0.13	<0.087	0.64	0.05	0.097	0.097	29.7

Site 14 - Rock Creek below Grassy Fork at Yamacraw
Station number: 3410597 Drainage area: 62.64 sq. mi.

Laboratory results

Sampling date	Discharge cfs	pH	Conductivity uS 25C	Alkalinity mg/l CaCO3	Acidity mg/l CaCO3	TDS mg/l	Calcium, total, mg/l	Zinc, total mg/l
1999 - April 27	52.30	7.10	126	16.60		84	3.56	
1999 - May 25	27.40	7.40	145	50.50		95	5.02	
1999 - June 22	7.25	8.00	354	64.00		236	7.95	
1999 - July 20	21.20	6.30	185	45.00	<0.1	123	11.5	
1999 - August 30	8.87	7.70	439	48.10	<0.1	293	6.26	
1999 - September 15	2.80	7.60	256	81.10	<0.1	172	12.12	
1999 - October 26	2.98	7.20	241	70.00	<0.1	155	8.24	
1999 - December 1	7.44	6.28	172	26.50	70.6	61	17.4	0.07
2000 - January 4	23.90	5.88	127	26.00	20.1	90	8.9	0.015
2000 - February 7	31.70	6.25	100	17.00	63.7	97.3	6.2	0.91
2000 - March 6	34.80	6.49	105	22.50	73.6	101	8.6	0.016
2000 - April 3	52.60	6.27	110	33.50	82.7	21	8	0.042
2000 - May 9	70.20	6.05	70	21.25	<1.0	17	2.9	<0.020
2000 - June 5	21.90	6.58	66	18.50	2.6	44.5	8.6	<0.020
2000 - July 10	8.32	5.68	160	37.00	25.0	92	20.8	<0.020
2000 - August 8	21.10	6.49	163	28.00	4.2	150.5	17.8	<0.020
2000 - September 5	4.58	6.44	632	55.54	11.3	155.5	21.7	<0.020
2000 - September 26	23.90	6.41	61	54.60	7.1	150.5	24.37	<0.020
2000 - October 23	6.45	6.65	180	61.30	12.8	175	19.9	<0.020
2000 - November 6	3.84	6.06	168	53.30	50.0	159.5	21.8	<0.020
2000 - December 11	24.90	6.25	149	35.40	31.5	534.5	18.9	<0.020
2001 - January 16	19.50	6.57	115	27.10	13.7	92	12.4	<0.020
2001 - February 12	72.20	7.07	83	17.19	11.1	62	8.5	<0.020
2001 - March 19	88.90	6.52	98	16.70	12.2	351.5	6.14	<0.020
2001 - April 24	46.40	6.63	91	22.69	6.1	64	8.48	<0.020
2001 - May 29	18.40	6.67		36.15	19.4	82.5	22.1	<0.020
2001 - June 26	11.40	7.09	185	39.40	34.6	147	25.4	<0.020
2001 - August 7	21.80	7.14	190	40.90	37.2	173	22.56	<0.020
2001 - September 5	8.85	7.21	205	50.99	51.7	169.5	28.12	<0.020
2001 - September 25	15.10	6.89	205	48.49	49.5	139.5	32.2	<0.020
2001- October 23	6.09	7.81	237	60.00	<8	118	24	<0.003
2001- November 28	33.20	6.99	140	31.00	<8	68	14.4	0.004
2001- December 18	112.00	7.00	97	22.00		62	9.16	<0.003
2002- January 30	106.00	6.34	86	19.00	<8	60	8.12	<0.003
2002- February 25	43.40	6.28	120	25.00	<8	26	9.95	<0.003

Site 14 - Rock Creek below Grassy Fork at Yamacraw
Station number: 3410597 Drainage area: 62.64 sq. mi.

Laboratory results

Sampling date	Aluminum, total, mg/l	Aluminum, dis., mg/l	Iron, total mg/l	Iron, dis. mg/l	Manganese total, mg/l	Manganese, dis., mg/l	Sulfate, dis. mg/l
1999 - April 27			0.83	0.1	0.16	0.11	50
1999 - May 25	3.72	1.61	0.78	0.16	0.11	0.06	12.5
1999 - June 22	2.2	2.2	0.94	<0.01	0.1	0.1	65
1999 - July 20	0.7	0.4	1.51	1.51	0.19	0.19	25
1999 - August 30	0.5	0.2	1.32	1.32	0.05	0.05	13
1999 - September 15	0.8	0.8	1.11	1.11	0.1	0.1	112.5
1999 - October 26	1.3	1.3	1.02	1.02	0.16	0.16	4
1999 - December 1	0.84	0.73	1.05	0.16	0.36	0.31	41
2000 - January 4	0.81	0.78	0.627	0.13	0.182	0.141	42.8
2000 - February 7	0.85	0.83	1.462	0.921	0.24	0.239	49.4
2000 - March 6	2.5	2.2	1.037	1.004	0.147	0.145	68.9
2000 - April 3	3.9	3.2	1.8	1.2	0.171	0.147	40.3
2000 - May 9	0.5	0.2	1.205	0.444	0.093	0.148	30.87
2000 - June 5	1.89	1.94	1.053	1.022	0.087	0.085	27.78
2000 - July 10	0.7	0.54	2.322	2.315	0.167	0.156	54.7
2000 - August 8	1.25	1.17	2.2	1.01	0.137	0.136	11.32
2000 - September 5	0.34	0.32	1.227	0.791	0.094	0.072	41
2000 - September 26	<0.1	<0.1	1.2	0.37	0.192	0.135	56.4
2000 - October 23	0.13	0.13	1.05	0.37	0.068	<0.050	43.6
2000 - November 6	0.39	0.19	0.825	0.259	0.061	0.058	75.11
2000 - December 11	0.28	0.26	1.3	0.82	0.2	0.19	47.1
2001 - January 16	0.79	0.55	1.15	0.489	0.135	0.134	25.1
2001 - February 12	0.1	<0.1	0.22	0.202	0.117	0.11	23.46
2001 - March 19	0.3	0.28	0.63	0.327	0.116	0.109	19.96
2001 - April 24	0.13	<0.1	0.44	0.329	0.102	0.094	14.61
2001 - May 29	0.89	0.89	0.458	0.439	0.1	0.102	53.3
2001 - June 26	0.61	0.21	1.179	0.628	0.101	0.084	26.8
2001 - August 7	<0.10	<0.10	1.059	0.618	0.101	0.113	25.3
2001 - September 5	0.14	<0.10	0.853	0.405	0.078	0.039	51.5
2001 - September 25	0.14	0.11	1.184	0.339	0.099	0.065	51.86
2001- October 23	<0.087	<0.087	0.92	0.98	0.042	0.045	57.8
2001- November 28	0.29	<0.087	0.98	0.52	0.09	0.002	32.1
2001- December 18	0.27	<0.087	0.71	0.35	0.09	0.07	21
2002- January 30	0.65	0.13	0.83	0.05	0.09	0.078	25
2002- February 25	0.12	<0.087	0.72	<0.014	0.1	0.1	30.2

Site 18 - Water Tank Hollow at culvert above mouth at Yamacraw
Station number: 3410594 Drainage area: 1.05 sq. mi.

Laboratory results

Sampling date	Discharge cfs	pH	Conductivity uS 25C	Alkalinity mg/l CaCO3	Acidity mg/l CaCO3	TDS mg/l	Calcium, total, mg/l	Zinc, total mg/l
1999 - April 27	0.73	6.90	61	16.60		41	1.17	
1999 - May 25	0.10	7.00	63	23.30		50	1.3	
1999 - June 22	0.01							
1999 - July 20	0.39	7.00	59	27.60	<0.1	39	2.46	
1999 - August 30	0.00							
1999 - September 15	0.00							
1999 - October 26	0.00							
1999 - December 1	0.01	5.86	83	23.00	36.1	50	5.1	0.08
2000 - January 4	1.05	5.69	46	15.50	14.3	60	2.5	0.015
2000 - February 7	0.66	6.49	60	18.50	44.4	33	2.7	0.068
2000 - March 6	0.65	6.64	60	22.00	61.9	67.5	2.2	0.025
2000 - April 3	0.92	6.15	62	17.00	72.0	39.5	1.7	0.016
2000 - May 9	0.95	5.64	50	17.00	1.3	33.5	<0.1	<0.020
2000 - June 5	0.05	6.30	46	18.50	3.2	53.5	2.8	<0.020
2000 - July 10	0.01	5.35	77	19.00	29.0	285	4.6	0.024
2000 - August 8	0.10	6.64	49	29.00	11.6	37.5	3.92	<0.020
2000 - September 5	0.01	6.85	35	28.82	42.4	208	6.5	<0.020
2000 - September 26	0.07	5.90	63	19.70	19.1	37.5	5.28	<0.020
2000 - October 23	0.00							
2000 - November 6	0.00							
2000 - December 11	0.01	5.68	57	17.90	7.1	58.5	4	<0.020
Sampling Ended								

Sampling date	Aluminum, total, mg/l	Aluminum, dis., mg/l	Iron, total mg/l	Iron, dis. mg/l	Manganese total, mg/l	Manganese, dis., mg/l	Sulfate, dis. mg/l
1999 - April 27			<0.01	<0.01	<0.01	<0.01	12.5
1999 - May 25	4.93	1.04	<0.01	<0.01	0.05	0.04	225.5
1999 - June 22							
1999 - July 20	1	1	0.11	0.11	<0.01	<0.01	12.5
1999 - August 30							
1999 - September 15							
1999 - October 26							
1999 - December 1	0.31	0.28	0.11	0.04	0.1	0.08	19
2000 - January 4	0.26	0.23	0.223	0.085	0.111	0.112	9.5
2000 - February 7	<0.1	<0.10	0.053	0.026	0.101	0.099	5.9
2000 - March 6	0.3	0.2	0.038	0.026	0.076	0.044	53.5
2000 - April 3	2.2	1.9	0.03	0.02	0.35	0.3	29.4
2000 - May 9	0.2	0.1	0.108	0.044	0.028	<0.010	14.4
2000 - June 5	2.82	2.68	0.059	0.058	0.049	0.046	4.73
2000 - July 10	<0.1	<0.1	0.136	0.128	0.177	0.165	18.1
2000 - August 8	0.66	0.16	0.177	0.099	<0.050	<0.050	22.23
2000 - September 5	0.2	0.15	0.208	0.151	0.128	0.064	14.81
2000 - September 26	<0.1	<0.1	0.17	0.11	0.097	<0.050	13.2
2000 - October 23							
2000 - November 6							
2000 - December 11	0.1	<0.1	0.102	0.03	<0.050	<0.050	7.2
Sampling Ended							

Site 19 - Water Tank Hollow at mouth at Yamacraw
Station number: 3410595 Drainage area: 0.92 sq. mi.

Laboratory results

Sampling date	Discharge cfs	pH	Conductivity uS 25C	Alkalinity mg/l CaCO3	Acidity mg/l CaCO3	TDS mg/l	Calcium, total, mg/l	Zinc, total mg/l
1999 - April 27	0.73	6.80	52	16.60		35	1.2	
1999 - May 25	0.10	6.90	64	30.40		43	1.31	
1999 - June 22	0.01							
1999 - July 20	0.39	6.90	62	33.00	<0.1	41	2.58	
1999 - August 30	0.00							
1999 - September 15	0.00							
1999 - October 26	0.00							
1999 - December 1	0.01	5.93	109	14.50	44.9	1	4.9	0.07
2000 - January 4	1.05	5.85	48	16.00	15.3	50	2.3	0.015
2000 - February 7	0.66	6.42	75	18.00	34.1	42	3.2	0.075
2000 - March 6	0.65	6.51	68	12.00	69.9	92.5	2.3	0.03
2000 - April 3	0.92	5.59	68	10.50	62.0	21.5	1.9	<0.010
2000 - May 9	0.59	5.94	40	13.25	77.6	19	<0.1	<0.020
2000 - June 5	0.05	5.42	55	12.75	68.6	48.75	3.2	0.02
2000 - July 10	0.01	3.77	115	<0.5	75.0	62.5	5.7	<0.020
2000 - August 8	0.10	3.94	159	<0.5	23.4	80	4.33	<0.020
2000 - September 5	0.01	3.24	68	<0.5	47.9	300	8.8	<0.020
2000 - September 26	0.07	5.96	67	22.10	12.7	80	5.31	<0.020
2000 - October 23	0.00							
2000 - November 6	0.00							
2000 - December 11	0.01	5.87	54	14.80	4.9	36.5	3.8	<0.020
2001 - January 16	0.16	6.43	54	10.8	2.9	71	2.9	<0.020
2001 - February 12	0.66	7.20	53	5.59	3.3	40.5	2.6	<0.020
2001 - March 19	1.66	6.49	53	7.21	2.9	21.5	2.27	<0.020
2001 - April 24	0.70	6.44	40	7.78	7.3	72	2.39	<0.020
2001 - May 29	0.49	6.40	59	12.74	2.0	65.5	2	<0.020
2001 - June 26	0.11	6.33	90	12.88	9.3	148	5.49	<0.020
2001 - August 7	0.90	6.66	60	10.10	6.1	19	2.01	<0.020
2001 - September 5	0.15	6.38	90	12.07	6.1	66	2.7	<0.020
2001 - September 25	0.15	6.12	65	13.02	28.1	52.5	3.2	<0.020
2001- October 23	0.08	7.09	75	21.00	<8	28	6.47	0.004
2001- November 28	0.19	6.65	60	15.00	<8	62	4.86	<0.003
2001- December 18	1.87	6.78	48	13.00	28.0	100	4.17	<0.003
2002- January 30	1.62	5.98	40	10.00	<8	48	3.15	<0.003
2002- February 25	0.87	5.91	51	12.00	<8	<10	3.16	<0.003

Site 19 - Water Tank Hollow at mouth at Yamacraw
Station number: 3410595 Drainage area. 0.92 sq. mi.

Laboratory results

Sampling date	Aluminum, total, mg/l	Aluminum, dis., mg/l	Iron, total mg/l	Iron, dis. mg/l	Manganese total, mg/l	Manganese, dis., mg/l	Sulfate, dis. mg/l
1999 - April 27			0.1	<0.01	<0.01	<0.01	37.5
1999 - May 25	5.1	0.9	0.15	0.05	0.04	<0.01	12.5
1999 - June 22							
1999 - July 20	0.5	0.5	0.25	0.25	0.07	0.07	3
1999 - August 30							
1999 - September 15							
1999 - October 26							
1999 - December 1	0.57	0.51	0.62	0.17	0.06	0.06	22
2000 - January 4	0.46	0.41	0.342	0.16	0.131	0.104	5.1
2000 - February 7	0.55	0.51	1.651	0.975	0.115	0.113	20.5
2000 - March 6	0.8	0.6	0.597	0.541	0.068	0.066	16.7
2000 - April 3	3.4	3.1	1.7	1.2	0.038	0.032	19
2000 - May 9	0.2	0.1	0.85	0.423	0.055	0.046	16.87
2000 - June 5	1.61	1.57	1.3	1.28	0.074	0.07	19.35
2000 - July 10	0.5	0.5	4.295	4.131	0.177	0.16	55.77
2000 - August 8	1.59	1.37	7.1	5.8	0.136	0.126	28.61
2000 - September 5	0.92	0.52	7.1	6.63	0.206	0.202	94.05
2000 - September 26	<0.1	<0.1	0.24	0.23	0.084	<0.050	18.3
2000 - October 23							
2000 - November 6							
2000 - December 11	<0.1	<0.1	0.06	0.03	<0.05	<0.05	9.3
2001 - January 16	0.12	0.1	0.02	0.016	<0.05	<0.05	11.5
2001 - February 12	<0.1	<0.1	<0.010	<0.010	<0.05	<0.05	12.14
2001 - March 19	<0.1	<0.1	0.076	0.041	<0.05	<0.05	8.44
2001 - April 24	<0.1	<0.1	0.015	<0.010	<0.05	<0.05	16.46
2001 - May 29	0.97	0.62	0.111	0.069	<0.05	<0.05	6.38
2001 - June 26	0.19	<0.1	0.141	0.06	<0.05	<0.05	4.94
2001 - August 7	<0.10	<0.10	0.18	0.191	<0.05	<0.050	4.53
2001 - September 5	0.37	0.21	0.92	0.124	<0.05	<0.050	11.1
2001 - September 25	<0.10	<0.10	0.726	0.677	<0.05	<0.050	16.46
2001- October 23	<0.087	<0.087	0.41	0.41	0.032	0.031	11.5
2001- November 28	<0.087	<0.087	0.15	0.02	0.02	<0.001	8.4
2001- December 18	<0.087	<0.087	0.08	0.02	0.013	0.002	8.1
2002- January 30	0.26	0.13	0.13	0.05	0.023	0.014	9.2
2002- February 25	<0.087	<0.087	0.06	0.02	0.01	0.01	8.2

APPENDIX F. BIOLOGICAL MONITORING FISH DATA

White Oak Creek

WO-01 White Oak upstream control

6-2-99
Phoxinus cumberlandensis – blackside dace – 11
Semotilus atromaculatus – creek chub – 80
Etheostoma obeyense – barcheek darter – 5
96/3

Number species = 3	3
Darter species = 1	3
Sunfish species = 0	1
Sucker species = 0	1
Intolerant species = 2	3
% green sunfish = 0.0%	5
% omnivores = 83.3%	1
% insectivorous cyprinids = 0.0%	1
% top carnivores = 0.0%	1
Total number = 96	3
% hybrids = none noted	5
% abnormal = 0.0%	5
Total IBI	32 - poor

WO-02 White Oak, below Cabin Branch

6-2-99
No Fish
IBI No fish

10-19-99
No Fish
IBI No fish

7-17-00
Semotilus atromaculatus – creek chub – 91
91/1

Number species = 1	1
Darter species = 0	1
Sunfish species = 0	1
Sucker species = 0	1
Intolerant species = 0	1
% green sunfish = 0.0%	5
% omnivores = 100.0%	1
% insectivorous cyprinids = 0.0%	1
% top carnivores = 0.0%	1
Total number = 91	3
% hybrids = none noted	5
% abnormal = none noted	5
Total IBI	26 very poor – poor

7-23-01
Campostoma oligolepis – largescale stoneroller – 3
Semotilus atromaculatus – creek chub – 7
Etheostoma obeyense – barcheek darter – 6
Phoxinus cumberlandensis – blackside dace – 60
76/4

Number species = 4	3
Darter species = 1	1
Sunfish species = 0	1
Sucker species = 0	1
Intolerant species = 2	3
% green sunfish = 0.0%	5
% omnivores = 14.9%	5
% insectivorous cyprinids = 0.0%	1
% top carnivores = 0.0%	1
Total number = 67	3
% hybrids = none noted	5
% abnormal = none noted	5
Total IBI	34 – poor

Rock Creek

RC-00 Control site

8-5-99
Campostoma oligolepis – largescale stoneroller – 9
Notropis telescopus – telescope shiner – 4
Semotilus atromaculatus – creek chub – 17
Hypentelium nigricans – northern hogsucker – 2
Ambloplites rupestris – rock bass – 4
Lepomis cyanellus – green sunfish – 1
Lepomis megalotis – longear sunfish – 16
Micropterus punctulatus – spotted bass – 1
Etheostoma blennioides – greenside darter – 1
Etheostoma obeyense – barcheek darter – 1
56/10

Number species = 10	3
Darter species = 2	3
Sunfish species = 2	3
Sucker species = 1	3
Intolerant species = 6	3
% green sunfish = 1.8%	5
% omnivores = 50.0%	1
% insectivorous cyprinids = 7.1%	1
% top carnivores = 8.9%	5
Total number = 56	3
% hybrids = none noted	5
% abnormal = none noted	5
Total IBI	40 – fair

RC-01 White Oak Junction

6-2-99
Cyprinella spiloptera – spotfin shiner – 3
Notropis atherinoides – emerald shiner – 7
Notropis buchanani – ghost shiner – 3
Notropis rubellus – roseyface shiner – 46
Ambloplites rupestris – rock bass – 1
Lepomis megalotis – longear sunfish – 10
Micropterus punctulatus – spotted bass – 1
Etheostoma caeruleum – rainbow darter – 1
Etheostoma stigmaeum – speckled darter – 3
75/9

Number species = 9	3
Darter species = 2	3
Sunfish species = 1	3
Sucker species = 0	1
Intolerant species = 5	3
% green sunfish = 0.0%	5
% omnivores = 9.3%	5
% insectivorous cyprinids = 65.3%	5
% top carnivores = 2.7%	3
Total number = 75	3
% hybrids = none noted	5
% abnormal = none noted	5
Total IBI	44 – fair

8-5-99
Semotilus atromaculatus – creek chub – 11
Lepomis cyanellus – green sunfish – 1
Lepomis megalotis – longear sunfish – 1
13/3

Number species = 3	1
Darter species = 0	1
Sunfish species = 2	3
Sucker species = 0	1
Intolerant species = 1	1
% green sunfish = 7.7%	3
% omnivores = 84.6%	1
% insectivorous cyprinids =0.0%	1
% top carnivores = 0.0%	1
Total number = 13	1
% hybrids = 0.0%	5
% abnormal = 0.0%	5
Total IBI	24 – very poor

10-19-99

Campostoma oligolepis – largescale stoneroller – 8
Cyprinella galactura – whitetail shiner – 2
Cyprinella spiloptera – spotfin shiner – 21
Luxlius chysocephalus – striped shiner – 2
Notropis atherinoides – emerald shiner – 54
Notropis ludibundus – sand shiner – 5
Hypentelium nigricans – northern hogsucker – 5
Ambloplites rupestris – rock bass – 1
Lepomis cyanellus – green sunfish – 1
Lepomis megalotis – longear sunfish – 7
Micropterus dolomieu – smallmouth bass – 2
Micropterus punctulatus – spotted bass – 2
Etheostoma caeruleum – rainbow darter – 3
Etheostoma camurum – bluebreast darter – 1
Etheostoma stigmaeum – speckled darter – 8
Percina caprodes – logperch – 1

123/16

Number species = 16	5
Darter species = 3	3
Sunfish species = 2	3
Sucker species = 1	3
Intolerant species = 7	3
% green sunfish = 0.8%	5
% omnivores = 52.0%	1
% insectivorous cyprinids = 18.7%	1
% top carnivores = 4.1%	3
Total number = 123	3
% hybrids = none noted	5
% abnormal = none noted	5
Total IBI	40 – fair

7-17-00

Campostoma oligolepis – largescale stoneroller – 1
Notropis rubellus – roseyface shiner – 1
Semotilus atromaculatus – creek chub – 12
Hypentelium nigricans – northern hogsucker – 1
Micropterus dolomieu – smallmouth bass – 2
Micropterus punctulatus – spotted bass – 1

18/6

Number species = 6	1
Darter species = 0	1
Sunfish species = 0	1
Sucker species = 1	3
Intolerant species = 3	3
% green sunfish = 0.0%	5
% omnivores = 77.8%	1
% insectivorous cyprinids = 5.6%	1
% top carnivores = 16.7%	5
Total number = 18	1
% hybrids = none noted	5
% abnormal = none noted	5
Total IBI	32 – poor

7-23-01
Campostoma oligolepis – largescale stoneroller – 3
Notropis telescopus – telescope shiner – 1
Semotilus atromaculatus – creek chub - 7
Ambloplites rupestris – rock bass – 1
Lepomis cyanellus – green sunfish – 1
Lepomis megalotis – longear sunfish - 3
Micropterus dolomieu – smallmouth bass – 2
Micropterus punctulatus – spotted bass – 2
20/8

Number species = 8	3
Darter species = 0	1
Sunfish species = 2	3
Sucker species = 0	1
Intolerant species = 4	3
% green sunfish = 5.0%	3
% omnivores = 50.0%	1
% insectivorous cyprinids = 5.0%	1
% top carnivores = 20.0%	5
Total number = 20	1
% hybrids = none noted	5
% abnormal = none noted	5
Total IBI	32 – poor

RC-02 (Paint Cliff)

6-2-99
No fish
IBI = no fish

8-5-99
Campostoma oligolepis – largescale stoneroller – 3
Notropis telescopus – telescope shiner – 11
Semotilus atromaculatus – creek chub – 1
Etheostoma camurum – bluebreast darter – 5
Etheostoma obeyense – barcheek darter – 8
29/5

Number species = 5	1
Darter species = 2	3
Sunfish species = 0	1
Sucker species = 0	1
Intolerant species = 3	3
% green sunfish = 0.0%	5
% omnivores = 13.8 %	5
% insectivorous cyprinids = 37.9%	3
% top carnivores = 0.0%	1
Total number = 29	1
% hybrids = none noted	5
% abnormal = none noted	5
Total IBI	34 poor

10-19-99
No fish
IBI = no fish

7-17-00

Campostoma oligolepis – largescale stoneroller – 8
Notropis atherinoides – emerald shiner – 2
Notropis telescopus – telescope shiner – 2
Semotilus atromaculatus – creek chub – 2
Hypentelium nigricans – northern hogsucker – 2
Noturus flavus – stonecat – 1
Ambloplites rupestris – rock bass – 2
Lepomis –megalotis – longear sunfish – 4
Micropterus dolomieu – smallmouth bass – 1
Micropterus punctulatus – spotted bass – 2
Etheostoma caeruleum – rainbow darter – 7
Etheostoma camurum – bluebreast darter – 2
Etheostoma obeyense – barcheek darter – 7

42/13

Number species = 13	3
Darter species = 3	3
Sunfish species = 1	3
Sucker species = 1	3
Intolerant species = 9	5
% green sunfish = 0.0%	5
% omnivores = 28.6 %	3
% insectivorous cyprinids = 4.8%	1
% top carnivores = 11.9%	5
Total number = 42	3
% hybrids = none noted	5
% abnormal = none noted	5
Total IBI	44 – fair

7-23-01

Campostoma oligolepis – largescale stoneroller – 7
Notropis telescopus – telescope shiner – 12
Semotilus atromaculatus – creek chub – 18
Hypentelium nigricans – northern hogsucker – 1
Ambloplites rupestris – rock bass – 1
Micropterus punctulatus – spotted bass – 1
Salmo trutta – brown trout – 1
Etheostoma baileyi – emerald darter – 2
Etheostoma obeyense – barcheek darter – 6

49/9

Number species = 9	3
Darter species = 2	3
Sunfish species = 0	1
Sucker species = 1	3
Intolerant species = 7	5
% green sunfish = 0.0%	5
% omnivores = 51.0%	1
% insectivorous cyprinids = 24.5 %	3
% top carnivores = 6.1%	5
Total number = 49	3
% hybrids = none noted	5
% abnormal = none noted	5
Total IBI	42 – fair

Koger Fork Bridge (RC-03)

6-2-99
Campostoma oligolepis – largescale stoneroller – 10
Cyprinella spiloptera - spotfin shiner – 6
Nocomis effusus – redtail chub – 1
Notropis ludibundus – sand shiner – 3
Notropis rubellus - roseyface shiner – 38
Semotilus atromaculatus – creek chub – 3
Hypentelium nigricans - northern hogsucker – 1
Ambloplites rupestris – rock bass – 2
Lepomis megalotis – longear sunfish – 2
Etheostoma caeruleum - rainbow darter – 9
Etheostoma camurum – bluebreast darter – 3
Etheostoma stigmaeum – speckled darter – 3
Percina caprodes – logperch - 1
82/13

Number species = 13	3
Darter species = 3	3
Sunfish species = 1	3
Sucker species = 1	3
Intolerant species = 8	5
% green sunfish = 0.0%	5
% omnivores = 20.7%	3
% insectivorous cyprinids = 53.7%	5
% top carnivores = 2.4%	3
Total number = 82	3
% hybrids = none noted	5
% abnormal = none noted	5
Total IBI	46 – fair-good

8-26-99
Notropis telescopus – telescope shiner – 5
Notropis sp. – sawfin shiner – 2
7/2

Number species = 2	1
Darter species = 0	1
Sunfish species = 0	1
Sucker species = 0	1
Intolerant species = 1	3
% green sunfish = 0.0%	5
% omnivorous cyprinids = 71.4%	5
% top carnivores = 0.0%	1
Total number = 7	1
% hybrids = 0.0%	5
% abnormal =0.0%	5
total IBI	29 – Poor

10-19-99

Campostoma oligolepis – largescale stoneroller – 11
Cyprinella galactura – whitetail shiner – 1
Luxlius chysocephalus – striped shiner – 1
Lythrurus ardens fasciolaris - rosefin shiner – 14
Notropis telescopus – telescope shiner – 35
Notropis volucellus – mimic shiner – 1
Semotilus atromaculatus - creek chub – 4
Noturus flavus – stonecat – 1
Ambloplites rupestris – rock bass – 1
Lepomis megalotis – longear sunfish – 5
Micropterus dolomieu – smallmouth bass – 1
Etheostoma caeruleum – rainbow darter – 5
Etheostoma obeyense – barcheek darter – 7

87/12

Number species = 12	3
Darter species = 2	3
Sunfish species = 1	3
Sucker species = 0	1
Intolerant species = 8	5
% green sunfish = 0	5
% omnivores = 19.5%	5
% insectivorous cyprinids = 57.5%	5
% top carnivores = 2.3%	3
total number = 87	5
% hybrids = none noted	5
% abnormal = none noted	5
Total IBI	48 – good

7-17-00

Campostoma oligolepis – largescale stoneroller – 36
Luxlius chysocephalus – striped shiner – 2
Notropis rubellus – roseyface shiner – 9
Notropis telescopus – telescope shiner – 8
Hypentelium nigricans – northern hogsucker – 1
Labidesthes sicculus – brook silverside – 2
Ambloplites rupestris – rock bass – 2
Lepomis cyanellus – green sunfish – 8
Micropterus punctulatus – spotted bass – 1
Etheostoma blennioides – greenside darter – 3
Etheostoma caeruleum – rainbow darter – 6
Etheostoma camurum – bluebreast darter – 4
Etheostoma stigmaeum – speckled darter – 1

83/13

Number species = 13	3
Darter species = 4	5
Sunfish species = 1	1
Intolerant species = 8	5
% green sunfish = 9.6%	3
% omnivores = 45.8%	1
% insectivorous cyprinids = 20.5 %	3
% top carnivores = 3.6%	3
Total number = 83	3
% hybrids = none noted	5
% abnormal =	5
total IBI	37 – poor – fair

7-23-01
Campostoma oligolepis – largescale stoneroller - 81
Notropis telescopus – telescope shiner – 34
Notropis volucellus – mimic shiner – 1
Semotilus atromaculatus – creek chub - 7
Hypentelium nigricans – northern hogsucker – 2 Ambloplites rupestris – rock bass – 3
Lepomis megalotis – longear sunfish – 1
Micropterus punctulatus – spotted bass – 2
Micropterus dolomieu – smallmouth bass – 2
Etheostoma baileyi – emerald darter – 11
Etheostoma blennioides – greenside darter – 3
Etheostoma caeruleum – rainbow darter – 17
Etheostoma camurum – bluebreast darter – 4
Etheostoma – obeyense – barcheek darter – 3
Percina caprodes – logperch – 2
173/15

Number species =15	5
Darter species = 5	5
Sunfish species = 1	3
Sucker species = 1	3
Intolerant species = 11	5
% green sunfish = 0.0%	5
% omnivores = 50.9%	1
% insectivorous cyprinids = 20.2%	3
% top carnivores = 4.0%	3
Total number = 173	5
% hybrids = none noted	5
% abnormal = none noted	5
Total IBI	48 – good

RC-04 (Grassy Fork)

6-2-99
Cyprinella spiloptera - spotfin shiner – 3
Notropis atherinoides - emerald shiner – 7
Notropis buchanani - ghost shiner – 53
Notropis rubellus – roseyface shiner – 46
Ambloplites rupestris – rock bass – 1
Lepomis cyanellus – green sunfish – 10
Lepomis megalotis – longear sunfish – 2
Micropterus punctulatus – spotted bass – 1
Etheostoma caeruleum – rainbow darter – 1
Etheostoma stigmaeum – speckled darter – 3

Number species = 10	3
Darter species = 2	1
Sunfish species = 2	3
Sucker species = 0	1
Intolerant species = 5	3
% green sunfish = 7.9%	3
% omnivores = 15.0%	5
% insectivorous cyprinids = 38.6%	3
% top carnivores = 1.6%	3
Total number = 127	3
Hybrids = none noted	5
Abnormal = none noted	5
Total IBI	38 – Poor - fair

8-26-99
Campostoma oligolepis – largescale stoneroller – 2
Cyprinella galactura – whitetail shiner – 1
Notropis rubellus – roseyface shiner – 1
Notropis telescopus – telescope shiner – 10
Etheostoma camurum – bluebreast darter – 3
Notropis sp. – sawfin shiner – 1

Number species = 6	1
Darter species = 1	1
Sunfish species = 0	1
Sucker species = 0	1
Intolerant species = 3	3
% green sunfish = 0.0%	5
% omnivores = 11.1%	5
% insectivorous cyprinids = 66.7%	5
% top carnivores = 0%	1
Total number = 18	1
Hybrids = none noted	5
Abnormal = none noted	5
Total IBI	34-Poor

10-19-99
Semotilus atromaculatus – creek chub – 1
Lepomis megalotis x Lepomis autris – longear sunfish x redbreast sunfish hybrid – 1

Number species = 2	1
Darter species = 0	1
Sunfish species = 1 (hybrid)	1
Sucker species = 0	1
Intolerant species = 0	1
% green sunfish = 0	5
% omnivores = 50.0%	1
% insectivorous cyprinids = 0.0%	1
% top carnivores = 0.0%	1
Total number = 2	1
Hybrids = 50.0%	1
Abnormal = none noted	5
Total IBI	22 – Very Poor

7-17-00
Campostoma oligolepis – largescale stoneroller – 3
Cyprinella galactura – whitetail shiner – 1
Cyprinella spiloptera – spotfin shiner – 3
Notropis rubellus - roseyface shiner – 7
Notropis telescopus – telescope shiner – 4
Semotilus atromaculatus – creek chub – 1
Hypentelium nigricans – northern hogsucker – 1
Labidesthes sicculus – brook silverside – 1
Lepomis megalotis – longear sunfish – 16
Micropterus punctulatus – spotted bass – 1
Etheostoma caeruleum – rainbow darter – 1
Etheostoma camurum – bluebreast darter – 1
Etheostoma cinereum - ashy darter – 1
Percina caprodes - logperch – 1

Number species = 14	3
Darter species = 3	3
Sunfish species 1	3
Sucker species = 1	3
Intolerant species = 7	3
Green sunfish = 0.0%	5
% omnivores = 11.6%	5
% insectivorous cyprinids = 34.9%	3
% top carnivores = 2.3%	3
Total Number = 43	3
Hybrids = 0	5
Abnormal = none noted	5
Total IBI	44 – Fair

7-23-01

Notropis rubellus – roseyface shiner – 1
Notropis telescopus – telescope shiner – 2
Hypentelium nigricans – northern hogsucker – 1
Noturus flavus – stonecat – 1
Lepomis megalotis – longear sunfish – 10
Ambloplites rupestris – rock bass – 3
Micropterus punctulatus – spotted bass – 1
Micropterus salmoides – largemouth bass – 1
Etheostoma baileyi – emerald darter – 3
Etheostoma obeyense – barcheek darter – 1

Number species = 10	3
Darter species = 2	3
Sunfish species = 1	3
Sucker species = 1	3
Intolerant species = 8	5
% green sunfish = 0.0%	5
% omnivores = 8.3%	5
% insectivorous cyprinids = 12.5%	1
% top carnivores = 20.8%	5
Total number = 24	3
% Hybrids =0.0%	5
% abnormal = 0.0%	5
Total IBI	46 – fair-good