*State of Ohio*
*Environmental Protection Agency*

**Division of Surface Water**

# Biological and Water Quality Study of the Moxahala Creek Watershed

**Perry, Morgan, Muskingum and Licking Counties**

OEPA Report DSW/EAS 2009-4-2

**April 24, 2009**

Ted Strickland, Governor, State of Ohio
Chris Korleski, Director

# Biological and Water Quality Survey of the Moxahala Creek Watershed

# 2008

Perry, Morgan, Muskingum and Licking Counties, Ohio
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OEPA Report DSW/EAS 2009-4-2

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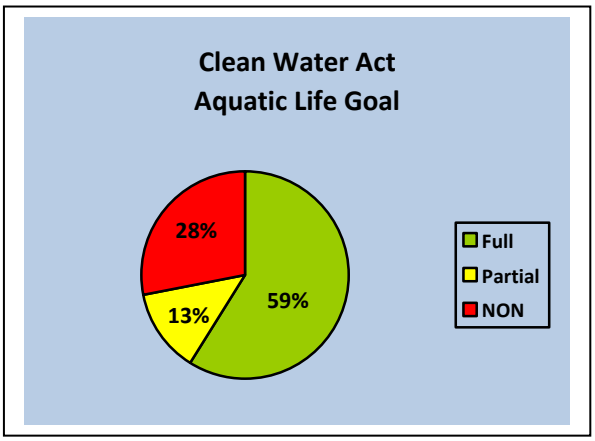


All rivers and streams in Ohio are used for various purposes such as recreation, water supply, or to support aquatic life. Ohio EPA evaluates each stream to determine the appropriate use designations and to also determine if the uses are meeting the goals of the federal Clean Water Act. Twenty-one streams in the Moxahala Creek watershed were evaluated for aquatic life and sixteen streams for recreational use potential in 2008 (see Figure 1 and Table 1 for sampling locations).

The Moxahala and Jonathan Creek mainstem (from Turkey Run to the mouth) were assigned the Limited Warmwater Habitat (LWH) aquatic life use designation based on a cursory evaluation in 1978. Based on the 2008 survey data, several streams in the Moxahala Creek watershed are recommended to be designated Limited Resource Water-Acid Mine Drainage (LRW-AMD) which include Moxahala Creek headwaters to Jonathan Creek, Andrews Run, Black Fork from RM 2.5 to mouth, Buckeye Fork, and Butcherknife Creek. Jonathan Creek from RM 22.4 to the mouth is recommended to be designated WWH changing the previous unverified EWH from headwaters to confluence of Turkey Run and improving the previous LWH use from Turkey Run to the mouth.

Based on the 2008 survey data, the recommended use designation for Ogg Creek from RM 1.4 to the mouth and a tributary to Moxahala Creek at RM 22.56 is Modified Warmwater Habitat (MWH) due to mining impacts. The Coldwater Habitat (CWH) use designation is recommended for the headwaters of Jonathan Creek to RM 22.4, the headwaters of Thompson Run to RM 0.4 and Salt Run. The Exceptional Warmwater Habitat (EWH) use designation was found to be appropriate for the following streams: Bowling Green Run and Valley Run. The EWH/CWH use designations are recommended for Hibbs Run. All other tributary streams evaluated in 2008 (11 waterbodies) will remain or are recommended WWH. All streams in this study should retain the Primary Contact Recreation use, along with the Agricultural and Industrial uses.

Overall, the Moxahala Creek watershed is mostly meeting the aquatic life goal of the Clean Water Act with 59% of the watershed fully attaining, 13% in partial attainment and 28% in non-attainment of the goal. Due to the extensive impacts from historic mining, none of the six sites on the Moxahala Creek mainstem are meeting the LRW-AMD aquatic life use designation. The biological community performance was mostly fair to very poor in the Moxahala subwatershed. In contrast, seven of the eight sites on the Jonathan Creek mainstem were meeting the WWH aquatic life use designation. The majority of the sites in the Jonathan Creek subwatershed had a biological community performance of good to excellent.

The 13 non-attainment sites were affected by acid mine drainage (AMD). Numerous metals, low pH, high total dissolved solids (TDS) and high acidity caused toxicity to the aquatic life. Partial attainment was found at several sites and was most likely due to low flow conditions, impounded habitat, non-point source (NPS) runoff from farm fields and AMD. While many of the streams in the Moxahala Creek watershed are meeting the goals of the Clean Water Act, abandoned mine land poses the greatest threat to the biological communities.

The recreational use goal of the Clean Water Act was met at 27.5% of the sites in the Moxahala Creek basin and was in non-attainment at 72.5% of the sites. Bacteria are most likely present in high numbers throughout the watershed because there are very few centralized waste water treatment systems. Elevated bacteria may also be associated with agricultural activities such as livestock with direct access to the creeks. Elevated bacteria were also found near the mouth of Moxahala Creek from sanitary sewer releases from South Zanesville.

*Table 1. Moxahala Creek watershed sampling locations from the 2008 survey.*

| Site Number* | **Stream /** Location | River Mile | Drainage Area | Latitude | Longitude |
|---|---|---|---|---|---|
| 1 | **Moxahala Creek** at Twp Rd 312 | 24.0 | 9 | 39.676990 | -82.120260 |
| 2 | **Moxahala Creek** at SR 13,37,93 | 21.8 | 23.3 | 39.703800 | -82.115000 |
| 3 | **Moxahala Creek** at Athens Road | 13.4 | 75 | 39.791029 | -82.081829 |
| 4 | **Moxahala Creek** at Lambert Road | 6.8 | 98 | 39.854881 | -82.056261 |
| 5 | **Moxahala Creek** at Moxadarla Road | 4.3 | 196 | 39.881784 | -82.037033 |
| 6 | **Moxahala Creek** at Pearl Park Adj. Grantcliff Ave | 0.6 | 302 | 39.895717 | -82.005942 |
| 7 | **Andrews Run** at SR 13 | 0.3 | 2.4 | 39.668666 | -82.134282 |
| 8 | **Black Fork** Adj. Tatmans Road | 3.2 | 9 | 39.719502 | -82.073491 |
| 9 | **Black Fork** Dst. Ogg Creek, dst. Seep (TR 747) | 2.5 | 23 | 39.730547 | -82.071070 |
| 10 | **Black Fork** at SR 669 downstream Ogg Creek | 1.9 | 24.4 | 39.737822 | -82.074749 |
| 11 | **Black Fork** at Ceramic Road & TR 1001 | 0.1 | 28.7 | 39.755539 | -82.087416 |
| 12 | **Ogg Creek** at SR 555 | 2.1 | 6.1 | 39.725424 | -82.035694 |
| 13 | **Ogg Creek** at Whitehouse Road near mouth | 0.2 | 13.3 | 39.727385 | -82.066766 |
| 14 | **Trib to Moxahala Cr.** @RM 22.56 at SR 13 | 0.1 | 0.42 | 39.692900 | -82.116600 |
| 15 | **Shawnee Run** at Milldale Road/Greenhouse Road | 0.1 | 2.7 | 39.894700 | -82.116600 |
| 16 | **Jonathan Creek** at SR 204 | 27.1 | 7.4 | 39.900300 | -82.388000 |
| 17 | **Jonathan Creek** at Hopewell Indian Road | 22.3 | 27.4 | 39.909061 | -82.327992 |
| 18 | **Jonathan Creek** off SR 204 dst Glass Rock trib | 17.4 | 70 | 39.874690 | -82.284870 |
| 19 | **Jonathan Creek** at CR 34 - Coopermill Road | 12.3 | 103 | 39.879696 | -82.216054 |
| 20 | **Jonathan Creek** at Workman Road | 7.6 | 125 | 39.866830 | -82.150790 |
| 21 | **Jonathan Creek** at Crock Road | 3.3 | 150 | 39.870560 | -82.096496 |
| 22 | **Jonathan Creek** at SR 93 | 1.1 | 193 | 39.877714 | -82.063159 |
| 23 | **Jonathan Creek** at Powell Road | 0.9 | 193 | 39.877106 | -82.060002 |
| 24 | **Bowling Green Run** at Boundaries Road | 0.1 | 11.1 | 39.918774 | -82.348878 |
| 25 | **Valley Run** at Laurel Hill Road | 5.4 | 9.7 | 39.928532 | -82.247689 |
| 26 | **Valley Run** at TR 333 - Cherry Hill Road | 3.5 | 17.3 | 39.925436 | -82.271608 |
| 27 | **Valley Run** at Hopewell Indian Road | 1.3 | 28.8 | 39.909978 | -82.301725 |
| 28 | **Trib to Jonathan Cr.** @RM 19.47 at TR 19 | 0.7 | 6 | 39.876870 | -82.323020 |
| 29 | **Trib to Jonathan Cr.** @ RM 17.55 Dst Oglebay Norton - TR92A | 0.1 | 0.9 | 39.877170 | -82.286450 |
| 30 | **Painter Creek** at TR 76 | 2.5 | 7.4 | 39.846629 | -82.277416 |
| 31 | **Painter Creek** at Cooperrider Road | 0.9 | 17.8 | 39.863750 | -82.282910 |
| 32 | **Trib to Jonathan Cr.** @ RM 13.74 at Snook Rd Dst. Suburban Landfill | 0.3 | 1.3 | 39.891288 | -82.237349 |
| 33 | **Turkey Run** at TR 49 (upper crossing) | 2.9 | 8.4 | 39.835013 | -82.206113 |
| 34 | **Turkey Run** at RR bridge near mouth | 0.3 | 14.2 | 39.867421 | -82.202818 |
| 35 | **Buckeye Fork** at Old Rainer Road | 4.9 | 8.1 | 39.799848 | -82.138888 |
| 36 | **Buckeye Fork** at Fletcher Road | 3.4 | 16.7 | 39.826608 | -82.138109 |
| 37 | **Buckeye Fork** at Hoover-Fultonrose Road (CR88) | 1.2 | 22.6 | 39.849416 | -82.124392 |
| 38 | **Butcherknife Creek** at SR 345 | 0.1 | 6.8 | 39.822099 | -82.138797 |
| 39 | **Kent Run** at Asbury Chapel Road | 8.9 | 9.8 | 39.930954 | -82.187366 |
| 40 | **Kent Run** at Slack Road | 3.7 | 15.1 | 39.896987 | -82.134084 |
| 41 | **Kent Run** at Lower Kroft Road Maysville WTP intake | 1.3 | 22.6 | 39.874620 | -82.116335 |
| 42 | **Thompson Creek** at Coppermill Road | 4.7 | 9.3 | 39.912220 | -82.086500 |
| 43 | **Thompson Creek** at US 22 | 0.4 | 15.3 | 39.882240 | -82.069150 |

*Table 1. Continued.*

| Site Number* | **Stream /** Location | River Mile | Drainage Area | Latitude | Longitude |
|---|---|---|---|---|---|
| 44 | **Hibbs Run** at Coopermill Road | 0.1 | 0.055 | 39.922800 | -82.091700 |
| 45 | **Salt Run** at Bagley Road | 0.1 | 18.1 | 39.882900 | -82.129100 |
| 46 | **Bush Creek** at SR 345 | 0.1 | 0.65 | 39.831400 | -82.136400 |
| 47 | **Painter Run** at Coopermill Road | 0.1 | 4.73 | 39.882100 | -82.215600 |

***The color of the site number corresponds to the narrative biological score (blue is exceptional to very good (meets EWH goals), green is good to marginally good (meets WWH goals), yellow is fair, orange is poor, and red is very poor (fair, poor, and very poor do not meet the goals of WWH).**

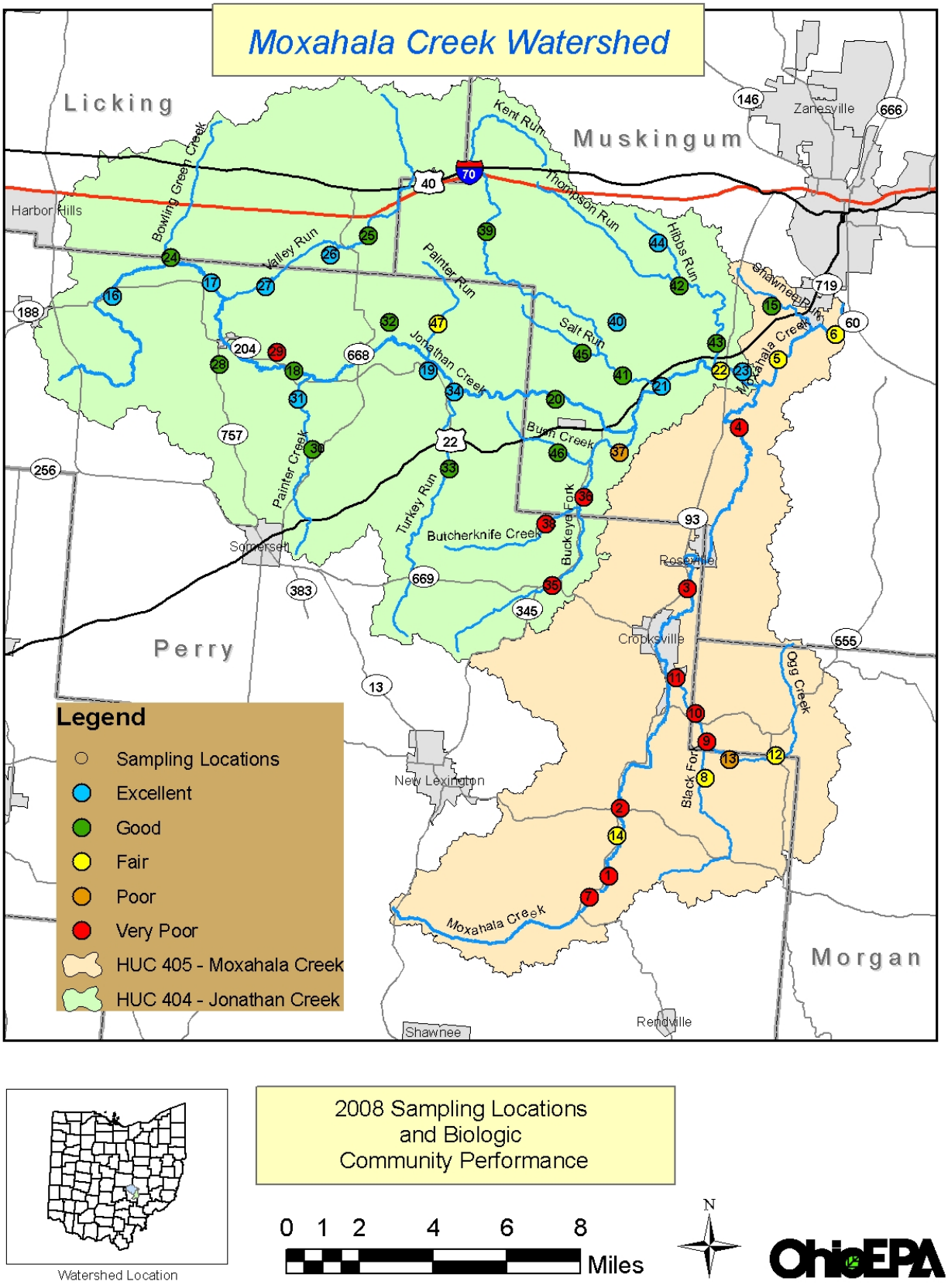


*Figure 1. Moxahala Creek sampling locations and biological community performance. Site numbers correspond to Table 1.*

*Table 2. Aquatic life use attainment status for sampling locations in the Moxahala Creek watershed, 2008. The Index of Biotic Integrity (IBI), Modified Index of Well-being (MIwb), and Invertebrate Community Index (ICI) scores are based on the performance of the biological community. Stream habitat reflects the ability to support a biological community. The Moxahala Creek watershed is located in the Western Alleghany Plateau (WAP) and Erie Ontario Lake Plain (EOLP) ecoregions. If biological impairment has occurred, the cause(s) and source(s) of the impairment are noted. NA = not applicable. For the Aquatic Life Use Designation, R denotes a recommendation that differs from the current use designation.*

| Stream | Sample Location River Mile | Sampling Type | Ecoregion | Aquatic Life Use Designation | Aquatic Life Attainment Status | IBI | MIwb | ICI[a] | Stream Habitat[b] | Aquatic Life Use Impairment Cause/Source |
|---|---|---|---|---|---|---|---|---|---|---|
| Moxahala Creek | 24.0 | Wading | WAP | LRW-AMD | **NON** | 12* | NA | VP* | Good | Acidity, pH, Sulfate, Fe, Al, Mn, Ni / AMD |
| Moxahala Creek | 21.8 | Wading | WAP | LRW-AMD | **NON** | 12* | 0.0* | VP* | Good | Acidity, pH, Sulfate, Fe, Al, Mn, Ni / AMD |
| Moxahala Creek | 13.4 | Wading | WAP | LRW-AMD | **NON** | 14* | 0.6* | 0* | Fair | Acidity, pH, Sulfate, Fe, Al, Mn, Ni / AMD |
| Moxahala Creek | 6.8 | Wading | WAP | LRW-AMD | **NON** | 12* | 0.0* | LF | Good | Acidity, pH, Sulfate, Fe, Al, Mn, Ni / AMD |
| Moxahala Creek | 4.3 | Wading | WAP | WWH | **NON** | 25* | 5.9* | HF* | Excellent | Nickel, Manganese, Aluminum/ AMD |
| Moxahala Creek | 0.6 | Boat | WAP | WWH | Partial | 29* | 7.9* | VG | Good | Mn, Al, Ammonia/ AMD, SSOs |
| Black Fork | 3.2 | Wading | WAP | WWH | Partial | 34* | NA | G | Good | Low D.O./Rural (home septic) |
| Black Fork | 2.5 | Wading | WAP | LRW-AMD | **NON** | 12* | 0.0* | 10 | Good | Fe, Mn, Sulfate, Al, Acidity/AMD |
| Black Fork | 1.9 | Wading | WAP | LRW-AMD | **NON** | 12* | 0.0* | 0* | Good | Fe, Mn, Sulfate, Al, Acidity/AMD |
| Black Fork | 0.1 | Wading | WAP | LRW-AMD | **NON** | 24 | 0.9* | VP* | Good | Fe, Mn, Sulfate, Al, Acidity/AMD |
| Ogg Creek | 2.1 | Wading | WAP | WWH | Partial | 36* | NA | VG | Good | NH3,Nitrate+Nitrite/Rural (home septic) |
| Ogg Creek | 0.2 | Wading | WAP | MWH-MD-R | **NON** | 20* | NA | LF* | Excellent | Fe, Sulfate, Al /AMD |
| Andrews Run | 0.3 | Headwater | WAP | LRW-AMD | **NON** | 20 | NA | VP* | Fair | Fe, Mn, Ni,Sulfate, Al, Acidity/AMD |
| Trib. To Moxahala @RM 22.56 | 0.1 | Wading | WAP | MWH-MD-R | Partial | 26 | NA | HF* | Fair | Fe, Mn, Ni,Sulfate, Al, Acidity/AMD |
| Shawnee Run | 0.1 | Wading | WAP | WWH-R | FULL | 44 | NA | MG | Fair | |
| Jonathan Creek | 27.1 | Wading | EOLP | CWH-R | FULL | 48 | NA | VG | Fair | |
| Jonathan Creek | 22.3 | Wading | EOLP | WWH-R | FULL | 52 | 10.4 | 42 | Fair | |
| Jonathan Creek | 17.4 | Wading | EOLP | WWH-R | FULL | 37[ns] | 9.5 | VG | Good | |
| Jonathan Creek | 12.3 | Wading | EOLP | WWH-R | FULL | 44 | 9.6 | 46 | Good | |
| Jonathan Creek | 7.6 | Wading | WAP | WWH-R | FULL | 43 | 9.2 | 40 | Excellent | |
| Jonathan Creek | 3.3 | Wading | WAP | WWH-R | FULL | 51 | 10.0 | 38 | Excellent | |
| Jonathan Creek | 1.1 | Wading | WAP | WWH-R | Partial | 44 | 6.9* | 32[ns] | Good | Direct habitat alterations/ dam |
| Jonathan Creek | 0.9 | Wading | WAP | WWH-R | FULL | 46 | 9.8 | VG | Excellent | |
| Bowling Green Run | 0.1 | Headwater | EOLP | WWH-R | FULL | 52 | NA | G | Good | |
| Valley Run | 5.4 | Headwater | EOLP | EWH | Partial | 50 | NA | G* | Good | Low D.O/NPS runoff, Rural (home septic) |
| Valley Run | 3.5 | Headwater | EOLP | EWH | FULL | 56 | NA | VG | Good | |

*Table 2. Continued.*

| Stream | Sample Location River Mile | Sampling Type | Ecoregion | Aquatic Life Use Designation | Aquatic Life Attainment Status | IBI | MIwb | ICI[a] | Stream[b] Habitat | Aquatic Life Use Impairment Cause/Source |
|---|---|---|---|---|---|---|---|---|---|---|
| Valley Run | 1.3 | Wading | EOLP | EWH | FULL | 52 | 10.2 | 46 | Excellent | |
| Trib. to Jonathan @RM 19.47 | 0.7 | Headwater | EOLP | WWH-R | FULL | 42 | NA | G | Fair | |
| Trib. to Jonathan @RM 13.74 | 0.3 | Headwater | EOLP | WWH-R | -- | NA | NA | G | NA | |
| Painter Creek | 2.5 | Headwater | EOLP | WWH-R | FULL | 48 | NA | G | Fair | |
| Painter Creek | 0.9 | Headwater | EOLP | WWH-R | FULL | 46 | NA | 48 | Good | |
| Turkey Run | 2.9 | Headwater | EOLP | WWH | FULL | 40 | NA | G | Excellent | |
| Turkey Run | 0.3 | Headwater | EOLP | WWH | FULL | 48 | NA | VG | Good | |
| Buckeye Fork | 4.9 | Headwater | WAP | LRW-AMD | **NON** | 12* | NA | VP* | Good | Mn, Ni,Sulfate, Al, Acidity/AMD |
| Buckeye Fork | 3.4 | Headwater | WAP | LRW-AMD | **NON** | 12* | NA | P | Fair | Mn, Ni,Sulfate, Al, Acidity/AMD |
| Buckeye Fork | 1.2 | Wading | WAP | LRW-AMD | FULL | 28 | 4.6 | 22 | Good | |
| Butcherknife Creek | 0.1 | Wading | WAP | LRW-AMD | **NON** | 12* | NA | LF | Good | Mn, Ni,Sulfate, Al, Acidity /AMD |
| Kent Run | 8.9 | Headwater | EOLP | WWH | FULL | 38[ns] | NA | VG | Good | |
| Kent Run | 3.7 | Wading | WAP | WWH | FULL | 54 | NA | VG | Excellent | |
| Kent Run | 1.3 | Wading | WAP | WWH | FULL | 40[ns] | 8.5 | E | Excellent | |
| Thompson Run | 4.7 | Headwater | WAP | CWH-R | FULL | 42[ns] | NA | G | Good | |
| Thompson Run | 0.4 | Headwater | WAP | WWH | FULL | 44 | NA | G | Good | |
| Hibbs Run | 0.1 | Wading | WAP | EWH/CWH-R | FULL | 50 | NA | VG[ns] | Excellent | |
| Salt Run | 0.1 | Wading | WAP | CWH-R | FULL | 46 | NA | G | Excellent | |
| Bush Creek | 0.1 | Wading | WAP | WWH | FULL | 40[ns] | NA | MG[ns] | Poor | |
| Painter Run | 0.1 | Wading | WAP | MWH-R | FULL | 38 | NA | F | Fair | |

| BIOCRITERIA | | | | | |
|---|---|---|---|---|---|
| Ecoregion | WAP | EOLP | Statewide | | |
| INDEX - Site Type | WWH | WWH | EWH | LRW[c] | MWH-MD |
| **IBI**: Headwater/Wade/Boat | 44/44/40 | 40/38/4 | 50/50/4 | 18/18/16 | 24 |
| **MIwb**: Wading/Boat | 8.4/8.6 | 7.9/8.7 | 9.4/9.6 | 4.5/5.0 | 5.5 |
| **ICI** | 36 | 34 | 46 | 8/poor | 30 |

[ns] Nonsignificant departure from biocriterion (≤4 IBI or ICI units; ≤0.5 MIwb units).
* Significant departure from biocriterion (>4 IBI or ICI units; >0.5 MIwb units). Poor and very poor results are underlined.
[a] Narrative evaluation used in lieu of ICI (E=Exceptional; VG=Very Good; G=Good; MG=Marginally Good; LF= Low Fair; HF= High Fair; P=Poor; VP=Very Poor).
[b] Narrative habitat evaluations are based on QHEI scores as follows: Excellent =75-100, Good = 60-74, Fair = 44-59, Poor = 30-43 and Very Poor <30
[c] LRW values are benchmarks, not codified biocriteria.

## INTRODUCTION

Moxahala Creek is located in Licking, Morgan and Muskingum counties (Figure 2) and has a drainage area of 302 square miles. Jonathan Creek (a major tributary to Moxahala Creek) drains 194 square miles. Moxahala Creek is a direct tributary of the Muskingum River entering just south of the City of Zanesville. There are twelve facilities (municipal or industrial) with National Pollutant Discharge Elimination System (NPDES) permits. Moxahala Creek has a watershed group that is addressing the acid mine drainage issues that are prevalent within Moxahala Creek proper.

*Figure 2. Moxahala Creek study area.*

During 2008, Ohio EPA conducted a water resource assessment of Moxahala Creek as well as numerous tributaries to Moxahala Creek and Jonathan Creek using standard Ohio EPA protocols as described in Appendix Table 13. Included in this study are assessments of the biological, surface water, sediment, and recreational (bacterial) condition. A total of 46 biological, 40 water chemistry, 43 bacterial, and 9 sediment stations were sampled in the Moxahala Creek basin.

Specific objectives of the evaluation were to:

- establish the present biological conditions in the Moxahala Creek basin by evaluating fish and macroinvertebrate communities,
- assess physical habitat influences on stream biotic integrity, identify the relative levels of organic, inorganic, and nutrient parameters in the sediments and surface water, and determine recreational water quality, and
- compare present results with historical conditions, determine the attainment status of the aquatic life use designations, and recommend use changes where appropriate.

The Moxahala Creek basin is located in the Erie-Ontario Lake Plain (EOLP) and Western Allegheny Plateau (WAP) ecoregions and many of the streams are currently assigned the Limited Warmwater Habitat (LWH) aquatic life use designation in the Ohio Water Quality Standards (WQS) based on a desktop review, as well as the Primary Contact Recreation (PCR), Agricultural Water Supply (AWS) and Industrial Water Supply (IWS) uses.

The findings of this evaluation may factor into regulatory actions taken by the Ohio EPA (e.g. NPDES permits, Director's Orders, or the Ohio Water Quality Standards (OAC 3745-1), and may eventually be incorporated into State Water Quality Management Plans, the Ohio Nonpoint Source Assessment, Total Maximum Daily Loads (TMDLs) and the biennial Integrated Water Quality Monitoring and Assessment Report (305[b] and 303[d] report).

# RESULTS

## Water Chemistry

Surface water chemistry samples were collected five times from the Moxahala Creek watershed at 40 locations (Figure 1, Table 1) between June 24 and September 24, 2008. Monthly grab samples were collected at three sentinel stations within the watershed from February 11, 2008 through January 14, 2009. Stations were established in free-flowing sections of the stream and were primarily collected from bridge crossings. Surface water samples were collected directly into appropriate containers, preserved and delivered to Ohio EPA's Environmental Services laboratory. Collected water was preserved using appropriate methods, as outlined in Part II and Part III of the Manual of Ohio EPA Surveillance Methods and Quality Assurance Practices (Ohio EPA 2006d).

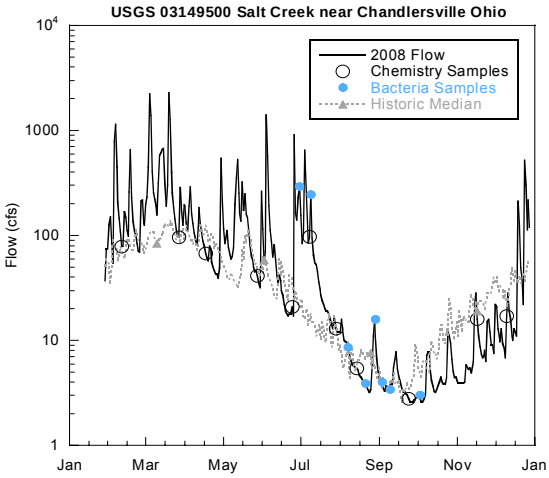


**Figure 3. Flow conditions in Salt Creek (Muskingum River) furring 2008. Samples were collected in Moxahala and Jonathan Creek.**

The Moxahala Creek watershed does not have a United States Geological Survey (USGS) gage station, therefore the USGS gage data from Salt Creek (Muskingum River) near Chandlersville were used to show flow trends in the Moxahala Creek watershed in 2008 (Figure 3.) Dates when water samples and bacteria samples were collected in the study area are noted on the graph. Flow conditions during the summer field season started out above the historic median and ended below the historic median at the end of the field season. Both water and bacteria samples captured a variety of flow conditions in the Moxahala Creek watershed during the field season.

Surface water samples were analyzed for metals, nutrients, bacteria, pH, temperature, conductivity, dissolved oxygen, percent saturation, suspended and dissolved solids, semivolatile organic compounds and organochlorinated pesticides (Appendix Tables 1 - 3). Parameters which were in exceedance of the Ohio WQS criteria are reported in Table 3. Bacteriological samples were collected from 40 locations, and the results are reported in the Recreation Use section.

Organic chemical analyses were conducted on water samples collected from 9 locations (Appendix Table 2). Aside from the herbicides acetochlor, atrazine and bis(2-Ethylhexyl)phthalate, all other organic chemicals were reported as not detected. All of the detected herbicides were below the Ohio WQS criteria.

**Metals**

Numerous metals were detected in Moxahala Creek watershed and in Buckeye Fork. Pre-law coal mining in the region is the cause of these metal exceedances.

Metals were measured at 40 locations with 17 parameters tested (Appendix Table 1). Areas throughout the Moxahala sub-watershed and within Buckeye Fork in the Jonathan Creek sub-watershed were mined for coal before reclamation laws were instituted. Prior to 1977, coal mining companies did not have to return the ground to its original grade, but instead left large piles of coal waste (gob), highwalls, mine pits of toxic water and underground mine discharges to surface waters. These remaining mining wastes and discharges contribute large amounts of acid mine drainage (AMD) which is comprised of high acidity, iron, aluminum, manganese, nickel, zinc, total dissolved solids, and low pHs.

Zinc and nickel in Butcherknife Creek, Buckeye Fork and Andrews Run (Table 3) violated the Ohio WQS aquatic life outside mixing zone average and the total dissolved solid results violated the WQS of 1500 mg/l. Iron values throughout the Moxahala watershed exceeded the water quality criterion for the protection of agricultural uses. Numerous locations had iron, manganese, nickel, conductivity, sodium, sulfate and aluminum with many exceedances of reference conditions ($90^{th}$ percentile level) for the Western Allegheny Plateau ecoregion.

Acidity and alkalinity target values were developed as surrogate modeling TMDL parameters in the 2005 Sunday Creek TMDL (Ohio EPA 2005). The Sunday Creek TMDL target values were chosen for the

Moxahala Creek AMDAT (Ohio University 2005) since the Sunday Creek watershed is a neighboring watershed to the south and has similar coal mining issues. A relationship between acidity and pH was established and an acidity target value of -67 mg/l was determined to achieve the minimum pH WQS criterion of 6.5 standard units (S.U.). A negative 67 mg/l of acidity translates to a net alkalinity of 67 mg/l. Both alkalinity and acidity were consistently outside of the developed target values throughout the coal mined areas of the Moxahala Creek watershed. Moxahala Creek (upstream from Jonathan Creek), Butcherknife Creek, Buckeye Fork and Andrews Run all had numerous pH violations ranging from 2.7 S.U. to 5.82 S.U.

Jonathan Creek had a positive water quality influence on Moxahala Creek adding a significant amount of alkalinity to Moxahala Creek. The pH in Moxahala Creek was consistently within the range of the WQS criteria (6.5 to 9.0 S.U.) below the confluence of Jonathan Creek (see Figure 4). Similarly, Shelly Materials, Inc. East Fultonham Limestone Quarry discharges highly alkaline water to Buckeye Fork. As a result, the acidity of Buckeye Fork was neutralized which resulted in precipitation of metals and an increase in pH within the range of the WQS criterion. Because of the neutralization of the acidity, Buckeye Fork did not have a negative impact to Jonathan Creek.

Aluminum sample results throughout the Moxahala Creek and Buckeye Fork watersheds were over the US EPA target values for chronic (continuous) concentrations and acute (maximum) concentrations (Table 4). Aluminum is not toxic to aquatic organisms in a neutral pH environment. However, in a highly acidic (high acidity) environment, aluminum is toxic to aquatic organisms at levels as low as 87 µg/l (US EPA 1995). Alkalinity in the form of $CaCO_3$ is displaced on the gills of fish by aluminum ions ($Al^{+3}$) which causes osmoregulatory loss of important blood ions leading to a toxic effect (USGS 2006). Only four species of fish and a total of 5 individuals were found in Moxahala Creek upstream from the Jonathan Creek confluence. Immediately downstream from the Jonathan Creek confluence, 80 fish were found with a total of 19 different species. Buckeye Fork had 4 green sunfish at RM 3.5 and no fish were found further upstream.

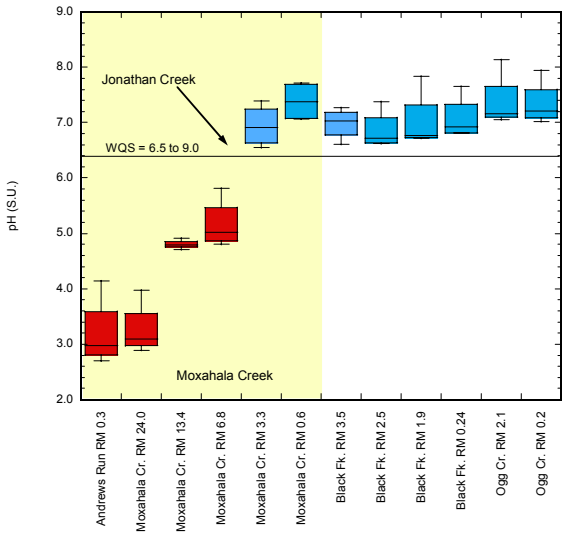


**Figure 4. Moxahala Creek subwatershed pH values collected during the 2008 field season showing the positive effect of Jonathon Creek upon entering Moxahala Creek.**

The Jonathan Creek watershed had five tributaries with metals WQS criteria exceedances. Valley Run at RM 3.5 exceeded the copper criterion and Turkey Run at RM 0.25 exceeded the lead criterion. The Turkey Run site is at an old railroad trestle which may be the cause of the exceedance. Bowling Green Run and an unnamed tributary to Jonathan Creek at RM 13.74 (Snook Road) had mercury criterion exceedances. The source of the mercury may be from Suburban Landfill which has a permitted discharge upstream. Buckeye Fork at RM 1.42 exceeded the selenium WQS, and could be associated with the limestone mine discharge upstream.

No WQS criterion exceedances were found in the mainstem of Jonathan Creek. The Jonathan Creek subwatershed land use is comprised of 42 percent pasture, hay and cultivated row crops. The upper glaciated portion of the subwatershed comprises almost all the agricultural activity in Jonathan Creek. Table 5 shows that there are very few nutrient contributions from agriculture in Jonathan Creek that led to exceedances of the reference values. Groundwater contributions may help to keep a steady flow into the streams even during drier periods. The ammonia reference value exceedances in Buckeye Fork can be attributed to AMD. Dissolved oxygen values below the level needed for the protection of aquatic life were found at several tributaries within the Moxahala Creek watershed (see Table 3). Low flow conditions during the September sampling run was the most likely cause along with nonpoint source contributions (agricultural activities) and failing home septic treatment systems.

*Table 3. Exceedances of Ohio Water Quality Standards criteria (OAC3745-1) for chemical/physical parameters measured in the Moxahala Creek and Jonathan Creek watersheds, 2008. Bacteria exceedances are presented in the RecreationUse Section.*

| Stream/RM | Location | Parameter (value – ug/l unless noted) |
|---|---|---|
| *Moxahala Creek* | | |
| 24.0 | Township Road 312 | pH (3.97, 2.89, 3.14, 3.06 [b]) Iron (18600, 22000, 23800, 27500 [c]) |
| 12.7 | Athens Road | pH (4.91, 4.79, 4.71 [b]) pH (Datasonde 7-8-2008 7 records from 5.45 to 5.71 [b]) pH (Datasonde 8-19/21-2008 47 records from 4.37 to 4.4 [b]) |
| 6.8 | Lambert | pH (5.82, 4.93, 5.1, 4.8 [b]) |
| 3.3 | Moxadarla Road | None |
| 0.6 | Grant Cliff Road – Pearl Park | None |
| *Black Fork* | | |
| 3.5 | Adj. Tatman Road | D.O. (1.86 mg/l [a,b]) |
| 2.5 | Township Road 747 | Iron (19600, 11850, 31200, 33200, 25500 ug/l [c]) |
| 1.93 | State Route 669 | Iron (24600, 17100, 38500, 48300, 43400 ug/l [c]) |
| 0.24 | Ceramic Road TR 1001 | Iron (10300, 8260, 7340, 7120 ug/l [c]) |
| *Ogg Creek* | | |
| 2.1 | State Route 555 | None |
| 0.2 | Whitehouse Road | Iron (6570, 6810, 5630 ug/l [c]) |
| *Andrews Run* | | |
| 0.3 | State Route 13 | pH (4.14, 2.7, 3.04, 2.91 [b]) Iron (4300, 48500, 61900 ug/l [c]) Zinc (428, 435 ug/l [b]) Nickel (179 ug/l [b]) TDS (1570 mg/l [b]) |
| *Jonathan Creek* | | |
| 27.1 | State Route 204 | None |
| 22.32 | Hopewell Indian Road | None |
| 17.4 | Off SR 204 dst. Glass Rock trib. | None |
| 12.2 | County Road 34, Coopermill Road | None |
| 7.6 | Workman Road | None |
| 3.35 | Crock Road | None |
| 1.1 | State Route 93 | None |
| 0.9 | Powell Road dst. dam | None |
| *Valley Run* | | |
| 5.4 | Laurel Hill Road | D. O. (3.47 mg/l [a,b]) |
| 3.5 | Cherry Hill Road | Copper (14.6 [b]), D. O. (4.95 mg/l [a,b]) |
| 1.28 | Hopewell Indian Road | D. O. (4.36, 4.36 mg/l [a,b]) |
| *Painter Creek* | | |
| 2.68 | Cooperrider Road | None |
| 0.85 | Township Road 76 | D.O. (1.17 mg/l [a,b]) |
| *Turkey Run* | | |
| 2.9 | Township Road 49 | None |
| 0.25 | Railroad Bridge @ Mouth | Lead (478 ug/l [b]) pH (6.14 [b]) |
| *Buckeye Fork* | | |
| 4.9 | Old Rainer Road | Nickel (273, 241, 294, 322, 298 ug/l [b]) Zinc (440, 454, 505, 441 ug/l [b]) TDS (1510, 1640 mg/l [b]) pH (3.05, 3.44, 3.36, 3.28, 3.19 [b]) |
| 3.41 | Fletcher Road | Nickel (223, 191, 247, 289 ug/l [b]) Zinc (397, 394 ug/l [b]) TDS (1520 mg/l [b]) pH (3.41, 4.23, 3.77, 3.51, 3.5 [b]) |
| 1.42 | Fultonrose Road | Selenium (5.5, 11.8 ug/l [b]) Nickel (169, 171 ug/l [b]) pH (5.9, 6.29 [b]) |

*Table 3. Continued.*

| Stream/RM | Location | Parameter (value – ug/l unless noted) |
|---|---|---|
| *Kent Run* | | |
| 8.85 | Asbury Chapel Road | None |
| 3.68 | Slack Road | None |
| 1.35 | Lower Croft Rd. – Maysville WTP Intake | None |
| *Thompson Creek* | | |
| 4.73 | Coopermill Road | None |
| 0.39 | U. S. Rt. 22 | D.O. (3.45 mg/l [b]) |
| Miscellaneous Tributaries | | |
| Bowling Green Run - Boundaries Road | | Mercury (0.37 ug/l[d]) |
| Trib, to Jonathan Ck. @ RM 19.47 – Twp. Rd. 19 | | None |
| Trib, to Jonathan Ck. @ RM 17.55 – Twp. Rd. 92A | | Iron (5130[c] ) |
| Trib, to Jonathan Ck. @ RM 13.74 – Snook Rd | | Mercury (0.23 ug/l[d]) D.O. (4.9 mg/l[b]) |
| Butcherknife Creek @ State Route 345 | | Nickel (213, 267 ug/l [b]) Zinc (371 ug/l [b]) TDS (1640 mg/l [b]) pH (3.82, 4.79, 4.62, 4.01, 3.92 [b]) |

[a] Exceedance of the aquatic life Outside Mixing Zone Maximum water quality criterion (for D.O., below minimum).

[b] Exceedance of the aquatic life Outside Mixing Zone Average water quality criterion (for D.O., below 24 hour average).

[c] Exceedance of the statewide water quality criteria for the protection of agricultural uses.

[d] Exceedance of the Human Health drink and non-drink criterion.

*Table 4. Summary statistics for select AMD inorganic and field chemistry water quality parameters sampled in the Moxahala Creek study area, 2008. The 90th percentile value from reference sites from the Western Allegheny Plateau ecoregion is shown for comparison. Values above reference conditions or developed values are shaded.*

| | | Iron | Manganese | Nickel | Conductivity | Sodium | Sulfate | Acidity[2] | Alkalinity[3] | Aluminum[4] |
|---|---|---|---|---|---|---|---|---|---|---|
| **Units** | | µg/l | µg/l | µg/l | omhos/cm | mg/l | mg/l | mg/l | mg/l | µg/l |
| **Reference Values** | | 2494 (Headwater) 1257 (Wadeable) 2285 (Sm. River) | 1230 (Headwater) 438 (Wadeable) 385 (Sm. River) | 40 (Headwater) 40 (Wadeable) 40 (Sm. River) | 750 (Headwater) 1070 (Wadeable) 726 (Sm. River) | 21.5 (Headwater) 18.7 (Wadeable) 32.2 (Sm. River) | 622 (Headwater) 420 (Wadeable) 126 (Sm. River) | -67 (Headwater) -67 (Wadeable) -67 (Sm. River) | 67 (Headwater) 67 (Wadeable) 67 (Sm. River) | 87 Continuous Concentration 750 Maximum Concentration |
| **Stream** | **River Mile[1]** | Mean | Mean | Mean | Mean | Mean | Mean | Mean | Mean | Mean |
| Moxahala Cr. | 24[H] | 22975 | 1402 | 105 | 1402 | 19.5 | 714 | 130 | <5 | 9093 |
| Moxahala Cr. | 13.4[W] | 1296 | 1078 | 77 | 1078 | 34.3 | 596 | 37 | <5 | 4530 |
| Moxahala Cr. | 6.8[W] | 1365 | 990 | 59 | 990 | 27.8 | 474 | 22 | 5 | 2457 |
| Moxahala Cr. | 3.3[W] | 679 | 885 | 330 | 885 | 36 | 324 | <5 | 57 | 458 |
| Moxahala Cr. | 0.6[S] | 499 | 890 | 32 | 890 | 35.4 | 337 | <5 | 57 | 325 |
| Andrews Run | 0.3[H] | 49550 | 1813 | 166 | 1813 | 25.3 | 944 | 219 | <5 | 14850 |
| Black Fork | 3.5[H] | 573 | 347 | 1 | 347 | 16.6 | 52.7 | 3 | 99 | 146 |
| Black Fork | 2.5[W] | 25438 | 947 | 11 | 947 | 76 | 374 | 13 | 52 | 814 |
| Black Fork | 1.93[W] | 34380 | 1005 | 10 | 1005 | 80.8 | 391 | <5 | 54 | 281 |
| Black Fork | 0.24[W] | 6050 | 868 | 12 | 868 | 69.4 | 357 | 3.2 | 41 | 203 |
| Ogg Creek | 2.1[H] | 650 | 293 | 1 | 293 | 10.6 | 19 | <5 | 101 | 369 |
| Ogg Creek | 0.2[H] | 4592 | 809 | 10 | 809 | 67.2 | 238 | <5 | 150 | 1514 |
| Buckeye Fork | 4.9[H] | 1908 | 16982 | 285 | 1396 | 11.4 | 663 | 94 | <5 | 12662 |
| Buckeye Fork | 3.41[H] | 752 | 13762 | 219 | 1268 | 11.4 | 760 | 69 | <5 | 9446 |
| Buckeye Fork | 1.42[W] | 286 | 6806 | 134 | 1386 | 80 | 677 | <5 | 74 | 2326 |
| Butcherknife Cr. | 0.08[H] | 462 | 13363 | 177 | 1154 | 13.2 | 659 | 43 | 3.2 | 5558 |

1 - H – Headwater, W- Wadeable, S- Small River
2 – A net acidity of -67 mg/l was developed in the Sunday Creek TMDL to help determine WWH use designation.
3 - Minimum of 67 mg/l of alkalinity was developed in the Sunday Creek TMDL to help determine WWH use designation.
4 – U.S. EPA criteria for continuous and maximum concentrations.

*Table 5. Summary statistics for select nutrient water quality parameters sampled in the Jonathan Creek study area, 2008. The 90th percentile value from reference sites from the corresponding ecoregion is shown for comparison. The table below delineates the different ecoregions. Values above reference conditions are shaded yellow.*

| | | Ammonia—N | Nitrate+Nitrite-N | Phosphorus-T |
|---|---|---|---|---|
| **Stream** | **River Mile** | Mean | Mean | Mean |
| Jonathan Creek | 27.1 | 0.033 | 1.844 | 0.0276 |
| Jonathan Creek | 22.32 | 0.0468 | 1.29 | 0.0338 |
| Jonathan Creek | 17.4 | 0.031 | 0.86 | 0.0142 |
| Jonathan Creek | 12.2 | 0.025 | 0.744 | 0.052 |
| Jonathan Creek | 7.6 | 0.025 | 0.706 | 0.473 |
| Jonathan Creek | 3.35 | 0.029 | 0.865 | 0.0115 |
| Jonathan Creek | 1.1 | 0.025 | 1.886 | 0.0496 |
| Jonathan Creek | 0.9 | 0.025 | 0.606 | 0.213 |
| Bowling Green Run | 0.1 | 0.025 | 0.806 | 0.026 |
| Valley Run | 5.4 | 0.038 | 0.558 | 0.0252 |
| Valley Run | 3.5 | 0.048 | 1.488 | 0.0762 |
| Valley Run | 1.28 | 0.035 | 0.861 | 0.0214 |
| Trib, to Jonathan Ck. @ RM 19.47 | 0.75 | 0.038 | 0.546 | 0.0322 |
| Trib, to Jonathan Ck. @ RM 17.55 | 0.1 | 0.068 | 0.676 | 0.018 |
| Painter Creek | 2.68 | 0.03 | 0.562 | 0.0364 |
| Painter Creek | 0.85 | 0.033 | 0.545 | 0.0257 |
| Trib, to Jonathan Ck. @ RM 13.74 | 0.32 | 0.04 | 4.848 | 0.0254 |
| Turkey Run | 2.9 | 0.035 | 0.478 | 0.0124 |
| Turkey Run | 0.25 | 0.031 | 0.778 | 0.0123 |
| Buckeye Fork | 4.9 | 0.16 | 0.198 | 0.0098 |
| Buckeye Fork | 3.41 | 0.11 | 0.206 | 0.0572 |
| Buckeye Fork | 1.42 | 0.096 | 0.566 | 0.0084 |
| Butcherknife Creek | 0.08 | 0.141 | 0.35 | 0.005 |
| Kent Run | 8.85 | 0.033 | 0.378 | 0.0244 |
| Kent Run | 3.68 | 0.025 | 0.414 | 0.013 |
| Kent Run | 1.35 | 0.03 | 0.30 | 0.0094 |
| Thompson Creek | 4.73 | 0.025 | 0.336 | 0.021 |
| Thompson Creek | 0.39 | 0.048 | 0.84 | 0.0186 |

| **Ecoregion/Stream Size** | **Ammonia—N** | **Nitrate+Nitrite-N** | **Phosphorus-T** |
|---|---|---|---|
| WAP/Headwater | 0.06 | 0.606 | 0.09 |
| WAP/Wadeable | 0.06 | 1.054 | 0.11 |
| EOLP/Headwater | 0.190 | 2.701 | 0.214 |
| EOLP/Wadeable | 0.125 | 1.817 | 0.200 |

**Recreation Use**

Water quality criteria for determining attainment of the designated recreation use are established in the Ohio Water Quality Standards (Table 7-13 in OAC 3745-1-07) based upon the presence or absence of bacteria indicators in the water column. Indicator organisms used for these determinations are fecal coliform bacteria and *Escherichia coli*.

Fecal coliform bacteria are microscopic organisms that are present in large numbers in the feces and intestinal tracts of humans and other warm-blooded animals. *E. coli* typically comprises approximately 97 percent of the organisms found in the fecal coliform bacteria of human feces (Dufour, 1977), but there is currently no simple way to differentiate between human and animal sources of coliform bacteria in surface waters, although methodologies for this type of analysis are becoming more practicable. These microorganisms can enter water bodies where there is a direct discharge of human and animal wastes, or may enter water bodies along with runoff from soils where these wastes have been deposited.

Pathogenic (disease causing) organisms are typically present in the environment in such small amounts that it is impractical to monitor them directly. Fecal coliform bacteria, including *E. coli*, by themselves are usually not pathogenic. However, some strains of *E. coli* can be pathogenic, causing serious illness. Although not necessarily agents of disease, fecal coliform bacteria and *E. coli* may indicate the potential presence of pathogenic organisms that enter the environment through the same pathways. When fecal coliform bacteria or *E. coli* are present in high numbers in a water sample, it invariably means that the water has received fecal matter from one source or another. Swimming or other recreation-based contact with water having a high fecal coliform or *E. coli* count may result in ear, nose, and throat infections, as well as stomach upsets, skin rashes, and diarrhea. Young children, the elderly, and those with depressed immune systems are most susceptible to infection.

**Bacteria**

Elevated bacteria was found throughout the watershed. Failing home septic systems, sanitary sewer overflows and livestock are the most likely sources of bacteria.

The Moxahala Creek basin is designated as Primary Contact Recreation (PCR) in OAC Rule 3745-1-09. Water bodies with a designated recreation use of PCR "...are waters that, during the recreation season, are suitable for fullbody contact recreation such as ... swimming, canoeing, and SCUBA diving with minimal threat to public health as a result of water quality" [OAC 3745-1-07 (B)(4)(b)]. The recreation use water quality criteria applicable to the Moxahala Creek basin for the current rule are reported in Table 7-13 of OAC 3745-1-07. At least one of the two bacteriological standards (fecal coliform or *E. coli* ) must be met. These criteria apply outside of the mixing zone. For the PCR use, the following applies: fecal coliform - geometric mean fecal coliform content (either the most probable number method (MPN) or the membrane filter(MF) technique), based upon not less than five samples within a thirty-day period, shall not exceed 1,000 per 100 ml and fecal coliform content (either MPN or MF) shall not exceed 2,000 per 100 ml in more than ten percent of the samples taken during any thirty-day period. *E. coli* - geometric mean *E. coli* content (either MPN or MF), based upon not less than five samples within a thirty-day period, shall not exceed 126 per 100 ml and *E. coli* content (either MPN or M F) shall not exceed 298 per 100 ml in more than ten percent of the samples taken during any thirty-day period. Bacteriological results from environmental samples are typically reported as colony forming units (cfu) per 100 ml of water. The current criteria are effective May 1$^{st}$ through October 15$^{th}$ each year (Table 7).

Ohio EPA is currently in the process of adopting new WQS criterion for bacteria. The new standard will be based on *E. coli* only and will allow for using all samples of bacteria collected over the entire recreation season (new recreation season will be May 1$^{st}$ through October 31$^{st}$) in calculating the geometric mean. The new *E. coli* standard for Class B streams (all Moxahala Creek basin streams) is a geometric mean of <161 and maximum value ≤523. The geometric mean can be based on two or more samples and will be the only basis for attainment status when more than one sample is collected (Table 6).

Summarized bacteria results are listed in Tables 6 and 7, and the complete dataset is reported in Appendix Table 4. Forty locations in the Moxahala Creek basin were tested for bacteria levels three to eight times, from June 30$^{th}$ – October 2$^{nd}$, 2008. Evaluation of fecal coliform and *E. coli* results revealed that only six locations fully met the current criteria and 34 locations were in non-attainment of the current criteria. Under the proposed new criteria, 11 locations fully met the current criteria and 29 locations were in non-attainment

of the proposed, new criteria. The locations not attaining the PCR were most likely due to failing home septic systems, sanitary sewer overflows and/or livestock with free access to the creeks.

Bacteria colonies are most likely present in high numbers throughout the watershed because of the rural nature of the watershed with few centralized sanitary sewer systems. Bacteria may also be associated with agricultural activities such as pasture land runoff and manure land application. High bacteria results and non-attainment was found at Kent Run at RM 1.35 (lower Kroft Road) where the Maysville Water District has an auxiliary water intake. Highly elevated *E. coli* and fecal coliform colonies were found in Moxahala Creek adjacent to Pearl Park at RM 0.6 and was most likely due to failing collection systems (sanitary sewer overflows) from South Zanesville. According to the Muskingum County Commissioners, the south system has numerous and challenging problems but they are actively working to address and correct these issues.

*Nuisance Prevention Sampling*

Nuisance prevention bacterial sampling was conducted on September 4$^{th}$, 9$^{th}$ and 16$^{th}$ in 2008. The five unsewered areas that were sampled include Rehoboth, Moxahala, Old Rainer Road, Six Mile Turn (Moore's Junction) and Glenford. The Rehoboth site is in the Rush Creek watershed so it does not affect Moxahala Creek.

The bacterial samples were collected following Ohio EPA Sampling Methods for Documentation of a Public Health Nuisance under OAC Rule 3745-1-04 (F) & (G) August 20, 1998. The samples were kept on ice after collection and during transportation to the Division of Environmental Services under chain of custody. All samples were collected and delivered under the six hour holding time.

Numerous sites were in violation of Ohio's Water Quality Standards. Road side ditches and drainage ways in these small yet densely populated areas had exceedances of both the current rule and the proposed rule. One mainstem site sampled on Jonathan Creek and one site sampled on Moxahala Creek were within all bacterial criteria. The complete dataset is reported in Appendix Table 4.

*Table 6. A summary of E. coli data for the 40 locations sampled in the Moxahala Creek Basin, June 30th – October 2nd, 2008. Attainment based on comparing the geometric mean, when more than one sample collected, to the Primary Contact Recreation (PCR) criteria of the proposed standard (Ohio Administrative Code 3745-1-07). All values are expressed in colony forming units (cfu) per 100 ml of water. Gray shaded values exceed the proposed PCR criterion for Class B streams.*

| | | | | *E. coli* | | Recreation Attainment Status | Source of Bacteria? |
|---|---|---|---|---|---|---|---|
| Site # | Location | River Mile | # | Geometric Mean | Maximum Value | | |
| 1 | Moxahala Creek | 24 | 5 | 16 | 460 | FULL | |
| 2 | Moxahala Creek | 13.4 | 5 | 26 | 2500 | FULL | |
| 3 | Moxahala Creek | 6.8 | 5 | 148 | 4500 | FULL | |
| 4 | Moxahala Creek | 3.3 | 5 | 239 | 2400 | **NON** | FHSS, Livestock |
| 5 | Moxahala Creek | 0.6 | 5 | 382 | 27000 | **NON** | Sanitary Sewer Overflows (South Zanesville) |
| 6 | Andrews Run | 0.3 | 5 | 6 | 10 | FULL | |
| 7 | Black Fork | 3.5 | 5 | 252 | 2700 | **NON** | FHSS, Livestock |
| 8 | Black Fork | 2.5 | 5 | 36 | 3800 | FULL | |
| 9 | Black Fork | 1.93 | 5 | 34 | 300 | FULL | |
| 10 | Black Fork | 0.24 | 5 | 39 | 320 | FULL | |
| 11 | Ogg Creek | 2.1 | 5 | 420 | 2900 | **NON** | FHSS, Livestock |
| 12 | Ogg Creek | 0.2 | 5 | 177 | 5200 | **NON** | FHSS, Livestock |
| 13 | Jonathan Creek | 27.1 | 8 | 336 | 3900 | **NON** | FHSS, Agriculture |
| 14 | Jonathan Creek | 22.32 | 8 | 224 | 4400 | **NON** | FHSS, Agriculture |
| 15 | Jonathan Creek | 17.4 | 7 | 913 | 4900 | **NON** | FHSS, Agriculture |
| 16 | Jonathan Creek | 12.2 | 7 | 365 | 190000 | **NON** | FHSS, Agriculture |
| 17 | Jonathan Creek | 7.6 | 6 | 194 | 9300 | **NON** | FHSS, Agriculture |
| 18 | Jonathan Creek | 3.35 | 8 | 180 | 19500 | **NON** | FHSS, Agriculture |
| 19 | Jonathan Creek | 1.1 | 8 | 207 | 33000 | **NON** | FHSS, Agriculture |
| 20 | Jonathan Creek | 0.9 | 7 | 136 | 37000 | **NON** | FHSS, Agriculture |
| 21 | Bowling Green Run | 0.1 | 5 | 710 | 1800 | **NON** | Agriculture |
| 22 | Valley Run | 5.4 | 4 | 769 | 3400 | **NON** | FHSS, Agriculture |
| 23 | Valley Run | 3.5 | 5 | 1529 | 5500 | **NON** | FHSS, Agriculture |
| 24 | Valley Run | 1.28 | 7 | 654 | 6550 | **NON** | FHSS, Agriculture |
| 25 | Trib. to Jonathan @ RM19.47 | 0.75 | 5 | 1685 | 22000 | **NON** | FHSS, Agriculture |
| 26 | Trib. to Jonathan @ RM17.55 | 0.1 | 4 | 8972 | 15000 | **NON** | Failing Home Septic Systems |
| 27 | Painter Creek | 2.68 | 5 | 692 | 3700 | **NON** | Failing Home Septic Systems |
| 28 | Painter Creek | 0.85 | 5 | 809 | 4900 | **NON** | Failing Home Septic Systems |

*Table 6. Continued.*

| | | | | *E. coli* | | Recreation Attainment Status | Source of Bacteria? |
|---|---|---|---|---|---|---|---|
| Site # | Location | River Mile | # | Geometric Mean | Maximum Value | | |
| 29 | Trib. to Jonathan @ RM13.74 | 0.32 | 3 | 553 | 1500 | **NON** | Landfill, Agriculture |
| 30 | Turkey Run | 2.9 | 5 | 508 | 1800 | **NON** | FHSS, Agriculture |
| 31 | Turkey Run | 0.25 | 5 | 463 | 2000 | **NON** | FHSS, Agriculture |
| 32 | Buckeye Fork | 4.9 | 4 | 18 | 130 | FULL | |
| 33 | Buckeye Fork | 3.41 | 5 | 27 | 330 | FULL | |
| 34 | Buckeye Fork | 1.42 | 4 | 85 | 1100 | FULL | |
| 35 | Butcherknife Creek | 0.08 | 5 | 85 | 4400 | FULL | |
| 36 | Kent Run | 8.85 | 4 | 1814 | 21000 | **NON** | FHSS, Agriculture |
| 37 | Kent Run | 3.68 | 5 | 965 | 25000 | **NON** | FHSS, Agriculture |
| 38 | Kent Run | 1.35 | 7 | 127 | 27000 | **NON** | FHSS, Agriculture |
| 39 | Thompson Creek | 4.73 | 5 | 1358 | 20000 | **NON** | FHSS, Agriculture |
| 40 | Thompson Creek | 0.39 | 5 | 633 | 4000 | **NON** | FHSS, Agriculture |

*Table 7. A summary of fecal coliform and E. coli data for the 40 locations sampled in the Moxahala Creek Basin, June 30th – October 2nd, 2008. Attainment based on comparing the geometric mean and maximum value to the Primary Contact Recreation (PCR) criteria in the current rule (Ohio Administrative Code 3745-1-07, Table 7-13). All values are expressed in colony forming units (cfu) per 100 ml of water. Gray shaded values exceed PCR criteria.*

| | | | | Fecal coliform | | *E. coli* | | Recreation Attainment Status | Source of Bacteria? |
|---|---|---|---|---|---|---|---|---|---|
| Site # | Location | River Mile | # | Geometric Mean | Maximum Value | Geometric Mean | Maximum Value | | |
| 1 | Moxahala Creek | 24 | 3 | 8 | 400 | 8 | 460 | FULL | FHSS |
| 2 | Moxahala Creek | 13.4 | 3 | 10 | 4400 | 8 | 2500 | **NON** | FHSS |
| 3 | Moxahala Creek | 6.8 | 3 | 104 | 4300 | 71 | 4500 | **NON** | FHSS |
| 4 | Moxahala Creek | 3.3 | 3 | 99 | 2900 | 51 | 2400 | **NON** | FHSS, Livestock |
| 5 | Moxahala Creek | 0.6 | 3 | 113 | 35000 | 63 | 27000 | **NON** | Sanitary Sewer Overflows (South Zanesville) |
| 6 | Andrews Run | 0.3 | 3 | 6 | 10 | 6 | 10 | FULL | |
| 7 | Black Fork | 3.5 | 3 | 352 | 6400 | 119 | 2700 | **NON** | FHSS, Livestock |
| 8 | Black Fork | 2.5 | 3 | 46 | 8100 | 5 | 3800 | **NON** | FHSS |
| 9 | Black Fork | 1.93 | 3 | 5 | 5700 | 5 | 300 | **NON** | FHSS |
| 10 | Black Fork | 0.24 | 3 | 20 | 4900 | 21 | 320 | **NON** | FHSS |
| 11 | Ogg Creek | 2.1 | 3 | 374 | 2700 | 265 | 2900 | **NON** | FHSS, Livestock |
| 12 | Ogg Creek | 0.2 | 3 | 239 | 7900 | 82 | 5200 | **NON** | FHSS, Livestock |
| 13 | Jonathan Creek | 27.1 | 5 | 410 | 5000 | 229 | 3900 | **NON** | FHSS, Agriculture |
| 14 | Jonathan Creek | 22.32 | 5 | 404 | 2000 | 126 | 4400 | **NON** | FHSS, Agriculture |
| 15 | Jonathan Creek | 17.4 | 5 | 1022 | 17000 | 790 | 4900 | **NON** | FHSS, Agriculture |
| 16 | Jonathan Creek | 12.2 | 4 | 220 | 21000 | 117 | 190000 | **NON** | FHSS, Agriculture |
| 17 | Jonathan Creek | 7.6 | 3 | 117 | 20000 | 46 | 9300 | **NON** | FHSS, Agriculture |
| 18 | Jonathan Creek | 3.35 | 5 | 78 | 29500 | 45 | 19500 | **NON** | FHSS, Agriculture |
| 19 | Jonathan Creek | 1.1 | 5 | 112 | 55000 | 59 | 33000 | **NON** | FHSS, Agriculture |
| 20 | Jonathan Creek | 0.9 | 5 | 103 | 44000 | 74 | 37000 | **NON** | FHSS, Agriculture |
| 21 | Bowling Green Run | 0.1 | 3 | 815 | 4000 | 498 | 1800 | **NON** | Agriculture |
| 22 | Valley Run | 5.4 | 3 | 1049 | 7000 | 469 | 3400 | **NON** | FHSS, Agriculture |
| 23 | Valley Run | 3.5 | 3 | 1294 | 8000 | 945 | 5500 | **NON** | FHSS, Agriculture |
| 24 | Valley Run | 1.28 | 5 | 720 | 12500 | 463 | 6550 | **NON** | FHSS, Agriculture |
| 25 | Trib. to Jonathan @ RM19.47 | 0.75 | 3 | 7040 | 51000 | 3151 | 22000 | **NON** | FHSS, Agriculture |
| 26 | Trib. to Jonathan @ RM17.55 | 0.1 | 2 | 14832 | 33000 | 10606 | 15000 | **NON** | FHSS, Agriculture |
| 27 | Painter Creek | 2.68 | 3 | 497 | 3800 | 385 | 3700 | **NON** | FHSS, Agriculture |
| 28 | Painter Creek | 0.85 | 3 | 745 | 3900 | 479 | 4900 | **NON** | FHSS, Agriculture |

*Table 7. Continued.*

| | | | | Fecal coliform | | *E. coli* | | Recreation Attainment Status | Source of Bacteria? |
|---|---|---|---|---|---|---|---|---|---|
| Site # | Location | River Mile | # | Geometric Mean | Maximum Value | Geometric Mean | Maximum Value | | |
| 29 | Trib. to Jonathan @ RM13.74 | 0.32 | 1 | N/A | 2800 | N/A | 1500 | **NON** | Landfill, Agriculture |
| 30 | Turkey Run | 2.9 | 3 | 496 | 2100 | 358 | 1800 | **NON** | FHSS, Agriculture |
| 31 | Turkey Run | 0.25 | 3 | 396 | 4000 | 273 | 2000 | **NON** | FHSS, Agriculture |
| 32 | Buckeye Fork | 4.9 | 3 | 16 | 380 | 9 | 130 | FULL | |
| 33 | Buckeye Fork | 3.41 | 3 | 17 | 480 | 13 | 330 | FULL | |
| 34 | Buckeye Fork | 1.42 | 3 | 61 | 1900 | 36 | 1100 | FULL | |
| 35 | Butcherknife Creek | 0.08 | 3 | 82 | 1000 | 37 | 4400 | FULL | |
| 36 | Kent Run | 8.85 | 2 | 586 | 19000 | 374 | 21000 | **NON** | FHSS, Agriculture |
| 37 | Kent Run | 3.68 | 3 | 309 | 44000 | 231 | 25000 | **NON** | FHSS, Agriculture |
| 38 | Kent Run | 1.35 | 5 | 135 | 18000 | 39 | 27000 | **NON** | FHSS, Agriculture |
| 39 | Thompson Creek | 4.73 | 3 | 524 | 37000 | 348 | 20000 | **NON** | FHSS, Agriculture |
| 40 | Thompson Creek | 0.39 | 3 | 437 | 27000 | 241 | 4000 | **NON** | FHSS, Agriculture |

**Sediment Quality**

Sediment samples were collected from nine locations in the Moxahala Creek study area by the Ohio EPA during July - September, 2008. Samples were analyzed for metals, semivolatile organic compounds, organochlorinated pesticides, PCBs, nutrients, and particle size. Specific chemical parameters tested and results are listed in Appendix Tables 5 and 6. Sediment data were evaluated using guidelines established in *Development and Evaluation of Consensus-Based Sediment Quality Guidelines for Freshwater Ecosystems* (MacDonald *et.al*. 2000), and *Ohio Specific Sediment Reference Values (SRVs)* for metals (Ohio EPA 2003). The consensus-based sediment guidelines define two levels of ecotoxic effects. A *Threshold Effect Concentration* (TEC) is a level of sediment chemical quality below which harmful effects are unlikely to be observed, and is comparable to background conditions. A *Probable Effect Concentration* (PEC) indicates a level above which harmful effects are likely to be observed.

**Sediment Organic Chemicals**

NONE DETECTED

(PCBs, pesticides, semivolatile organics)

Sediment samples were conservatively sampled by focusing on depositional areas of fine grain material (silts and clays). These areas typically are represented by higher contaminant levels, compared to sands and gravels. All sediment sampling occurred in areas along the stream bank, which were represented by sparse deposits of fine grained material. These nearbank areas comprised only a small fraction of the bottom substrates of the streams surveyed. Bottom substrates at sediment sites were dominated by gravel and cobble material. Organic chemical parameters were tested at all nine sampling locations – sampling locations are noted in Table 8. All organic chemicals were reported as not detected - organic chemical measurements in sediment were within acceptable ecological levels.

Select detectable levels of metals are presented in Table 8. Values above ecological screening guidelines are noted with various colors of shading. Two significant observations concerning the sediment metals data included the following: 1) at Ogg Creek RM 0.2 the arsenic level was above the *Probable Effect Concentration*, iron was above the Sediment Reference value and mercury was above the Threshold Effect Concentration (TEC) value, and 2) at Jonathan Creek RM 3.35 arsenic and nickel were above the TEC. These elevated sediment metals conditions did not correlate with co-located biological sampling results. Exceptional biological integrity was documented in Jonathan Creek at RM 12.2, a location with two metal parameters at levels considered likely to cause harmful effects to stream biology. The elevated metals at Ogg Creek were possibly caused by the AMD discharges into the stream. The high metals in Ogg Creek could be the cause of the low-fair macroinvertebrate community score at that site. The sparse deposits of fine grained material at each sampling site contributed to low exposure levels of sediment contaminants to biological communities. The source of the elevated metals in Jonathan Creek is unknown but is thought to be associated with the natural geology in the area.

*Table 8. Chemical parameters measured above screening levels in sediment samples collected in the Moxahala Creek study area, 2008. Results are reported in mg/kg dry weight. Contamination levels were determined for parameters using consensus-based sediment quality guidelines (MacDonald et.al. 2000). Sediment reference values are listed in the Ohio EPA Ecological Risk Assessment Guidance (2003). Shaded numbers indicate values above the following: Probable Effect Concentration – PEC (red), Threshold Effect Concentration -TEC (yellow), and Sediment Reference Value (orange). Sampling locations are indicated by stream and river mile (RM).*

| Stream | River Mile | Arsenic | Iron | Mercury | Nickel |
|---|---|---|---|---|---|
| Moxahala Creek | 6.8 | 6.48 | 45,200 | 0.032 | 11.6 |
| Black Fork | 3.5 | 5.15 | 21,700 | 0.036 | 18.7J |
| Black Fork | 1.93 | 8.59 | 49,100 | 0.057 | 21.2J |
| Jonathan Creek | 12.2 | 6.74 | 14,100 | 0.034 | 10.8 |
| Jonathan Creek | 3.35 | 11.9 | 18,900 | <0.031 | 30.4 |
| Trib. to Jonathan Creek @ RM 13.74 | 0.32 | 16.9 | 39,800 | <0.03 | 16.2 |
| Kent Run | 1.35 | 5.86 | 23,300 | 0.043 | 14.2 |
| Valley Run | 1.28 | 4.89 | 12,600 | <0.033 | 9.86 |
| Ogg Creek | 0.2 | 40.0 | 243,000 | 0.184 | 14.2J |

J - The analyte was positively identified, but the quantitation was below the reporting limit (RL).
< - Not detected at or above the method detection limit (MDL value reported with the less than symbol).

**Effluent Dischargers**

**Village of Roseville Waste Water Treatment Plant (WWTP)** (Ohio EPA Permit # 0PC00020*ED)
Roseville WWTP is located at 7250 County Road 90, Roseville, Muskingum County. This facility treats domestic household sanitary waste water. The WWTP serves both Villages of Roseville and Crooksville for a combined population of approximately 4,400. The plant was built in 1989. The plant is designed to treat 671,000 gpd and has a daily average flow of 570,000 gallons. The plant consists of three aerated lagoons and chlorination (if needed) before discharging to Moxahala Creek at RM 13.63. The plant has effluent limits based on lagoon design (see Appendix Table 7). Currently, the plant is not exceeding the effluent limits set in the NPDES permit. The WWTP does have wet weather issues. The WWTP receives 8,000 gpd of low strength industrial waste water. The entire service area is said to be connected to the sanitary sewer. Other high density areas outside the Village limits are not served by central sewers but are within service distance.

**Village of Roseville Water Treatment Plant (WTP)** (Ohio EPA Permit # 0IW00122*DD)
The Village of Roseville WTP is located at 451 ½ Gordon Street, Roseville, Muskingum County. This facility produces potable drinking water for the Village of Roseville's 1,925 citizens. The plant consists of iron/manganese oxidation, softening, settling, stabilization, filtration and chlorination. The plant's design discharge is 54,000 gpd into Porter Run.

**Village of Crooksville WTP** (Ohio EPA Permit # 0IV00021*BD)
The Village of Crooksville WTP is located at County Road 6 (a quarter mile west of State Route 93), Crooksville, Perry County. This facility produces 600,000 gpd of potable drinking water for the Village of Crooksville's 2,474 citizens. The plant consists of sedimentation, permanganate oxidation, alum precipitation, filtration, pH adjustment and chlorination. The plant is designed to discharge 44,600 gpd into an unnamed tributary of Moxahala Creek (RM 17.15).

**Perry County Commissioners: Crown Wehrle Estates WWTP** (Ohio EPA Permit # 0PG00023*GD)
Crown Wehrle Estates WWTP is located at the intersection of County Road 2 and 30 in Thorn Township, Perry County. The WWTP treats 80,000 gpd of domestic sanitary waste water and serves the communities of Thornport, Robinwood and Heron Bay with a combined 275 households. The plant has extended aeration with sand filters and disinfection and was built in 1975 and upgraded in 2005. The plant discharges to Jonathan Creek at RM 33.2.

**Perry County Commissioners: Northern Perry County WWTP** (Ohio EPA Permit # 0PK00003*AD)
This is a proposed facility that will provide sewer service for the Village of Glenfort. Other communities proposed to be served by this facility include: Fireman's Park, Holiday Harbor, Thornport and adjacent developed areas and will serve approximately 2730 people. The plant is designed to treat 600,000 gpd and meet BADCT limits. The plant will discharge into Jonathan Creek at RM 19.8.

**Sidwell Materials, Inc.** (Ohio EPA Permit # 0IJ00041*BD)
Sidwell Materials is located at 4620 Limestone Valley Road, near White Cottage, Muskingum County. This facility has two storm water impoundments collecting water from aggregate stock pile areas and limestone mining area. The impoundments discharge to Jonathon Creek at RMs 2.5 and 1.98.

**Cecil Hoffman: dba Hopewell Heights MHP** (Ohio EPA Permit # 0PV00032*AD)
Hopewell Heights Mobile Home Park is located at 940 North Hopewell Road, Hopewell, Muskingum County. The 5,000 gpd extended aeration plant discharges into an unnamed tributary of Kent Run at RM 14.95. The plant is designed to treat domestic sanitary waste water for 21 mobile homes.

**Hopewell Elementary School** (Ohio EPA Permit 4PT00124*AD)
Hopewell Elementary School located at 11100 West Pike, Hopewell, Ohio, Licking County. The school WWTP serves 373 staff and students with a 5,000 gpd extended aeration treatment plant treating sanitary and cafeteria waste waters. The plant discharges to an unnamed tributary Kent Run at RM 11.42.

**Suburban Landfill, Inc.** (Ohio EPA Permit # 0IN00176*ED)
Suburban Landfill is a domestic sanitary solid waste landfill. The landfill is located at 3415 Township Road 447, Glenfort in Hopewell Township, Perry County. The collection pond is designed to collect storm water from the site and remove sediment. The pond discharges into an unnamed tributary of Jonathan Creek at RM 13.74. No leachate is treated in the sediment pond.

**Oglebay Norton Industrial Sands Inc. – Glass Rock Plant** (Ohio EPA Permit # 0IJ00000*ED)
Oglebay Norton is located at 2446 Glass Rock Road, ½ mile east of Glass Rock, Perry County. Oglebay Norton mines and processes quartzite to prepare industrial grade sand for the glass and ceramic industries. The Glass Rock plant has four discharges. Outfalls 001 and 002 are sediment pond discharges (discharging 585,000 gpd combined) at the processing plant and discharge to an unnamed tributary of Jonathan Creek at RM 17.55. Outfalls 008 and 009 are sediment pond discharges (discharging 17,000 gpd combined) at the mining areas and discharge to an unnamed tributary of Painter Creek at RM 0.95.

**B & D Commissary** (Ohio EPA Permit # 0IH00048*ED)
B & D Commissary is located at 5705 State Route 204 NE, Mt. Perry, Perry County. B & D manufactures cookie and pizza dough. The WWTP is a 10,000 gpd extended aeration plant that serves ~ 80 employees. Waste water from the processing building first goes through one of two 1000 gallon grease traps before entering the head of the WWTP and again passing through a 1,200 gallon grease trap and then a 3,000 gallon trash/grease trap and then the treatment plant. The discharge is to an unnamed tributary of Turkey Run at RM 0.45.

**Maysville Regional Water District** (Ohio EPA Permit # 0IV00061*AD)
Maysville water treatment plant is located at 6255 Maysville Pike (State Route 22), Zanesville, Muskingum County. The Maysville WTP is a potable drinking water plant that uses Frazier's Quarry as a primary surface water source and Kent Run as an auxiliary source. The plant discharges septic tank and reject process water (26,900 gpd) into an unnamed tributary of Jonathan Creek at RM 4.2.

**Ohio Oil Gatherings Corp. II – Sego Terminal** (Ohio EPA Permit # 0IN00127*CD)
Ohio Oil is located at 6892 State Route 22, east of Sego, Perry County. The facility is a bulk petroleum crude oil storage plant. The facility collects storm water runoff in the petroleum loading area and the runoff goes through an oil and grease interceptor prior to discharge to an unnamed tributary to Turkey Run at RM 2.03.

**Shelly Materials, Inc. – East Fultonham Quarry** (Ohio EPA Permit # 0IJ00027*ED)
Shelly Materials is located at 6305 Saltillo Road (State Route 345), East Fultonham, Muskingum County. This is a limestone mining and processing plant making construction aggregate. Outfalls 001, 002 and 008 are sediment ponds in the aggregate processing area. Ponds at outfalls 001 and 002 discharge storm water, quarry dewatering waters and wash water to Bush Creek at RM 0.3 and 0.05, respectively. The pond at outfall 008 discharges to Buckeye Fork at RM 1.9. Ponds at outfalls 004 and 005 are sedimentation ponds receiving storm water runoff and active quarry dewatering waters. These outfalls discharge to Bush Creek at RM 0.22 and Buckeye Fork at RM 2.49. Discharges for outfalls 007 and 008 are proposed as new quarry sites are needed. Outfall 011 discharges storm water, quarry dewatering waters and wash water to Buckeye Fork at RM 1.45. Upstream of this facility, Buckeye Fork is impacted from AMD and had pH results in the 3 to 4 S.U. range. Much of the water discharged from this facility is highly alkaline resulting in "instream treatment of the AMD" and resulting in precipitation of metals and neutralizing the highly acidic waters.

**Stream Physical Habitat**

Stream habitat was evaluated using the Qualitative Habitat Evaluation Index (QHEI) (Rankin 1989) at 46 fish sampling locations (Appendix Table 8). Within the Moxahala Creek and Jonathan Creek watersheds, good to excellent stream habitat was recorded at 39 sites (85%), fair habitat was noted at 6 locations (13%), and poor habitat was documented at one location (Table 9). The average QHEI score for both watersheds combined was 66.3, consistent with good overall habitat quality. Many of the stream sites were predominated by high quality substrates, including gravel, sand, and cobble. Extensive embeddedness of the bottom substrates occurred at 18 of the 46 fish sites (39%). Embeddedness is the degree that cobble, gravel, and boulder substrates are surrounded, impacted in, or covered by fine sand and silt, and in the case of AMD streams, metals that precipitate out of solution, especially iron. Extensive amounts of silt and fine sand are detrimental to bottom spawning fish and impair macroinvertebrate populations.

*Figure 5. Moxahala Creek at Lambert Road (RM 6.9).*

The Moxahala Creek watershed is comprised of 67,840 acres, of which approximately 8,300 acres were strip mined and 8,400 acres were mined underground (Moxahala Creek AMDAT 2005). The major issue affecting stream habitat within the Moxahala Creek mainstem is acid mine drainage, iron floc, sands and coal fines from unreclaimed mining. The sands and fines are unstable and continually shift throughout the stream smothering previously exposed beneficial substrates. The iron floc gives the stream a yellow or orange color (Figure 5). Channel modifications occurred in several stream segments and are believed to be caused by previous coal mining activities. Sedimentation and channel modifications cause reduced habitat diversity for aquatic life; however, the biggest negative effect to biological diversity in Moxahala Creek is AMD. The lowest quality stream habitat (QHEI=63) in Moxahala Creek occurred at RM 24.0 where the instream habitat had many good qualities, but due to the cementatory nature of the iron floc, the positive features of the habitat had no real function. Tributaries to Moxahala such as Black Fork also had good habitat but had iron floc and embeddedness.

The major issue affecting Jonathan Creek stream habitat is sedimentation. The upper portion of Jonathan Creek is located within the EOLP ecoregion and predominately has an agricultural land-use. Large row crop and cattle operations along with silica mining contribute much of the sand and silt encountered in the stream. The lower section of Jonathan Creek is within the WAP ecoregion and had the highest quality stream habitat (QHEI=90) at RM 7.6. This section typically has a good riparian corridor. Additionally, beneficial instream cover, such as logs, aquatic macrophytes, bedrock slabs, boulders, cobble, and undercut banks are moderately abundant in Jonathan Creek. Pools deeper than one meter are common throughout the mainstem waterway. An old mill dam at RM 1.0 has lowered the stream habitat quality to a QHEI of 65.0. Lowhead dams can negatively affect the biological community because they tend to create a pool of stagnant water during low flows. Lowhead dams can also be a hazard to people who are wading, swimming or boating. If the old mill dam were removed on Jonathan Creek, the habitat would quickly improve and would also allow for potential recreation opportunities such as canoeing or kayaking.

Numerous tributaries to Jonathan Creek had excellent habitat such as Valley Run, Kent Run, Hibbs Run, Thompson Run, Salt Run and Turkey Run. Two tributaries to Jonathan were affected by AMD and channel modification (Buckeye Fork and Butcherknife Creek). The poorest quality tributary to Jonathon Creek was Bush Creek with a QHEI score of 38.5 at one site near its mouth.

*Table 9. Stream physical habitat summarized results using the QHEI for the Moxahala Creek study area, 2008.*

| Stream | River Mile | Location | QHEI | Comments |
|---|---|---|---|---|
| **EXCELLENT** | | | | |
| Moxahala Creek | 4.3 | TR 261 – dst. Jonathan Creek | 81.5 | |
| Jonathan Creek | 7.6 | Workman Road | 90.0 | |
| Jonathan Creek | 3.3 | Crock Rd. @ White Cottage | 87.5 | |
| Jonathan Creek | 0.8 | Powell Road | 76.5 | |
| Thompson Run | 4.7 | Coopermill Road | 72.5 | |
| Hibbs Run | 0.1 | Coopermill Road | 77.0 | |
| Kent Run | 8.9 | Asbury Chapel Road | 70.0 | Coal fines in stream, extensively embedded |
| Kent Run | 3.7 | Slack Road | 81.5 | |
| Kent Run | 1.6 | Lower Kroft Road, adj. Bagley Rd. | 75.0 | Coal fines in stream |
| Salt Run | 0.1 | Bagley Road | 76.0 | |
| Buckeye Fork | 4.8 | Adj. SR 345, dst. TR 441 | 72.0 | Coal fines in stream, acid mine drainage |
| Turkey Run | 2.8 | TR 49 – upper crossing | 75.0 | |
| Turkey Run | 0.4 | RR bridge near mouth | 72.0 | |
| Valley Run | 3.5 | Cherry Hill Road | 74.0 | Extensively embedded |
| Valley Run | 0.5 | George Ice Road | 83.5 | |
| Ogg Creek | 0.2 | Near mouth, adj. TR 747 | 80.0 | Coal fines in stream, acid mine drainage |
| **GOOD** | | | | |
| Moxahala Creek | 24.0 | TR 312, south of Moores Junction | 63.0 | Iron floc, extensive sand embedded. |
| Moxahala Creek | 21.9 | State Route 37 | 65.0 | Iron floc, recovered channel mod. |
| Moxahala Creek | 6.9 | Lambert Road | 65.0 | Coal fines in stream, iron floc |
| Moxahala Creek | 0.6 | CR 6 @ South Zanesville | 70.5 | |
| Jonathan Creek | 27.0 | State Route 204 | 55.0 | Extensively embedded |
| Jonathan Creek | 17.0 | Dst. SR 204, near Glass Rock | 64.5 | Moderately embedded |
| Jonathan Creek | 12.2 | CR 34 @ Mount Perry | 67.0 | Extensively embedded |
| Jonathan Creek | 1.3 | SR 93 near Avondale | 65.0 | No riffle - impounded |
| Shawnee Run | 0.1 | Milldale Rd./Greenhouse Rd. | 57.5 | |
| Black Fork | 3.5 | Adjacent Tatmans Road | 63.5 | No functional riffle - no flow |
| Black Fork | 2.3 | Downstream Ogg Creek | 70.0 | Iron floc, moderately embedded |
| Black Fork | 2.0 | State Route 669 | 65.5 | Iron floc, extensively embedded |
| Black Fork | 0.1 | Ceramic Rd. near Crooksville | 62.0 | Extensive embeddedness |
| Thompson Run | 0.5 | US 22 | 63.5 | Extensive embeddedness |
| Buckeye Fork | 3.5 | Fletcher Road | 58.0 | Channel modified |
| Buckeye Fork | 1.4 | Fultonrose Rd. @ E. Fultonham | 65.0 | Extensively embedded , white floc |
| Butcherknife Creek | 0.1 | State Route 345 | 61.5 | Channel modified, acid mine drainage |
| Painter Creek | 2.5 | TR 76 @ Gower Road | 55.0 | Extensively embedded, no functioning riffle |
| Painter Creek | 0.9 | Copperrider Road | 69.5 | Extensive embeddedness |
| Valley Run | 5.1 | Laurel Hill Road | 60.5 | Extensively embedded |
| Ogg Creek | 2.0 | SR 555, south of Deavertown | 67.0 | No functional riffle – interstitial flow |
| Bowling Green Run | 0.2 | Boundaries Road | 61.5 | Extensively embedded |
| Trib. to Jonathan Cr. | 19.47, 0.4 | TR 19 near Glenford | 57.5 | Extensively embedded |
| **FAIR** | | | | |
| Moxahala Creek | 13.4 | Dst. Roseville WWTP | 57.0 | Large sand bedload, iron floc |
| Jonathan Creek | 22.2 | Hopewell Indian Road | 57.5 | Extensively embedded, channel modified |
| Andrew Run | 0.4 | State Route 13 | 54.0 | Extensively embedded |
| Trib. to Moxahala Cr. | 22.56, 0.2 | SR 13, south of Moores Junction | 51.0 | Extensively embedded, iron floc |
| Painter Run | 0.2 | Coppermill Road | 44.5 | Sparse cover, no functional riffle |

*Table 9. Continued.*

| Stream | River Mile | Location | QHEI | Comments |
|---|---|---|---|---|
| **POOR** | | | | |
| Bush Creek | 0.2 | State Route 345 | 38.5 | Extensively embedded, channel modified, no riffle, limestone dust on bottom |

| General narrative ranges assigned to QHEI scores. | | | |
|---|---|---|---|
| Narrative Rating | | QHEI Range | |
| | | Headwaters (≤20 sq mi) | Larger Streams |
| Excellent | | ≥70 | ≥75 |
| Good | | 55 to 69 | 60 to 74 |
| Fair | | 43 to 54 | 45 to 59 |
| Poor | | 30 to 42 | 30 to 44 |
| Very Poor | | <30 | <30 |

## Fish Community

A total of 41,879 fish representing 50 species were collected from the Moxahala Creek watershed between June and September, 2008. Relative numbers and species collected per location are presented in Appendix Table 9, and IBI and MIwb scores are presented in Appendix Table 10. Sampling locations were evaluated using Warmwater Habitat (WWH), Exceptional Warmwater Habitat (EWH), Modified Warmwater Habitat (MWH) or Limited Resource Water (LRW) biocriteria. A summary of the fish data are presented in Table 11.

**Fish Biocriteria Full Attainment**

Watershed: 67%
Moxahala Creek: 0%
Jonathan Creek: 96%

The Moxahala watershed sites sampled during 2008 achieved the applicable WWH, EWH, MWH, or LRW fish biocriterion at 30 of the 45 sites evaluated (67%). Two sites were partially achieving the biocriterion. Thirteen sites were not achieving the LRW and WWH biocriteria, representing 29% of the watershed sites. Of these 13 sites, the entire Moxahala Creek mainstem (six sites) and two sites on the Black Fork and two sites on Buckeye Fork were represented by very poor fish communities. All sites which did not achieve the fish biocriterion were impacted by acid mine drainage from past mining activities.

*Table 10. Average IBI scores for Moxahala Creek, upstream and downstream from the Jonathan Creek confluence, 2008.*

| | IBI |
|---|---|
| Upstream Jonathan Creek | 12.5 |
| Downstream Jonathan Creek | 27.0 |

Because of the extensive impact from coal mining in the Moxahala basin, the number of fish collected in the Moxahala Creek mainstem was only 674 individuals, but in Jonathan Creek the number was 16,411. IBI and MIwb scores were much higher in Jonathan Creek as well with an overall average IBI score of 45, compared to an average score of 17.3 in Moxahala Creek. The positive water quality influence of Jonathan Creek on the lower Moxahala Creek is noted in Table 10, where IBI scores doubled in Moxahala Creek downstream from the Jonathan Creek confluence. Due to the effects of acid mine drainage from old abandoned subsurface mines, Moxahala Creek did not meet LRW biocriterion/benchmark or WWH biocriteria in the 25 miles of stream monitored during 2008 (0% attainment). Acutely toxic conditions were noted in the entire length of Moxahala Creek upstream from the confluence with Jonathan Creek. Fish were absent from the two most upstream sampling locations (RM 24.0 and 21.8). Jonathan Creek fish communities were in the good to exceptional range throughout the 28 miles of monitored stream. Aside from the lowhead dam impoundment located at RM 1.1, the entire length of Jonathan Creek met the WWH fish biocriteria (96% full attainment).

A total of 18 small tributary streams (31 sites) were sampled in the watershed during 2008. Thirteen of these streams were fully achieving the applicable WWH, EWH, MWH, or LRW IBI biocriterion for fish. Two tributaries were nearly fully achieving the WWH biocriterion (Ogg Creek and Valley Run). Three streams were not achieving the applicable fish biocriterion (Black Fork, Buckeye Fork, and Butcherknife Creek). All impaired tributary stream sites were impacted by acid mine drainage. Very poor fish communities were documented in the Black Fork (3 of 4 sites), Buckeye Fork (2 of 3 sites), and Butcherknife Creek. These very poor conditions suggest acutely toxic conditions.

In the Jonathan Creek subwatershed, Ohio endangered (E), threatened (T), or special concern fish species collected during this survey included the eastern sand darter, a special concern species. Fish species collected from the Jonathan Creek subwatershed which are sensitive to water pollution included black redhorse, bigeye chub, mimic shiner, brindled madtom, eastern sand darter, and banded darter. Pollution sensitive fish comprised 2.1 percent of the fish community. There were no sensitive fish species found in the Moxahala Creek subwatershed.

*Table 11. Fish community summaries based on pulsed D.C. electrofishing sampling conducted by Ohio EPA in the Jonathan Creek and Moxahala Creek watersheds from July – October, 2008. Relative numbers and weight are per 1.0 km for boat sites and 0.3 km for wading sites. NA= not applicable*

| Stream | River Mile | Sampling Method | Fish Species (Total) | Relative Number | Relative Weight (kg) | QHEI (Habitat) | IBI | MIwb | Narrative Evaluation |
|---|---|---|---|---|---|---|---|---|---|
| Moxahala Creek | 24.0 | Wading | 0 | 0 | NA | 63.0 | **12*** | NA | Very Poor |
| Moxahala Creek | 21.8 | Wading | 0 | 0 | 0.0 | 65.0 | **12*** | **0.0*** | Very Poor |
| Moxahala Creek | 13.4 | Wading | 3 | 6 | 0.2 | 57.0 | **14*** | **0.6*** | Very Poor |
| Moxahala Creek | 6.8 | Wading | 1 | 3 | 0.04 | 65.0 | **12*** | **0.0*** | Very Poor |
| Moxahala Creek | 4.3 | Wading | 19 | 60 | 3.7 | 81.5 | **25*** | **5.9*** | Poor/Fair |
| Moxahala Creek | 0.6 | Boat | 20 | 341 | 48.7 | 70.5 | **29*** | **7.9*** | Fair |
| Black Fork | 3.2 | Wading | 13 | 702 | NA | 63.5 | **34*** | NA | Fair |
| Black Fork | 2.5 | Wading | 2 | 26 | 0.16 | 70.0 | **12*** | **0.0*** | Very Poor |
| Black Fork | 1.9 | Wading | 4 | 42 | 0.2 | 65.5 | **12*** | **0.0*** | Very Poor |
| Black Fork | 0.1 | Wading | 6 | 108 | 0.5 | 62.0 | **24*** | **0.9*** | Poor/Very Poor |
| Ogg Creek | 2.1 | Wading | 11 | 1394 | NA | 67.0 | **36*** | NA | Fair |
| Ogg Creek | 0.2 | Wading | 4 | 80 | NA | 80.0 | **20** | NA | Poor |
| Andrews Run | 0.3 | Wading | 4 | 185 | NA | 54.0 | **20** | NA | Poor |
| Trib. to Moxa @ RM 22.56 | 0.1 | Wading | 5 | 459 | NA | 51.0 | **26** | NA | Poor |
| Shawnee Run | 0.1 | Wading | 14 | 1128 | NA | 57.5 | **44** | NA | Good |
| Jonathan Creek | 27.1 | Wading | 19 | 2940 | NA | 55.0 | **48** | NA | Very Good |
| Jonathan Creek | 22.3 | Wading | 21 | 3828 | 43.4 | 57.5 | **52** | **10.4** | Exceptional |
| Jonathan Creek | 17.4 | Wading | 24 | 3298 | 29.0 | 64.5 | **37$^{ns}$** | **9.5** | Marg. Good/Exceptional |
| Jonathan Creek | 12.3 | Wading | 24 | 2215 | 26.5 | 67.0 | **44** | **9.6** | Good/Exceptional |
| Jonathan Creek | 7.6 | Wading | 21 | 1735 | 17.8 | 90.0 | **43** | **9.2** | Marg. Good/Very Good |
| Jonathan Creek | 3.3 | Wading | 28 | 1330 | 38.0 | 87.9 | **51** | **10.0** | Exceptional |
| Jonathan Creek | 1.1 | Boat | 13 | 416 | 38.1 | 65.0 | **44** | **6.9*** | Very Good/Fair |
| Jonathan Creek | 0.9 | Wading | 30 | 1762 | 72.9 | 76.5 | **46** | **9.8** | Very Good/Exceptional |
| Bowling Green Run | 0.1 | Wading | 22 | 3766 | NA | 61.5 | **52** | NA | Exceptional |
| Valley Run | 5.4 | Wading | 22 | 2038 | NA | 60.5 | **50** | NA | Exceptional |
| Valley Run | 3.5 | Wading | 25 | 2140 | NA | 74.0 | **56** | NA | Exceptional |
| Valley Run | 1.3 | Wading | 23 | 2710 | 25.9 | 83.5 | **52** | **10.2** | Exceptional |
| Trib. Jonathan @ RM 19.5 | 0.7 | Wading | 22 | 4030 | NA | 57.5 | **42** | NA | Good |
| Painter Creek | 2.5 | Wading | 23 | 2102 | NA | 55.0 | **48** | NA | Very Good |
| Painter Creek | 0.9 | Wading | 21 | 2224 | NA | 69.5 | **46** | NA | Very Good |
| Turkey Run | 2.9 | Wading | 19 | 1106 | NA | 75.0 | **40** | NA | Marginally Good |
| Turkey Run | 0.2 | Wading | 21 | 872 | NA | 72.0 | **48** | NA | Very Good |
| Buckeye Fork | 4.9 | Wading | 0 | 0 | NA | 72.0 | **12*** | NA | Very Poor |
| Buckeye Fork | 3.4 | Wading | 1 | 8 | NA | 58.0 | **12*** | NA | Very Poor |
| Buckeye Fork | 1.2 | Wading | 8 | 256 | 7.7 | 65.0 | **28** | **4.6** | Fair/Poor |
| Butcherknife Creek | 0.1 | Wading | 1 | 6 | NA | 61.5 | **12*** | NA | Very Poor |
| Kent Run | 8.9 | Wading | 17 | 2812 | NA | 70.0 | **38$^{ns}$** | NA | Fair |
| Kent Run | 3.7 | Wading | 18 | 5320 | NA | 81.5 | **54** | NA | Exceptional |
| Kent Run | 1.4 | Wading | 17 | 5100 | 14.4 | 75.0 | **40$^{ns}$** | **8.5** | Marginally Good/Good |

*Table 11. Continued.*

| Stream | River Mile | Sampling Method | Fish Species (Total) | Relative Number | Relative Weight (kg) | QHEI (Habitat) | **IBI** | **MIwb** | Narrative Evaluation |
|---|---|---|---|---|---|---|---|---|---|
| Thompson Run | 4.7 | Wading | 16 | 2416 | NA | 72.5 | **42**$^{ns}$ | NA | Marginally Good |
| Thompson Run | 0.4 | Wading | 21 | 1910 | NA | 63.5 | **44** | NA | Good |
| Hibbs Run | 0.1 | Wading | 14 | 1430 | NA | 77.0 | **50** | NA | Exceptional |
| Salt Run | 0.1 | Wading | 12 | 834 | NA | 76.0 | **46** | NA | Very Good |
| Bush Creek | 0.1 | Wading | 15 | 1408 | NA | 38.5 | **40**$^{ns}$ | NA | Marginally Good |
| Painter Run | 0.2 | Wading | 16 | 2966 | NA | 44.5 | **38** | NA | Fair |

| **BIOCRITERIA** | | | | |
|---|---|---|---|---|
| Ecoregion | WAP | EOLP | Statewide | |
| INDEX - Site Type | WWH | WWH | EWH | LRW |
| **IBI**: Headwater/Wading/Boat | 44/44/40 | 40/38/40 | 50/50/48 | 18/18/16 |
| **MIwb**: Wading/Boat | 8.4/8.6 | 7.9/8.7 | 9.4/9.6 | 4.5/5.0 |

$^{ns}$ Nonsignificant departure from biocriterion (≤4 IBI or ICI units; ≤0.5 MIwb units).
* Significant departure from biocriterion (>4 IBI or ICI units; >0.5 MIwb units). Poor and very poor results are underlined.

**Macroinvertebrate Community**

The macroinvertebrate communities from 48 locations in the Moxahala Creek watershed were sampled in 2008. Qualitative samples were collected from all sampling locations. Quantitative samples, used to generate Invertebrate Community Index (ICI) scores, were collected from five locations in Jonathan Creek, one location in Moxahala Creek, and six locations in six tributaries. A summary of the macroinvertebrate data are presented in Table 12. The ICI metrics and the raw data are presented in Appendix Tables 11 and 12. Sampling locations were evaluated using Warmwater Habitat (WWH), Limited Resource Water (LWH), Exceptional Warmwater Habitat (EWH) or Modified Warmwater Habitat (MWH) biocriteria.

Moxahala Creek watershed sites sampled during 2008 achieved the applicable LRW, MWH, WWH or EWH macroinvertebrate biocriterion/ benchmark at 37 of the 46 sites evaluated (80%). Seven sites were not achieving the LRW benchmark biocriterion (all rated as very poor quality), one site was not meeting the EWH biocriterion (rated as good quality), and one site was not meeting the WWH biocriterion (rated as fair quality).

**Macroinvertebrate Biocriteria Full Attainment**
Watershed: 80%
Moxahala Creek: 28%
Jonathan Creek: 100%

Moxahala Creek and Jonathan Creek macroinvertebrate communities were evaluated at a total of 14 sites. Macroinvertebrate communities for the entire length (100%) of Jonathan Creek were meeting the WWH biocriterion. Pollution sensitive macroinvertebrate taxa were common in Jonathan Creek, where sensitive taxa numbers ranged between 19 and 32 per site (excluding the impounded site at RM 1.1). Severe biological degradation was observed in the Moxahala Creek macroinvertebrate communities at the most upstream sites (RMs 24.0 – 13.4) where acid mine drainage effects were most severe. The macroinvertebrate communities in this upper reach of Moxahala Creek were of very poor quality, with zero to one pollution sensitive taxa per site. pH levels in this section of stream were below 5.0 S.U., with values reported as low as 2.9 S.U (Figure 4). Some improvement in macroinvertebrate quality occurred in Moxahala Creek downstream from the confluence with Jonathan Creek, where communities achieved high fair to very good conditions further downstream. Improvement was associated with high quality water dilution from Jonathan Creek.

A total of 19 smaller tributary streams (32 sites) were sampled in the watershed during 2008. Twenty-seven (27) of these stream sites were fully meeting the applicable EWH, WWH, MWH, or LRW biocriterion/benchmark for macroinvertebrate populations. Four of the five tributary sites were not meeting LRW benchmark values, with all reflective of very poor water quality. These very poor quality sites occurred on Black Fork Moxahala Creek, Andrews Run, and Buckeye Fork. All of these sites are designated with the LRW aquatic life use designation, due to acid mine drainage impacts. The macroinvertebrate community from one low gradient tributary site (Valley Run – RM 5.4) was rated as good, but did not achieve the EWH biocriterion. This was most likely due to low flow conditions exacerbated by periods of runoff from agricultural activities (grazing), and failing home septic systems.

*Table 12. Summary of macroinvertebrate data collected from artificial substrates (quantitative sampling) and natural substrates (qualitative sampling) in the Moxahala Creek and Jonathan Creek watersheds, June – September, 2008.*

| Stream | River Mile | Data Codes | Qual. Taxa | Total Taxa | Qual./Total EPT[a] | Sensitive Taxa Qual./Total | Density (#/ft.$^2$) | ICI | Narrative Evaluation |
|---|---|---|---|---|---|---|---|---|---|
| Moxahala Creek | 24.0 | X19 | 2 | 2 | 0 / 0 | 0 / 0 | Low | NA | Very Poor* |
| Moxahala Creek | 21.8 | | 5 | 5 | 1 / 1 | 0 / 0 | Low | NA | Very Poor* |
| Moxahala Creek | 13.4 | X15,25 | 11 | 13 | 1 / 1 | 1 / 1 | 6 | **0*** | Very Poor* |
| Moxahala Creek | 6.9 | | 9 | 9 | 4 / 4 | 2 / 2 | Low | NA | Low Fair |
| Moxahala Creek | 4.3 | | 25 | 25 | 7 / 7 | 6 / 6 | Low | NA | High Fair* |
| Moxahala Creek | 0.8 | X13 | 40 | 40 | 14/14 | 15/15 | High-Low | NA | Very Good |
| Andrews Run (Moxahala Trib. @ RM 24.79) | 0.3 | X19 | 1 | 1 | 0 / 0 | 0 / 0 | Low | NA | Very Poor* |
| Trib. to Moxahala Creek @ RM 22.56 | 0.1 | | 19 | 19 | 3 / 3 | 4 / 4 | Mod.-Low | NA | High Fair |
| Black Fork Moxahala Cr. Ref. | 3.6 | X19 | 46 | 46 | 12/12 | 11/11 | Mod.-Low | NA | Good |
| Black Fork Moxahala Cr. Mod. Ref. | 2.5 | X15 | 13 | 23 | 2 / 3 | 1 / 2 | Low | **10** | Poor |
| Black Fork Moxahala Cr. | 1.9 | X25 | 7 | 14 | 1 / 1 | 1 / 2 | Low | **0** | Very Poor* |
| Black Fork Moxahala Cr. Mod. Ref. | 0.2 | | 9 | 9 | 0 / 0 | 2 / 2 | Low | NA | Very Poor* |
| Ogg Creek Ref. | 2.1 | X15,19 | 44 | 64 | 11/13 | 12/22 | 265 | **40**[b] | Very Good |
| Ogg Creek | 0.1 | X9 | 23 | 23 | 4 / 4 | 1 / 1 | Mod.-Low | NA | Low Fair |
| Shawnee Run | 0.1 | X19 | 30 | 30 | 9 / 9 | 4 / 4 | Mod.-Low | NA | Marginally Good |
| Jonathan Creek | 27.1 | X19 | 57 | 57 | 15/15 | 22/22 (4 CW) | Moderate | NA | Very Good |
| Jonathan Creek | 22.4 | X15 | 61 | 81 | 10/11 | 18/27 (3 CW) | 1228 | **42** | Very Good |
| Jonathan Creek | 17.5 | X15 | 53 | 74 | 14/17 | 20/32 | 99 | **28**[b] | Very Good |
| Jonathan Creek Ref. | 12.2 | | 55 | 71 | 11/15 | 26/31 | 560 | **46** | Exceptional |
| Jonathan Creek | 7.6 | X15 | 41 | 56 | 16/17 | 22/29 | 666 | **40** | Good |
| Jonathan Creek | 3.3 | X4 | 34 | 53 | 12/17 | 15/23 | 418 | **38** | Good |
| Jonathan Creek | 1.1 | X15 | 24 | 52 | 4/11 | 7/13 | 223 | **32** | Marginally Good |
| Jonathan Creek | 0.8 | | 41 | 41 | 15/15 | 19/19 | Mod.-High | NA | Very Good |
| Bowling Green Run | 0.1 | | 50 | 50 | 11/11 | 16/16 | Mod.-Low | NA | Good |
| Valley Run | 5.4 | X19 | 39 | 39 | 9 / 9 | 14/14 | Mod.-Low | NA | Good* |
| Valley Run | 3.5 | | 48 | 48 | 14/14 | 20/20 | Moderate | NA | Very Good |
| Valley Run | 1.4 | X5,12 | 61 | 83 | 11/14 | 15/26 | 758 | **46** | Exceptional |
| Trib. to Jonathan Creek @ RM 19.47 | 0.1 | X19 | 41 | 41 | 12/12 | 12/12 | Mod.-Low | NA | Good |
| Painter Creek | 2.5 | | 34 | 34 | 12/12 | 11/11 | Mod.-Low | NA | Good |
| Painter Creek | 0.9 | | 57 | 74 | 14/19 | 20/32 | 1447 | **48** | Exceptional |
| Trib. to Jonathan Creek @ RM 13.74 | 0.3 | X19 | 36 | 36 | 11/11 | 12/12 | Mod.-High | NA | Good |
| Painter Run | 0.1 | X19 | 27 | 27 | 2 / 2 | 8 / 8 | Moderate | NA | High Fair |
| Turkey Run | 2.8 | X19 | 25 | 25 | 10/10 | 10/10 | Low | NA | Good |
| Turkey Run | 0.3 | | 43 | 43 | 12/12 | 15/15 | Mod.-Low | NA | Very Good |
| Buckeye Fork | 5.5 | X19 | 8 | 8 | 0 / 0 | 0 / 0 | Low | NA | Very Poor* |

*Table 12. Continued.*

| Stream | River Mile | Data Codes | Qual. Taxa | Total Taxa | Qual. EPT[a] | Sensitive Taxa Qual./Total | Density (#/ft.$^2$) | **ICI** | Narrative Evaluation |
|---|---|---|---|---|---|---|---|---|---|
| Buckeye Fork | 3.4 | | 15 | 15 | 2 / 2 | 0 / 0 | Low | NA | Poor |
| Buckeye Fork | 1.5 | | 10 | 26 | 3/ 5 | 2/7 | 12 | **22** | Fair |
| Butcherknife Creek | 0.1 | X19 | 11 | 11 | 2 / 2 | 0 / 0 | Low | NA | Low Fair |
| Bush Creek | 0.1 | X19 | 27 | 27 | 11/11 | 7 / 7 | High-Low | NA | Marginally Good |
| Kent Run | 8.9 | X19 | 52 | 52 | 15/15 | 18/18 (3 CW) | High-Low | NA | Very Good |
| Kent Run | 3.6 | | 44 | 44 | 15/15 | 17/17 | Mod.-Low | NA | Very Good |
| Kent Run | 1.3 | | 57 | 57 | 17/17 | 24/24 | Mod.-High | NA | Exceptional |
| Salt Run | 0.1 | X19 | 35 | 35 | 14/14 | 12/12 (4 CW) | Mod.-Low | NA | Good |
| Thompson Run | 4.8 | X19 | 42 | 42 | 12/12 | 15/15 (4 CW) | Mod.-Low | NA | Good |
| Thompson Run | 0.3 | | 39 | 39 | 14/14 | 11/11 | Mod.-Low | NA | Good |
| Hibbs Run | 0.1 | X19 | 33 | 33 | 15/15 | 15/15 (3 CW) | Mod.-Low | NA | Very Good |

| Biocriteria | | | | | |
|---|---|---|---|---|---|
| Ecoregion | WAP | WAP | WAP | EOLP | EOLP |
| INDEX – Site Type | LRW[c] | WWH | EWH | WWH | EWH |
| ICI | 8 | 36 | 46 | 36 | 46 |

[a] EPT = total Ephemeroptera (mayflies), Plecoptera (stoneflies), and Trichoptera (caddisflies) taxa richness.
[b] Narrative evaluation used in lieu of ICI score to assess biological quality. ICI results were influenced by low flow conditions.
[c] LRW value is a benchmark, not a codified criterion.
* Significant departure from biocriterion (>4 ICI units) or narrative ranges. Poor and very poor results are underlined.
Data codes: X9= intermittent or near-intermittent conditions; X13= suspected disturbance by vandalism; X15 = current >0.0 feet per second but < 0.3 fps; X19=drainage area <10 sq.mi.; X4= 2HDs only; X5=3HDs only; X12=suspected high water influences; X25= < 50 organisms on the HD (% metrics automatically scored 0)
CW = Coldwater taxa

## WATERSHED ASSESSMENTS UNITS

The Moxahala Creek basin is comprised of two 10-digit Hydrologic Unit Code (HUC 10) watersheds, subdivided into eleven 12-digit HUC (HUC12) watersheds. Moxahala Creek has four HUC12 watersheds and Jonathan Creek has seven HUC12 watesheds. Data from individual sampling locations in a HUC12 assessment unit are accumulated and analyzed; summary information for each Moxahala Creek watershed assessment unit (WAU) is presented in this section. Data used in this analysis were collected in 2008. High magnitude causes and sources contributing to the biological impairment (partial and non-attainment) are noted. The Jonathan Creek watershed assessment unit exceeded the statewide goal of 80 percent full attainment of biological integrity (however the Federal CWA goal is 100% attainment so both HUCs evaluated for Moxahala Creek are considered impaired).

*Table 13. Results for the Moxahala Creek watershed using the HUC12 methodology.*

| **HUC-10** HUC-12 (drainage area in $mi^2$) | **Headwater Sites (# sites; <20 $mi^2$)** | | | **Wading Stream (miles; ≥ 20 $mi^2$ <50 $mi^2$ )** | | | **Principal Stream (miles; ≥ 50 $mi^2$ <500 $mi^2$)** | | |
|---|---|---|---|---|---|---|---|---|---|
| | **Full** | **Partial** | **Non** | **Full** | **Partial** | **Non** | **Full** | **Partial** | **Non** |
| **0504000404** Jonathan Creek (headwaters to Moxahala Creek confluence) | | | | | | | | | |
| 401 (29.4) | 1 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 |
| 402 (27.99) | 2 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 |
| 403 (14.03) | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 404 (23.4) | 1 | 0 | 3 | 1 | 0 | 0 | 0 | 0 | 0 |
| 405 (22.8) | 3 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 |
| 406 (15.4) | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 407 (60.58) | 5 | 0 | 0 | 0 | 0 | 0 | 5 | 1 | 0 |
| **TOTAL** | **17** | **1** | **3** | **4** | **0** | **0** | **5** | **1** | **0** |
| Causes/Sources of Impairment<br>**Jonathon Creek** - Direct habitat alterations/ dam<br>**Valley Run -** Low D.O/NPS runoff, Rural (home septic)<br>**Buckeye Fork-** Mn, Ni,Sulfate, Al, Acidity/AMD<br>**Butcherknife Run -** Mn, Ni,Sulfate, Al, Acidity/AMD | | | | | | | | | |
| **050400040** Moxahala Creek (all of Moxahala Creek without Jonathan Creek watershed) | | | | | | | | | |
| 501 (28.7) | 0 | 2 | 1 | 0 | 0 | 3 | 0 | 0 | 0 |
| 502 (39.06) | 0 | 1 | 2 | 0 | 0 | 1 | 0 | 0 | 0 |
| 503 (18.3) | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| 504 (22.1) | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 2 |
| **TOTAL** | **1** | **3** | **3** | **0** | **0** | **4** | **0** | **1** | **3** |
| Causes/Sources of Impairment<br>**Moxhaha Creek** - Acidity, pH, Sulfate, Fe, Al, Mn, Ni, Ammonia / AMD, SSOs<br>**Black Fork –** Low D.O., Fe, Mn, Sulfate, Al, Acidity/ Rural (home septic), AMD<br>**Ogg Creek** – Fe, Sulfate, Al , NH3,Nitrate+Nitrite/Rural (home septic), AMD<br>**Andrews Run** – Fe, Mn, Ni,Sulfate, Al, Acidity/AMD<br>**Trib to Moxahala at RM 22.56 -** Fe, Mn, Ni,Sulfate, Al, Acidity/AMD | | | | | | | | | |

## RECOMMENDATIONS

All of the streams in the Moxahala Creek watershed currently listed in the Ohio Water Quality Standards are assigned one or more of the following aquatic life use designations: Warmwater Habitat (WWH), Limited Warmwater Habitat (LWH) – acid mine drainage, Modified Warmwater Habitat (MWH) due to mining impacts, Exceptional Warmwater Habitat (EWH), and Limited Resource Water (LRW) – acid mine drainage (LRW-AMD). Kent Run, Black Fork and Ogg Creek are the only streams within the survey watershed that had aquatic life use designations verified through past Ohio EPA biological sampling. All other streams were originally designated for aquatic life uses in the 1978 Ohio WQS. The techniques used then did not include standardized approaches to the collection of instream biological data or numerical biological criteria. This study used biological data to evaluate and establish aquatic life uses for a number of streams in the Moxahala Creek watershed.

LWH streams were temporarily designated in the 1978 water quality standards as not meeting specific WWH criteria. Criteria for the support of the LWH use designation are the same as the criteria for the support of the use designation WWH. However, individual criteria are varied on a case-by-case basis and supersede the criteria for WWH where applicable. For streams assigned the LWH use in the Moxahala Creek watershed, the following WWH criteria are exempt: dissolved solids, pH, iron and zinc. No additional stream segments will be designated LWH.

An Acid Mine Drainage Abatement and Treatment (AMDAT) Plan for the Moxahala Creek Watershed (Ohio University 2005) was prepared by The Institute for Government Administration and Rural Development (ILGARD) at Ohio University. In addition, Midwest Biological Institute (MBI) conducted an extensive biological survey of the Moxahala Creek subwatershed (Rankin 2004) in support of the AMDAT. The AMDAT recommended that the use designation for Moxahala Creek be upgraded from LRW to WWH. However because of the extensive amount of mining impairment, it is unlikely that Moxahala Creek will meet WWH habitat in a reasonable amount of time. The conservative cost for all restoration projects based on 2005 dollars is 50 million dollars plus annual operation and maintenance costs. If the restoration projects are completed in the Moxahala Creek watershed, then upgrading the LRW use designation to WWH will be reconsidered in the future.

Twenty-one streams in the Moxahala Creek watershed were evaluated for aquatic life and sixteen streams were evaluated for recreation use potential in 2008 (Table 2). Significant findings include the following:

- The Moxahala Creek existing use designation should remain LRW-AMD upstream from the confluence with Jonathan Creek. Based on biology and habitat scores, the lower section of Moxahala Creek is recommended for upgrade to WWH. Based on the performance of the biological communities, Jonathan Creek should be listed as WWH for its entire length. This is an upgrade for the lower 11 miles of stream, which is currently listed as LWH, and the first comprehensive assessment for the upper 17 miles of stream, which is unverified EWH.
- Shawnee Run, Thompson Run, Salt Run, Bush Creek, and Turkey Run are currently listed as LWH streams. Biological monitoring during this study confirmed that these streams should be designated WWH. Hibbs Run has an LWH existing use designation; however, biological results confirmed that the appropriate use is EWH and CWH.
- Based on this biological and water quality study, eight streams within the Moxahala Creek watershed listed in the Ohio WQS as Limited Warmwater Habitat are recommended as WWH or EWH.
- Ogg Creek (RM 1.4 to mouth) and should be upgraded from LRW-AMD to MWH due to mining impacts based on the biological community.
- Existing use designations for Buckeye Fork (LRW), Kent Run (WWH), Butcherknife Creek (LRW), Valley Run (EWH), and Ogg Creek (WWH - from the headwaters to RM 1.4) should be maintained. Painter Run's existing use designation is unverified EWH and is recommended MWH based on stream habitat and biological results.
- Six streams evaluated in this study are not currently listed in the Ohio WQS. These streams include Andrews Run, Painter Creek, Bowling Green Run, two unnamed tributaries to Jonathan Creek (@ RMs 13.74 and 19.47), and two unnamed tributaries to Moxahala Creek (@ RMs 22.56 and 24.79). The recommended use designations are noted in Table 14.

- The Coldwater Habitat (CWH) aquatic life use designation is recommended for the entire length of two streams (Salt Run and Hibbs Run), and the upper section of two streams (Jonathan Creek and Thompson Run).
- The Moxahala Creek mainstem and tributaries affected by AMD should follow recommendations set in the Acid Mine Drainage Abatement and Treatment (AMDAT) Plan for the Moxahala Creek Watershed for stream restoration. The treatment options described in the AMDAT include instream treatment, active and passive treatment, along with rehabilitation of current treatment works.
- Buckeye Fork and Butcherknife Creek were not included in the initial AMDAT. A reconnaissance survey should be done to determine the extent of the problems and if they should become part of the AMDAT. Currently, the alkaline discharge from the Shelly Materials, Inc. East Fultonham Limestone Quarry is acting as an AMD treatment structure for Buckeye Fork. This type of treatment should continue to prevent future impairments to Jonathan Creek below Buckeye Fork.
- Better housekeeping and management practices need to occur at the Oglebay Norton Industrial Sands Inc. facility to prevent and decrease nonpoint sand runoff into an unnamed tributary to Jonathan Creek at RM 17.55 and into Jonathan Creek downstream from the tributary.
- The Muskingum County Commissioners need to work with the City of Zanesville to address the chronic sanitary sewer overflows (SSOs) from the South System that are impacting both the biological community and the recreation use of the lower section of Moxahala Creek.
- A study should be conducted on the feasibility of removing the lowhead dam on Jonathan Creek which is the only location on the mainstem that is not meeting WWH.

All 21 streams in this study should retain the Primary Contact Recreation use, along with the Agricultural Water Supply and Industrial Water Supply uses. Kent Run at RM 1.3, Dry Run at RM 2.23, and Black Fork at RM 4.69 should remain PWS.

Table 14. *Waterbody use designation recommendations for the Moxahala Creek basin.* *Designations based on the 1978 and 1985 water quality standards appear as asterisks (*). A plus sign (+) indicates a new recommendation or confirmation of an existing use based on the findings of this report. L – Limited Warmwater Habitat, varied criteria year around: exempt from the WWH total dissolved solids, pH, iron, and zinc criteria. O – designation based on non-Ohio EPA biological field assessment.*

| Water Body Segment | Use Designations | | | | | | | | | | | | | Comments |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Aquatic Life Habitat | | | | | | Water Supply | | | Recreation | | | |
| | SRW | WWH | EWH | MWH | SSH | CWH | LRW | PWS | AWS | IWS | BW | PCR | SCR | |
| Moxahala Creek - Jonathan Creek to the mouth | | + | | | | | | | + | + | | + | | |
| - all other segments | | | | | | | + | | + | + | | + | | Acid mine drainage. |
| Shawnee Run | | + | | | | | | | + | + | | + | | |
| Jonathan Creek – SR 204 Bridge (RM 27.08 to mouth) | | + | | | | | | | + | + | | + | | |
| – headwaters to SR 204 Bridge (RM27.08) | | | | | | + | | | + | + | | + | | |
| Thompson Run - RM 4.73 to mouth | | + | | | | | | | + | + | | + | | |
| - Headwaters to RM 4.73 | | | | | | + | | | + | + | | + | | |
| Hibbs Run | | | + | | | + | | | + | + | | + | | |
| Kent Run – at RM 1.3 | | + | | | | | | + | + | + | | + | | |
| - all other segments | | + | | | | | | | + | + | | + | | |
| Salt Run | | | | | | + | | | + | + | | + | | |
| Buckeye Fork | | | | | | | + | | + | + | | + | | Acid mine drainage. |
| Bush Creek | | + | | | | | | | + | + | | + | | |
| Twomile Run | | | | | | | | | + | + | | + | | Primary Headwater Class III Pending |
| Butcherknife Creek | | | | | | | + | | + | + | | + | | Acid mine drainage. |
| Turkey Run | | + | | | | | | | + | + | | + | | |
| Painter Run | | | | + | | | | | + | + | | + | | Channel modification |
| Tributary to Jonathan Creek (RM 13.74) | | + | | | | | | | + | + | | + | | |
| Painter Creek | | | + | | | | | | + | + | | + | | |
| Tributary to Jonathan Creek (RM 19.47) | | + | | | | | | | + | + | | + | | |
| Valley Run | | | + | | | | | | + | + | | + | | |
| Berry Run | * | | * | | | | | | * | * | | * | | |
| Bowling Green Run | | + | | | | | | | + | + | | + | | |
| Morrison Run | | | | | | | O | | + | + | | + | | Acid mine drainage |
| Porter Run | | | | | | | O | | + | + | | + | | Acid mine drainage |
| Elk Run | | | | | | | O | | + | + | | + | | Acid mine drainage |
| Riders Run | | | | | | | O | | + | + | | + | | Acid mine drainage |
| Burley Run | | | | | | | O | | + | + | | + | | Acid mine drainage |
| Snake Run | | | | | | | O | | + | + | | + | | Acid mine drainage |
| Black Fork – headwaters to south Morgan Co. line (RM 2.8) | | + | | | | | | | + | + | | + | | |
| - at RM 4.69 | | + | | | | | | + | + | + | | + | | |
| - RM 2.8 to mouth | | | | | | | + | | + | + | | + | | |
| Dry Run – at RM 2.23 | | *L | | | | | | + | * | * | | * | | Acid mine drainage |
| - all other segments | | *L | | | | | | | * | * | | * | | Acid mine drainage |

*Table 14. Continued.*

| Water Body Segment | Use Designations | | | | | | | | | | | | Comments |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Aquatic Life Habitat | | | | | | Water Supply | | | Recreation | | |
| | SRW | WWH | EWH | MWH | SSH | CWH | LRW | PWS | AWS | IWS | BW | PCR | SCR | |
| Ogg Creek – headwaters to former Jones lake outlet (RM 1.4) | | + | | | | | | | + | + | | + | | |
| - RM 1.4 to mouth | | | | + | | | | | + | + | | + | | Acid mine drainage. |
| McLuney Creek | | | | | | | O | | + | + | | + | | Acid mine drainage |
| Bear Creek | | | | | | | O | | + | + | | + | | Acid mine drainage |
| Tributary to Moxahala Creek (RM 22.56) | | | | + | | | | | + | + | | + | | Acid mine drainage. |
| Andrews Run (Unnamed Trib. to Moxahala Cr. , RM 24.79) | | | | | | | + | | + | + | | + | | Acid mine drainage. |

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## REFERENCES*

Dufour, A.P. (1977). *Escherichia coli*: The fecal coliform. Am. Soc. Test. Mater. Spec.Publ. 635: 45-58.

Karr, J. R. 1991. Biological integrity: A long-neglected aspect of water resource management. Ecological Applications 1(1): 66-84.

Karr, J.R., K.D. Fausch, P.L. Angermier, P.R. Yant, and I.J. Schlosser. 1986. Assessing biological integrity in running waters: a method and its rationale. Ill. Nat. Hist. Surv. Spec. Publ. 5. 28 pp.

MacDonald, D., C. Ingersoll, T. Berger. 2000. Development and evaluation of consensus-based sediment quality guidelines for freshwater ecosystems. Arch. Environ. Contam. Toxical.: Vol.39, 20-31.

Miner R. and D. Borton. 1991. Considerations in the development and implementation of biocriteria, Water Quality Standards for the 21st Century, U.S. EPA, Offc. Science and Technology, Washington, D.C., 115 pp.

Ohio Environmental Protection Agency. 2008a. 2008 updates to Biological Criteria for the Protection of Aquatic Life: Volume II and Volume II Addendum. Users manual for biological field assessment of Ohio surface waters. Div. of Surface Water, Ecol. Assess. Sect., Columbus, Ohio.

Ohio Environmental Protection Agency. 2008b. 2008 updates to Biological Criteria for the Protection of Aquatic Life: Volume III. Standardized biological field sampling and laboratory methods for assessing fish and macroinvertebrate communities. Div. of Surface Water, Ecol. Assess. Sect., Columbus, Ohio.

Ohio Environmental Protection Agency. 2006a. Methods for assessing habitat in flowing waters: Using the Qualitative Habitat Evaluation Index (QHEI). Ohio EPA Tech. Bull. EAS/2006-06-1. Div. of Surface Water, Ecol. Assess. Sect., Columbus, Ohio.

Ohio Environmental Protection Agency. 2008b. Ohio EPA manual of surveillance methods and quality assurance practices, updated edition. Division of Environmental Services, Columbus, Ohio.

Ohio Environmental Protection Agency. 2005. Total Maximum Daily Loads for the Sunday Creek Watersheds. Aug. 2005. Division of Surface Water, Columbus, Ohio.

Ohio Environmental Protection Agency. 2003. Ecological risk assessment guidance manual. Feb. 2003. Division of Emergency and Remedial Response, Columbus, Ohio.

Ohio Environmental Protection Agency. 2001a. Sediment sampling guide and methodologies, 2nd edition. Nov. 2001. Division of Surface Water, Columbus, Ohio.

Ohio Environmental Protection Agency. 1989a. Addendum to Biological criteria for the protection of aquatic life: Volume II. Users manual for biological field assessment of Ohio surface waters. Div. Water Qual. Plan. & Assess., Ecol. Assess. Sect., Columbus, Ohio.

Ohio Environmental Protection Agency. 1989b. Biological criteria for the protection of aquatic life: Volume III. Standardized biological field sampling and laboratory methods for assessing fish and macroinvertebrate communities. Div. Water Quality Plan. & Assess., Ecol. Assess. Sect., Columbus, Ohio.

Ohio Environmental Protection Agency. 1987a. Biological criteria for the protection of aquatic life: Volume I. The role of biological data in water quality assessment. Div. Water Qual. Monit. & Assess., Surface Water Section, Columbus, Ohio.

Ohio Environmental Protection Agency. 1987b. Biological criteria for the protection of aquatic life: Volume II. Users manual for biological field assessment of Ohio surface waters. Div. Water Qual. Monit. & Assess., Surface Water Section, Columbus, Ohio.

Ohio University. 2005. Acid Mine Drainage Abatement and Treatment Plan for the Moxahala Creek Watershed. The Institute for Local Government and Rural Development (ILGARD), Athens, Ohio.

Rankin, E. T. 1995. The use of habitat assessments in water resource management programs, pp. 181-208. in W. Davis and T. Simon (eds.). Biological Assessment and Criteria: Tools for Water Resource Planning and Decision Making. Lewis Publishers, Boca Raton, FL.

Rankin, E.T. 1989. The qualitative habitat evaluation index (QHEI): rationale, methods, and application. Div. Water Qual. Plan. & Assess., Ecol. Assess. Sect., Columbus, Ohio.

Rankin, E. T. 2004. Fish and Macroinvertebrate Study of Moxahala Creek, 2004 Field Year. MBI Technical Report MB/2005-2. Prepared for Ohio DNR, Division of Mineral Resources Management by the Midwest Biodiversity Institute, Columbus, Ohio.

Suter, G.W., II. 1993. A critique of ecosystem health concepts and indexes. Environmental Toxicology and Chemistry, 12: 1533-1539.

United States Geological Survey, 2006. Benthic community response to limestone tributary drainage in a mine-acid impaired river system: implications for restoration of fishes. Northern Appalachian Research Laboratory. Study Plan Number 08037. http://www.lsc.usgs.gov/SPN.asp?StudyPlanNum=08037

Yoder, C.O. 1995. Policy issues and management applications for biological criteria, pp. 327-344. in W. Davis and T. Simon (eds.). Biological Assessment and Criteria: Tools for Water Resource Planning and Decision Making. Lewis Publishers, Boca Raton, FL.

Yoder, C. O. 1991**.** Answering some concerns about biological criteria based on experiences in Ohio, *in* G. H. Flock (ed.) Water quality standards for the 21st century. Proceedings of a National Conference, U. S. EPA, Office of Water, Washington, D.C.

Yoder, C.O. 1989. The development and use of biological criteria for Ohio surface waters. U.S. EPA, Criteria and Standards Div., Water Quality Stds. 21st Century, 1989: 139-146.

Yoder, C.O. and E.T. Rankin. 1995. The role of biological criteria in water quality monitoring, assessment, and regulation. Environmental Regulation in Ohio: How to Cope With the Regulatory Jungle. Inst. of Business Law, Santa Monica, CA. 54 pp.

*Some of the references not in the report can be found in the Appendix Table 13 which includes Methods, Biosurvey Background Information, and Notice to Users.