# ACID MINE DRAINAGE ABATEMENT AND TREATMENT (AMDAT) PLAN FOR THE MIDDLE BASIN OF THE RACCOON CREEK WATERSHED

by

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September 2003

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# SECTION 1 AMD ABATEMENT AND TREATMENT PLAN

## ABSTRACT

The Raccoon Creek Middle Basin study includes all area that drains into the mainstem from River Mile 80.6 to river Mile 37.5. This report assesses 184 square miles of drainage area, encompassing two major sub-watersheds and several smaller tributaries. The basin extends into Athens, Hocking and Vinton Counties. According to several published studies, including two USGS reports and a 1996 report by the Raccoon Creek Project Partners, Acid Mine Drainage (AMD) is the leading source of impairment and aquatic habitat degradation in the Middle Basin. Pierce Run is consistently identified in these studies as a significant source of AMD. Previous biological assessment of the Middle Basin in 1981 and 1995 identified AMD-related impairments in Strongs Run, Rockcamp Run, and Pierce Run, and indicated that these streams were in partial- or non-attainment of the Warmwater Habitat (WWH) biocriteria.

The Middle Basin Acid Mine Drainage Abatement and Treatment (AMDAT) Plan supports these findings, and identifies prioritized projects in the Pierce Run and Rockcamp Run sub-watersheds. It is hoped that the completion of reclamation and the application of abatement strategies at the identified locations will lead to significant and immediate response of the biologic resources and overall health of the stream. This plan attempts to reach this goal by applying strategies that provide the appropriate level of technology and are cost effective.

Project costs for the plan total $1,000,109 including design, construction, post construction monitoring and maintenance. The cost for the individual AMD abatement projects are; Oreton Hollow Seep (PR00135) $418,702, Tributary PR0015 Highwall Seep (PR0015) $319,425, Hawks Mine (MSSR0034) $223,684, and Railroad Seep (MSSR0039) $19,548. There is one small conventional reclamation project included in the restoration strategy. The Hawk Station Surface Mine will cost $18,750 to reclaim. The small area of just under two acres did not have a quantified effect on Raccoon Creek but the area, which is adjacent to the mainstem, includes 140 feet of unstable stream bank consisting of coal refuse and mine spoils.

## METHODS

The study area is broken down into three primary sub-watersheds and four mainstem sections. Sampling sites are named according to their location within a defined sub-watershed or mainstem section (Figure 1). The section of the mainstem stretching from the beginning of the study area at the US Route 50 Bridge over the mainstem (boundary of Raccoon Creek

Headwaters) to immediately upstream of the confluence with Elk Fork is designated as the Mainstem to Elk Fork (MSEF). There are no large individual tributaries in this section. Elk Fork, with its major tributaries Wolf Run and Puncheon Fork, is designated as EF. The mainstem section below the confluence of Elk Fork to upstream of the confluence of Pierce Run is designated as the Mainstem to Pierce Run (MSPR). The Pierce Run sub-watershed is designated as PR. The mainstem section below Pierce Run to upstream of the confluence with Strongs Run is designated Mainstem to Strongs Run (MSSR). This section contains the Rockcamp Run sub-watershed discharging to the mainstem at river mile 60. Strongs Run is designated SR, and the final mainstem section that runs from below the discharge of Strongs Run to just upstream of the confluence with Little Raccoon Creek is designated as Mainstem to Little Raccoon (MSLR).

**Table 1: Primary Sections and Subwatersheds in the Raccoon Creek Middle Basin**

| Stream Section | Sample Site Designation | River Reach in River Miles |
|---|---|---|
| Mainstem to Elk Fork | MSEF | RM 83 to RM 68 |
| Elk Fork | EF | Discharges at RM 68 |
| Mainstem to Pierce Run | MSPR | RM 64 to RM 64 |
| Pierce Run | PR | Discharges at RM 64 |
| Mainstem to Strongs Run | MSSR | RM 64 to RM 43 |
| Strongs Run | SR | Discharges at RM 43 |
| Mainstem to Little Raccoon | MSLR | RM 43 to RM 37 |

A three-phased approach was used to prioritize pollution sources based on net acidity and metal loads. A Hanna Combination pH Specific Conductivity meter was used to measure pH and specific conductance, in order to determine a stream’s likelihood of discharging water with acid mine drainage characteristics. The meter was calibrated using a two-point calibration method each day it was in use.

During Phase I, 175 field pH readings were collected on the tributaries to the Raccoon Creek mainstem to determine if they exhibited AMD characteristics. If a stream did exhibit low pH at the discharge to Raccoon Creek, the stream was further screened for other field parameters. AMD-identified sites were reviewed for proximity to known mining areas on the Ohio Department of Natural Resources (ODNR) abandoned underground mine maps and the USGS quadrangles for known surface mines.

Phase II analysis involved characterizing the tributaries to the mainstem, identified during Phase I, exhibiting AMD characteristics. AMD tributaries identified and studied during phase II included Pierce Run and Rockcamp Run. Elk Fork, the largest tributary to the mainstem in the study area, did not appear to be an AMD contributor although it was also further assessed during Phase II. Because of the size of the Elk Fork sub-basin, field investigators felt it was necessary to assess the basin to determine if Elk Fork's mainstem was being degraded by AMD. Water quality samples and flow measurements were collected during high and low flow regimes in these tributaries. The waters discharging from Strongs Run to Raccoon Creek were also sampled during high and low flow regimes.

The purpose of phase III was to identify and characterize AMD point sources in the tributaries studied during Phases I and II. A qualitative description was prepared for each point source and water samples and discharge measurements were collected. Point source identification was possible in Pierce Run and Rockcamp Run

Samples were collected in either a bucket and split into two bottles, or directly from the stream in appropriate locations. Samples were placed in either a bottle or cubitainer. The 250 ml bottle was acidified with 5 ml of 20% HCl solution; the other container was a cubitainer with the air squeezed out of the headspace. Samples were not filtered. Samples were analyzed at ODNR's Cambridge lab. Parameters measured were the ODNR Group I suite (pH, total acidity as $CaCO_3$, total alkalinity, specific conductance, total suspended solids, sulfate, total iron, total manganese, total aluminum, hardness and total dissolved solids). Group I is sufficient to prioritize sources based on acidity and metal loads.

Discharge was measured during each sampling event in order to calculate loading (concentration*discharge) using methods appropriate to flow volume. For large flow volumes a pygmy meter was used. The meter was calibrated daily. For moderate discharges a collapsible cutthroat Baski flume was used. Flume throat size (4" or 8") was selected in order to keep the stage in the flume between 0.2 and 0.5 feet. For small discharges, the flow was dammed and piped into a length of PVC to capture with a bucket; a stopwatch was then used to measure filling time. Samples were packed in ice immediately to limit reactions and shipped to arrive at the lab on a daily basis. It was not possible to calculate accurate flow measurement at most sampling locations in the mainstem. For this reason the mainstem was assessed using the net value of the acidity and alkalinity concentration.

Loading is calculated as the product of discharge with acidity, alkalinity or metal concentration and is expressed in lb/day for treatment considerations. In this report, metal loading is the sum of the individual loads of the three Group I metals, iron, manganese and aluminum.

**Identification of Hydrologic Unit**

| | |
|---|---|
| **Name:** | Raccoon Creek Middle Basin Watershed |
| **Tributary To:** | Ohio River Basin |
| **Location:** | Athens, Vinton Meigs, and Gallia Counties |
| **Quadrangles:** | Allensville, Zaleski, Albany, Hamden, McArthur, Mineral, Mulga, Vales Mills, Wilkesville, Rio Grande, Vinton |
| **Drainage:** | 184 square miles |

**AMD Effects on Water Quality and Biological Resources**

**Watershed Description**

In the Raccoon Creek watershed, acid mine drainage (AMD) from abandoned underground and surface coal mines has severely degraded water quality and reduced the diversity and abundance of fish and macroinvertebrate populations. The entire Raccoon Creek basin drains 683.5 square miles of the Western Allegheny Plateau Ecoregion in southeastern Ohio. The portion of the watershed of interest for this project begins at the bridge for US 50 over the mainstem (RM 80.6) to just upstream of the Little Raccoon Creek discharge (RM 37.5). The two major tributaries in this portion of the watershed are Elk Fork (59.9 square miles) and Strongs Run (17.4 square miles); two minor subsheds of note are Pierce Run (12.7 square miles) and Rockcamp Run (2.9 square miles) The entire reach of Raccoon Creek is 111.9 miles long. This report assesses 43.1 miles of the mainstem and 184 square miles of drainage area.

The average annual temperature in the area was 53°F between 1931-1980, with an annual average precipitation of 40-41 inches per year (Harstine, 1991). The topography of the watershed is typical of the unglaciated Appalachian Plateau physiographic province. The terrain consists of steep hillsides combined with narrow valleys and highly erodible soils. Rock outcrops and overhangs are common elements of the topography. The elevation ranges from 1,015 feet above sea level at the source of Brushy Fork to 518 feet above sea level at the mouth. The average fall of the river is 3.8 feet per mile (Krolczyk, 1954).

Seventy to seventy-five percent of the entire Raccoon Creek watershed is forested. The remaining land is cropland (four percent), pastureland (15 percent), urban land (four percent), active or past mined land (10 percent), or other uses (one percent). The headwaters area has seen little agricultural activity due to the steep topography. The major sources of employment in this sparsely populated watershed are manufacturing and professional services.

**Bedrock Geology**

The strata exposed in eastern Athens County and western Vinton County belong to the Pennsylvanian System, which is divided in ascending stratigraphic order (youngest to oldest) into the Pottsville, Allegheny, Conemaugh, and Monongahela Groups. In Ohio, these four groups contain 50 different coal seams, all of which have been historically mined to some degree. In Ohio sedimentary deposits, divisions between the major Pennsylvanian groups were originally made on the basis of the amount of mineable coal, and constitute a practical, rather than a lithological, framework. However, general trends and patterns of lithological change can be recognized both within and among groups. From the base of the Pottsville Group to the top of the Monongahela Group, the percentage of sandstone decreases while the percentages of shale and limestone increase. Coal beds mined in Athens and Vinton counties include the Brookville (No. 4), Clarion (No. 4a), Lower Kittanning (No. 5), Middle Kittanning (No. 6), Lower Freeport (No. 6a), Upper Freeport (No. 7), and Pittsburgh (No. 8). Of these, the thickest, most persistent, and most economically important coal is the Middle Kittanning.

Within the Raccoon Creek watershed, strata are derived from the uppermost Pottsville Group, the Allegheny Group, the Conemaugh Group, and the lowermost Monongahela Group. These deposits consist of cyclical packages of alternating sandstone, shale, coal, clay, and limestone beds. In the Middle Basin of Raccoon Creek, strata are derived primarily from the Allegheny Group, with minor representation of Pottsville and Conemaugh Group sediments. The bedrock geology is dominated by shale, coal, and fine-grained sandstones, with discontinuous exposures of medium-grained sandstones and brackish-to-marine limestones.

**Mining History**

Coal mining in Raccoon Creek watershed has taken place since the 1840s and continues today. Coal mining in Ohio began around 1800. Mining took place almost completely underground, and consisted almost entirely of manual labor, until the 1910s. Large earth moving equipment and techniques were introduced to the mining industry around 1940, providing the capacity to move large amounts of earth very quickly. Increased efficiency led to more surface mining, which today accounts for about half of the coal removal in Ohio: fifty-two companies mined 152 sites to produce 30.6 million tons of coal in Ohio in 1997 (Office of Surface Mining Reclamation and Enforcement, 1999). Ohio ranked 11$^{th}$ nationally in production of coal in 1995, in part due to Ohio's location on the northern tip of the Appalachian Coal Basin (Ohio Division of Mines and Reclamation, 1999). One of the largest coal fields in the United States, the Appalachian Coal Basin covers 72,000 square miles in several states, including Ohio, Pennsylvania, West Virginia, and Kentucky (National Energy Foundation, 1995).

Four kinds of mining techniques have been used in the watershed. S*trip mining* is used when the coal seam is near to the ground's surface. The soil and rock overburden is removed and the coal is taken out before the overburden is replaced. In *drift mining*, a tunnel is driven into the side of a hill at a coal outcrop. The coal is mined out by following the contour of the bed. Drift mines are commonly found along stream bottoms where erosion has exposed a coal seam. *Slope mining* uses tunnels on a low enough incline to permit mine cars to enter. More than half of all coal mined in the watershed was taken from drift or slope mines (Ahmad, 1979). A vertical opening is driven into the coal in *shaft mining*. This technique proceeds along the coal seam with excessive depth increasing entry, exit and ventilation hazards.

Shaft and deep mines were originally used until the 1940s, before strip mines became more common. From the 1940s to the present, strip mining has replaced underground mining as the dominant method. According to calculations based on digitized layers of surface and underground mines on U.S. Geological Survey 1:24,000, 7.5 minute quadrangles, approximately 25,610 acres of underground mines and 21,550 acres of surface mines were established in the Raccoon Creek watershed. In addition to coal and limestone, clay, sand and iron ore are found in the basin, though the high-grade iron ore was essentially depleted in the early 1900s.

**Hydrogeology And Acid Mine Drainage**

The following discussion is adapted from the Pennsylvania DEP web page:
<http://www.dep.state.pa.us/dep/deputate/minres/bamr/amd/science_of_amd.htm>

The formation of AMD is primarily a function of the geology, hydrology and mining technology employed at the mine site. AMD is formed by a series of complex geo-chemical and microbial reactions that occur when water comes in contact with pyrite (iron disulfide minerals) in coal, refuse or the overburden of a mine operation. The resulting water is usually high in acidity and dissolved metals. The metals stay dissolved in solution until the pH rises to a level where precipitation occurs.

There are four commonly accepted chemical reactions that represent the chemistry of pyrite weathering to form AMD. An overall summary reaction is as follows:

$$4\ FeS_2 + 15\ O_2 + 14\ H_2O \rightarrow 4\ Fe(OH)_3 \downarrow + 8\ H_2SO_4$$

*Pyrite + Oxygen + Water → "Yellowboy" + Sulfuric Acid*

The first reaction in the weathering of pyrite includes the oxidation of pyrite by oxygen. Sulfur is oxidized to sulfate and ferrous iron is released. This reaction generates two moles of acidity for each mole of pyrite oxidized.

$$2\ FeS_2 + 7\ O_2 + 2\ H_2O \rightarrow 2\ Fe^{2+} + 4\ SO_4^{2-} + 4\ H^+ \qquad \textbf{(1)}$$

*Pyrite + Oxygen + Water → Ferrous Iron + Sulfate + Acidity*

The second reaction involves the conversion of ferrous iron to ferric iron. The conversion of ferrous iron to ferric iron consumes one mole of acidity. Certain bacteria increase the rate of oxidation from ferrous to ferric iron. This reaction rate is pH dependant with the reaction proceeding slowly under acidic conditions (pH 2-3) with no bacteria present and several orders of magnitude faster at pH values near 5. This reaction is referred to as the "rate determining step" in the overall acid-generating sequence.

$$4\ Fe^{2+} + O_2 + 4\ H^+ \rightarrow 4\ Fe^{3+} + 2\ H_2O \qquad \textbf{(2)}$$

*Ferrous Iron + Oxygen + Acidity → Ferric Iron + Water*

The third reaction that may occur is the hydrolysis of iron. Hydrolysis is a reaction that splits the water molecule. Three moles of acidity are generated as a byproduct. Many metals are capable of undergoing hydrolysis. The formation of ferric hydroxide precipitate (solid) is pH dependant. Solids form if the pH is above about 3.5 but below pH 3.5 little or no solids will precipitate.

$$4\ Fe^{3+} + 12\ H_2O \rightarrow 4\ Fe(OH)_3 + 12\ H^+ \qquad \textbf{(3)}$$

*Ferric Iron + Water → Ferric Hydroxide (yellowboy) + acidity*

The fourth reaction is the oxidation of additional pyrite by ferric iron. The ferric iron is generated in reaction steps 1 and 2. This is the cyclic and self-propagating part of the overall reaction and takes place very rapidly, and continues until either ferric iron or pyrite is depleted. In this reaction, iron is the oxidizing agent, not oxygen.

$$FeS_2 + 14\ Fe^{3+} + 8\ H_20 \rightarrow 15\ Fe_2+ + 2\ SO_4^{2-} + 16\ H^+ \ \textbf{(4)}$$

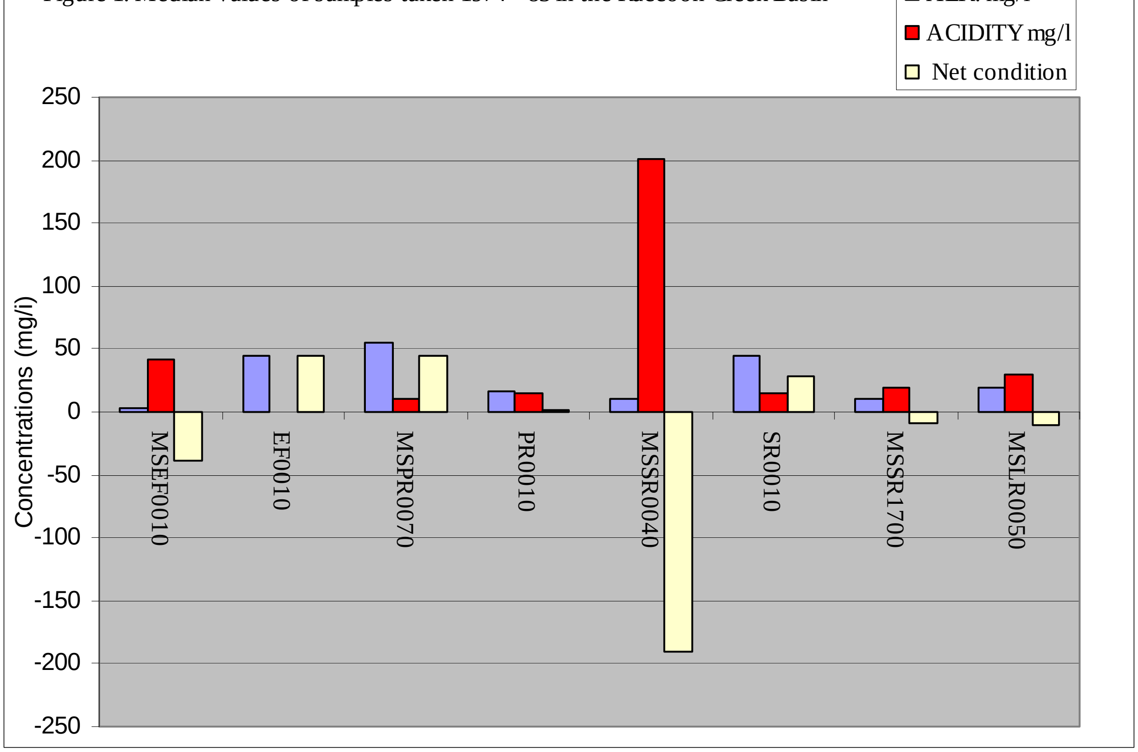
*Pyrite + Ferric Iron + Water → Ferrous Iron + Sulfate + Acidity*

**Historical Water Quality**

In the mid 1980's the USGS partnered with ODNR to develop water-resource investigation reports to assist with prioritizing reclamation in the Raccoon Creek basin. The data from those reports is very useful for establishing the context of the chemical quality in the basin over the past 20 years.

The study "Surface Water Quality of Coal-Mine Lands in Raccoon Creek Basin, Ohio" (Water-Resources Investigations Report 85-4060) analyzed eight AMD parameters from 1975 through 1983 and provides the data for samples collected at 41 sites in November of 1983. The conclusions drawn from the report do not focus on AMD problems specific to the Middle Basin study area. Figure 1 graphs the median net concentration values for nine sites that lie with in the study area. The data set included over 400 samples taken between 1974 and 1984. Median values were computed basin wide and for individual sites. The sites have been renamed to reflect the current site identification scheme.

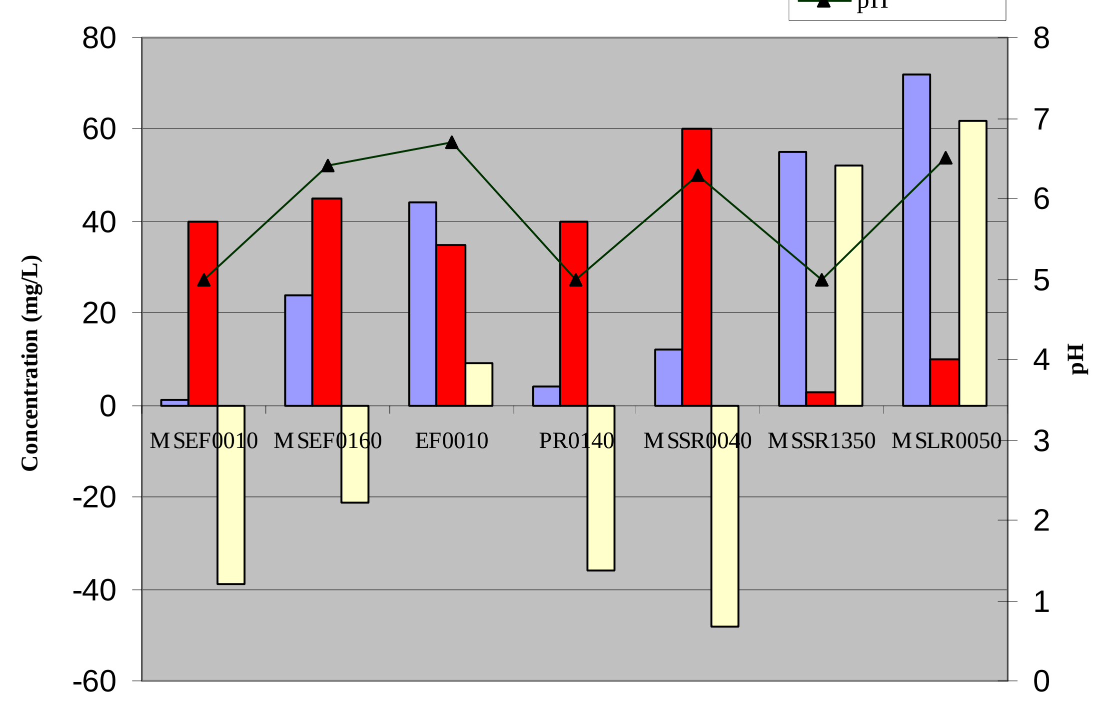
Figure 1. Median values of samples taken 1974 - '83 in the Raccoon Creek Basin




MSEF0010, located at the upper end the study area, reflects the affect of AMD on the headwaters of Raccoon Creek (See Map #1 for site locations). Moving downstream, Elk Fork (EF0010) discharges a net alkaline condition. MSPR0070, a mainstem site, shows the highest median alkalinity. The other two major tributaries in this reach are Pierce Run (PR0010), discharging water with nearly a zero net condition and Strongs Run (SR0010), discharging net alkaline water upstream of MSSR1700. Sites MSSR0040 (downstream of Pierce Run and Rockcamp Run) MSSR1700, and MSLR0050 (the downstream endpoint of the study area) are all mainstem Raccoon Creek sites and all remain in a net acidic state. The worst conditions are near MSSR0040.

Figure #2 graphs relevant portions of the data collected in November 1983. Samples were taken during low flow conditions. Not all of the sites used in developing the median value historical database were sampled during the November 1983 event. The waters enter the Middle Basin study area at MSEF0010 with a net acidic concentration of 39 mg/l and reach a peak of acidity concentration at MSSR0040. In the November sampling the stream made a dramatic change, reverting to a highly alkaline conditions on reaching the final sampling location MSLR 0050. The report does not specifically address the Middle Basin section of the Raccoon Creek watershed. The only portion of the Middle Basin that is described as being degraded chemically by mine drainage is the Pierce Run subwatershed.

Figure 2. Concentration conditions Raccoon Creek Mainstem
1983 USGS Study
MSLR0050 reported flow = 64 cfs



The USGS also produced the water resources report (88-4022) entitled "Chemical Quality, Benthic Organisms, and Sedimentation in Streams Draining Coal-Mined Lands in Raccoon Creek Basin, July 1984 Through September 1986". This investigation provides data from several sampling events for four sites in the Middle Basin study area. Table #1 shows data for sites MSEF0010, EF0010, PR0010, and MSLR0050 (downstream endpoint for study area) over varying flow regimes. The reference flow refers to the recorded flow at MSLR0050 (See Map #2 for site locations).

The general trend of this data reflects a varying condition at the head of the study area, such that concentrations were net alkaline during lower flow regimes, net acidic at elevated flow volumes, and then during higher flow events (above 300cfs) returned to net alkalinity. At the downstream end (MSLR0050) the water consistently remained alkaline but appeared to be dropping in alkaline concentration as the flow volume increased.

**Table 2: Chemical Water Quality for Sites in the Raccoon Creek Middle Basin (USGS, 1988).**

**Each sampling event captures data from the Upper end of the study area (MSEF0010), two main tributaries (EF0010, PR0010), and the downstream terminus (MSLR0050) of the study area.**

| 1984 September | **pH** | **Alkalinity mg/l** | **Acidity mg/l** | **Net** |
|---|---|---|---|---|
| MSEF0010 | | no data | no data | |
| EF0010 | 7.1 | 56 | 0 | 56 |
| PR0010 | 6.1 | 8 | 9.9 | -1.9 |
| MSLR0050 | 6.8 | 39 | 0 | 39 |
| Reference flow: (cfs) | | 2.7 | | |

| 1985 June | **pH** | **Alkalinity mg/l** | **Acidity mg/l** | **Net** |
|---|---|---|---|---|
| MSEF0010 | 5.0 | 2 | 25 | -23 |
| EF0010 | 7.3 | 27 | 0 | 27 |
| PR0010 | 5.6 | 4 | 27 | -23 |
| MSLR0050 | 7.1 | 18 | 0 | 18 |
| Reference flow: (cfs) | | 54 | | |

| 1986 April | **pH** | **Alkalinity mg/l** | **Acidity mg/l** | **Net** |
|---|---|---|---|---|
| MSEF0010 | 5.1 | 2 | 12 | -10 |
| EF0010 | 7.1 | 23 | 0 | 23 |
| PR0010 | 6.3 | 6 | 6 | 0 |
| MSLR0050 | 6.7 | 10 | 0 | 10 |
| Reference flow: (cfs) | | 156 | | |

| 1985 September | **pH** | **Alkalinity mg/l** | **Acidity mg/l** | **Net** |
|---|---|---|---|---|
| MSEF0010 | 6.8 | 9 | 0 | 9 |
| EF0010 | 7.8 | 62 | 0 | 62 |
| PR0010 | | no data | no data | 0 |
| MSLR0050 | 7.1 | 26 | 0 | 26 |
| Reference flow: (cfs) | | 4.4 | | |

| 1986 June | **pH** | **Alkalinity mg/l** | **Acidity mg/l** | **Net** |
|---|---|---|---|---|
| MSEF0010 | 6.5 | 12 | 0 | 12 |
| EF0010 | 7.6 | 38 | 0 | 38 |
| PR0010 | 6.5 | 8 | 5 | 3 |
| MSLR0050 | 6.7 | 6 | 0 | 6 |
| Reference flow: (cfs) | | 28 | | |

| 1985 December | **pH** | **Alkalinity mg/l** | **Acidity mg/l** | **Net** |
|---|---|---|---|---|
| MSEF0010 | 7.3 | 5 | 0 | 5 |
| EF0010 | 6.6 | 12 | 0 | 12 |
| PR0010 | 6.0 | 12 | 9.9 | 2.1 |
| MSLR0050 | 6.9 | 8 | 0 | 8 |
| Reference flow: (cfs) | | 393 | | |

| 1986 August | **pH** | **Alkalinity mg/l** | **Acidity mg/l** | **Net** |
|---|---|---|---|---|
| MSEF0010 | 7.0 | 26 | 0 | 26 |
| EF0010 | 7.1 | 44 | 0 | 44 |
| PR0010 | 6.2 | 5 | 6 | -1 |
| MSLR0050 | 7.0 | 38 | 0 | 38 |
| Reference flow: (cfs) | | 6.2 | | |

The report "Water Quality Assessment of the Raccoon Creek Watershed" (Hughes *et al*., 1996) was the result of a joint project supported by the Raccoon Creek partners. The study was designed to sample the headwaters and Elk Fork basins in June of 1996 with limited follow up sampling that occurred in 1997. The purpose of the project was to augment the existing database developed through the two USGS investigations. The data does not significantly deviate from trends established in earlier reports. Figures #3 and #4 provide concentrations for mainstem sampling sites. The water enters the study area at a net acidic condition, then receives some buffering from Elk Fork, as reflected at site MSPR0015 in each graph. In 1996 the stream maintained a constant net alkaline condition through the study area, but pH dropped below 6.0 downstream of Pierce Run at site MSSR0600. In 1997 (Figure #4) the stream reverted to net acidic conditions after receiving discharges from Pierce Run, Rockcamp Run and other AMD contributors.

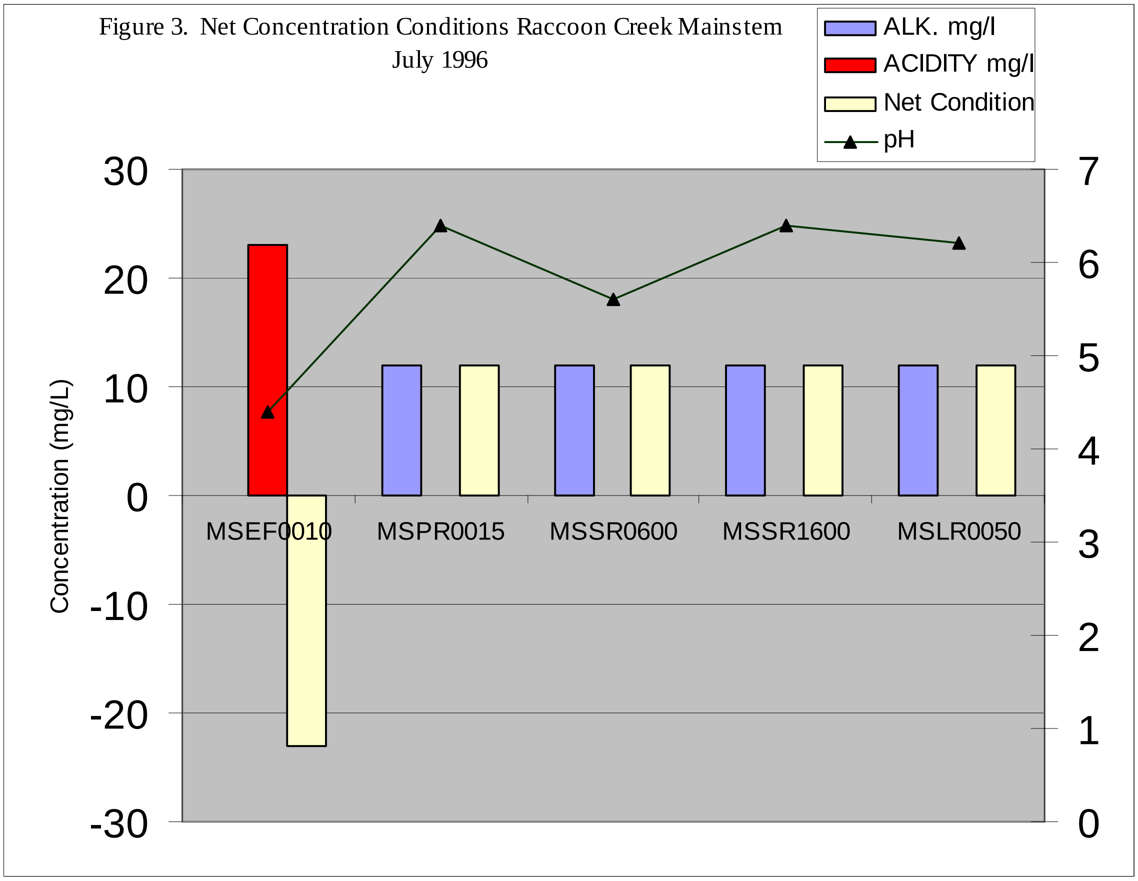
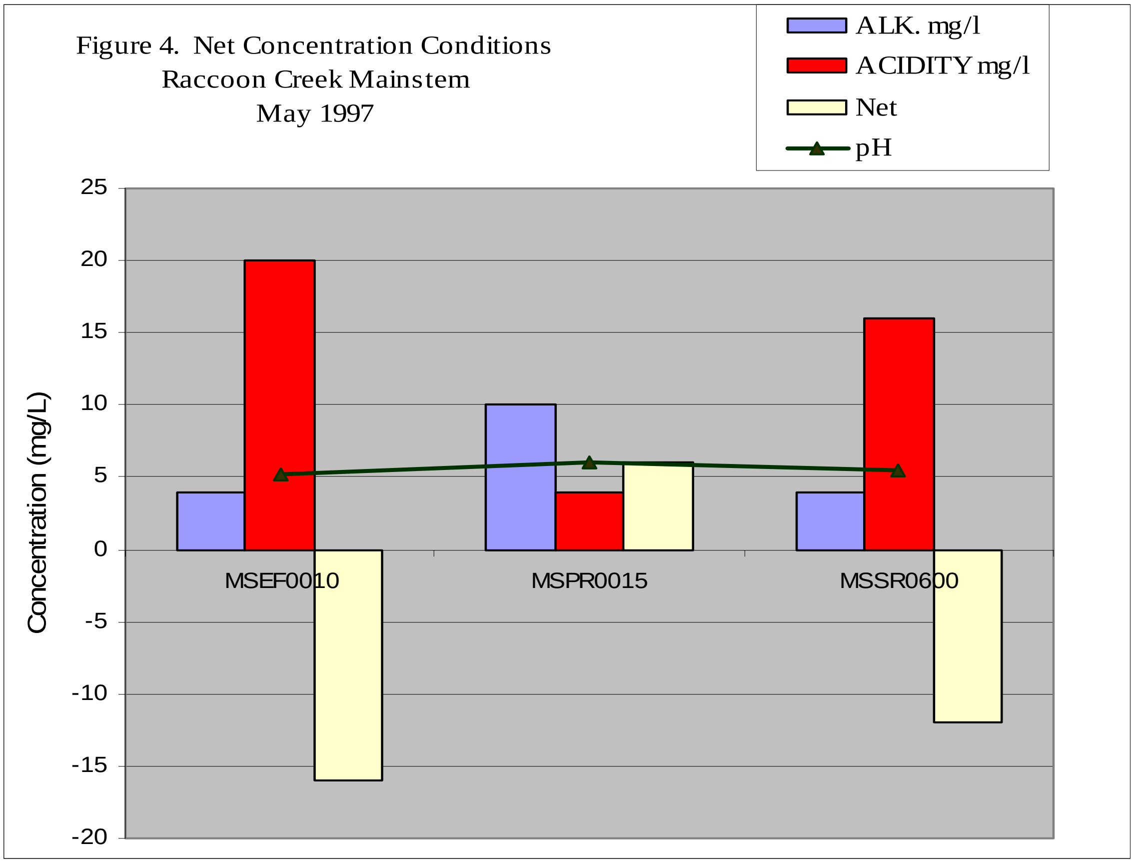



Figure 3. Net Concentration Conditions Raccoon Creek Mainstem
July 1996




Conclusions for this report do not focus on AMD causes specific to the Middle Basin. The report does confirm the USGS data showing Elk Fork as a constant alkaline contributor and Pierce Run as a constant acid contributor. (See Map #3 for site locations).

**Target Alkalinity Levels**

The Ohio EPA's TMDL for Upper Raccoon Creek developed a target parameter and concentration levels for comparing in-stream conditions and desired water quality. This allows for a determination of changes that must occur in the watershed so that the WWH use designation can be achieved. Though pH is listed on the TMDL as a cause for non-attainment, pH fluctuations cannot be modeled. Metals are also listed as a cause of impairment, but Ohio does not currently have surface water quality standards for the metals of interest-aluminum, iron, and manganese (TMDL for the Upper Raccoon Creek Basin, P.13, Ohio EPA, 2002). Alkalinity was chosen as a surrogate in modeling water quality conditions. Ohio EPA's modeling team used the USEPA water quality criteria to determine a corresponding minimum net alkalinity level. The OEPA model calculated that water meeting USEPA criteria for iron (1.0 mg/L), aluminum (.75 mg/L), and manganese (2.0 mg/L) should have a corresponding net alkalinity of at least 20 mg/l.

Net alkalinity concentrations of 20 mg/l then correspond to a pH of at least 6.5, thereby meeting Ohio's Warmwater Habitat (WWH) criteria. The Raccoon Creek Watershed Project Partners have accepted the 20 mg/L target as our goal for in-stream concentration conditions in the mainstem of Raccoon Creek.

## Current Mainstem Water Quality

The 184 square mile middle basin has been divided into seven subwatersheds. Mainstem to Elk Fork (MSEF) begins at the upper end of the study area and reaches to just upstream of the Elk Fork discharge. Elk Fork (EF) is the largest tributary to the Raccoon Creek in the study area. Mainstem to Pierce Run (MSPR) begins just downstream of the Elk Fork discharge, and concludes upstream of Pierce Run. The Pierce Run (PR) sub-basin is one of the major tributaries in this section and a known contributor of AMD to Raccoon Creek. Mainstem to Strongs Run (MSSR) starts just downstream of Pierce Run and concludes upstream of Strongs Run. This segment includes Rockcamp Run. Strongs Run (SR) is the second largest tributary in middle basin. The final segment is Mainstem to Little Raccoon Creek (MSLR) (See Map #4).

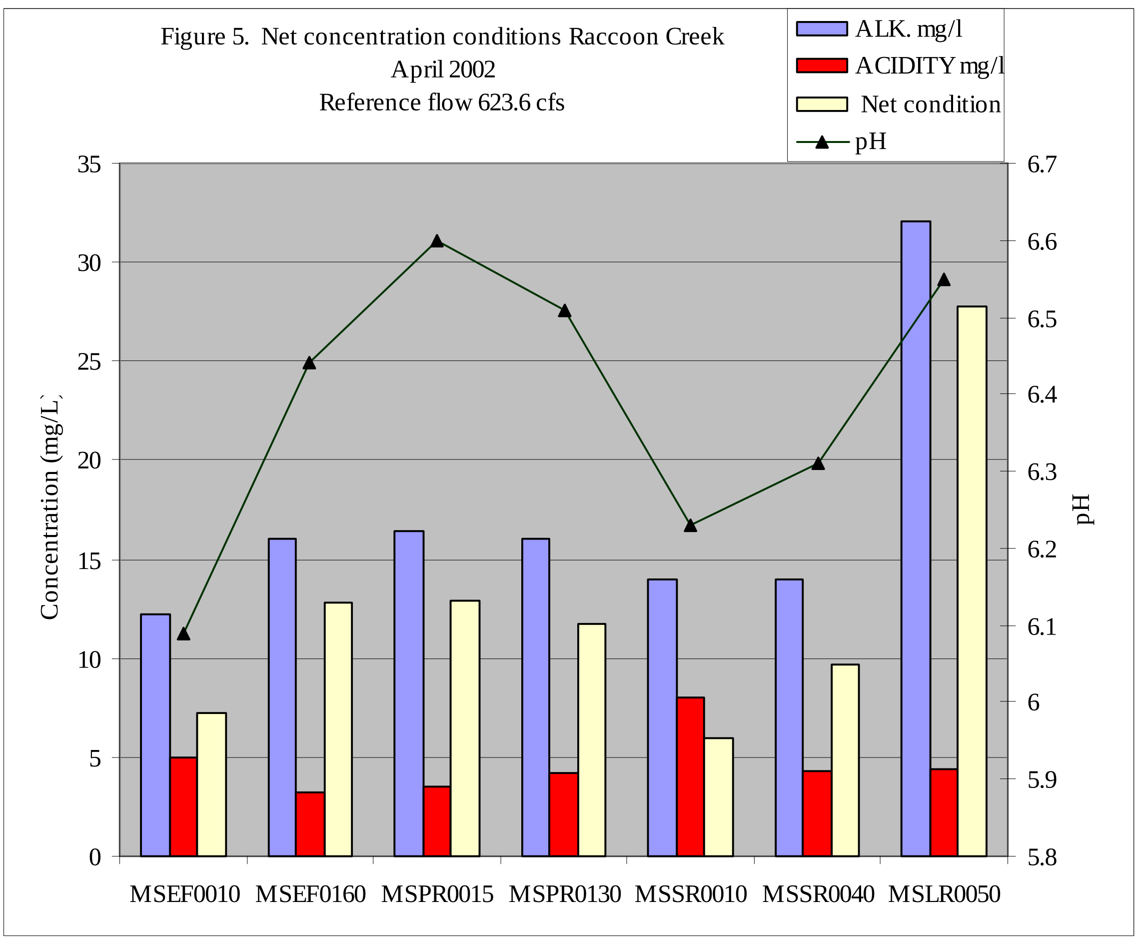
During each sampling event a determination of the flow volume was calculated for the endpoint of the study area. The flow at this sampling site, MSLR 0050, is the reference site that is used in discussion in this report. The reference site flow is used to distinguish the relative flow regime across the study area (low, medium, or high.) The flow is determined in the field when possible, or by calculation using the formula:

**(Q1 – Q2/.643) * .898**, where Q1 is the reported flow at the USGS Adamsville gauge (station number 03202000.) and Q2 is the flow at the gage on Little Raccoon Creek (03201980), corrected for its location in the Little Raccoon drainage basin. Q1 minus the corrected Q2 gives the value for Raccoon Creek calculated flow minus Little Raccoon Creek(See Map #1 for site locations). That volume is then corrected for its location. The flow reference site drains 89.8% of the basin. The OEPA TMDL modeling team developed the above flow-calculating formula that allows for an understanding of conditions at the time of sampling. (See Map #4 for site locations).

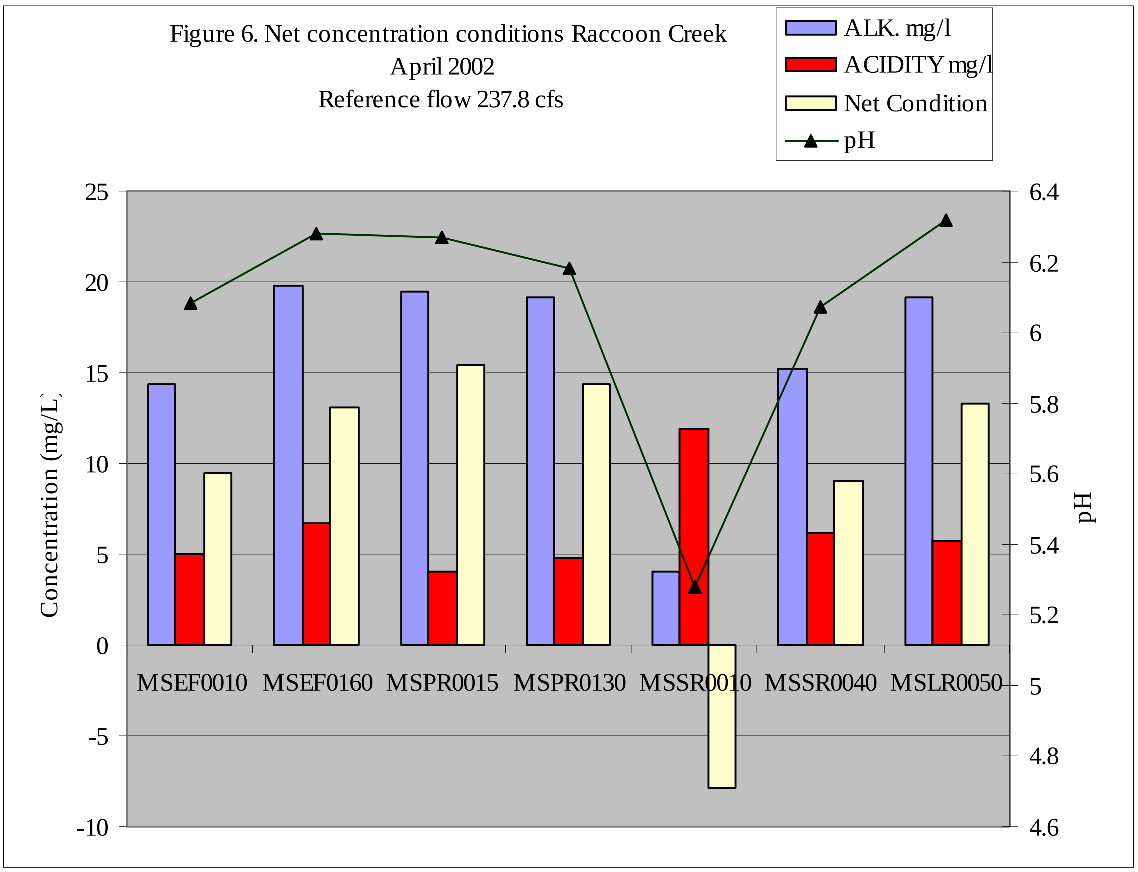
### Mainstem of Raccoon Creek

The mainstem was sampled over a wide range of flow regimes in 2002. The basin was assessed twice in April with calculated discharge rates at the reference site of 624 cubic feet per second (cfs) and 238 cfs. It was again assessed in August when the discharge was measured in the field at 25 cfs.

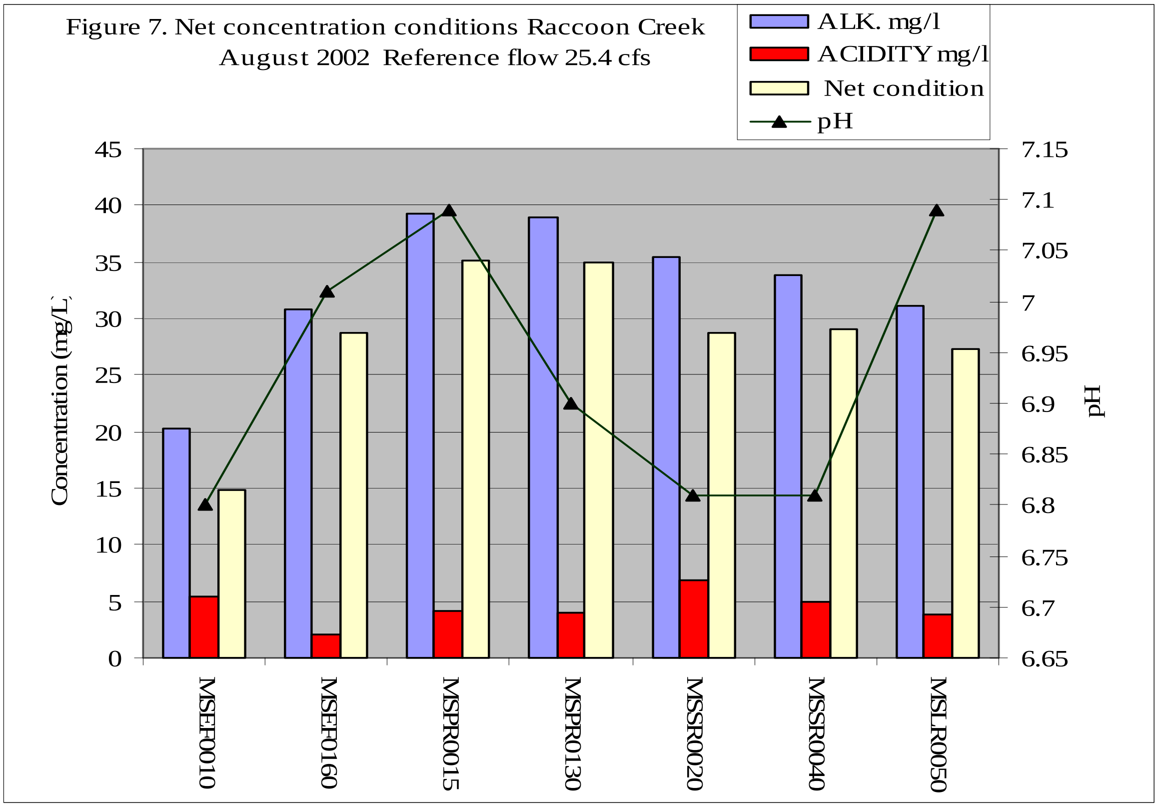
The three sampling events, even with such wide variation in flow regimes, reflect the same general trend. The water quality in the middle basin is dependent on the impact that AMD is having on the headwaters of the stream. As the water enters the study area it does not generally meet the target level of net 20mg/L alkalinity. The alkalinity improves, but then drops during high flows (less during lower flow) at site MSSR0010. This site is just downstream of the Pierce Run discharge. Downstream of MSSR0010 the water quality recovers to net alkaline conditions at the final sampling location. During the 600 cfs sampling event (Figure #5) water chemistry meets the target net alkaline concentration of >20mg/l at MSLR0050. The pH drops .3 standard units between sites MSPR0130 and MSSR0010. A drop of .3 units is significant in a stream the size of Raccoon Creek This drop is a result of the discharge of Pierce Run into the mainstem of Raccoon Creek. During this high flow event the stream was able to maintain a net alkaline condition but with a very low net alkalinity of 6mg/L (See map #5 for site locations).




The second sampling event in April (Figure #6) was conducted at approximately half the flow of the earlier April sampling event (reference site flow = 237.8 cfs) and produced a similar trend. The water enters the study area with approximately 9 mg/l of alkalinity. Alkalinity increases through the Elk Fork discharge area at sites MSPR0015 and MSPR0130, and then drops after the stream receives the Pierce Run discharge. At this medium flow level the stream reverts to net acidic conditions with a drop in pH from 6.2 to 5.3. The downstream reach recovers alkalinity, but not enough to meet the target goal of > 20 mg/l of net alkalinity. Each of the April sampling events point to Pierce Run as the greatest limiting factor in the study area, as reflected by site MSSR0010.



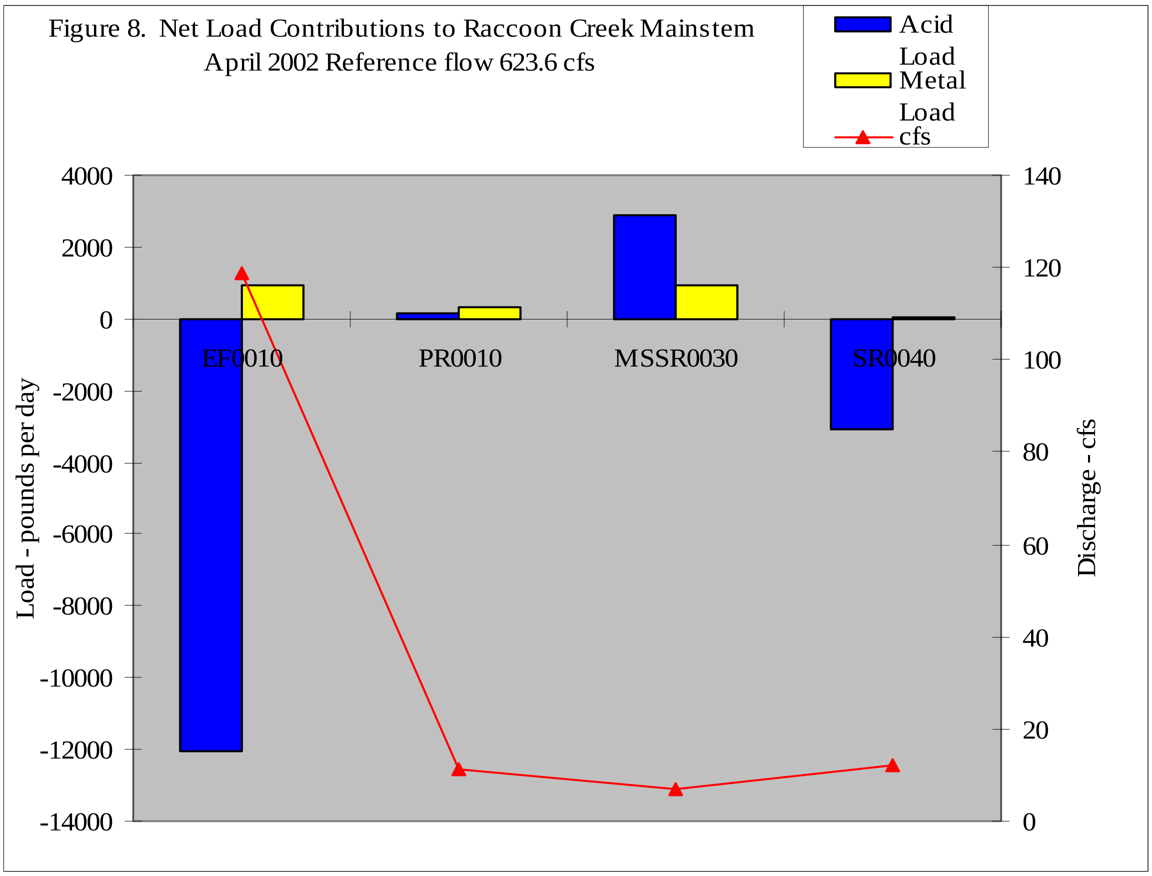

The last basin-wide sampling event was conducted in August during low and relatively stable stream conditions (Fig. 7). The reference site discharge was measured in the field at 25 cfs. Previous studies suggested that the basin would suffer the worst acid concentration conditions during low flow, but the sampling results actually show otherwise. There was one modification to the sampling locations during this event- MSSR0010 was moved downstream far enough to warrant a new site number, MSSR0020. The site was moved to assure that the downstream mainstem sample was well past the mixing zone of the Pierce Run discharge into Raccoon Creek. The water entered the study area at a slightly elevated alkaline concentration in comparison with other basin sampling events, but the overall trend remained the same. Alkalinity increased until the stream received the Pierce Run discharge. The net alkalinity concentration at MSSR0040 did drop but remains above the 20mg/l target level through the study area.




**Significant Tributaries to Raccoon Creek**

During phase I field reconnaissance, 175 field pH readings were taken to determine which tributaries might be degrading the mainstem. Only 36 of those readings indicated pH below 6.0, and over half of these were in either the Rockcamp Run or Pierce Run subwatersheds. The rest were in the Mainstem to Elk Fork reach or in Elk Fork, and were above a pH of 5.0. The four tributaries that were selected for phase II sampling include Elk Fork (EF0010), Rockcamp Run (MSSR0030), Pierce Run (PR0010) and Strongs Run (SR0040.) The data provided for these sites reflect the discharging load (samples were taken at the mouth of the stream) to the mainstem. The negative acid load reflects an alkaline load to the mainstem (See Map #6 for site locations).

The phase II loading data for the selected tributary streams also indicates consistent trends. Elk Fork and Strongs Run produce net alkaline loads during each sampling event. The buffering capacities provided by these discharges correspond well to the increase in net alkalinity in both the mainstem MSPR segment and below Strongs Run through the MSLR reach. Also, the data indicate that alkaline loads in these two streams tend to increase with increased flow volumes. Pierce Run and Rockcamp Run produced net acidic loads during most sampling events and in each of the basin wide sampling events shown below. The Pierce Run load is strongly correlated to the downward trend in quality in the downstream site MSSR0010 or MSSR0020 (figures #8, #9, #10). The metal load is the total contribution of the concentration of iron, aluminum, and manganese multiplied by the discharge rate at the location the sample was taken.



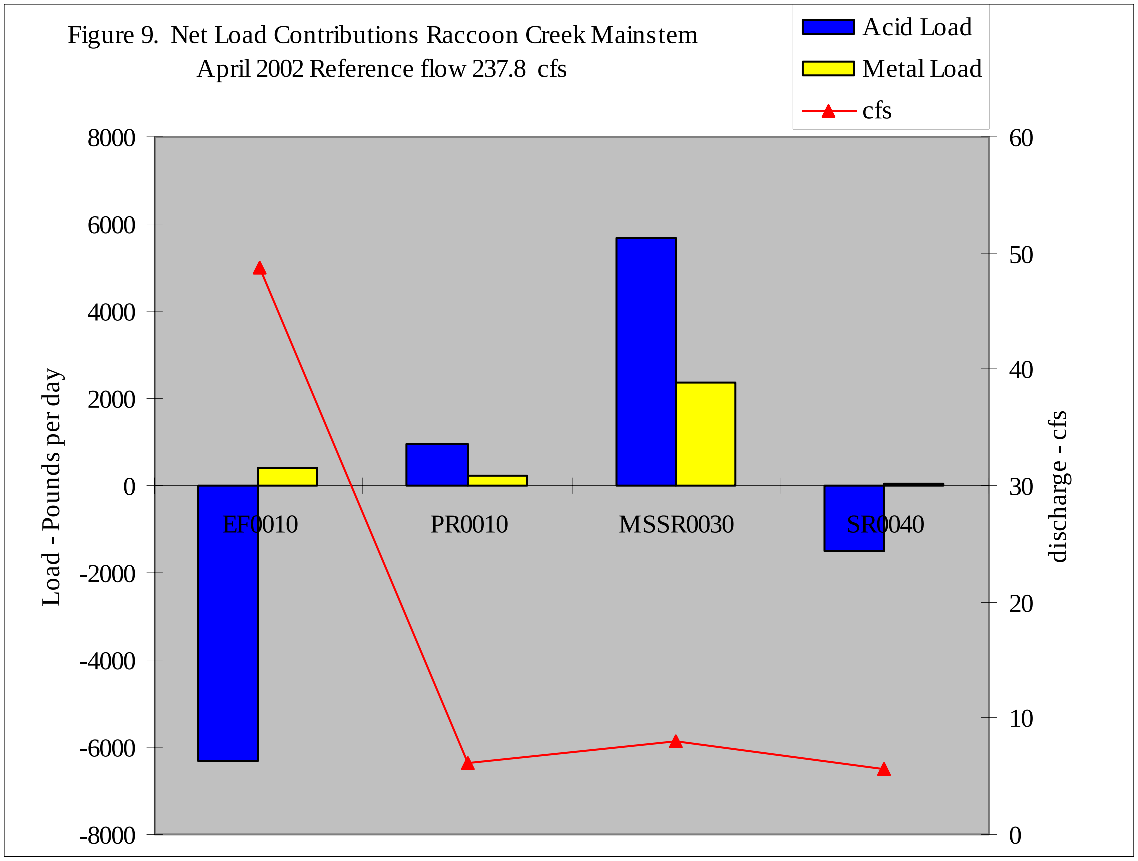


Figure 9. Net Load Contributions Raccoon Creek Mainstem
April 2002 Reference flow 237.8 cfs
Acid Load
Metal Load
cfs
Load - Pounds per day
8000
6000
4000
2000
0
-2000
-4000
-6000
-8000
EF0010
PR0010
MSSR0030
SR0040
discharge - cfs
60
50
40
30
20
10
0

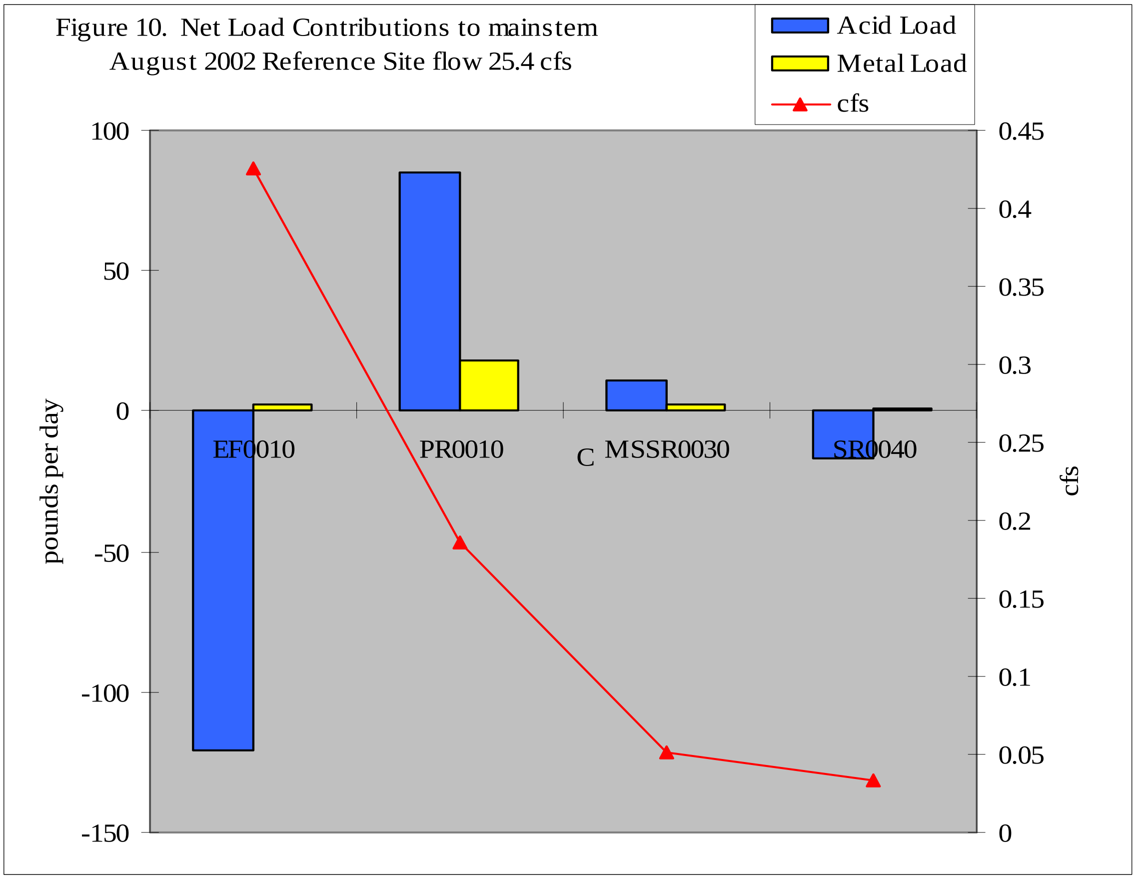


Figure 10. Net Load Contributions to mainstem
August 2002 Reference Site flow 25.4 cfs
Acid Load
Metal Load
cfs
100
50
0
-50
-100
-150
pounds per day
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
cfs
EF0010
PR0010
C
MSSR0030
SR0040

## Sub-watersheds

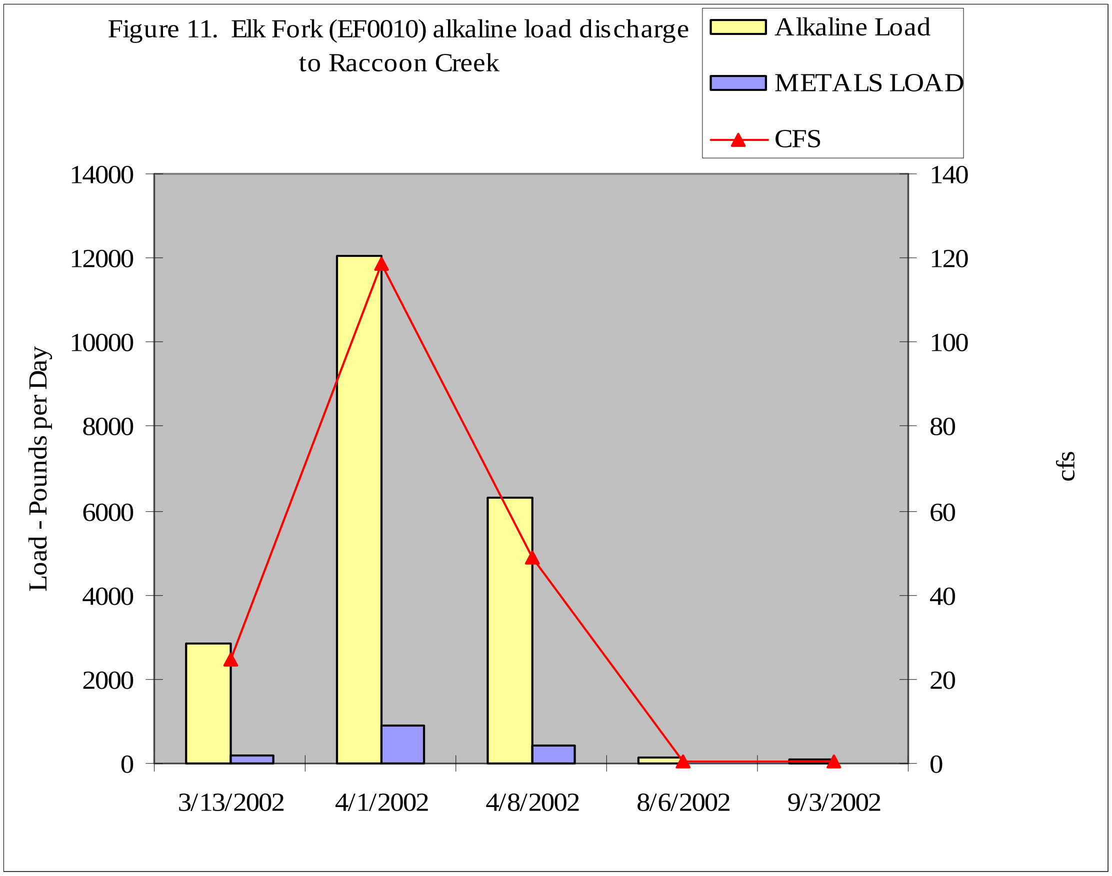
Three sub-watersheds were selected for further sampling. Elk Fork was selected because of its importance as a refuge for biology in the watershed and because it is a source of alkalinity to the mainstem of Raccoon Creek. Pierce Run and Rockcamp Run were selected due to their significant contribution of acid load to the mainstem.

### Elk Fork

**Name:** Elk Fork
**Tributary To:** Raccoon Creek
**Location:** Vinton County
**Quadrangles**: Allensville, Zaleski, Hamden, McArthur
**Drainage:** 59.9 square miles

The Elk Fork subwatershed received a basin-wide assessment in March and September of 2002. Historically the stream has been a consistent net alkaline contributor to the mainstem. But because of the size and quality of the sub-basin, the creek provides a valuable resource as a part of the Vinton County landscape and warrants a detailed determination of its chemical characteristics.

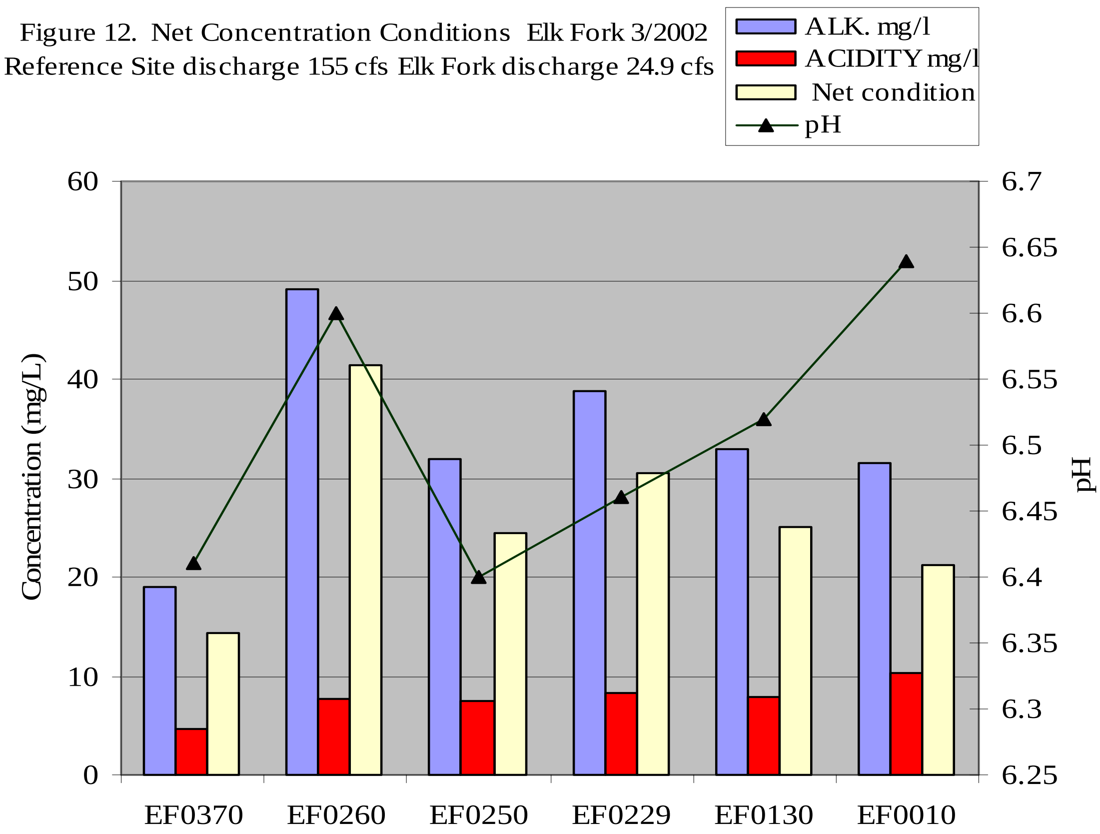
Figure #11 displays the data for all samples that were taken at the confluence of Elk Fork and Raccoon Creek (EF0010).



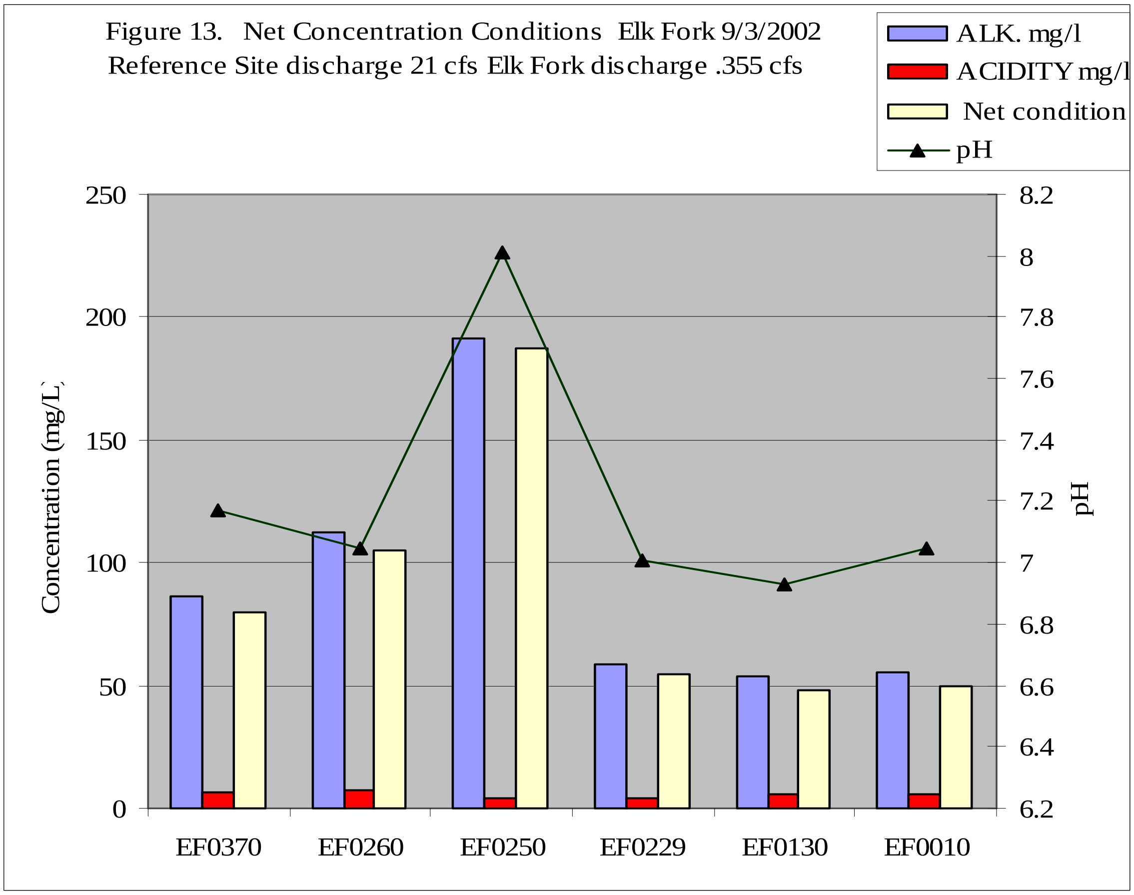

The graph confirms the consistent alkaline load discharging to Raccoon Creek over varying flow regimes. The metals load represented on the graph is the sum of the iron, aluminum and manganese loads carried by the stream.

Each of the Elk Fork sub-basin sampling events shows that adequate levels of alkalinity are maintained along the entire reach of Elk Fork's mainstem. In March, Elk Fork (Site EF0010) delivered net alkaline discharge of 21 mg/l to Raccoon Creek at a rate of 25 cfs, under a moderate basin-wide flow regime (Fig. #12). See Map #7 for sample locations.

Figure 12. Net Concentration Conditions Elk Fork 3/2002
Reference Site discharge 155 cfs Elk Fork discharge 24.9 cfs



In September under a much lower flow regime (Elk Fork: .355 cfs, Reference Site: 21cfs) Elk Fork (Site EF 0010) produced even higher alkalinity values across the sub-basin (Figure #13).




While alkaline conditions vary in Elk Fork, and alkalinity levels drop in the lower reach, conditions do not reach a level assumed to be affecting aquatic life. Even at the highest measured discharge levels the alkalinity levels are at or above the 20mg/l target level at the confluence with Raccoon Creek.

*Priority Sites:*

There are no priority sites within the Elk Fork subwatershed. There are areas of the Elk Fork basin that have been surface mined with much of it having been reclaimed. Some small tributaries to Elk Fork are not supporting healthy aquatic assemblages. It is not apparent whether this is due to AMD or the small drainage area and limited flow. As the graphs show there is a limited amount of acid present in mainstem samples from Elk Fork. The cost to abate AMD for this small load does not provide enough benefit to undergo further consideration as priority projects for treatment in this report. However, other factors that may or may not be mining related (siltation) should be considered as opportunities to improve the physical habitat of the stream.

*Location/access:*

The Elk Fork drainage basin discharges into Raccoon Creek in Vinton Township, Vinton County near the intersection of State Route 32 and County Road 43B with nearly all of the drainage basin located in Vinton County. The headwaters are located near Mt Pleasant, Ohio, which sits on the Vinton and Hocking County border along State Route 93. The Mead WesVaco/US Forest Service manage through partnership the Raccoon Creek Ecological Management Area located in the Elk Fork Basin. This 16,000 acre forest is not accessible by auto in most cases but is open to foot travel.

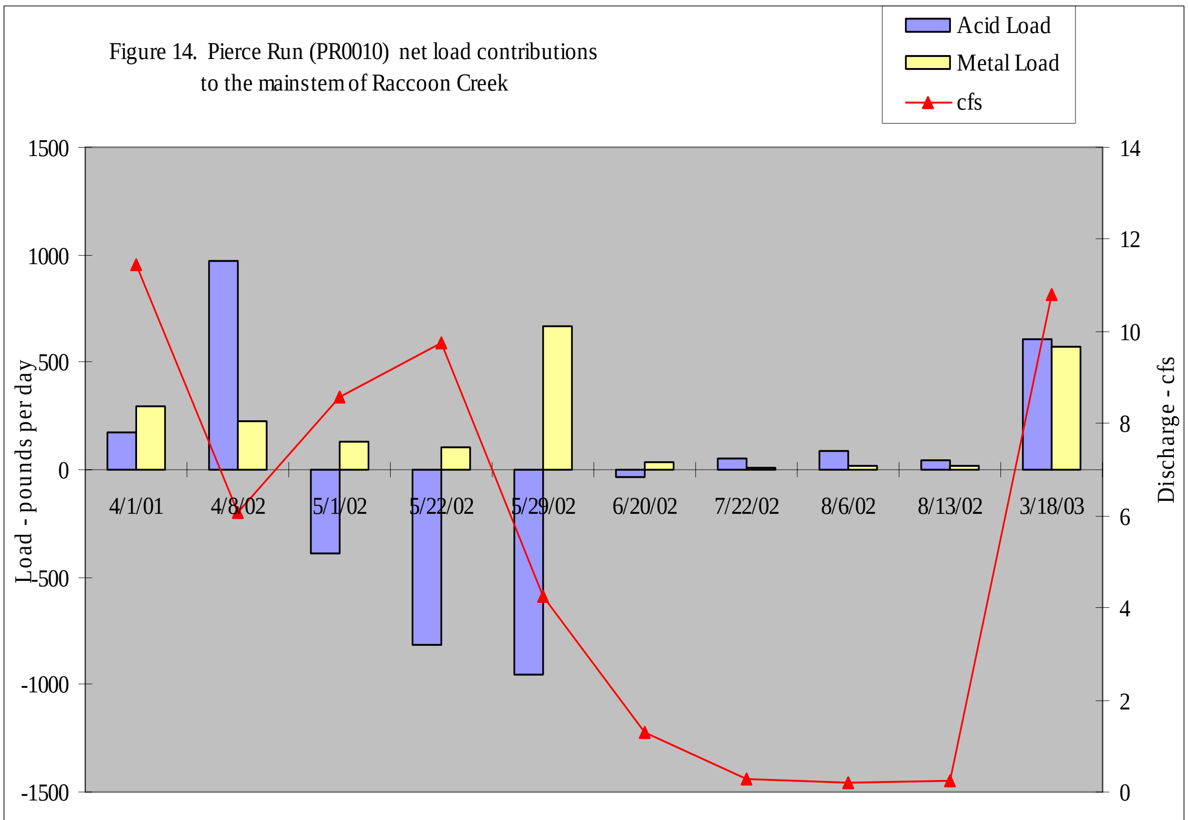
**Pierce Run**

| | |
|---|---|
| **Name:** | Pierce Run |
| **Tributary To:** | Raccoon Creek |
| **Location:** | Vinton County |
| **Quadrangles:** | McArthur, Mulga, Wilkesville |
| **Drainage:** | 12.7 square miles |

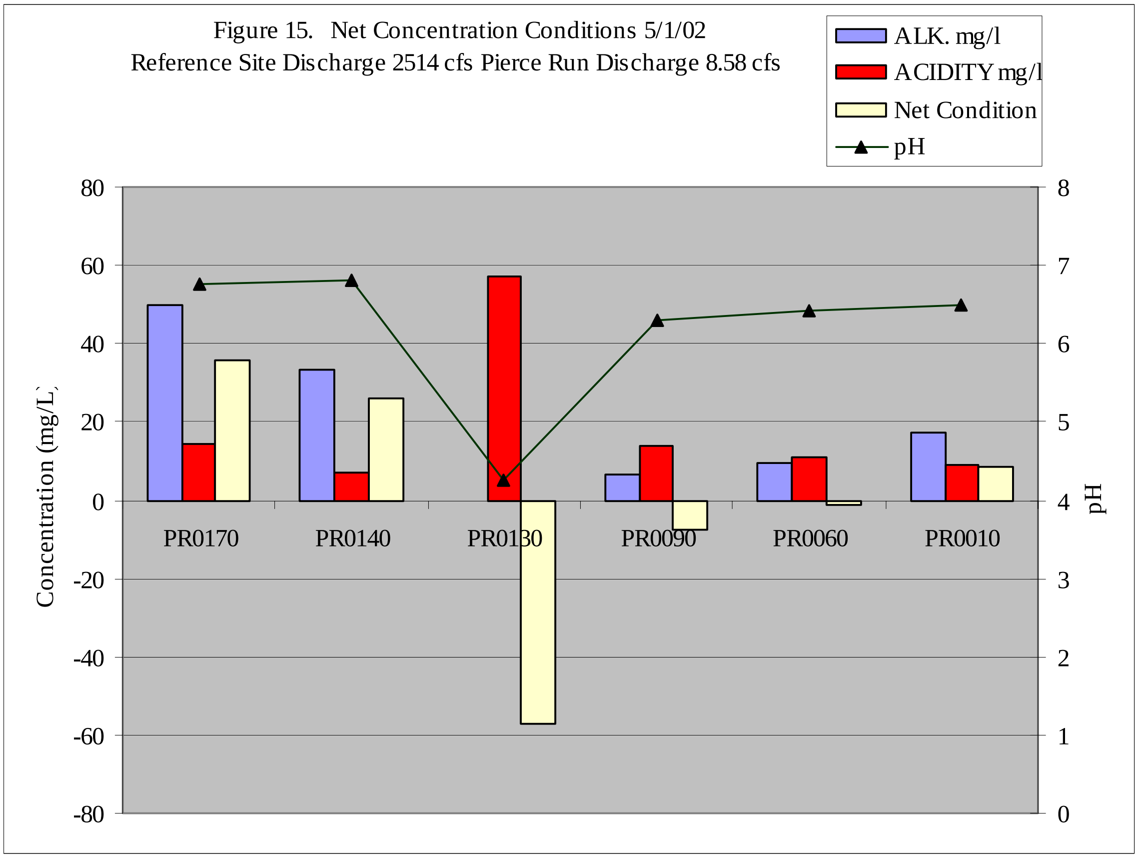
Pierce Run was identified as a source of AMD to Raccoon Creek prior to the current Middle Basin study. It is the only tributary in the study area to receive mention in any of the historical water quality literature. The Pierce Run sub-basin does not exhibit a very consistent water quality trend, and alternates between net alkaline and acidic states. This may be due to influx of treated discharge from active surface mining and coal preparation facilities in the headwaters of the sub-basin. Figure 14 shows that samples taken in May and into June of 2002 in the mainstem of Pierce Run very near the confluence with Raccoon Creek were in a net alkaline state (negative values on the pollutant load graphs represent an alkaline load.)

The Entire Pierce Run mainstem was assessed on four occasions: twice in May, once in June, and once in August of 2002 (providing four PR0010 samples). The May sampling events took place during very high basin-wide flow regimes (reference site flow conditions of 2514 cfs and 1665 cfs.) The June sampling occurred under much more moderate flows, (Reference Site flow: 119 cfs) and in August during a low flow scenario of 5 cfs at the reference site. The discharge of Pierce Run was sampled on six more occasions during basin wide sampling that occurred during assessment of the mainstem of Raccoon Creek. The corresponding Pierce Run discharge is provided for each date samples were collected. These ten samples representing PR0010 provide a good look at the changes in contribution to Raccoon Creek through the variation of season and discharge levels.  While net conditions do change between very high and low flow events, it is not apparent what factors play into the variation.  Some of the fluctuation between acidic and alkaline conditions may be due to the coal preparation facility in the headwaters of the stream.  The remaining effect comes from the complex combination of surface runoff and deep mine discharge sites that enter into the Pierce Run mainstem.  There are numerous tributaries in the sub basin, some of which are not substantially degraded by AMD and provide relatively high alkaline water to the mainstem.

Figure 14.  Pierce Run (PR0010)  net load contributions to the mainstem of Raccoon Creek




The sub basin sampling that took place along Pierce Run's mainstem indicates two specific sources provide the bulk of the AMD degrading the stream.  Each of the May sub-basin assessments  (Fig.#15 and #16) shows a net alkaline discharge for Pierce Run at its mouth (for graphs depicting concentration conditions, negative values reflect acidic conditions).  Whether this condition is a result of the active mining operations or dilution from elevated levels of surface run-off is not easily determined. However, the sampling data for each occasion show a change from net alkaline conditions to net acid conditions between sites PR0140 and PR0130.  The deep mine seep at this location has since been sampled and labeled PR0135.  On each occasion the water quality improved downstream of the seep until discharging with net alkalinity at PR0010. (See Map # 8 for site locations).



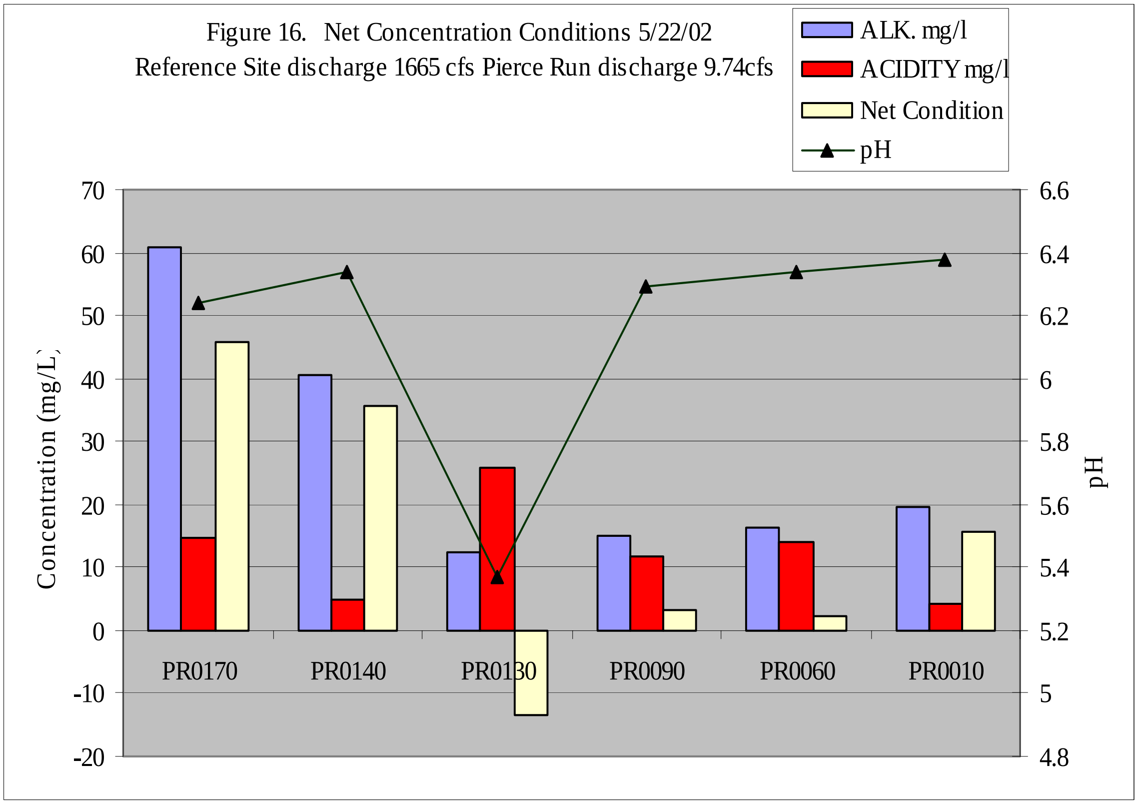
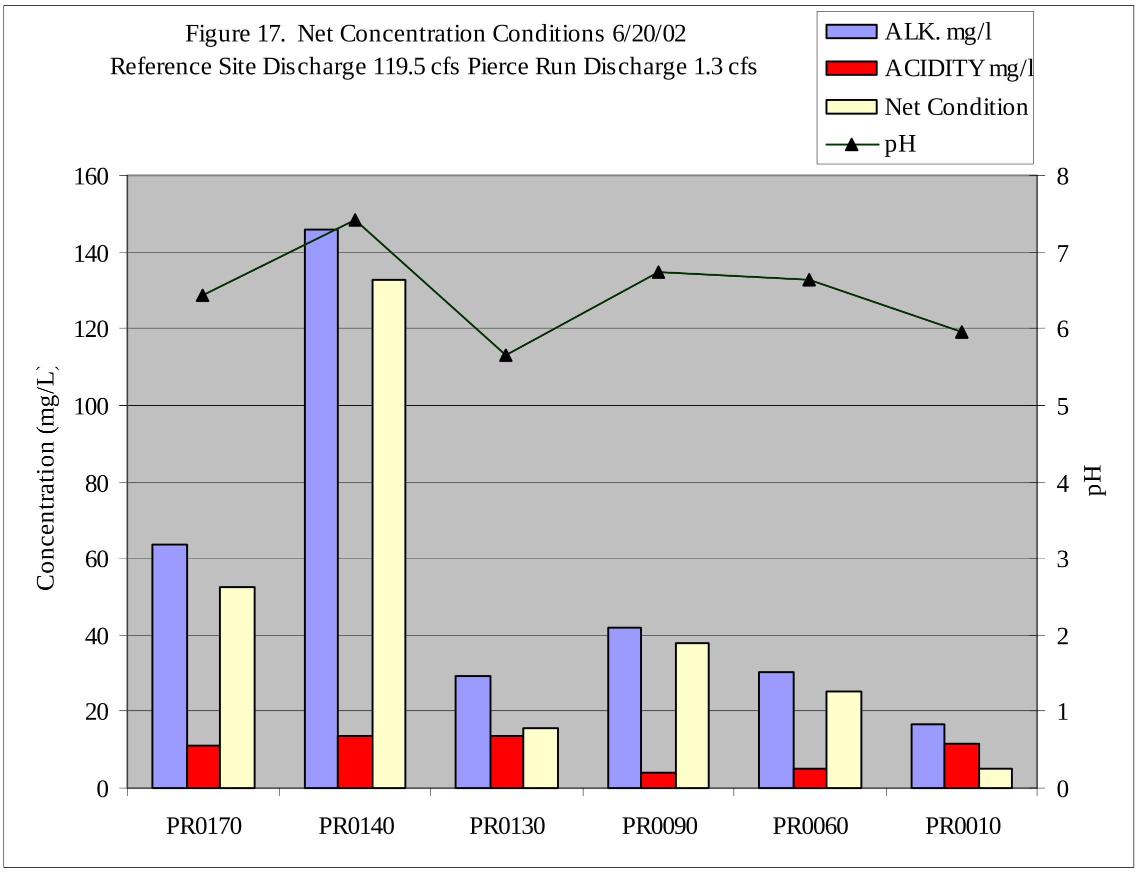
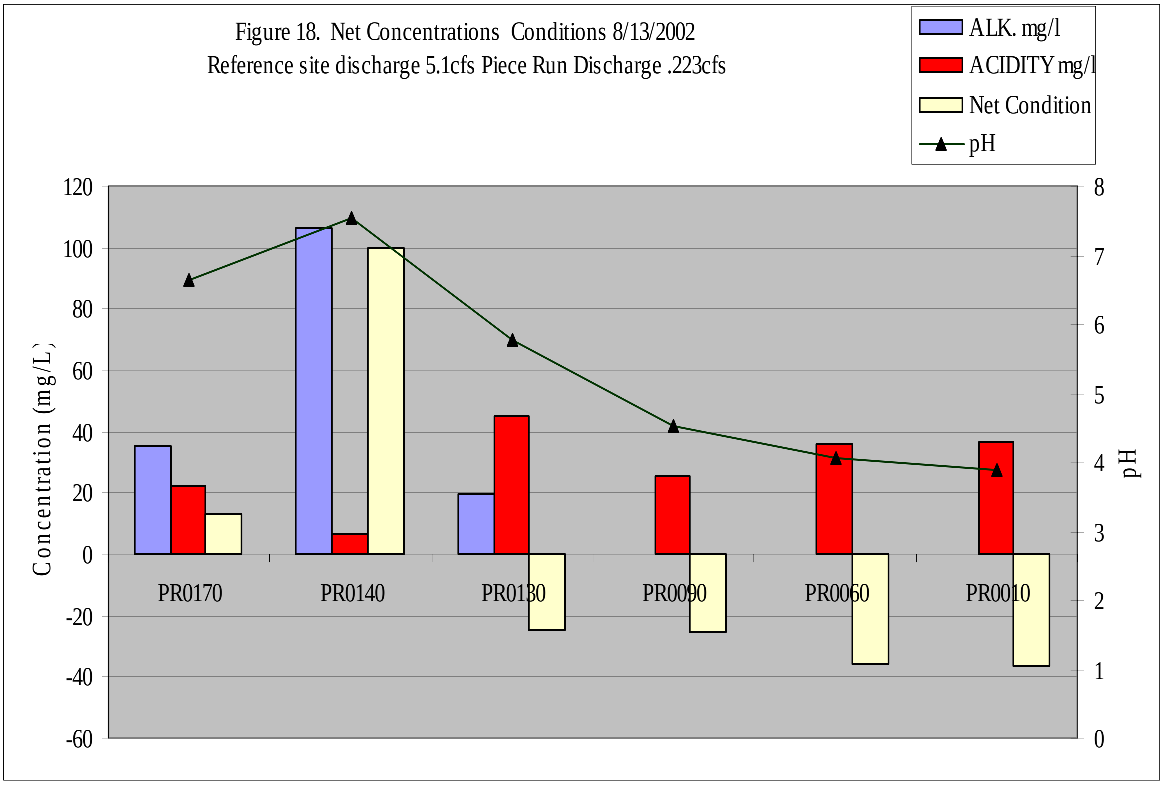


Figure 16. Net Concentration Conditions 5/22/02
Reference Site discharge 1665 cfs Pierce Run discharge 9.74cfs
ALK. mg/l
ACIDITY mg/l
Net Condition
pH
Concentration (mg/L)
pH
70
60
50
40
30
20
10
0
-10
-20
6.6
6.4
6.2
6
5.8
5.6
5.4
5.2
5
4.8
PR0170
PR0140
PR0130
PR0090
PR0060
PR0010

The June sampling data (Fig. #17) does not show net acidic conditions in Pierce Run, but the seep at site PR0135 again degrades the water causing a reduction in net alkalinity from 130 mg/l to 15 mg/l. It removes nearly all of the buffering capacity available in the stream. At this low flow Pierce Run exhibited a new trend. This sampling event shows the stream degrading between PR0060 and the final site PR0010. The stream loses over a half point of pH from 6.6 to 5.9 and almost all of its net alkalinity from 25 mg/L to 4 mg/L.



The August sampling (Fig. #18) shows even worse net conditions in Pierce Run, as the impact of PR0135's discharge to the stream consumes all the available alkalinity. The stream reverts to net acidic conditions and degrades further before reaching Raccoon Creek. The observed low flow trend of degradation downstream of site PR0130 led to the identification of the second priority sight in the Pierce Run sub-watershed. This site has since been sampled and labeled PR0016. This site is located adjacent to the junction of State Route 32 in Vinton County Road 10, upstream of the mouth of Pierce Run tributary 0015 (sampled at PR0015).




A complete acid load mass balance for Pierce Run was attempted in March of 2003. Unfortunately, the discharge measurements did not allow for an accurate accounting and balancing of the chemical conditions of the stream. Table 3 provides the data for the mass balance samples taken in March of 2003. The sum of the tributary discharge was just over 4 cfs, less than the measured discharge at the confluence of Pierce Run. The sum of the acid and alkaline loads from all the tributaries in the watershed equaled 102 pounds per day of alkalinity. The calculated load for Pierce Run at its confluence was 610 lbs per day of acidity. Such discrepancies in flow and calculated loads make modeling the chemical conditions difficult. The data does show that eight of the eleven tributaries provide an alkaline load to the mainstem of

Pierce Run. Tributaries PR0040, 0050, 0070, 0112 and 0115 had acidity values less than 5mg/L. The sampling event also confirmed sites PR0016 and PR0135 as the biggest contributors of acid to the Pierce Drainage system. The sum of the three acidic sources (tributary PR0015, PR0135, PR0137) account for the entire acid load measured at PR0010. Due to elevated flows over the anticipated summer dry season it was not possible to conduct a mass-balance sampling event at low flow. It is recommended that when conditions allow a second sampling is done.

**Table 3: March 2003 Pierce Run Watershed Water Quality Data**

| | **Site ID** | **Flow (cfs)** | **Acid /Alkaline Load(#'s/day)** | | | |
|---|---|---|---|---|---|---|
| Pierce Run confluence | PR0010 | 10.79 | 610 | Acid | | |
| Sum of all Tributaries: | | **6.78** | 102 | Alkaline | Acidity | alkalinity |
| Individual tributaries | PR0015 | 1.681 | 418.921224 | Acid | 46.3 | 0 |
| | PR0040 | 0.108 | -7.5279579 | Alkaline | 3.45 | 16.4 |
| | PR0050 | 0.137 | -16.798014 | Alkaline | 4.02 | 26.8 |
| | PR0070 | 1.498 | -63.778156 | Alkaline | 4.99 | 12.9 |
| | PR0112 | 1.05 | -63.863307 | Alkaline | 4.8 | 16.1 |
| | PR0115 | 0.725 | -9.2484725 | Alkaline | 4.29 | 6.66 |
| | PR0135 | 0.121 | 133.838437 | Acid | 205.5 | 0 |
| | PR0137 | 0.152 | 48.9656362 | Acid | 59.85 | 0 |
| | PR0150 | 0.137 | -11.783682 | Alkaline | 5.82 | 21.8 |
| | PR0160 | 0.331 | -312.26207 | Alkaline | 9.73 | 185 |
| | PR0180 | 0.355 | -53.693082 | Alkaline | 27.3 | 55.4 |
| | PR0190 | 0.488 | -164.9541 | Alkaline | 11.9 | 74.7 |

(See Map # 8 for site locations)

*Priority Sites:*

**PR0135: Oreton Hollow Seep**

The Pierce Run subwatershed has been extensively deep mined and continues to be surface mined. There are countless diffuse seeps from early 1900’s auger and drift mines, barren spoil piles, and even sites reclaimed under early state reclamation programs that seep acidic water from slopes and road cuts. The most consistent offender is the deep mine seep site PR0135. The initial discharge from the mine comes out at one single location on the side of a steep hill. It travels in a channel for a short distance before entering a wetland area covering approximately two acres. The wetland is filled to the depth of two to three feet in some locations with iron and aluminum precipitate. The water flows over the deposited metals as a shallow sheet flow and discharges to Pierce Run at a number of locations. Investigation along the streambed near the wetland found soil piping that transported flow subsurface from the wetland to Pierce Run.

PR0135 is associated with an entry to mine complex Vn-80 in Section 33, Vinton Township, Vinton County, Ohio. Historic mine maps show an extensive underground mine in the area. The entry at PR0135 was the main entry to the west side of the complex. Numerous openings were located up drainage from the main entry on the east and west side of the mine, but are no longer present. The Waterloo Coal Company is working on an active strip mine permit with limits extending within 25 yards of PR0135. The area has recently been strip-mined, resulting in the removal of at least the mine entries and possibly much of the old mine. It is not clear how this may affect the quality or quantity of water discharging at PR0135. The mine map dates the last work to have been certified in October of 1924 and that the mine had been active as early as 1907. The coal seam being mined was the Clarion (no. 4a) seam, and the mine was owned and operated by the Oreton Mining Company.

PR0135 was sampled three times (May, June, and August) during the summer of 2002. Discharge was not measured during these first three samples. Table 4 briefly describes the acid and metals concentrations as the water exits the deep mine portal, which has collapsed almost entirely.

**Table 4: 2002 Water Quality Data for PR0135 Oreton Hollow Seep**

| Date | pH | ACIDITY mg/l | ALK. mg/l | IRON mg/l | ALUMINUM mg/l | MANGANESE mg/l |
|---|---|---|---|---|---|---|
| 5/22/2002 | 3.87 | 860 | 0 | 409 | 40.1 | 4.59 |
| 6/20/2002 | 2.65 | 1015 | 0 | 324 | 43.5 | 5.94 |
| 8/13/2002 | 2.38 | 1160 | 0 | 215 | 53.8 | 6.98 |

PR0135 was then revisited and sampled during the months of June and July of 2003. Both water quality samples and discharge measurements were collected on five occasions. Table 5 provides the water quality data for these sampling events. During this period the chemical water quality data appears to be relatively stable. The discharge from the seep ranged from 20 to 30 gallons per minute (GPM) and acidity levels were consistently at or slightly above 1000 mg/L. Peak degradation conditions for each category are highlighted in bold text in the graph. These conditions show that acidity concentration and loading along with the greatest combined metal load (iron, aluminum and manganese) peaked during the highest measured discharge level while metal concentrations peaked during the lowest discharge level. On average the seep is producing 426.9 pounds of acid a day and 190 pounds of combined metals a day at a discharge of 33.2 gallons per minute.

**Table 5: 2003 Water Quality Data for PR0135 Oreton Hollow Seep**

| Date | pH | Gallons Per Minute | ACIDITY mg/l | ACIDITY LOADING | METALS LOADING lbs/day | IRON mg/l | ALUMINUM mg/l | MANGANESE mg/l |
|---|---|---|---|---|---|---|---|---|
| 6/25/2003 | 4.31 | 37.0496 | 1003 | 445.92 | 218.01 | 443 | 39.1 | 6.61 |
| 7/1/2003 | 4.24 | 22.8928 | 1108 | 304.38 | 149.83 | **494** | **42.7** | **6.88** |
| 7/9/2003 | **4.19** | 31.9424 | 910 | 348.81 | 162.43 | 384 | 32.3 | 6.04 |
| 7/15/2003 | 4.36 | **42.5152** | **1195** | **609.66** | **251.59** | 448 | 37.1 | 6.37 |
| 7/22/2003 | 4.38 | 31.9424 | 1111 | 425.85 | 170.76 | 396 | 41.5 | 6.48 |
| Average Values | 4.296 | 33.26848 | 1065.4 | 426.92 | 190.52 | 433 | 38.54 | 6.476 |
| Peak Discharge 42.5 GPM | | | | | | | | |
| Lowest Discharge 22.9 GPM | | | | | | | | |

**Tributary PR0015 – Unnamed tributary to Pierce Run**

PR0015 is the last tributary to discharge to Pierce Run before its confluence with Raccoon Creek. During the initial reconnaissance of the Pierce Run subwatershed PR0015 did not appear to affect the acidity conditions in Pierce Run. Samples above and below the tributary showed improvement in the net chemical condition. The final two phase II sub-basin assessments indicated otherwise, when samples taken above and below PR0015 indicated a degrading net chemical condition below the tributary. The mass-balance sampling event confirmed and quantified the acidic discharge of PR0015, demonstrating that PR0015 produces 16% of the total flow in Pierce Run and 69% of the acid load (See Table 4).

Investigation along the PR0015 tributary identified water discharging through an exposed coal seam associated with mine complex Vn- 96. The mine complex has one visible drift entry that has collapsed. Water does not discharge at the surface via the old entry, but it is apparent that some water is being transferred as base flow through to the stream near the collapsed entry. The majority of the discharge is being transported through the coal seam that has been exposed by the construction of SR 32, and by erosion. Vn-96 is located in Section 19 of Vinton Township, Vinton County, Ohio. The Thompson Coal Company originally owned the mine, and the historic map indicates their certification in 1933 to mine the Clarion (no.4a) coal seam. The complex had two entrances, one located adjacent to SR32 (where water is now discharging through the coal seam,) and a main entrance further south along Vinton County Rd. 10. The main entrance has also collapsed. Water does seep from the mine in a few places along the hillside facing CR 10. It collects in a very shallow pond in the floodplain of Pierce Run and tributary PR0015, but does not contribute to either one of these streams through surface flow. It may be providing some base flow, but generally appears to evaporate over time.

When investigating the coal seam seep (sampled and labeled PR0016) it became apparent that the upstream water in the receiving stream (tributary 0015) did not carry an AMD signature. Field pH readings show pH between 7 to 7.5. Below the exposed coal seam and collapsed mine entry the pH regularly dropped to below 4.0 and below 3.5 on a few occasions. It was not possible to measure the amount of water discharging through the coal seam to quantify the flow. Attempts to measure discharge above and below the seep did not provide an accurate measurement of the contribution to the PR0015 tributary flow. The quantity of flow coming from the coal seam seep was not great enough to raise the flow by a measurable amount between upstream and downstream measurements. It was possible to quantify the result of the seep discharge into PR0015 by obtaining a stream discharge downstream of the seep.

The PR0015 tributary was sampled weekly for seven weeks in June and July of 2003. To document the coal seam seep (PR0016) samples were taken downstream of the exposed seam and mine complex (PR0015), directly from the seeping coal seam (PR0016) and upstream (PR0017.) Table 6 provides the data for the samples taken at PR0015. Site PR0015 is a stream sample taken at far enough downstream of PR0016 to allow for sufficient mixing. Because the stream is affected by surface runoff and groundwater recharge the flow along with peak degradation conditions vary a great deal. A moderately strong trend developed with higher metal and acid concentrations occurring at lower discharge rates. Peak acid loading occurred at a much higher discharge rate, and at the peak discharge rate sufficient alkalinity was present to produce a net alkaline load.

Two average values are given for the data in Table 6. The first is that of all samples collected during the time period. The second does not include the highest measured discharge and the data that resulted from analyzing that sample. While both are important it is likely that abating the acid load from PR0015 will focus on net acidic conditions. Further sampling in the tributary may refine the trends developed during this study and pinpoint the discharge rate at which the tributary may be net acidic or net alkaline. For treatment purposes the difference between the average acidity concentration and acid load may be significant enough to affect the design of the treatment alternative.

**Table 6: 2003 Water Quality Data for PR0015**

| PR0015 | Date | pH | Gallons Per Minute | ACIDITY mg/l | ALKALINITY mg/l | Net Load lbs/day | METALS LOADING lbs/day | IRON mg/l | ALUMINUM mg/l | MANGANESE mg/l |
|---|---|---|---|---|---|---|---|---|---|---|
| Treatment | 6/11/2003 | 3.79 | 193.54 | 54.50 | 0.00 | 126.57 | 58.85 | 20.70 | 3.92 | 0.64 |
| Load | 6/25/2003 | 3.08 | 170.24 | 161.00 | 0.00 | **328.90** | 87.84 | 32.00 | 9.73 | 1.12 |
| | 7/1/2003 | **2.93** | 61.38 | **293.00** | 0.00 | 215.80 | 63.95 | 68.10 | **16.70** | 1.73 |
| | 7/9/2003 | 3.50 | 148.29 | 80.00 | 0.00 | 142.36 | 47.17 | 19.10 | 5.67 | 1.65 |
| | 7/15/2003 | 3.66 | 91.39 | 97.80 | 0.00 | 107.26 | 33.33 | 22.70 | 6.33 | 1.26 |
| | 7/22/2003 | 3.62 | 54.66 | 120.00 | 0.00 | 78.70 | **193.48** | **263.00** | 8.49 | **22.50** |
| | 8/5/2003 | 6.46 | **452.48** | 10.40 | 43.00 | -177.01 | 40.94 | 5.37 | 1.22 | 0.93 |
| | *Negative Value represents a positive alkaline net load | | | | | | | | | |
| Ave. Values | | 3.86 | 167.42 | 116.67 | 6.14 | 117.51 | 75.08 | 61.57 | 7.44 | 4.26 |
| Ave. value when net acidic | | 3.43 | 119.91 | 134.38 | | 166.60 | 80.77 | 70.93 | 8.47 | 4.82 |
| Peak Discharge 452.5 GPM Lowest Discharge 54.66 GPM | | | | | | | | | | |

Table 7 provides data for the samples collected at PR0016. These samples were collected as the water was exiting the coal seam. It was not possible to determine the rate of discharge as the water exited the coal seam and free fell into the PR0015 tributary. The water seeps through the exposed outcrop in many locations. Over the course of sampling the amount of water discharging through the outcrop did decrease substantially, but at no point did flow cease entirely. The chemical water quality proved to be very consistent and highly acidic.

**Table 7: 2003 Water Quality Data for PR0016**

| Date | pH | Gallons Per Minute | ACIDITY mg/l | IRON mg/l | ALUMINUM mg/l | MANGANESE mg/l |
|---|---|---|---|---|---|---|
| 6/11/2003 | 2.44 | NA | 1987 | 513 | 87 | 2.4 |
| 6/25/2003 | 2.41 | NA | 1875 | 459 | 86.3 | 2.41 |
| 7/1/2003 | 2.46 | NA | 1846 | 443 | 85.2 | 2.34 |
| 7/9/2003 | 2.36 | NA | 1867 | 420 | 85.8 | 2.41 |
| 7/15/2003 | 2.47 | NA | 1950 | 408 | 93.2 | 2.55 |
| 7/22/2003 | 2.58 | NA | 1964 | 458 | 95.4 | 2.61 |
| 8/5/2003 | 2.4 | NA | 1944 | 432 | 93.1 | 2.6 |
| Average Values | 2.45 | | 1919.00 | 447.57 | 89.43 | 2.47 |

Water quality samples were also collected upstream (PR0017, Table 8) of the exposed coal seam in the tributary. The point of sampling this location was to determine if the coal seam seep was the only major AMD contributor and if the chemical signature of the water at this location was appropriate for use in a treatment scenario. The water does provide a consistent net alkaline load but also carries a low concentration of acidity.

**Table 8: 2003 Water Quality Data for PR0017**

| Date | pH | Gallons Per Minute | ACIDITY mg/l | ALKALINITY mg/l | Net Load lbs/day | METALS LOADING lbs/day | IRON mg/l | ALUMINUM mg/l | MANGANESE mg/l |
|---|---|---|---|---|---|---|---|---|---|
| 6/11/2003 | 7.04 | 193.536 | 2.96 | 40 | -86.02 | 2.99 | 0.50 | 0.25 | 0.54 |
| 6/25/2003 | 6.98 | 170.24 | 5.82 | 47.5 | -85.15 | 3.46 | 0.65 | 0.25 | 0.79 |
| 7/1/2003 | 7 | 61.376 | 8.68 | 56.7 | -35.37 | 2.05 | 1.47 | 0.35 | 0.96 |
| 7/9/2003 | 6.56 | 148.288 | 8.58 | 69.4 | -108.23 | 5.77 | 1.22 | 0.25 | 1.76 |
| 7/15/2003 | 6.89 | 91.392 | 7.68 | 55.4 | -52.33 | 2.45 | 0.81 | 0.25 | 1.16 |
| 7/22/2003 | 6.96 | 54.656 | 8.67 | 70 | -40.22 | 2.97 | 1.68 | 0.25 | 2.58 |
| 8/5/2003 | 6.94 | 452.48 | 6.61 | 63.3 | -307.81 | 11.66 | 0.89 | 0.25 | 1.00 |
| *Negative Value represents a positive alkaline net load | | | | | | | | | |
| Ave. Values | 6.91 | 167.42 | 7.00 | 57.47 | -102.16 | 4.48 | 1.03 | 0.26 | 1.26 |

*Location/Access:*

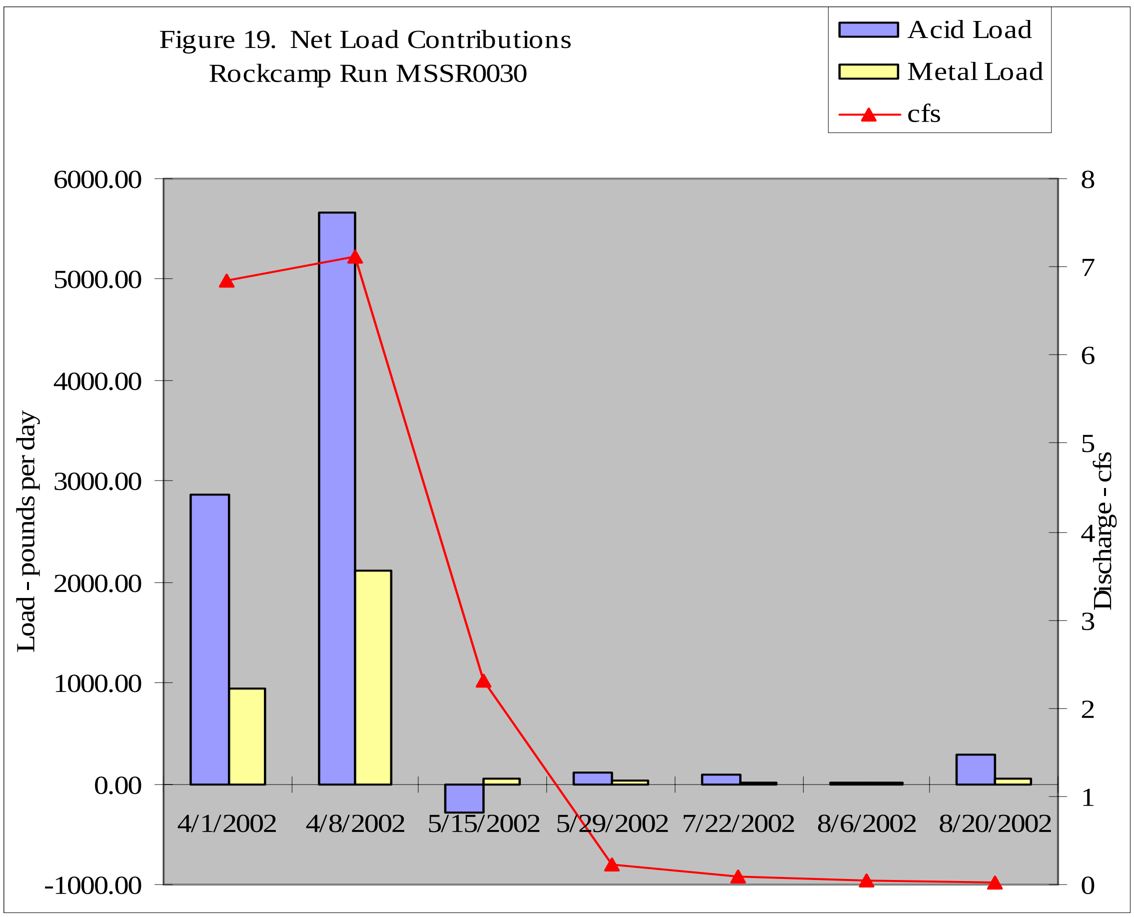
Most of the Pierce Run subwatershed is easily accessible via State Route 160, which runs east-west along most of the length of the mainstem and through the headwaters. The confluence of Pierce Run is only accessible by foot. The easiest way to travel to the mouth is to park along the Tennessee Gas pipeline right of way where it crosses Vinton County Rd 10. By walking east along the pipeline you will quickly access the mainstem. This is the location of sampling site PR0010.

The Oreton Hollow Seep, PR0135, is very difficult to access. Along SR 160 from the abandoned town of Oreton is a brick vault that was housed in the General Store. Parking at the vault and crossing the stream (south of the road) provides access to the edge of a wetland filled with iron and aluminum deposits from the PR0135 seep. Accessing the seep requires skirting the wetland and following the water flowing into the wetland to its source, the PR00135 seep. The walk is very difficult and walking through the wetland is not advised. The precipitate is deep enough that it is possible to become stuck. Depending on the condition of the underbrush it can take a half an hour to reach the location of PR0135.

**Rockcamp Run**

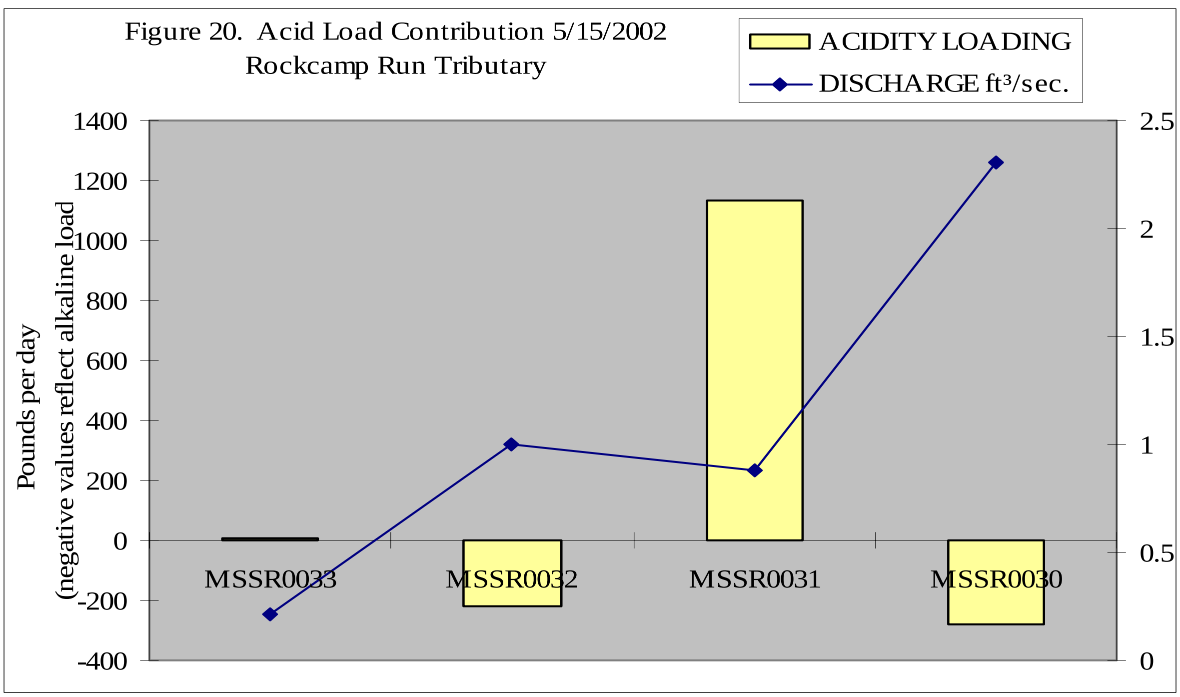
| | |
|---|---|
| **Name:** | **Rockcamp Run** |
| **Tributary To:** | Raccoon Creek |
| **Location:** | Vinton County |
| **Quadrangles:** | Mulga, McArthur |
| **Drainage:** | 2.9 Square Miles |

The Rockcamp Run tributary is the most consistent AMD contributor in the Middle Basin study area. Regardless of flow conditions, it tends to be net acidic (Fig. #19) with concentrations at the confluence ranging from 39 mg/l to 198 mg/l of acidity. Alkaline conditions were only recorded once out of seven sampling events. MSSR0030 represents the confluence of the three Rockcamp Run tributaries.



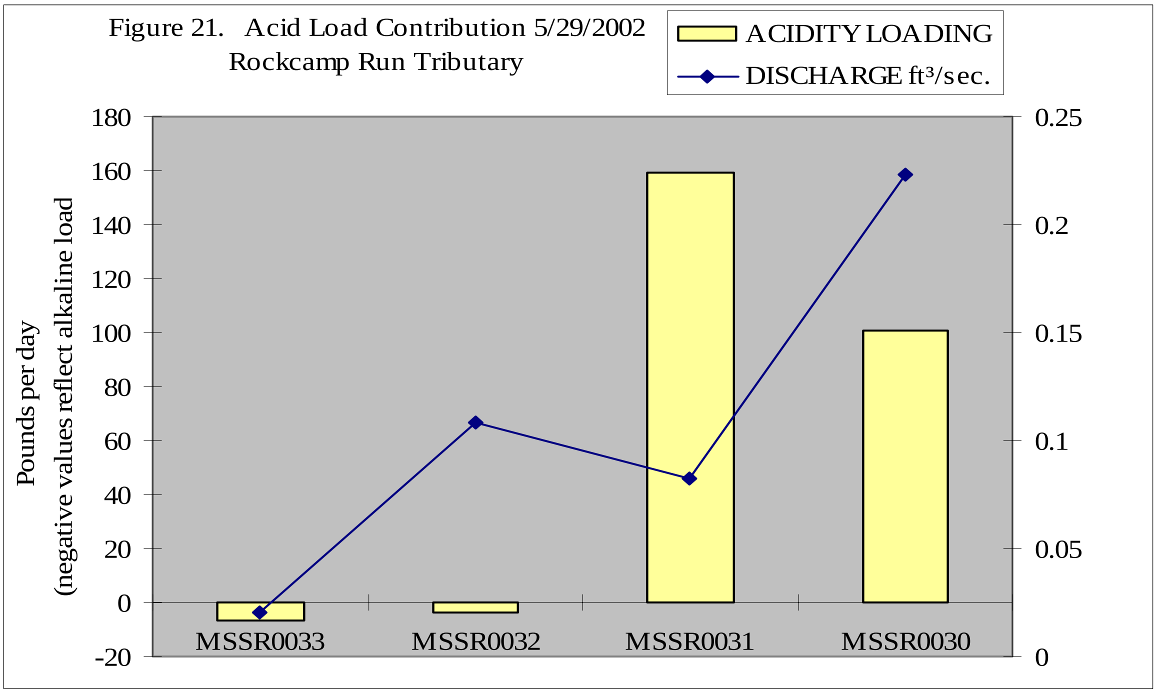

Three tributaries that are themselves affected by AMD to varying degrees feed the sub-watershed. Much of tributary MSSR0031's base flow comes from a deep mine discharge that has the greatest and most consistent impact. It does not appear to dry up during the driest of the annual flow cycles and carries high concentrations of acidity (238 to 358 mg/l) to the mainstem. During the drier months tributary MSSR0031 provides the only water reaching the confluence of Rockcamp Run with Raccoon Creek. Tributary MSSR0032 has undergone significant change during the study period. ODNR-DMRM contracted with the Sands Hill Coal Company to reclaim a 13-acre coal refuse pile that covered most of the small tributary's drainage area. During the Middle Basin study the pile was under various stages of reclamation that may have significantly affected water chemistry in the adjacent stream. Sampling at MSSR0032 produced variable results ranging from net acidic to net alkaline conditions during the study period. The third tributary, MSSR0033, does not significantly affect water quality within the Rockcamp Run sub-basin. It has also fluctuated between alkaline and acidic conditions, but its contribution to the overall flow in Rockcamp Run has never reached more than 10% and it is often dry in the summer months.

Figures 20-22 provide the data for each of the subbasin sampling events in Rockcamp Run. Each event points directly to MSSR0031 as the alrgest and most significant source of AMD in the watershed. See Map #9 for sample locations.



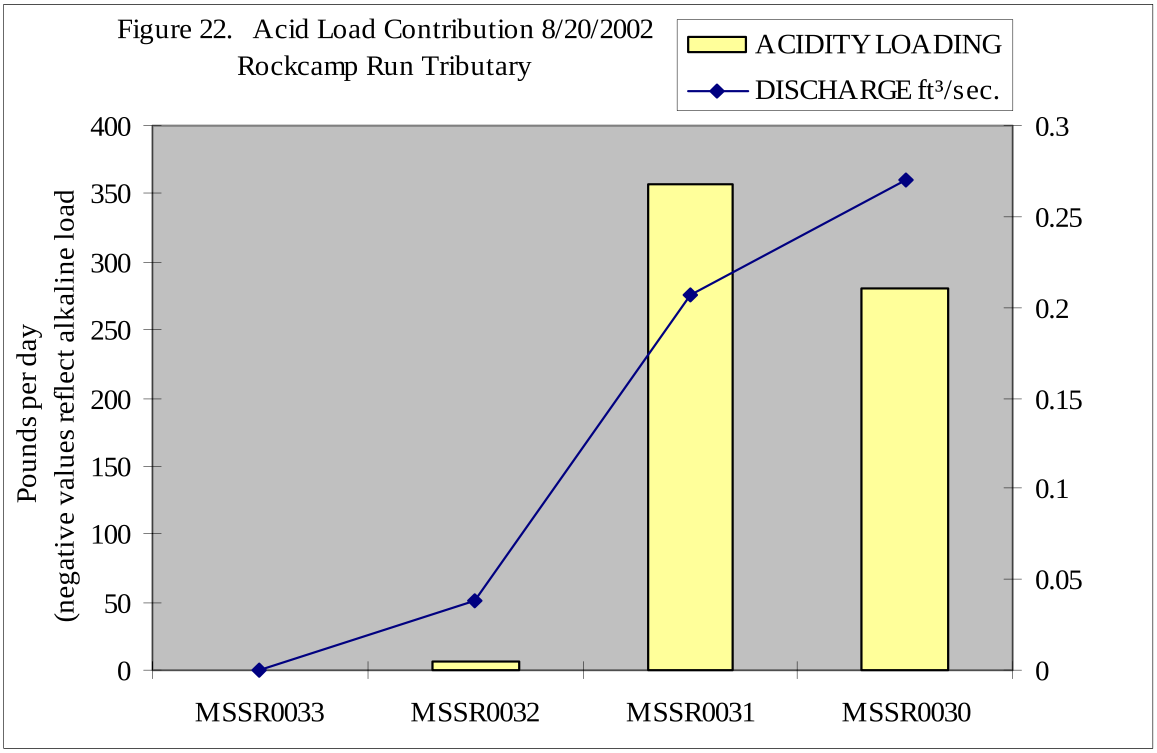

It was surprising to see the data from the May 15, 2002 sampling event showing a net alkaline discharge (Fig #20). The acid load contributed by MSSR0031 is very high yet the stream is net alkaline, producing almost 300 pounds per day of alkalinity. It is not clear what factors allow the mainstem of Rockcamp Run to receive such a high acid load and yet maintain net alkaline conditions.

A second May sub watershed assessment was conducted on May 29, 2003. The results of this event (Fig. #21) were more in line with what was expected of the tributary. The calculated parameter loads, when compared with the first May assessment (May 15, 2002) had dropped substantially given a substantial decrease in flow volume. There was little change in the signature of the data for the three tributaries, and the Rockcamp Run discharge (MSSR0030) was net acidic.




A final low flow assessment of the Rockcamp Run sub-basin occurred on August 20, 2003. Figure #22 shows that nearly all the flow and resulting acid load was being generated by

MSSR0031. At such a dry time of year it is expected that the tributary, which is being fed by a deep mine discharge, would provide most of the base flow and acid load to Rockcamp Run.




While the Rockcamp Run discharge can be highly acidic and may be limiting the recovery in the receiving segment of Raccoon Creek, it does not have the effect that Pierce Run has on the mainstem. The sampling results for the Raccoon Creek mainstem site downstream of Rockcamp Run (MSSR0040) generally show improvement rather than degradation. Table 9 indicates that on three of eight sampling occasions (bold, italic numbers) the alkalinity concentration level dropped downstream of Rockcamp Run but never by more than 5 mg/l. On most occasions the pH above and below Rockcamp Run has remained constant with little net change. PH varied during the spring of 2002 at a time when flow conditions were high.

**Table 9: Variation in pH in the Mainstem of Raccoon Creek Upstream and Downstream of the Rockcamp Run Discharge.**

| Date | Upstream Concentration | pH | Downstream Concentration | pH | Net pH Change |
|---|---|---|---|---|---|
| 4/1/2002 | 5.96 mg/l alkalinity | 6.2 | 9.7 mg/l alkalinity | 6.3 | 0.1 |
| 4/8/2002 | 7.84 mg/l acidity | 5.3 | 9.02 mg/l alkalinity | 6.1 | 0.8 |
| 5/15/2002 | 16.06 mg/l alkalinity | 6.6 | ***15.42*** mg/l alkalinity | 5.9 | -0.7 |
| 5/29/2002 | 13.71 mg/l alkalinity | 6.2 | 14.15 mg/l alkalinity | 6.2 | 0 |
| 7/22/2002 | 18.52 mg/l alkalinity | 6.6 | ***13.85*** mg/l alkalinity | 6.5 | -0.1 |
| 8/6/2002 | 28.67 mg/l alkalinity | 6.8 | 29.0 mg/l alkalinity | 6.8 | 0 |
| 8/20/2002 | 16.12 mg/l alkalinity | 6.5 | ***11.4*** mg/l alkalinity | 6.5 | 0 |

It is possible that the Raccoon Creek mainstem site (MSSR0040) is being affected some by a deep mine discharge labeled MSSR0039. This mine complex is not in the Rockcamp Run subwatershed. It is situated less than a half mile downstream of Rockcamp Run and discharges water along a railroad grade that is adjacent to the mainstem of Raccoon Creek. Water from the collapsed portal travels less than 75 feet before entering Raccoon Creek. This site does tend to dry up during the annual low flow cycle and did so during the summer of 2002. Samples were taken three times during the 2002 summer sampling. The first two occurred in May and the third in July. In June and August there was not sufficient flow to collect surface water samples. It is likely the water was still reaching Raccoon Creek during these months as base flow that originated in the mine complex. Even during times with no surface flow from the entry iron precipitate is still evident along bank of Raccoon Creek. The site was sampled four times during the month of July in 2003. The flow coming from MSSR0039 does not reach a very high rate reaching a maximum of 10 gallons per minute and, as mentioned, dropping to nearly zero during dry periods. Though the flows are not substantial the concentration of metals and acidity are very high, allowing for the contribution of MSSR0039 to rise rapidly with increased flow.

*Priority Sites:*

**MSSR 0034- Hawks Mine 656**

Even though all three of the tributaries in the Rockcamp Run subwatershed are affected by AMD, the data shows that the effect on Raccoon Creek is dominated by tributary MSSR0031 and the Hawk Mine No. 656 seep labeled MSSR0034. The Hawks Mine seep is associated with mining complex Vn-102 located in section 30, Wilkesville Township, Vinton County, Ohio. The historic mine map dates the works to 1978 when the final mine map was submitted to the State of Ohio by the Waterloo Coal Company. They were permitted to mine the Clarion (no. 4) coal seam. The location of the discharging MSSR0034 seep is not mapped as one of the original entries identified for the complex. Although the site resembles a portal it may just be the result of subsidence. The 1978 map indicates that entries for Vn-102 are located in the MSSR0032 tributary, along a reach of stream that was recently reclaimed during the refuse pile reclamation project mentioned in the initial discussion of the Rockcamp Run subwatershed. Since the reclamation was complete it has not been determined whether these openings are still accessible or have been removed. No water has been observed discharging from these former mine entry sites.

MSSR0034's discharge falls 8 to 10 feet before collecting in a pool that feeds tributary MSSR0031. Once it enters the tributary the water only travels a short distance before flowing into an impoundment created during the mining process. The impoundment flows through a limestone and refuse check dam before exiting its small hollow and joining the other two tributaries of Rockcamp Run near its mouth

MSSR0034 was sampled seven times between June and early August. The chemical signature of MSSR0034 remained relatively stable during the sampling period with acidity levels on most occasions ranging from 400 to 470 mg/L.

**Table 10: 2003 Water Quality Data for MSSR 0034 Hawks Mine Seep**

| Date | pH | Gallons Per Minute | ACIDITY mg/l | ACIDITY LOADING Lbs/day | METALS LOADING lbs/day | IRON mg/l | ALUMINUM mg/l | MANGANESE mg/l |
|---|---|---|---|---|---|---|---|---|
| 6/11/03 | 3.10 | 42.52 | 340.00 | 173.46 | 86.52 | 158.00 | 10.20 | 0.82 |
| 6/25/03 | 3.50 | 54.66 | 442.00 | 289.90 | 138.91 | 198.00 | 12.00 | 1.07 |
| 7/1/03 | 3.40 | 37.05 | 449.00 | 199.62 | 93.59 | 197.00 | 11.40 | 1.39 |
| 7/9/03 | 3.25 | 27.24 | 417.00 | 136.30 | 60.14 | 173.00 | 9.48 | 0.88 |
| 7/15/03 | 3.45 | 22.89 | 467.00 | 128.29 | 56.87 | 194.00 | 11.30 | 1.00 |
| 7/22/03 | 3.50 | 48.38 | 435.00 | 252.56 | 111.87 | 181.00 | 10.10 | 0.92 |
| 8/5/03 | 3.77 | 9.50 | 350.00 | 39.90 | 18.56 | 154.00 | 7.46 | 0.78 |
| Ave. Values | 3.42 | 34.61 | 414.29 | 174.29 | 80.92 | 179.29 | 10.28 | 0.98 |
| Peak Discharge 54.66 GPM | | | | | | | | |
| Lowest Discharge 9.5 GPM | | | | | | | | |

**Hawk Station Surface Mine**

The Hawk Station Surface Mine is a 1.5-acre unreclaimed surface mine adjacent to the mainstem of Raccoon Creek. The area produces an unquantified sediment and AMD load to

Raccoon Creek due to the amount of exposed coal refuse and mining spoils. The area also includes approximately 140 feet of stream bank that is exposed and eroding heavily.

**MSSR0039 –Railroad Seep**

It is very difficult to distinguish the individual effects of Rockcamp Run and deep mine seep MSSR0039 on Raccoon Creek. The water from MSSR0039 discharges into the mixing zone of the confluence of Raccoon Creek and Rockcamp. The seep is associated with the mining complex Vn-8 and is located in Section 24, Wilkesville Twp, Vinton County, Ohio. The location of the seep is not mapped as one of the two entries into the complex, but it is probable that the seep originates from an unmarked entry. This entry, if it existed as such, is now completely collapsed. As stated, the discharge volume from this seep has never risen above 10 gallons per minute, but the concentrations of metals and acidity are very high regardless of flow conditions in the basin. Its close proximity to the mainstem of Raccoon Creek and its location along the same reach as Rockcamp Run indicate that remediation should be considered for this site.

Table 11 displays the results of sampling that took place at MSSR0039. The water discharging from the seep is highly acidic with very high metal concentrations. The discharge from this site does seem to decline during dry periods as it leveled off from a high of over 9 gallons in per minute on July 1st to around 4.2 gallons per minute during the last three sample events. During 2002 sampling, even though discharge was not measured, the site did reduce in flow to the point where no water was discharging at the surface.

**Table 11: 2003 Water Quality Data for MSSR 0039 Railroad Grade Seep**

| Date | pH | Gallons Per Minute | ACIDITY mg/l | ACIDITY LOADING | METALS LOADING lbs/day | IRON mg/l | ALUMINUM mg/l | MANGANESE mg/l |
|---|---|---|---|---|---|---|---|---|
| 5/15/02 | 2.73 | | 1166.00 | | | 273.00 | 60.70 | 1.35 |
| 5/29/02 | 2.49 | | 1402.00 | | | 308.00 | 70.90 | 1.69 |
| 7/22/02 | 2.45 | | 1893.00 | | | 430.00 | 93.60 | 1.81 |
| 7/1/03 | 2.36 | 9.50 | 2449.00 | 279.12 | 88.92 | 663.00 | 112.00 | 2.56 |
| 7/9/03 | 2.25 | 5.24 | 2818.00 | 177.25 | 47.45 | 626.00 | 123.00 | 2.89 |
| 7/15/03 | 2.33 | 4.22 | 2564.00 | 129.84 | 30.63 | 479.00 | 121.00 | 2.78 |
| 7/22/03 | 2.49 | 4.23 | 2289.00 | 116.19 | 29.21 | 455.00 | 116.00 | 2.59 |
| 8/5/03 | 2.56 | 4.22 | 2167.00 | 109.74 | 30.31 | 481.00 | 113.00 | 2.56 |
| Ave. Values | 2.46 | 5.48 | 2093.50 | 162.43 | 45.31 | 464.38 | 101.28 | 2.28 |
| Peak Discharge 9.5 GPM | | | | | | | | |
| Lowest Discharge 4.22 GPM | | | | | | | | |

*Location/Access:*

Rockcamp Run is accessible via County Road 9 (Hawk Station Rd.) in Vinton County. County Rd. 9 crosses each of the tributaries that come together to form Rockcamp Run above its confluence with Raccoon Creek. Each of the tributaries was sampled very near the road crossing. The mouth to Rockcamp Run is accessible from the old railroad grade adjacent to MSSR0039. To access the mouth and the MSSR0039 seep, turn left at the intersection of County Road 10 and County Road 9. Travel across the mainstem of Raccoon Creek and turn right onto Clarion Rd. Travel across the mainstem of Raccoon Creek again and immediately turn right onto the abandoned railroad grade. The railroad grade is safe to drive on, and provides access to the MSSR0039 discharge site. To access MSSR0030 drive past the MSSR0039 seep approximately 100 yards (the last point at which you can turn around) and park. Continue along the railroad grade on foot to the intersection with Rockcamp Run. This is less than a quarter of a mile from Rockcamp Creek's confluence with Raccoon Creek and where site MSSR0030 was sampled.

The Hawks Mine Discharge, MSSR0034, is not accessible from the road. To access the site, first contact Marvin McKinney, currently the only resident living in Hawk Station. There is an abandoned access road that can be traveled by four-wheel drive or on foot, but it is necessary to receive permission from Mr. McKinney. Once on the access road, drive as far back as possible and park. The tributary is on the left facing up drainage. Walk toward the stream and follow it up drainage and the seep should be evident as it is quite visible and the sound of the water cascading from the discharge site is audible. The seep is not too hard to locate when following the stream back to the red plume of iron precipitate.

## Biological Health

Biological data is used to examine the impact that acid mine drainage has on the aquatic community of the Raccoon Creek watershed. Macroinvertebrates are the group most frequently used in the biological monitoring of water quality. Their relative advantages as indicators of a stream's health over other groups of aquatic organisms are well documented (Rosendberg and Resh, 1993). Macroinvertebrate and fish assessments of polluted streams provide comprehensive data on the health of a watershed and offer water quality information not readily detected by chemical means. Using stream biological assessments, in conjunction with chemical and physical parameters, to examine water quality before and after AMD remediation, reclamation, or treatments, can be of great value. It is the biology of the stream that ultimately reveals its true health both before and after AMD recovery efforts. Acid mine drainage has both direct and indirect impacts on the chemical, physical, biological, and ecological integrity of the stream environment (Table 12). Specific responses of macroinvertebrates in acid mine drainage streams include a decrease in tolerant organisms and reduction in ecosystem productivity.

**Table 12: Biological responses to habitat impairment and degradation (Rankin, 1995)**

| Chemical | Physical | Biological | Ecological |
|---|---|---|---|
| Increased acidity | Substrate modification | Behavioral | Habitat modification |
| Reduction in pH | Turbidity | Respiratory | Niche loss |
| Destruction of buffering system | Sedimentation | Reproduction | Bioaccumulation within food chain |
| | Absorption of metals into sediment | Acute and chronic toxicity | Loss of food source |
| Increase in metal concentrations | Decrease in light penetration | Acid-base balance failure in organisms | Elimination of sensitive species |
| | | Migration or avoidance | Reduction in primary productivity |
| | | | Food chain modifications |

**Biological Health Assessment**

The Ohio EPA uses several structural indices to measure habitat quality and assess the health of aquatic communities in order to determine use designations. Indices used by the Ohio EPA are the Index of Biological Integrity (IBI), the Invertebrate Community Index (ICI) and the Qualitative Habitat Evaluation Index (QHEI).

The IBI is a measure of fish species populations and species diversity. The criteria used to establish the index reflect the biological performance exhibited in natural or least-impacted habitats. The IBI index is a number that reflects total native species composition, indicator species composition, pollutant intolerant and tolerant species composition, and fish condition. The highest possible score is 60, with higher scores indicating healthier aquatic ecosystems. Depending on the pollution tolerance of individual species, the IBI is a general indicator of which species are likely to be found in a given stream (Ohio EPA, Division of Surface Water, 2001).

The ICI is derived from measurements of the macro-invertebrate communities living in a stream or river. The ICI is particularly useful in evaluating stream health because a large number of macro-invertebrate taxa are known to be either pollution tolerant or intolerant. Like the IBI, the ICI scale is 0-60, with higher scores reflecting healthier macro-invertebrate communities and therefore more biologically diverse aquatic ecosystems (Ohio EPA, Division of Surface Water, 2001).

The QHEI is a quantitative assessment of the physical characteristics and in-stream geography of streams and rivers. The QHEI is essential in evaluating land use practices and stream disturbance. Six variables comprise the QHEI metric: substrate type and quality, in-stream cover, channel morphology, riparian zone, pool quality, and riffle quality. The QHEI scale is 0-100, with higher scores reflecting less disturbed and therefore higher quality streams.

The Ohio Water Quality Standards stated in chapter 3745-1 of the Ohio Administrative Code consist of designated uses and chemical, physical, and biological criteria for surface waters, and are designed to represent measurable properties of the environment. Rivers and streams in Ohio receive "use designations" that reflect the aquatic habitat the stream can support and how the water is used. Water quality standards are then established to support those uses. In applications of Ohio water quality standards to management of water resource issues, aquatic life use criteria frequently control protection and restoration requirements. Generally, emphasis on protecting aquatic life results in attaining water quality suitable for all uses, hence the emphasis of aquatic life uses in water quality reports and planning. The four different aquatic life uses currently defined in the Ohio WQS which are potentially applicable to streams in the Raccoon Creek watershed, and the intent of each with respect to the role of biological criteria, are described in the following section. Table 13 summarizes the minimum biological criteria scores for each habitat designation in the Western Allegheny Plateau Ecoregion, of which southeast Ohio is a member.

**Table 13: Ecoregion Biocriteria: Western Allegheny Plateau (OEPA, 1997)**

| | EWH | WWH | MWH | LRW-AMD |
|---|---|---|---|---|
| QHEI | 75 | 60 | 45 | NA |
| ICI | 46 | 36 | 30 | 8 |
| IBI* | 50 | 44 | 24 | 18 |

*wading and headwaters streams

*Warmwater Habitat*

This designation defines the typical warmwater assemblage of aquatic organisms in Ohio's rivers and streams; waters so designated are capable of maintaining a balanced, integrated, and adaptive community of warmwater aquatic organisms. Biological criteria are stratified across five ecoregions for the WWH designation. This aquatic use designation represents the principal restoration target for the majority of water resource management planning in Ohio.

*Exceptional Warmwater Habitat (EWH)*

This designation is for waters capable of supporting and maintaining an exceptional or unusual community of warmwater aquatic organisms. These assemblages of organisms are characterized by a high diversity of species, particularly those that are highly intolerant, rare, threatened, endangered, or special status species. Biological criteria for EWH apply uniformly across Ohio. The EWH designation represents a protection goal for water resource management efforts dealing with Ohio's best water resources.

*Modified Warmwater Habitat (MWH)*

This designation applies to streams and rivers that have been found incapable of maintaining a balanced, integrated, and adaptive community of warmwater organisms. Streams and rivers designated MWH have been subjected to extensive and essentially permanent hydrological modifications. Aquatic assemblages in these streams generally comprise species that are tolerant of low dissolved oxygen, silt, and high nutrient concentrations. Biological criteria for MWH designation are stratified across five ecoregions and three major modification types-channelization, free-flowing water impoundments, and extensive sedimentation due to mine runoff.

*Limited Resource Water (LRW)*

This designation applies to waters that have been found lacking the capacity to support any appreciable assemblage of aquatic organisms. Use attainability analysis has demonstrated that extant organisms are substantially degraded, and that the potential for recovery to levels characteristic of any other aquatic designation is precluded. Causative factors for the LRW designation include extensive channel modifications, acid mine drainage, and other factors relating to extensive urbanization. No formal biological criteria exist for the LRW aquatic use designation. The LRW-AMD designation applies to streams and rivers that have been subjected to severe acid mine drainage pollution from abandoned minelands or gob piles, and where there is no near-term prospect for reclamation. The representative aquatic assemblages are generally composed of species that are tolerant to low pH, silt, metals, and overall poor habitat quality.

**Summary of Middle Basin Biological Assessment, 2002**

The Midwest Biodiversity Institute was contracted to perform a biological analysis of the Middle Basin of Raccoon Creek in August and September of 2002. The specific objectives of the biological assessment were to: evaluate the physical habitat and biological integrity of the Raccoon Creek Middle Basin study area, especially in relation to AMD; assess impacts from mining activities, non-point sources of pollution, and habitat alterations; determine attainment status of aquatic life designations, and recommend changes where appropriate; and expand a baseline of biological data for assessing AMD impacts, and compare results of this survey with previous surveys to assess any changes in water quality and biological integrity. The full text of the Middle Basin 2002 report can be found in Appendix 2.

Physical habitat at assessment sites was evaluated using the Qualitative Habitat Evaluation Index (QHEI) developed by the Ohio EPA for streams and rivers in Ohio (Rankin, 1989; 1995). Biotic communities were assessed using three indices, the Index of Biotic Integrity (IBI), the Invertebrate Community Index (ICI), and the Modified Index of well-being (MIwb). Fish communities were sampled using wading method pulsed electrofishing gear as specified by the Ohio EPA (1987).

The biological assessment report summarizes both data collected by Ohio EPA in 1995 (Ohio EPA, 1997) and new data collected in 2002. Of the 42 sites that were subjected to biological assessment in 2002, 10 met either WWH or LRW designations; two sites were partially attaining WWH designations; 18 were not attaining either WWH or LRW designations; and 12 sites were designated Primary Headwaters sites and were not assessed using the previously described methods (for a full discussion of Primary Headwaters streams, see the discussion in the full text of the Report, Appendix 2). Of the sites designated “impaired”, seven sites showed evidence of mine effects both in the severity of biotic degradation and in existing precipitates on stream substrates. A full list of habitat designations and habitat evaluation indices scores can be found in Appendix Table 2 of the Middle Basin Biological Report (Appendix 2).

*Middle Basin mainstem*

The Middle Basin portion of the Raccoon Creek mainstem was not sampled in 2002. Previous assessment (1995) indicated that all mainstem sites sampled were in full or partial attainment of the WWH habitat designation (see table 2, Appendix 2). Fish community data was collected at 42 Middle Basin sites in 2002, for a total of 85 fish sampling sites since 1995. Of these sites, six mainstem sites are identified as AMD impacted (Table 14.) Five of these sites have an IBI score of 40 or greater, while only one site has a score between 30 and 40 (RM 84.1).

**Table 14: AMD-impacted mainstem sites as identified by fish community assessment**

| Stream segment* | Impairment | Probable Source |
|---|---|---|
| RM 84.1 | AMD | Raccoon Creek Headwaters |
| RM 72.2 | AMD | Unknown |
| RM 40.2 | AMD | Rockcamp Run/Pierce Run |
| RM 35.6 | AMD | Rockcamp Run/Pierce Run |
| RM 63.8 | AMD | Unknown |
| RM 50.1 | AMD | Rockcamp Run/Pierce Run |

*Listed in order from most to least impaired based on IBI score

Macroinvertebrate sampling in the Middle Basin mainstem identified AMD-impacted sites (Table 15). Both fish community assessment and macroinvertebrate sampling also indicated that several small mainstem tributaries are AMD-impaired, but these streams do not affect the mainstem water quality and are therefore not addressed in this document.

**Table 15: AMD-impacted mainstem sites as identified by macroinvertebrate sampling**

| Stream segment* | Impairment | Probable Source |
|---|---|---|
| RM 50.1 | AMD | Rockcamp Run/Pierce Run |
| RM 50.1 | AMD | Rockcamp Run/Pierce Run |
| RM 72.3 | AMD | Unknown |
| RM 63.8 | AMD | Unknown |
| RM 84.3 | AMD | Raccoon Creek Headwaters |
| RM 35.6 | AMD | Rockcamp Run/Pierce Run |
| RM 39.0 | AMD | Rockcamp Run/Pierce Run |
| RM 39.9 | AMD | Rockcamp Run/Pierce Run |

*Listed in order from most to least impaired based on rating

*Major Tributaries: Elk Fork*

According to the 2002 Middle Basin report, assessment of Elk Fork indicates a significant improvement in most IBI scores and macroinvertebrate assemblages from 1981 to 1995 and 2002. Discussion in the report attributes the majority of the improvement to reduction in

AMD, with secondary benefits from sewage upgrades. The data collected during the 2002 fish community and macroinvertebrate assessments support these findings. The primary impairments identified in 2002 were sedimentation (attributed to historical mining activities) and other land uses in the watershed. Fish community assessments indicate that two tributaries to Elk Fork (RM 11.10, RM 10.75) are AMD-impaired.

*Major Tributaries: Strongs Run, Robinson Run*

Strongs Run was sampled extensively in the 1990s after the Meigs #3 Mine accident and resulting discharge. Analysis of this sampling data indicates that approximately three years after the accident, the stream biota returned to pre-discharge conditions. According to the 2002 fish community and macroinvertebrate assessments, Strongs Run and Robinson Run are now largely attaining or partially attaining the WWH aquatic life habitat designation (see Biological Report, Appendix 2). However, macroinvertebrate assessment identified two sites in Rockcamp Run as AMD-impaired. Habitat quality in both streams was identified as good, with sediment metrics showing the greatest deviation from reference levels (see Biological Report, Appendix 2). Possible identified impacts to these streams include sedimentation and streambank erosion from agricultural land uses.

*Major Tributaries: Pierce Run*

Pierce Run is currently designated LRW-AMD, and the 2002 Middle Basin report supports this habitat designation. According to the report, Pierce Run is characterized by severe biological degradation due to periodic mine discharges. The resulting aquatic communities consist of few or no organisms, with small and very tolerant communities of fish and macroinvertebrates. Narrative ratings of macroinvertebrates ranged from very poor (RM 6.44) to poor (all other sites). Both fish community and macroinvertebrate assessments identified several sites in Pierce Run as AMD-impaired (Table 16).

**Table 16: AMD-impaired sites in Pierce Run**

| **Fish Assessment** | | **Macroinv. Assessment** | |
|---|---|---|---|
| Segment* | Impairment | Segment* | Impairment |
| RM 3.10 | AMD | RM 6.40 | AMD |
| RM 6.40 | AMD | Tributary, RM 3.22 | AMD |
| Tributary, RM 3.22 | AMD | RM 3.10 | AMD |
| RM 5.50 | AMD | RM 0.70 | AMD |
| RM 1.70 | AMD | RM 5.50 | AMD |
| | | RM 1.70 | AMD |

*Listed in order from most to least impaired based on score

The Middle Basin report also indicates that Pierce Run has experienced direct habitat modifications that will hinder biotic recovery even if AMD is reduced. Full attainment of the WWH designation should target habitat restoration and erosion control, in addition to the more severe AMD impairments that currently limit aquatic assemblages. Ohio EPA (1995) reported that Pierce Run contributed to AMD effects observed in the mainstem of Raccoon Creek, and the 2002 Middle Basin report supports this observation.

## Proposed Treatment

### Treatment selection and cost

Abatement strategies for three (PR00135, Tributary PR0015, and MSSR0034) of the four treatment projects focus on utilizing clean water sources (acid- and debris-free) as the delivery mechanism to mix highly alkaline water with AMD. A previous demonstration project in the Little Raccoon Creek sub-watershed-Buffer Run, the Buckeye Furnace Reclamation Project-proved that constructing leach beds utilizing the steal slag could provide highly alkaline water for extended periods of time, and that this system requires little to no maintenance. Created during the steel making process, steel slag is a finely ground by-product that has been refined through reprocessing to eliminate remnant metals. Steel slag is not the lowest cost base material available to treat AMD, but it can be very effective. The material is highly permeable, allowing for efficient production of alkalinity. By using an application that does not allow clogging by the precipitation of iron hydroxide or woody debris (common for open limestone channels), steel slag can produce much higher alkalinity relative to limestone over a given period of time.

Table 17 provides the cost breakdown for each of the priority site projects. Treatment for PR0135 will utilize a steel slag leach bed by creating a retention pond up drainage of the deep mine seep. Water free from AMD degradation is currently collected approximately fifty yards up drainage, in a sediment control structure in place for a permitted active strip mine. This pond will need to be replaced with a larger structure but provides a good analogue for the structure needed to employ the steel slag leach bed technique. An aerobic wetland will be constructed downstream of the treatment mixing zone to allow for the deposition of metals before discharge into Pierce Run. The estimated cost for constructing this project is $418,702.The project is designed to function for 16 years before neutralizing materials will need to be replaced. The second Pierce Run project in tributary PR0015 will also utilize the slag leach bed and gather source water directly from the tributary upstream of the coal seam seep. A settling structure will be constructed to separate the debris from the water before entering the leach bed. Tributary PR0015 will have an additional Open Limestone Channel (OLC) and a downstream aerobic wetland to reduce metal load to Pierce Run. The estimated cost of the project is $319, 425 and the project is also designed to function for 16 years.

The location of the Hawks Mine discharge (MSSR0034) is also well suited for a steel slag leach bed. The discharge is located in a valley with adequate flood plain to construct a catch basin and a leach bed. The water directly up drainage of the discharge has a neutral pH and is undisturbed by AMD. Downstream of the discharge there is space to construct a channel with enough elevation change to allow for mixing. Downstream of the treatment site is an impoundment that, with limited restoration work, can serve as an aerobic wetland. The Hawks Mine Project is estimated to cost $223,684.

The MSSR0039 Railroad Seep is situated in a spot that does not allow for application of many treatment techniques. The discharge is located on a steep hillside that, other than for a brief interruption by the railroad grade, falls directly in to the mainstem of Raccoon Creek. In this case complete treatment of the water before it enters the stream is highly unlikely given the short travel distance. It is possible, however, to eliminate some of the pollution and effectively reduce the load reaching the stream. The chemistry of the water discharging from the site is optimum for dissolving limestone without immediate precipitation of metals. With a pH of below 3.0 and high acidity the water will aggressively dissolve limestone and quickly discharge into the stream. The initial reduction in acidity will occur before pH has risen to the point that iron begins to precipitate. This keeps the efficiency of limestone dilution high and requires little maintenance. The project is estimated to cost $19,548.

The final project is the Hawk Station Surface Mine site, with an estimated construction cost of $19,548. This project will employ common reclamation techniques to provide positive drainage for surface water, by constructing adequate discharge waterways while maintaining a stable stream bank along 140 feet of Raccoon Creek. The site will be capped to eliminate infiltration and the production of AMD, and vegetation will be established to eliminate erosion.

**Table 17: Remediation project costs for Middle Basin priority sites**

| SITE | PRODUCT | COST |
|---|---|---|
| PR0135: Oreton Hollow | Aerobic Wetland | 238,295.00 |
| | Retention Pond | 7,835.00 |
| | Access and Revegetation | 3,385.00 |
| | Engineering | 65,379.00 |
| | Evaluation and Maint. | 34,336.00 |
| | Slag Leachbed | 69,472.00 |
| | **TOTAL** | **418,702.00** |
| **Cost/ton of acid removed** | **over the life of the project** | **263.90** |
| PR0015: Highwall Seep | Aerobic Wetland | 201,157.00 |
| | Open Limestone Channel | 2,813.00 |
| | Access and Revegetation | 5,487.00 |
| | Engineering | 52,364.00 |
| | Evaluation and Maint. | 29,784.00 |
| | Slag Leachbed | 27,820.00 |
| | **TOTAL** | **319,425.00** |
| **Cost/ton of acid removed** | **over the life of the project** | **452.26** |
| MSSR0034 Hawk Mine | Aerobic Wetland | 115,210.00 |
| | Access and Revegetation | 15,877.00 |
| | Engineering | 32,775.00 |
| | Evaluation and Maint. | 32,200.00 |
| | Slag Leachbed | 27,612.00 |
| | **TOTAL** | **223,684.00** |
| **Cost/ton of acid removed** | **over the life of the project** | **317.70** |
| MSSR0039 Railroad Seep | Open Limestone Channel | 6,373.00 |
| | Access and Revegetation | 1,987.00 |
| | Engineering | 4,180.00 |
| | Evaluation and Maint. | 7,008.00 |
| | **TOTAL** | **19,548.00** |
| **Cost/ton of acid removed** | **over the life of the project** | **388.76** |
| Hawk Surface Mine | 1.5 acres*10,000/acre* | 15,000.00 |
| | Design | 3,750.00 |
| | **TOTAL** | **18,750.00** |
| | **GRAND TOTAL** | **1,000,109.00** |

**Benefits and Cost Effectiveness**

The benefits of eliminating acid mine drainage problems are difficult to quantify, although attempts have been made. Qualitatively, the benefits are ecological, aesthetic and economic. The economic impacts may be direct or indirect. Direct economic benefits arise from restoration activities including increased tourism, recreation opportunities and increased property values. Indirect benefits include diversity and abundance of fish and game for anglers and hunters, reduced erosion and siltation and consequent reduction of flood risks and downstream sedimentation. Indirect benefits also include attributes of healthy streams and watersheds that are difficult to quantify, but are nonetheless important to society. These kinds of indirect benefits include the purification of air and water, detoxification and decomposition of wastes, regulation of climate, regeneration of soil fertility, and production and maintenance of biodiversity (Daily *et al.*, 1997).

In the thesis “Determining the Value of Improved Water Quality in the Hocking River Valley to Boaters and Fishers” by Ohio State University graduate student Allan Sommers (2001), an attempt was made to place a value on water quality and the subsequent improvement of water quality to people who utilize the resource. Though the study did not occur in the Raccoon Creek Watershed it did occur in the Southeast Ohio region in a watershed directly north and adjacent to the Raccoon Creek Watershed.

The result of surveying fisherman showed that they do place value on the quality of water and it is reflected in the number of fishing trips that are taken. Sommers’ thesis states that the current environmental quality provides an adjusted annual benefit of $1.45 million to fishers traveling to the Hocking River Valley. This is based on a benefit of $12.45 per trip. If an improvement in environmental quality were to occur the survey response indicated that the value of the average annual benefit would increase by $1.3 million (p. 100). The benefit can be translated into a willingness to pay for the improvements. And depending on what can be done to improve the water quality it could be viewed as a willingness to pay for reclamation or AMD abatement.

A study conducted in Oklahoma found that 27% of those with fishing licenses fished in streams and rivers (Fisher *et al.*, 2002). The study authors also noted that in the sub-region of eastern Oklahoma, stream fishing generated approximately $24 million in 1993, and that Americans as a group spend about $24 billion on fishing and fishing-related recreation. Improvements in the fishability of Raccoon Creek, which are shown by the Biological Assessment to be connected to improvements in water quality, should result in increases in visits to the Raccoon Creek watershed. Raccoon Creek already provides substantial recreation opportunities. The physical habitats of the mainstem should eventually support an improving warmwater fishery as the habitat stressors identified in this report are abated.

While stretches of the mainstem currently do not meet warmwater habitat designation, much of it does and all sections have good fish habitat with migrating fish populations. There is also the opportunity for both incremental and large improvements in the quality of the stream. The prioritized projects in this document cover those areas where the largest improvements could be seen with reclamation efforts. The projects in Pierce Run and the Rockcamp Run sub-basins will directly affect a reach of Raccoon Creek from approximately river mile 64 through 40, the most degraded segment of mainstem in the study area

The cost effectiveness of reclamation can be measured by calculating pounds of acid removed per dollar spent. In comparison with other projects that are planned in the Raccoon Creek watershed the cost of removing one ton of acid is higher, but with adequate reason. Much of the planned implementation for the Headwaters of Raccoon Creek AMDAT will utilize OLC's that on average cost less than the slag leach beds planned for the Middle Basin in this document. The severity of the problem in the Headwaters is greater, aiding the overall cost per ton reduction. The greatest factor affecting acid-reduction costs in the Middle Basin is the additional prescribed step of constructing wetlands for metal/suspended solid retention. Most other projects in the basin have not included this step, as a number of constraints hinder wetland construction. Wetlands are expensive to build and require space, which can be limited on project sites. In the Middle Basin, project sites have ample space to create wetland areas.

The benefit of reducing the suspended solid/metals load to the mainstem of the Raccoon Creek Middle Basin will be seen in significant improvement in the habitat along this reach. Table 18 provides the summary of the average cost of one ton of acid per project with and without the wetland. The cost of the wetland significantly increases the average cost of removal of pollution. Without the additional wetland cost these projects are in line with, if not lower than, other projects that have employed slag leach beds.

**Table 18: Cost Effectiveness of Priority Site Projects**

| | **WITH WETLAND** | | **WITHOUT WETLAND** | |
|---|---|---|---|---|
| Site | project cost | cost/ton | project cost | cost/ton |
| PR0135 | 418,702.00 | 263.90 | 180,407.00 | 113.71 |
| PR0015 | 319,425.00 | 452.26 | 118,268.00 | 167.45 |
| MSSR0034 | 223,684.00 | 317.70 | 108,474.00 | 154.07 |

**Funding Opportunities**

There are various existing funding sources, which are dedicated to AMD remediation and others that can be adapted to assist in the watershed restoration.

Ohio Department of Natural Resources, Division of Mineral Resources Management

1) Federally Funded Abandoned Mine Land Program: Federal excise taxes on coal are returned to the State of Ohio for reclamation of abandoned mine land sites that adversely affect the public's health and safety, and general welfare.
2) Acid Mine Drainage Set-Aside Program: Up to ten percent of Ohio's federal excise tax monies are set aside for acid mine drainage abatement. Priority is given to leveraging these funds with watershed restoration groups and other government agencies.
3) State Abandoned Mine Land Program: State excise taxes on coal and industrial minerals are dedicated to reclamation projects that improve water quality in impacted streams. Priority is given to leveraging these funds with other partners.

Office of Surface Mining (OSM), Reclamation and Enforcement

1) Appalachian Clean Streams Initiative: The mission of the ACSI is to facilitate and coordinate citizens groups, university researchers, the coal industry, corporations, the environmental community, and local, state, and federal government agencies that are involved in cleaning up streams polluted by acid mine drainage. OSM provides funds for ACSI projects on an annual basis.
2) Direct Grants to Watershed Groups: A grant process for directly funding citizen watershed groups efforts to restore acid mine drainage impacted streams on a project basis.

Natural Resource Conservation Services

1) Forestry Incentives Program (FIP) aides in tree planting, timber stand improvement, site preparation for natural regeneration, and other related activities.
2) Wetland Reserve Program This program is a voluntary program to restore wetlands. Participating landowners can establish conservation easements of either permanent or 30-year duration, or can enter into restoration cost-share agreements where no easement is involved. In exchange for establishing a permanent easement, the landowner receives payment up to the agricultural value of the land and 100 percent of the restoration costs for restoring the wetlands. The 30-year easement payment is 75 percent of what would

be provided for a permanent easement on the same site and 75 percent of the restoration cost. The voluntary agreements are for a minimum ten year duration and provide for 75 percent of the cost of restoring the involved wetlands.

3) Rural Abandoned Mine Program (RAMP): This program provides technical and financial assistance to land users who voluntarily enter into five to ten year contracts for reclamation of up to 320 acres of eligible abandoned coal-mined lands and waters. This program is not currently funded on a federal level.

Environmental Protection Agency

1) EPA Section 319 Non-point Source Grant Program: Funding is available for planning, education and remediation of watershed pollution problems including acid mine drainage.
2) Office of Water -Watershed Protection and Flood Prevention/PL566 Program: This program provides technical and financial assistance to address resource and related economic problems on a watershed basis that address watershed protection, flood prevention, water supply, water quality, erosion and sediment control, wetland creation and restoration, fish and wildlife habitat enhancement, and public recreation. Technical assistance and cost sharing with varied amount are available for implementation of NRCS-authorized watershed plans.

United States Army Corps of Engineers

1) Section 905b-Water Resource Development Act (86): Recent additions to the Army Corps conventional mission include a habitat restoration grant program for the completion of feasibility studies and project construction where a Federal interest can be verified. A principal non-Federal sponsor must be identified for this cost-share program.

United States Fish and Wildlife Service

1) Partners for Fish and Wildlife Program: This program assists private landowners by providing technical and financial assistance to establish self-sustaining native habitats.
2) Clean Water Action Plan Fund: The purpose of this fund is to restore streams, riparian areas and wetlands resulting in direct and measurable water quality improvements.
3) Five Star Challenge Restoration Grants: The purpose of this program is to provide modest financial assistance to support community-based wetland and riparian restoration projects that build diverse partnerships and foster local natural source stewardship

Lindbergh Foundation

1) Lindbergh Grants: This program financially assists organizations that are making significant contributions toward the balance between technology and nature through the conservation of natural resources. The Lindbergh Grants provides a maximum grant of $10,580. The program is considered a provider of seed money and credibility for pilot projects that subsequently receive larger sums from other sources.

Turner Foundation

1) Water/Toxins Program: The program wants to protect rivers, lakes, wetlands, aquifers, oceans and other water systems from contamination, degradation, and other abuses; to stop the further degradation of water-dependent habitats from new dams, diversions and other large infrastructure projects; to reduce wasteful water use via conservation; to support efforts to improve public policies affecting water protection, including initiatives to secure pollution prevention and habitat protection.

The Acorn Foundation

1) The Acorn Foundation supports projects dedicated to building a sustainable future for the planet and to restoring a healthy global environment. The Acorn Foundation funds community-based projects which: preserve and restore habitats supporting biological diversity and wildlife; advocate for environmental justice, particularly in low-income and indigenous communities; and prevent or remedy toxic pollution.

## Future Monitoring

### Pre-construction monitoring

All proposed treatment options require intense, short-term, pre-design water quality sampling. Each site selected for treatment should receive monthly sampling for six months capturing high and low flows before entering into a design phase. Parameters for analysis should be determined by the project design steering committee. They should include at a minimum ODNR Group I and possibly Group II filtered samples.

### Post-construction monitoring

Performance of the AMD projects must be monitored for two years on a quarterly basis post construction for ODNR group I parameters. The monitoring needs to be done at the discharge of the treatment site.

### Long-term watershed monitoring

Long term monitoring for both biological and chemical parameters is necessary to develop a base of information to understand the effectiveness of the proposed AMD treatment and abatement strategies. Macroinvertebrate and fish assessment should be duplicated every three to five years while restoration activities are occurring. A shorter frequency on the tributary sites (three years) and a longer (five year) frequency on the mainstem sites would be sufficient to develop the needed information. Water quality samples analyzed for ODNR group II parameters should be collected during these assessments.

Water chemistry long-term sampling should be wrapped into a combined monitoring plan with the Little Raccoon Creek and Headwaters of Raccoon Creek AMDAT's. The Headwaters long-term management plan includes quarterly sampling for ODNR group I parameters and stream discharge at seven mainstem sites and four selected tributaries. The Middle Basin strategy should mirror this approach. Mainstem sites to sample include; MSEF0010, MSPR0015, MSPR0130, MSSR0020, MSSR0040, MSLR0050. The tributaries to be monitored by collecting mouth samples include Elk Fork at site EF0010, Pierce Run at site PR0010, Strongs Run at site SR0040 and Rockcamp Run at MSSR0030. The Rockcamp and Pierce Run tributaries are both priority sites for AMD abatement. If post implementation monitoring suggests these tributaries are longer degrading the mainstem they could be removed from the long-term site list.

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# SECTION 2: ATTACHMENTS

## APPENDIX ONE: WATER QUALITY DATA FOR PRIORITY SITES

| Site ID | SAMPLE DATE | pH | COND. mS/cm | DISCHARGE ft³/sec. | ACIDITY mg/l | ALK. mg/l | ACIDITY LOADING | IRON mg/l | ALUMINUM mg/l | MANGANESE mg/l | METALS LOADING lbs/day |
|---|---|---|---|---|---|---|---|---|---|---|---|
| MSEF0010 | 4/1/2002 | 6.09 | 258 | 168.6 | 4.99 | 12.2 | -6542.99 | 0.47 | 0.25 | 0.904 | 1476.99 |
| MSEF0010 | 4/8/2002 | 6.08 | 313 | 167.08 | 4.95 | 14.4 | -8498.45 | 0.381 | 0.25 | | 568.71 |
| MSEF0010 | 8/6/2002 | 6.8 | 420 | 0 | 5.35 | 20.2 | 0.00 | 0.704 | 0.25 | 0.596 | 0.00 |
| MSEF0160 | 4/1/2002 | 6.44 | 255 | 0 | 3.22 | 16 | 0.00 | 0.525 | 0.25 | 0.711 | 0.00 |
| MSEF0160 | 4/8/2002 | 6.28 | 293 | 0 | 6.69 | 19.8 | 0.00 | 0.454 | 0.25 | 1.03 | 0.00 |
| MSEF0160 | 8/6/2002 | 7.01 | 377 | 0 | 2.12 | 30.8 | 0.00 | 0.435 | 0.25 | 0.336 | 0.00 |
| EF0010 | 3/13/2002 | 6.64 | 411 | 24.9 | 10.3 | 31.6 | -2854.71 | 0.463 | 0.25 | 0.67 | 185.76 |
| EF0010 | 4/1/2002 | 6.67 | 309 | 118.7 | 3.72 | 22.6 | -12062.47 | 0.542 | 0.276 | 0.603 | 909.87 |
| EF0010 | 4/8/2002 | 6.42 | 316 | 48.8 | 4.03 | 28 | -6296.10 | 0.644 | 0.25 | 0.676 | 413.29 |
| EF0010 | 8/6/2002 | 7.2 | 462 | 0.426 | 4.87 | 57.7 | -121.14 | 0.501 | 0.25 | 0.289 | 2.39 |
| EF0010 | 9/3/2002 | 7.05 | 849 | 0.03 | 5.77 | 55.3 | -8.00 | 0.613 | 0.25 | 0.87 | 0.28 |
| EF0130 | 3/13/2002 | 6.52 | 455 | 11.297 | 7.86 | 32.9 | -1522.58 | 0.484 | 0.25 | 0.845 | 96.22 |
| EF0130 | 9/3/2002 | 6.93 | 1170 | 0 | 5.85 | 53.5 | 0.00 | 0.43 | 0.25 | 1.22 | 0.00 |
| EF0229 | 3/14/2002 | 6.46 | 459 | 9.96 | 8.22 | 38.7 | -1634.02 | 0.68 | 0.294 | 0.794 | 94.99 |
| EF0229 | 9/3/2002 | 7.01 | 690 | 0.355 | 4.45 | 58.7 | -103.66 | 0.67 | 0.25 | 1.32 | 4.29 |
| EF0250 | 3/14/2002 | 6.4 | 376 | 2.5 | 7.52 | 32 | -329.41 | 0.433 | 0.25 | 0.461 | 15.43 |
| EF0250 | 9/3/2002 | 8.01 | 796 | 0 | 3.95 | 191 | 0.00 | 0.46 | 0.25 | 0.329 | 0.00 |
| EF0260 | 3/14/2002 | 6.6 | 408 | 0.73 | 7.6 | 49.1 | -163.06 | 0.45 | 0.25 | 0.392 | 4.30 |
| EF0260 | 9/13/2002 | 7.41 | 548 | 0 | 7.18 | 112 | 0.00 | 0.253 | 0.25 | 0.615 | 0.00 |
| EF0370 | 3/14/2002 | 6.41 | 210 | 0.61 | 4.59 | 19 | -47.31 | 0.249 | 0.25 | 0.123 | 2.05 |
| EF0370 | 9/3/2002 | 7.17 | 275 | 0 | 6.71 | 86.6 | 0.00 | 0.179 | 0.25 | 0.522 | 0.00 |
| MSPR0015 | 4/1/2002 | 6.6 | 254 | 337.5 | 3.54 | 16.4 | -23361.38 | 0.533 | 0.328 | 0.71 | 2860.12 |
| MSPR0015 | 4/8/2002 | 6.27 | 305 | 0 | 4.05 | 19.5 | 0.00 | 0.535 | 0.25 | 1 | 0.00 |
| MSPR0015 | 8/6/2002 | 7.09 | 410 | 0 | 4.09 | 39.2 | 0.00 | 0.497 | 0.25 | 0.312 | 0.00 |
| MSPR0130 | 4/1/2002 | 6.51 | 269 | 0 | 4.22 | 16 | 0.00 | 0.617 | 0.294 | 0.709 | 0.00 |
| MSPR0130 | 4/8/2002 | 6.18 | 301 | 0 | 4.83 | 19.2 | 0.00 | 0.792 | 0.261 | 1 | 0.00 |
| MSPR0130 | 5/22/2002 | 5.8 | 469 | 0 | 11.3 | 7.77 | 0.00 | 3.75 | 1.04 | 1.47 | 0.00 |
| MSPR0130 | 7/22/2002 | 6.91 | 369 | 0 | 3.45 | 29 | 0.00 | 1.22 | 0.25 | 0.484 | 0.00 |
| MSPR0130 | 8/6/2002 | 6.9 | 352 | 0 | 4 | 39 | 0.00 | 1.74 | 0.25 | 0.516 | 0.00 |
| PR0010 | 4/1/2001 | 5.83 | 485 | 11.47 | 10 | 7.2 | 172.86 | 2.68 | 0.625 | 1.47 | 295.44 |
| PR0010 | 4/8/2002 | 4.73 | 649 | 6.07 | 31.4 | 1.58 | 974.27 | 3.44 | 1.07 | 2.27 | 222.00 |
| PR0010 | 5/1/2002 | 6.49 | 430 | 8.58 | 9.03 | 17.4 | -386.54 | 1.65 | 0.25 | 0.967 | 132.69 |
| PR0010 | 5/22/2002 | 6.38 | 221 | 9.74 | 4.13 | 19.7 | -816.27 | 0.983 | 0.378 | 0.549 | 100.35 |
| PR0010 | 5/29/2002 | 6.33 | 899 | 4.241 | 8.6 | 50.5 | -956.46 | 2.12 | 0.703 | 26.3 | 666.25 |
| PR0010 | 6/20/2002 | 5.96 | 1170 | 1.301 | 11.8 | 16.7 | -34.31 | 1.86 | 0.404 | 2.13 | 30.84 |

| Site ID | SAMPLE DATE | pH | COND. mS/cm | DISCHARGE ft³/sec. | ACIDITY mg/l | ALK. mg/l | ACIDITY LOADING | IRON mg/l | ALUMINUM mg/l | MANGANESE mg/l | METALS LOADING lbs/day |
|---|---|---|---|---|---|---|---|---|---|---|---|
| PR0010 | 7/22/2002 | 4.43 | 1120 | 0.264 | 37.4 | 0 | 53.14 | 3.26 | 1.16 | 3.2 | 10.85 |
| PR0010 | 8/6/2002 | 3.37 | 1450 | 0.186 | 84.6 | 0 | 84.70 | 8.13 | 4.67 | 5.22 | 18.08 |
| PR0010 | 8/13/2002 | 3.87 | 1370 | 0.223 | 36.5 | 0 | 43.81 | 4.38 | 1.87 | 5.75 | 14.44 |
| PR0010 | 3/18/2003 | 5.68 | 588 | 10.79 | 15 | 4.49 | 610.39 | 7.17 | 1.16 | 1.52 | 573.31 |
| PR0015 | 3/18/2003 | 3.71 | 451 | 1.681 | 46.3 | 0 | 418.92 | 16.5 | 3.11 | 0.496 | 182.32 |
| PR0015 | 6/11/2003 | 3.79 | 549 | 0.432 | 54.5 | 0 | 126.73 | 20.7 | 3.92 | 0.635 | 58.85 |
| PR0015 | 6/25/2003 | 3.08 | 922 | 0.38 | 161 | 0 | 329.30 | 32 | 9.73 | 1.12 | 87.84 |
| PR0015 | 7/1/2003 | 2.93 | 1260 | 0.137 | 293 | 0 | 216.06 | 68.1 | 16.7 | 1.73 | 63.95 |
| PR0015 | 7/9/2003 | 3.5 | 649 | 0.331 | 80 | 0 | 142.53 | 19.1 | 5.67 | 1.65 | 47.17 |
| PR0015 | 7/15/2003 | 3.66 | 777 | 0.204 | 97.8 | 0 | 107.39 | 22.7 | 6.33 | 1.26 | 33.33 |
| PR0015 | 7/22/2003 | 3.62 | 779 | 0.122 | 120 | 0 | 78.80 | 263 | 8.49 | 22.5 | 193.48 |
| PR0015 | 8/5/2003 | 6.46 | 389 | 1.01 | 10.4 | 43 | -177.22 | 5.37 | 1.22 | 0.925 | 40.94 |
| PR0016 | 6/11/2003 | 2.44 | 3280 | 0 | 1987 | 0 | 0.00 | 513 | 87 | 2.4 | 0.00 |
| PR0016 | 6/25/2003 | 2.41 | 3310 | 0 | 1875 | 0 | 0.00 | 459 | 86.3 | 2.41 | 0.00 |
| PR0016 | 7/1/2003 | 2.46 | 2940 | 0 | 1846 | 0 | 0.00 | 443 | 85.2 | 2.34 | 0.00 |
| PR0016 | 7/9/2003 | 2.36 | 3230 | 0 | 1867 | 0 | 0.00 | 420 | 85.8 | 2.41 | 0.00 |
| PR0016 | 7/15/2003 | 2.47 | 3330 | 0 | 1950 | 0 | 0.00 | 408 | 93.2 | 2.55 | 0.00 |
| PR0016 | 7/22/2003 | 2.58 | 3050 | 0 | 1964 | 0 | 0.00 | 458 | 95.4 | 2.61 | 0.00 |
| PR0016 | 8/5/2003 | 2.4 | 3350 | 0 | 1944 | 0 | 0.00 | 432 | 93.1 | 2.6 | 0.00 |
| PR0017 | 6/11/2003 | 7.04 | 338 | 0.432 | 2.96 | 40 | -86.13 | 0.497 | 0.25 | 0.537 | 2.99 |
| PR0017 | 6/25/2003 | 6.98 | 429 | 0.38 | 5.82 | 47.5 | -85.25 | 0.648 | 0.25 | 0.791 | 3.46 |
| PR0017 | 7/1/2003 | 7 | 440 | 0.137 | 8.68 | 56.7 | -35.41 | 1.47 | 0.347 | 0.96 | 2.05 |
| PR0017 | 7/9/2003 | 6.56 | 469 | 0.331 | 8.58 | 69.4 | -108.36 | 1.22 | 0.25 | 1.76 | 5.77 |
| PR0017 | 7/15/2003 | 6.89 | 420 | 0.204 | 7.68 | 55.4 | -52.40 | 0.813 | 0.25 | 1.16 | 2.45 |
| PR0017 | 7/22/2003 | 6.96 | 483 | 0.122 | 8.67 | 70 | -40.27 | 1.68 | 0.25 | 2.58 | 2.97 |
| PR0017 | 8/5/2003 | 6.94 | 385 | 1.01 | 6.61 | 63.3 | -308.18 | 0.891 | 0.25 | 1 | 11.66 |
| PR0040 | 3/18/2003 | 6.71 | 199 | 0.108 | 3.45 | 16.4 | -7.53 | 0.05 | 0.25 | 0.05 | 0.20 |
| PR0050 | 3/18/2003 | 7.08 | 218 | 0.137 | 4.02 | 26.8 | -16.80 | 0.057 | 0.025 | 0.05 | 0.10 |
| PR0060 | 5/1/2002 | 6.42 | 435 | 8.498 | 9.55 | 10.8 | -57.18 | 3.98 | 1.07 | 1.16 | 284.67 |
| PR0060 | 5/22/2002 | 6.34 | 555 | 0 | 11.6 | 14.9 | 0.00 | 5.71 | 1.12 | 1.5 | 0.00 |
| PR0060 | 6/20/2002 | 6.63 | 1680 | 0 | 4.89 | 30.1 | 0.00 | 2.33 | 0.25 | 2.33 | 0.00 |
| PR0060 | 8/13/2002 | 4.06 | 1530 | 0 | 35.9 | 0 | 0.00 | 0.902 | 1.18 | 2.22 | 0.00 |
| PR0070 | 3/17/2003 | 6.65 | 119 | 1.498 | 4.99 | 12.9 | -63.78 | 0.208 | 0.25 | 0.074 | 4.30 |
| PR0090 | 5/1/2002 | 6.22 | 559 | 6.505 | 14 | 6.48 | 263.30 | 8.01 | 3.07 | 1.57 | 443.89 |

| Site ID | SAMPLE DATE | pH | COND. mS/cm | DISCHARGE ft³/sec. | ACIDITY mg/l | ALK. mg/l | ACIDITY LOADING | IRON mg/l | ALUMINUM mg/l | MANGANESE mg/l | METALS LOADING lbs/day |
|---|---|---|---|---|---|---|---|---|---|---|---|
| PR0090 | 5/22/2002 | 6.29 | 674 | 7.29 | 14.1 | 16.4 | -90.25 | 9.65 | 2.39 | 1.75 | 542.28 |
| PR0090 | 6/20/2002 | 6.75 | 1450 | 0 | 4.01 | 41.7 | 0.00 | 2.67 | 0.529 | 2.49 | 0.00 |
| PR0090 | 8/13/2002 | 4.52 | 1560 | 0 | 25.3 | 0 | 0.00 | 2.15 | 0.498 | 2.09 | 0.00 |
| PR0112 | 3/18/2003 | 6.75 | 194 | 1.05 | 4.8 | 16.1 | -63.86 | 0.359 | 0.389 | 0.136 | 5.01 |
| PR0115 | 3/17/2003 | 6.6 | 166 | 0.725 | 4.29 | 6.66 | -9.25 | 0.518 | 0.25 | 0.286 | 4.12 |
| PR0120 | 3/17/2003 | 6.29 | 968 | 5.011 | 25 | 16.7 | 223.86 | 15.8 | 3.64 | 2.67 | 597.65 |
| PR0130 | 3/17/2003 | 5.91 | 1000 | 4.244 | 34.9 | 15.3 | 447.73 | 18.9 | 4.33 | 2.7 | 593.62 |
| PR0130 | 5/1/2002 | 4.25 | 851 | 4.16 | 57 | 0 | 1276.30 | 18 | 4.77 | 1.95 | 554.72 |
| PR0130 | 5/22/2002 | 5.37 | 756 | 4.29 | 25.9 | 12.4 | 311.73 | 12.3 | 3.27 | 2.04 | 407.52 |
| PR0130 | 6/20/2002 | 5.65 | 963 | 0 | 13.5 | 29.2 | 0.00 | 18.2 | 5.86 | 2.49 | 0.00 |
| PR0130 | 8/13/2002 | 5.77 | 1670 | 0 | 44.8 | 19.8 | 0.00 | 14.6 | 3.7 | 1.68 | 0.00 |
| PR0135 | 3/17/2003 | estimate | | 0.121 | 205.5 | 0 | 133.84 | | | | 0.00 |
| PR0135 | 5/1/2002 | 4.77 | 1880 | 0 | 241 | 1.18 | 0.00 | 163 | 39.9 | 2.22 | 0.00 |
| PR0135 | 5/22/2002 | 3.87 | 2790 | 0 | 860 | 0 | 0.00 | 409 | 40.1 | 4.59 | 0.00 |
| PR0135 | 6/20/2002 | 2.65 | 3300 | 0 | 1015 | 0 | 0.00 | 324 | 43.5 | 5.94 | 0.00 |
| PR0135 | 8/13/2002 | 2.38 | 4490 | 0 | 1160 | 0 | 0.00 | 215 | 53.8 | 6.98 | 0.00 |
| PR0135 | 6/25/2003 | 4.31 | 3570 | 0.0827 | 1003 | 0 | 446.47 | 443 | 39.1 | 6.61 | 218.02 |
| PR0135 | 7/1/2003 | 4.24 | 3550 | 0.0511 | 1108 | 0 | 304.75 | 494 | 42.7 | 6.88 | 149.84 |
| PR0135 | 7/9/2003 | 4.19 | 3190 | 0.0713 | 910 | 0 | 349.23 | 384 | 32.3 | 6.04 | 162.44 |
| PR0135 | 7/15/2003 | 4.36 | 3630 | 0.0949 | 1195 | 0 | 610.40 | 448 | 37.1 | 6.37 | 251.59 |
| PR0135 | 7/22/2003 | 4.38 | 3440 | 0.0713 | 1111 | 0 | 426.37 | 396 | 41.5 | 6.48 | 170.76 |
| PR0137 | 3/17/2003 | estimate | | 0.152 | 59.85 | 0 | 48.97 | | | | 0.00 |
| PR0140 | 3/17/2003 | 7.02 | 936 | 4.123 | 9.69 | 56.7 | -1043.25 | 7.06 | 1.41 | 2.28 | 239.09 |
| PR0140 | 5/22/2002 | 6.34 | 645 | 4.9 | 5.03 | 40.7 | -940.77 | 3.94 | 0.713 | 1.77 | 169.77 |
| PR0140 | 5/1/2002 | 6.81 | 556 | 3.738 | 6.85 | 33.1 | -528.14 | 2.81 | 0.561 | 1.51 | 98.42 |
| PR0140 | 6/20/2002 | 7.42 | 1570 | 0 | 1.69 | 146 | 0.00 | 1.36 | 0.334 | 1.81 | 0.00 |
| PR0140 | 8/13/2002 | 7.54 | 1510 | 0 | 6.47 | 106 | 0.00 | 0.907 | 0.25 | 0.951 | 0.00 |
| PR0150 | 3/18/2003 | 6.73 | 215 | 0.137 | 5.82 | 21.8 | -11.78 | 0.17 | 0.25 | 0.05 | 0.35 |
| PR0160 | 3/18/2003 | 7.57 | 1290 | 0.331 | 9.73 | 185 | -312.26 | 0.838 | 0.363 | 1.63 | 5.05 |
| PR0170 | 5/1/2002 | 6.75 | 1020 | 1.392 | 14.2 | 50 | -268.23 | 11.1 | 1.83 | 3.44 | 122.92 |
| PR0170 | 5/22/2002 | 6.24 | 1150 | 1.79 | 14.8 | 60.7 | -442.23 | 15.9 | 3.1 | 4.15 | 223.53 |
| PR0170 | 6/20/2002 | 6.44 | 1730 | 0.435 | 11.2 | 63.8 | -123.16 | 19.3 | 2.06 | 5.41 | 62.82 |
| PR0170 | 8/13/2002 | 6.65 | 1820 | 0 | 22 | 35 | 0.00 | 13.6 | 0.595 | 4.94 | 0.00 |

| Site ID | SAMPLE DATE | pH | COND. mS/cm | DISCHARGE ft³/sec. | ACIDITY mg/l | ALK. mg/l | ACIDITY LOADING | IRON mg/l | ALUMINUM mg/l | MANGANESE mg/l | METALS LOADING lbs/day |
|---|---|---|---|---|---|---|---|---|---|---|---|
| PR0180 | 3/18/2003 | 6.73 | 1350 | 0.355 | 27.3 | 55.4 | -53.69 | 26.4 | 4.43 | 4.57 | 67.79 |
| PR0190 | 3/18/2003 | 6.94 | 1340 | 0.488 | 11.9 | 74.7 | -164.95 | 11.8 | 0.677 | 4.85 | 45.61 |
| MSSR0010 | 4/1/2002 | 6.23 | 369 | 0 | 8.04 | 14 | 0.00 | 1.74 | 0.475 | 1.08 | 0.00 |
| MSSR0010 | 4/8/2002 | 5.28 | 546 | 0 | 11.9 | 4.06 | 0.00 | 3.24 | 1.02 | 2.12 | 0.00 |
| MSSR0020 | 5/15/2002 | 6.62 | 268 | 0 | 4.44 | 20.5 | 0.00 | 1.95 | 1.1 | 0.796 | 0.00 |
| MSSR0020 | 5/29/2002 | 6.22 | 334 | 0 | 5.79 | 19.5 | 0.00 | 1.42 | 0.367 | 0.933 | 0.00 |
| MSSR0020 | 7/22/2002 | 6.58 | 513 | 0 | 3.28 | 21.8 | 0.00 | 1.71 | 0.25 | 0.743 | 0.00 |
| MSSR0020 | 8/6/2002 | 6.81 | 366 | 0 | 6.83 | 35.5 | 0.00 | 2.07 | 0.25 | 0.533 | 0.00 |
| MSSR0020 | 8/20/2002 | 6.53 | 478 | 0 | 8.78 | 24.9 | 0.00 | 1.58 | 0.376 | 1.2 | 0.00 |
| MSSR0030 | 4/1/2002 | 3.49 | 569 | 6.84 | 77.8 | 0 | 2864.31 | 19.7 | 4.35 | 1.34 | 936.81 |
| MSSR0030 | 4/8/2002 | 2.63 | 1200 | 7.11 | 148 | 0 | 5663.89 | 45.6 | 6.9 | 2.78 | 2120.17 |
| MSSR0030 | 4/2/2003 | 4.79 | 763 | 1.602 | 36.9 | 1.84 | 302.31 | 13.5 | 2.52 | 1.82 | 154.17 |
| MSSR0030 | 5/15/2002 | 6.46 | 398 | 2.31 | 7.24 | 30 | -282.99 | 2.33 | 1.15 | 0.945 | 55.14 |
| MSSR0030 | 5/29/2002 | 3.05 | 906 | 0.223 | 84.2 | 0 | 101.06 | 17.7 | 4.07 | 2.51 | 29.21 |
| MSSR0030 | 7/22/2002 | 2.91 | 1490 | 0.082 | 198 | 0 | 87.39 | 28.8 | 7.63 | 5.61 | 18.60 |
| MSSR0030 | 8/6/2002 | 3.79 | 587 | 0.0511 | 39 | 0 | 10.73 | 2 | 2.29 | 4.08 | 2.31 |
| MSSR0030 | 8/20/2002 | 3 | 1390 | 0.27 | 193 | 0 | 280.48 | 19.5 | 9.75 | 8.04 | 54.31 |
| MSSR0031 | 4/2/2003 | 2.93 | 1690 | 0.137 | 329 | 0 | 242.61 | 73.5 | 11.1 | 4.68 | 65.98 |
| MSSR0031 | 5/15/2002 | 3.1 | 1350 | 0.884 | 238 | 0 | 1132.43 | 65.4 | 7.49 | 2.29 | 358.50 |
| MSSR0031 | 5/29/2002 | 2.77 | 1720 | 0.0827 | 358 | 0 | 159.36 | 77.3 | 13.1 | 4.72 | 42.43 |
| MSSR0031 | 8/20/2002 | 2.78 | 2060 | 0.207 | 320 | 0 | 356.54 | 41.4 | 13.9 | 11.1 | 74.14 |
| MSSR0032 | 4/2/2003 | 6.98 | 728 | 0.717 | 7.75 | 69.4 | -237.92 | 0.221 | 0.341 | 1.08 | 6.35 |
| MSSR0032 | 5/15/2002 | 6.9 | 390 | 1.004 | 6.69 | 47.4 | -220.00 | 0.685 | 1.02 | 0.859 | 13.89 |
| MSSR0032 | 5/29/2002 | 5.89 | 559 | 0.108 | 14.9 | 21.3 | -3.72 | 0.59 | 2.93 | 5.34 | 5.16 |
| MSSR0032 | 8/20/2002 | 4.44 | 584 | 0.038 | 32 | 0 | 6.55 | 0.237 | 1.08 | 3.96 | 1.08 |
| MSSR0033 | 4/2/2003 | 5.34 | 406 | 0.0949 | 21 | 4.48 | 8.44 | 8.66 | 1.9 | 0.295 | 5.56 |
| MSSR0033 | 5/15/2002 | 5.63 | 304 | 0.21 | 15 | 9.15 | 6.61 | 9.31 | 2.13 | 0.329 | 13.33 |
| MSSR0033 | 5/29/2002 | 6.45 | 394 | 0.0207 | 7.95 | 65.1 | -6.37 | 1.83 | 0.497 | 0.454 | 0.31 |
| MSSR0034 | 6/11/03 | 3.10 | 1130.00 | 0.09 | 340.00 | 0.00 | 173.67 | 158.00 | 10.20 | 0.82 | 86.52 |
| MSSR0034 | 6/25/03 | 3.50 | 1820.00 | 0.12 | 442.00 | 0.00 | 290.25 | 198.00 | 12.00 | 1.07 | 138.91 |
| MSSR0034 | 7/1/03 | 3.40 | 1750.00 | 0.08 | 449.00 | 0.00 | 199.86 | 197.00 | 11.40 | 1.39 | 93.59 |
| MSSR0034 | 7/9/03 | 3.25 | 1670.00 | 0.06 | 417.00 | 0.00 | 136.47 | 173.00 | 9.48 | 0.88 | 60.14 |

| Site ID | SAMPLE DATE | pH | COND. mS/cm | DISCHARGE ft³/sec. | ACIDITY mg/l | ALK. mg/l | ACIDITY LOADING | IRON mg/l | ALUMINUM mg/l | MANGANESE mg/l | METALS LOADING lbs/day |
|---|---|---|---|---|---|---|---|---|---|---|---|
| MSSR0034 | 7/15/03 | 3.45 | 2080.00 | 0.05 | 467.00 | 0.00 | 128.45 | 194.00 | 11.30 | 1.00 | 56.87 |
| MSSR0034 | 7/22/03 | 3.50 | 1270.00 | 0.11 | 435.00 | 0.00 | 252.87 | 181.00 | 10.10 | 0.92 | 111.87 |
| MSSR0034 | 8/5/03 | 3.77 | 1380.00 | 0.02 | 350.00 | 0.00 | 39.95 | 154.00 | 7.46 | 0.78 | 18.56 |
| MSSR0039 | 5/15/2002 | 2.73 | 2490 | 0 | 2.73 | 0 | 0.00 | 273 | 60.7 | 1.35 | 0.00 |
| MSSR0039 | 5/29/2002 | 2.49 | 3080 | 0 | 1402 | 0 | 0.00 | 308 | 70.9 | 1.69 | 0.00 |
| MSSR0039 | 7/22/2002 | 2.45 | 2640 | 0 | 1893 | 0 | 0.00 | 430 | 93.6 | 1.81 | 0.00 |
| MSSR0039 | 7/1/2003 | 2.36 | 3760 | 0.02 | 2449 | 0 | 279.45 | 663 | 112 | 2.56 | 88.92 |
| MSSR0039 | 7/9/2003 | 2.25 | 4410 | 0.01 | 2818 | 0 | 177.46 | 626 | 123 | 2.89 | 47.45 |
| MSSR0039 | 7/15/2003 | 2.33 | 3730 | 0.01 | 2564 | 0 | 130.00 | 479 | 121 | 2.78 | 30.63 |
| MSSR0039 | 7/22/2003 | 2.49 | 3730 | 0.01 | 2289 | 0 | 116.33 | 455 | 116 | 2.59 | 29.21 |
| MSSR0039 | 8/5/2003 | 2.56 | 3620 | 0.01 | 2167 | 0 | 109.87 | 481 | 113 | 2.56 | 30.31 |
| MSSR0040 | 4/1/2002 | 6.31 | 274 | 0 | 4.3 | 14 | 0.00 | 1.21 | 0.469 | 0.762 | 0.00 |
| MSSR0040 | 4/8/2002 | 6.07 | 332 | 186 | 6.18 | 15.2 | -9030.32 | 1.44 | 0.529 | 1.1 | 3079.24 |
| MSSR0040 | 5/15/2002 | 6.69 | 269 | 0 | 5.88 | 21.3 | 0.00 | 2.01 | 1.13 | 0.804 | 0.00 |
| MSSR0040 | 5/29/2002 | 6.16 | 335 | 0 | 4.35 | 18.5 | 0.00 | 1.46 | 0.493 | 0.895 | 0.00 |
| MSSR0040 | 7/22/2002 | 6.54 | 505 | 0 | 5.69 | 19.5 | 0.00 | 2.45 | 0.368 | 0.761 | 0.00 |
| MSSR0040 | 8/6/2002 | 6.81 | 379 | 0 | 4.9 | 33.9 | 0.00 | 2.14 | 0.434 | 0.539 | 0.00 |
| MSSR0040 | 8/20/2002 | 6.48 | 474 | 0 | 10.2 | 21.6 | 0.00 | 1.9 | 0.449 | 1.25 | 0.00 |
| SR0040 | 4/1/2002 | 7.05 | 228 | 12.2 | 2.77 | 49.6 | -3075.16 | 0.531 | 0.29 | 0.154 | 64.17 |
| SR0040 | 4/8/2002 | 6.74 | 231 | 5.6 | 5.34 | 55.5 | -1511.92 | 0.898 | 0.25 | 0.19 | 40.42 |
| SR0040 | 8/6/2002 | 7.31 | 242 | 0.0335 | 7.31 | 99.2 | -16.57 | 2.67 | 0.25 | 1.62 | 0.82 |
| MSLR0050 | 4/1/2002 | 6.55 | 260 | 0 | 4.38 | 32.1 | 0.00 | 1.64 | 0.343 | 0.6 | 0.00 |
| MSLR0050 | 4/8/2002 | 6.32 | 314 | 204.6 | 5.76 | 19.1 | -14690.79 | 0.602 | 0.25 | 0.938 | 1975.57 |
| MSLR0050 | 8/6/2002 | 7.09 | 421 | 0 | 3.82 | 31.1 | 0.00 | 0.225 | 0.25 | 0.339 | 0.00 |

**PR0135 Oreton Seep**

| Site ID | SAMPLE DATE | pH | COND. mS/cm | Gallons per Minute | ACIDITY mg/l | ALK. mg/l | Net Loading | IRON mg/l | ALUMINUM mg/l | MANGANESE mg/l | METALS LOADING lbs/day |
|---|---|---|---|---|---|---|---|---|---|---|---|
| PR0135 | 6/25/2003 | 4.31 | 3570 | 37.0496 | 1003 | 0 | 445.92899 | 443 | 39.1 | 6.61 | 218.02 |
| PR0135 | 7/1/2003 | 4.24 | 3550 | 22.8928 | 1108 | 0 | 304.38267 | 494 | 42.7 | 6.88 | 149.84 |
| PR0135 | 7/9/2003 | 4.19 | 3190 | 31.9424 | 910 | 0 | 348.81101 | 384 | 32.3 | 6.04 | 162.44 |
| PR0135 | 7/15/2003 | 4.36 | 3630 | 42.5152 | 1195 | 0 | 609.66797 | 448 | 37.1 | 6.37 | 251.59 |
| PR0135 | 7/22/2003 | 4.38 | 3440 | 31.9424 | 1111 | 0 | 425.85608 | 396 | 41.5 | 6.48 | 170.76 |

**PR0015 SR 32 Coal Seam Seep**

| Site ID | SAMPLE DATE | pH | COND. mS/cm | Gallons per minute | ACIDITY mg/l | ALK. mg/l | Net Loading | IRON mg/l | ALUMINUM mg/l | MANGANESE mg/l | METALS LOADING lbs/day |
|---|---|---|---|---|---|---|---|---|---|---|---|
| PR0015 | 6/11/2003 | 3.79 | 549 | 193.536 | 54.5 | 0 | 126.57254 | 20.7 | 3.92 | 0.635 | 58.85 |
| PR0015 | 6/25/2003 | 3.08 | 922 | 170.24 | 161 | 0 | 328.90368 | 32 | 9.73 | 1.12 | 87.84 |
| PR0015 | 7/1/2003 | 2.93 | 1260 | 61.376 | 293 | 0 | 215.79802 | 68.1 | 16.7 | 1.73 | 63.95 |
| PR0015 | 7/9/2003 | 3.5 | 649 | 148.288 | 80 | 0 | 142.35648 | 19.1 | 5.67 | 1.65 | 47.17 |
| PR0015 | 7/15/2003 | 3.66 | 777 | 91.392 | 97.8 | 0 | 107.25765 | 22.7 | 6.33 | 1.26 | 33.33 |
| PR0015 | 7/22/2003 | 3.62 | 779 | 54.656 | 120 | 0 | 78.70464 | 263 | 8.49 | 22.5 | 193.48 |
| PR0015 | 8/5/2003 | 6.46 | 389 | 452.48 | 10.4 | 43 | -177.0102 | 5.37 | 1.22 | 0.925 | 40.94 |
| | | | | | | | | | | | |
| PR0016 | 6/11/2003 | 2.44 | 3280 | 0 | 1987 | 0 | 0 | 513 | 87 | 2.4 | 0 |
| PR0016 | 6/25/2003 | 2.41 | 3310 | 0 | 1875 | 0 | 0 | 459 | 86.3 | 2.41 | 0 |
| PR0016 | 7/1/2003 | 2.46 | 2940 | 0 | 1846 | 0 | 0 | 443 | 85.2 | 2.34 | 0 |
| PR0016 | 7/9/2003 | 2.36 | 3230 | 0 | 1867 | 0 | 0 | 420 | 85.8 | 2.41 | 0 |
| PR0016 | 7/15/2003 | 2.47 | 3330 | 0 | 1950 | 0 | 0 | 408 | 93.2 | 2.55 | 0 |
| PR0016 | 7/22/2003 | 2.58 | 3050 | 0 | 1964 | 0 | 0 | 458 | 95.4 | 2.61 | 0 |
| PR0016 | 8/5/2003 | 2.4 | 3350 | 0 | 1944 | 0 | 0 | 432 | 93.1 | 2.6 | 0 |
| | | | | | | | | | | | |
| PR0017 | 6/11/2003 | 7.04 | 338 | 193.536 | 2.96 | 40 | -86.02288 | 0.497 | 0.25 | 0.537 | 2.99 |
| PR0017 | 6/25/2003 | 6.98 | 429 | 170.24 | 5.82 | 47.5 | -85.14724 | 0.648 | 0.25 | 0.791 | 3.46 |
| PR0017 | 7/1/2003 | 7 | 440 | 61.376 | 8.68 | 56.7 | -35.36731 | 1.47 | 0.347 | 0.96 | 2.05 |
| PR0017 | 7/9/2003 | 6.56 | 469 | 148.288 | 8.58 | 69.4 | -108.2265 | 1.22 | 0.25 | 1.76 | 5.77 |
| PR0017 | 7/15/2003 | 6.89 | 420 | 91.392 | 7.68 | 55.4 | -52.33471 | 0.813 | 0.25 | 1.16 | 2.45 |
| PR0017 | 7/22/2003 | 6.96 | 483 | 54.656 | 8.67 | 70 | -40.22463 | 1.68 | 0.25 | 2.58 | 2.97 |
| PR0017 | 8/5/2003 | 6.94 | 385 | 452.48 | 6.61 | 63.3 | -307.8131 | 0.891 | 0.25 | 1 | 11.66 |

**MSSR0039 Railroad Grade Seep**

| Site ID | SAMPLE DATE | pH | COND. mS/cm | Gallons per Minute | ACIDITY mg/l | ALK. mg/l | ACIDITY LOADING | IRON mg/l | ALUMINUM mg/l | MANGANESE mg/l | METALS LOADING lbs/day |
|---|---|---|---|---|---|---|---|---|---|---|---|
| MSSR0039 | 5/15/2002 | 2.73 | 2490.00 | 0.00 | 166.00 | 0.00 | 0.00 | 273.00 | 60.70 | 1.35 | 0.00 |
| MSSR0039 | 5/29/2002 | 2.49 | 3080.00 | 0.00 | 1402.00 | 0.00 | 0.00 | 308.00 | 70.90 | 1.69 | 0.00 |
| MSSR0039 | 7/22/2002 | 2.45 | 2640.00 | 0.00 | 1893.00 | 0.00 | 0.00 | 430.00 | 93.60 | 1.81 | 0.00 |
| MSSR0039 | 7/1/2003 | 2.36 | 3760.00 | 9.50 | 2449.00 | 0.00 | 279.12 | 663.00 | 112.00 | 2.56 | 88.92 |
| MSSR0039 | 7/9/2003 | 2.25 | 4410.00 | 5.24 | 2818.00 | 0.00 | 177.25 | 626.00 | 123.00 | 2.89 | 47.45 |
| MSSR0039 | 7/15/2003 | 2.33 | 3730.00 | 4.22 | 2564.00 | 0.00 | 129.84 | 479.00 | 121.00 | 2.78 | 30.63 |
| MSSR0039 | 7/22/2003 | 2.49 | 3730.00 | 4.23 | 2289.00 | 0.00 | 116.19 | 455.00 | 116.00 | 2.59 | 29.21 |
| MSSR0039 | 8/5/2003 | 2.56 | 3620.00 | 4.22 | 2167.00 | 0.00 | 109.74 | 481.00 | 113.00 | 2.56 | 30.31 |

**MSSR 0034 Hawks Mine Seep**

| Site ID | SAMPLE DATE | pH | COND. mS/cm | Gallons Per Minute | ACIDITY mg/l | ALK. mg/l | ACIDITY LOADING | IRON mg/l | ALUMINUM mg/l | MANGANESE mg/l | METALS LOADING lbs/day |
|---|---|---|---|---|---|---|---|---|---|---|---|
| MSSR0034 | 6/11/03 | 3.10 | 1130.00 | 42.52 | 340.00 | 0.00 | 173.46 | 158.00 | 10.20 | 0.82 | 86.52 |
| MSSR0034 | 6/25/03 | 3.50 | 1820.00 | 54.66 | 442.00 | 0.00 | 289.90 | 198.00 | 12.00 | 1.07 | 138.91 |
| MSSR0034 | 7/1/03 | 3.40 | 1750.00 | 37.05 | 449.00 | 0.00 | 199.62 | 197.00 | 11.40 | 1.39 | 93.59 |
| MSSR0034 | 7/9/03 | 3.25 | 1670.00 | 27.24 | 417.00 | 0.00 | 136.30 | 173.00 | 9.48 | 0.88 | 60.14 |
| MSSR0034 | 7/15/03 | 3.45 | 2080.00 | 22.89 | 467.00 | 0.00 | 128.29 | 194.00 | 11.30 | 1.00 | 56.87 |
| MSSR0034 | 7/22/03 | 3.50 | 1270.00 | 48.38 | 435.00 | 0.00 | 252.56 | 181.00 | 10.10 | 0.92 | 111.87 |
| MSSR0034 | 8/5/03 | 3.77 | 1380.00 | 9.50 | 350.00 | 0.00 | 39.90 | 154.00 | 7.46 | 0.78 | 18.56 |

## APPENDIX 2: MIDDLE BASIN BIOLOGICAL REPORT

# FISH AND MACROINVERTEBRATE STUDY OF THE MIDDLE BASIN OF RACCOON CREEK

*MBI Technical Report MB/2003-1-3*

# Fish and Macroinvertebrate
# Study of the Middle Basin of Raccoon Creek

2002 Field Year

Athens, Meigs, Jackson, Vinton and Gallia Counties, Ohio

Sept 23, 2003

MBI Technical Report MB/2003-1-3

prepared for

Division of Mineral Resources Management
Ohio Department of Natural Resources

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## Acknowledgements

The following are acknowledged for their significant contribution to this report.
Fish and Habitat Data Collection – Tony Minamyer
Macroinvertebrate Data Collection and Identification – Scott O'dee

Reviewers -

This evaluation and report would not have been possible without the assistance of the following individuals in the field: Tony Minamyer and Scott O'dee, crew leaders; interns: Mike Copeland and and the support of the Brian Armitage of the MBI and Scott Miller, Chip Rice, Rachel Hoy, Elizabeth Flemming and others at ILGARD, Ohio University.

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## Forward

This report generally follows the format used in Ohio EPA Technical Support Documents ("TSDs") and the purpose of an Ohio EPA TSD and this report are generally similar. Those familiar with a TSD should be able to use this report without much difficulty. There are some differences, however, in that a focus of this report is identifying waters affected by acid mine drainage (AMD) and other mine related stressors. This cannot be completely accomplished without an assessment of other stressors to aid in the process of discriminating among the various causes of impairment. We are also interested in generating useful endpoints for other watershed restoration efforts. In the Western Allegheny Plateau (WAP) ecoregion this typically includes understanding the effects of fine sediments on aquatic life and attainment of aquatic life uses. To accomplish this we will use data from this report and reference data from the WAP ecoregion to generate sediment endpoints for TMDL efforts.

The major objectives of a biosurvey are typically to: 1) determine the extent to which use aquatic life use designations are either attained or impaired; 2) determine the appropriate and attainable aquatic life use designation; and 3) determine the stressors responsible for any impairments or threats. The following discussion on the hierarchy of indicators is taken from Ohio EPA:

> Hierarchy of Indicators
>
> A carefully conceived ambient monitoring approach, using cost-effective indicators comprised of ecological, chemical, and toxicological measures, can ensure that all relevant pollution sources are judged objectively on the basis of environmental results. Ohio EPA relies on a tiered approach in attempting to link the results of administrative activities with true environmental measures. This integrated approach is outlined in Figure 1 and includes a hierarchical continuum from administrative to true environmental indicators. The six "levels" of indicators include: 1) actions taken by regulatory agencies (permitting, enforcement, grants); 2) responses by the regulated community (treatment works, pollution prevention); 3) changes in discharged quantities (pollutant loadings); 4) changes in ambient conditions (water quality, habitat); 5) changes in uptake and/or assimilation (tissue contamination, biomarkers, wasteload allocation); and, 6) changes in health, ecology, or other effects (ecological condition, pathogens). In this process the results of administrative activities (levels 1 and 2) can be linked to efforts to improve water quality (levels 3, 4, and 5) which should translate into the environmental "results" (level 6). Thus, the aggregate effect of billions of dollars spent on water pollution control since the early 1970s can now be determined with quantifiable measures of environmental condition. Superimposed on this hierarchy is the concept of stressor, exposure, and response indicators. Stressor indicators generally include activities which have the potential to degrade the aquatic environment such as pollutant discharges (permitted and unpermitted), land use effects, and habitat modifications. Exposure

indicators are those which measure the effects of stressors and can include whole effluent toxicity tests, tissue residues, and biomarkers, each of which provides evidence of biological exposure to a stressor or bioaccumulative agent. Response indicators are generally composite measures of the cumulative effects of stress and exposure and include the more direct measures of community and population response that are represented here by the biological indices which comprise Ohio's biological criteria. Other response indicators could include target assemblages, i.e., rare, threatened, endangered, special status, and declining species or bacterial levels which serve as surrogates for the recreational uses. These indicators represent the essential technical elements for watershed-based management approaches. The key, however, is to use the different indicators within the roles which are most appropriate for each. Describing the causes and sources associated with observed impairments revealed by the biological criteria and linking this with pollution sources involves an interpretation of multiple lines of evidence including water chemistry data, sediment data, habitat data, effluent data, biomonitoring results, land use data, and biological response signatures within the biological data itself. Thus the assignment of principal causes and sources of impairment represents the association of impairments (defined by response indicators) with stressor and exposure indicators. The principal reporting venue for this process on a watershed or subbasin scale is a biological and water quality report. These reports then provide the foundation for aggregated assessments such as the Ohio Water Resource Inventory (305[b] report), the Ohio Nonpoint Source Assessment and other technical bulletins.

Ohio Water Quality Standards: Designated Aquatic Life Use

The Ohio Water Quality Standards (WQS; Ohio Administrative Code 3745-1) consist of designated uses and chemical, physical, and biological criteria designed to represent measurable properties of the environment that are consistent with the goals specified by each use designation. Use designations consist of two broad groups, aquatic life and non-aquatic life uses. In applications of the Ohio WQS to the management of water resource issues in Ohio's rivers and streams, the aquatic life use criteria frequently result in the most stringent protection and restoration requirements, hence their emphasis in biological and water quality reports. Also, an emphasis on protecting for aquatic life generally results in water quality suitable for all uses. The five different aquatic life uses currently defined in the Ohio WQS are described as follows:

1) Warmwater Habitat (WWH) - this use designation defines the "typical" warmwater assemblage of aquatic organisms for Ohio rivers and streams; this use represents the principal restoration target for the majority of water resource management efforts in Ohio.

2) Exceptional Warmwater Habitat (EWH) - this use designation is reserved for waters which support “unusual and exceptional” assemblages of aquatic organisms which are characterized by a high diversity of species, particularly those which are highly intolerant and/or rare, threatened, endangered, or special status (i.e., declining species); this designation represents a protection goal for water resource management efforts dealing with Ohio’s best water resources.

3) Cold-water Habitat (CWH) - this use is intended for waters which support assemblages of cold water organisms and/or those which are stocked with salmonids with the intent of providing a put-and-take fishery on a year round basis which is further sanctioned by the Ohio DNR, Division of Wildlife; this use should not be confused with the Seasonal Salmonid Habitat (SSH) use which applies to the Lake Erie tributaries which support periodic “runs” of salmonids during the spring, summer, and/or fall.

4) Modified Warmwater Habitat (MWH) - this use applies to streams and rivers which have been subjected to extensive, maintained, and essentially permanent hydromodifications such that the biocriteria for the WWH use are not attainable and where the activities have been sanctioned by state or federal law; the representative aquatic assemblages are generally composed of species which are tolerant to low dissolved oxygen, silt, nutrient enrichment, and poor quality habitat.

5) Limited Resource Water (LRW) - this use applies to small streams (usually <3 mi. drainage area) and other water courses which have been irretrievably altered to the extent that no appreciable assemblage of aquatic life can be supported; such waterways generally include small streams in extensively urbanized areas, those which lie in watersheds with extensive drainage modifications, those which completely lack water on a recurring annual basis (i.e., true ephemeral streams), or other irretrievably altered waterways.

6) Limited Resource Water - Acid Mine Drainage (LRW-AMD) -this use applies to streams and rivers which have been subjected to severe acid mine drainage pollution from abandoned mine lands or gob piles, and where there is no near term prospect for reclamation; the representative aquatic assemblages are generally composed of species which are tolerant to low pH, silt, metals, and poor quality habitat.

Chemical, physical, and/or biological criteria are generally assigned to each use designation in accordance with the broad goals defined by each. As such the system of use designations employed in the Ohio WQS constitutes a “tiered” approach in that varying and graduated levels of protection are provided by each. This hierarchy is especially apparent for parameters such as dissolved oxygen, ammonia-nitrogen, temperature, and the biological criteria. For other parameters such as heavy metals, the technology to construct an equally graduated set of criteria has been lacking, thus the same water quality criteria may apply to two or three different use designations.

## *Introduction*

The Raccoon Creek watershed has a long history of underground and surface mining (ILGARD 2003). A byproduct of this historic activity has been acid mine drainage, sedimentation, and metal loadings in tributaries in the vicinity of these mines. Remediation efforts thus far have already shown substantial improvements in aquatic life from abatement of certain impacts in the Raccoon Creek watershed (Ohio EPA 1997). This report focuses on identifying mining impaired waterways in the Middle Basin of the Raccoon Creek watershed which extends from upstream of Little Raccoon Creek (~RM 39.8) to Raccoon Creek at US 50 at RM 80 (Map 1). The major tributary in this reach is Elk Fork. Some recent biological assessment work in this area was done by Ohio EPA and others between 1993 and 2000, although most work was concentrated in the upper Raccoon Creek and Little Raccoon Creek watersheds. This study is designed to fill gaps in the biological data coverage of previous Ohio EPA studies and to compare changes in biological condition from earlier studies (Ohio EPA 1983, 1985, 1991). This additional biological data is needed to provide sufficient spatial coverage of this watershed so that all significant sources of AMD are identified and to create a baseline to measure the success of abatement actions. In addition, we hope to develop substrate targets for waters as TMDL endpoints for impaired waters in this watershed. To accomplish this, it is important to ascertain the relative contribution of headwater streams to observed impairments in larger waters (e.g., Raccoon Creek).

Specific objectives of this portion of the study were to:
1) evaluate the physical habitat and the biological integrity of the Middle Basin of Raccoon Creek study area especially in relation to AMD,
2) assess impacts from mining activities, nonpoint sources of pollution, and habitat alterations,
3) determine attainment status of aquatic life and recommend changes where appropriate, and
4) expand a baseline of biological data for assessing AMD and compare results of this survey with previous surveys to assesses changes in water quality and biological integrity.

*Benefits of Stream and River Restoration*

Stream restoration is assumed to be cost-effective in many cases and many statues drive stream restoration without clear links back to services that streams and rivers provide to society. More explicit examination of the benefits of clean water and the restoration of aquatic life would help bolster support of watershed restoration efforts. Many of the services that healthy streams provide to society are not always obvious, but can be immense (Daily et al. 1997). As summarized by Daily et al. (1997):

> “Human societies derive many essential goods from natural ecosystems, including seafood, game animals, fodder, fuelwood, timber, and pharmaceutical products. These goods represent important and familiar parts of the economy. What has been less appreciated until recently is that natural ecosystems also perform fundamental life-support services without which

> human civilizations would cease to thrive. These include the purification of air and water, detoxification and decomposition of wastes, regulation of climate, regeneration of soil fertility, and production and maintenance of biodiversity, from which key ingredients of our agricultural, pharmaceutical, and industrial enterprises are derived. This array of services is generated by a complex interplay of natural cycles powered by solar energy and operating across a wide range of space and time scales. The process of waste disposal, for example, involves the life cycles of bacteria as well as the planet-wide cycles of major chemical elements such as carbon and nitrogen. Such processes are worth many trillions of dollars annually. Yet because most of these benefits are not traded in economic markets, they carry no price tags that could alert society to changes in their supply or deterioration of underlying ecological systems that generate them. Because threats to these systems are increasing, there is a critical need for identification and monitoring of ecosystem services both locally and globally, and for the incorporation of their value into decision-making processes."

In southeast Ohio, the more obvious economics benefits of clean waters and functioning watersheds are sufficient by themselves to drive watershed restoration efforts. Southeast Ohio has recently become a recreation destination for other areas of Ohio. For streams, a predominant use of these resources is for fishing. In a study in Oklahoma about 27% of those with fishing licenses fished in streams and rivers (Fisher et al. 2002). For the subregion of eastern Oklahoma, stream fishing generated about $24 million of activity for 1993. Nationally, Americans spend about $24 billion dollars a year on fishing. Improvements in fishability, which as we will show later is correlated with biological integrity, should result in repeat visits to the Raccoon Creek watershed for fishing and related recreation (e.g., canoeing). Raccoon Creek already has substantial recreational use and the physical habitats of the mainstem should eventually support an improving warmwater fishery as the stressors identified here are abated. Thus there are substantial economic and ecological benefits that should result from improving aquatic and water quality conditions in Raccoon Creek.

***Methods***

All chemical, physical, and biological field, laboratory, data processing, and data analysis methodologies and procedures adhere to those specified in the *Manual of Ohio EPA Surveillance Methods and Quality Assurance Practices* (Ohio Environmental Protection Agency 1989a) and *Biological Criteria for the Protection of Aquatic Life, Volumes I-III* (Ohio Environmental Protection Agency 1987a, 1987b, 1989b, 1989c), and *The Qualitative Habitat Evaluation Index (QHEI): Rationale, Methods, and Application* (Rankin 1989) and Rankin (1995) for aquatic habitat assessment. Chemical, physical and biological sampling locations are listed in Table 1. Determining aquatic life use attainment status means describing the degree to which environmental indicators are either above or below criteria specified by the Ohio Water Quality Standards (WQS; Ohio Administrative Code 3745- 1) with the most appropriate indicator typically being the Ohio EPA biological criteria (OAC 3745-1-07; Table 7-14). These are confined to ambient assessments and apply to rivers and streams outside of mixing zones. Numerical biological criteria are based on multimetric biological indices including the Index of Biotic Integrity (IBI) and modified Index of Well-Being (MIwb), indices measuring the response of the fish community, and the Invertebrate Community Index (ICI), which indicates the response of the macroinvertebrate community. Numerical endpoints are stratified by ecoregion, use designation, and stream or river size. Three attainment status results are possible at each sampling location - Full, partial, or non-attainment. Full attainment means that all of the applicable indices meet the Ohio WQS biocriteria or the LRW-AMD benchmarks. Partial attainment means that one or more of the applicable indices fails to meet the biocriteria or the LRW-AMD benchmarks. Nonattainment means that none of the applicable indices meet the biocriteria or the LRW-AMD benchmarks; or, for WWH and EWH streams, one of the organism groups reflects poor or very poor performance. An aquatic life use attainment table (see Table 2) is constructed based on the sampling results and is arranged by sampling locations indicated by river mile, the applicable biological indices, the use attainment status (i.e., full, partial, or non), the Qualitative Habitat Evaluation Index (QHEI), and comments and observations for each sampling location.

The IBI and ICI are multimetric indices patterned after an original IBI described by Karr (1981) and Fausch et al. (1984). The ICI was developed by Ohio EPA (1987b) and further described by DeShon (1995). The Miwb is a measure of fish community abundance and diversity using numbers and weight information and is a modification of the original Index of Well- Being originally applied to fish community information from the Wabash River (Gammon 1976; Gammon et al. 1981). Performance expectations for the principal aquatic life uses in the Ohio WQS (Warmwater Habitat [WWH], Exceptional Warmwater Habitat [EWH], and Modified Warmwater Habitat [MWH]) were developed using the regional reference site approach (Hughes et al. 1986; Omernik 1987). This fits the practical definition of biological integrity as the biological performance of the natural habitats within a region (Karr and Dudley 1981).

*Habitat Assessment*
Physical habitat was evaluated using the Qualitative Habitat Evaluation Index (QHEI) developed by the Ohio EPA for streams and rivers in Ohio (Rankin 1989, 1995). Various attributes of the habitat are scored based on the overall importance of each to the maintenance of viable, diverse, and functional aquatic faunas. The type(s) and quality of substrates, amount and quality of instream cover, channel morphology, extent and quality of riparian vegetation, pool, run, and riffle development and quality, and gradient are some of the habitat characteristics used to determine the QHEI score which generally ranges from less than 20 to 100. The QHEI is used to evaluate the characteristics of a stream segment, as opposed to the characteristics of a single sampling site. As such, individual sites may have poorer physical habitat due to a localized disturbance yet still support aquatic communities closely resembling those sampled at adjacent sites with better habitat, provided water quality conditions are similar. QHEI scores from hundreds of segments around the state have indicated that values greater than 60 are generally conducive to the existence of warmwater faunas whereas scores less than 45 generally cannot support a warmwater assemblage consistent with the WWH biological criteria. Scores greater than 75 frequently typify habitat conditions which have the ability to

support exceptional warmwater faunas. General narrative ranges of the QHEI are as follows: < 30 – Very Poor; 30-44 – Poor; 45-59 – Fair; 60-74 – Good; ≥ 75 Excellent.

*Macroinvertebrate Community Assessment*
The ICI for macroinvertebrates requires a station to be sampled quantitatively using multiple-plate, artificial substrate samplers (modified Hester/Dendy) in conjunction with a qualitative assessment of the available natural substrates. Because we focused on small streams during the 2002 survey, we only collected a qualitative sample. Assessments of qualitative macroinvertebrate data result in narrative ratings ranging from very poor to excellent and coincide with narrative ranges applied to the ICI. Qualitative Community Tolerance Values (QCTVs) were used in association with EPT and other indicator taxa to arrive at a narrative rating for a site. The QCTV approximates an ICI rating by calculating a median of the weighted mean ICI for each taxa (generated from statewide data) from those collecting during a narrative assessment. A weighted ICI is based upon ICI scores from each site where the taxon has been found, weighted by the abundance data for that taxon from artificial substrate (quantitative) samples collected throughout Ohio.

The use of the QCTV is limited to relative comparisons between sites and for determining narrative assessments (i.e., it is not used in place of ICI scores). We followed the Ohio EPA lead and used the numerical LRW-AMD benchmark for attainment status as an ICI score of 8. For qualitative only data in a LRW-AMD stream, a very poor narrative evaluation or a poor evaluation at a site where EPT taxa were not considered to be common or predominant on the natural substrates, was assessed as non-attainment status. A poor narrative evaluation at a qualitative only site was assessed as achieving the LRW-AMD benchmark if there were any EPT taxa observed to be common or predominant on the natural substrates.

*Fish Community Assessment*
During 2002 fish were sampled using wading method pulsed DC electrofishing gear as specified in Ohio EPA (1987b). The wading method was used at a frequency one sample at each site.

*Causal Associations*
The identification of impairment in rivers and streams is straightforward - the numerical biological criteria are used to judge aquatic life use attainment and impairment (partial and non-attainment). The rationale for using the biological criteria, within a weight of evidence framework, has been extensively discussed elsewhere (Karr et al. 1986; Karr 1991; Ohio EPA 1987a,b; Yoder 1989; Miner and Borton 1991; Yoder 1991; Yoder 1995). Identifying the causes and sources of the observed impairments relies on an interpretation of multiple lines of evidence including water chemistry data, sediment data, habitat data, effluent data, land use data, knowledge of mining sources, and biological results (Yoder and Rankin 1995, Simon 2003). Thus the assignment of principal causes and sources of impairment in this report represent the association of impairments (based on response indicators) with stressor and exposure indicators. The reliability of the identification of probable causes and sources is increased where many such prior

associations have been identified, or have been experimentally or statistically linked together. The ultimate measure of success in water resource management is the restoration of lost or damaged ecosystem attributes including aquatic community structure and function. While there have been criticisms of misapplying the metaphor of ecosystem "health" compared to human patient "health" (Suter 1993), in this document we are referring to the process for evaluating biological integrity and causes or sources associated with observed impairments, not whether human health and ecosystem health are analogous concepts.

*Prevalent Causes and Sources of Impairment in the WAP Ecoregion*

Ecoregions are useful for developing biocriteria because they identify regions of similarity in terms of biological assemblages. They are also useful, however, in identifying important stressors because they tend to be more similar within than across ecoregions. Knowledge of prevalent stressors throughout an ecoregion or subecoregion can be informative for stressor identification in a watershed that is a part of a particular ecoregion. The prevalent stressors in the WAP ecoregion are illustrated in Figure 1. These stressors are dominated by nonpoint sources from mining (metals, pH, siltation) and agriculture (siltation, habitat alterations, nutrients, and flow alterations). As we discuss later, these are also the primary sources of potential impairment in the Middle Basin of Raccoon Creek.

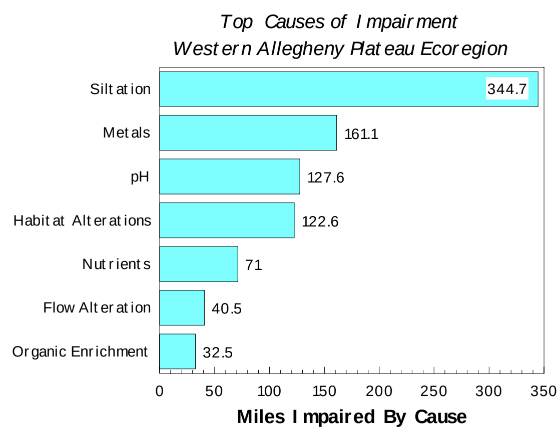



*Figure 1. Prevalent causes of aquatic life impairment in the WAP ecoregion from the Ohio Water Resource Inventory (Ohio EPA 2000).*

*Detecting Impairment in Small Headwater Streams*

The biological methods used here were developed in streams generally greater than 3 sq mi, but often work fine in smaller waters that are not flow limited. In streams smaller than 3 sq mi in some areas of Ohio, low summer flows can be "naturally" limiting to aquatic life in certain instances. It can be difficult to separate out "natural" affects of low flow from certain anthropogenic influences that can worsen such effects. Here we consider natural to mean least impacted conditions in a region given broad scale anthropogenic changes not "pristine" or "pre-Columbian." Historical data from Trautman (1981) suggests that headwater streams had greater year-round flows before the original forests were cut because of wetlands and large trees in and near streams and a greater ability of these systems to hold surface and subsurface water. Ohio EPA's measures of least impacted relate to streams under second growth forest with natural channel conditions or with agricultural activities that do not encroach on stream margins or short circuit natural flow patterns in these waters substantially. These are the conditions reflected in Ohio's biocriteria through the choice of reference sites from which biocriteria were derived.

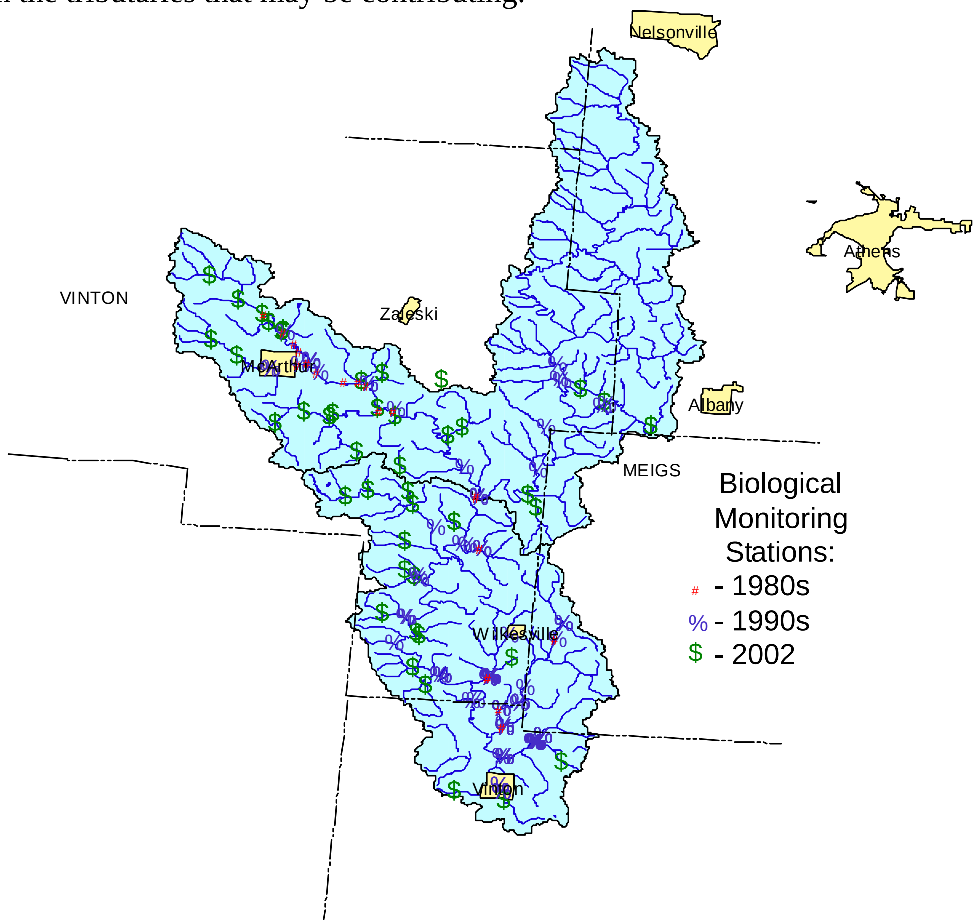
In very small "primary" headwater streams which are less than 3 sq mi and usually less than 1 sq mi, Ohio EPA has proposed alternate sampling methods that include amphibians, macroinvertebrates, and a subset of habitat parameters (Ohio EPA 2000; 2002). Even in larger streams than are typically considered PHW (> 1-2 sq mi), low flows during summer can confound assessment of biological impairments. Macroinvertebrates, in particular, can move downward in the riffle areas to reach interstitial flow and be unavailable to samplers using typical qualitative methods as employed by Ohio EPA. If pools have large numbers of fish, available invertebrates may be further suppressed. In such situations, best professional judgment can be used to decide whether invertebrates reflect anthropogenic impacts or whether the stream is better assessed with headwater methods. For some of the smaller streams in this study we made such decisions and relied on fish community data alone or made the decision that the water would be more appropriately assessed with headwater methodologies (i.e., we did not considered it impaired, see Table 2).

## Results

This report summarizes data collected by Ohio EPA as part of their technical support document (Ohio EPA 1997) based on 1995 data and new data collected during 2002 in small tributaries of Raccoon Creek and some other data collected between this period to provide a complete geographic picture of the condition of the Middle Basin of Raccoon Creek. Table 1 summarizes the locations of the 2002 samples. Map 1 is a map of the locations by sampling year and Map 2 illustrates locations of 2002 fish and macroinvertebrate assessments by narrative category. Table 2 is an attainment table of biological data from 2002 and Appendix Table 2 is an attainment table from the 1995 survey and data collected by Ohio EPA as part of the Meigs Mine spill with other miscellaneous data collected by Ohio EPA in the intervening years. Table 5 summarizes the causes and sources of impairment of the 2002 data and earlier data taken from Ohio EPA's data collection efforts from 1995 (Ohio EPA 1997). Figure 2 is a ranking of samples by IBI collected between 1995 and 2002 that are considered the most current and accurate for a given site. Figure 3 is a similar graph for the macroinvertebrates ranked by total and EPT taxa. Of the 42 sites for which we were able to collect biological data in 2002, 10 were meeting either LRW or WWH aquatic life uses, 2 were partially attaining WWH uses, 18 were not attaining WWH or LRW uses and 12 were deemed as potential primary headwater streams and were not assessed with the data we collected. Of the impaired waters, 7 of the sites had evidence of mine effects in severity of the degraded biota and evidence of precipitates on the substrates. Below we provide more detail on the status, trends, and condition for the streams of the Middle Basin of Raccoon Creek,

*Raccoon Creek Mainstem*

We consider the Middle Basin of Raccoon Creek to reach from upstream of Little Raccoon Creek (~RM 39.8) to Raccoon Creek at US 50 at RM 80 (Map 1). The mainstem of Raccoon Creek was not sampled in 2002, but in 1995 biological communities were in full or partial attainment of WWH biocriteria at all sites sampled through the Middle Basin.  According to the Ohio EPA TSD (Ohio EPA 1997): “The stream segment between Radcliff (RM 63.8) and Humpback Bridge (RM 50.1) had an impact from acid mine tributaries in the area, although less severe than that observed in the upper section of Raccoon Creek. Impacts on the Raccoon Creek mainstem from the Meigs #31 Mine discharges in 1993 into Sugar Run and Strongs Run were minimal in 1995.” Data from both the biological data and from chemical data collected in 1995 or recently by ILGARD indicate there are still episodic AMD impacts from upstream and from mines in the Middle Basin of Raccoon Creek. The remainder of the report will focus primarily on the tributaries that may be contributing.




*Map 1. Location of biological monitoring stations in the Middle Basin of Raccoon Creek during the 1980s, 1990s, and the 2002 survey,*

Fish community data was collected at 42 Sites in 2002 with cumulatively over 80 sites sampled between 1995 and 2002 in the Middle Basin of Raccoon Creek (Map 1). Figure 2 ranks the sites from highest to lowest IBI scores. No site scored in the EWH range, although most sites were fair-good quality. Major tributaries (> 10 sq mi drainage) include Elk Fork (60 sq mi), Strongs Run (~17 sq mi), Wolf Run (11 sq mi), and Pierce Run (~12 sq mi). We will treat each of these tributaries individually and the others in the aggregate by predominant stressor type: mining affected or habitat and sediment affected.

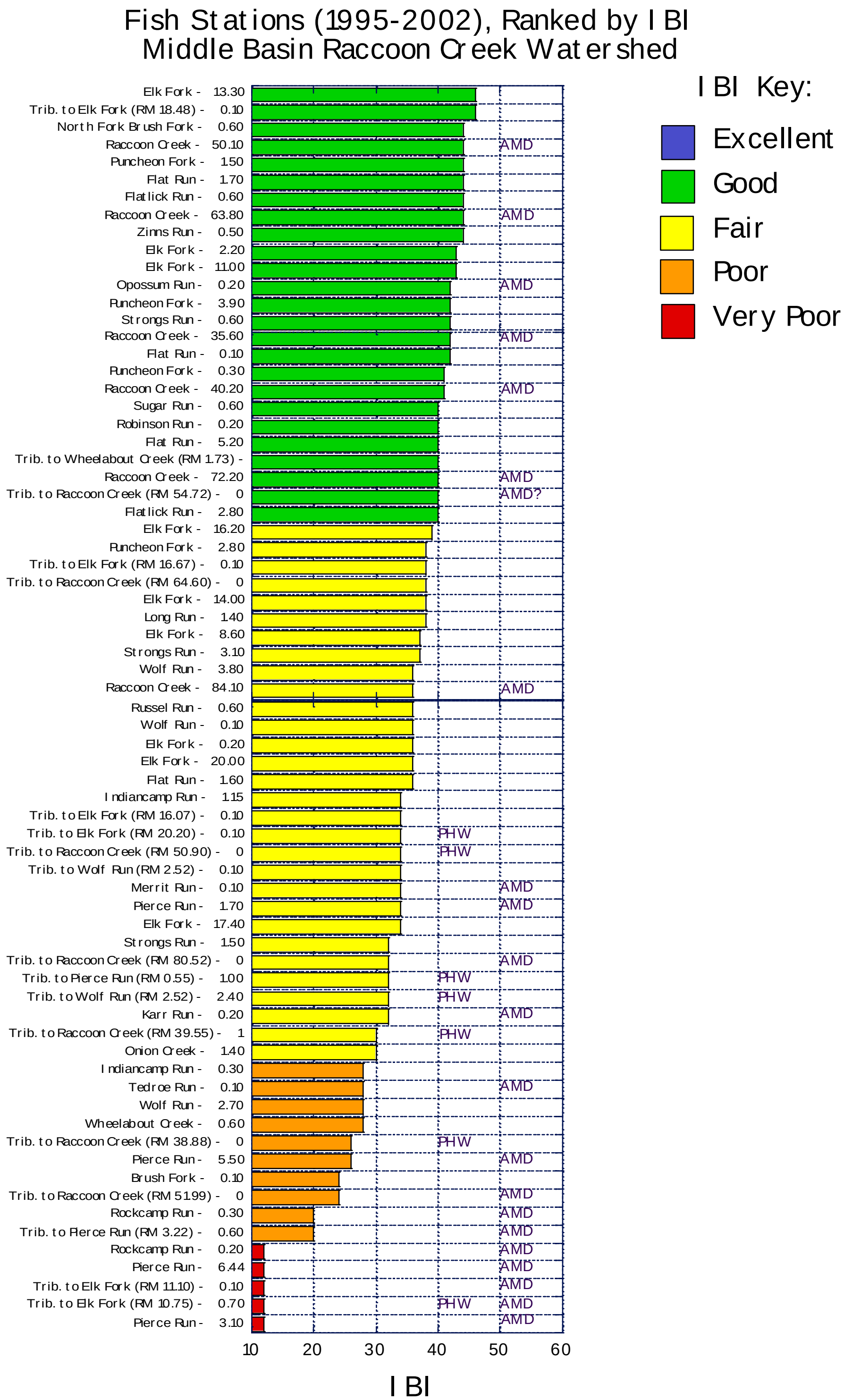



*Figure 2. Bar chart of stations in the Middle Basin of Raccoon Creek ranked by IBI score. Sites affected by acid mine drainage are denoted as AMD; sites that may be candidates for Primary Headwater Habitat are denoted as PHW.*

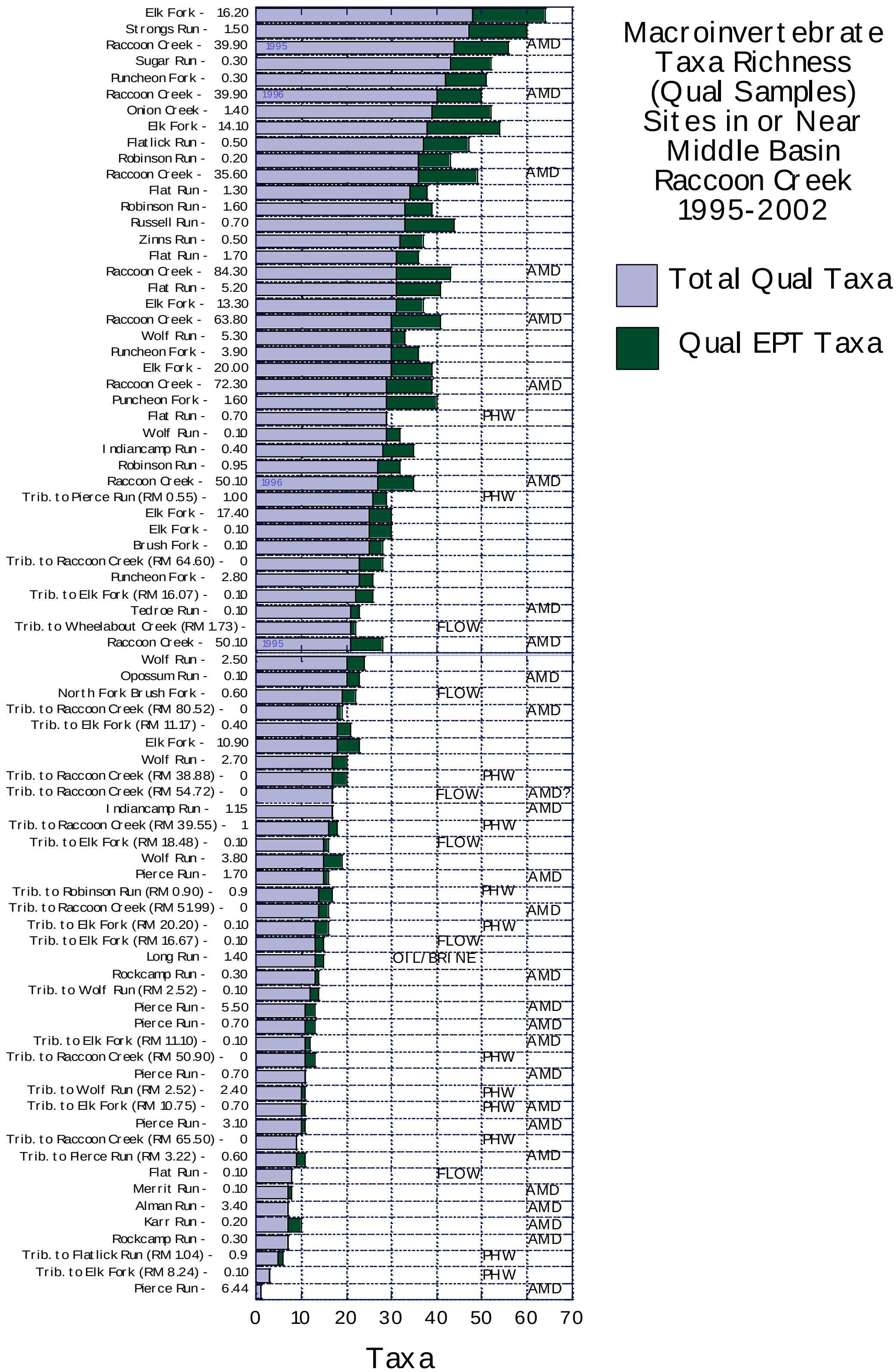
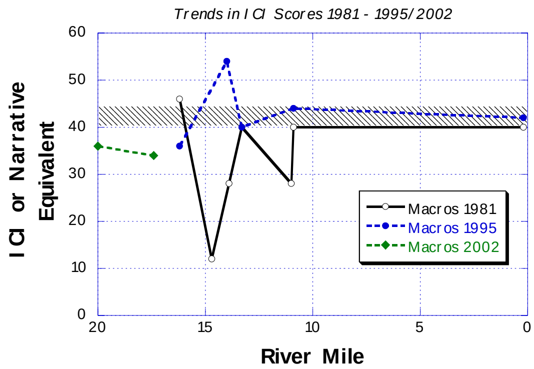



*Figure 3. Bar chart of stations in the Middle Basin of Raccoon Creek ranked by total qualitative taxa. Sites affected by acid mine drainage are denoted as AMD; sites that may be candidates for Primary Headwater Habitat are denoted as PHW; sites affected by low flow are denoted as FLOW..*




## *Elk Fork*

Elk Fork demonstrated a significant improvement in most IBI scores and macroinvertebrate assemblages (mostly based on narrative assessments) from 1981 to 1995 and 2002. The majority of the improvement were attributed to reduction in acid mine drainage with secondary benefits from sewage upgrades. The following is the description from Ohio EPA (1997):

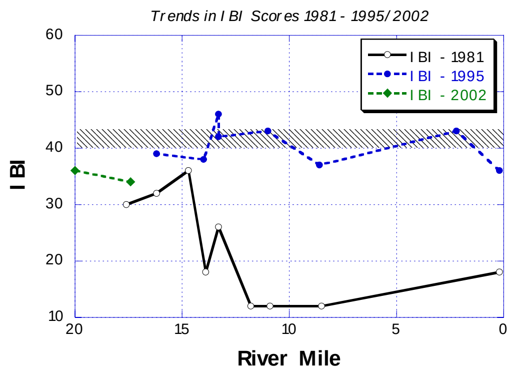



*Figure 4. Plot of ICI vs. RM (top) and IBI vs. RM (bottom) in Elk Fork from 1981, 1995, and 2002. Macroinvertebrate sites marked with an asterisk are estimated ICI values derived from narrative assessments.*

> "In comparison with the results from the 1981 intensive survey, the structure, composition and organization of the fish community in 1995 were reflective of tremendous improvements in the environmental conditions of Elk Fork. Every community measure was significantly advanced (e.g., species richness, relative abundance, composition/organization, and structural evenness). Community indices were typically very near or fully consistent with the ecoregionally derived WWH biological criteria. Although incomplete, biological recovery was clearly indicated in 1995. Improved chemical water quality appeared the most significant factor responsible for the recovery, as chemical impacts from mine drainage appeared largely ameliorated in 1995. However, pervasive sedimentation and its detrimental effects to substrate quality were still present and now appear the major factor limiting biological performance in the mainstem."

The data collected during the 2002 survey were similar to the 1995 Ohio EPA results. The primary impacts identified in 2002 were sedimentation from old mining activities and other land uses in the watershed delivered through the tributaries.

*Strongs Run, Sugar Run, and Robinson Run*

Strongs Run, Sugar Run and Robinson Run were sampled extensively in the 1990s in response to the Meigs #31 Mine accident and resulting discharge. Data from prior to this discharge to examine potential dewatering effects from subsurface mining did not indicate any AMD effects originating from this stream or its tributaries. Although the spill eliminated most of the aquatic life due from Strongs Run due to extremely low pH values, the chemical effects ceased when pumping from the mine ceased and the stream biota itself recovered in about 3 years to pre-discharge populations. The biota of Robinson Run and Sugar Run were not subject to extremely low pH water as was Strongs Run, however, mine water with high total iron concentrations and dissolved solids were pumped to these streams and exerted an impact to these streams that was less extreme than that observed in Strongs Run. Strongs Run and the nearby Robinson Run and Sugar Run are now largely attaining or close to attaining aquatic life biocriteria (Appendix Table 1). Possible impacts to these streams would be primarily sedimentation and erosion from agricultural uses. Habitat quality in these streams is good with sediment metrics showing the greatest deviation from reference levels. Any efforts throughout these watersheds to reduce erosion and sedimentation should enhance aquatic assemblages in these streams.

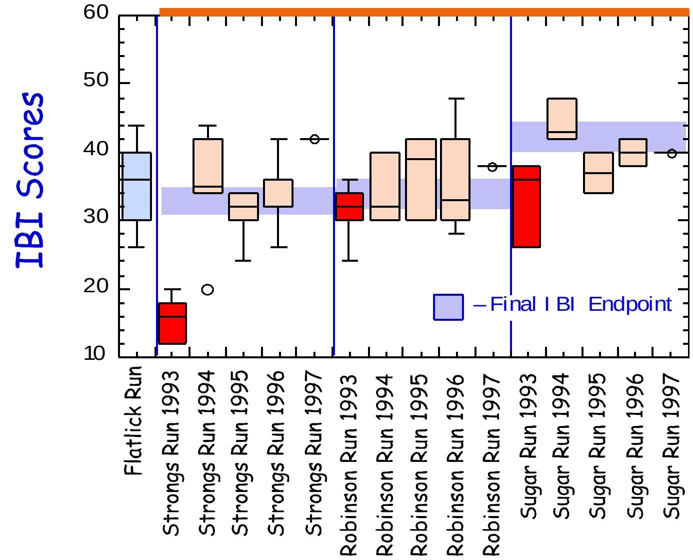



*Figure 5. IBI scores by year for Strongs Run, Robinson Run, and Sugar Run, tributaries of Raccoon Creek in southeast Ohio. All data post-discharge from Meigs 32 Mine event in 1993.*

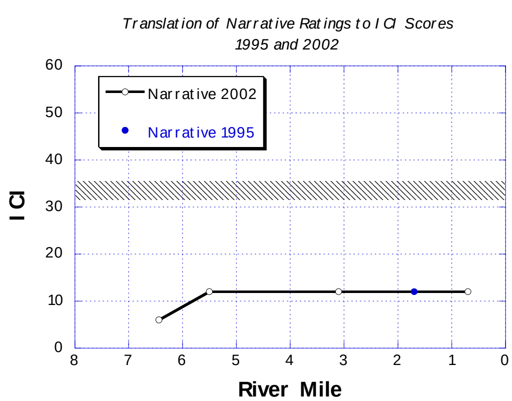
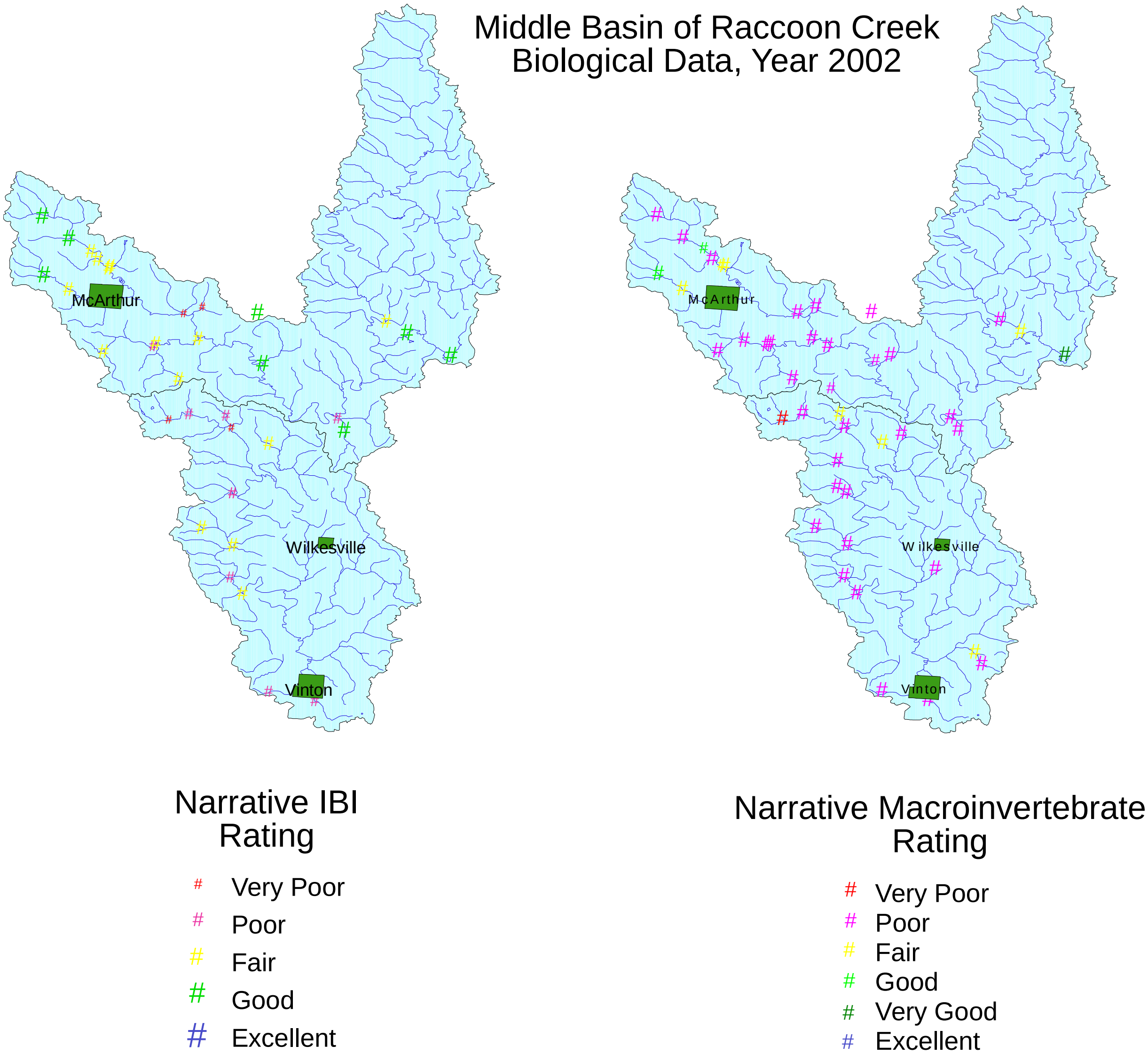



*Figure 6. ICI vs. river mile for Pierce Run from 1995 and 2002. ICI scores were estimated from narrative assessments.*

*Pierce Run*

Pierce Run is designated as a LRW-AMD and we concur that this is the appropriate aquatic life use at this time. Any aquatic life use below the interim goal (e.g., WWH) is considered temporary and needs to be reassessed periodically. This stream is characterized by a severe biological degradation from periodic mine discharges that result in few or no organisms and very tolerant assemblages of fish and macroinvertebrates. The poor and very poor sites on Map 2 in the center for the watershed are from Pierce Run and its tributaries. Narrative ratings of macroinvertebrates ranged from very poor (RM 6.44) to poor (other sites) with 0-2 EPT taxa. Pierce Run has also had direct habitat modifications that will hinder recovery if AMD is reduced. Full recovery of WWH in Pierce Run should target habitat restoration and erosion control as well as the more severe AMD impairments that are limiting aquatic assemblages. Ohio EPA (1995) reported that Pierce Run was a contributor to the AMD effects observed in the mainstem of Raccoon Creek and our data supports that possibility.




*Map 2. Map of fish IBI (left) and narrative macroinvertebrate assessments (right) for the Middle Basin of Raccoon Creek from 2002. Size of point for IBI is based on IBI score; narrative assessments of macroinvertebrate data are categorical.*

*Wolf Run*

Wolf Run is currently designated as LRW-AMD in the Ohio WQS. The 1995 Ohio EPA report recommend that Wolf Run be resampled during the next survey and its use designation reassessed. We observed a substantial improvement in the fish assemblages of Wolf Run with IBI scores moving from the minimum of 12 (one site sampled in 1981) to scores ranging from 28-36. The 1981 station had no fish species and samples in 2002 ranged from 7 to 12 species including the moderately sensitive longear sunfish and rosefin shiner. Although the macroinvertebrate assemblages were considered poor, they were affected by low flows as was discussed earlier and still had more sensitive taxa (Qual EPT 3-4) than streams which showed stronger AMD affects (e.g., Pierce Run, Qual EPT 0-1).

There are still limitations to the aquatic communities in this stream, however, they appear to be predominantly related to habitat degradation and siltation from land disturbance from agriculture and residential activities. As with other streams in this part of the Raccoon Creek watershed, small streams can be influenced by low base flows that tend to magnify the effects of stressors like siltation and sedimentation. A common effect of excess sedimentation is loss of pool volume and increased embeddedness in riffle/run areas. These actions worsen the effects of low flow by reducing drought refuges in pools and inhibiting movement of taxa into and through the bottom substrates that leaves them susceptible to the effects of droughts. These streams have their aquatic assemblages continually reset almost annually which results in a predominance by tolerant and pioneering taxa and excludes more sensitive species that are not well adapted to periodic stresses from low flow.

**Other Small Streams**

We will deal with the remaining small streams by grouping them by the two major impact types in this watershed, mine effects and sediment effects; streams affected by both stressor types will be covered with the mine affected streams.

*Mine Effected Tributaries*

It can be difficult to identify streams that have serious acid mine drainage affects on streams on the basis of chemical data alone, especially when chemical impacts are episodic or seasonal. Impacts in some streams are obvious (frequent extremely low pH or high metal loads), however, biological data can provide accurate measures of the extent and magnitude of impacts and provide a baseline for restoration actions. As restoration strategies reduce the overall loading of acid and other mining associated parameters, episodic loadings may be more frequent and biological data more important in identifying remaining problems. Although the aggregate indices are important for measuring impairment and attainment, the subcomponents of the biological indices can be very useful in diagnosing impairments. Water chemistry data is essential for understanding the loading of parameters to streams and predicting downstream effects, how they may be affecting biological assemblages, and are critical in engineering solutions to abate AMD.

Table 3 summarizes some of the fish components of the IBI at sites affected by AMD and those unimpaired or affected by other stressors. One biological signature of AMD affected streams is low numbers and biomass of fish. Acute events (e.g., low pH) that may occur during storm events greatly reduce the abundance of all fish and sensitive species are generally much slower to recolonize such streams. This is evident in the Middle Basin of Raccoon Creek watershed where streams characterized as having AMD effects have only 8.8 non-tolerant fish per 300 m.

Table 3. Summary fish community statistics for small streams in the Middle

| Basin Raccoon Creek Watershed affected by AMD and not impaired or affected by other stressors. | | | | | | |
|---|---|---|---|---|---|---|
| Effect | IBI | Sensitive Species | Total Species | Sculpins & Darters | Headwater Species | Percent Pioneering |
| AMD | 18.8 | 0.13 | 3.6 | 0.0 | 0.3 | 59.6 |
| Other | 35.4 | 0.70 | 8.9 | 1.0 | 1.9 | 58.4 |
| Effect | Percent Insectivores | Cyprinid Species | DELT Anomalies | Percent(No.) Simple Lithophils | Total Relative Number | Relative Number w/o Tolerants |
| AMD | 13.8 | 1.8 | 0.0 | 4.4(0.5) | 70.5 | 8.8 |
| Other | 30.4 | 3.7 | 0.0 | 21.5(2.9) | 309.1 | 87.0 |

Based on the biological signatures and other evidence of AMD impacts (e.g., precipitates) we identified the following streams/sites (excluding the larger streams treated above) as showing evidence of AMD during the 2002 survey: Trib to Pierce Run at RM 3.72 (09-658), Trib to Raccoon Creek at RM 51.99 (09-655), Trib to Raccoon Creek at RM 54.72 (09-656), Trib to Raccoon Creek at RM 80.52 (09-0669), Trib to Elk Creek at RM 10.75 (09-660), Trib to Elk Creek at RM 11.10 (09-661), and Rockcamp Creek (09-552). Of these the two tributaries to Elk Fork and the tributary to Pierce Run were the most severely impaired. The direct tributaries to Raccoon Creek were not as severely impaired as the others. Rockcamp Creek was more severely impaired as recently as 1995 when no fish were collected (IBI=12), compared to two species in 2002 (IBI = 20). The area near Pierce Run is likely the greatest contributor to problems associated with the Raccoon Creek mainstem. The two Elk Fork tributaries do not likely contribute much if any impact to Raccoon Creek. These two sites are extremely small (< 1 sq mi) and no impact is evident from these tributaries in Elk Fork itself. More information on loading of acidity, etc., can be found in the water chemistry section of the AMDAT report.

*NPS and Habitat Impacted Waters*

Although a major focus of this report is to identify AMD impacts in this watershed it is essential to understand the other stressors that are limiting aquatic life. To accurately attribute impairments to AMD, the relative contribution and overlap with NPS impairments needs to be evaluated. Various data types help in the assessment of NPS stressors. As with AMD impacts, biological signatures help in categorizing and attributing various NPS stressors as limiting factors to biological integrity. Water chemistry data is also important (e.g., nutrients, dissolved oxygen, TSS and TDS, BOD, etc.). For habitat and sediment related impacts a key tool is the QHEI and its subcomponents.

QHEI assessments were collected at 42 sites in 2002 and 43 sites between 1995 and 2001 in the Middle Basin of Raccoon Creek. Besides mine drainage impacts, habitat and sedimentation/siltation are the primary impairments identified in these watersheds and throughout the WAP ecoregion (see Figure 1). While our primary focus in this study is on the Middle Basin of Raccoon Creek, some of the analyses we will present on habitat and sediment stressors include data from elsewhere in the Raccoon Creek basin and from the Western Allegheny Plateau ecoregion (WAP). Some of the effects of habitat loss occur at a larger scale than a subwatershed and examination of data from a broader geographic area increases resolution of relationships between the biota and habitat that might not be evident in an analysis of a small spatial area.

Table 4 summarizes mean QHEI and metric scores for the sites in the entire Raccoon Creek watershed and in the Middle Basin of Raccoon Creek along with WAP and other ecoregion reference sites and selected watersheds (11 digit) in the WAP ecoregion for comparison. The entire Raccoon Creek watershed and the Middle Basin of Raccoon Creek both scored in the lower range of watersheds in the WAP ecoregion in terms of QHEI and metric scores.

In general the WAP ecoregion has fewer direct channel modification than ecoregions such as the HELP and ECBP ecoregions. "Reference" sites in the HELP ecoregion in northwest Ohio do not meet the same definition of least impacted as in the other ecoregions, including the WAP, and wadeable reference sites in the HELP are considered "best available" rather than "least impacted." Small streams in this region have nearly all been channel modified at some point in time for some or all of the reach of these streams and this is reflected in the low QHEI and metric scores by watershed (Table 3).

Raccoon Creek scored noticeably lower in the riffle metric (1.03) than most other watersheds (Table 4). Even when streams less than 10 sq mi were excluded the riffle scores are still low in this watershed (1.54). Low riffle scores are attributable to low flow, poor substrates, or a combination of these factors. Streams in Raccoon Creek are generally more embedded than reference watersheds although watersheds with similar embeddedness ratings in the WAP ecoregion generally had higher riffle scores. This supports observations that streams as a whole are more flow limited in Raccoon Creek than in most other WAP watersheds.

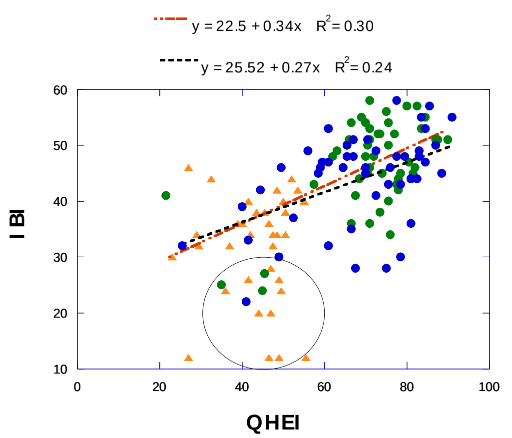



*Figure 7. Plot of QHEI vs. IBI for reference sites in the WAP randomly divided into two data sets (green and blue solid circles). Plotted on the same graph (orange triangles) are sites from the Middle Basin of Raccoon Creek from 2002.*

Figure 7 illustrates relationships between QHEI and IBI at reference sites in the WAP randomly divided into two data sets (green and blue solid circles). Plotted on the same graph are sites from the Middle Basin of Raccoon Creek from 2002 (orange triangles, Figure 7). The similarity of the regressions with randomly selected sites divided into two databases provides a way to validate the accuracy of the regression.

It is clear that the habitat conditions in Raccoon Creek are skewed towards the lower scores observed in the WAP ecoregion. Sites that deviate substantially from the regression lines are more likely affected by one or more other stressors (circled area) such as AMD.

Substrate is one of the most important habitat attributes that we measure. Much of a fish's or macroinvertebrate's life histories are associated with the substrates of streams. In Midwest streams coarse substrates that are generally low in fine sizes are most typical (e.g., Trautman 1981) of reference streams. Filling of interstitial spaces in riffles and loss of pool volume from eroded fines are two of the most limiting stressors in streams where silts and sediments are delivered to streams in greater amounts than can be exported. Figure 7 is similar to Figure 6 above except that the QHEI substrate score is the independent variable. As with QHEI, the substrate metric scores in Raccoon Creek are lower than reference conditions and this is associated with lower IBI scores. Other metrics such as cover and riparian scores are similar to other ecoregions. The substrate score is probably the best overall metric to target for restoration efforts because it is readily measurable and can be targeted by various existing types of BMPs.

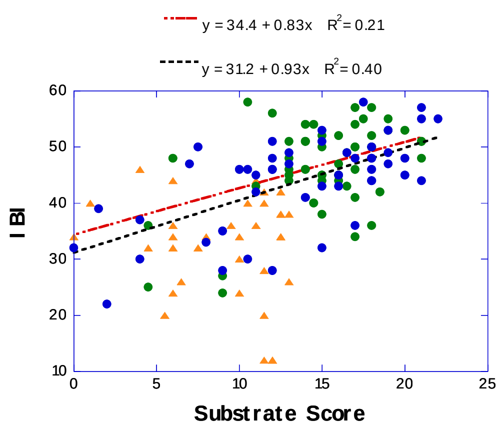



*Figure 8. Plot of the QHEI substrate score vs. IBI for reference sites in the WAP ecoregion randomly divided into two data sets (green and blue solid circles). Plotted on the same graph (orange triangles) are sites from the Middle Basin of Raccoon Creek from 2002.*

The relationships illustrated in Figures 7 and 8 can form the basis for deriving restoration endpoints for habitat and substrate stressors in a watershed. Appendix 1 summarizes a potential process for the derivation of targets for habitat and substrate for southeast Ohio.

*Table 4. Mean QHEI and QHEI metric scores by selected Huc 11 Watersheds in mainly in the WAP ecoregion of Ohio. Sites with drainage areas <= 50 sq mi. For comparison statistics for reference sites by ecoregion and for several watersheds outside of the WAP ecoregion with mean QHEI values > 75 or < 30 were included.*

| Huc 11 Code | Watershed | Mean QHEI | Mean Subs | Mean Silt | Mean Embed | Mean Cover | Mean Rip. | Mean Chan | Mean Pool | Mean Rif | N |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Entire Raccoon Creek Watershed | 57.28 | 10.12 | 2.78 | 2.82 | 11.77 | 7.07 | 12.97 | 6.85 | 1.30 | 150 |
| - | Middle Basin Raccoon | 56.47 | 10.26 | 2.73 | 2.83 | 11.76 | 6.85 | 12.88 | 6.55 | 1.03 | 95 |
| 05040003 030 | Kokosing River (below North Branch to above Jelloway Creek) | 80.75 | 18.38 | 1.75 | 1.75 | 15.00 | 6.63 | 17.75 | 10.00 | 5.25 | 4 |
| 05060002 120 | Scioto River (below Pee Pee Creek to above Sunfish Creek) | 75.92 | 15.84 | 2.13 | 2.29 | 14.53 | 8.47 | 16.53 | 8.82 | 4.05 | 19 |
| 05040004 020 | Wakatomika Creek (headwaters to below Brushy Fork) | 75.42 | 15.25 | 2.33 | 2.42 | 13.00 | 7.50 | 16.50 | 9.67 | 3.50 | 6 |
| | **WAP ecoregion least impacted reference sites, <= 50 SQ MI** | **70.79** | **14.74** | **2.22** | **2.00** | **13.05** | **7.32** | **17.05** | **7.14** | **3.56** | **74** |
| | **HELP ecoregion least impacted reference sites, <= 50 SQ MI** | **49.38** | **10.38** | **2.96** | **2.88** | **8.83** | **4.46** | **12.13** | **4.21** | **2.21** | **12** |
| | **IP ecoregion least impacted reference sites, <= 50 SQ MI** | **69.06** | **15.94** | **2.20** | **1.96** | **12.34** | **6.87** | **15.71** | **6.90** | **3.19** | **35** |
| | **EOLP ecoregion least impacted reference sites, <= 50 SQ MI** | **70.59** | **15.07** | **2.27** | **2.11** | **12.87** | **7.17** | **15.69** | **7.89** | **4.07** | **83** |
| | **ECBP ecoregion least impacted reference sites, <= 50 SQ MI** | **70.96** | **15.13** | **2.24** | **2.18** | **13.63** | **6.36** | **15.63** | **8.13** | **3.68** | **112** |
| 05030101 180 | Yellow Creek (headwaters to above Town Fork) | 68.25 | 14.44 | 2.61 | 2.42 | 12.67 | 6.61 | 16.28 | 7.44 | 3.58 | 18 |
| 05030204 090 | Federal Creek | 68.23 | 15.00 | 2.04 | 1.73 | 11.08 | 7.73 | 15.04 | 8.69 | 2.54 | 13 |
| 05030204 100 | Hocking River (below Athens/RM 33.1 to Ohio River [except Federal Creek) | 67.83 | 13.89 | 2.22 | 2.67 | 12.56 | 6.61 | 14.50 | 9.33 | 3.56 | 9 |
| 05030201 100 | Little Muskingum River (above Clear Fork to Ohio River) | 65.04 | 14.30 | 2.13 | 2.24 | 11.67 | 6.50 | 14.81 | 7.02 | 2.52 | 27 |
| 05030201 100 | Ohio River tributaries (below Sunfish Cr to above Little Muskingum River | 65.04 | 14.30 | 2.13 | 2.24 | 11.67 | 6.50 | 14.81 | 7.02 | 2.52 | 27 |
| 05030101 340 | Cross Creek | 64.33 | 14.44 | 2.19 | 2.19 | 10.72 | 8.36 | 15.28 | 4.92 | 4.94 | 18 |
| 05030201 090 | Little Muskingum River (headwaters to above Clear Fork) | 64.03 | 15.19 | 2.26 | 2.16 | 11.32 | 6.87 | 14.76 | 5.87 | 2.13 | 34 |
| 05030204 050 | Hocking River (below Enterprise to above Monday Creek) | 63.06 | 12.18 | 2.71 | 2.88 | 11.88 | 6.88 | 14.06 | 7.00 | 2.12 | 17 |
| 05030101 190 | Yellow Creek (above Town Fork to Ohio River) | 62.25 | 13.46 | 1.96 | 2.17 | 10.33 | 8.17 | 16.00 | 5.67 | 3.46 | 12 |
| 05030201 010 | Sunfish Creek and Ohio R (below Fish Cr (WV) to below Sunfis | 61.50 | 14.03 | 2.11 | 2.00 | 10.50 | 5.72 | 15.64 | 5.94 | 2.78 | 18 |
| 05030101 090 | Little Beaver Creek (below West Fork to Ohio River) | 61.10 | 15.00 | 2.19 | 2.44 | 11.42 | 6.65 | 12.62 | 5.98 | 2.81 | 26 |
| 05030204 070 | Sunday Creek | 60.55 | 12.32 | 2.49 | 2.48 | 12.95 | 6.94 | 12.94 | 5.88 | 1.89 | 64 |
| 05030204 060 | Monday Creek | 60.34 | 12.32 | 2.36 | 2.37 | 12.04 | 7.42 | 12.63 | 6.49 | 2.17 | 77 |
| 05030106 040 | Ohio River tributaries (below Cross Cr to below Short Creek) | 59.35 | 11.50 | 3.25 | 3.05 | 11.00 | 7.45 | 14.00 | 6.25 | 2.15 | 10 |
| 05030101 070 | Middle Fork Little Beaver Creek (headwaters to above West Fo | 58.14 | 11.90 | 2.96 | 3.17 | 10.81 | 6.22 | 12.33 | 7.50 | 2.60 | 36 |
| 05030204 040 | Clear Creek | 57.78 | 13.02 | 2.54 | 2.93 | 11.17 | 4.00 | 11.98 | 6.96 | 2.30 | 23 |
| 05030201 110 | East Fork of Duck Creek | 57.54 | 12.94 | 2.63 | 2.52 | 9.97 | 5.90 | 14.26 | 6.08 | 1.43 | 62 |
| 05030101 080 | West Fork Little Beaver Creek | 56.85 | 13.15 | 2.75 | 3.00 | 11.10 | 5.55 | 12.15 | 5.35 | 2.15 | 10 |
| 05030201 120 | Duck Creek [except East Fork] and Ohio River tribs (below Li | 56.14 | 12.60 | 2.77 | 2.79 | 9.61 | 6.30 | 14.22 | 5.67 | 0.92 | 51 |
| 05030202 100 | Ohio River tributaries (below Hocking R to above Shade R) | 56.08 | 10.00 | 2.50 | 3.00 | 13.17 | 5.75 | 11.17 | 8.00 | 2.67 | 6 |
| 05030106 200 | Ohio River tributaries (below McMahon Creek to below Fish Cr | 52.70 | 12.70 | 3.40 | 3.70 | 11.80 | 8.30 | 12.00 | 3.20 | 0.70 | 5 |
| 05030204 010 | Hocking River (headwaters to Enterprise [except Clear and Ru | 51.46 | 11.72 | 2.85 | 3.37 | 9.22 | 4.59 | 9.41 | 6.52 | 1.91 | 23 |
| 04100010 010 | Wolf Creek, Cedar Creek, Crane Creek and Turtle Creek | 27.24 | 3.38 | 3.68 | 3.76 | 5.38 | 3.72 | 5.91 | 3.90 | 0.33 | 45 |
| 04100007 090 | Little Auglaize River (above Dog Cr to Auglaize River [excep | 27.07 | 6.64 | 3.43 | 3.57 | 2.43 | 3.21 | 5.79 | 3.57 | 0.57 | 7 |
| 04100009 050 | Maumee River (below Bad Creek to below Beaver Creek) | 24.75 | 6.92 | 3.50 | 3.50 | 2.33 | 2.00 | 5.00 | 2.67 | 0.17 | 6 |
| 04100007 070 | Little Auglaize River (headwaters to above Dog Cr) | 23.77 | 1.36 | 3.95 | 3.82 | 4.55 | 2.59 | 7.18 | 3.36 | 0.18 | 11 |

Table 3. Aquatic life use attainment status for stations sampled in the Raccoon Creek basin based on data collected during 2002. The Index of Biotic Integrity (IBI), Modified Index of well-being (MIwb), and Invertebrate Community Index (ICI) are measures of biotic community condition and the Qualitative Habitat Evaluation Index (QHEI) is a measure of the ability of the physical habitat to support a biotic community.

| Station | Fish RM | Macro. RM | IBI | Macro. Narrative Rating[a] | QHEI | Existing Aq Life Use/Rec. Use | Attainment Status[b] |
|---|---|---|---|---|---|---|---|
| Elk Fork - 09530 | | | | | | | |
| S09530 20.002002 | 20.00 | 20.00 | 36* | MG | 48.0 | WWH | PARTIAL |
| S09530 17.602002 | 17.40 | 17.40 | 34* | F | 37.0 | WWH | NON |
| Flat Run - 09532 | | | | | | | |
| S09532 0.702002 | - | 0.70 | NA | P | - | WWH PHW | NA |
| S09532 0.102002 | 0.10 | 0.10 | 42.0[ns] | P | 48.5 | WWH | Full[d] |
| Wolf Run - 09533 | | | | | | | |
| S09533 5.302002 | 5.00 | 5.30 | 36* | P* | 45.0 | LRW-AMD WWH | FULL/Non |
| S09533 3.802002 | - | 3.80 | NA | P* | - | LRW-AMD WWH | FULL/Non |
| S09533 2.502002 | 2.70 | 2.70 | 28* | P* | 51.0 | LRW-AMD WWH | FULL/Non |
| S09533 0.202002 | 0.10 | 0.10 | 36* | P* | 52.5 | LRW-AMD WWH | FULL/Non |
| Puncheon Fork - 09534 | | | | | | | |
| S09534 3.902002 | 3.90 | 3.90 | 42 [ns] | MG | 53.5 | WWH | FULL |
| S09534 2.802002 | 2.80 | 2.80 | 38* | F* | 43.5 | WWH | NON |
| Indiancamp Run - 09551 | | | | | | | |
| S09551 0.302002 | 1.15 | 1.15 | 34 | P* | 50.5 | LRW/WWH | FULL/Non |
| Rockcamp Run - 09552 | | | | | | | |
| S09552 0.202002 | 0.30 | 0.30 | 20 | P* | 46.0 | LRW | NON-T |
| Pierce Run - 09553 | | | | | | | |
| S09553 6.422002 | 6.50 | 6.44 | 12* | VP* | 52.5 | LRW | NON-T |
| S09553 5.472002 | 5.80 | 5.50 | 26 | P* | 49.5 | LRW | Partial |
| S09553 3.102002 | 3.10 | 3.10 | 12* | P* | 35.0 | LRW | NON-T |
| S09553 0.702002 | 0.00 | 0.70 | NA | P* | | LRW | NON-T |
| Brush Fork - 09555 | | | | | | | |
| S09555 0.102002 | 0.10 | 0.10 | 24 | P* | 51.5 | LRW/WWH | FULL/Non |
| Flat Run - 09557 | | | | | | | |
| S09557 5.202002 | 5.20 | 5.20 | 40 [ns] | G | 50.0 | WWH | FULL |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| S09557 1.602002 | 1.70 | 1.70 | 44 | F* | 40.5 | WWH | PARTIAL |
| Trib. to Wheelabout Creek (RM 1.73) - 09597 | | | | | | | |
| S09597 2.202002 | 2.20 | 2.20 | 40 ns | P | 63.0 | WWH | FULL[d] |
| Trib. to Raccoon Creek (RM 38.88) - 09650 | | | | | | | |
| S09650 0.102002 | 0.10 | 0.10 | 26 | P | 51.0 | WWH PHW | NA[e] |
| Trib. to Raccoon Creek (RM 39.55) - 09651 | | | | | | | |
| S09651 1.302002 | 1.30 | 1.30 | 30 | P | 25.0 | WWH PHW | NA[e] |
| Trib. to Robinson Run (RM 0.90) - 09652 | | | | | | | |
| S09652 0.902002 | - | 0.90 | - | P | - | WWH PHW | NA[e] |
| Trib. to Flatlick Run (RM 1.04) - 09652 | | | | | | | |
| S09653 0.902002 | - | 0.10 | - | P | - | WWH PHW | NA[e] |
| Trib. to Raccoon Creek (RM 50.90) - 09654 | | | | | | | |
| S09654 0.102002 | 0.10 | 0.10 | 34 | P | 44.0 | WWH PHW | NA[e] |
| Trib. to Raccoon Creek (RM 51.35) - 09655 | | | | | | | |
| S09655 0.102002 | 0.10 | 0.10 | 24* | P* | 38.0 | WWH | NON-T |
| Trib. to Raccoon Creek (RM 54.72) | | | | | | | |
| S09656 0.402002 | 0.13 | 0.40 | 40 | P | 43.5 | WWH | Full[d] |
| Trib. to Pierce Run (RM 0.55) | | | | | | | |
| S09657 1.002002 | 0.50 | 1.00 | 32 | P | 39.0 | WWH PHW | NA[e] |
| Trib. to Pierce Run (RM 3.22) | | | | | | | |
| S09658 0.602002 | 0.60 | 0.60 | 20* | P* | 49.0 | WWH | NON-T |
| Trib. to Elk Fork (RM 8.24) | | | | | | | |
| S09659 1.002002 | - | 0.1 | - | P | - | WWH PHW | NA[e] |
| Trib. to Elk Fork (RM 10.75) | | | | | | | |
| S09660 0.702002 | 0.70 | 0.70 | 12 | P | 51.0 | WWH PHW | NA[e] |
| Trib. to Elk Fork (RM 11.10) | | | | | | | |
| S09661 0.102002 | 0.10 | 0.10 | 12* | P* | 61.5 | WWH | NON-T |
| Trib. to Elk Fork (RM 16.07) | | | | | | | |
| S09662 0.102002 | 0.10 | 0.10 | 34* | F* | 56.5 | WWH | NON |
| Trib. to Elk Fork (RM 16.67) | | | | | | | |
| S09663 0.102002 | 0.10 | 0.10 | 38* | P* | 56.5 | WWH | NON |
| Trib. to Elk Fork (RM 18.48) | | | | | | | |
| S09664 0.102002 | 0.10 | 0.10 | 46 | P | 29.0 | WWH | Full[d] |
| Trib. to Elk Fork (RM 20.20) | | | | | | | |
| S09665 0.102002 | 0.10 | 0.10 | 34 | P | 49.5 | WWH PHW | NA[e] |
| Trib. to Wolf Run (RM 2.52) | | | | | | | |
| S09666 | 2.40 | 2.40 | 32 | P | 49.5 | WWH | NA[e] |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 2.402002 | | | | | | PHW | |
| S09666 0.102002 | 0.10 | 0.10 | 34* | P* | 37.0 | WWH | NON-T |
| Trib. to Raccoon Creek (RM 64.60) | | | | | | | |
| S09667 0.702002 | 0.70 | 0.70 | 38* | F* | 51.5 | WWH | NON |
| Trib. to Raccoon Creek (RM 65.50) | | | | | | | |
| S09668 0.102002 | - | 0.10 | - | P | - | WWH PHW | NA[e] |
| Trib. to Raccoon Creek (RM 80.52) | | | | | | | |
| S09669 0.102002 | 0.10 | 0.10 | 32* | P* | 31.5 | None WWH | NON-T |
| North Fork Brush Fork | | | | | | | |
| S09670 0.602002 | 0.60 | 0.60 | 44 | P | 58.0 | None WWH | Full[d] |
| Ecoregion Biocriteria: Western Allegheny Plateau (WAP) | | | | | | | |
| | Index Site Type | WWH | EWH | MWH | LRW-AMD | | |
| | IBI – Wading & Headwater | 44 | 50 | 24/24 | 18 | | |
| | Mod. Iwb - Wading | 8.4 | 9.4 | 6.2/5,5 | 4.0 | | |
| | ICI | 36 | 46 | 22/30 | 8 | | |

Footnotes:

a - A qualitative narrative evaluation based on best professional judgement and sampling attributes such as community composition, EPT taxa richness, and QCTV scores were used when quantitative data were not available (E-exceptional, G-good, MG-marginally good, F-fair, P-poor, VP-very poor).
b - Attainment status is given for existing use designations, except where a use designation change is recommended, in which case, the attainment status for the recommended use is given.
c - Limited Resource Water - acid mine drainage (LRW-AMD) benchmarks based on best professional judgment driven by the need to protect against acutely toxic stream conditions. Macroinvertebrate qualitative only data were evaluated based on densities of EPT taxa on the natural substrates (see Methods Section), a narrative VP* or P* indicates departure from the benchmark.
d – Macroinvertebrate data not used because of low flow limitation during sampling.
e - PHW – Attainment of WWH not deemed appropriate, possible candidate for Primary Headwater designation, which is not currently approved.
N/A - Miwb not applicable at headwater sites (< 20 mi ). 2
ns - Nonsignificant departure from biocriteria (<4 IBI or ICI units, or <0.5 MIwb units).
* - Indicates significant departure from applicable biocriteria (>4 IBI or ICI units, or >0.5 MIw uits). Underlined scores are in the Poor or Very Poor range.

*Use Change Recommendations*

Aquatic life use designations are based on the potential of streams to attain Ohio's listed aquatic life uses (EWH, WWH, MWH, and LRW). Recommendations on changes in aquatic life uses designations are based on a combination of biological, chemical, and physical data with biological data being the ultimate arbiter for the aquatic life use. The CWA protect existing uses of waterbodies as of 1975. Thus any stream that has been designated based on ambient monitoring data, subsequent to 1975 cannot have that use lowered (unless the action was in error). Waterbodies can, however, have their designations changed to a higher tier if ambient data indicates that the high use can now be attained.

Of particular interest in the WAP ecoregion is the LRW-AMD aquatic life use. This is reserved for streams where the biological, chemical, or physical data suggest that a stream is subjected to severe acid mine drainage pollution from abandoned mine activities with no near term prospect for reclamation. Such a LRW use does not indicate that no protective actions are warranted. In fact, is important that the physical nature of the stream be protected if future AMD restoration actions are to be successful.

Another consideration is the potential adoption of a Primary Headwater (PHW) use by Ohio EPA at some time. Several very small streams we sampled are potential candidates for one the PHW categories. Because the sampling methods we used do not apply to PWH streams in many situations we recommended that use designation recommendations and aquatic life assessment be deferred until such a use is in place.

Three tributaries now designated as LRW-AMD were not found to be severely limited by mine drainage effects during this study. We recommend that Wolf Run, Indiancamp Run, and Brush Fork (e.g., 09-555) be considered by Ohio EPA to be redesignated as a WWH aquatic life use. We consider the habitat conditions of these streams to have the ready potential to achieve a WWH level aquatic life use.

## Conclusions

The mainstem of the Middle Basin of Raccoon Creek has recovered substantially from AMD impacts that existed in the 1980s, however there are still AMD impacts, largely in the vicinity of Pierce Run. In addition, NPS stressors, largely excessive fine sediments contribute to the observed aquatic impairment. Multiple stressors are the rule rather than the exception in most streams and the Middle Basin of Raccoon Creek is no exception. However the lack of large point source and urban impacts does simplify the process of identify the responsible stressor "agents."

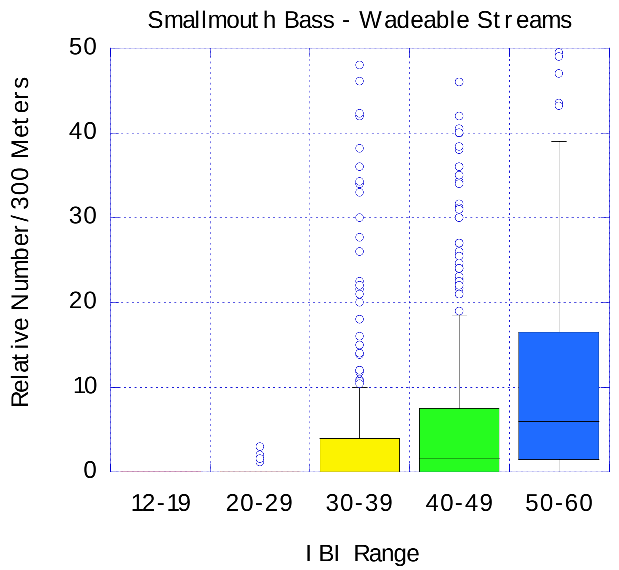



*Figure 9. Box and whisker plot illustrating increases in smallmouth relative abundance with increase IBI scores.Data from wadeable streams across Ohio (Ohio EPA data).*

For the Middle Basin of Raccoon Creek the further restoration of the aquatic community will bring the greatest benefits of aquatic restoration. While the restoration that has occurred to this point has been dramatic, improve to and beyond the baseline WWH biocriteria bring large improvements in the fishability of such streams. Associations between sport fish populations and biological integrity are often geometric. The biomass of catchable sport fish in Raccoon Creek would greatly increase if biological assemblages remain consistently above the baseline biocriteria. Decreases below the biocriteria usually indicate that populations are fluctuating and such communities are generally characterized by smaller, juvenile fish. In the case of Raccoon Creek periodic AMD can limit population increases. High sediment loads also tend to inhibit fish reproduction and growth and suppress invertebrate biomass by limiting suitable habitat area (interstitial areas in substrates). Streams that consistently exceed biocriteria levels are able to build up populations represented by older (larger) individuals. Smallmouth bass abundance in Ohio, for example, are strongly correlated with IBI (Figure 9). It is not difficult to extrapolate increase in sportfish numbers as biocriteria levels are met and maintained.

The highly forested nature of the Raccoon Creek watershed bodes well for long term restoration of this watershed. Raccoon Creek itself generally has a natural channel form and QHEI scores in the 60s. The components of the QHEI that are low are related to substrate conditions which indicate excessive fine substrates impacting the higher quality coarser materials. As sedimentation in the watershed is reduced these finer materials will be gradually exported out of the tributaries and Raccoon Creek and invertebrates and fish assemblages will improve. Raccoon Creek itself generally has a good riparian zone and good instream cover and structure that are important for sport species such as spotted bass, channel and flathead catfish. Improvement of the habitat conditions will improve biodiversity and biological integrity in Raccoon Creek. If watershed restoration efforts are successful, we should see increases in IBI and invertebrate quality, increases in sport and sensitive species, and improved recreational uses of this system. Because sedimentation will be an important stressor to reduce along with AMD, we would suggest future sampling include measures of substrate condition such as pebble counts or the Riffle Stability Index (Kappesser 1993) for larger streams. Such data may provide a more sensitive measure of progress with regard to reductions in sedimentation than QHEI alone.

| Table 5. Waterbody and/or site assessment summaries for data collected in 1995 by Ohio EPA or data collected in 2002 by MBI. | | | | |
|---|---|---|---|---|
| Stations(s) | Segment RMs | Cause/Source of Impairment Comments | Existing Aq Life Use | Attainment Status |
| 1995 Ohio EPA Data and Assessment | | | | |
| Raccoon Creek* - 09500 (Ohio EPA 1995 Data) | | | | |
| Multiple | 89.54 to 66.64 | Causes: Manganese, zinc<br>Sources: Acid mine drainage (AMD)<br>*The upper Raccoon Creek mainstem is biologically and chemically impaired due to AMD primarily from the East Branch Raccoon Creek.*<br>**Mining Effects: AMD Detected** | WWH | Full:<br>11.66 mi<br>Partial<br>11.24 mi |
| Multiple | 66.64 to 37.55 | Causes: Metals<br>Sources: Acid mine drainage (AMD)<br>*The Raccoon Creek mainstem from Radcliff to Vinton appears to be pulsed with AMD impacts during periods of high rainfall from AMD tribs between RM 60.46 (Pierce Run) and RM 53.84 (Karr Run)..*<br>**Mining Effects: AMD Detected** | WWH | Full:<br>5.94 mi<br>Partial<br>22.91 mi |
| Russell Run* (79.43) (Ohio EPA 1995 Data) | | | | |
| S09558<br>0.701995 | 0.6/0.7 | Causes: Oil and grease<br>Sources: Oil and gas operations<br>*Chemical parameters tested did not show high levels of parameters; partial attainment due to fair fish community performance, but good benthic community performance.*<br>**Mining Effects: None Detected** | WWH | Partial |
| Long Run (74.6) (Ohio EPA 1995 Data) | | | | |
| S09556<br>1.401995 | 1.4/1.4 | Causes: Oil and brine<br>Sources: Oil and gas operations<br>*Comments: Chemical parameters tested did not show high levels of parameters; fair benthic and fish community performance.*<br>**Mining Effects: None Detected** | WWH | Non |
| Zinns Run* (63.51) ) (Ohio EPA 1995 Data) | | | | |
| S09554<br>0.501995 | 0.5/0.5 | No Impairment<br>Although some chemical parameters (pH, aluminum, iron, and manganese) were elevated above ecoregion expectations, the substrates were not | WWH | Full |

| | | | | | |
|---|---|---|---|---|---|
| | | | characteristic of AMD, and benthic/fish had good performance. **Mining Effects: None Detected** | | |
| Karr Run* (53.84) ) (Ohio EPA 1995 Data) | | | | | |
| S09550 0.201995 | 0.2/0.2 | | Causes: Metals, pH Sources: Acid mine drainage (AMD) *Comments: Chemical samples not collected but an AMD impact was evident: orange stained substrate rocks, poor benthic and fair fish communities.* **Mining Effects: AMD Detected** | LRW-AMD | Partial |
| Opossum Run* (46.05) ) (Ohio EPA 1995 Data) | | | | | |
| S09548 0.201995 | 0.1/0.1 | | Causes: Iron, manganese, pH; siltation; oil and grease Sources: Possible acid mine drainage (AMD), oil and gas activities Comments: Visible signs of a pollutional impact included oil on water surface and silted substrates. Fair benthic/good fish performance. **Mining Effects: AMD Possible** | WWH | Partial |
| 2002 Data | | | | | |
| Station | Fish RM | Macro. RM | Cause/Source of Impairment Comments | Existing Aq Life Use | Attainment Status |
| Elk Fork - 09530 | | | | | |
| S09530 20.002002 | 20.00 | 20.00 | Cause: Habitat; Source: Hydromod. *Some local agriculture related hydomodification in watershed* **Mining Effects: None Detected** | WWH | PARTIAL |
| S09530 17.602002 | 17.40 | 17.40 | Cause: Habitat; Source: Hydromod. *Some local agriculture related hydomodification in watershed* **Mining Effects: None Detected** | WWH | NON |
| Flat Run - 09532 | | | | | |
| S09532 0.702002 | - | 0.70 | Cause: Nat. Low Flow; Source: Natural *Natural low flow levels, more of a HW location* **Mining Effects: None Detected** | PHW | - |
| S09532 0.102002 | 0.10 | 0.10 | Unimpaired *Natural low flow Level affect macroinvertebrates (See Text)* **Mining Effects: None Detected** | WWH | Full |
| Wolf Run - 09533 | | | | | |

| | | | | | |
|---|---|---|---|---|---|
| S09533 5.302002 | 5.00 | 5.30 | Cause: Habitat/Silt/Flow; Source: Agriculture/Land *Some habitat disturbance and excess siltation and natural low flow levels,* **Mining Effects: None Detected** | LRW/WWH | FULL/Non |
| S09533 3.802002 | - | 3.80 | Cause: Habitat/Silt/Flow; Source: Housing/Agriculture *Some habitat disturbance and excess siltation and natural low flow levels,* **Mining Effects: None Detected** | LRW/WWH | FULL/Non |
| S09533 2.502002 | 2.70 | 2.70 | Cause: Habitat/Silt/Flow; Source: Housing/Agriculture *Some habitat disturbance and excess siltation and natural low flow levels,* **Mining Effects: None Detected** | LRW/WWH | FULL/Non |
| S09533 0.202002 | 0.10 | 0.10 | Cause: Habitat/Silt/Flow; Source: Agriculture/Land *Some habitat disturbance and excess siltation and natural low flow levels,* **Mining Effects: None Detected** | LRW/WWH | FULL/Non |
| Puncheon Fork - 09534 | | | | | |
| S09534 3.902002 | 3.90 | 3.90 | Not Impaired *Some excess siltation and natural low flow levels* **Mining Effects: None Detected** | FULL/Non | FULL |
| S09534 2.802002 | 2.80 | 2.80 | Cause: Silt/Flow; Source: Agriculture *Some excess siltation and natural low flow levels,* **Mining Effects: None Detected** | WWH | NON |
| Indiancamp Run - 09551 | | | | | |
| S09551 0.302002 | 1.15 | 1.15 | Cause: Habitat/Flow; Source: Riparian Loss *Some habitat disturbance, natural low flow levels,* **Mining Effects: None Detected** | LRW/WWH | FULL/Non |
| Rockcamp Run - 09552 | | | | | |
| S09552 0.202002 | 0.30 | 0.30 | Cause: AMD,; Habitat; Source: Land Disturbance *Some habitat disturbance from waste piles near stream,* **Mining Effects: AMD Detected** | LRW/WWH | FULL/Non |
| Pierce Run - 09553 | | | | | |
| S09553 6.422002 | 6.50 | 6.44 | Cause: AMD/Habitat/Sediment; Source: Mining *Some AMD effects obvious; also habitat loss,* **Mining Effects: AMD Detected** | LRW | NON-T |
| S09553 5.472002 | 5.80 | 5.50 | Cause: AMD/Habitat/Sediment; Source: Mining *Some AMD effects obvious;* | LRW | FULL |

| | | | | | |
|---|---|---|---|---|---|
| | | | *also habitat loss,* **Mining Effects: AMD Detected** | | |
| S09553 3.102002 | 3.10 | 3.10 | Cause: AMD/Habitat/Sediment; Source: Mining *AMD effects most severe; also habitat loss,* **Mining Effects: AMD Detected** | LRW | NON-T |
| S09553 0.702002 | - | 0.70 | Cause: AMD/Habitat/Sediment; Source: Mining *Some AMD effects obvious; also habitat loss,* **Mining Effects: AMD Detected** | LRW | FULL |
| Brush Fork - 09555 | | | | | |
| S09555 0.102002 | 0.10 | 0.10 | Cause: Sedimentation; Source: Bank erosion, upstream agriculture *Bank erosion has resulted in excessive sediment,* **Mining Effects: None Detected** | LRW/WWH | FULL/Non |
| Flat Run - 09557 | | | | | |
| S09557 5.202002 | 5.20 | 5.20 | No Impairment *Rowcrop agriculture may contribute to downstream nutrients* **Mining Effects: None Detected** | WWH | FULL |
| S09557 1.602002 | 1.70 | 1.70 | Cause: Habitat, Nutrients; Source: *Agriculture Rowcrop agriculture and loss of riparian; low gradient – deep pools buffer effects* **Mining Effects: None Detected** | WWH | PARTIAL |
| Trib. to Wheelabout Creek (RM 1.73) - 09597 | | | | | |
| S09597 2.202002 | 2.20 | 2.20 | Not Impaired *Low flow effects macro. samples – there are some potential ag sources of silt* **Mining Effects: None Detected** | WWH | Full |
| Trib. to Raccoon Creek (RM 38.88) - 09650 | | | | | |
| S09650 0.102002 | 0.10 | 0.10 | Potential Headwater Habitat *Low flow effects macro. and fish samples – although there is elevated bank erosion and excess silt* **Mining Effects: None Detected** | WWH/PHW | NA |
| Trib. to Raccoon Creek (RM 39.55) - 09651 | | | | | |
| S09651 1.302002 | 1.30 | 1.30 | Potential Headwater Habitat *Low flow and small size (0.3 sq mi) effects macro. and fish samples – although there has been channelization and excess silt* **Mining Effects: None** | WWH/PHW | NA |

| | | | | | |
|---|---|---|---|---|---|
| | | | **Detected** | | |
| Trib. to Raccoon Creek (RM 39.55) - 09651 | | | | | |
| S09651<br>0.102002 | -- | 0.10 | Potential Headwater Habitat<br>*Low flow and small size (0.3 sq mi) effects macro. and fish samples – although there has been channelization and excess silt*<br>**Mining Effects: None Detected** | WWH/PHW | NA |
| Trib. to Robinson Run (RM 0.9) - 09652 | | | | | |
| S09652<br>0.102002 | -- | 0.10 | Potential Headwater Habitat<br>*Low flow (dry first visit) and small size effects macro. samples – although there are ag effects and excess silt*<br>**Mining Effects: None Detected** | WWH/PHW | NA |
| Trib. to Flatlick Run (RM 1.04) - 09653 | | | | | |
| S09653<br>0.102002 | -- | 0.10 | Potential Headwater Habitat<br>*Low flow (dry first visit) and small size effects macro. samples – although there are ag effects and excess silt*<br>**Mining Effects: None Detected** | WWH/PHW | NA |
| Trib. to Raccoon Creek (RM 50.90) - 09654 | | | | | |
| S09654<br>0.102002 | 0.10 | 0.10 | Potential Headwater Habitat<br>*Low flow (dry first visit) and small size effects macro. and fish samples – although there are potential silviculture effects and excess silt*<br>**Mining Effects: None Detected** | WWH/PHW | NA |
| Trib. to Raccoon Creek (RM 51.99) - 09655 | | | | | |
| S09655<br>0.102002 | 0.10 | 0.10 | Cause: AMD/Sediment; Source: Mining. Forestry<br>*Orange precipitate on substrate, gas-line vegetation spraying*<br>**Mining Effects: AMD Detected** | WWH | NON-T |
| Trib. to Raccoon Creek (RM 54.72) | | | | | |
| S09656<br>0.402002 | 0.13 | 0.40 | Fish Unimpaired<br>*Low flow and small size (0.8) effects macro. samples – there was a mine loving midge taxa collected*<br>**Mining Effects: Uncertain** | WWH | Full |
| Trib. to Pierce Run (RM 0.55) | | | | | |
| S09657<br>1.002002 | 0.50 | 1.00 | Potential Headwater Habitat<br>*Low flow (intermittent) and small size effects macro. and fish samples. Nice site in forested area.* | WWH/PHW | NA |

| | | | | | |
|---|---|---|---|---|---|
| | | | **Mining Effects: None Detected** | | |
| Trib. to Pierce Run (RM 3.22) | | | | | |
| S09658 0.602002 | 0.60 | 0.60 | Cause: AMD/Sediment; Source: Mining. *Orange precipitate on substrate* **Mining Effects: AMD possible** | WWH | NON-T |
| Trib. to Elk Fork (RM 8.24) | | | | | |
| S09659 1.002002 | - | 0.1 | Potential Headwater Habitat *Low flow (intermittent) and small size effects macro. samples. Small, sandy site* **Mining Effects: None Detected** | WWH/PHW | NA |
| Trib. to Elk Fork (RM 10.75) | | | | | |
| S09660 0.702002 | 0.70 | 0.70 | Cause: Unknown; Source: Unknown *Very small, possible HW, refuse and old asphalt in an near stream, precipitate on substrate* **Mining Effects: AMD possible** | WWH/PWH | NA |
| Trib. to Elk Fork (RM 11.10) | | | | | |
| S09661 0.102002 | 0.10 | 0.10 | Cause: AMD/Habitat; Source: Mining. *Orange precipitate on substrate* **Mining Effects: AMD possible** | WWH | NON-T |
| Trib. to Elk Fork (RM 16.07) | | | | | |
| S09662 0.102002 | 0.10 | 0.10 | Cause: Habitat; Source: Industrial *Pulp mill runoff – some sawdust in stream; decent flow* **Mining Effects: None Detected** | WWH | NON |
| Trib. to Elk Fork (RM 16.67) | | | | | |
| S09663 0.102002 | 0.10 | 0.10 | Cause: Habitat/Silt; Source: Hydromod/Ag. *Ag effects, channelized; exposed gas line in stream* **Mining Effects: None Detected** | WWH | NON-T |
| Trib. to Elk Fork (RM 18.48) | | | | | |
| S09664 0.102002 | 0.10 | 0.10 | Unimpaired (Fish) *Some riparian removal and ag near stream, small size and low flow affects macros* **Mining Effects: None Detected** | WWH | Full |
| Trib. to Elk Fork (RM 20.20) | | | | | |
| S09665 0.102002 | 0.10 | 0.10 | Potential Headwater Habitat *Low flow effects macro. and fish samples.* **Mining Effects: None Detected** | WWH/PHW | NA |
| Trib. to Wolf Run (RM 2.52) | | | | | |
| S09666 2.402002 | 2.40 | 2.40 | Potential Headwater Habitat *Low flow and tiny size* | WWH/PHW | NA |

| | | | | | |
|---|---|---|---|---|---|
| | | | *effects macro. and fish samples.* **Mining Effects: None Detected** | | |
| S09666 0.102002 | 0.10 | 0.10 | Cause: Silt; Unknown; Source: Ag.? *Oily sheen observed on stream; beaver activity, flow slow* **Mining Effects: None Detected** | WWH | NON |
| Trib. to Raccoon Creek (RM 64.60) | | | | | |
| S09667 0.702002 | 0.70 | 0.70 | Not Impaired (Fish) *Low flow affects macro. and fish samples.* **Mining Effects: None Detected** | WWH | Full |
| Trib. to Raccoon Creek (RM 65.50) | | | | | |
| S09668 0.102002 | - | 0.10 | Potential Headwater Habitat *Low flow affects macro. and fish samples.* **Mining Effects: None Detected** | WWH/PHW | NA |
| Trib. to Raccoon Creek (RM 80.52) | | | | | |
| S09669 0.102002 | 0.10 | 0.10 | Cause: AMD/Silt; Source: Mining?. *Orange tinge to flow and precipitate on substrate* **Mining Effects: AMD possible** | None | NON-T |
| North Fork Brush Fork | | | | | |
| S09670 0.602002 | 0.60 | 0.60 | Not Impaired (Fish) *Low flow affects macro. samples; some fine sediments from ag present.* **Mining Effects: None Detected** | None | Full |
| | | | | | |
| Footnotes: | | | | | |
| | | | | | |

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## Appendix 1. Using the Qualitative Habitat Evaluation Index to Derive TMDL Targets for Sediment Impairment in Southeast Ohio

*Introduction*

Habitat destruction and related sediment and nutrient impacts are among the most prevalent causes of aquatic life impairment in the United States. Here we outline how subcomponents of the QHEI can be used to create aquatic life restoration targets for the TMDL process in southeastern Ohio.

*The Concept of Loadings and Restoration Targets*

The concept of estimate pollutant loading targets has its history associated with the severe point source problems that were in existence when the Clean Water Act was written. Although the effects on aquatic life are largely related to concentrations of pollutants in the receiving water, it was necessary to calculate the load of a pollutant that needed to be reduced to reach a concentration target to estimate concentrations at various flows and to allow an engineering solution to the problem.

Although loading targets for point sources and other pollutants (acid loading for discrete mine impacts) are obviously important for engineering solutions to these impairments, precise estimates of loads may not be essential to quantify and fix other types of impairments, especially where “loadings” may not be directly related to instream concentrations or condition and where such “pollutants” or stressors are strongly affected by other stream conditions such as habitat, flow, temperature, shading, etc. Rather than spending resources on estimating precise loadings of pollutants, it may be more useful to understand the interactions with the co-factors that influence the effects of the stressor of interest (e.g., sediment) on the biota, which are the primary goal of aquatic life use restoration.

Gross erosion rate, for example, is by itself not a good predictor of ecological effects. Parts of Southeast, Southwest, and Northeast Ohio have the some of the greatest potential erosion rates, however, the high gradient (high stream power) and generally natural stream habitats in these areas can often assimilate or export fine sediments. Local habitat conditions as well as local channel form can have a great influence on the effects of sediment loading to a stream system.

The use of a loading approach is best when: 1.) the relationship between the endpoint and stressors is direct (e.g., direct toxicity from that parameter), and 2.) the relationship between the stressor and endpoint is relatively simple (e.g., effects are largely affected by a single other variable such as hardness and heavy metals). When the effect of a pollutant or stressor is potentially influenced by a moderate to large number of other factors, the most effective approach may be to rely on direct instream monitoring of effects (e.g., biocriteria) and statistically modeling the multiple influences on these parameters with other ambient measures (e.g., habitat, sediment condition measures) or, for example, measures derived from remote sensing (e.g., landuse).

*Linking Biological Measures with Sediment and Habitat Stressors*

To use an ambient "modeling" approach to setting sediment endpoints for TMDLs, there must be a measurable link between the response variable (IBI, IBI metric, species abundance) and the stressor (substrate condition, habitat quality). For endpoints such as the IBI there is a significant relationship between the IBI and the overall QHEI score and between the IBI and components of the QHEI, both statewide and in the Western Allegheny Plateau ecoregion (WAP). Figure 1 illustrates the correlation between the QHEI and IBI for all reference sites (least impacted or natural and physically modified[1] reference sites). This illustrates a fairly strong link for direct habitat influences on aquatic life. Figure 2 illustrates the strong relationship between the substrate metric and the overall habitat score indicated the importance of this component.

The substrate metric of the QHEI is composed of some measures of predominant size and condition, specifically the pervasiveness of embeddedness and silt cover throughout a station.  Figure 3 illustrates the relationship of embeddedness to IBI at the same reference sites used earlier. There is a clear association of the IBI with embeddedness with a WAP ecoregion IBI biocriteria value of 44 for headwater and wadeable streams. Fewer than 25% of streams with moderate embeddedness achieving this IBI score and very few streams with severe embeddedness achieve this value. Thus we can use the low-no embeddedness range as an endpoint for sediment impaired streams.

Figure 4 illustrates a random selection of sites in the WAP ecoregion and a subset of these that were reference sites. We have used a linear regression line as to help us derive average expectation between the substrate metric and the IBI for this ecoregion. A line drawn from an IBI value of 44 (WAP biocriteria for headwater and wading sites) provides a useful baseline substrate metric goal of about 13-14 for WWH streams.

The endpoints derived above are site-specific goals for restoration, but it needs to be reinforced that watershed management activities need to occur through a watershed. Sampling coverage can never reach 100% of the watershed, but instead is designed to sample enough sites, where possible, to provide estimates of condition in various parts of watersheds. Statewide data illustrates that habitat has effects at scales greater than a reach or station. Figures 5-7 illustrate the effects of the scale of impact on QHEI and the substrate metric and their influence on the IBI and the expected number of sensitive fish species in Ohio. Habitat measures are medians for any data within that subbasin and IBIs are 90$^{th}$ percentiles within these watersheds are a measure of best remaining biological condition. There are significant relationships between these variables suggesting that the degree of habitat loss in a watershed exerts a strong influence on the achievement of biological integrity. This argues for watershed wide application of best management practices rather than an effort to fix only sites that were monitored. Raccoon Creek and certain other WAP watersheds typically fall toward the higher end on these relationships indicating that these streams, from a physical habitat perspective are highly restorable.

[1] Physically modified reference sites are station that have had direct physical manipulation of habitat (e.g., channelization, dredging, etc), but that do not have influence from point sources or acute impacts from livestock or agriculture. Nutrients are typically elevated from loss of riparian and/or encroachment of landuses, but enrichment is not supplemented by heavy manure or fertilizer runoff.

This may not be not hold true, however in certain very extensively impacted subwatersheds thus scale of impact should be considered in restoration activities.

The baseline TMDL restoration goals for the Western Allegheny Plateau ecoregion are listed below:

QHEI Substrate Metric Endpoint for WWH streams:

**13-14**

QHEI Embeddedness Measure:

**Low-None**

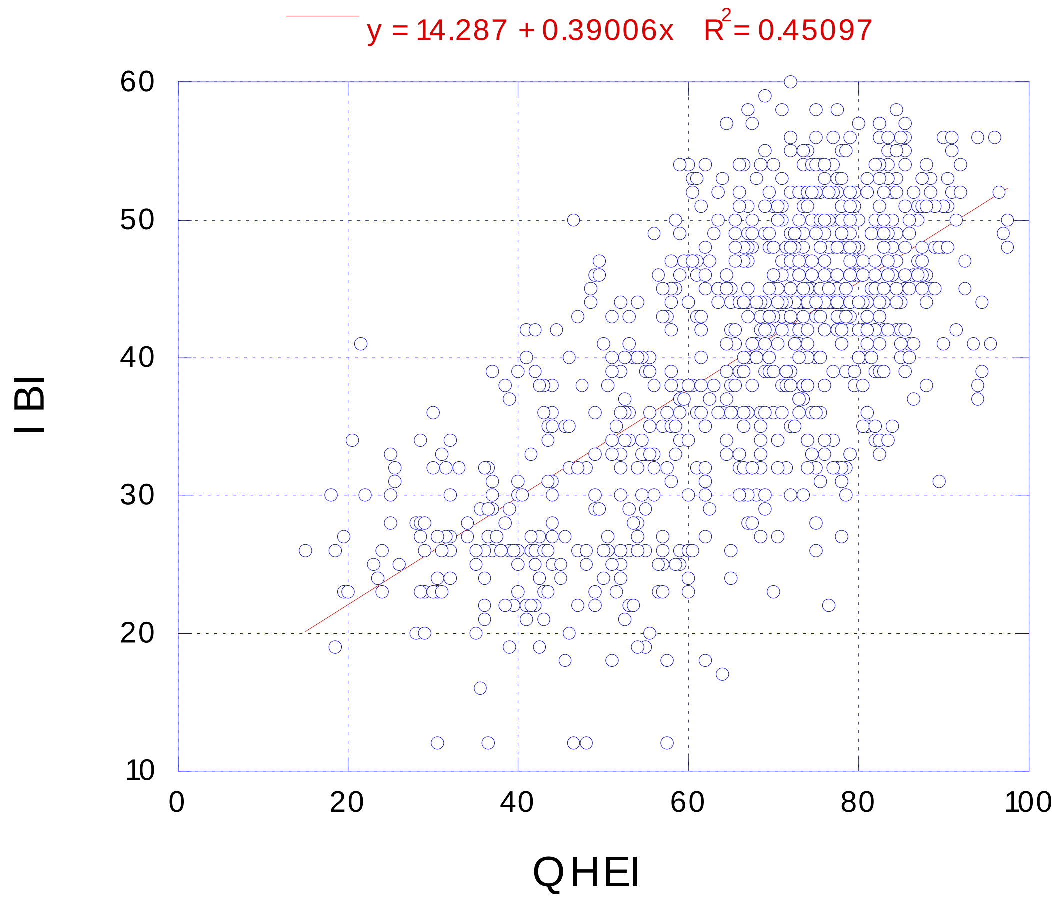
Mean Watershed Substrate Endpoint:

**13-14**

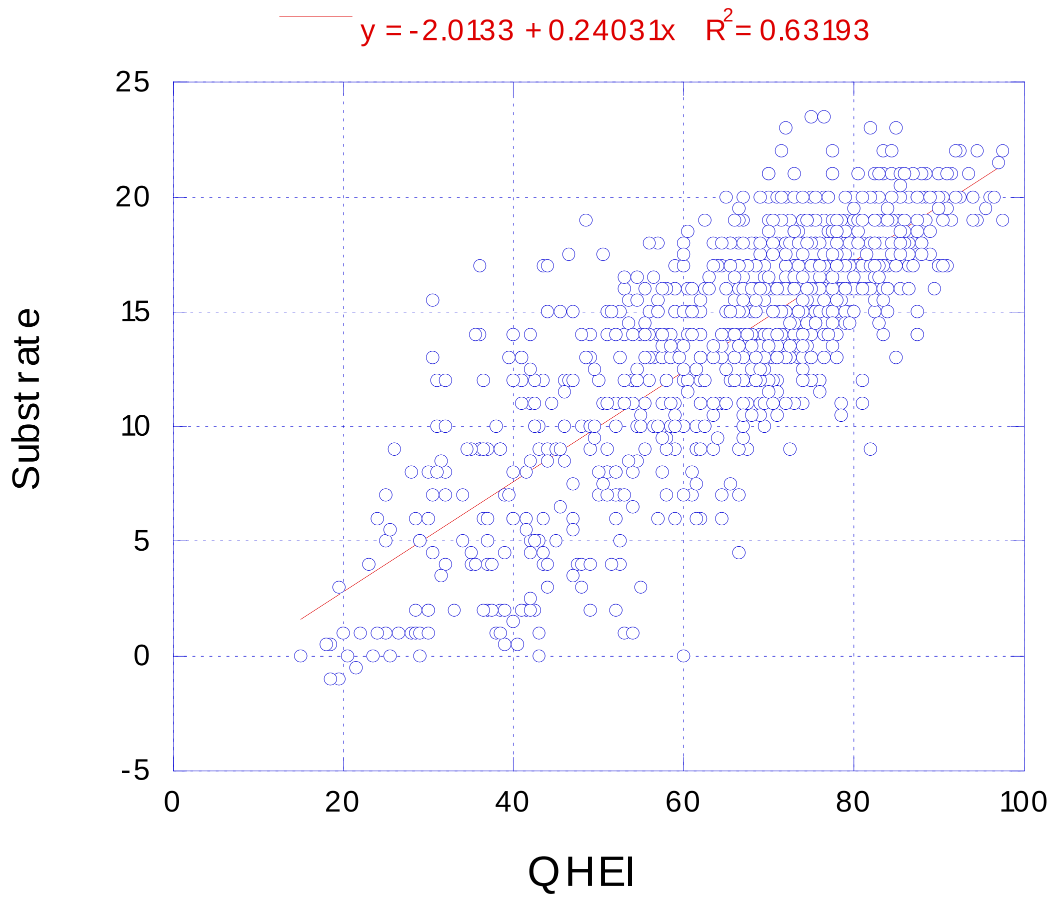
Examination of the plots used to derive these goals shows some scatter or variability around these endpoints. These are useful endpoints to drive restoration activities even with some variability. The biological data will be the ultimate arbiter of success. If these physical goals are achieved and the IBI does not recover after sufficient time has elapsed the watershed will be reexamined for other remaining stressors. Similarly the stream may recover biologically under certain conditions without reaching the final substrate goals, especially the overall substrate score endpoint.

Some low gradient streams may find it difficult to reach a 13-14 score, however, proper stream and watershed restoration actions may be sufficient to restore other habitat features in these stream that did not require a "TMDL" under the regulation. Such factors, however, may have been more limiting than substrate in some instances (e.g., instream cover, channel condition metrics). Thus, to restore the biology it will be important to consider BMPs that restore other features of habitat other than sediment measures alone that are derived because sediment is considered to be a "pollutant" while other habitat limitations are considered "pollution" by the TMDL process. This is illustrate well in Figure 8 that show the relationship between the degree of channelization as measured by the QHEI and the QHEI substrate metric. It is clear that better quality substrates are associated with natural or "recovered" sites and that poor channel condition results in fine substrates, not likely to achieve the endpoints presented here. This strongly supports the use of BMPs that focus on channel restoration where channelization or channel simplifications is associated with sediment impairments.

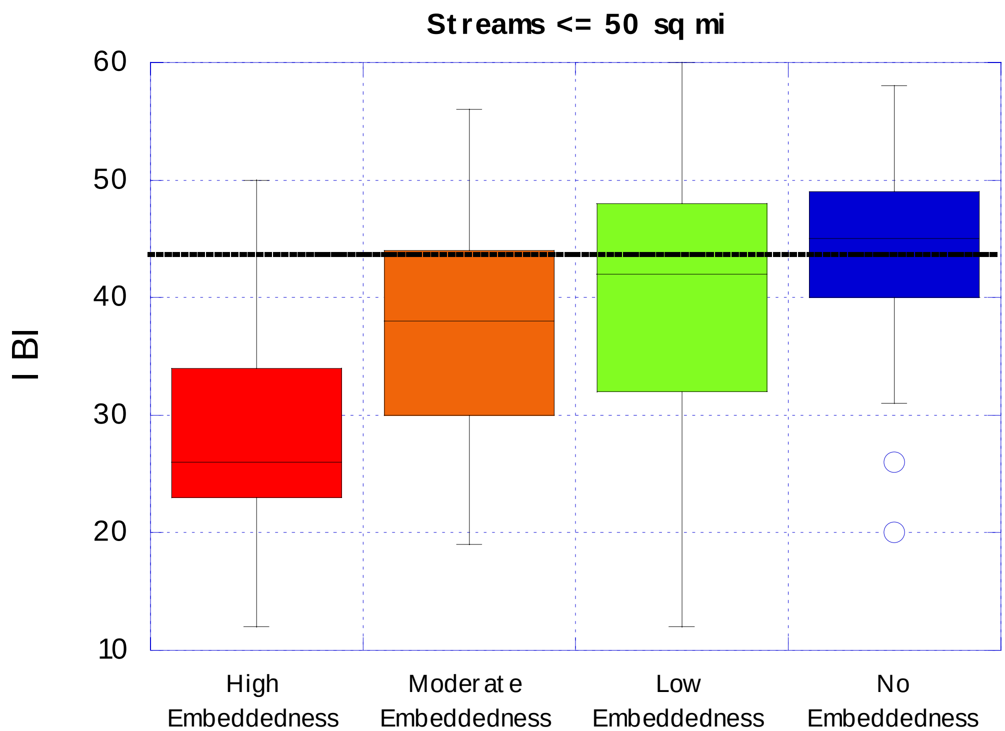
Finally a goal of using this type of information to develop "TMDLs" or restoration endpoints is to 1.) develop and refine a model that will incorporate stream types and other stream classification procedures into this process as that data becomes available, and 2.) to examine links between IBI, the QHEI substrate metric, and pebble count procedures (e.g., zig-zag method) to provide a bit more precise measure of surface substrate and an useful interim measure of progress.



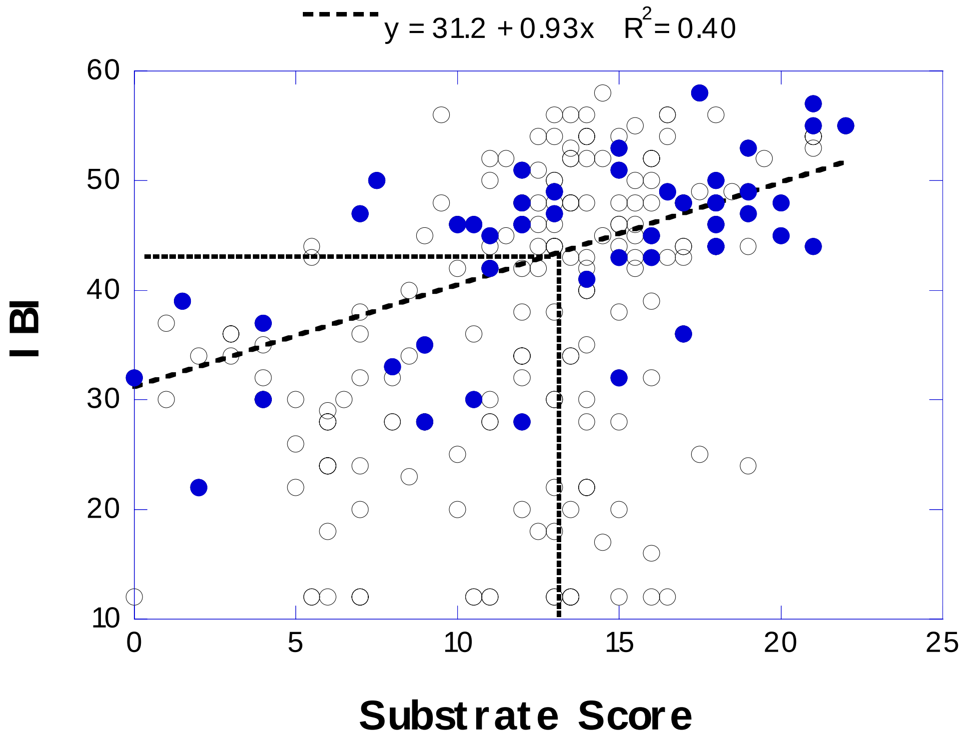

Appendix Figure 1. Relationship between QHEI and IBI for all reference sites in Ohio (natural and physically modified).



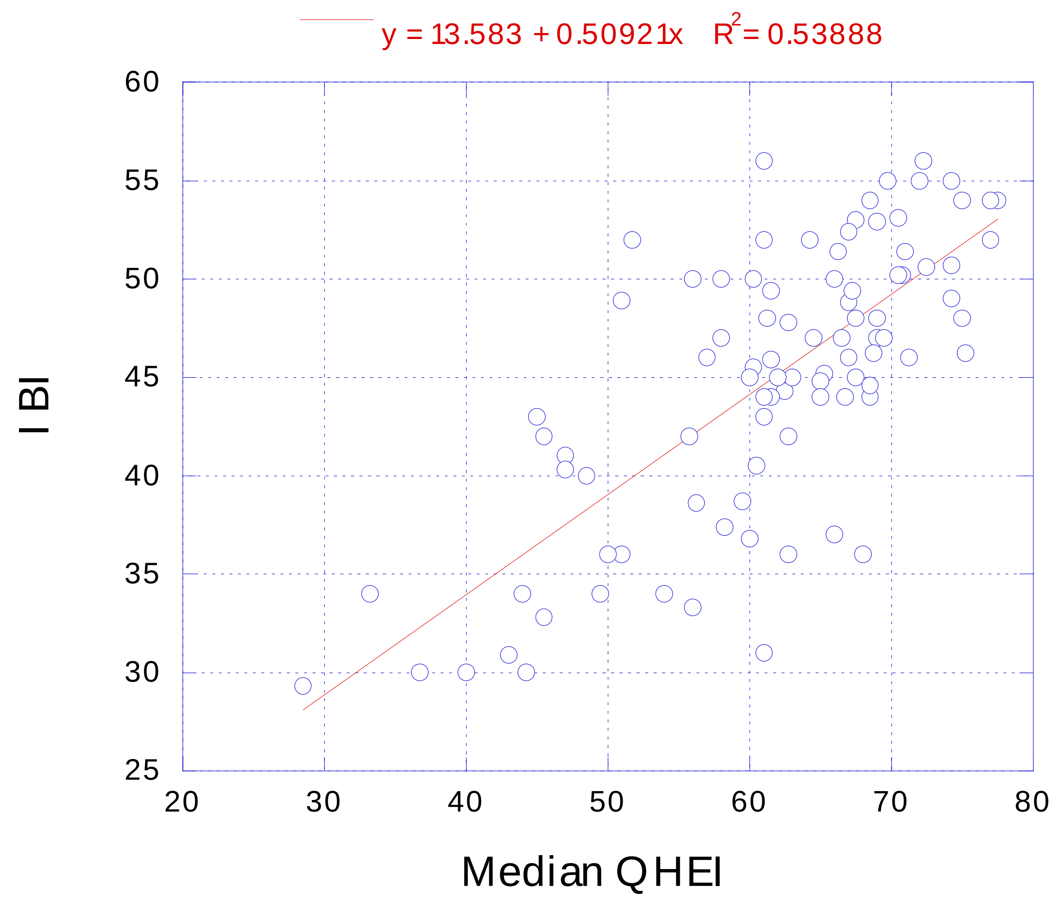

Appendix Figure 2. Relationship between the QHEI and the substrate metric of the QHEI for all reference sites in Ohio (natural and physically modified).



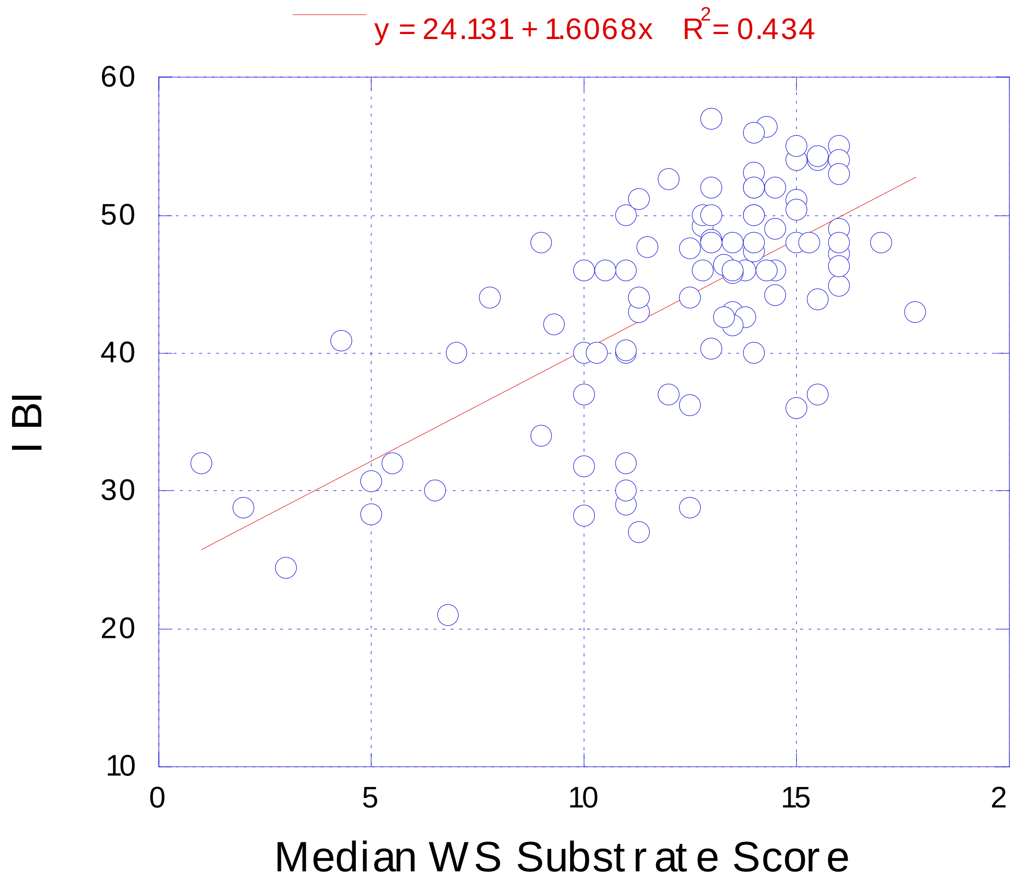

Appendix Figure 3. Relationship between the embeddedness subcomponent of the substrate metric of the QHEI and IBI for all reference sites in Ohio (natural and physically modified) of less than or equal to 50 sq mi drainage size.



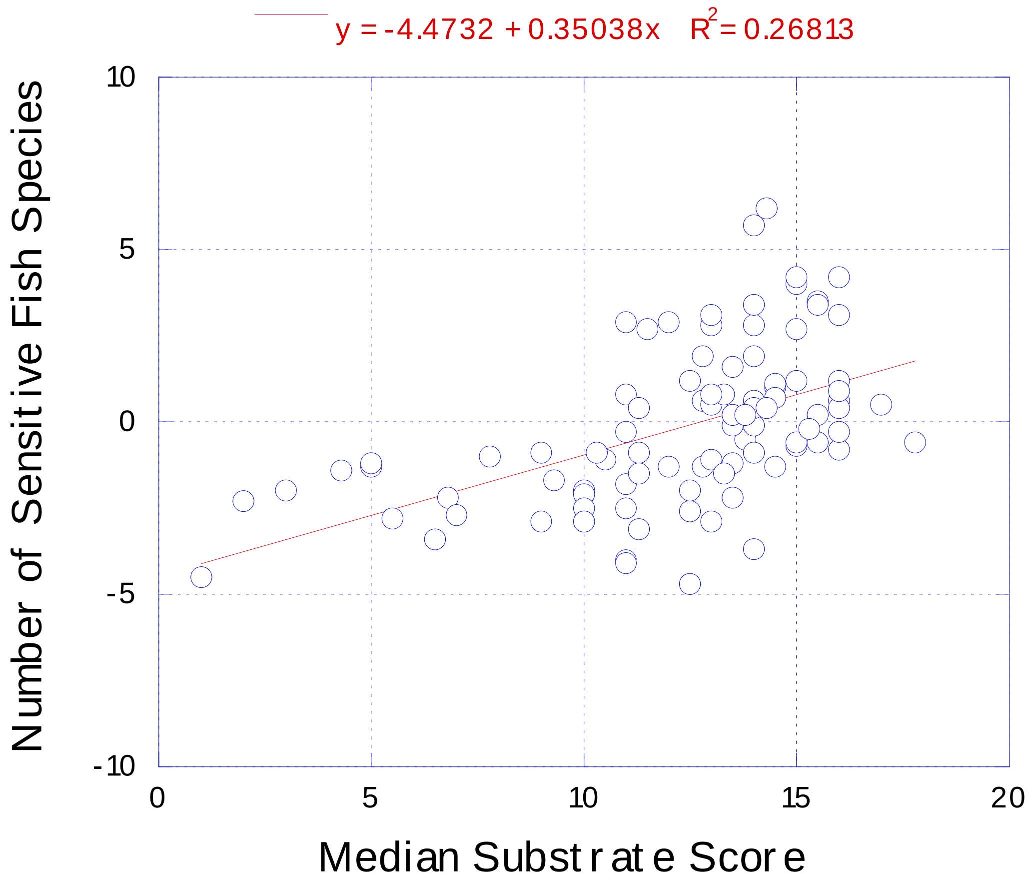

Appendix Figure 4. Relationship between the embeddedness substrate metric of the QHEI and IBI for a random subset of all sites and reference sites (natural and physically modified) in the Western Allegheny Plateau ecoregion. Dash lines drawn to the regression line indicate average substrate score needed to protect .



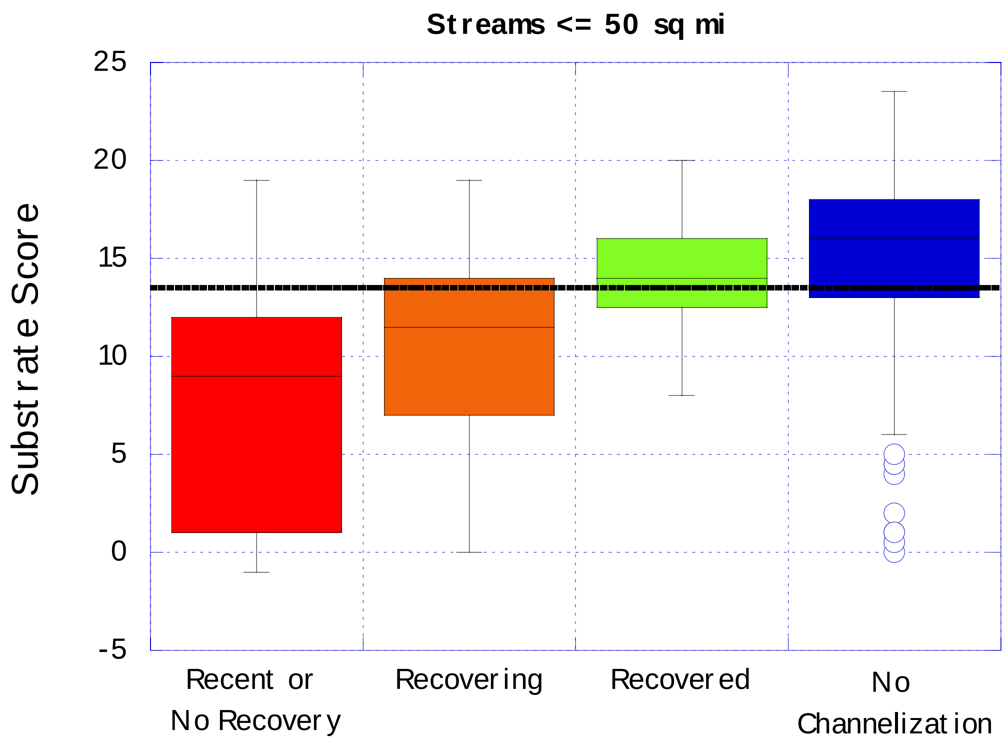

Appendix Figure 5. Relationship between the median QHEI scores in each of 93 Ohio subbasins and 90th percentile IBI scores in these subbasins (measure of best sites remaining).




Appendix Figure 6. Relationship between the median watershed QHEI substrate metric scores in each of 93 Ohio subbasins and 90th percentile IBI scores in these subbasins (measure of best sites remaining).




Appendix Figure 7. Relationship between the median watershed QHEI substrate metric scores in each of 93 Ohio subbasins and 90th percentile expected sensitive fish species numbers in these subbasins (measure of best sites remaining). Expected numbers of sensitive fish species were calculated as the number observed minus the minimum number expected to score a 5 for a given drainage size for the IBI.




Appendix Figure 8. Relationship between the channelization subcomponent of the channel condition metric of the QHEI and the substrate metric of the QHEI for all reference sites in Ohio (natural and physically modified) of less than or equal to 50 sq mi drainage size.

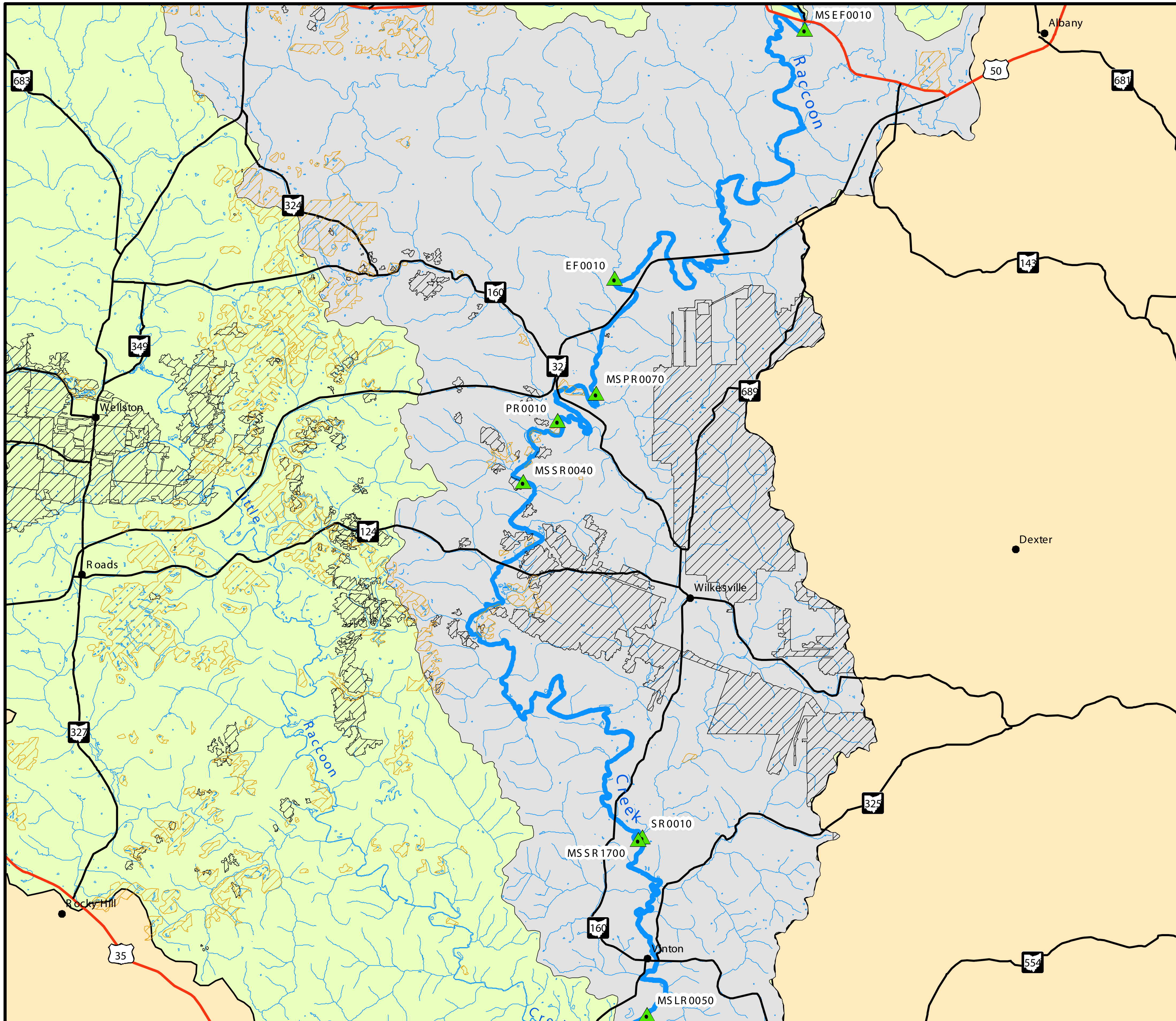
Appendix Table 2. Attainment table for sites in or in the vicinity of the Middle Basin Raccoon Creek watershed collected prior to 2002. Data primarily from Ohio EPA sources. Key to to individual index biocrieria status: Y – Yes, N – No, T- Score indicates toxic impact.

| Station ID | Fish RM | Macro. RM | IBI | IBI Status | MIwb | MIwb Status | ICI | Macro. Narr | Macro. Status | QHEI | Aq Life Use | Status | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Raccoon Creek - [09-500] Year: 1996 | | | | | | | | | | | | | |
| S0950050.101996 | - | 50.10 | - | | - | | 14.0 | | N | - | WWH | NON | 01 |
| S0950039.901996 | - | 39.90 | - | | - | | 34.0 | | Y | - | WWH | FULL | 01 |
| Raccoon Creek - [09-500] Year: 1995 | | | | | | | | | | | | | |
| S0950072.201995 | 72.20 | 72.30 | 40.0 | Y | 8.12 | Y | 46.0 | | Y | 62.0 | WWH | FULL | 01 |
| S0950063.001995 | 63.80 | 63.80 | 44.0 | Y | 8.67 | Y | 48.0 | | Y | 60.5 | WWH | FULL | 01 |
| S0950050.101995 | 50.10 | 50.10 | 44.0 | Y | 7.59 | N | 32.0 | | Y | 63.0 | WWH | PARTIAL | 01 |
| S0950040.201995 | 40.20 | 39.90 | 41.0 | Y | 7.88 | N | 38.0 | | Y | 47.0 | WWH | PARTIAL | 01 |
| S0950035.601995 | 35.60 | 35.60 | 42.0 | Y | 8.53 | Y | - | G | Y | 62.5 | WWH | FULL | 01 |
| S0950029.201995 | 29.90 | 29.10 | 48.0 | Y | 9.25 | Y | 46.0 | | Y | 67.5 | WWH | FULL | 01 |
| S0950010.201995 | 10.00 | 10.20 | 40.0 | Y | 9.53 | Y | 48.0 | | Y | 69.5 | WWH | FULL | 01 |
| S095005.401995 | 5.40 | - | 40.0 | Y | 8.38 | Y | - | | - | 55.0 | WWH | FULL | 01 |
| Raccoon Creek - [09-500] Year: 1994 | | | | | | | | | | | | | |
| S0950039.901994 | 39.90 | 39.90 | 44.0 | Y | 9.49 | Y | - | G | Y | - | WWH | FULL | 01 |
| Raccoon Creek - [09-500] Year: 1993 | | | | | | | | | | | | | |
| S0950050.101993 | 50.20 | 50.10 | 36.0 | N | 6.82 | N | - | G | Y | 63.0 | WWH | PARTIAL | 01 |
| S0950040.101993 | 40.10 | 40.10 | 36.0 | N | 7.78 | N | - | G | Y | 72.5 | WWH | PARTIAL | 01 |
| S0950039.901993 | 39.90 | 39.90 | 35.0 | N | 9.00 | Y | 26.0 | | N | 71.0 | WWH | PARTIAL | 01 |
| S0950029.201993 | 29.30 | 29.10 | 44.0 | Y | 8.42 | Y | - | G | Y | 64.5 | WWH | FULL | 01 |
| Raccoon Creek - [09-500] Year: 1990 | | | | | | | | | | | | | |
| S0950063.001990 | - | 63.00 | - | | - | | 42.0 | | Y | - | WWH | FULL | 01 |
| S0950040.201990 | 40.20 | 40.10 | 35.0 | N | 7.53 | N | 46.0 | | Y | 48.5 | WWH | PARTIAL | 01 |
| S0950010.201990 | 10.00 | 10.20 | 35.0 | N | 8.75 | Y | 46.0 | | Y | 81.0 | WWH | PARTIAL | 01 |
| Elk Fork - [09-530] Year: 1995 | | | | | | | | | | | | | |
| S0953016.201995 | 16.20 | 16.20 | 39.0 | N | | | 36.0 | | Y | 70.0 | WWH | PARTIAL | 01 |
| S0953013.901995 | 14.00 | 14.10 | 38.0 | N | | | 54.0 | | Y | 67.5 | WWH | PARTIAL | 01 |
| S0953013.301995 | 13.30 | 13.30 | 42.0 | Y | 6.76 | Y | 14.0 | MG | Y | 75.0 | LRW | FULL | 01 |
| S0953010.901995 | 11.00 | 10.90 | 43.0 | Y | 8.03 | Y | 44.0 | | Y | 52.0 | WWH | FULL | 01 |
| S095308.501995 | 8.60 | - | 37.0 | N | 7.96 | Y | - | | | 54.0 | WWH | PARTIAL | 01 |
| S095302.201995 | 2.20 | - | 43.0 | Y | 8.27 | Y | - | | | 65.5 | WWH | FULL | 01 |
| S095300.201995 | 0.20 | 0.10 | 36.0 | Y | 8.30 | Y | 42.0 | | Y | 58.0 | LRW | FULL | 01 |
| Elk Fork - [09-530] Year: 1981 | | | | | | | | | | | | | |
| S0953017.601981 | 17.60 | - | 30.0 | N | | | - | | | 70.0 | WWH | NON | 01 |
| S0953016.201981 | 16.20 | 16.20 | 32.0 | N | | | - | E | Y | 65.0 | WWH | PARTIAL | 01 |

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| S09530 14.861981 | 14.70 | - | 36.0 | N | | | - | | | - | WWH | NON | 01 |
| S09530 13.901981 | 13.90 | - | 18.0 | T | | | 0.0 | | | - | WWH | NON-T | 01 |
| S09530 13.301981 | 13.30 | - | 26.0 | T | 2.98 | T | 0.0 | | | - | WWH | NON-T | 01 |
| S09530 11.801981 | 11.80 | - | 12.0 | T | - | | 0.0 | | | - | WWH | NON-T | 01 |
| S09530 10.901981 | 10.90 | - | 12.0 | T | 3.41 | T | 0.0 | | | - | WWH | NON-T | 01 |
| S09530 8.501981 | 8.50 | - | 12.0 | T | 2.31 | T | 0.0 | | | - | WWH | NON-T | 01 |
| S09530 0.201981 | 0.20 | 0.10 | 18.0 | T | 3.10 | T | - | G | Y | - | WWH | NON-T | 01 |
| Wolf Run - [09-533] Year: 1981 | | | | | | | | | | | | | |
| S09533 0.201981 | 0.20 | - | 12.0 | T | - | | 0.0 | | | - | LRW | NON-T | 01 |
| Puncheon Fork - [09-534] Year: 1995 | | | | | | | | | | | | | |
| S09534 1.501995 | 1.50 | 1.60 | 44.0 | Y | | | - | G | Y | 66.0 | WWH | FULL | 01 |
| S09534 0.301995 | 0.30 | 0.30 | 41.0 | Y | | | - | MG | Y | 65.0 | LRW/WWH | FULL/ FULL | 01 |
| Puncheon Fork - [09-534] Year: 1981 | | | | | | | | | | | | | |
| S09534 0.301981 | 0.30 | - | 12.0 | T | | | 0.0 | | | - | WWH | NON-T | 01 |
| Robinson Run - [09-544] Year: 1999 | | | | | | | | | | | | | |
| S09544 0.201999 | 0.20 | - | 30.0 | N | | | 0.0 | | | - | WWH | NON | 01 |
| Robinson Run - [09-544] Year: 1998 | | | | | | | | | | | | | |
| S09544 0.201998 | 0.20 | - | 40.0 | Y | | | 0.0 | | | 64.5 | WWH | FULL | 01 |
| Robinson Run - [09-544] Year: 1997 | | | | | | | | | | | | | |
| S09544 0.201997 | 0.20 | - | 38.0 | N | | | 0.0 | | | - | WWH | NON | 01 |
| Robinson Run - [09-544] Year: 1996 | | | | | | | | | | | | | |
| S09544 1.601996 | - | 1.60 | - | | - | | 42.0 | | Y | - | WWH | FULL | 01 |
| S09544 0.201996 | 0.20 | 0.20 | 31.0 | N | | | 22.0 | | N | 60.0 | WWH | NON | 01 |
| Robinson Run - [09-544] Year: 1995 | | | | | | | | | | | | | |
| S09544 1.601995 | 1.60 | 1.60 | 26.0 | N | | | 46.0 | | Y | - | WWH | NON-T | 01 |
| S09544 0.201995 | 0.20 | 0.20 | 39.0 | N | | | 46.0 | | Y | 59.5 | WWH | PARTIAL | 60 |
| S09544 0.101995 | 0.10 | - | 42.0 | Y | | | | | | - | WWH | FULL | 60 |
| Robinson Run - [09-544] Year: 1994 | | | | | | | | | | | | | |
| S09544 1.501994 | - | 1.60 | | | - | | - | G | Y | - | WWH | FULL | 01 |
| S09544 0.201994 | 0.20 | - | 32.0 | N | | | | | | - | WWH | NON | 01 |
| Robinson Run - [09-544] Year: 1993 | | | | | | | | | | | | | |
| S09544 1.601993 | 1.60 | 1.60 | 25.0 | T | | | - | MG | Y | - | WWH | NON-T | 01 |
| S09544 1.501993 | 1.50 | - | 36.0 | N | | | | | | 46.5 | WWH | NON | 01 |
| S09544 0.201993 | 0.20 | - | 33.0 | N | | | | | | 66.5 | WWH | NON | 01 |
| Sugar Run - [09-545] Year: 1998 | | | | | | | | | | | | | |
| S09545 0.601998 | 0.60 | - | 40.0 | Y | | | | | | 71.5 | WWH | FULL | 01 |
| Sugar Run - [09-545] Year: 1997 | | | | | | | | | | | | | |
| S09545 0.601997 | 0.60 | - | 40.0 | Y | | | | | | - | WWH | FULL | 01 |
| Sugar Run - [09-545] Year: 1996 | | | | | | | | | | | | | |
| S09545 0.601996 | 0.60 | 0.30 | 40.0 | Y | | | 46.0 | | Y | 71.0 | WWH | FULL | 01 |
| Sugar Run - [09-545] Year: 1995 | | | | | | | | | | | | | |
| S09545 1.351995 | 1.50 | - | 12.0 | T | - | | | | | - | WWH | NON-T | 01 |
| S09545 0.601995 | 0.60 | | 40.0 | Y | | | | | | - | WWH | FULL | 01 |
| S09545 0.101995 | 0.10 | 0.2 | 37.0 | N | | | 38.0 | | | - | WWH | PARTIAL | 60 |
| Sugar Run - [09-545] Year: 1994 | | | | | | | | | | | | | |
| S09545 0.101994 | 0.60 | 0.10 | 43.0 | Y | | | - | MG | Y | - | WWH | FULL | 60 |
| Sugar Run - [09-545] Year: 1993 | | | | | | | | | | | | | |
| S09545 0.601993 | 0.60 | 0.10 | 33.0 | N | | | | MG | Y | 62.5 | WWH | PARTIAL | 01 |
| Strongs Run - [09-546] Year: 1999 | | | | | | | | | | | | | |
| S09546 0.601999 | 0.60 | - | 28.0 | N | | | | | | - | EWH/ WWH | NON/ NON | 01 |
| Strongs Run - [09-546] Year: 1998 | | | | | | | | | | | | | |
| S09546 0.601998 | 0.60 | - | 34.0 | N | | | | | | 70.0 | EWH/ WWH | NON/ NON | 01 |

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Strongs Run - [09-546] Year: 1997 | | | | | | | | | | | | | |
| S09546 0.601997 | 0.60 | - | 42.0 | N | | | | | | 66.5 | EWH/WWH | NON/FULL | 01 |
| Strongs Run - [09-546] Year: 1996 | | | | | | | | | | | | | |
| S09546 3.101996 | 3.10 | - | 37.0 | N | | | | | | 69.5 | EWH/WWH | | 01 |
| S09546 0.601996 | 0.60 | 1.50 | 32.0 | N | | | 54.0 | | Y | 68.0 | EWH/WWH | PARTIAL/PARTIAL | 01 |
| Strongs Run - [09-546] Year: 1995 | | | | | | | | | | | | | |
| S09546 6.701995 | 6.70 | - | 12.0 | T | - | | 0.0 | | ? | - | EWH/WWH | NON-T | 60 |
| S09546 2.301995 | 2.30 | - | 12.0 | T | - | | 0.0 | | ? | - | EWH/WWH | NON-T | 60 |
| S09546 1.501995 | 1.50 | 1.50 | 32.0 | N | | | 34.0 | | N | 66.0 | EWH/WWH | NON/NON | 01 |
| S09546 0.601995 | 0.60 | - | 24.0 | T | | | 0.0 | | ? | - | EWH/WWH | NON-T | 01 |
| Strongs Run - [09-546] Year: 1994 | | | | | | | | | | | | | |
| S09546 1.501994 | 1.50 | 1.50 | 40.0 | N | | | - | MG | N | - | EWH/WWH | NON/FULL | 01 |
| S09546 0.701994 | 0.70 | - | 44.0 | N | | | | | | - | EWH/WWH | NON/FULL | 01 |
| S09546 0.601994 | 0.60 | - | 34.0 | N | | | | | | - | EWH/WWH | NON/FULL | 01 |
| Strongs Run - [09-546] Year: 1993 | | | | | | | | | | | | | |
| S09546 1.501993 | 1.50 | 1.50 | 18.0 | T | | | - | MG | N | - | EWH/WWH | NON-T/ NON-T | 01 |
| S09546 0.601993 | 0.60 | - | 15.0 | T | | | | | ? | 64.0 | EWH/WWH | NON-T/ NON-T | 01 |
| Strongs Run - [09-546] Year: 1991 | | | | | | | | | | | | | |
| S09546 1.501991 | - | 1.50 | - | | - | | 34.0 | | N | - | EWH/WWH | NON/NON | 01 |
| Strongs Run - [09-546] Year: 1990 | | | | | | | | | | | | | |
| S09546 5.901990 | - | 5.90 | - | | - | | 28.0 | | N | - | EWH/WWH | NON/NON | 01 |
| S09546 1.501990 | - | 1.50 | - | | - | | 46.0 | | Y | - | EWH/WWH | FULL/FULL | 01 |
| Strongs Run - [09-546] Year: 1989 | | | | | | | | | | | | | |
| S09546 5.901989 | - | 5.90 | - | | - | | - | G | N | - | EWH/WWH | NON/FULL | 01 |
| S09546 1.501989 | - | 1.50 | - | | - | | 40.0 | | N | - | EWH/WWH | NON/FULL | 01 |
| Strongs Run - [09-546] Year: 1988 | | | | | | | | | | | | | |
| S09546 5.901988 | - | 5.90 | - | | - | | 24.0 | | N | - | EWH/WWH | NON/NON | 01 |
| S09546 0.601988 | - | 0.60 | - | | - | | 26.0 | | N | - | EWH/WWH | NON/NON | 01 |
| Strongs Run - [09-546] Year: 1987 | | | | | | | | | | | | | |
| S09546 0.601987 | 0.60 | 0.60 | - | | - | | - | F | N | - | EWH/WWH | NON/NON | 01 |
| Williams Run - [09-547] Year: 1993 | | | | | | | | | | | | | |
| S09547 0.101993 | 0.10 | - | | | - | | | | | 55.5 | EWH | QHEI Only | 01 |
| Opossum Run - [09-548] Year: 1995 | | | | | | | | | | | | | |
| S09548 0.201995 | 0.20 | 0.10 | 42.0 | Y | | | - | F | Y | 63.5 | LWH/WWH | FULL/PARTIAL | 05 |
| Flatlick Run - [09-549] Year: 1996 | | | | | | | | | | | | | |
| S09549 2.801996 | 2.80 | - | 40.0 | Y | | | | | | 67.0 | LWH/WWH | FULL/FULL | 01 |
| S09549 0.601996 | 0.60 | 0.50 | 44.0 | Y | | | 40.0 | | Y | - | LWH/WWH | FULL/FULL | 01 |
| Flatlick Run - [09-549] Year: 1995 | | | | | | | | | | | | | |
| S09549 0.701995 | 0.70 | - | 38.0 | N | | | | | | 59.5 | LWH/WWH | FULL/NON | 05 |
| S09549 0.601995 | 0.60 | 0.50 | 30.0 | N | | | 52.0 | | Y | 60.0 | LWH/WWH | FULL/PARTIAL | 01 |
| Flatlick Run - [09-549] Year: 1994 | | | | | | | | | | | | | |
| S09549 0.601994 | 0.60 | 0.50 | 32.0 | N | | | - | G | Y | - | LWH/WWH | FULL/PARTIAL | 01 |
| Flatlick Run - [09-549] Year: 1993 | | | | | | | | | | | | | |
| S09549 0.701993 | 0.70 | - | 40.0 | Y | | | | | | - | LWH/WWH | FULL/FULL | 01 |
| S09549 0.601993 | 0.60 | 0.60 | 28.0 | N | | | - | MG | Y | 67.0 | LWH/WWH | FULL/PARTIAL | 01 |
| Flatlick Run - [09-549] Year: 1991 | | | | | | | | | | | | | |
| S09549 0.601991 | 0.60 | 0.60 | - | | - | | 38.0 | | Y | - | LWH/WWH | FULL/NON | 01 |
| Flatlick Run - [09-549] Year: 1990 | | | | | | | | | | | | | |
| S09549 0.601990 | 0.60 | 0.60 | - | | - | | 38.0 | | Y | - | LWH/WWH | FULL/FULL | 01 |
| Flatlick Run - [09-549] Year: 1989 | | | | | | | | | | | | | |
| S09549 0.601989 | 0.60 | 0.60 | - | | - | | - | P | Y | - | LWH/WWH | FULL/NON | 01 |
| Flatlick Run - [09-549] Year: 1988 | | | | | | | | | | | | | |
| S09549 0.601988 | 0.60 | 0.60 | - | | - | | 28.0 | | Y | - | LWH/WWH | FULL/NON | 01 |
| Flatlick Run - [09-549] Year: 1987 | | | | | | | | | | | | | |
| S09549 0.601987 | 0.60 | 0.60 | - | | - | | - | MG | Y | - | LWH/WWH | FULL/FULL | 01 |
| Karr Run - [09-550] Year: 1995 | | | | | | | | | | | | | |
| S09550 | 0.20 | 0.20 | 32. | Y | | | - | P | Y | 56. | LWH | FULL | 05 |

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.201995 | | | 0 | | | | | | | 5 | | | |
| Indiancamp Run - [09-551] Year: 1995 | | | | | | | | | | | | | |
| S09551 0.301995 | 0.30 | 0.40 | 28.0 | Y | | | - | F | Y | 82.0 | LWH | FULL | 01 |
| Rockcamp Run - [09-552] Year: 1995 | | | | | | | | | | | | | |
| S09552 0.201995 | 0.20 | 0.30 | 12.0 | Y | - | | - | P | Y | 64.0 | LWH | FULL | 05 |
| Pierce Run - [09-553] Year: 1995 | | | | | | | | | | | | | |
| S09553 1.701995 | 1.70 | 1.70 | 34.0 | Y | | | - | P | Y | 52.0 | LWH | FULL | 05 |
| Zinns Run - [09-554] Year: 1995 | | | | | | | | | | | | | |
| S09554 0.501995 | 0.50 | 0.50 | 44.0 | Y | 8.00 | | - | G | Y | 68.5 | WWH | FULL | 01 |
| Zinns Run - [09-554] Year: 1991 | | | | | | | | | | | | | |
| S09554 0.501991 | - | 0.50 | - | | - | | - | MF | Y | - | WWH | FULL | 01 |
| Zinns Run - [09-554] Year: 1990 | | | | | | | | | | | | | |
| S09554 0.501990 | - | 0.50 | - | | - | | 24.0 | | Y | - | WWH | NON | 01 |
| Zinns Run - [09-554] Year: 1989 | | | | | | | | | | | | | |
| S09554 0.501989 | - | 0.50 | - | | - | | 16.0 | | Y | - | WWH | NON | 01 |
| Zinns Run - [09-554] Year: 1988 | | | | | | | | | | | | | |
| S09554 0.501988 | - | 0.50 | - | | - | | 26.0 | | Y | - | WWH | NON | 01 |
| Long Run - [09-556] Year: 1995 | | | | | | | | | | | | | |
| S09556 1.401995 | 1.40 | 1.40 | 38.0 | N | | | - | F | N | 68.5 | WWH | NON | 01 |
| Flat Run - [09-557] Year: 1995 | | | | | | | | | | | | | |
| S09557 1.601995 | 1.60 | 1.30 | 36.0 | Y | | | - | G | Y | 50.5 | LWH | FULL | 05 |
| Russell Run - [09-558] Year: 1995 | | | | | | | | | | | | | |
| S09558 0.701995 | 0.60 | 0.70 | 36.0 | N | | | - | G | Y | 47.5 | WWH | PARTIAL | 05 |
| Merrit Run - [09-559] Year: 1995 | | | | | | | | | | | | | |
| S09559 0.101995 | 0.10 | 0.10 | 34.0 | N | | | - | P | T | 62.5 | WWH | NON-T | 01 |
| Tedroe Run - [09-560] Year: 1995 | | | | | | | | | | | | | |
| S09560 0.101995 | 0.10 | 0.10 | 28.0 | Y | | | - | F | Y | 54.0 | LWH | FULL | 05 |
| Onion Creek - [09-561] Year: 1995 | | | | | | | | | | | | | |
| S09561 1.401995 | 1.40 | 1.40 | 30.0 | Y | 5.06 | | - | VG | Y | 76.5 | LWH | FULL | 05 |
| Laurel Run - [09-562] Year: 1995 | | | | | | | | | | | | | |
| S09562 0.101995 | - | 0.10 | - | | - | | - | G | Y | - | WWH | FULL | 01 |
| Wheelabout Creek - [09-570] Year: 2000 | | | | | | | | | | | | | |
| S09570 0.602000 | 0.60 | 0.60 | 28.0 | N | | | - | G | N | 67.0 | EWH | NON | 05 |
| Trib. to Elk Fork (RM 11.17) - [09-578] Year: 1995 | | | | | | | | | | | | | |
| S09578 0.401995 | - | 0.40 | - | | - | | - | F | N | - | WWH | NON | 01 |
| Trib. to Elk Fork (RM 11.17) - [09-578] Year: 1981 | | | | | | | | | | | | | |
| S09578 0.401981 | - | 0.10 | 12.0 | T | - | | - | P | Y | - | LRW | NON-T | 01 |
| S09578 0.401981 | 0.40 | 0.10 | 12.0 | T | - | | - | P | T | - | WWH | NON-T | 01 |
| Siverly Creek - [09-581] Year: 2000 | | | | | | | | | | | | | |
| S09581 0.302000 | - | 0.30 | - | | - | | - | G | Y | - | NONE/ WWH | FULL | |
| Siverly Creek - [09-581] Year: 1997 | | | | | | | | | | | | | |
| S09581 0.301997 | 0.90 | - | 40.0 | Y | | | | | | 67.0 | NONE/ WWH | FULL | 05 |
| Sugar Run - [09-582] Year: 1999 | | | | | | | | | | | | | |
| S09582 0.201999 | - | 0.10 | - | | - | | - | P | T | - | NONE | NON-T | |
| Sugar Run - [09-582] Year: 1994 | | | | | | | | | | | | | |
| S09582 0.201994 | 0.20 | - | 26.0 | Y | 1.47 | | - | | ? | 38.0 | NONE | | 05 |
| Carbondale Creek - [09-586] Year: 2000 | | | | | | | | | | | | | |
| S09586 0.302000 | 0.50 | 0.30 | 12.0 | Y | 1.78 | | - | VP | T | 51.5 | NONE | NON-T | 05 |
| Trib. to Raccoon Creek (RM 98.96) - [09-589] Year: 1995 | | | | | | | | | | | | | |
| S09589 0.101995 | 0.10 | 0.10 | 37.0 | N | 6.87 | | - | F | N | 37.0 | WWH | NON | 01 |
| Dunkle Creek - [09-590] Year: 2000 | | | | | | | | | | | | | |
| S09590 0.902000 | - | 0.70 | - | | - | | - | MG | Y | - | NONE | FULL | |
| Dunkle Creek - [09-590] Year: 1996 | | | | | | | | | | | | | |
| S09590 0.901996 | 0.90 | - | 34.0 | Y | 4.32 | | | | | 64.0 | NONE | | 05 |
| Little Beaver Creek - [09-595] Year: 1999 | | | | | | | | | | | | | |
| S09595 0.401999 | - | 0.40 | - | | - | | - | F | N | - | NONE | NON | |
| Trib. to Carbondale Creek (RM 0.67) - [09-596] Year: 2000 | | | | | | | | | | | | | |
| S09596 0.102000 | 0.10 | 0.10 | 16.0 | Y | - | | - | G | Y | 66.0 | NONE | FULL | 05 |



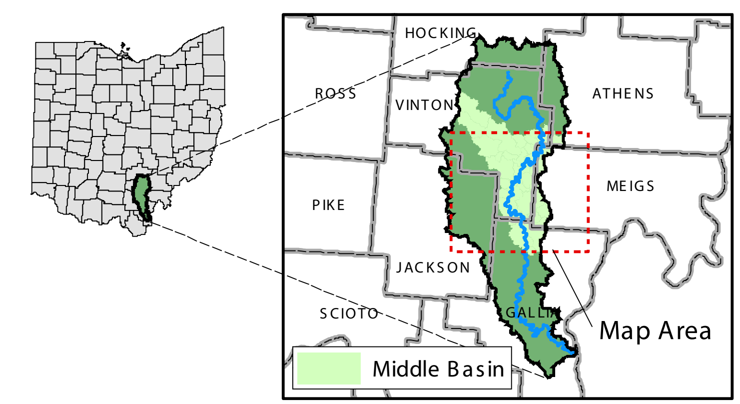

# Raccoon Creek Middle Basin AMDAT

## Map 1 - Long-Term Sites Sampled For USGS Water Resources Report 85-4060

### Map Features

- Middle Basin Sample Site
- Middle Basin
- Raccoon Creek Watershed
- Deep_Mines
- Surface_Mines
- Streams
- Village/City
- 93 State Highway
- 50 U.S. Highway

0 1 2 4
Scale in Miles




10 5 0 10
Scale in Miles

Ohio GIS Net
Sources: PUCO. USGS 7.5 minute quadrangles.
Ohio Department of Natural Resources.
For Planning Purposes Only.
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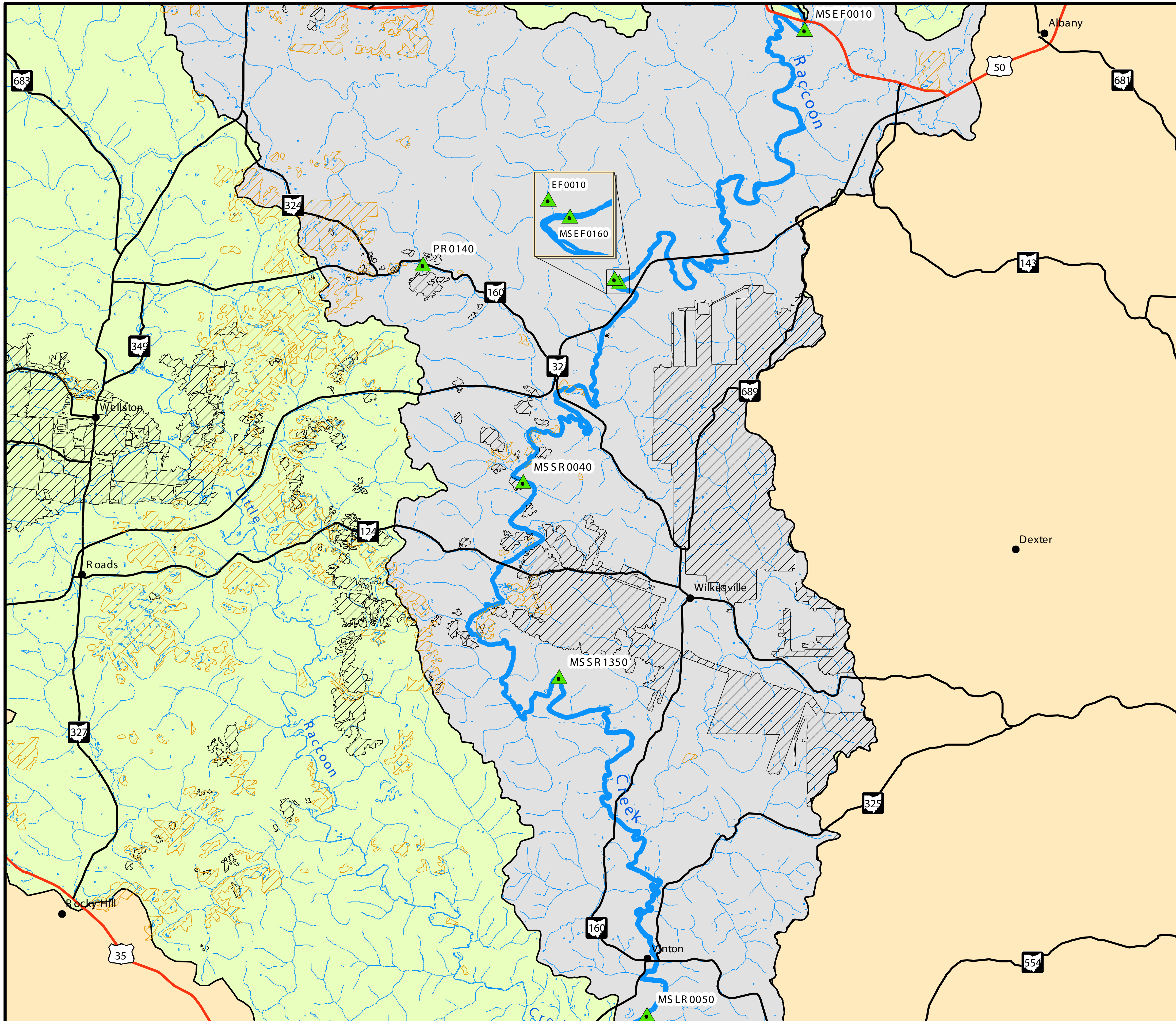


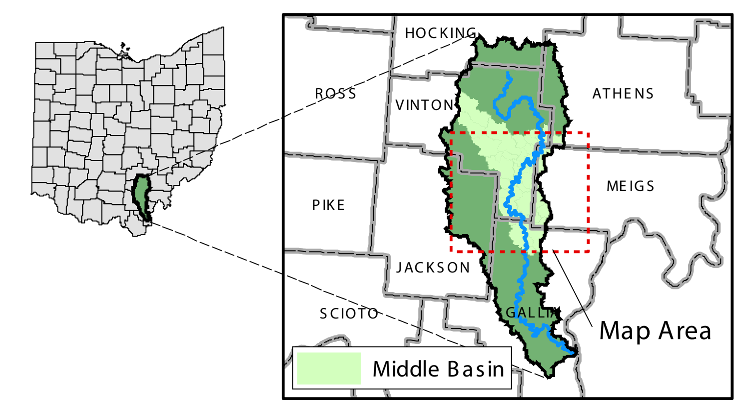

# Raccoon Creek Middle Basin AMDAT

Map 2 - Sites Sampled During November 1983
For USGS Water Resources Report 85-4060

Map Features

- Middle Basin Sample Site
- Middle Basin
- Raccoon Creek Watershed
- Deep_Mines
- Surface_Mines
- Streams
- Village/City
- 93 State Highway
- 50 U.S. Highway

0 1 2 4
Scale in Miles




10 5 0 10
Scale in Miles

Ohio GIS Net
Sources: PUCO. USGS 7.5 minute quadrangles.
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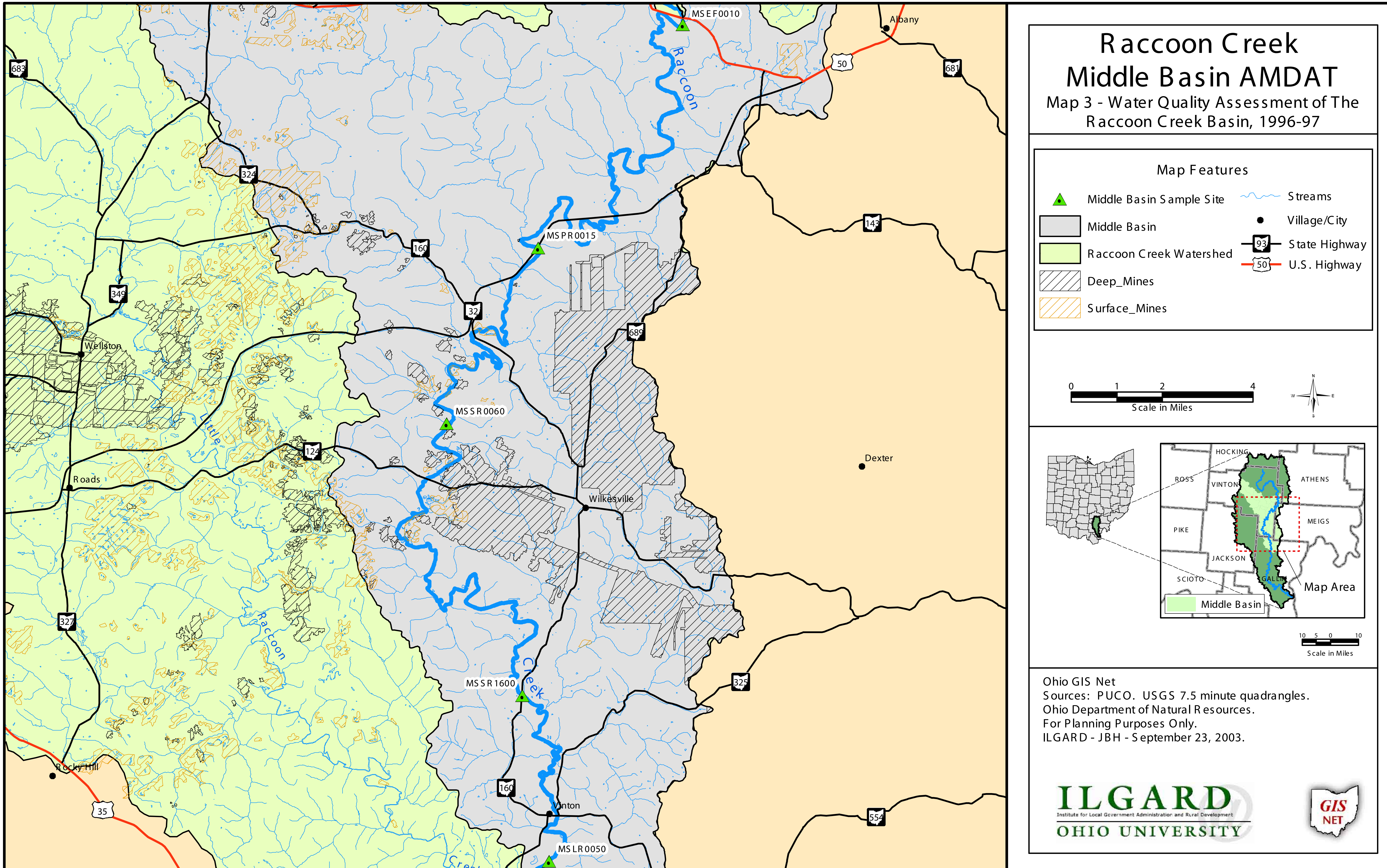


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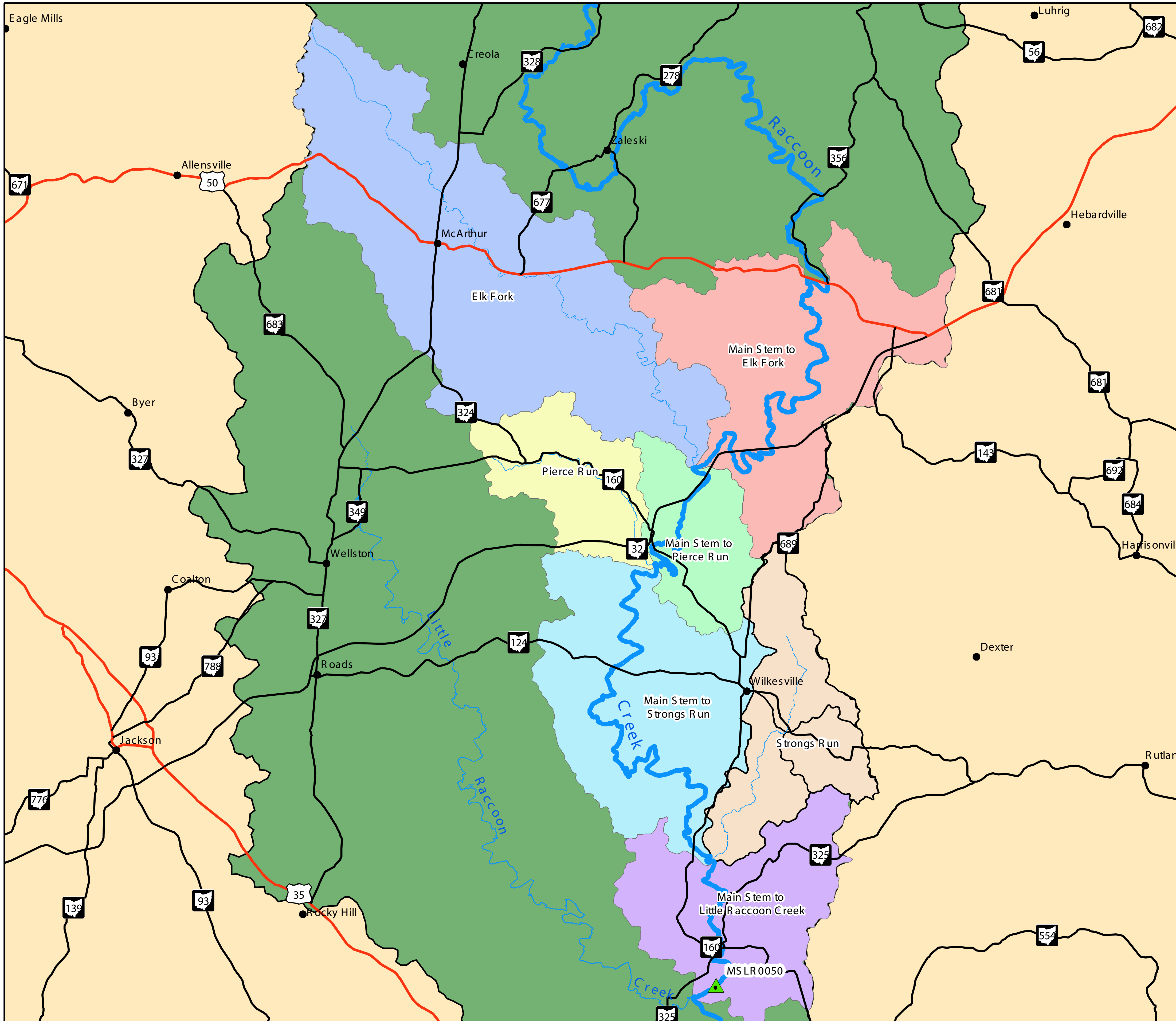


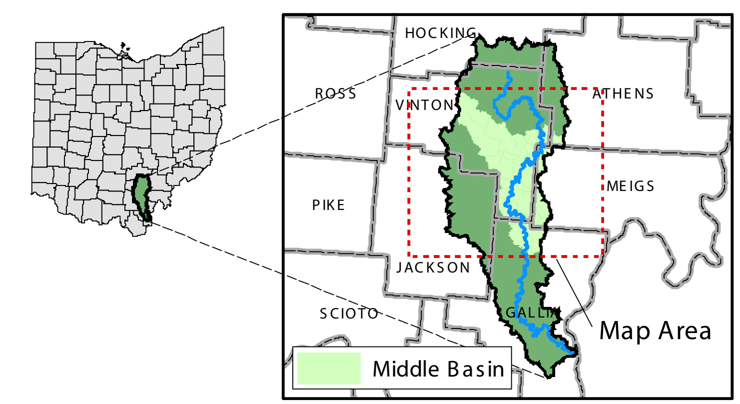

# Raccoon Creek
# Middle Basin AMDAT

## Map 4 - Sub-Watersheds Delineated.
## Reference Flow Site MSLR0050

**Sub Watershed Delineation**

- MSEF - Main Stem to Elk Fork
- EF - Elk Fork
- MSPR - Main Stem to Pierce Run
- PR - Pierce Run
- MSSR - Main Stem to Strongs Run
- MSLR - Main Stem to Little Raccoon Creek
- Strongs Run
- Reference Flow Site MSLR0050

0 1 2 4
Scale in Miles

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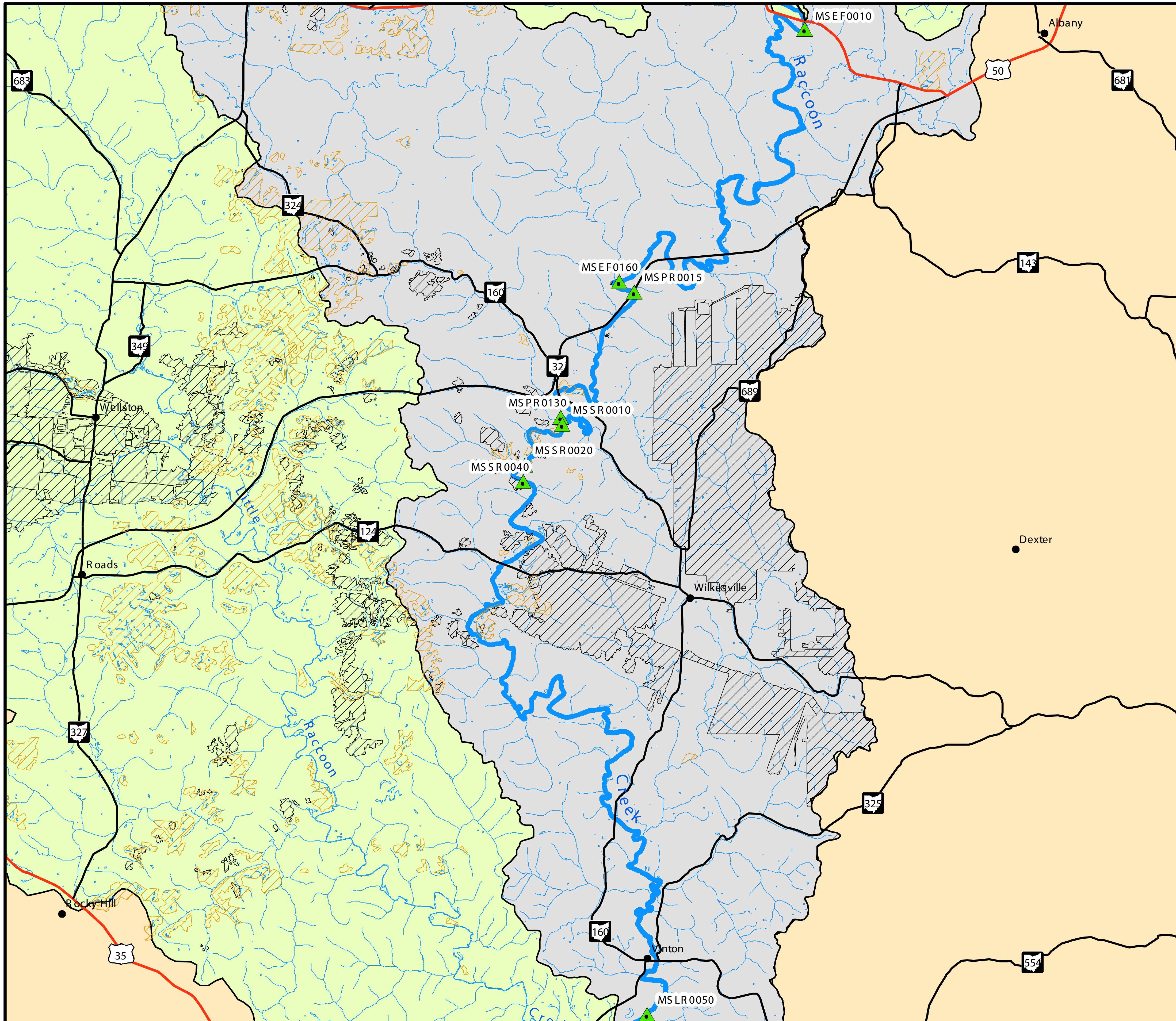
# Raccoon Creek Middle Basin AMDAT

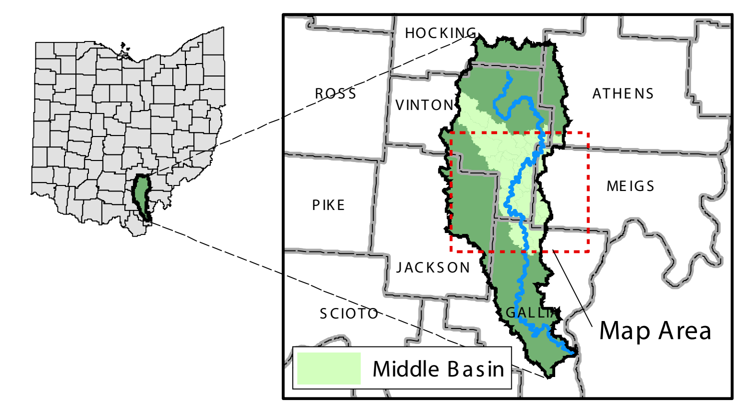
## Map 5 - Net Concentration Conditions on the Mainstem of Raccoon Creek




### Map Features

- Middle Basin Sample Site
- Middle Basin
- Raccoon Creek Watershed
- Deep_Mines
- Surface_Mines
- Streams
- Village/City
- 93 State Highway
- 50 U.S. Highway

0 1 2 4
Scale in Miles

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Sources: PUCO. USGS 7.5 minute quadrangles.
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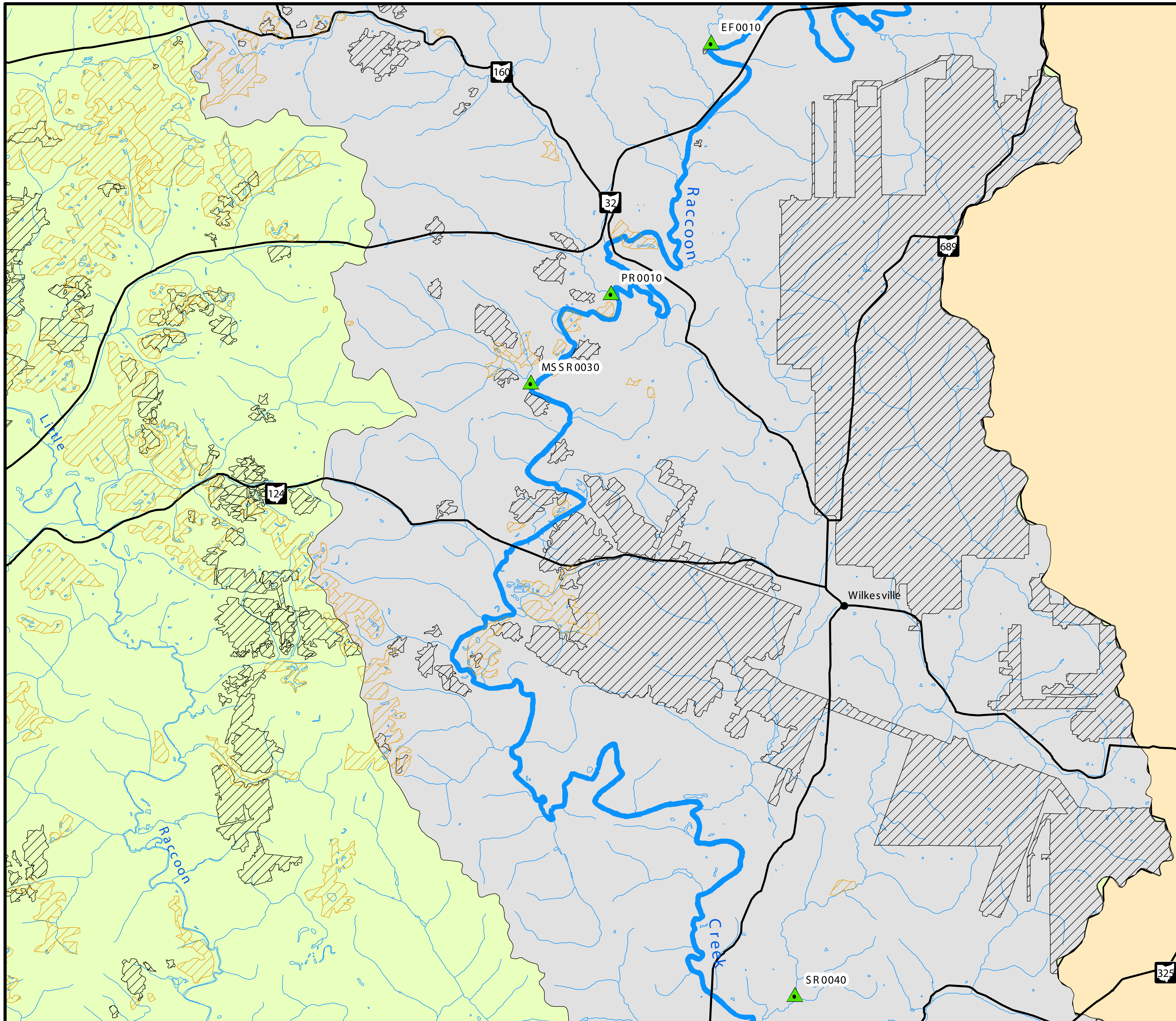
# Raccoon Creek Middle Basin AMDAT

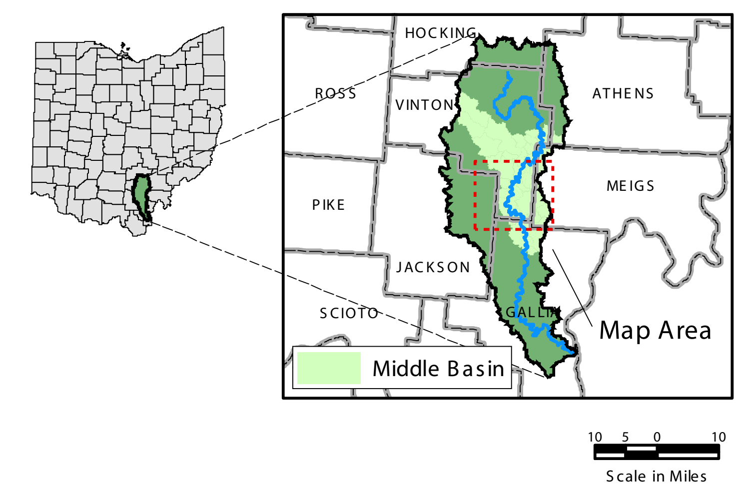
## Map 6 - Sampling Locations For The Discharge of The Major Tributaries




### Map Features

- Middle Basin Sample Site
- Middle Basin
- Raccoon Creek Watershed
- Deep_Mines
- Surface_Mines
- Streams
- Village/City
- State Highway
- U.S. Highway

0 1 2 4
Scale in Miles




Ohio GIS Net
Sources: PUCO. USGS 7.5 minute quadrangles.
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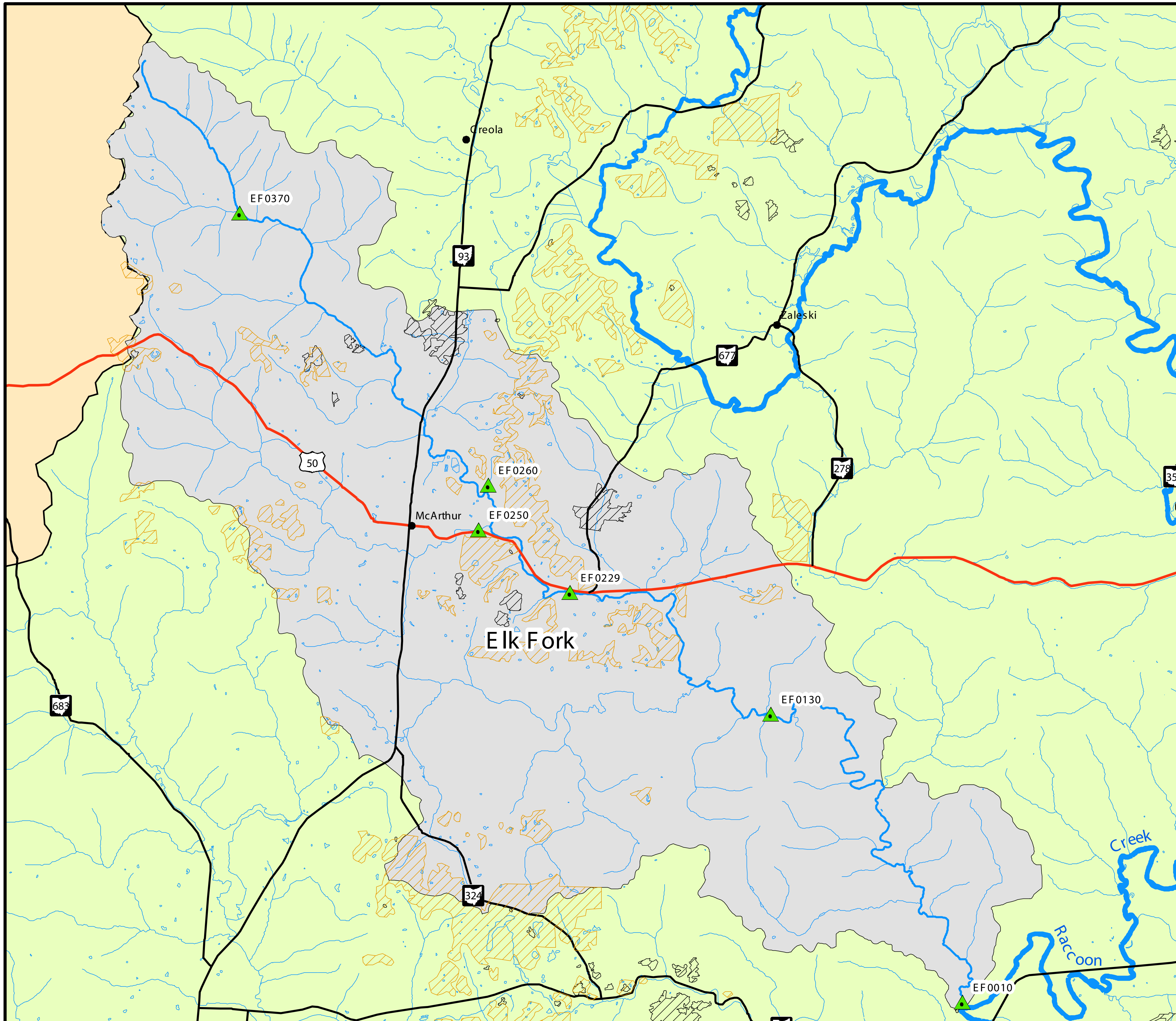
# Raccoon Creek Middle Basin AMDAT

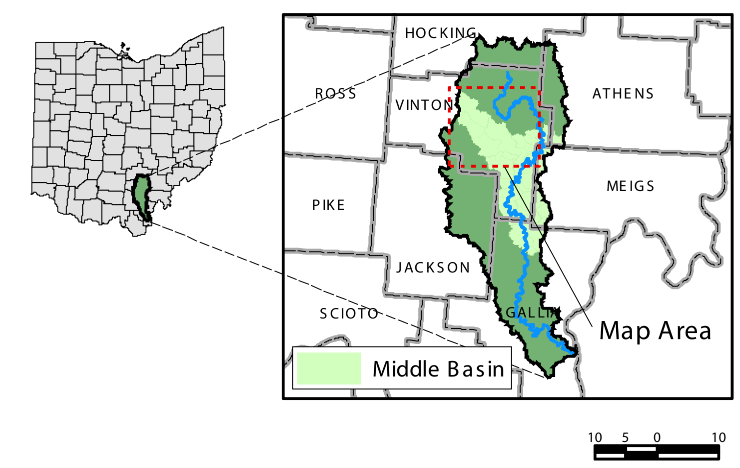
## Map 7 - Elk Fork Sub-Watershed




**Map Features**

- Middle Basin Sample Site
- Raccoon Creek Watershed
- Deep_Mines
- Surface_Mines
- Streams
- Village/City
- 93 State Highway
- 50 U.S. Highway

0 0.5 1 2
Scale in Miles




Ohio GIS Net
Sources: PUCO. USGS 7.5 minute quadrangles.
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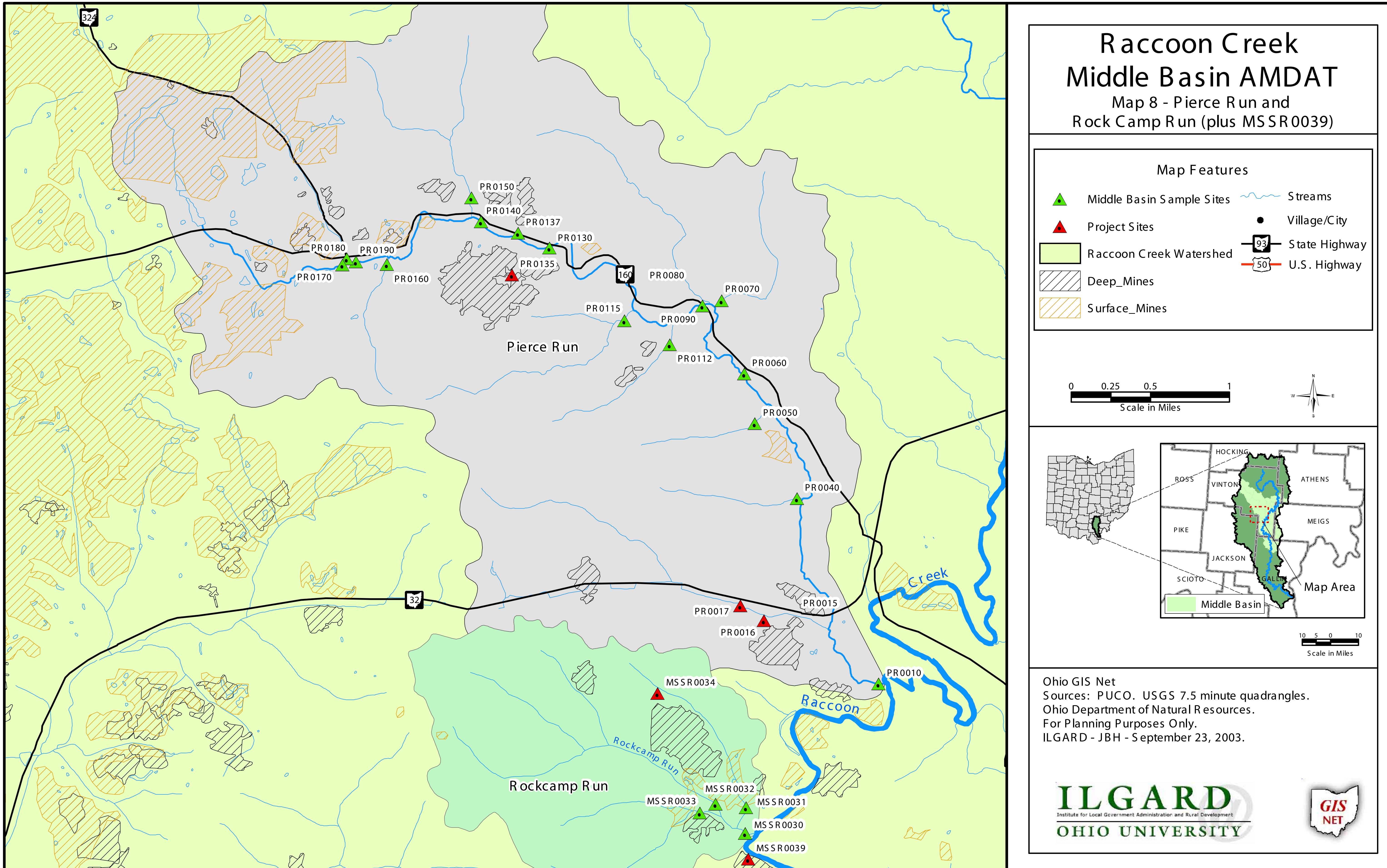


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