Appendix

D

LOADING ANALYSIS INFORMATION
MOXAHALA CREEK WATERSHED

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D1 Background

Twenty-one streams in the Moxahala Creek watershed, which includes Jonathan Creek, were evaluated in 2008 for their ability to support aquatic life, and sixteen streams were assessed for support of the recreation use. In each case, portions of the Moxahala Creek watershed were found to fall short of the goals set forth by the Clean Water Act. As a result of these findings, this study was carried out to identify pollutant loads that are contributing to non-attainment of water quality goals and quantify any needed reductions of pollutants in order to meet water quality goals. Complete assessment results can be found in the *Biological and Water Quality Study of the Moxahala Creek Watershed, 2008* (Ohio EPA 2009). Table D-1 summarizes the impairments and the actions taken through the TMDL to address them.

Table D-1. Summary of impairments and methods used to address impairments

Assessment Unit	Narrative Description	Causes of Impairment (Beneficial use in parentheses)[1]	Action Taken
Jonathan Creek (05040004 04)			
04 01 *Priority points: 7*	Valley Run	Dissolved oxygen (ALU)	*E. coli* TMDL as surrogate
		E. coli (RU)	*E. coli* TMDL
04 02 *Priority points: 4*	Headwaters Jonathan Creek	No impairment (ALU)	No action necessary
		E. coli (RU)	*E. coli* TMDL
04 03 *Priority points: 3*	Turkey Run	No impairment (ALU)	No action necessary
		E. coli (RU)	*E. coli* TMDL
04 04 *Priority points: 4*	Buckeye Fork	Aluminum (ALU)	Not addressed
		Manganese (ALU)	Not addressed
		Nickel (ALU)	Not addressed
		Sulfates (ALU)	Not addressed
		Acidity (cold titration) (ALU)	Not addressed
		No impairment (RU)	No action necessary
04 05 *Priority points: 3*	Kent Run	No impairment (ALU)	No action necessary
		E. coli (RU)	*E. coli* TMDL
		Insufficient data to assess (PDWSU)	No action necessary
04 06 *Priority points: 1*	Thompson Run	No impairment (ALU)	No action necessary
		E. coli (RU)	*E. coli* TMDL
04 07 *Priority points: 5*	Painter Creek-Jonathan Creek	Direct habitat alterations (Category 4C; ALU)	Temperature TMDL as surrogate
		E. coli (RU)	*E. coli* TMDL
		No impairment (PDWSU)	No action necessary

Assessment Unit	Narrative Description	Causes of Impairment (Beneficial use in parentheses)[1]	Action Taken
Moxahala Creek (05040004 05)			
05 01 *Priority points: 3*	Black Fork	Dissolved oxygen (ALU)	*E. coli* TMDL as surrogate
		Aluminum (ALU)	Acidity/alkalinity TMDL[2]
		Manganese (ALU)	Acidity/alkalinity TMDL[2]
		Sulfates (ALU)	Acidity/alkalinity TMDL[2]
		Iron (ALU)	Acidity/alkalinity TMDL[2]
		Acidity (cold titration) (ALU)	Acidity/alkalinity TMDL[2]
		Ammonia (total) (ALU)	*E. coli* TMDL as surrogate
		Nitrate/nitrite (nitrate+nitrite as N) (ALU)	*E. coli* TMDL as surrogate
		E. coli (RU)	*E. coli* TMDL
		No impairment (PDWSU)	No action necessary
05 02 *Priority points: 1*	Upper Moxahala Creek	pH (ALU)	Acidity/alkalinity TMDL[2]
		Aluminum (ALU)	Acidity/alkalinity TMDL[2]
		Manganese (ALU)	Acidity/alkalinity TMDL[2]
		Sulfates (ALU)	Acidity/alkalinity TMDL[2]
		Iron (ALU)	Acidity/alkalinity TMDL[2]
		Acidity (cold titration) (ALU)	Acidity/alkalinity TMDL[2]
		Nickel (ALU)	Acidity/alkalinity TMDL[2]
		No impairment (RU)	No action necessary
05 03 *Priority points: 1*	Middle Moxahala Creek	pH (ALU)	Acidity/alkalinity TMDL[2]
		Aluminum (ALU)	Acidity/alkalinity TMDL[2]
		Sulfates (ALU)	Acidity/alkalinity TMDL[2]
		Acidity (cold titration) (ALU)	Acidity/alkalinity TMDL[2]
		Nickel (ALU)	Acidity/alkalinity TMDL[2]
		No impairment (RU)	No action necessary
05 04 *Priority points: 5*	Lower Moxahala Creek	pH (ALU)	Acidity/alkalinity TMDL[2]
		Aluminum (ALU)	Acidity/alkalinity TMDL[2]
		Manganese (ALU)	Acidity/alkalinity TMDL[2]
		Sulfates (ALU)	Acidity/alkalinity TMDL[2]
		Nickel	Acidity/alkalinity TMDL[2]

Assessment Unit	Narrative Description	Causes of Impairment (Beneficial use in parentheses)[1]	Action Taken
		Acidity (cold titration)	Acidity/alkalinity TMDL[2]
		Ammonia (total)	*E. coli* TMDL as surrogate
		E. coli (RU)	*E. coli* TMDL

[1] ALU = aquatic life use
RU = recreation use
PDWSU = public drinking water supply use
[2] TMDLs taken from ILGARD (2005).

D2 Linkage Discussion

D2.1 Recreation Use

Agricultural activities and the rural nature of the majority of the watershed, with few centralized wastewater treatment systems, have led to widespread elevated bacteria loading. Areas of concern that were highlighted during the 2008 assessment sampling include sanitary sewer releases from South Zanesville (Moxahala Creek adjacent to Pearl Park at RM 0.6) and at Kent Run at RM 1.35 (lower Kroft Road) where the Maysville Water District has an auxiliary water intake.

D2.2 Aquatic Life Use

There are relatively few and discrete areas of aquatic life use non-attainment in the Jonathan Creek sub-watershed in comparison to the Moxahala mainstem and many of its other tributaries. Valley Run, a headwater tributary to Jonathan Creek, exhibited impairment attributed to low dissolved oxygen concentrations as a result of upstream unsewered communities, and a lowhead dam causes non-attainment as it impounds Jonathan Creek near the State Route 93 bridge at Avondale.

The major cause of impairment throughout the Moxahala Creek watershed, especially along the Moxahala mainstem and tributaries, is in-stream loading of pollutants related to acid mine drainage (AMD). Numerous metals, low pH, and high acidity caused toxicity to aquatic life. Abandoned coal mines within the Black Fork tributary to the Moxahala, such as “Tropic” and “Whitehouse Seep” (just upstream of the Ogg Creek confluence) contribute much of the AMD loading in the Moxahala Creek watershed. In addition, Ogg Creek and the headwaters of Black Fork are impacted by nutrient loading from upstream failing home sewage treatment systems.

D3 Analysis Methods

D3.1 Justification of Methods

Bacteria, Dissolved Oxygen, Ammonia and Nitrate-Nitrite: Load Duration Curves
In order to determine the magnitude of impairment due to a particular pollutant and differentiate between types of sources of pollutants contributing to impairment, load duration curves (LDCs) were developed for selected sites that are in non-attainment of WQS following the methods

described in the U.S. EPA document *An Approach for Using Load Duration Curves in the Development of TMDLs* (U.S. EPA 2007); see Figure D-1 and Table D-2 for examples.

Load duration curves can assist in distinguishing between point and nonpoint sources that contribute to pollutant loading by highlighting the flow conditions under which impairment occurs. At lower stream flow levels, decreased in-stream dilution of pollutant inputs occurs due to dry weather conditions with diminished amounts of runoff. Because of this, any point source pollutant contributions to the stream will result in relatively higher concentrations of that pollutant. A high proportion of samples under dry weather or low flow conditions that fall above the target curve indicate the likelihood of nearby pollutant point sources. Under elevated flow conditions, point sources are assumed to be masked by in-stream dilution; therefore high pollutant loading is caused by precipitation washoff or erosion of contaminated land surfaces.

It is important to note that the load duration curve method does not enable one to attribute impairment to any particular source; instead it is a tool used to determine the flow conditions under which impairment occurs and therefore the probable types of sources contributing to that impairment.

Temperature: Paired Site Approach

The mainstem of Jonathan Creek meets water quality goals in all sampling locations except for where the stream is impounded by a dam that is located at approximately RM 1.0 downstream of the State Route 93 bridge, near Avondale. A second lowhead dam impounds a small reach of Jonathan Creek upstream of the dam in Avondale, at RM 3.5 in White Cottage. Because the vast majority of Jonathan Creek meets water quality goals and the nature of the impairment at SR-93 is well understood, an empirical approach was selected to establish a load reduction goal for Jonathan Creek at SR-93. A study was developed to track daily temperature loading of the dam pools at Avondale and White Cottage and compare the temperature characteristics of the dam pool sites to a set of stream sites in full attainment which serve as a local benchmark or 'reference condition'.

Acid Mine Drainage: AMDAT

The most pervasive water quality impacts in the Moxahala Creek watershed result from acid mine drainage (AMD). Acid mine drainage was cited as a source of aquatic life use non-attainment in thirteen sampling sites in the Moxahala Creek watershed. AMD was cited as a source of partial attainment in several other sites.

The Institute for Local Government Administration and Rural Development (ILGARD) at Ohio University published an AMDAT/TMDL (Acid Mine Drainage Abatement and Treatment Plan/Total Maximum Daily Load) report in 2005, in coordination with other entities, with the objective of creating a plan "to improve surface water quality that has been adversely affected by coal mining practices that occurred prior to the passages of the Surface Mining Control and Reclamation Act (SMCRA) in 1977" and to identify areas where restoration projects can ameliorate chemical loading and positively affect stream health (ILGARD 2005).

The Moxahala AMDAT/TMDL targets and needed load reductions are established empirically using WWH-attaining sites in an adjacent watershed as a reference condition and using extensive field measurements to establish acid loadings at each point source in the Moxahala watershed. The fine geographic scale of field measurements makes it very unlikely that significant AMD-contributing sources in the Moxahala watershed were not addressed by the recommendations of this study.

D3.2 Load Duration Curves

An outline of LDC development, specific to the Moxahala Creek watershed, is as follows:

1. An historical daily flow record was obtained for the USGS Gage 3145000 on adjacent South Fork Licking River for the period of record containing November 2000 through March 2009. Dates outside of the recreation season (May 1 through October 31) were excluded from the record. This flow record was then ordered and ranked to determine, for each daily flow, the percentage of the period of record when that flow was equaled or exceeded. This flow exceedance range constitutes the basis for the x-axis in each LDC graph.
2. In-stream pollutant loads were determined for each sampling event using stream sample pollutant concentration in conjunction with flow data for each sampling location. At the appropriate flow exceedance, the corresponding pollutant concentration for a stream sample was plotted as a point on the y-axis of the LDC. In order to determine the sample sites' flow, sampling locations were assigned scaled flows based on the ratio of each sampling location's drainage area compared to that of the USGS gage site.
3. Target pollutant loads were calculated by applying the appropriate pollutant WQS concentration value at each flow exceedance value for the entire flow duration interval.
4. A margin of safety was added to account for any lack of knowledge concerning the relationship between load and wasteload allocations and water quality.
5. An allowance for future growth, based upon population growth projections, was factored into any needed load reductions.
6. The LDCs were divided into five hydrologic regimes and within each regime the total required nonpoint load reduction percentage is calculated by incorporating the margin of safety and allowance for future growth into the target load and determining the difference between this target and the existing load in each flow regime. Wasteload allocations to point source dischargers are allocated based on the design flow of the facility at the concentration of the applicable WQS. MS4 communities are assigned a wasteload allocation based upon the proportion of the HUC draining to the LDC site location that is within the MS4 boundary, and this amount is proportionately subtracted from the nonpoint source load allocation.

A "TMDL table" is associated with each LDC, detailing the information that is graphically presented in the LDC figure. Each table contains the following information for each hydrologic regime:

- number of samples
- median sample pollutant load
- total maximum daily load (TMDL)
- wasteload allocation (WLA) for each point source
- nonpoint load allocation (LA)
- margin of safety (MOS) load
- allowance for future growth (AFG) load
- nonpoint (LA) % load reduction required

Examples of a load duration curve and TMDL table are presented below.

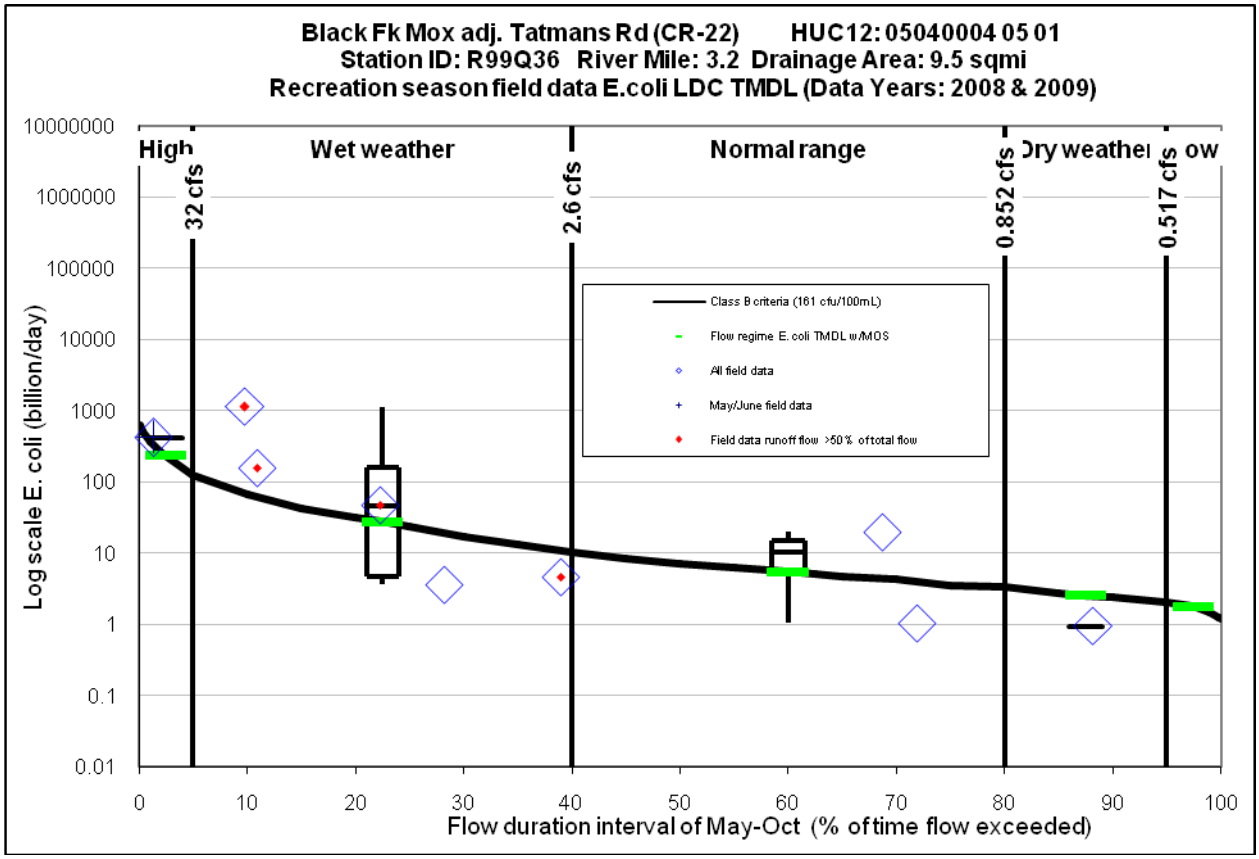

Figure D-1. Example load duration curve.

Table D-2. Example TMDL table calculations (from above load duration curve).

Flow regime TMDL analysis		Wet	Normal	Dry	
E. coli **(billion bacteria/day)**	**High**	**weather**	**range**	**weather**	**Low**
Duration interval	0-5%	5-40%	40-80%	80-95%	95-100%
Samples per regime	1	5	2	1	0
Median sample load	416	47	10	0.9	N/A
TMDL	232.371	27.569	5.514	2.572	1.788
WLA:	0.0	0.0	0.0	0.0	0.0
LA	174.278	20.677	4.135	1.929	1.341
MOS: 20%	46.474	5.514	1.103	0.514	0.358
AFG: 5%	11.619	1.378	0.276	0.129	0.089
Nonpoint (LA) % load reduction required	**58%**	**56%**	**60%**	**None**	No Data

Values were adjusted for rounding.

D3.2.1 Bacteria (*E. coli*)

Recreation use was not supported in multiple assessment units where the geometric mean of at least one stream sampling site did not meet its water quality standard. Forty sites were sampled as a part of the Ohio EPA's monitoring and assessment in 2008 to determine recreation use attainment, and 29 (73%) were found to be in non-attainment.

This study was carried out to develop *E. coli* total maximum daily loads (TMDL) as required by Section 303(d) of the Clean Water Act and the United States Environmental Protection Agency's Water Quality Planning and Management Regulations (Title 40 of the Code of Federal Regulations, Part 130). This overall TMDL report defines in-stream bacterial conditions, potential sources, bacteria targets and needed reductions and recommends implementation strategies.

TMDL numeric targets for *E. coli* bacteria are derived from bacteriological water quality standards. The criteria for *E. coli* specified in OAC 3745-1-07 are applicable outside the effluent mixing zone and vary for waters determined as primary contact recreation (PCR). Furthermore, this criterion designates streams that support frequent primary contact recreation – Class A streams. No streams in the watershed are designated as Class A streams. All streams assessed in this watershed are Class B PCR. Class B streams support infrequent primary contact recreation activities. For Class B streams the standard states that the geometric mean of more than one *E. coli* sample taken in each recreational season (May 1 through October 31) shall not exceed 161 colony-forming units (cfu) per 100 mL.

Of the 29 sites found to be in recreation use non-attainment during the summer of 2008, a subset of six sampling locations was established on five different streams within the watershed, and these sites were used for further study of the causes of recreation use non-attainment in non-attaining nested subwatersheds (12-digit hydrologic units). These six sites included two sites on the mainstem of Jonathan Creek and one tributary site to Jonathan Creek (Valley Run) and one mainstem Moxahala Creek site and two Moxahala Creek tributary sites (Black Fork and Ogg Creek). Nested subwatersheds addressed by these LDCs are shown in Table D-3.

Table D-3. Nested subwatersheds represented by each LDC site.

Load Duration Curve Site	Nested Subwatershed Location (05040004)	Nested Subwatersheds Represented (05040004)
Valley Run upstream of Berry Run @ Laurel Hill Rd.	04 01	04 01 (above RM 5.4)
Jonathan Creek near White Cottage @ Crock Rd.	04 07	04 01 (below RM 5.4) 04 02 04 03 04 07 (above RM 3.35)
Jonathan Creek downstream of SR-93 Dam Pool	04 07	04 07 (below RM 3.35) 04 05 04 06
Ogg Creek south of Deavertown @ SR-555	05 01	05 01 (above Ogg Creek RM 2.1 only)
Black Fork upstream of Ogg adj. to Tatmans Rd.	05 01	05 01 (above Black Fork RM 3.2 only)
Moxahala Creek at South Zanesville @ CR-6	05 04	05 01 (excluding Ogg Ck & Black Fk) 05 03 05 04

For a given impaired site, each hydrologic condition (high flows, wet weather conditions, normal range conditions, dry weather conditions or low flows) was assigned a target bacteria loading rate (cfu/day) by multiplying the class B *E. coli* water quality standard, 161 cfu/100 ml, by the median flow of each hydrologic class at that site and a constant, used to convert cubic feet per second to milliliters per day: $T = Q_m * S * C$; where T = target bacteria load, Q_m = median flow for a specific hydrologic class, S = water quality standard (161 cfu/100 ml) and C = a unit conversion constant (cubic feet per second to milliliters per day). Median observed bacteria

loads in each hydrologic condition were compared to the median target value in that condition, after incorporating a margin of safety and allowance for future growth, in order to quantify needed reductions.

Wasteload Allocation

There are four permitted sanitary dischargers in the Jonathan and Moxahala Creek basin: B & D Commissary (0IH00048*ED), which discharges to an unnamed tributary of Turkey Run at RM 0.45; Hopewell Heights MHP (0PV0032*AD), which discharges to an unnamed tributary of Kent Run at RM 14.95; and Village of Roseville WWTP (0PC00020*ED), which discharges to Moxahala Creek at RM 13.63. In addition, a general sanitary sewer permitee, Hopewell Elementary (4GS00015*AG), discharges into Kent Run.

Each sanitary discharger is assigned a wasteload allocation (WLA) based upon the design flow of the treatment facility and the Class B water quality standard applicable to its receiving water. These WLAs are listed in the TMDL table that corresponds with each sampling site, in section D5. Because any facility operates at most times at some fraction of its design flow, the WLA for these facilities includes an amount of reserve capacity up to the design flow.

The wasteload allocation for each facility is accounted for in each downstream site's LDC in the watershed; for example, the WLA for B&D Commissary is included in the LDC of the most immediate downstream site, *Jonathan Creek @ Crock Rd (RM 3.35)*, as well as *Moxahala Creek @ CR-6 (RM 0.58)*, downstream of the confluence with Jonathan Creek.

Municipal Separate Storm Sewer System (MS4)
Allocations for the one regulated MS4 in this watershed were determined based on the area of the MS4 draining to each assessment location. Townships, municipalities, and urbanized areas as documented in geographic information system (GIS) database files were used to determine the total regulated area for the MS4. These areas were then used to calculate WLAs based on the proportion of the upstream drainage area located within the MS4 boundaries. Storm water runoff was only assumed to occur during *High* flows, *Wet Weather* and *Normal* flow conditions.

Load Allocation

The load duration curve method was selected to assign in-stream bacteria loads at a given site to one or several potential bacteria sources (see U.S. EPA 2007). In a load duration curve, patterns of bacteria impairment can be examined and addressed relative to the flow conditions under which they occur, and this allows a set of potential bacteria sources specific to a given site to be highlighted (see Table D-4). Under the highest flow conditions, point sources are likely to be masked by in-stream dilution; therefore high bacteria measurements in these conditions are associated with precipitation washoff or erosion of contaminated land surfaces. Impairments under normal range flows can be caused by a mixture of point and nonpoint sources. Under the lowest flow conditions, recreation use impairments are generally attributable to sources not associated with runoff events, such as a failing HSTS or in-stream livestock.

Table D-4. Typical contributing sources as a function of LDC flow condition.

Contributing Source Area	Flow Condition from LDC				
	High	Wet Weather	Normal Range	Dry Weather	Low
Point source				M	H
Livestock direct-access to streams				M	H
Home sewage treatment systems	M	M-H	H	H	H
Riparian areas		H	H	M	
Storm water: Impervious		H	H	H	
Combined sewer overflow (CSO) or sanitary sewer overflow (SSO)	H	H	H		
Storm water: Upland	H	H	M		
Field drainage: Natural condition	H	M			
Field drainage: Tile system	H	H	M-H	L-M	
Bank erosion	H	M			

Note: H: high likelihood; M: medium likelihood; L: low likelihood; blank: not likely.

Sampling locations were visited under a range of different flow conditions during the recreation season. Daily loading of bacteria was calculated for each site utilizing *E. coli* stream sample data. Existing in-stream loads, target loads and load duration curves were calculated from the collected data. Using these data and notes about land use, recommendations regarding sources and potential implementation were developed.

D3.2.2 Dissolved Oxygen, Ammonia and Nitrate-Nitrite

Improperly functioning home septic systems fail to treat household wastewater that contains nutrients (such as nitrate-nitrite and ammonia) and *E. coli* bacteria (U.S. EPA 2002). In temperate freshwater systems, nutrients are in short supply relative to biological capacity, which means that nuisance productivity of aquatic plants and algae can be controlled by limiting the amount of nutrients entering the water. Low dissolved oxygen concentrations may occur as excessive amounts of nutrients are metabolized by aquatic plants and algae and these aquatic plants and algae are subsequently decomposed.

HSTSs can affect water quality under multiple stream flow conditions. HSTSs discharging directly to a stream or river, such as many aeration or illicit systems, behave similarly to a point source. These types of systems primarily affect water quality under dry, low-flow conditions. HSTSs discharging indirectly to a stream via a tile drain or intermittent ditch may exhibit effects akin to a non-point source. Wastewater discharged to a dry tile or ditch may be of insufficient volume to sustain flow to the stream, but pollutants can accumulate and eventually be flushed by rainfall. These types of systems primarily affect water quality under wet-weather, high-flow conditions. Additional pollutant delivery pathways associated with HSTSs exist, but those discussed above are believed to be the most significant in the Moxahala Creek watershed.

Home septic systems are cited in the *Biological and Water Quality Study of the Moxahala Creek Watershed* as a common source of aquatic life use impairment among several assessment locations: Black Fork Moxahala Creek (at Tatmans Rd a.k.a. CR-22), Ogg Creek (at SR-555) and Valley Run (at Laurel Hill Rd.). The direct cause of aquatic life impairment is attributed to low dissolved oxygen in the case of Black Fork and Valley Run and the combination of ammonia and nitrate-nitrite in Ogg Creek. *E. coli* are microscopic organisms present in large abundance in human feces (Dufour 1977) and the presence of high concentrations of *E. coli* in stream water

is used as an indication of sources of human or animal waste entering the stream. Required reductions for in-stream *E. coli* are used as a means to address home septic systems where they have been identified as a cause of aquatic life use impairment.

For the purpose of this TMDL, *E. coli* is used as an indicator for the degree of nutrient enrichment and low D.O. contributed by home septic systems. Load duration curves developed for *E. coli*, as outlined in Section D3.2, address the aquatic life use impairments caused by the associated nutrient enrichment.

D3.2.3 Validation of Hydrology

A series of flow measurements was made at the Jonathan Creek @ Crock Road sampling site in order to determine the accuracy of predicted stream flow measurements using drainage-area weighted flow data from Salt Creek @ SR-146 USGS stream gage station. Measurements were made at a range of flow levels (from 10.67 cfs to 267.23 cfs, actual flow) during the recreation season of 2008 (Table D-5). Measured flows were compared with USGS daily average flows, for the day that the flow measurement was made, via a linear regression (Figure D-2). The r-squared value of the best fit linear regression is 0.83. (A perfect gage reading to flow measurement relationship would equal 1, while no relationship would equal zero.)

Table D-5: Jonathan Creek @ Crock Rd. measured flows versus predicted flows

Date	Measured Flow	Drainage-area yield predicted flow
7/3/2008	162.5	197.4
7/10/2008	267.23	184.99
7/23/2008	69.48	21.43
8/21/2008	10.58	10.94
8/19/2008	12.54	10.83

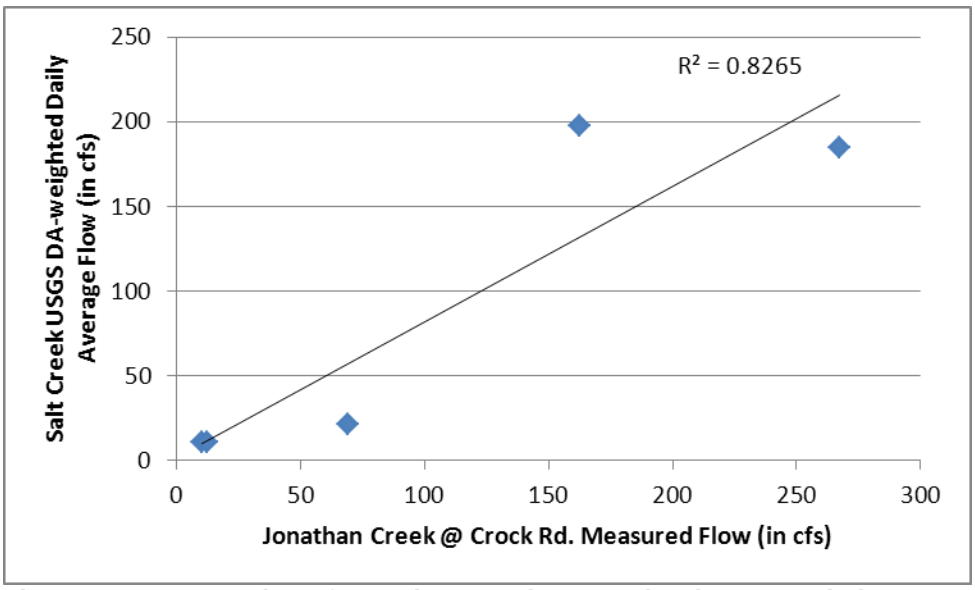

Figure D-2. Regression of Jonathan Creek @ Crock Rd Measured Flows vs. Salt Creek USGS Drainage Area Weighted Daily Average Flows

D3.2.4 Margin of Safety

The Clean Water Act requires that a TMDL include a margin of safety (MOS) to account for any lack of knowledge concerning the relationship between load and wasteload allocations and water quality. U.S. EPA guidance explains that the MOS may be implicit (i.e., incorporated into the TMDL through conservative assumptions in the analysis) or explicit (i.e., expressed in the TMDL as loadings set aside for the MOS).

An implicit MOS is incorporated in various ways, including in the derivation of the *E. coli* water quality criterion and in not considering the die-off of pathogens as part of the TMDL calculations. The implicit MOS is also enhanced by the use of the geometric mean target (which is a seasonal target) to calculate daily loads. In addition, an explicit MOS has been applied as part of all of the bacteria TMDLs by reserving 20% of the allowable load because of the broad fluctuation of *E. coli* concentrations that occurs in nature and the relatively low numbers of data points available for this analysis. The explicit MOS in each allocation is shown in the TMDL allocation tables throughout section D4.1.1.

D3.2.5 Allowance for Future Growth

The Moxahala Creek watershed lies within Licking, Morgan, Muskingum, and Perry Counties. The average population change projection from 2010 to 2020 of the four counties is an increase of 5%. In order to ensure recreation use attainment in the future, an allowance for future growth (AFG) factor of 5% was applied to each TMDL (ODD 2004).

D3.2.6 Critical Conditions

In-stream bacteria loads differ by source and can occur under varying stream flow conditions, from washoff of land-deposited bacteria under wet weather conditions to failing home sewage treatment systems (HSTSs) in low flow conditions. Nonpoint sources to which bacteria loads are allocated in the Jonathan and Moxahala Creek basin include both washoff and failing HSTSs. Because TMDLs are established for all flow ranges where there is sufficient data, the target will be met overall.

D3.2.7 Seasonality

Stream recreation occurs in a variety of forms, from wading to fishing to canoeing, and in a wide range of stream flow conditions. In order to ensure that recreation use is protected whenever recreation might occur, *E. coli* TMDLs are established for all flow conditions during the recreation season (May 1 through October 31), when people are most likely to fish, wade, swim and boat in the stream.

D3.3 Paired Site Analysis: Temperature

During 2008 biological stream sampling, Jonathan Creek at SR 93 (RM 1.1) was found to be in partial aquatic life use attainment due to a significantly lower Modified Index of well-being (MIwb) score than the WWH use designation. The MIwb is a metric based on the composition of fish species in a stream. The source of this impairment was attributed to stream habitat alteration caused by a dam located 0.1 RM downstream of the sampling point at RM 1.0, Jonathan Creek dam pool downstream SR 93 upstream Powell Rd, Avondale.

It is well known that dams alter biological communities through segmentation of habitat and blocking migration of aquatic species, while at the same time altering stream discharge and flow periodicity (Allan 1995). Stream temperature can have a strong influence on the distribution of fish species because fish body temperatures and metabolic rates are closely related to ambient stream conditions (Spotila, et al. 1979). Changes to a stream's daily temperature regime are a measurable, direct effect of flow-altering impoundments as the relatively larger volume of an impoundment has a greater amount of thermal inertia than a free flowing stream. Daily temperature fluctuations in a dam impoundment can be suppressed, relative to free flowing reaches, in this way (Allan 1995).

D3.3.1 Target and Deviation

Through paired site sampling and statistical comparison, daily water temperature ranges are used as a measureable surrogate to illuminate the impact of dams in impounded versus free-flowing reaches of Jonathan Creek. Where a statistically significant difference occurs in temperature range, the temperature range of the free-flowing sites is used as a target for impounded sites. Any statistically significant deviation from the free-flowing sites is considered a deviation from target conditions which contributes to non-attainment of aquatic life use goals.

D3.3.2 Study Design

Two sets of three sites in Jonathan Creek were selected to represent both the free-flowing and impounded portions of Jonathan Creek.

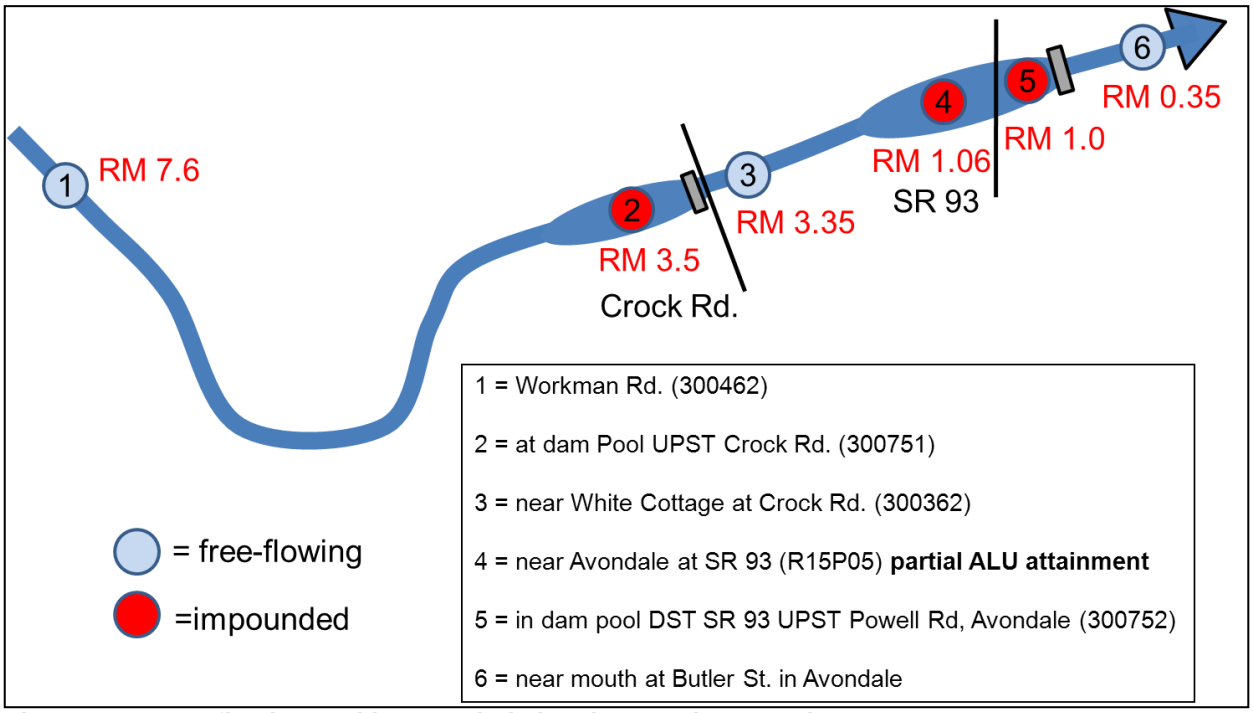

Figure D-3. Free-flowing and impounded sites in Jonathan Creek

Free-flowing Reference Sites

The most upstream and downstream sites in the study, *Jonathan Creek at Workman* and *Jonathan Creek DST SR 93 dam pool at Powell Rd*, respectively, and *Jonathan Creek near White Cottage at Crock Road* were selected in order to identify reference conditions where the

creek is free of any flow-altering impoundment. These sites are each in full attainment of their aquatic life use designation.

Dam-impounded Sites
One sampling site was established within the Gladstone Mill dam pool in Newton Township at White Cottage at RM 3.4 (*Jonathan Creek at dam pool UPST Crock Rd*). No recent biological surveys have sampled within the portion of Jonathan Creek that is impounded by this dam. Further downstream, two sites were sampled within the impounded stretch of Jonathan Creek near SR-93, where partial ALU attainment has been identified. One site was located at the SR-93 bridge and the second just above the dam itself, *Jonathan Creek in dam pool DST SR-93 UPST Powell Rd, Avondale*.

D3.3.3 Data Collection and Analysis

Temperature sensors were placed in the stream at each site and, depending on the stream depth, either propped on the stream bottom or floated so that the sensors were approximately one-half of the depth of the water column. The temperature sensors were deployed for 48 hours while hourly temperature was measured and recorded.

Temperature ranges were grouped into two categories, depending on the characteristics of the sampling location: 1) *free-flowing* (*Jonathan Creek at Workman* RM 7.6, *Jonathan Creek near White Cottage at Crock Road* RM 3.35, *Jonathan Creek downstream SR-93 dam pool* RM 0.4) and 2) *impounded* sites (*Jonathan Creek at dam pool upstream Crock Rd* RM 3.5, *Jonathan Creek near Avondale at SR-93* RM 1.06, *Jonathan Creek in dam pool downstream SR-93 upstream Powell Rd* RM 0.4). These two site categories were analyzed by unpaired t-tests of the null hypothesis of no difference between temperature ranges of the water column in *free-flowing* versus *impounded* sites. The unpaired t-test was used because the two sample categories are independent samples from different sample populations.

D3.3.4 Margin of Safety and Allowance for Future Growth

The scenario outlined in this TMDL assumes that the entire impoundment is removed. There is no greater improvement that can occur, therefore no margin of safety or allowance for future growth is used.

D3.3.5 Critical Conditions and Seasonality

Temperature range is a relative measure that is independent of actual stream temperature. Shifts in stream temperature ranges caused by a dam impoundment are equally likely to affect populations of aquatic life under any season or flow condition, therefore this TMDL is inclusive of any seasonal or critical condition.

D3.4 Acid Mine Drainage: Moxahala AMDAT

Descriptions of target identification, margin of safety and critical conditions are included on pages 21 and 22 of the AMDAT/TMDL document and are excerpted and/or condensed below. For the complete study, please refer to Appendix F.

D3.4.1 Target and Deviation

The goal for this plan is to restore AMD impacted waters throughout the Moxahala Creek watershed to meet WWH criteria wherever possible. To accomplish this goal, water quality targets were established... However since pH values cannot be modeled as a loading, alkalinity and acidity are used as a surrogate for all AMD parameters.

The establishment of in-stream numeric targets is a significant component of the AMDAT/TMDL process. The numeric targets serve as a measure of comparison between observed in-stream conditions and conditions that are expected to restore the stream to its designated uses. The AMDAT/TMDL identifies the load reductions and other actions that are necessary to meet the target, thus resulting in the attainment of applicable water quality standards.

Due to the overwhelming prevalence of Acid Mine Drainage (AMD) in the Moxahala Watershed,capturing and treating all the affected water would be very difficult and cost prohibitive. As a result the mouths of subwatersheds were selected as the points where targets will be met. However, it should be noted that in order to meet targets at the segment ends, many of the upstream sites must meet the target.

In choosing an alkalinity target that would be meaningful for the Moxahala Creek Watershed,water chemistry data that was collected in Moxahala Creek at two reference sites were compared to other reference sites throughout Ohio's Western Alleghany Plateau (WAP) eco-region, and other targets that were established for watersheds in the vicinity; Sunday Creek, Monday Creek, and Raccoon Creek. From these selected watersheds, the range of alkalinity values in which a site still meets WWH varies widely, 204 to 30 mg/l. Ideally, water quality sites within the Moxahala Watershed whose biological data meet the WWH use designation should be used to set a target alkalinity value, however there are only two sites that meet WWH. Two sites are not a large enough data-set to establish target values. Ohio EPA WAP ecoregion values from reference sites have alkalinity values that range from 134 -203 mg/l depending on size of stream and IBI range. However, these values are much higher than other target values used in similar reports; Monday Creek TMDL 30 mg/l alkalinity, Raccoon TMDL 20 mg/l alkalinity, Sunday Creek TMDL 67 mg/l alkalinity, and Sunday Creek AMDAT 90 mg/l alkalinity. Therefore a target net alkalinity value of 67mg/l was chosen as the target for this AMDAT/TMDL report. This is the same target used in the Sunday Creek TMDL. Sunday Creek Watershed is adjacent to Moxahala and has similar causes of impairment and water quality. The alkalinity target of 67 mg/l is the 10th percentile of the data points that meet WWH in the Sunday Creek Watershed. A low end target was chosen instead of a higher end target because the high cost of AMD remediation. The net alkalinity target had to be at a minimum so as to not unnecessarily burden the existing and future remediation resources.

D3.4.2 Loading Analysis

A multi-tiered study was carried out by Ohio University researchers and the Ohio Department of Natural Resources to first determine the locations of AMD in the watershed and then further characterize the acid loading being produced by AMD sources. In summary, 23 tributary sites and eight mainstem sites were sampled under a range of flow conditions for discharge and AMD related water quality parameters.

Reformatted loading results from the Moxahala AMDAT study are presented in this report in section D8.

It is important to note that AMD-impaired streams within the Jonathan Creek portion of this TMDL study area, Buckeye Fork and Butcherknife Creek, were not included in the Moxahala AMDAT report. These areas are excluded from this TMDL report in anticipation of future AMDAT study.

D3.4.3 Method Uncertainty

The alkalinity target developed for the Moxahala basin, based on WWH-attaining reference sites in an adjacent watershed, involves some uncertainty due to the reliance on sites in a different watershed. This uncertainty is unavoidable because very few sites within the Moxahala Creek watershed attain the WWH designation.

The empirical mass-balance approach used to determine acid loading, and therefore required alkalinity loads, in this study used either actual measured discharge or visually estimated discharge at each point source of acid loading. Some uncertainty exists in this method because of the assumption that the low and high flows that were measured are typical of an average year and do not vary widely over a larger timescale.

D3.4.4 Margin of Safety

> The alkalinity target of 67 mg/l is the 10th percentile of the data points that meet WWH in the Sunday Creek Watershed. Therefore there is a 10% margin of safety or the equivalent 18 mg/l of alkalinity. The site with the lowest amount of alkalinity that still met WWH was on Johnson run with 49 mg/l of alkalinity, thus 67-49 = 18 mg/l of alkalinity...

D3.4.5 Allowance for Future Growth

The AMD impacts in this watershed are a result of ‘pre-law’ mining activities that took place before the adoption of the Surface Mining Control and Reclamation Act (SMCRA) in 1977 and the recommendations of this report are intended to address the restoration required as a result of past mining activities. Due to contemporary regulation, no new sources of AMD from ongoing or future mining are anticipated in this watershed and therefore there is no allowance for future growth in AMD loading.

D3.4.6 Critical Conditions

> During high flow regimes the acid loading to the Moxahala Creek are typically higher than during the low flow... Therefore high flow conditions are considered the critical condition for this study. Flow data measured during high flow conditions were used to determine... target alkalinity loads, and the needed acid load reduction. Using the high flow as the design flow... to calculate the target alkalinity loads ensures the worst case scenario is represented…

D3.4.7 Seasonality

Because critical conditions are flow-dependent, the seasons with the highest precipitation infiltration and runoff will contribute the most to pollutant loading. In this region, the greatest

annual runoff typically occurs during late winter and early spring. These seasonal conditions are taken into account through the use of high flow regimes for establishing TMDL targets.

D4 Results

D4.1 Load Duration Curves

In the sequence of figures and tables below, the load duration curve for each site (Figures D-4 through D-9) is shown followed by the TMDL table for that site (Tables D-6 through D-11).

D4.1.1 Bacteria (*E. coli*)

In general, the greatest required reductions in *E. coli* loading, in terms of both the amount of reduction needed and the geographic spread of needed reduction exist under *High* and *Wet Weather* stream flow conditions. Reductions in nonpoint source contributions of *E. coli* are recommended to reduce loading under these stream flow conditions.

Among many possibilities, some typical nonpoint sources of *E. coli* include manure spreading, stream bank erosion, and washoff from livestock feeding operations. Scenarios where high *E. coli* loads exist under normal range flow conditions, or high loads occur under all conditions, can be attributed to a mixture of point and nonpoint sources. Site investigation using digital mapping, aerial photography or an on-the-ground visit can help further develop priorities for implementation based on the LDC evidence for either point or nonpoint sources of *E. coli*.

In some locations, such as Valley Run and Ogg Creek, *E. coli* loading needs to be reduced under a wider range of flow conditions including *Dry Weather*. High *E. coli* loading under dry weather conditions is indicative of a point source contribution of *E. coli* to the stream. General examples of bacteria point sources include combined sewer overflows (CSOs), municipal separate storm sewer systems (MS4s) or wastewater treatment plants. High bacteria levels under low flow conditions may also indicate concentrated cattle grazing in the stream channel, leaking sewer lines, or failing home sewage treatment systems.

Necessary nonpoint source reductions ranged from 54% (in dry weather and normal flow range) to 100% at wet weather conditions.

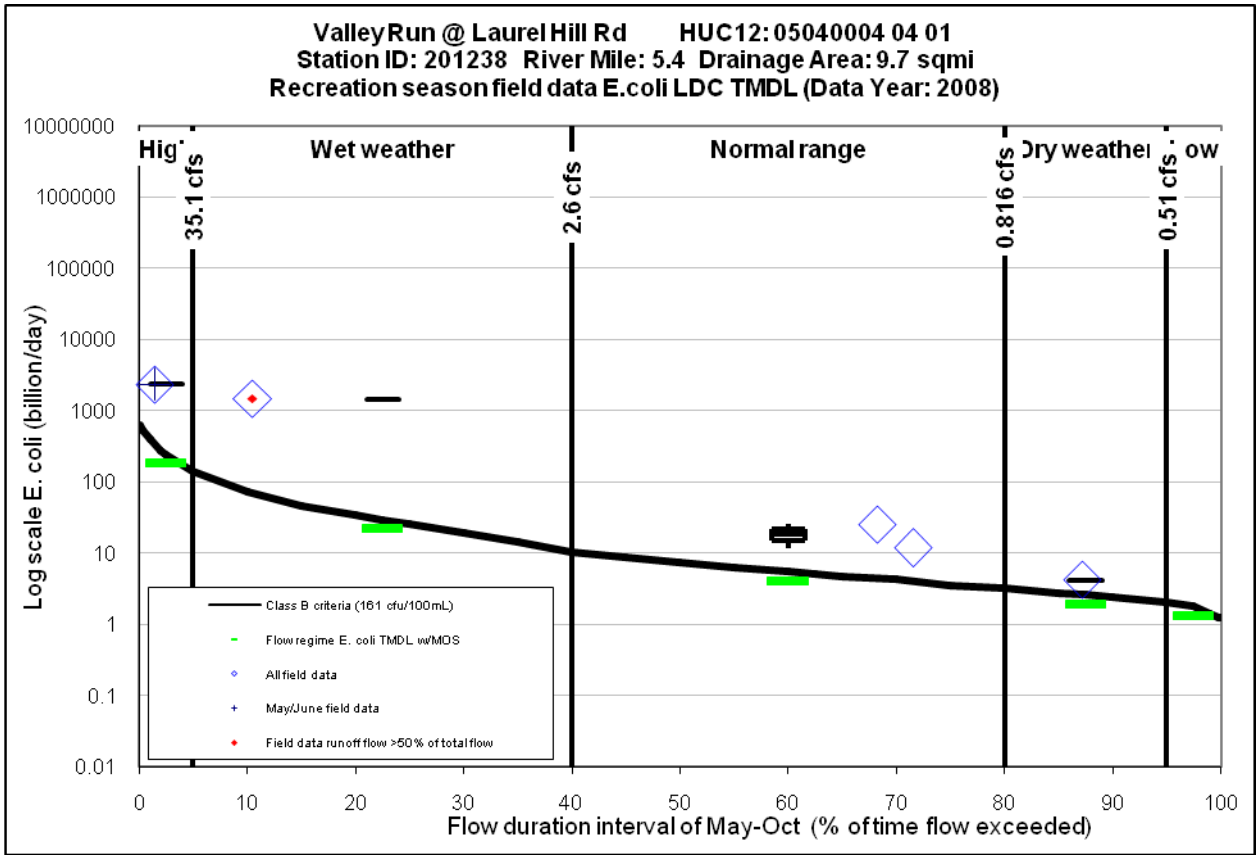

Figure D-4. Load duration curve for site on Valley Run @ Laurel Hill Rd.

Table D-6. TMDL table for site on Valley Run @ Laurel Hill Rd.

Flow regime TMDL analysis *E. coli* (billion bacteria/day)	High	Wet weather	Normal range	Dry weather	Low
Duration interval	0-5%	5-40%	40-80%	80-95%	95-100%
Samples per regime	1	1	2	1	0
Median sample load	2333	1,461	19	4	N/A
TMDL	246.156	29.539	5.514	2.584	1.780
WLA	0.0	0.0	0.0	0.0	0.0
LA	184.617	22.154	4.135	1.938	1.335
MOS: 20%	49.231	5.908	1.103	0.517	0.356
AFG: 5%	12.308	1.477	0.276	0.129	0.089
Nonpoint (LA) % load reduction required	**92%**	**98%**	**78%**	**54%**	No Data

Values were adjusted for rounding.

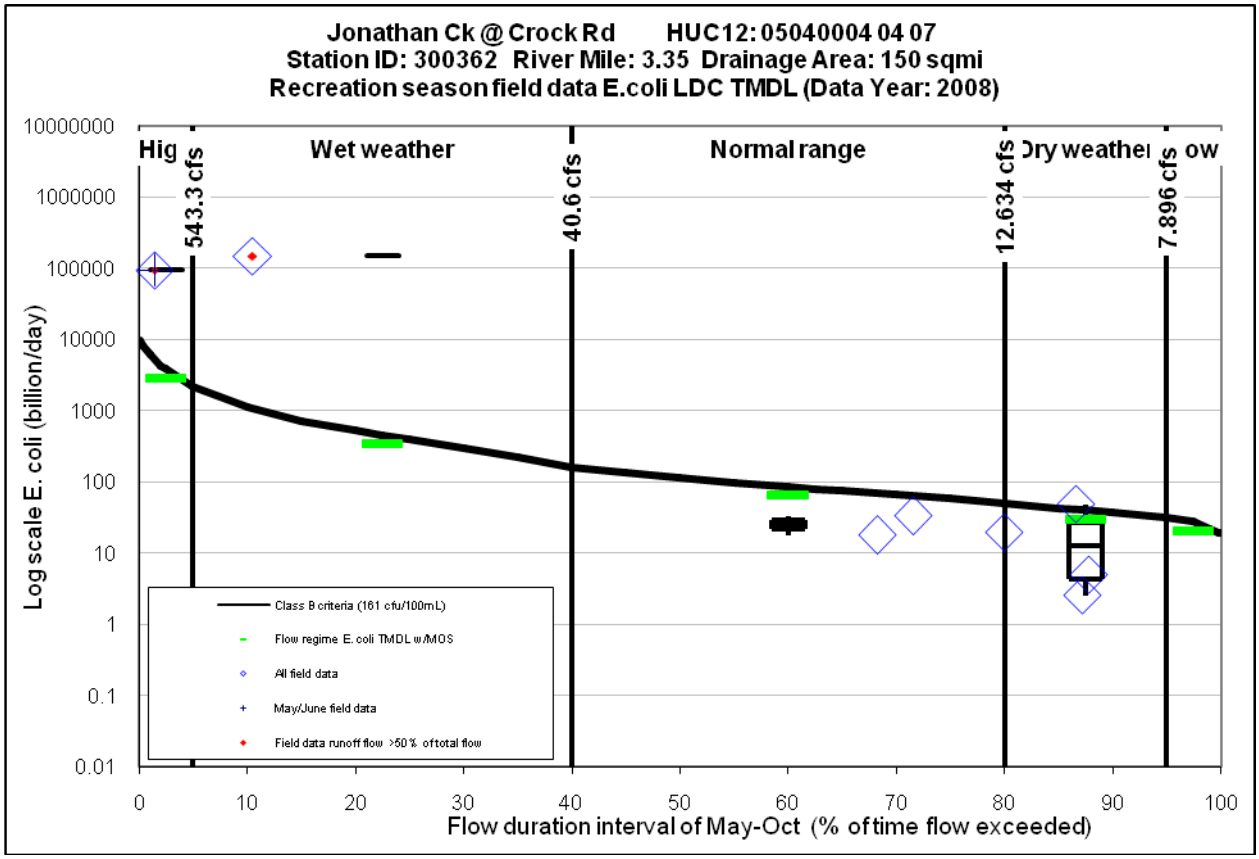

Figure D-5. Load duration curve for site on Jonathan Creek near White Cottage @ Crock Rd.

Table D-7. TMDL table for site on Jonathan Creek near White Cottage @ Crock Rd.

Flow regime TMDL analysis		**Wet**	**Normal**	**Dry**	
E. coli (billion bacteria/day)	**High**	**weather**	**range**	**weather**	**Low**
Duration interval	0-5%	5-40%	40-80%	80-95%	95-100%
Samples per regime	1	1	2	4	0
Median sample load	93,240	146,303	25	12.5	N/A
TMDL	3807.008	457.714	86.314	40.026	27.594
WLA: total	1.808	0.271	0.101	0.061	0.061
WLA: B&D Commissary	0.061	0.061	0.061	0.061	0.061
WLA: Zanesville MS4	1.747	0.210	0.040	0.0	0.0
LA	2853.448	343.014	64.635	29.954	20.631
MOS: 20%	761.402	91.543	17.263	8.009	5.521
AFG: 5%	190.350	22.886	4.316	2.002	1.380
Nonpoint (LA) % load reduction required	**97%**	**100%**	**None**	**None**	No Data

Values were adjusted for rounding.

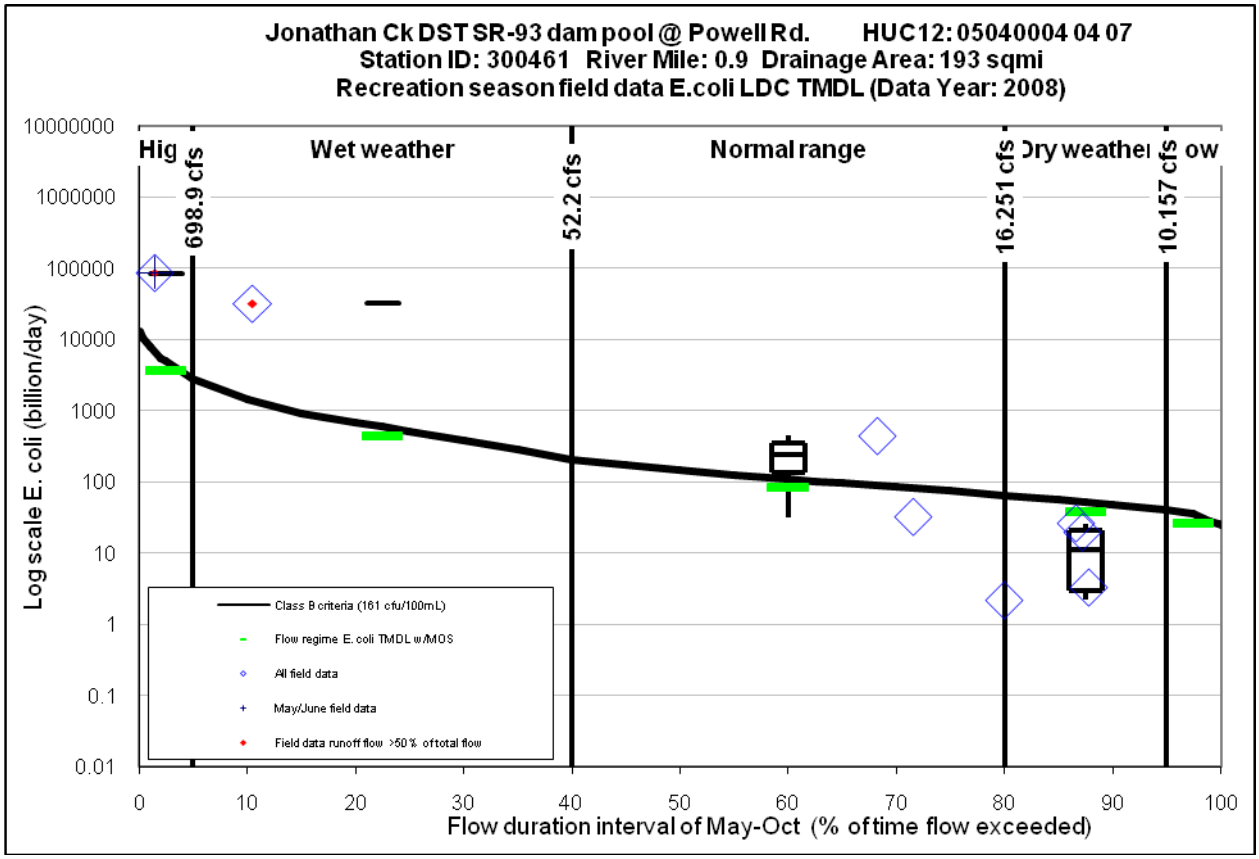

Figure D-6. Load duration curve for site on Jonathan Ck DST SR-93 dam pool @ Powell Rd.

Table D-8. TMDL table for site on Jonathan Ck DST SR-93 dam pool @ Powell Rd.

Flow regime TMDL analysis		**Wet**	**Normal**	**Dry**	
E. coli (billion bacteria/day)	**High**	**weather**	**range**	**weather**	**Low**
Duration interval	0-5%	5-40%	40-80%	80-95%	95-100%
Samples per regime	1	1	2	4	0
Median sample load	85,118	31,651	240	11.4	N/A
TMDL	4897.243	588.926	110.793	51.554	35.552
WLA: total	34.756	4.285	0.904	0.121	0.121
WLA: B&D Commissary	0.061	0.061	0.061	0.061	0.061
WLA: Hopewell Elementary	0.030	0.030	0.030	0.030	0.030
WLA: Hopewell Heights MHC	0.030	0.030	0.030	0.030	0.030
WLA: Zanesville MS4	34.635	4.164	0.783	0.0	0.0
LA	3638.184	437.417	82.198	38.552	26.550
MOS: 20%	979.443	117.779	22.153	10.305	7.104
AFG: 5%	244.861	29.445	5.538	2.576	1.776
Nonpoint (LA) % load reduction required	**96%**	**99%**	**66%**	**None**	No Data

Values were adjusted for rounding.

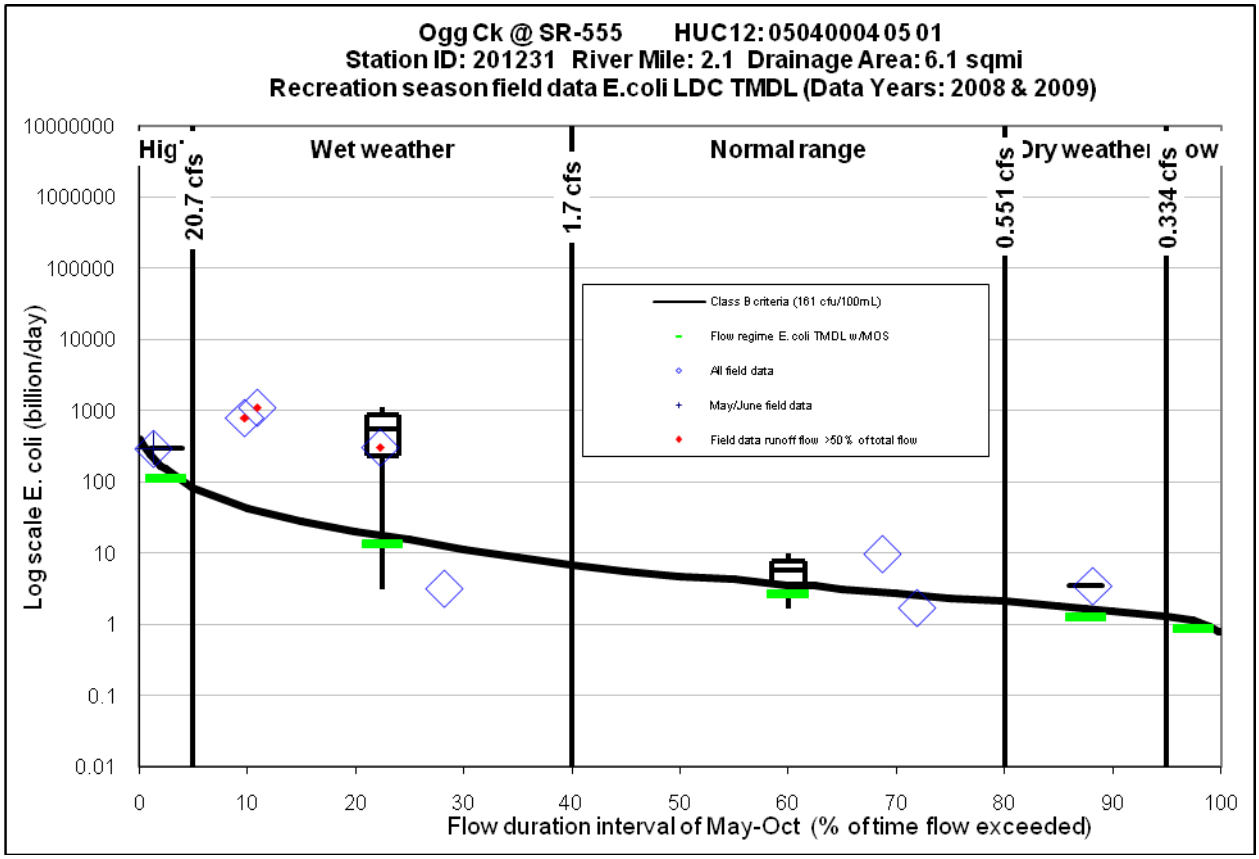

Figure D-7. Load duration curve for site on Ogg Ck S. of Deavertown @ SR-555.

Table D-9. TMDL table for site on Ogg Ck S. of Deavertown @ SR-555.

Flow regime TMDL analysis		Wet	Normal	Dry	
***E. coli* (billion bacteria/day)**	**High**	**weather**	**range**	**weather**	**Low**
Duration interval	0-5%	5-40%	40-80%	80-95%	95-100%
Samples per regime	1	4	2	1	0
Median sample load	294	544	6	3	N/A
TMDL	150.057	17.723	3.545	1.662	1.158
WLA	0.0	0.0	0.0	0.0	0.0
LA	112.542	13.292	2.658	1.247	0.868
MOS: 20%	30.011	3.545	0.709	0.332	0.232
AFG: 5%	7.503	0.886	0.177	0.083	0.058
Nonpoint (LA) % load reduction required	**62%**	**98%**	**54%**	**64%**	No Data

Values were adjusted for rounding.

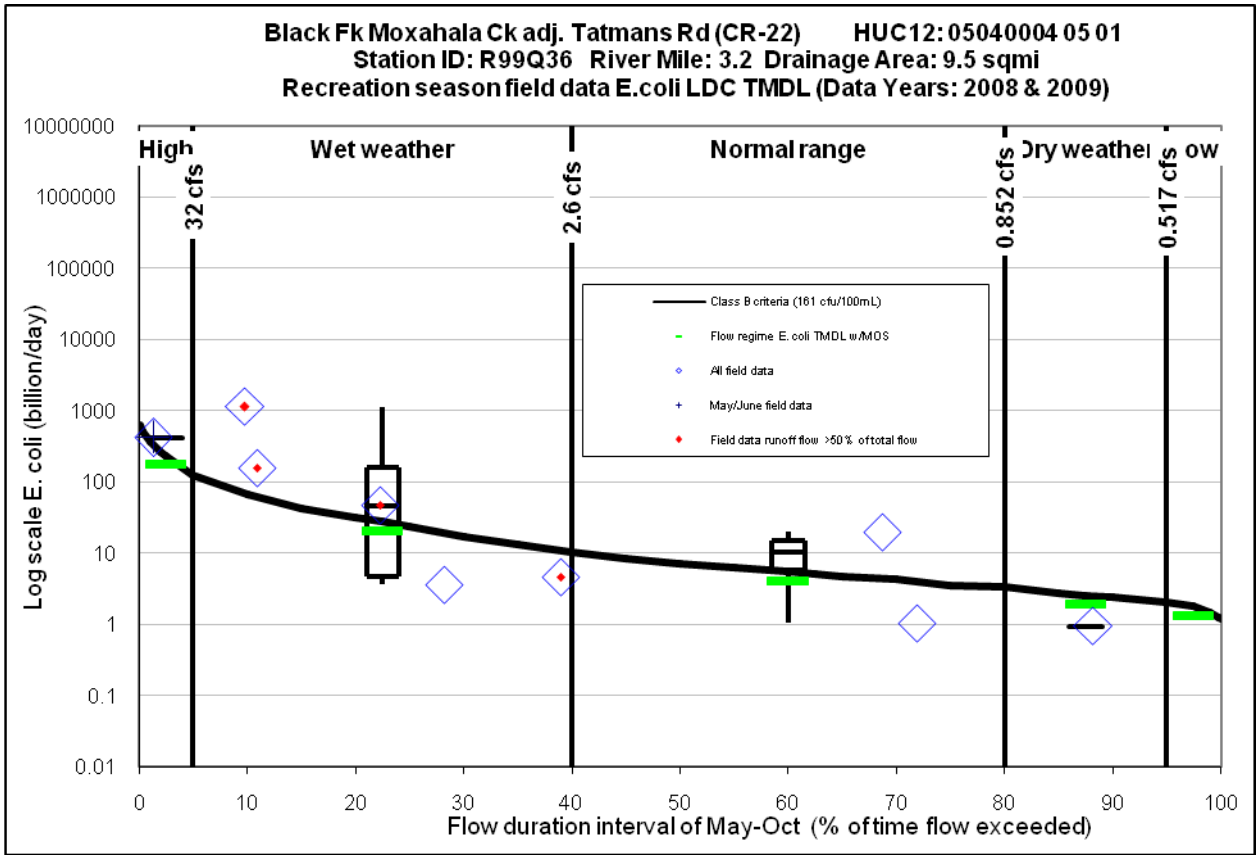

Figure D-8. Load duration curve for site on Black Fk Moxahala Ck adj. Tatmans Rd (CR-22).

Table D-10. TMDL table for site on Black Fk Moxahala Ck adj. Tatmans Rd (CR-22).

Flow regime TMDL analysis		**Wet**	**Normal**	**Dry**	
***E. coli* (billion bacteria/day)**	**High**	**weather**	**range**	**weather**	**Low**
Duration interval	0-5%	5-40%	40-80%	80-95%	95-100%
Samples per regime	1	5	2	1	0
Median sample load	416	47	10	0.9	N/A
TMDL	232.371	27.569	5.514	2.572	1.788
WLA:	0.0	0.0	0.0	0.0	0.0
LA	174.278	20.677	4.135	1.929	1.341
MOS: 20%	46.474	5.514	1.103	0.514	0.358
AFG: 5%	11.619	1.378	0.276	0.129	0.089
Nonpoint (LA) % load reduction required	**58%**	**56%**	**60%**	**None**	No Data

Values were adjusted for rounding.

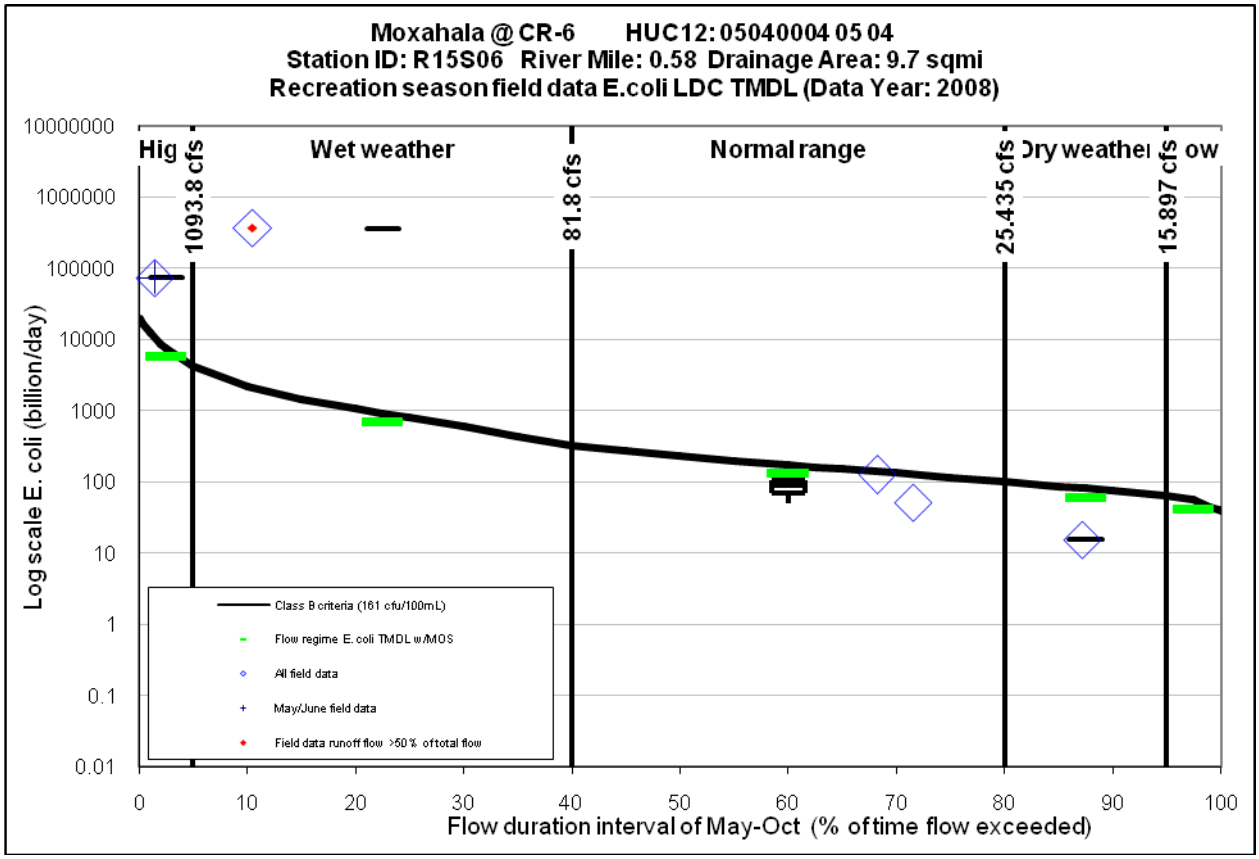

Figure D-9. Load duration curve for site on Moxahala Ck @ CR-6.

Table D-11. TMDL table for site on Moxahala Ck @ CR-6.

Flow regime TMDL analysis		**Wet**	**Normal**	**Dry**	
***E. coli* (billion bacteria/day)**	**High**	**weather**	**range**	**weather**	**Low**
Duration interval	0-5%	5-40%	40-80%	80-95%	95-100%
Samples per regime	1	1	2	1	0
Median sample load	72,666	361,495	88	16	N/A
TMDL	7,664.727	921.634	174.108	80.919	55.874
WLA: total	0.420	0.420	0.420	0.420	0.420
B&D Commissary	0.061	0.061	0.061	0.061	0.061
Hopewell Hts. MHC	0.030	0.030	0.030	0.030	0.030
Roseville WWTP	0.329	0.329	0.329	0.329	0.329
LA	5748.125	690.805	130.161	60.269	41.485
MOS: 20%	1532.945	184.327	34.822	16.184	11.175
AFG: 5%	383.236	46.082	8.705	4.046	2.794
Nonpoint (LA) % load reduction required	**92%**	**100%**	**None**	**None**	No Data

Values were adjusted for rounding.

D4.1.2 Dissolved Oxygen, Ammonia and Nitrate-Nitrite

Refer to section D4.1.1 for TMDLs for Black Fork Moxahala Creek (at Tatmans Rd a.k.a. CR-22), Ogg Creek (at SR-555) and Valley Run (at Laurel Hill Rd.) where nutrient loading is directly linked to *E. coli* loading.

D4.2 Paired Site Analysis: Temperature

Temperature ranges over a 48-hour sampling period from 8/25/09 to 8/27/09 varied between *free-flowing* and *impounded* sites, with *impounded* sites having a significantly reduced average temperature range of 2.73 degrees F compared to *free-flowing* sites at 9.09 degrees F (p= 0.04), based on an unpaired T-test (see Figure D-10).

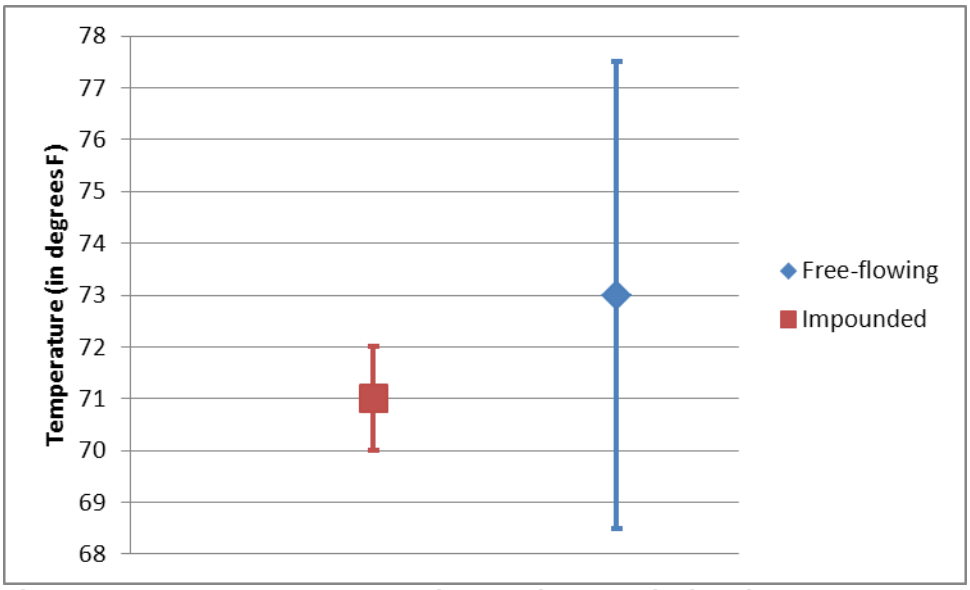

Figure D-10. Temperature ranges in Jonathan Creek sites (Max., Average, Min.).

Average temperature ranges at impounded sites need to be increased by 6.36 degrees F. Converting the portion of the stream at SR-93 from impounded to free-flowing, by the removal of the dam at Avondale, would eliminate the measurable impacts to stream temperature ranges caused by dam impoundments in Jonathan Creek.

A similar conclusion can be reached about the upstream Gladstone Mill dam near White Cottage. Its removal would return the near-field stream temperature regime to the same condition as the free flowing portions of the stream; however, there is currently no biological assessment in the impounded portion of the stream to elucidate any impacts that this dam may be having on fish or macroinvertebrate ecology.

D4.3 Acid Mine Drainage: Moxahala AMDAT

The results tables presented in this section (Tables D-12 through D-15) are excerpted and summarized from the *Acid Mine Drainage Abatement and Treatment Plan for the Moxahala Creek Watershed* (ILGARD 2005). Please see Appendix F for the complete report.

Alkalinity of stream water is a measure of its acidity-neutralizing capacity. Increased alkalinity raises water pH and acid buffering capacity thereby reducing the ability of stream water to carry dissolved metals in solution. The following acid load reductions can also be interpreted as required increases in alkalinity (ILGARD 2005).

Table D-12. Loading results for the Black Fork Moxahala Creek nested subwatershed (05040004 05 01).

Site	Existing acid load (lbs/day)	Target acidity load (lbs/day)	Needed load reduction (lbs/day)
Whitehouse Seep (BF-10)	1535	-857	2392
Dry Run Seep #2 (DR-2)	195	-10	205
Dry Run Seep #3 (DR-3)	1961	-208	2169

Values were adjusted for rounding.

Table D-13. Loading results for the Upper Moxahala Creek (Andrews, Bear Ck, McLuney Creek) nested subwatershed (05040004 05 02).

Site	Existing acid load (lbs/day)	Target acidity load (lbs/day)	Needed load reduction (lbs/day)
Sunny Hill #1 (AC-33)	5228	-596	5824
Gob Pile B discharge (AC-44)	4449	-403	4852
Sunny Hill East (AC-29)	1169	-165	1334
Murph's Gob Pile (AC-36)	325	-16	341
West Hopper Boil (AC-37)	2811	-129	2940
Andrew South Pits (AC-13)	163	-238	401
Howard William Lake project (AC-20)	3737	-2086	5823
Mouth of Andrews Creek (AC-01)	18700	-4305	23005
Andrews Creek (AC-45)	13841	-3220	17061
Andrews Creek (AC-46)	18626	-3505	22131
Lindamood South (BR-18)	42	-10	52
Garcia and Dorsey North (BR-30)	554	-88	643
Dorsey Strip (BR-29)	220	-72	292
Lindamood Seep (BR-22)	140	-24	164
Gene Sumner North (BR-26)	238	-124	362
Stort's Mine North (BR-25)	97	-107	204
Stort's Mine North (37)	13	8	21
Gildee North (BR-15)	86	-43	129
Dennis/Chestnut(BR-13)	375	-206	581
Bear Creek (BR-38)	1794	-884	2677
Bear Creek (BR-40)	742	-1130	1873
Bear Creek Mouth (BR-01)	4765	-3547	8312
McLuney Creek mainstem (ML-20)	908	-647	1555
Rort Seep (ML-rort)	335	-273	608
Newlon (ML-14&16)	1285	-384	1669
McLuney South (ML-49)	511	-372	883
Treadway (ML-6)	1019	-373	1392
Tunnel Hill (ML-38)	1007	-628	1635
McLuney Creek mainstem (ML-13)	923	-1509	2433
McLuney Creek (ML-39)	3627	-3627	7254
McLuney Creek Mouth (ML-01)	5289	-5062	10351

Values were adjusted for rounding.

Table D-14. Loading results for the Middle Moxahala Creek (Snake Run, Burley Run) nested subwatershed (05040004 05 03).

Site	Existing acid load (lbs/day)	Target acidity load (lbs/day)	Needed load reduction (lbs/day)
Snake Run (SN-8)	508	-239	747
Snake Run mouth (SN-1)	790	-445	1234
Burley Run (BU-25)	602	-486	1087
Burley Run Railroad South (BU-24)	215	-68	284
Lewis Hollow (BU-26)	1426	-562	1988
Burley Run N. & Jenkins Hollow (BU-3)	827	-803	1630
Burley Run (BU-4)	1781	-728	2509
Burley Run (BU-1)	2170	-1483	3653

Values were adjusted for rounding.

Table D-15. Loading results for the Lower Moxahala Creek (Riders Run) nested subwatershed (05040004 05 04).

Site	Existing acid load (lbs/day)	Target acidity load (lbs/day)	Needed load reduction (lbs/day)
Toth (RR-4)	69	-12	81
Toth (RR-5)	34	-56	90
Oxford (RR-15)	22	-5	26
Oxford (RR-16)	28	-6	34
Toth (RR-2)	319	-437	756
Oxford (RR-10)	110	-62	172
Riders Run mouth (RR-13)	369	-952	1321

Values were adjusted for rounding.

D5 References

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