# Appendix B

## Acid Mine Drainage Analysis
## for
## Yellow Creek and Little Yellow Creek Watersheds

# Yellow Creek Watershed Acid Mine Drainage Analysis

## Purpose of document

The purpose of this document is to identify streams in the Yellow Creek watershed that are not meeting their potential attainment status as listed in Rule OAC 3745-01 because of impacts from acid mine drainage (AMD). In addition, a proposal of concentration reductions for AMD signature parameters will be provided. An impact, in this context, is defined as the preclusion of attainment of any applicable biological criteria.

## Relation to TMDL

The analysis described by this document is not a complete TMDL; however, concentration reductions of AMD parameters are proposed. These reductions are developed by statistical comparison of AMD receiving streams with both full and non/partial biological attainment. The following analysis completes several preliminary steps of developing a TMDL, including a calculation of target values for chemical parameters without water quality standards and comparison of observed conditions to target values. The following analysis does not estimate existing loads, calculate loading capacities, or make allocations.

## Acid Mine Drainage defined

AMD is the seepage or runoff of groundwater and precipitation which has come into contact with coal or coal mine waste materials called 'gob'. Drainage from these materials is often acidic[1] and discharges from underground mines, surface mines, or mine waste disposal areas. AMD is often associated with abandoned coal mine lands (AML). AMD in Ohio is typically characterized by low pH, high metal concentrations, and low buffering capacity because of the lack of alkalinity. AMD can have a devastating effect with varying severity upon the aquatic life of a stream or river.

## Chemical and physical effects of AMD

The effect of AMD on a receiving stream is temporally and spatially variable and will depend upon the volume, frequency, and chemistry of the drainage, as well as the attenuating capacity of the receiving stream. AMD characteristics are created by the mineral composition of the rock strata over which it flows. Thus, if the local geology is rich in a particular mineral, the drainage is likely to reflect it. The water chemistry at any given location along an AMD-receiving stream can vary significantly, but often these water bodies include some or all of the following signatures:

[1] Mine Drainage can also be alkaline, depending upon local geology. Acidic drainage appears to be more pervasive in the Yellow Creek basin study area, thus within this report AMD refers specifically to acidic drainage.

- The pH of the stream may be very low, especially if measured in close proximity to the drainage. However, the effect upon pH may be negligible if the stream is adequately buffered. In such situations, pH may not noticeably change downstream of the drainage, but an increase in acidity and decrease in alkalinity is sometimes observed.

- Elevated iron may be observed downstream of the discharge. Partitioning of the iron isotopes is highly dependant upon meteorological conditions. When iron-bearing minerals in coal, such as pyrite ($FeS_2$), are exposed to oxygen and water, the iron oxidation is catalyzed microbiologically and released to solution. Pyrite oxidation is by far the greatest contributor. The general stoichiometry is as follows:

  $$2FeS_2(s) + 7O_2(g) + 2H_2O(l) \rightarrow 2Fe^{2+}(aq) + 4SO_4^{2-}(aq) + 4H^+(aq)$$

  Dissolved iron is transported to the receiving stream where its chemical speciation and potential for transport or precipitation will depend upon various physiochemical processes.

- Other elevated metal and semi-metal concentrations originate from impurities within the coal seam including aluminum, arsenic, cadmium, copper, lead, manganese, and zinc. These constituents may be observed at toxic levels downstream of an AMD drainage. Elevated aluminum and manganese concentrations are nearly ubiquitously associated with AMD.

- Metal precipitates may be observed on the stream bed below the point of discharge. This is a result of dissolved metals in the drainage reacting with water to form various hydroxides. Precipitated manganese, aluminum, and iron oxides can reduce quality and quantity of habitat within a stream or river by filling macropores within the substrate. One such precipitate, ferric hydroxide, is responsible for the reddish-orange color commonly associated with AMD impacted streams. Ferric hydroxide is often called “yellow boy”. Precipitation of aluminum typically forms grayish-white solids; whereas, manganese precipitate is bluish-black.

- Elevated sulfate may be observed downstream of AMD. Sulfate is a byproduct of the oxidation of iron-bearing minerals and the production of AMD. Sulfate is generally considered to be non-toxic to aquatic life (except perhaps at extreme concentrations), but can be used as an indicator of AMD in a stream system. Elevated sulfate concentrations can create nuisance conditions to recreational waters because of noxious odors.

- Depletion of alkalinity as well as an increase in acidity, hardness, conductivity, total dissolved solids, and various other chemical parameters from AMD is very common. Generally, these parameters are secondary indicators of the previously-mentioned adverse water-quality affects.

- Low dissolved oxygen (DO) may be observed in AMD streams as well. Similar to pH, low DO water quality is more likely in close proximity to the drainage. The oxidation of iron-bearing minerals and the further oxidation of ferrous iron in solution are significant oxygen-consumptive processes. Thus, where AMD discharges exist, the in-stream DO is typically significantly depleted. The depletion is created by the oxygen consumptive processes previously discussed. Because of natural re-aeration, depressed DO may increase over time and not be observed at far-field downstream locations.

AMD can have multiple adverse impacts upon a receiving stream. These impacts commonly include depletion of DO, reduction in pH, depletion of alkalinity buffering capacity, elevated heavy-metal concentrations, and degraded stream habitat. The magnitude of the impacts is dependent upon many factors including the AMD seep characteristics and the hydrology as well as geology of the drainage area. Important specific factors of AMD impacts include the volume and frequency of the discharge, chemistry of the drainage, and attenuating capacity of the receiving stream and meteorology during discharge.

**Effects of AMD upon aquatic life**

AMD can have various chemical and physical effects upon the aquatic life of a stream or river. In some drainage basins of southern, southeastern, and eastern Ohio, AMD is the dominant cause of water quality impairment resulting in stream segments almost devoid of aquatic organisms. If less severe, AMD may be a secondary or tertiary cause of impairment, acting as one of several stressors impacting the biota of a stream.

The primary effect of AMD on aquatic life is related to pH and the concentration of toxic dissolved metals. Depressed DO, osmotic disturbance due to high dissolved solids, and habitat degradation due to metal precipitation also impacts aquatic life. Several of the dominant chemical and physical effects of AMD are discussed in more detail below.

- If pH is severely low, it will be the primary cause of toxicity to aquatic organisms. Most aquatic organisms have a defined range of pH tolerance. Standard units of pH below the acceptable range may result in an imbalance of sodium and chloride ions in the blood of organisms, as hydrogen ions are taken into cells and sodium is expelled. This biochemical change can lead to respiratory or osmoregulatory failure. The pH also affects the speciation of heavy metals originating from AMD seeps. Low pH values typically drive toxic heavy metals into a dissolved (bioavaliable) speciation creating increased impairment from these metals.

- The presence of heavy metals in AMD increases its toxicity to aquatic organisms. The chemistry of heavy metals in natural waters is complex, and as each metal can exist in multiple forms or species. It is widely agreed that the dissolved species of heavy metals are the most toxic. This is related to the fact that the dissolved species are the most bioavailable. Aluminum, iron, and manganese are the major heavy metals found to compound the adverse effects of acidic drainage. Aluminum is believed to have the most pronounced impact, though each may act synergistically with hydrogen ions to disrupt the biochemistry of an organism. Various trace metals, such as cadmium, copper, and zinc, may also be present in AMD, and are extremely toxic at low concentrations.

- AMD can have physical effects upon the aquatic community as well. Most notable is the degradation of habitat quality due to the deposition of metal precipitates. This deposition can fill interstitial spaces between larger substrate materials, reducing the diversity of habitat available to benthic macroinvertebrates. Metal precipitates can affect fish populations by accumulating on gills and other tissues, thus reducing overall vitality, or by smothering eggs, impacting reproduction, and reducing predation.

Several natural characteristics of a stream can mitigate the effect of AMD upon aquatic life. These include the potential for dilution, buffering capacity, hardness, and dissolved organic matter. These factors are discussed below.

- The potential for dilution in the receiving stream is perhaps the simplest and most important mitigating factor. Small headwater streams are the most likely to be devastated by AMD, whereas large rivers may have sufficient flow to assimilate the drainage with negligible effect.

- Buffering capacity, as measured by total alkalinity, describes the receiving water's ability to assimilate low pH inflows without significantly lowering the instream pH. Adequately buffered receiving waters help to maintain pH within a tolerable range for aquatic life. Additionally, heavy metals are typically less soluble in near-neutral water, so they more readily precipitate in well-buffered streams, reducing their toxic impact because of reduced bioavailability.

- A receiving water with elevated hardness, as measured by the concentration of calcium and magnesium, is more protective of aquatic species from AMD than soft waters. This is believed to be due to a competitive effect between calcium, magnesium, and heavy-metal cations for binding sites on the tissue of aquatic organisms.

- Elevated concentrations of dissolved organic matter (DOM) are believed to ameliorate some of the effects of dissolved heavy metals. Organic molecules can act as chelating agents, and react with the dissolved metal species to form metal complexes. The resulting complex is much less toxic than the free metal ion.

AMD has multiple adverse affects on the aquatic life of a stream. The dominant causes of impairment include low pH and toxic heavy-metal concentrations. Secondary effects include the degradation of habitat and depressed DO concentrations. Important mitigating factors of AMD impacts include the potential for dilution, hardness, buffering capacity, and DOM concentration in the receiving stream.

## Generalized Primary Screening

Field observations during the Yellow Creek survey indicated a number of streams within the basin may have potential water quality impacts caused by AMD. To be certain of the source of streams with water quality impacts, observational and numeric screening was used in this analysis to identify stream segments receiving AMD and subsequently to determine those streams that are impaired by AMD. The initial screening parameters and associated concentrations utilized to identify streams which receive AMD were developed from the United States Department of Agriculture, Natural Resource Conservation Service (previously Soil Conservation Service, 1985).

The suggested values to categorize AMD discharge impacts on streams can be viewed in Table B1. This table provides guidelines for comparison of the Yellow Creek basin sites with non or partial biological attainment to determine if AMD may be the cause of the water quality problem. This comparison was completed utilizing severe impact water quality (Table B1) to determine if further investigation into this drainage is warranted. Additional data analysis will be completed if data appears that the stream is impacted by AMD.

Table B1. Association between select mine drainage chemical parameters and the degree of impact on surface water quality, Source: U.S. Department of Agriculture, Soil Conservation Service, 1985; *Assessment and treatment of areas in Ohio impacted by abandoned mines*.

| | **No Mining Impact *** | **Minimal Impact** | **Moderate Impact** | **Severe Impact** |
|---|---|---|---|---|
| **pH (S.U.)** | 6.5 – 9.0 # | 5.5 – 6.4 | 4.5 – 5.4 | **< 4.5** |
| **Total Fe (mg/L)** | < 1.0 | 1.1 – 5.0 | 5.1 – 10.0 | **> 10.0** |
| **Total Mn (mg/L)** | < 0.05 | 0.06 – 2.0 | 2.1 – 4.0 | **> 4.0** |
| **Sulfate (mg/L)** | < 250 | 251 – 600 | 601 – 960 | **> 961** |
| **Sp. Conductance (umhos/cm)** | **< 685** | **686 – 900** | **901 – 1200** | **>1200** |

* The document wording is: *No detectable mine drainage impact*.
# Statewide water quality criteria never to be violated (OAC 3745-1-07).

Therefore, two types of observations on water quality were used to help identify the possible presence of AMD impacts for initial screening:

(1) visual discoloration of stream sediments with the yellow-orange ferric-iron hydroxide known colloquially as "yellow boy" to such a magnitude that it violated water quality standards (Section 3745-1-04 of OAC), where it is stated that waters of the state "*shall be free from materials entering the waters as a result of human producing color, odor or other conditions in such a degree as to create a nuisance*"; and

(2) stream locations showing less than full attainment of biological criteria (e.g., partial or non-attainment) that also had concentrations of AMD chemicals of concern (e.g., either pH, sulfate, iron, manganese, conductivity) at levels reported to have moderate to severe negative impact on surface water quality, or where two or more AMD chemicals of concern were at levels reported to have minimal impact. For these streams statistics of chemistry results were compared to the USDA screening values listed in Table AMD1.

Those streams judged to be AMD impacted within the Yellow Creek basin due to visual discoloration of water and/or bottom sediments with yellow-boy are listed in Table B2. Those streams judged to be AMD impacted due to association of impaired biological communities with elevated levels of AMD chemicals of concern are identified in Table B3.

Because the streams listed in Table AMD2 which are not biologically impaired are meeting attainment, comparison of this data to Table AMD1 was not completed. Instead, comparison of this data to basin specific targets is completed. Reasoning and techniques for this evaluation are discussed in detail in the following 'Numerical Target' section of this document.

Comparison of the biologically impaired streams listed within the Table B3 analytical results is completed to provide evidence of the cause of impairment. The water quality values obtained from the 2005 field season sampling for sites listed in Table AMD3 were compared to the USDA values in Table AMD1. Results of this comparison are listed in Table B4. As can be noted from this table, three of the sites are categorized as severe impact and three sites fell within the minimal impact rating. This analysis is helpful as a preliminary screening technique and was used in the Yellow Creek TSD. However, the suggested screening values in Table B1 would possibly fail to identify streams with a secondary or tertiary AMD impact. The concern of utilizing generalized AMD targets is that the assimilative capacity of streams vary from basin to

**Table B2. Yellow Creek - full biological attainment headwater streams - selected water chemistry results from the 2005 sampling season**

| Sampling Site | Parameter | Water Chemistry Results per Event | | | | |
|---|---|---|---|---|---|---|
| **Goose Creek** (H) | Acidity-CaCO3 (mg/L) | <5.0 | <5.0 | <5.0 | <5.0 | |
| RM 1.9, CWH, FULL | Alkalinity-CaCO3 (mg/L) | 121 | 133 | 134 | 129 | |
| QHEI 63.0 | Aluminum (µg/L) | 643 | 536 | <200 | 278 | |
| DA 2.5 mi$^2$ | Specific Conductance (µmhos/cm) | 959 | 1,050 | 1,070 | 1,090 | |
| HUC 05030101-180-010 | Total Dissolved Solids (mg/L) | 754 | 770 | 856 | 908 | |
| | Iron (µg/L) | 1,290 | 1,480 | 557 | 615 | |
| | Manganese (µg/L) | 148 | 236 | 176 | 219 | |
| | Sulfate (mg/L) | 504 | 494 | 517 | 517 | |
| **Hollow Rock Run** (H) | Acidity-CaCO3 (mg/L) | <5.0 | <5.0 | <5.0 | <5.0 | |
| RM 2.2, WWH existing - CWH recommended, FULL | Alkalinity-CaCO3 (mg/L) | 145 | 137 | 132 | 141 | |
| QHEI 48.5 | Aluminum (µg/L) | <200 | <200 | <200 | 205 | |
| DA 6.4 mi$^2$ | Specific Conductance (µmhos/cm) | 1,150 | 1,200 | 1,240 | 1,250 | |
| HUC 05030101-190-050 | Total Dissolved Solids (mg/L) | 924 | 946 | 998 | 994 | |
| | Iron (µg/L) | <50 | 114 | 291 | 302 | |
| | Manganese (µg/L) | 12 | 21 | 37 | 51 | |
| | Sulfate (mg/L) | 582 | 530 | 580 | 565 | |
| **Ralston Run** (H) | Acidity-CaCO3 (mg/L) | <5.0 | <5.0 | <5.0 | <5.0 | <5.0 |
| RM 0.3, EWH, Full | Alkalinity-CaCO3 (mg/L) | 120 | 124 | 114 | 111 | 143 |
| QHEI 71.5 | Aluminum (µg/L) | <200 | <200 | <200 | <200 | <200 |
| DA 5.6 mi$^2$ | Specific Conductance (µmhos/cm) | 409 | 414 | 376 | 374 | 462 |
| HUC 05030101-180-040 | Total Dissolved Solids (mg/L) | 258 | 240 | 236 | 238 | 308 |
| | Iron (µg/L) | 145 | 179 | 785 | 730 | 126 |
| | Manganese (µg/L) | 91 | 94 | 98 | 101 | 76 |
| | Sulfate (mg/L) | 93 | 91 | 87 | 87 | 102 |
| **Trail Run** (H) | Acidity-CaCO3 (mg/L) | <5.0 | <5.0 | <5.0 | <5.0 | |
| RM 0.3, EWH, Full | Alkalinity-CaCO3 (mg/L) | 162 | 168 | 156 | 164 | |
| QHEI 63.5 | Aluminum (µg/L) | 218 | <200 | 332 | <200 | |
| DA 3.3 mi$^2$ | Specific Conductance (µmhos/cm) | 841 | 877 | 822 | 909 | |
| HUC 05030101-180-020 | Total Dissolved Solids (mg/L) | 622 | 620 | 596 | 660 | |
| | Iron (µg/L) | 745 | 375 | 1,390 | 409 | |
| | Manganese (µg/L) | 408 | 275 | 527 | 239 | |
| | Sulfate (mg/L) | 332 | 319 | 289 | 333 | |
| **Wolf Run** (H) [AKA Wolf Creek in WQS] | Acidity-CaCO3 (mg/L) | <5.0 | <5.0 | <5.0 | <5.0 | <5.0 |
| RM 1.5, WWH, Full | Alkalinity-CaCO3 (mg/L) | 20 | 19 | 31 | 26 | 33 |
| QHEI 69.0 | Aluminum (µg/L) | 915 | 880 | <200 | 1,640 | <200 |
| DA 3.3 mi$^2$ | Specific Conductance (µmhos/cm) | 847 | 848 | 857 | 773 | 864 |
| HUC 05030101-180-010 | Total Dissolved Solids (mg/L) | 628 | 630 | 562 | 576 | 664 |
| | Iron (µg/L) | 311 | 288 | 66 | 742 | 73 |
| | Manganese (µg/L) | 1,970 | 1,900 | 1,140 | 1,490 | 930 |
| | Sulfate (mg/L) | 454 | 458 | 443 | 368 | 370 |
| **Yellow Creek** (H) | Acidity-CaCO3 (mg/L) | <5.0 | <5.0 | <5.0 | <5.0 | |
| RM 30.0, WWH, FULL | Alkalinity-CaCO3 (mg/L) | 106 | 126 | 90 | 153 | |
| QHEI 65.5 | Aluminum (µg/L) | 420 | <200 | 1,500 | <200 | |
| DA 14.4 mi$^2$ | Specific Conductance (µmhos/cm) | 424 | 529 | 401 | 765 | |
| HUC 05030101-180-010 | Total Dissolved Solids (mg/L) | 264 | 302 | 252 | 468 | |
| | Iron (µg/L) | 1,470 | 1,240 | 3,970 | 1,990 | |
| | Manganese (µg/L) | 304 | 413 | 480 | 1,000 | |
| | Sulfate (mg/L) | 82 | 112 | 86 | 154 | |

**Table B3. Yellow Creek - non/partial biological attainment headwater and wadeable streams - selected wate chemistry results from the 2005 sampling season**

| Sampling Site | Parameter | Water Chemistry Results per Event | | | | |
|---|---|---|---|---|---|---|
| **Alder Lick Run** (H) | Acidity-CaCO3 (mg/L) | <5.0 | <5.0 | <5.0 | <5.0 | |
| RM 0.2, WWH, Partial | Alkalinity-CaCO3 (mg/L) | 131 | 188 | 192 | 274 | |
| QHEI 69.0 | Aluminum (µg/L) | 238 | <200 | <200 | <200 | |
| DA 3.0 $mi^2$ | Specific Conductance (µmhos/cm) | 1,100 | 1,750 | 1,640 | 2,180 | |
| HUC 05030101-100-260 | Total Dissolved Solids (mg/L) | 826 | 1,570 | 1,390 | 2,050 | |
| | Iron (µg/L) | 817 | 545 | 447 | 304 | |
| | Manganese (µg/L) | 943 | 514 | 284 | 296 | |
| | Sulfate (mg/L) | 512 | 968 | 824 | 1,140 | |
| **Bailey Run** (H) | Acidity-CaCO3 (mg/L) | <5.0 | <5.0 | <5.0 | <5.0 | <5.0 |
| Chemistry RM 1.95, Biology RM 0.7, CWH, NON | Alkalinity-CaCO3 (mg/L) | 74 | 87 | 80 | 82 | 123 |
| QHEI 83.5 | Aluminum (µg/L) | <200 | <200 | <200 | <200 | <200 |
| DA 2.5 $mi^2$ | Specific Conductance (µmhos/cm) | 255 | 277 | 289 | 286 | 331 |
| HUC 05030101-100-260 | Total Dissolved Solids (mg/L) | 140 | 176 | 182 | 180 | 196 |
| | Iron (µg/L) | 2,940 | 3,590 | 3,200 | 3,480 | 4,320 |
| | Manganese (µg/L) | 5,300 | 4,960 | 2,980 | 3,080 | 5,530 |
| | Sulfate (mg/L) | 22 | 11 | 25 | 25 | 8 |
| **Brush Creek** (H) | Acidity-CaCO3 (mg/L) | <5.0 | <5.0 | <5.0 | <5.0 | |
| RM 6.0, EWH, Partial | Alkalinity-CaCO3 (mg/L) | 81 | 79 | 97 | 81 | |
| QHEI 89.5 | Aluminum (µg/L) | <200 | <200 | <200 | <200 | |
| DA 7.4 $mi^2$ | Specific Conductance (µmhos/cm) | 803 | 814 | 1,040 | 889 | |
| HUC 05030101-190-020 | Total Dissolved Solids (mg/L) | 536 | 520 | 686 | 580 | |
| | Iron (µg/L) | 2,030 | 1,660 | 2,180 | 904 | |
| | Manganese (µg/L) | 501 | 462 | 487 | 534 | |
| | Sulfate (mg/L) | 314 | 312 | 410 | 328 | |
| **Riley Run** (H) | Acidity-CaCO3 (mg/L) | <5.0 | <5.0 | <5.0 | <5.0 | |
| RM 4.8, WWH, NON | Alkalinity-CaCO3 (mg/L) | 140 | 106 | 180 | 186 | |
| QHEI 56.0 | Aluminum (µg/L) | <200 | 2,290 | <200 | <200 | |
| DA 3.6 $mi^2$ | Specific Conductance (µmhos/cm) | 858 | 450 | 976 | 1,020 | |
| HUC 05030101-190-030 | Total Dissolved Solids (mg/L) | 618 | 308 | 746 | 762 | |
| | Iron (µg/L) | 181 | 3,940 | 698 | 500 | |
| | Manganese (µg/L) | 274 | 182 | 1,410 | 1,340 | |
| | Sulfate (mg/L) | 314 | 132 | 364 | 428 | |
| **Salisbury Run** (H) | Acidity-CaCO3 (mg/L) | <5.0 | <5.0 | 88 | 125 | |
| RM 0.1, CWH, NON | Alkalinity-CaCO3 (mg/L) | 14 | 16 | 5 | 5 | |
| QHEI 56.0 | Aluminum (µg/L) | 4,740 | 1,150 | 3,280 | 4,810 | |
| DA 2.3 $mi^2$ | Specific Conductance (µmhos/cm) | 658 | 565 | 1,070 | 1,380 | |
| HUC 05030101-190-040 | Total Dissolved Solids (mg/L) | 476 | 396 | 786 | 898 | |
| | Iron (µg/L) | 21,100 | 16,400 | 43,500 | 40,200 | |
| | Manganese (µg/L) | 886 | 648 | 1,610 | 2,330 | |
| | Sulfate (mg/L) | 304 | 253 | 486 | 648 | |
| **Wells Run** (H) | Acidity-CaCO3 (mg/L) | <5.0 | 20 | <5.0 | 42 | |
| RM 0.3, CWH, NON | Alkalinity-CaCO3 (mg/L) | 14 | 5 | 7 | 5 | |
| QHEI 54.0 | Aluminum (µg/L) | 473 | 778 | 1,110 | 1,830 | |
| DA 2.2 $mi^2$ | Specific Conductance (µmhos/cm) | 476 | 724 | 766 | 1,090 | |
| HUC 05030101-100-260 | Total Dissolved Solids (mg/L) | 316 | 518 | 552 | 746 | |
| | Iron (µg/L) | 6,810 | 10,800 | 13,000 | 13,300 | |
| | Manganese (µg/L) | 796 | 1,510 | 1,750 | 2,660 | |
| | Sulfate (mg/L) | 199 | 334 | 345 | 490 | |
| **Yellow Creek** (W) | Acidity-CaCO3 (mg/L) | <5.0 | <5.0 | <5.0 | <5.0 | <5.0 |
| Chemistry RM 2.51, Biology RM 3.3, WWH, Partial | Alkalinity-CaCO3 (mg/L) | 61.0 | 91.4 | 94.8 | 107.0 | 88.4 |
| QHEI 63.0 | Aluminum (µg/L) | <200 | 225 | <200 | <200 | 205 |
| DA 224 $mi^2$ | Specific Conductance (µmhos/cm) | 264 | 530 | 559 | 509 | 573 |
| HUC 05030101-190-050 | Total Dissolved Solids (mg/L) | 204 | 184 | 362 | 326 | 380 |
| | Iron (µg/L) | 712 | 2,140 | 1,880 | 1,470 | 1,850 |
| | Manganese (µg/L) | 96 | 159 | 195 | 81 | 238 |
| | Sulfate (mg/L) | 73.1 | 146.0 | 147.0 | 127.0 | 162.0 |

basin and may include a multitude of factors including for example habitat characteristics such gradient, velocity, sunlight cover; meteorological factors such as temperature, rainfall, solar radiation; and many other factors known and unknown. Identification of such streams is a specific objective of this study, thus the watershed-specific analysis of water-chemistry data is believed to provide the most suitable target values.

**Table B4. Streams within the Yellow Creek basin with documented biological impairment due to suspected acid mine drainage (AMD) chemicals of concern utilizing USDA proposed values**

| Stream | River Mile | Location | pH (S.U.) | Fe (µg/l) | Mn (µg/l) | SO4 (mg/l) | Spec. Cond. (µmhos/cm) | IBI | ICI | Attainment Status |
|---|---|---|---|---|---|---|---|---|---|---|
| **Salisbury Run (06-913)** | **0.10** | **Twp. Rd. 776** | | | | | | **12** | **VP** | **NON-CWH** |
| geometric mean | | | 5.7 | 41817 | 1937 | 561 | 1215 | | | |
| median (50% percentile) | | | | 41850 | 1970 | 567 | 1225 | | | |
| 75% percentile | | | | 42675 | 2150 | 607 | 1305 | | | |
| maximum | | | | 43500 | 2330 | 648 | 1380 | | | |
| minimum | | | 3.71 | | | | | | | |
| **Wells Run (06-081)** | **0.20** | **Upstream SR 7** | | | | | | **12** | **P** | **NON-CWH** |
| geometric mean | | | 6.2 | 10619 | 1538 | 326 | 732 | | | |
| median (50% percentile) | | | | 11900 | 1630 | 339 | 745 | | | |
| 75% percentile | | | | 13075 | 1977 | 381 | 847 | | | |
| maximum | | | | 13300 | 2660 | 490 | 1090 | | | |
| minimum | | | 4.6 | | | | | | | |
| **Alder Lick Run (06-080)** | **0.10** | **Adj. Fife Coal Rd.** | | | | | | **40** | **F** | **Partial-WWH** |
| geometric mean | | | 7.7 | 496 | 449 | 826 | 1620 | | | |
| median (50% percentile) | | | | 496 | 405 | 896 | 1695 | | | |
| 75% percentile | | | | 613 | 621 | 1011 | 1857 | | | |
| maximum | | | | 817 | 943 | 1140 | 2180 | | | |
| minimum | | | 7.51 | | | | | | | |
| **Brush Creek (06-905)** | **6.10** | **Twp. Rd. 290** | | | | | | **36** | **E** | **Partial-EWH** |
| geometric mean | | | 7.8 | 525 | 79 | 302 | 864 | | | |
| median (50% percentile) | | | | 619 | 75 | 295 | 834 | | | |
| 75% percentile | | | | 662 | 100 | 302 | 887 | | | |
| maximum | | | | 730 | 122 | 353 | 985 | | | |
| minimum | | | 7.55 | | | | | | | |
| **Riley Run (06-917)** | **4.80** | **Co. Rd. 13 (April Rd.)** | | | | | | **36** | **P** | **NON-WWH** |
| geometric mean | | | 7.4 | 398 | 803 | 366 | 949 | | | |
| median (50% percentile) | | | | 500 | 1340 | 364 | 976 | | | |
| 75% percentile | | | | 599 | 1375 | 390 | 998 | | | |
| maximum | | | | 698 | 1410 | 428 | 1020 | | | |
| minimum | | | 7.26 | | | | | | | |
| **Yellow Creek (06-900)** | **2.51** | **S.R. 213** | | | | | | **44** | **24** | **Partial-WWH** |
| geometric mean | | | 7.8 | 1677 | 143 | 133 | 482 | | | |
| median (50% percentile) | | | | 1880 | 159 | 146 | 541 | | | |
| 75% percentile | | | | 2120 | 178 | 154 | 557 | | | |
| maximum | | | | 2280 | 238 | 162 | 573 | | | |
| minimum | | | 7.63 | | | | | | | |

**AMD Impact Key:**
##### = None
##### = Minimal
##### = Moderate
##### = Severe

**Basin Specific AMD Water Quality Screening Targets**

To assure these indirect AMD impacts are not missed, drainage specific targets have been development from a database of water-chemistry sample and biological sampling results from a 2005 Yellow Creek watershed survey conducted by the Ohio EPA. AMD impacted sites are defined as those passing primary screening as discussed in the previous section. These sites typically are immediately downstream a major point source or those in a known AMD receiving stream. The water-chemistry database from this survey was utilized to develop targets stratified by stream-size at the sample collection site for suspected AMD impacted streams.

Sample sites are divided into three categories: headwater, wadeable, and river. Headwater sites are those with a drainage area less than 20 square miles. Wadeable sites are those with a drainage area greater than twenty and less than 200 square miles. River sites are those with a drainage area greater than 200 square miles. The majority of the Yellow Creek analysis was completed on headwater streams. Wadeable and river sites biological attainment did not appear to be significantly affected by AMD parameters. One wadeable drainage and no river drainages were analyzed for AMD, because no river sites are suspected of having a significant AMD impact.

The stratified water-chemistry database was analyzed to determine the median, as well as 75$^{th}$, 90$^{th}$, and 95$^{th}$ percentiles, for each of the target parameters. Results of these dataset statistics for the primarily screened headwater and wadeable streams are listed in Table B5. To create this table and other analysis within this section, if analytic results were below detection, the values for these parameters were set at the value of minimum detection for that analytical method. This assumption affects some of the parameters such as acidity in headwaters significantly as can be observed in the table.

Sample results exceeding the stated statistical targets (median and 90$^{th}$-precentile) are not proof-positive that an AMD impact exists. Rather, values exceeding the targets are merely intended to be suggestive that an AMD impact probably exists.

**Table B5. Water-chemistry screening statistics of the target database**

| Parameter | Units | Sample Size | Median | Percentile 75th | Percentile 90th | Percentile 95th |
|---|---|---|---|---|---|---|
| ***Headwater Sites (Drainage Area < 20 $mi^2$)*** | | | | | | |
| Acidity as $CaCO_3$ | *mg/L* | 184 | 5 | 5 | 5 | 5 |
| Alkalinity as $CaCO_3$ | *mg/L* | 184 | 92 | 74 | 56 | 25 |
| Aluminum, Total | *µg/L* | 184 | 354 | 461 | 1,049 | 1,974 |
| Specific Conductance | *µmhos/cm* | 184 | 336 | 567 | 711 | 880 |
| Total Dissolved Solids | *mg/L* | 184 | 208 | 360 | 497 | 623 |
| Iron, Total | *µg/L* | 184 | 309 | 635 | 1,073 | 1,695 |
| Manganese, Total | *µg/L* | 184 | 121 | 288 | 507 | 664 |
| Sulfate, Total | *mg/L* | 184 | 51 | 155 | 231 | 302 |
| ***Wadeable Sites (20$mi^2$ < Drainage Area < 200$mi^2$)*** | | | | | | |
| Acidity as $CaCO_3$ | *mg/L* | 66 | 9 | 10 | 10 | 11 |
| Alkalinity as $CaCO_3$ | *mg/L* | 66 | 99 | 86 | 50 | 36 |
| Aluminum, Total | *µg/L* | 66 | 418 | 628 | 1,004 | 1,089 |
| Specific Conductance | *µmhos/cm* | 66 | 537 | 583 | 725 | 782 |
| Total Dissolved Solids | *mg/L* | 66 | 342 | 370 | 487 | 528 |
| Iron, Total | *µg/L* | 66 | 331 | 534 | 975 | 1,265 |
| Manganese, Total | *µg/L* | 66 | 80 | 135 | 200 | 239 |
| Sulfate, Total | *mg/L* | 66 | 138 | 151 | 188 | 221 |

## Deviation from Watershed Specific Screening Values

The numeric targets are not water-quality standards. In fact, there are no Ohio water-quality standards for the protection of aquatic-life for any of the target parameters. Ohio EPA Technical Bulletin MAS/1997-9-1 suggests standards for total-recoverable iron; however, the document specifically states the values are not protective in streams impacted by AMD.

Streams with a potential AMD impact are identified by comparison of individual water-chemistry sample results to the target values. Table B6 presents the results of selected AMD signature parameters analyzed for both biologically attaining and Table B7 biologically non or partially attaining sites where a significant deviation from the target values exists. These tables also include the aquatic-life use designation and attainment status of each site, QHEI, drainage area, and the 14-digit hydrologic unit (HUC) in which the site is contained. Table B6 and B7 uses the following conventions:

- Values exceeding the median are displayed in *italics.*
- Values exceeding the 75$^{th}$ percentile are underlined.
- Values exceeding the 90$^{th}$ percentile are in bold.
- Values exceeding the 95$^{th}$ percentile are in bold and underlined.

This analysis indicates streams with biological impairment have significantly larger values of screening parameters than those streams with biological attainment. For biologically attaining

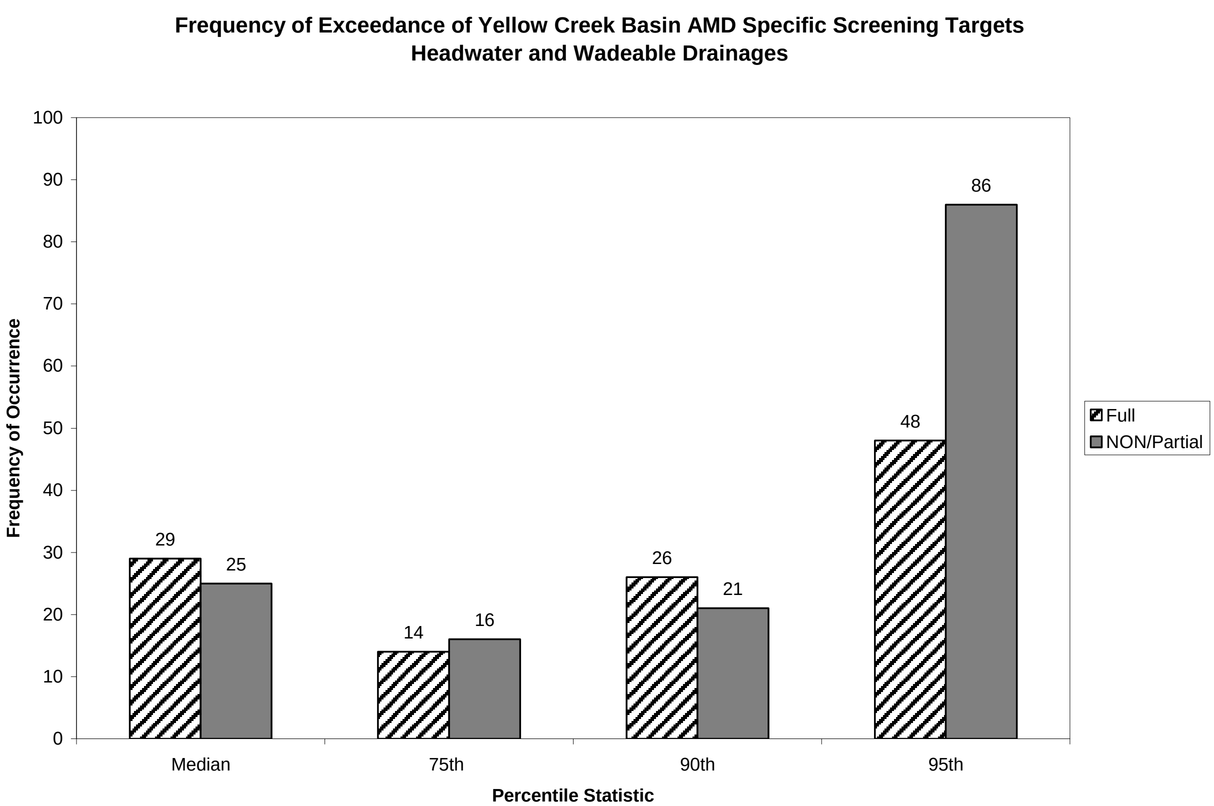


**Figure B1. Histogram of Yellow Creek basin specific AMD screening target parameters for Full and Non/Partial Biological Attainment Groups**

**Table B6. Yellow Creek biological attaining headwater stream screening of AMD water quality impact potential utilizing drainage specific statistics**

| Sampling Site | Parameter | Water Chemistry Results per Event | | | | |
|---|---|---|---|---|---|---|
| **Goose Creek** (H) | Acidity-CaCO3 (mg/L) | <5.0 | <5.0 | <5.0 | <5.0 | |
| RM 1.9, CWH, FULL | Alkalinity-CaCO3 (mg/L) | 121 | 133 | 134 | 129 | |
| QHEI 63.0 | Aluminum (µg/L) | 643 | 536 | <200 | 278 | |
| DA 2.5 $mi^2$ | Specific Conductance (µmhos/cm) | **959** | **1,050** | **1,070** | **1,090** | |
| HUC 05030101-180-010 | Total Dissolved Solids (mg/L) | **754** | **770** | **856** | **908** | |
| | Iron (µg/L) | **1,290** | **1,480** | *557* | *615* | |
| | Manganese (µg/L) | *148* | *236* | *176* | *219* | |
| | Sulfate (mg/L) | **504** | **494** | **517** | **517** | |
| **Hollow Rock Run** (H) | Acidity-CaCO3 (mg/L) | <5.0 | <5.0 | <5.0 | <5.0 | |
| RM 2.2, WWH existing - CWH recommended, FULL | Alkalinity-CaCO3 (mg/L) | 145 | 137 | 132 | 141 | |
| QHEI 48.5 | Aluminum (µg/L) | <200 | <200 | <200 | 205 | |
| DA 6.4 $mi^2$ | Specific Conductance (µmhos/cm) | **1,150** | **1,200** | **1,240** | **1,250** | |
| HUC 05030101-190-050 | Total Dissolved Solids (mg/L) | **924** | **946** | **998** | **994** | |
| | Iron (µg/L) | <50 | 114 | 291 | 302 | |
| | Manganese (µg/L) | 12 | 21 | 37 | 51 | |
| | Sulfate (mg/L) | **582** | **530** | **580** | **565** | |
| **Ralston Run** (H) | Acidity-CaCO3 (mg/L) | <5.0 | <5.0 | <5.0 | <5.0 | <5.0 |
| RM 0.3, EWH, Full | Alkalinity-CaCO3 (mg/L) | 120 | 124 | 114 | 111 | 143 |
| QHEI 71.5 | Aluminum (µg/L) | <200 | <200 | <200 | <200 | <200 |
| DA 5.6 $mi^2$ | Specific Conductance (µmhos/cm) | *409* | *414* | *376* | *374* | *462* |
| HUC 05030101-180-040 | Total Dissolved Solids (mg/L) | *258* | *240* | *236* | *238* | *308* |
| | Iron (µg/L) | 145 | 179 | 785 | 730 | 126 |
| | Manganese (µg/L) | 91 | 94 | 98 | 101 | 76 |
| | Sulfate (mg/L) | *93* | *91* | *87* | *87* | *102* |
| **Trail Run** (H) | Acidity-CaCO3 (mg/L) | <5.0 | <5.0 | <5.0 | <5.0 | |
| RM 0.3, EWH, Full | Alkalinity-CaCO3 (mg/L) | 162 | 168 | 156 | 164 | |
| QHEI 63.5 | Aluminum (µg/L) | 218 | <200 | 332 | <200 | |
| DA 3.3 $mi^2$ | Specific Conductance (µmhos/cm) | **841** | **877** | **822** | **909** | |
| HUC 05030101-180-020 | Total Dissolved Solids (mg/L) | **622** | **620** | **596** | **660** | |
| | Iron (µg/L) | 745 | *375* | **1,390** | *409* | |
| | Manganese (µg/L) | 408 | *275* | **527** | *239* | |
| | Sulfate (mg/L) | **332** | **319** | **289** | **333** | |
| **Wolf Run** (H) [AKA Wolf Creek in WQS] | Acidity-CaCO3 (mg/L) | <5.0 | <5.0 | <5.0 | <5.0 | <5.0 |
| RM 1.5, WWH, Full | Alkalinity-CaCO3 (mg/L) | **20** | **19** | **31** | **26** | **33** |
| QHEI 69.0 | Aluminum (µg/L) | 915 | 880 | <200 | **1,640** | <200 |
| DA 3.3 $mi^2$ | Specific Conductance (µmhos/cm) | **847** | **848** | **857** | **773** | **864** |
| HUC 05030101-180-010 | Total Dissolved Solids (mg/L) | **628** | **630** | **562** | **576** | **664** |
| | Iron (µg/L) | *311* | 288 | 66 | 742 | 73 |
| | Manganese (µg/L) | **1,970** | **1,900** | **1,140** | **1,490** | **930** |
| | Sulfate (mg/L) | **454** | **458** | **443** | **368** | **370** |
| **Yellow Creek** (H) | Acidity-CaCO3 (mg/L) | <5.0 | <5.0 | <5.0 | <5.0 | |
| RM 30.0, WWH, FULL | Alkalinity-CaCO3 (mg/L) | 106 | 126 | *90* | 153 | |
| QHEI 65.5 | Aluminum (µg/L) | *420* | <200 | **1,500** | <200 | |
| DA 14.4 $mi^2$ | Specific Conductance (µmhos/cm) | 424 | **529** | 401 | **765** | |
| HUC 05030101-180-010 | Total Dissolved Solids (mg/L) | *264* | *302* | *252* | 468 | |
| | Iron (µg/L) | **1,470** | **1,240** | **3,970** | **1,990** | |
| | Manganese (µg/L) | 304 | 413 | 480 | **1,000** | |
| | Sulfate (mg/L) | *82* | *112* | *86* | *154* | |

**Table B7. Yellow Creek biological impaired headwater and wadeable stream screening of AMD water quality impact potential utilizing drainage specific statistics**

| Sampling Site | Parameter | Water Chemistry Results per Event | | | | |
|---|---|---|---|---|---|---|
| **Alder Lick Run** (H) | Acidity-CaCO3 (mg/L) | <5.0 | <5.0 | <5.0 | <5.0 | |
| RM 0.2, WWH, Partial | Alkalinity-CaCO3 (mg/L) | 131 | 188 | 192 | 274 | |
| QHEI 69.0 | Aluminum (µg/L) | 238 | <200 | <200 | <200 | |
| DA 3.0 $mi^2$ | Specific Conductance (µmhos/cm) | 1,100 | 1,750 | 1,640 | 2,180 | |
| HUC 05030101-100-260 | Total Dissolved Solids (mg/L) | 826 | 1,570 | 1,390 | 2,050 | |
| | Iron (µg/L) | 817 | 545 | 447 | 304 | |
| | Manganese (µg/L) | 943 | 514 | 284 | 296 | |
| | Sulfate (mg/L) | 512 | 968 | 824 | 1,140 | |
| **Bailey Run** (H) | Acidity-CaCO3 (mg/L) | <5.0 | <5.0 | <5.0 | <5.0 | <5.0 |
| Chemistry RM 1.95, Biology RM 0.7, CWH, NON | Alkalinity-CaCO3 (mg/L) | 74 | 87 | 80 | 82 | 123 |
| QHEI 83.5 | Aluminum (µg/L) | <200 | <200 | <200 | <200 | <200 |
| DA 2.5 $mi^2$ | Specific Conductance (µmhos/cm) | 255 | 277 | 289 | 286 | 331 |
| HUC 05030101-100-260 | Total Dissolved Solids (mg/L) | 140 | 176 | 182 | 180 | 196 |
| | Iron (µg/L) | 2,940 | 3,590 | 3,200 | 3,480 | 4,320 |
| | Manganese (µg/L) | 5,300 | 4,960 | 2,980 | 3,080 | 5,530 |
| | Sulfate (mg/L) | 22 | 11 | 25 | 25 | 8 |
| **Brush Creek** (H) | Acidity-CaCO3 (mg/L) | <5.0 | <5.0 | <5.0 | <5.0 | |
| RM 6.0, EWH, Partial | Alkalinity-CaCO3 (mg/L) | 81 | 79 | 97 | 81 | |
| QHEI 89.5 | Aluminum (µg/L) | <200 | <200 | <200 | <200 | |
| DA 7.4 $mi^2$ | Specific Conductance (µmhos/cm) | 803 | 814 | 1,040 | 889 | |
| HUC 05030101-190-020 | Total Dissolved Solids (mg/L) | 536 | 520 | 686 | 580 | |
| | Iron (µg/L) | 2,030 | 1,660 | 2,180 | 904 | |
| | Manganese (µg/L) | 501 | 462 | 487 | 534 | |
| | Sulfate (mg/L) | 314 | 312 | 410 | 328 | |
| **Riley Run** (H) | Acidity-CaCO3 (mg/L) | <5.0 | <5.0 | <5.0 | <5.0 | |
| RM 4.8, WWH, NON | Alkalinity-CaCO3 (mg/L) | 140 | 106 | 180 | 186 | |
| QHEI 56.0 | Aluminum (µg/L) | <200 | 2,290 | <200 | <200 | |
| DA 3.6 $mi^2$ | Specific Conductance (µmhos/cm) | 858 | 450 | 976 | 1,020 | |
| HUC 05030101-190-030 | Total Dissolved Solids (mg/L) | 618 | 308 | 746 | 762 | |
| | Iron (µg/L) | 181 | 3,940 | 698 | 500 | |
| | Manganese (µg/L) | 274 | 182 | 1,410 | 1,340 | |
| | Sulfate (mg/L) | 314 | 132 | 364 | 428 | |
| **Salisbury Run** (H) | Acidity-CaCO3 (mg/L) | <5.0 | <5.0 | 88 | 125 | |
| RM 0.1, CWH, NON | Alkalinity-CaCO3 (mg/L) | 14 | 16 | 5 | 5 | |
| QHEI 56.0 | Aluminum (µg/L) | 4,740 | 1,150 | 3,280 | 4,810 | |
| DA 2.3 $mi^2$ | Specific Conductance (µmhos/cm) | 658 | 565 | 1,070 | 1,380 | |
| HUC 05030101-190-040 | Total Dissolved Solids (mg/L) | 476 | 396 | 786 | 898 | |
| | Iron (µg/L) | 21,100 | 16,400 | 43,500 | 40,200 | |
| | Manganese (µg/L) | 886 | 648 | 1,610 | 2,330 | |
| | Sulfate (mg/L) | 304 | 253 | 486 | 648 | |
| **Wells Run** (H) | Acidity-CaCO3 (mg/L) | <5.0 | 20 | <5.0 | 42 | |
| RM 0.3, CWH, NON | Alkalinity-CaCO3 (mg/L) | 14 | 5 | 7 | 5 | |
| QHEI 54.0 | Aluminum (µg/L) | 473 | 778 | 1,110 | 1,830 | |
| DA 2.2 $mi^2$ | Specific Conductance (µmhos/cm) | 476 | 724 | 766 | 1,090 | |
| HUC 05030101-100-260 | Total Dissolved Solids (mg/L) | 316 | 518 | 552 | 746 | |
| | Iron (µg/L) | 6,810 | 10,800 | 13,000 | 13,300 | |
| | Manganese (µg/L) | 796 | 1,510 | 1,750 | 2,660 | |
| | Sulfate (mg/L) | 199 | 334 | 345 | 490 | |
| **Yellow Creek** (W) | Acidity-CaCO3 (mg/L) | <5.0 | <5.0 | <5.0 | <5.0 | <5.0 |
| Chemistry RM 2.51, Biology RM 3.3, WWH, Partial | Alkalinity-CaCO3 (mg/L) | 61.0 | 91.4 | 94.8 | 107.0 | 88.4 |
| QHEI 63.0 | Aluminum (µg/L) | <200 | 225 | <200 | <200 | 205 |
| DA 224 $mi^2$ | Specific Conductance (µmhos/cm) | 264 | 530 | 559 | 509 | 573 |
| HUC 05030101-190-050 | Total Dissolved Solids (mg/L) | 204 | 184 | 362 | 326 | 380 |
| | Iron (µg/L) | 712 | 2,140 | 1,880 | 1,470 | 1,850 |
| | Manganese (µg/L) | 96 | 159 | 195 | 81 | 238 |
| | Sulfate (mg/L) | 73.1 | 146.0 | 147.0 | 127.0 | 162.0 |

streams, of 208 analytic values, 48 were greater then the 95$^{th}$ percentile and 91 were less than the median screening target. For biologically non or partially biological attaining sites, of 240 analytic values, 86 were greater than the 95$^{th}$ percentile and 92 were less than the median target. This indicates that almost twice as many of the Non/Partial as the attaining site samples exceeded the 95 percentile of the sample population. This observation suggests that a reasonable goal for abatement of the Non/Partial status is to reduce overall AMD signature concentrations of biologically impaired streams to those concentration values of the attaining streams.

**Numeric Water Quality Targets and Current Condition Reduction Percentages**

Numeric targets provide a means of comparison between observed and desirable instream water-quality conditions. The water-chemistry parameters used as indicator targets in this analysis are acidity, alkalinity, total dissolved solids, total aluminum, total iron, total manganese, and specific conductivity. Sulfate is not included in mitigation analysis because of its insignificant toxicity to biological organisms. TDS and specific conductivity were included because of their ability to be determined quickly by on-site analysis and ease of use as preliminary screening tools to assess progress toward AMD mitigation goals.

These water quality targets are developed specifically from the Yellow Creek basin by statistical analysis. These targets are utilized to determine reduction percentages for AMD to streams that are biologically impaired. Parameters utilized for reduction percentage targets were acidity, total aluminum, total iron, total manganese, specific conductivity, and total dissolved solids. Percent increase for alkalinity is also provided. The rationale for the use of these parameters and the method used to develop the numeric targets are described below.

The target parameters listed above were selected for three reasons. First, each is commonly associated with the previously-described signatures of AMD in receiving streams. Second, the method used to measure each parameter is a standardized, consistent analytical procedure with an acceptable range of error. Third, there is sufficient variation for each parameter in existing water-quality databases so that impacted (denoted as NON/Partial) and non-impacted (denoted as Full) sites can be distinguished.

Causes and sources of impairment indicate those streams that potentially either receive AMD or that are biologically impacted by AMD. Water quality chemistry data from each of these sites were compared to the USDA screening matrix for AMD streams. Table B1 presents the USDA standards for signature AMD parameters used for the Yellow Creek AMD analysis. Additional screening was completed by developing Yellow Creek drainage specific targets and completion of comparisons. For streams within the watershed that significantly exceed the basin specific values for AMD signature parameters, a paired watershed basin approach was completed by statistical data analysis.

To begin the analysis, two groups were developed for each basin size (headwater and wadeable). These groups were Full and Non/Partial biological attainment groups. For parameters that had nearly normal data sets, a two tailed two sample $t$ test was utilized to complete the analysis. This method is robust for data sets that are nearly normal, but not completely normal, with exception to significantly long tailed distributions (Ramsey & Schafer, 1997, p.58). Therefore this hypothesis test appeared to be appropriate for all data sets analyzed except acidity.

Other factors may be wrongfully declared the biological impairment factor when in fact lack of habitat has created this impairment. Therefore, to assure that habitat is not creating the observed

AMD impairments, another data analysis for each group was completed. The Qualitative Habitat Evaluation Index was analyzed with the two tailed two sample *t* test. For this test, a 5.0% significance with unpaired data and unequal variance was utilized. The null hypothesis is defined as no significant difference between the sample means. The results of the two sample *t* for the QHEI data are provided in Table AMD8. Statistical results indicate that the null hypothesis can not be rejected (*t* Probability = 0.5611>0.05).

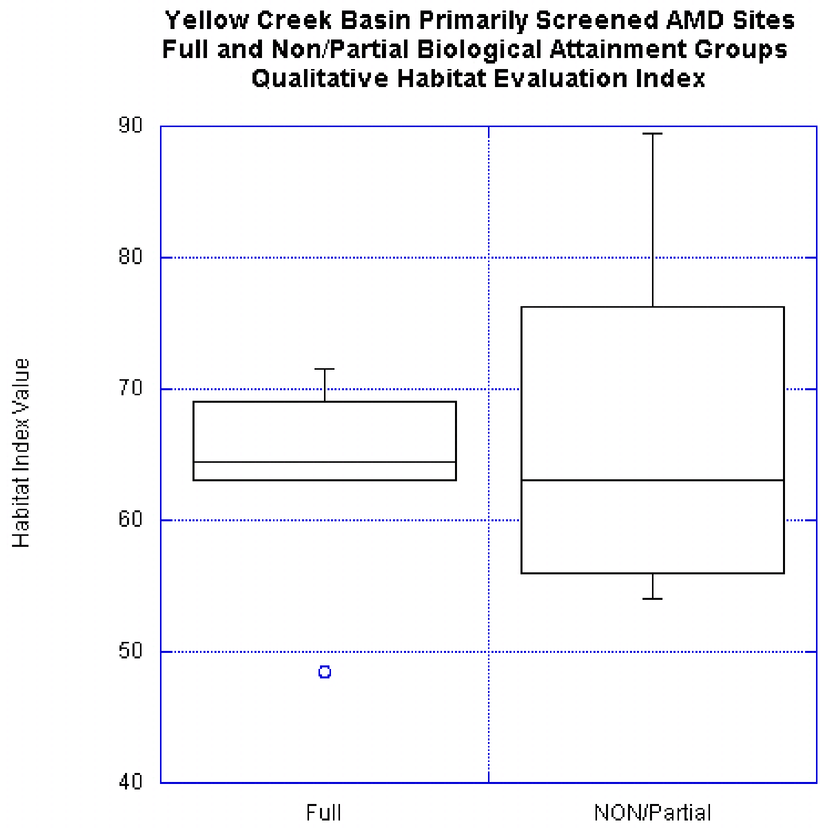


**Figure B2.** **Qualitative Habitat Evaluation Index values for Full and NON/Partial biological attainment of primarily screened AMD headwater and wadeable streams of the Yellow Creek basin**

**Table B8.** **Two sample Student *t* test for unpaired QHEI data with unequal variance**

| | Full | NON/Partial |
|---|---|---|
| Count | 6 | 7 |
| Mean | 63.5 | 67.2857 |
| Variance | 64.7 | 201.488 |
| Std. Dev. | 8.04363 | 14.1947 |
| Std. Err | 3.2838 | 5.36507 |
| Mean Difference | -3.78571 | |
| Degrees of Freedom | 9 | |
| *t* Value | -0.60184 | |
| *t* Probability | 0.5611 | |

Therefore, there is no significance difference between the sample means. This analysis indicates the habitat for Full and NON/Partial biological attainment primarily screened AMD streams are similar overall. Therefore, habitat is not the overlying cause of the difference for the two stream group attainments.

Headwater Streams

Data for statistical analysis was selected from headwater and wadeable streams which were determined to receive AMD drainage by the prescreening analysis discussed in the previous Drainage Specific AMD Targets section. Of these sampling sites, the data was separated for each chemical parameter and again split into two groups. These groupings were full biological attainment (Full) and biologically impaired. Impairment could be either non-attaining or partial attainment (NON/Partial).

Data from the paired watershed headwater sites for multiple parameters is presented in Figure B3. In this figure, the box plot follows the typical convention of the interquartile range being represented by the box (i.e. $25^{th}$ and $75^{th}$ percentile are the low and high box limits respectively). In addition, the mean is shown as a line within the box. The bars indicate limits of the extreme values that do not fall outside of the outlier test. Outliers are greater than or less than one and one half the interquartile range from the mean. These data values are represented as round circles. As can be seen in the figure, Acidity-Full and Non/Partial as well as Aluminum-Full have flat data sets. This is because of the numerous amounts of less than detectable limit values. These values are set at the detection limit of the analysis.

To determine if an individualized parameter mean concentration is significantly different between Full and Non/Partial data sets a two tailed two sample t test was completed for each parameter. For this test, a 5.0% significance with unpaired data and unequal variances was utilized. The null hypothesis was defined as no significant difference between the mean statistic of the Full and Non/Partial data sets. This analysis was completed for each chemical analyte separately. Results of the headwater parameters are presented in Table B8. The alternative hypothesis is proven true for aluminum, iron, specific conductivity, manganese, and total dissolved solids. Reduction of these parameter concentrations to the level at which Full biological attainment is obtained is proposed. The reduction percentage is calculated by dividing the mean difference by the goal mean. Results of these calculations for the true alternative hypothesis are provided in Table B9.

Acidity and aluminum for headwater drainages were comprised of significantly non-normal distributions. The student t test assumes the distribution is normal. Therefore, an alternative two sample test is needed for these two parameters. Wilcoxon Rank-Sum (Mann-Whitney) tests were utilized to analyze the equivalent mean hypothesis test for these non-normal distributions. The $p$ values were 0.00013 and 0.00035 for acidity and aluminum, respectively. Because both of these parameters $p$ values were less than the 0.05 significance, the null hypothesis can be rejected. The means of the Full and NON/Partial data sets are not equal for these parameters are not equal and reduction for acidity and aluminum is needed. Proposed reduction percentages can be found in Table AMD8.

Wadeable Sites

Because only one wadeable site was found to be in Non/Partial biological attainment from suspected AMD sources and none of the Full attainment sites were suspected of AMD impacts, the paired watershed approach was altered for this analysis. All Full attainment wadeable drainage site analytical data collected in the Yellow Creek survey was utilized for the paired watershed approach analysis. Although the Full attainment sites were not suspected of receiving significant AMD loading, many of these sites receive tributary drainage with potential AMD seeps. Therefore, this approach would be reasonable. Again, the 5% significance with unpaired data and unequal variances as well as the null hypothesis defined as no significant difference of the two data set means were utilized in the two tailed two sample t test. Box plots of multiple parameters for the wadeable sites are shown in Figure B4. Results of the hypothesis test can be observed in Table B9. The alternative hypothesis is true for alkalinity, iron, and manganese. Percent reductions for iron and manganese and percent increase for alkalinity were calculated by utilizing the Full attainment mean as the mitigation standard. Percent reduction and increase were again calculated by dividing the mean difference by the goal mean. Results of these calculations can also be observed in Table B9.

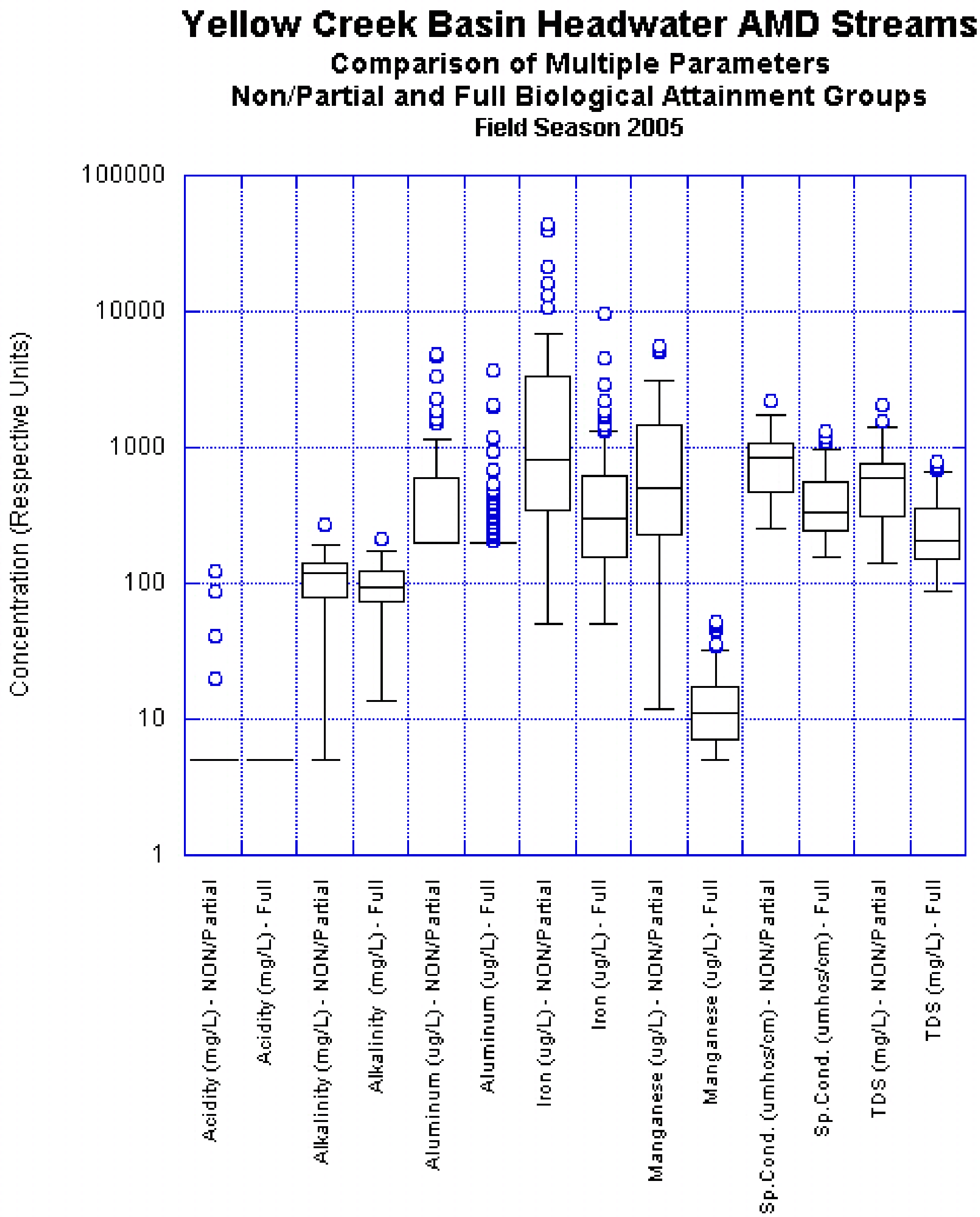


Figure B3. Headwater AMD stream multiple parameters for Non/Partial and Full biological attainment streams

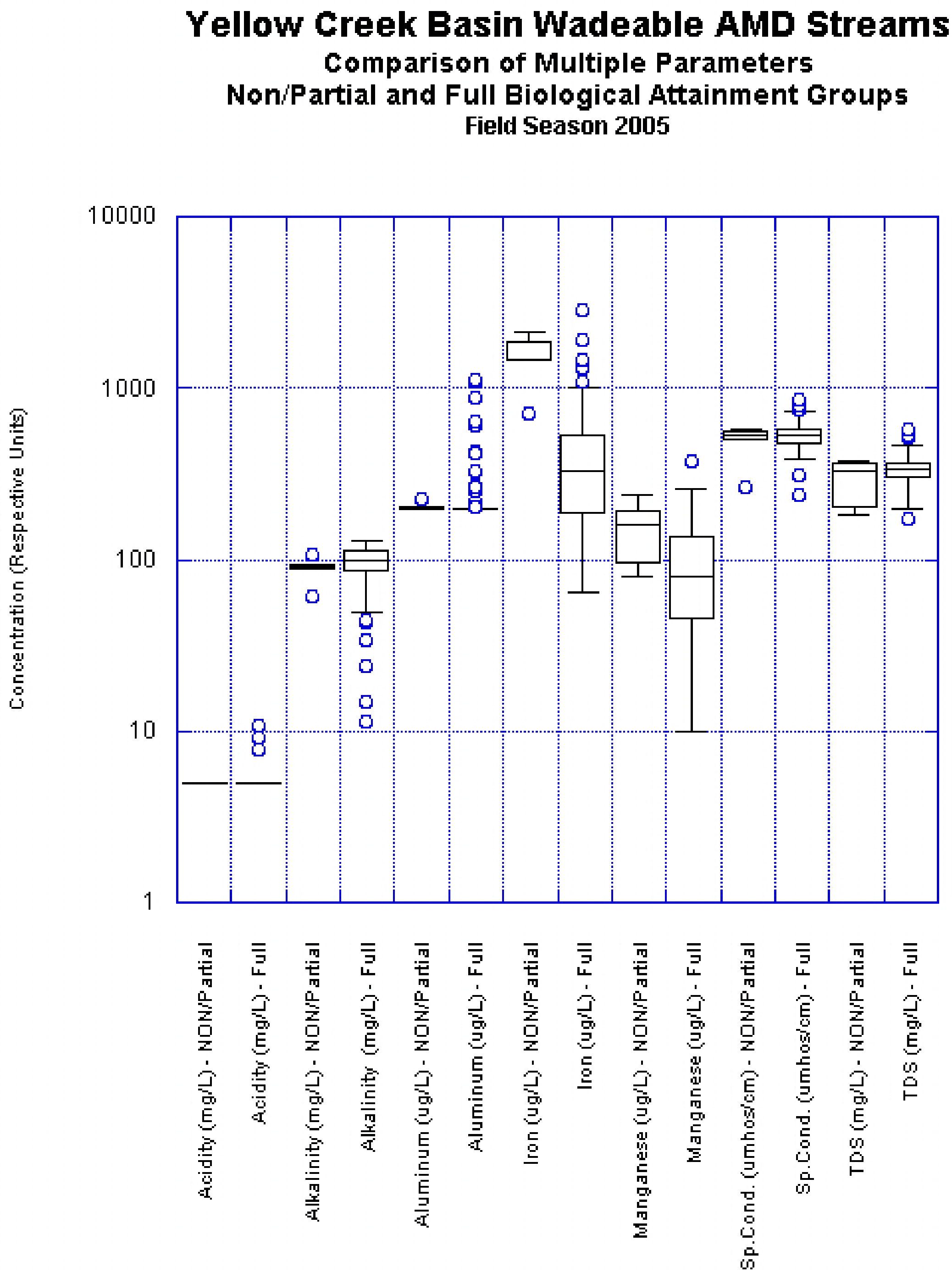


Figure B4. Wadeable AMD stream multiple parameters for Non/Partial and Full biological attainment streams

**Table B9.** Yellow Creek two tailed two sample t test for Non/Partial and Full biological attainment headwater streams that are AMD receiving waters ($H_o$ = no significant difference)*

| Statistic | Acidity as $CaCO_3$ (mg/L) | | Alkalinity as $CaCO_3$ (mg/L) | | Aluminum, Total (ug/L) | | Iron, Total (ug/L) | | Specific Conductivity (umhos/cm) | | Manganese, Total (ug/L) | | Total Dissolved Solids (mg/L) | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | NON/Partial | Full | NON/Partial | Full | NON/Partial | Full | NON/Partial | Full | NON/Partial | Full | NON/Partial | Full | NON/Partial | Full |
| Minimum | 5 | 5 | 5 | 13.8 | 200 | 200 | 50 | 50 | 255 | 154 | 12 | 5 | 140 | 86 |
| Maximum | 125 | 5 | 274 | 212 | 4810 | 3720 | 43500 | 9520 | 2180 | 1320 | 5530 | 53 | 2050 | 794 |
| Samples | 51 | 184 | 49 | 183 | 51 | 184 | 51 | 184 | 51 | 184 | 51 | 184 | 51 | 184 |
| Mean | 10.0 | 5.0 | 105.7 | 97.5 | 671.9 | 272.5 | 4246.6 | 540.9 | 833.1 | 432.6 | 1053.0 | 14.5 | 616.2 | 277.8 |
| Median | 5 | 5 | 120 | 92.3 | 200 | 200 | 817 | 298.5 | 847 | 335.5 | 501 | 11 | 596 | 208 |
| RMS | 22.8 | 5.0 | 121.2 | 103.9 | 1231.1 | 430.6 | 9758.7 | 1054.8 | 921.6 | 486.3 | 1681.9 | 17.2 | 715.7 | 319.9 |
| Std Deviation | 20.8 | 0.0 | 60.1 | 36.2 | 1041.9 | 334.2 | 8873.6 | 908.0 | 398.1 | 222.8 | 1324.5 | 9.3 | 367.5 | 159.1 |
| Variance | 430.7 | 0.0 | 3608.2 | 1308.9 | 1085561.3 | 111708.3 | 78741586.0 | 824462.3 | 158453.7 | 49654.9 | 1754355.2 | 86.4 | 135058.5 | 25302.1 |
| Std Error | 2.9 | 0.0 | 8.6 | 2.7 | 145.9 | 24.6 | 1242.6 | 66.9 | 55.7 | 16.4 | 185.5 | 0.7 | 51.5 | 11.7 |
| Mean Difference | 5.0 | | 8.2 | | 399.3 | | 3705.7 | | 400.5 | | 1038.6 | | 338.4 | |
| Degrees of Freedom | | | 230 | | | | 233 | | 233 | | 233 | | 233 | |
| *t* Value | | | 1.2067 | | | | 5.5906 | | 9.3675 | | 10.695 | | 9.6746 | |
| *t* Probability | p value = 0.00013 | | 0.2288 | | p value = 0.0003576 | | <0.0001 | | <0.0001 | | <0.0001 | | <0.0001 | |
| Percent reduction** | 100.0% | | 0.0% | | 146.5% | | 685.1% | | 92.6% | | 7186.7% | | 121.8% | |

* 5.0% significance
** denotes % increase needed for Alkalinity

**Table B10.** Yellow Creek two tailed two sample t test for AMD signature Non/Partial and all Full biological attainment wadeable streams ($H_o$ = no significant difference)*

| Statistic | Acidity as $CaCO_3$ (mg/L) | | Alkalinity as $CaCO_3$ (mg/L) | | Aluminum, Total (ug/L) | | Iron, Total (ug/L) | | Specific Conductivity (umhos/cm) | | Manganese, Total (ug/L) | | Total Dissolved Solids (mg/L) | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | NON/Partial | Full | NON/Partial | Full | NON/Partial | Full | NON/Partial | Full | NON/Partial | Full | NON/Partial | Full | NON/Partial | Full |
| Minimum | 5.0 | 5.0 | 61.0 | 11.5 | 200.0 | 200.0 | 712.0 | 64.0 | 81.0 | 10.0 | 264.0 | 242.0 | 184.0 | 172.0 |
| Maximum | 5.0 | 10.8 | 107.0 | 131.0 | 225.0 | 1110.0 | 2140.0 | 2840.0 | 238.0 | 380.0 | 573.0 | 860.0 | 380.0 | 584.0 |
| Samples | 5.0 | 66.0 | 5.0 | 66.0 | 5.0 | 66.0 | 5.0 | 66.0 | 5.0 | 66.0 | 5.0 | 66.0 | 5.0 | 66.0 |
| Mean | 5.0 | 5.2 | 88.5 | 93.4 | 206.0 | 269.5 | 1610.4 | 468.0 | 153.8 | 100.5 | 487.0 | 548.6 | 291.2 | 352.0 |
| Median | 5.0 | 5.0 | 91.4 | 98.8 | 200.0 | 200.0 | 1850.0 | 330.5 | 159.0 | 79.5 | 530.0 | 536.5 | 326.0 | 342.0 |
| RMS | 5.0 | 5.3 | 89.8 | 97.6 | 206.2 | 330.6 | 1685.5 | 656.1 | 164.8 | 122.8 | 500.1 | 559.8 | 302.4 | 361.8 |
| Std Deviation | 0.0 | 0.9 | 16.9 | 28.4 | 10.8 | 193.0 | 556.2 | 463.3 | 66.1 | 71.2 | 127.1 | 112.3 | 91.1 | 84.1 |
| Variance | 0.0 | 0.9 | 286.7 | 805.0 | 117.5 | 37252.0 | 309350.8 | 214642.8 | 4363.7 | 5074.0 | 16160.5 | 12611.0 | 8301.2 | 7071.6 |
| Std Error | 0.0 | 0.1 | 7.6 | 3.5 | 4.8 | 23.8 | 248.7 | 57.0 | 29.5 | 8.8 | 56.9 | 13.8 | 40.7 | 10.4 |
| Mean Difference | -0.192424 | | -4.8997 | | -63.5 | | 1142.4 | | -61.5909 | | 53.3455 | | -60.8 | |
| Degrees of Freedom | | | 69 | | | | 69 | | 69 | | 69 | | 69 | |
| *t* Value | | | -0.37946 | | | | 5.2493 | | -1.1729 | | 1.6211 | | -1.5509 | |
| *t* Probability | p value = 0.6518 | | 0.7055 | | p value = 0.6416 | | <0.0001 | | 0.2449 | | 0.1096 | | 0.1255 | |
| Percent reduction** | 0.0% | | 0.0% | | 0.0% | | 244.1% | | 0.0% | | 0.0% | | 0.0% | |

* 5.0% significance
** denotes % increase needed for Alkalinity

Acidity and aluminum for wadeable drainages were comprised of significantly non-normal distributions, just as the respective headwater drainage sets. Because of the non-normality, Wilcoxon Rank-Sum (Mann-Whitney) tests were utilized to analyze the equivalent mean hypothesis test for these non-normal distributions. The p values were 0.6518 and 0.6416 for acidity and aluminum, respectively. Because both of these parameters p values were greater than the 0.05 significance, the null hypothesis can be accepted. The means of the Full and NON/Partial data sets are equal for these parameters; therefore, reduction of these parameters in wadeable streams is not requested. Results of these tests can be observed in Table AMD9.