Appendix

D

LOADING ANALYSIS INFORMATION
GREAT MIAMI RIVER (UPPER) WATERSHED

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D1 Introduction

Aquatic life use is not adequately supported in several areas of the upper Great Miami River (herein upper GMR) watershed according to Ohio EPA's 2008 biological and water quality survey (Ohio EPA 2011) (Table D-1). The dominant cause of impairment, in terms of intensity, is nutrient enrichment and this primarily occurs in the upper half of the Loramie Creek watershed. This is a region that contains its headwaters and their flowage into Lake Loramie, downstream of Lake Loramie and including sub-drainages of Mile Creek and Miami-Erie Canal, and through the mainstem down to and below the village of Newport. There are isolated segments of nutrient enrichment in the lower part of Loramie Creek watershed (namely the Turtle Creek subwatershed) and the lower reaches of the Little Muchinippi River watershed.

The dominant cause of impairment, in terms of spatial extent, and inexorably linked with nutrient enrichment is sedimentation/siltation and riverine habitat degradation. These forms of impairment are widespread across the upper GMR watershed but offer perhaps the most efficient approach to restoring a beneficial use. There are two isolated cases of other non-nutrient impairment – total dissolved solids in the headwaters of Loramie Creek watershed, and organic enrichment on the mainstem of the GMR several miles downstream of the Village of Indian Lake.

Recreation use impairment exists throughout the upper GMR watershed on both mainstem and tributary systems (Table D-1).

Based on the 2008 biological and water quality survey and subsequent water quality monitoring in 2009, a quantitative analysis was carried out to develop total maximum daily loads (TMDLs) for aquatic life and recreation use impairments as required by Section 303(d) of the Clean Water Act and the US Environmental Protection Agency's Water Quality Planning and Management Regulations (Title 40 CFR, Part 130). This TMDL report describes existing in-stream water quality, candidate sources of pollution (both point and pervasive in nature), water quality targets, and required load reductions to reach those targets.

Table D-1. Summary of impairments in the Great Miami River (upper) watershed and methods used to address impairments.

Assessment Unit (05080001)	**Narrative Description**	**Causes of Impairment** (Beneficial use in parentheses[1])	**Action Taken**
Headwaters Great Miami River (05080001 01)			
01 01 *Priority points: 3*	North Fork Great Miami River	No impairment (ALU)	No action necessary
		Bacteria (RU)	Bacteria TMDL
01 02 *Priority points: 1*	South Fork Great Miami River	No impairment (ALU)	No action necessary
		Bacteria (RU)	Bacteria TMDL
01 03 *Priority points: 1*	Indian Lake Great Miami River	Direct habitat alteration (ALU)	Habitat TMDL
		No data for assessment (RU)	No action necessary
Muchinippi Creek (05080001 02)			
02 01 *Priority points: 1*	Willow Creek	Direct habitat alteration (ALU)	Habitat TMDL
		No impairment (RU)	No action necessary

Assessment Unit (05080001)	Narrative Description	Causes of Impairment (Beneficial use in parentheses[1])	Action Taken
02 02 *Priority points: 1*	Headwaters Muchinippi Creek	No impairment (ALU)	No action necessary
		Bacteria (RU)	Bacteria TMDL
02 03 *Priority points: 5*	Little Muchinippi Creek	Direct habitat alterations (ALU)	Habitat TMDL
		Nutrients (ALU)	Nutrient TMDL
		Sedimentation/siltation (ALU)	Sediment TMDL
		Bacteria (RU)	Bacteria TMDL
02 04 *Priority points: 4*	Calico Creek-Muchinippi Creek	Direct habitat alterations (ALU)	Habitat TMDL
		Sedimentation/siltation (ALU)	Sediment TMDL
		Other flow regime alterations (ALU)	Habitat TMDL as surrogate
		No impairment (RU)	No action necessary
Bokengehalas Creek-Great Miami River (05080001 03)			
03 01 *Priority points: 2*	Cherokee Mans Run	No impairment (ALU)	No action necessary
		No data for assessment (RU)	No action necessary
03 02 *Priority points: 8*	Rennick Creek-Great Miami River	Sedimentation/siltation (ALU)	Sediment TMDL
		Other flow regime alterations (ALU)	Habitat TMDL as surrogate
		Direct habitat alterations (ALU)	Habitat TMDL
		Bacteria (RU)	Bacteria TMDL
03 03 *Priority points: 7*	Rum Creek	Direct habitat alterations (ALU)	Habitat TMDL
		Sedimentation/siltation (ALU)	Sediment TMDL
		Bacteria (RU)	Bacteria TMDL
03 04 *Priority points: 5*	Blue Jacket Creek	No impairment (ALU)	No action necessary
		Bacteria (RU)	Bacteria TMDL
03 05 *Priority points: 8*	Bokengehalas Creek	Sedimentation/siltation (ALU)	Sediment TMDL
		Direct habitat alterations (ALU)	Habitat TMDL
		Bacteria (RU)	Bacteria TMDL
03 06 *Priority points: 8*	Brandywine Creek-Great Miami River	Direct habitat alterations (ALU)	Habitat TMDL
		Other flow regime alterations (ALU)	Not addressed
		Organic enrichment (sewage) biological indicators (ALU)	Category 4B alternative
		Sedimentation/siltation (ALU)	Sediment TMDL

Assessment Unit (05080001)	Narrative Description	Causes of Impairment (Beneficial use in parentheses[1])	Action Taken
		Bacteria (RU)	Bacteria TMDL
Stoney Creek-Great Miami River (05080001 04)			
04 01 *Priority points: 5*	McKees Creek	No impairment (ALU)	No action necessary
		Bacteria (RU)	Bacteria TMDL
04 02 *Priority points: 3*	Lee Creek	No impairment (ALU)	No action necessary
		Bacteria (RU)	Bacteria TMDL
04 03 *Priority points: 5*	Stoney Creek	No impairment (ALU)	No action necessary
		Bacteria (RU)	Bacteria TMDL
04 04 *Priority points: 5*	Indian Creek	Insufficient data to assess (ALU)	No action necessary
		Bacteria (RU)	Bacteria TMDL
04 05 *Priority points: 5*	Plum Creek	No impairment (ALU)	No action necessary
		Bacteria (RU)	Bacteria TMDL
04 06 *Priority points: 6*	Turkeyfoot Creek-Great Miami River	Direct habitat alterations (ALU)	Habitat TMDL
		Sedimentation/siltation (ALU)	Sediment TMDL
		No impairment (RU)	No action necessary
Headwaters Loramie Creek (05080001 05)			
05 01 *Priority points: 6*	Headwaters Loramie Creek	Direct habitat alterations (ALU)	Habitat TMDL
		Nutrients (ALU)	Nutrient TMDL
		Total dissolved solids (ALU)	TDS TMDL (simple mass balance)
		Other flow regime alterations (ALU)	Not addressed – backwater from downstream reservoir
		Sedimentation/siltation (ALU)	Sediment TMDL
		Bacteria (RU)	Bacteria TMDL
05 02 *Priority points: 4*	Mile Creek	Nutrient/eutrophication biological indicators (ALU)	Nutrient TMDL
		Direct habitat alterations (ALU)	Habitat TMDL
		Bacteria (RU)	Bacteria TMDL
05 03 *Priority points: 9*	Lake Loramie-Loramie Creek	Nutrient/eutrophication biological indicators (ALU)	Nutrient TMDL
		Low flow alterations (ALU)	Not addressed – low flow from upstream reservoir
		Bacteria (RU)	Bacteria TMDL

Assessment Unit (05080001)	Narrative Description	Causes of Impairment (Beneficial use in parentheses[1])	Action Taken
Turtle Creek-Loramie Creek (05080001 06)			
06 01 *Priority points: 4*	Nine Mile Creek	No impairment (ALU)	No action necessary
		Bacteria (RU)	Bacteria TMDL
06 02 *Priority points: 7*	Painter Creek-Loramie Creek	Phosphorus (total) (ALU)	Nutrient TMDL
		Direct habitat alterations (ALU)	Habitat TMDL
		Bacteria (RU)	Bacteria TMDL
06 03 *Priority points: 4*	Turtle Creek	Nutrients (ALU)	Nutrient TMDL
		Direct habitat alterations (ALU)	Habitat TMDL
		No impairment (RU)	No action necessary
06 04 *Priority points: 5*	Mill Creek-Loramie Creek	No impairment (ALU)	No action necessary
		Bacteria (RU)	Bacteria TMDL

[1] ALU = aquatic life use
RU = recreation use

D2 Linkage Analysis

D2.1 Delivery of Source Loads to Waterbodies

The Great Miami River TMDL (upper watershed) does not support two beneficial uses – aquatic life use and recreation use. The causes of impairment to aquatic life use consist of, in order of prevalence, stream and riparian habitat modification, siltation and sedimentation, nutrient enrichment, and organic enrichment and total dissolved solids (TDS). The cause of recreation use impairment is through excessive concentrations of an indicator bacterium – *Escherichia coli*.

Stream and riparian habitat modification is not a pollutant *per se*; its existence prevents attainment of the aquatic life use standard indirectly through reduction in the stream assimilative capacity to handle other pollutants that may cause impairment. Sources of this impairment include encroachment from cropland farming, suburban residential and commercial development, and in-stream dredging among others. These sources are “delivered” to the impaired water body through physical alteration of riparian and in-stream structure and composition. Sources of siltation and sedimentation include those mentioned just above but add conventional cropland tillage practices and livestock access to the stream, among still many others. Delivery of these sources of sediment and silt include overland flow from rain events and sloughing of banks when slope stability decreases due to the encroachment.

Specific components of nutrient enrichment include ortho-phosphorus (dissolved reactive phosphorus) and nitrate-nitrite – as these are directly available to plants. However, other forms of nitrogen (e.g., ammonia) and phosphorus (e.g., organic P) transform through processes such as oxidation and mineralization to plant available forms. Hence, these transformation processes are also relevant to impairment. Phosphorus chemical species are typically the limiting factor in aquatic plant growth in Midwestern (USA) rivers and streams. It is also true for this study as

chemical monitoring of nitrogen and phosphorus for the entire upper Great Miami River watershed suggests P-limited stream systems (Figure D-1). N-limited systems are to the left of the optimal ratio line (i.e., less than a 16:1 N:P ratio) and P-limited systems are to the right of this line. As seen in Figure D-1, as the N:P ratio increases, the concentration of P decreases – it is consumed by the stream system (flora and sediment) – whereas the concentration of N is roughly constant or increases. N is replenished but P becomes limiting. Hence, focusing on P reduction produces immediate limitation for aquatic plant growth and subsequent enrichment effects. Further, P-limited systems occur primarily during the growing season in the GMR watershed where Figure D-2 shows low N:P ratios from June through October. Hence, controlling P may limit planktonic growth during the critical low flow season and reduce corresponding enrichment effects

Sources of phosphorus nutrient enrichment primarily stem from fertilization of cropland – both synthetic and organic sources – and to some extent golf courses and residential lawns, but the latter extent is masked by the predominant area of cropland in this study area. Other, more direct, sources include failing home septic systems and publicly owned treatment works (POTW) effluent. Pathways for pervasive sources are by transport of particulate and dissolved P from overland flow; dissolved P also makes it way to impaired waterbodies through subsurface flow and tile drainage when soil P concentrations are above natural thresholds (Sharpley et al. 2002).

Impairment due to organic enrichment and TDS are unique and discrete in the source attainability analysis. The former was found to emanate from POTW effluent (Indian Lake WPCD) where source loads have by-passed secondary treatment. The latter stems from excessive POTW discharge of TDS (Village of Botkins) as a result of excessive loads from incoming sources (Village of Botkins WTP). Nonpoint sources of TDS originate from agricultural and residential runoff, leaching of soil contamination. In addition, certain naturally occurring total dissolved solids arise from the weathering and dissolution of rocks and soils though their existence is minimal in the study area.

Excessive concentrations of the indicator bacterium – *Escherichia coli* – exceeding the water quality standard are due to both pervasive and direct sources. Pervasive sources stem from cropland fertilization using manure, and in particular when it is applied improperly (e.g., on frozen soil with an associated rainfall event) or applied excessively. Other pervasive sources stem from human waste via sludge management from POTW and from wildlife inhabiting the watershed. All of these sources reach impaired waterbodies through overland flow from rain or snowmelt events. Direct sources of this bacterium include improperly functioning of home septic systems and POTW and livestock access to streams. An assumption is made here that POTW operations contain proper disinfection techniques and they discharge at or below NPDES permit limits; hence their pathway is not considered as a source of impairment.

D2.2 Source Location and Analysis

Areas where nutrient enrichment and subsequent aquatic life use impairment occur in the upper half of the Loramie Creek watershed, including its headwaters and their flowage into Lake Loramie, downstream from Lake Loramie and including sub-drainages of Mile Creek and Miami-Erie Canal, and through the mainstem down to and below the village of Newport. There are isolated segments of nutrient enrichment in the lower part of Loramie Creek watershed (namely Turtle Creek subwatershed) and the lower reaches of the Little Muchinippi Creek watershed. Source descriptions specific to each study area include:

1) Turtle Creek is a headwater sub-basin and the impairment due to nutrient enrichment is in the upper third of the nested subwatershed (RM 8.42 and a drainage area of 8.3 mi^2). This area consists primarily of row crop agriculture with both synthetic and organic fertilization. Row-crop agriculture is selected as the sole source and remediation will be sought through a combination of reduced fertilization rate and agricultural management practices. The impairment is also due to habitat alteration and the deviation of existing habitat from the recommended habitat based on designated aquatic life use will be quantified.
2) The lower part of Little Muchinippi Creek (RM 0.62 and 35.5 mi^2) and an upstream tributary (RM 1.8 and 5.4 mi^2) are impaired for nutrients, habitat, and siltation. Nutrient sources will be addressed through reduced fertilization of row crop agriculture and limiting the concentration of total phosphorus from the sole POTW in this subwatershed – Jackson Center (1PB00018).
3) In the upper half of the Loramie Creek watershed, contributions of P stem from cropland runoff, failing home septic systems, and POTW effluent. POTW effluent consists of a major (Village of Minster - 2PB00036) and a significant minor (Lake Loramie/Shelby County SSD - 1PH00028) permitted facility. Both POTW systems contribute effluent year-round (as usual) but for the summer months their effluent comprises a majority of Loramie Creek flow as outfall from Lake Loramie is small to none. Flow alteration by the Lake Loramie impoundment, a significant impact for reducing downstream assimilative capacity, is a major yet un-addressed source of non-attainment for the Loramie Creek system. The primary source load contributions originate from fertilization of row crop agriculture, particularly in the Mile Creek sub-drainage (Darke and Mercer counties OH) where livestock operations are prevalent. Shelby and lower Auglaize counties are also heavy corn-soybean producing areas and contribute nutrients from these activities. Thus, two POTWs and row crop agriculture will be considered in load reduction strategies to address impairment due to enrichment

Impairment of aquatic life use at RM 153.45 of the Great Miami River mainstem is caused by habitat alteration, siltation, flow alteration, and organic enrichment/DO. Organic enrichment/DO is attributed to an upstream source – a WWTP (approximately 5 miles) named Indian Lake/Logan County (1PK00002). This source will be addressed through analysis of its BOD and TSS discharge loads before and after the POTW construction upgrade that occurred after the field survey in 2008. Siltation and habitat alteration causes are also considered – these are predominant causes relative to organic enrichment – and will be addressed as in above. Row crop agriculture and in-stream channel dredging to maintain field tile flow are sources. Flow alteration cannot be addressed as it is caused by an upstream impoundment – Indian Lake. Ideally the lake area should be maintained as a natural water course – a meandering prairie/grassed stream – but economic reasons (tourism, recreation, vacation home values) prevent addressing this source of impairment.

While habitat alteration and its primary source – row crop agriculture infringement on natural water courses – has been mentioned in situations with nutrient or other chemical-based impairment, it is a significant cause of impairment throughout the upper GMR watershed. In total, there were 24 sites with impairment attributed to habitat alteration, 8 sites attributed to siltation, and 5 sites attributed to flow alteration. Four of five flow alteration sites are downstream from two major impoundments – Indian Lake and Lake Loramie. The site not below an impoundment is addressed below. Today these waterbodies serve recreation and tourism needs at the expense of full aquatic biological integrity. The habitat alteration and siltation locations exist on the GMR mainstem, the Muchinippi Creek watershed including multiple tributaries, and several direct tributaries to the upper GMR mainstem. These

impairments are primarily in Logan County OH. Loramie Creek watershed is also beset with habitat alteration and this occurs primarily in Shelby County OH. As identified above, all sites impaired by habitat alteration and siltation have row crop agriculture and in-stream channel dredging as sources of impact.

Flow alteration on (big) Muchinippi Creek is caused by wood-debris impoundment (i.e., log-jams). The existence of excess woody-debris originates from intense agricultural management of the river course. Here removal of woody material from the vegetated riparian zone of an upstream watercourse to "improve" flow and thereby reduce flooding of cropland at a local level. Then, one witnesses the problem propagate downstream to another landowner's field. Flow alteration for this location will be addressed indirectly through restoration of habitat (alteration).

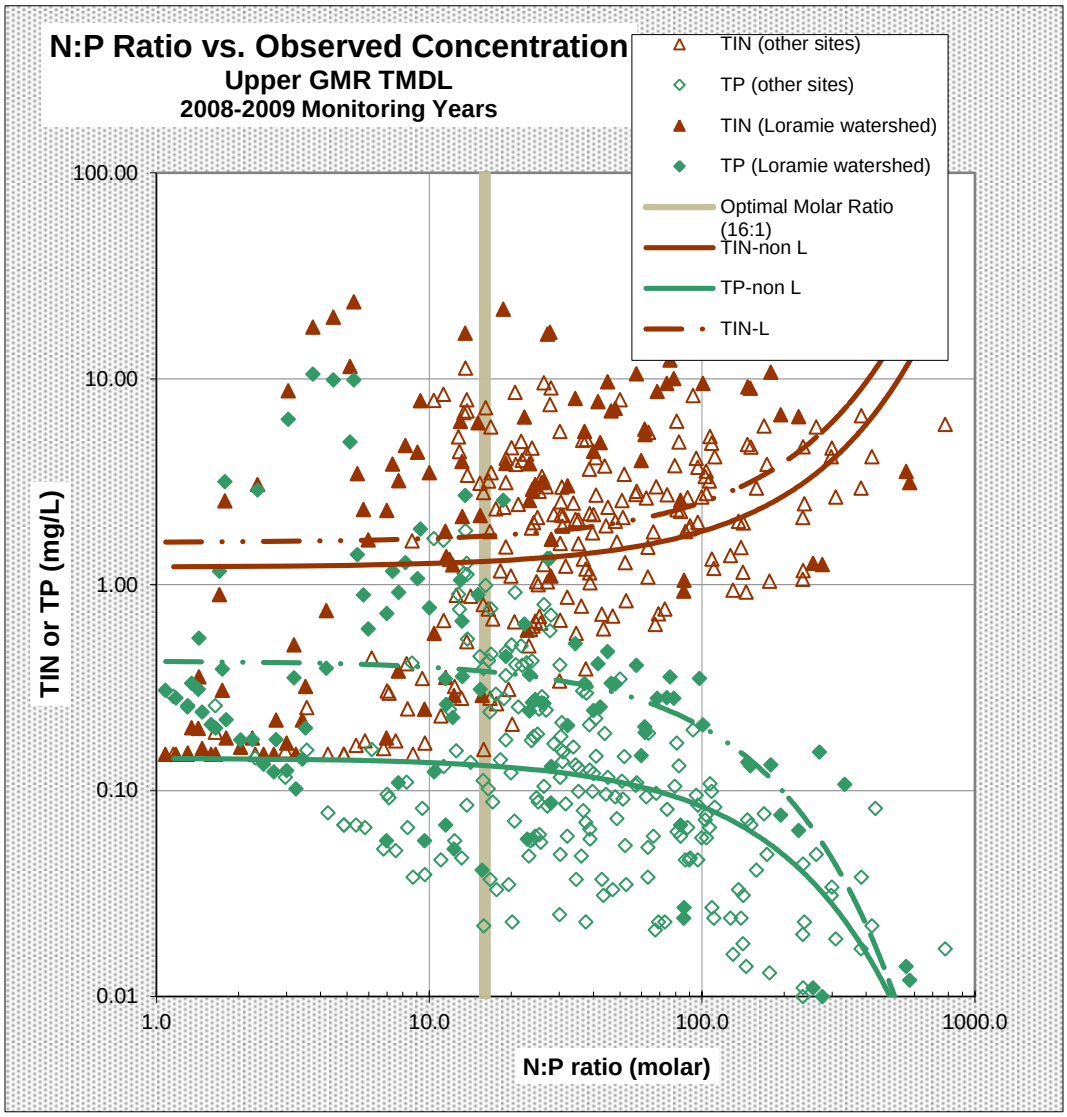


Figure D-1. Cross-plot of nutrient concentration (TIN or TP in mg/L) and molar N:P ratio for monitored locations in the upper Great Miami River.
Note: **TIN** = total inorganic nitrogen (ammonia + nitrite + nitrate), **TP** = total phosphorus (includes dissolved and particulate, includes ortho-P and organic P). The optimal N:P ratio to sustain planktonic growth is 16:1 (using molar concentrations). Monitoring sites are differentiated as only those in Loramie Creek watershed and all other sites in GMR watershed. Solid and dashed lines are exponential trends fitted to the point (monitored) data.

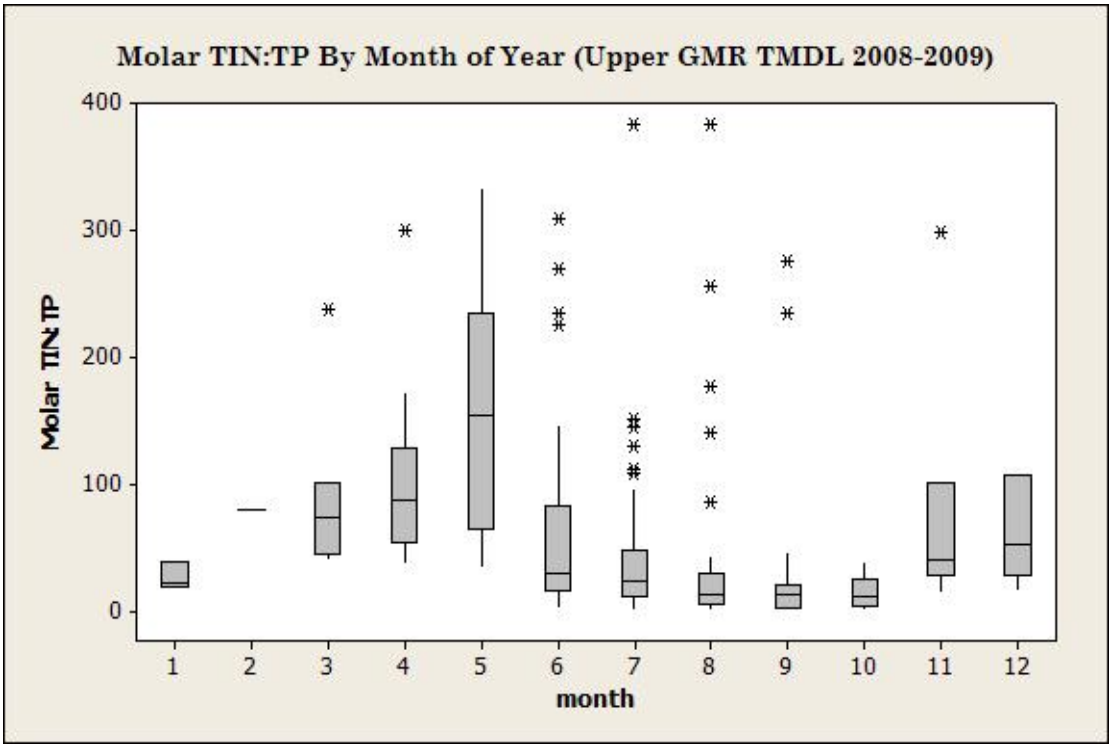


Figure D-2. Distribution of molar N:P ratio by month (1=January through 12=December) of year.

D3 Analysis Methods

The general approach to eliminating the impairment causes to the two beneficial uses – aquatic life and recreation – are summarized in Table D-2 below and distributed by assessment unit and nested subwatershed. Nearly all approaches have a direct analytical procedure for resolving the impairment. The exception are a surrogate approach or "not addressed" for impairments related to the two in-stream reservoirs – Indian Lake and Lake Loramie – in the study area.

Table D-2. Summary of causes of impairment and actions taken to address them in assessment units within the 05080001 01 through 05080001 06 ten-digit hydrologic units.

Causes of Impairment	Watershed Assessment Units						
	05080001 01			05080001 02			
	01	02	03	01	02	03	04
Aquatic Life Use							
Nutrient enrichment						D	
Habitat alterations			D	D		D	D
Sedimentation/siltation						D	D
Dissolved oxygen/organic enrichment							
Total dissolved solids							
Ammonia							
Other flow regime alterations							S
Recreation Use							
E. coli	D	D			D	D	

Causes of Impairment	Watershed Assessment Units											
	05080001 03						05080001 04					
	01	02	03	04	05	06	01	02	03	04	05	06
Aquatic Life Use												
Nutrient enrichment												
Habitat alterations		D	D		D	D						D
Sedimentation/siltation		D	D		D	D						D
Dissolved oxygen/organic enrichment						4B						
Total dissolved solids												
Ammonia												
Other flow regime alterations		S				N						
Recreation Use												
E. coli		D	D	D	D	D	D	D	D	D	D	

Causes of Impairment	Watershed Assessment Units						
	05080001 05			05080001 06			
	01	02	03	01	02	03	04
Aquatic Life Use							
Nutrient enrichment	D	D	D		D	D	
Habitat alterations	D	D			D	D	
Sedimentation/siltation	D						
Dissolved oxygen/organic enrichment							
Total dissolved solids	D						
Ammonia							
Other flow regime alterations	N		N				
Recreation Use							
E. coli	D	D	D	D	D		D

Definitions:

D – direct	TMDLs are calculated for this parameter.
N – not addressed	Impairment is not addressed in this report.
S – surrogate	TMDLs are calculated for a closely related cause and actions to reduce the impact of that cause should be sufficient to address this cause. There is substantial overlap in the sources of the loading of both parameters
Blank	Indicates that the assessment unit is not impaired for this cause.
4B	The 4B option is being used to address impairment.

D4 SWAT Analysis of Total Phosphorus – Loramie and Little Muchinippi Watersheds

D4.1 Background

Section D4 considers TMDL load development and allocation for all assessment units that are impaired for nutrient enrichment. Areas where nutrient enrichment and subsequent aquatic life use impairment occur in the upper half of the Loramie Creek watershed, including its

headwaters and their flowage into Lake Loramie, downstream of Lake Loramie and including sub-drainages of Mile Creek and Miami-Erie Canal, and through the mainstem down to and below the village of Newport. There are isolated segments of nutrient enrichment in the lower part of Loramie Creek watershed (namely Turtle Creek subwatershed) and the lower reaches of the Little Muchinippi River watershed. Boundaries of the study area along with mainstem and major tributaries and point source discharge locations are shown in Figure D-3.

Nutrient load development is based on total phosphorus as a water quality parameter. Loadings for this parameter are secured from the following watershed sources by:

1) Determining load contributions from nonpoint source activities originating on the watershed landscape, primarily from row-crop agriculture and associated crop fertilization from synthetic (commercial) and organic (animal manure) nutrient sources. Load estimates were determined by conference with local Soil and Water Conservation District staff and by calibration to crop yields provided by the National Agricultural Statistics Service.

2) Accounting for load contributions arising from all wastewater sources in the watershed (primarily those dischargers having conduit loads exceeding 0.02 MGD). Magnitudes for these loads were determined by provision of effluent concentration and flow from the Ohio EPA discharge monitoring reports (DMRs) available within SWIM (Surface Water Information Management System).

3) Estimating load contributions from residential septic systems (or onsite sewage systems). Loading magnitudes were estimated from county health officials and their annual reports, U.S. Census Bureau survey, and literature estimates for concentration and per capita flow rate.

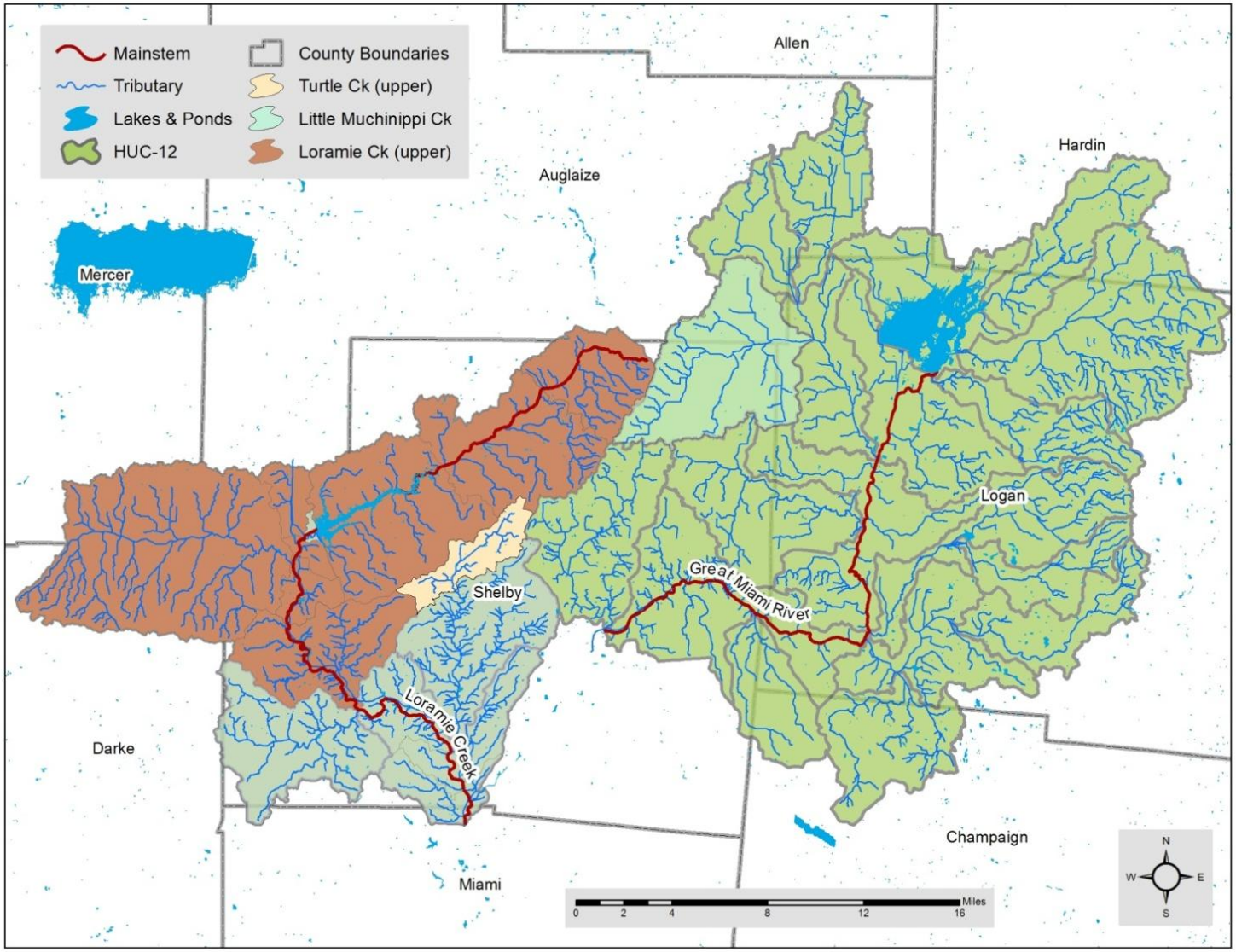


Figure D-3. Map showing boundaries of Great Miami River (upper zone) and component watersheds undergoing nutrient TMDL analysis.

Note: Shading shows Loramie Creek (upper impaired area), Turtle Creek (upper), and Little Muchinippi Creek watershed study areas. Mainstem segments (red) refer to Loramie Creek and Great Miami River.

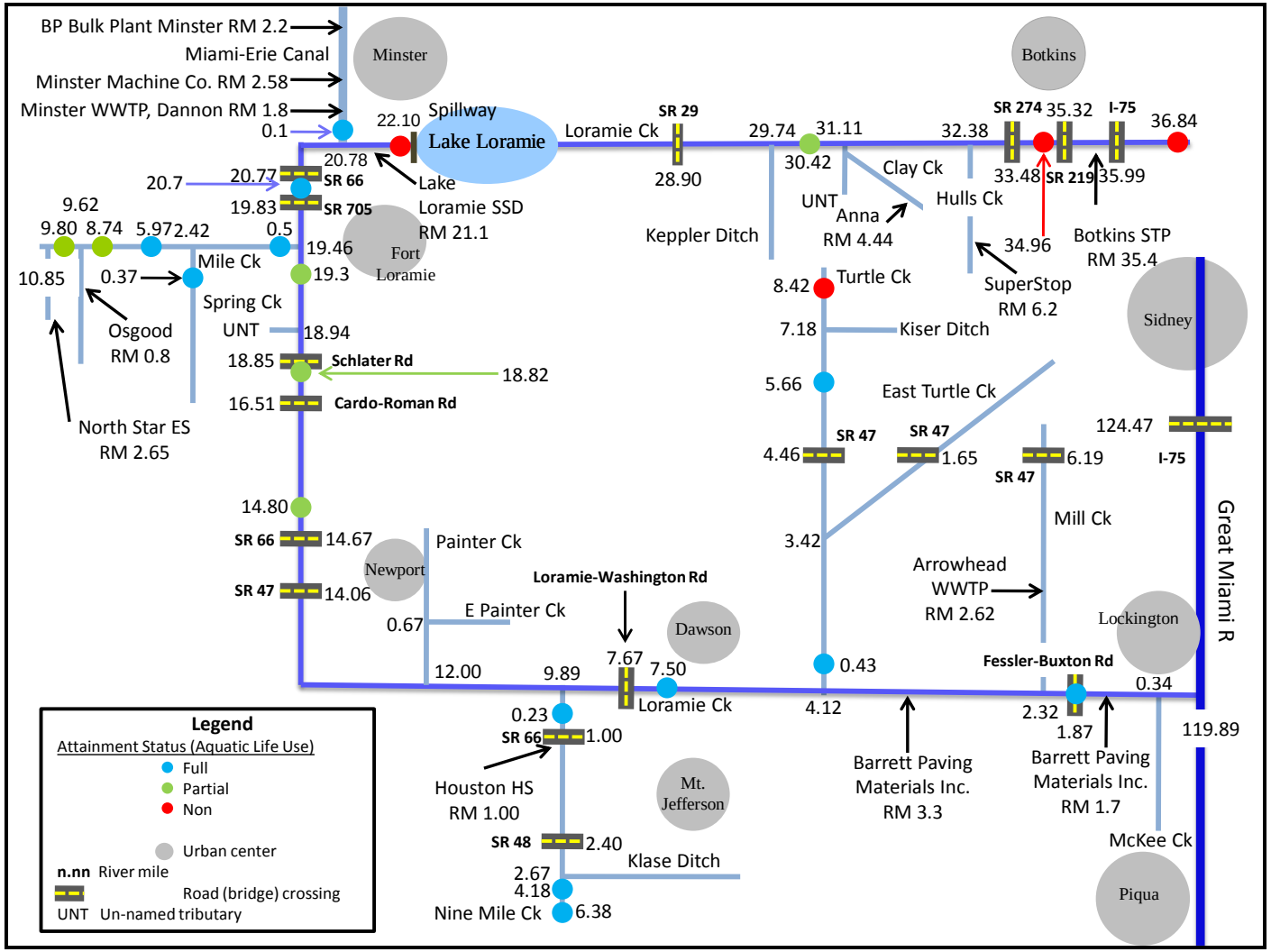


Figure D-4. Schematic of entire Loramie Creek watershed showing mainstem and tributary stream systems, Lake Loramie, WWTP facilities, urban centers, and aquatic life use attainment.

Note: WWTP facilities (in text) indicated by solid black arrow, unless otherwise noted, and corresponding river mile (HS = high school, ES = elementary school, MHP = mobile home park, BP = British Petroleum, STP = sewage treatment plant, SSD = sanitary sewer district). River mile references are to Ohio EPA river code system (zero reference from mouth of segment). Bridge crossings noted with road name and river mile (SR = state route, I = interstate).

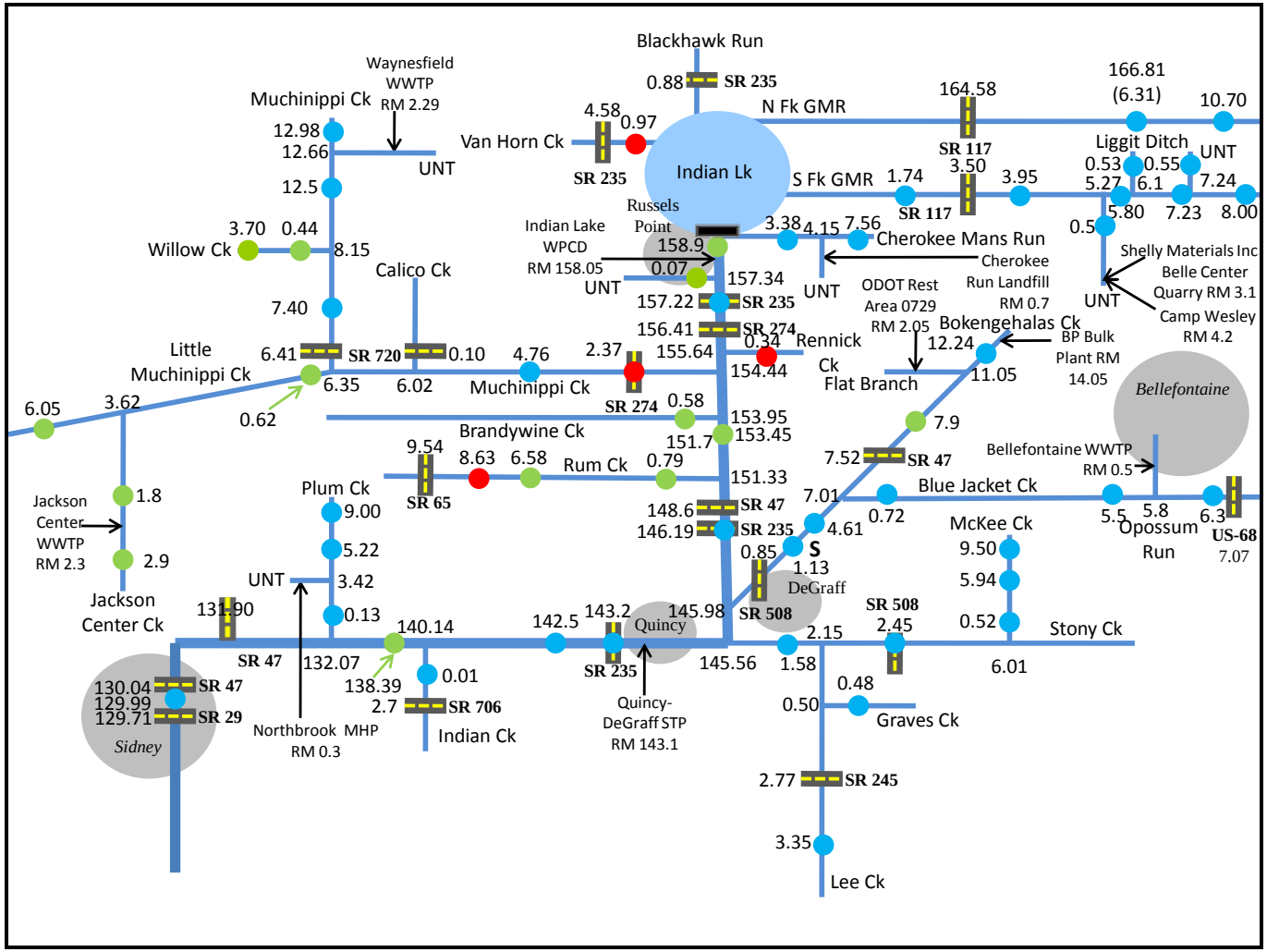


Figure D-5. Schematic of upper Great Miami River watershed showing mainstem and tributary stream systems, Indian Lake, WWTP facilities, urban centers, and aquatic life use attainment.

Note: See Figure D-4 for corresponding legend. WWTP facilities (in text) indicated by solid black arrow, unless otherwise noted, and corresponding river mile (HS = high school, ES = elementary school, MHP = mobile home park, STP = sewage treatment plant, SSD = sanitary sewer district). River mile references are to Ohio EPA river code system (zero reference from mouth of segment). Bridge crossings noted with road name and river mile (SR = state route, I = interstate).

D4.2 Nutrient (Total Phosphorus) Targets

The loading development for this study is based on statewide targets for total phosphorus concentrations (Table D-3) (Ohio EPA 1999). Using this statewide reference, targets for specific impaired assessment units (and their model-based subdivisions) are assigned according to aquatic life use designation and drainage area class in Table D-4. Assignment of target is based on the characteristics of the mainstem segment that drains each particular subbasin unit. It is important to note that these phosphorus targets are not codified in Ohio's water quality standards; therefore, there is a certain degree of flexibility in how they can be used to establish load reductions.

Table D-3. Target total phosphorus concentrations defined for Ohio (based on Ohio EPA 1999) as a function of aquatic life use designation and drainage basin area.

Watershed Type	Drainage Area Range (mi^2)	Concentration (mg-P/L)		
		EWH	WWH	MWH
Headwater	0 – 20	0.05	0.08	0.34
Wading	20 – 200	0.05	0.10	0.28
Small River	200 – 1000	0.10	0.17	0.25
Note: These targets apply to all waters in Ohio (a statewide reference).				

Table D-4. Total phosphorus targets (in mg-P/L) assigned to watershed assessment units or their corresponding model subdivisions (SWAT Sub) as a function of drainage area class and aquatic life use designation.
Note: Subbasin numbers in bold are impaired. All nested subwatershed references exist in the 8-digit hydrologic unit 05080001. E or R : existing use or revised use based on 2009 biological assessment. Drainage area class defined as hw = headwater, w = wading, sr = small river.

SWAT Sub	Nested Sub-watershed	DA (mi^2)	DA class	ALU	E or R	Impaired	Protect Use	Target (mg/L)
Loramie Creek Watershed								
1	06 02	174.1	w	WWH	E	P (upper 1/3)	WWH	0.1
2	06 02	151.7	w	WWH	E	P	WWH	0.1
3	05 03	84.3	w	WWH	E	Full	WWH	0.1
4	05 03	77.8	w	WWH	E	Full	WWH	0.1
5	05 03	77.3	w	WWH	E	NON	WWH	0.1
6	05 01	43.1	w	WWH	E	P	WWH	0.1
7	05 01	15.5	hw	WWH	E	NON	WWH	0.08
8	05 02	62.7	w	MWH	R	P	WWH*	0.1
9	05 03	4.5	hw	MWH	R	Full	WWH*	0.1
10	06 04	263.9	sr	WWH	E	Full	meets	
11	06 04	257.1	sr	WWH	E	Full	meets	
12	06 04	210.5	sr	WWH	E	Full	meets	
13	06 03	35.8	w	WWH	R	Full	meets	
14	06 03	8.3	hw	WWH	R	NON	WWH	0.08
15	06 01	26.1	w	MWH/WWH	E	Full	okay	
Little Muchinippi Creek Watershed								
101	-02-03	35.5	w	WWH	R	P	WWH	0.1
102	-02-03	5.4	hw	MWH	R	P	MWH**	0.34
103	-02-03	12.1	hw	WWH	R	Full	WWH*	0.1

protecting DST use, that is impaired, but local use meets

protecting DST use that is higher than local use

* WWH target for "hw" is 0.08 mg/L but is protecting DST use of WWH "w" (0.1 mg/L)

** protecting local use (MWH) even though DST use is impaired and WWH

Note that for nested subwatershed 05080001 02 03 (Subbasin 102), a more relaxed MWH target was assigned because 1) nutrients are third most relevant causes of impairment and 2) there is sufficient drainage area in this subbasin unit to warrant considerable responsibility from the NPS sector for reducing the load to meet the TMDL target.

D4.3 Description of Model – Soil and Water Assessment Tool (SWAT)

Nutrient loading, specifically that of mineral and organic phosphorus species, and flow in the Loramie Creek and Little Muchinippi Creek watersheds from the major pollution sectors – agricultural NPS, HSTS, and WWTP – were simulated using the Soil and Water Assessment

Tool (SWAT). SWAT is a river basin-scale model developed by the USDA Agricultural Research Service (ARS) at the Blackland (Texas) Research Center (Arnold et al. 1998; Srinivasan, R. et al. 1998). The particular version used was ArcSWAT 2009.93.7 which is a recent version of the model (2011 vintage) coupled with the ESRI ArcMap 9.3 SP1 interface. SWAT is a physically based model that operates on a daily time step (continuously) and efficiently over several years. It is not designed to simulate single-event flooding. SWAT has been used extensively in the United States for TMDL applications (e.g., Wisconsin, Illinois, Texas, and Ohio – Black R, Wabash R, and Stillwater R watersheds) and has been accepted by U.S. EPA as a modeling strategy for TMDL load development (U.S. EPA 1999). In-stream processing of nutrients is accomplished through a modified QUAL-2E (U.S. EPA 1987) kinetics model. QUAL-2E is an inherent component of the SWAT watershed model and can be activated (as in this study) or deactivated to simulated highly conservative in-stream transport. Regarding phosphorus species in QUAL-2E, there exist pools for organic and dissolved (mineral) phosphorus with transformations to and from sediment (benthic) and phytoplankton growth and death. Benthic chlorophyll is not considered in QUAL-2E.

A more sophisticated watershed model such as SWAT was chosen for this analysis because of the complexities involved in solving a nutrient load allocation. Namely, these are:

1) Importance of separating load responsibility between two WWTP (a major and significant minor) and intensive agriculture in Darke and Mercer counties, with both having high animal feeding operation (AFO) populations.
2) Miami-Erie Canal, an important tributary in the middle portion of the watershed, is the receiving water for Minster WWTP and is typically effluent dominated.
3) The Lake Loramie outlet typically has zero flow from July until September; hence, most of the Loramie Creek flow downstream from the spillway is typically provided by WWTP flow.
4) Impairment of aquatic life use due to nutrients and eutrophication is prevalent along the upper two-thirds of Loramie Creek length (22 miles of the total 36 miles).

Further, sufficient daily flow information exists at two downstream USGS (Miami Conservancy District [MCD]-operated) flow gauges for calibrating and validating model.

The advantages for using SWAT in this study over other watershed loading models such as GWLF (Generalized Watershed Loading Function) and HSPF (Hydrologic Simulation Program Fortran) include:

1) Model output is a daily load and partitions phosphorus into organic and mineral forms. GWLF does not simulate at this temporal and parameter scale. Calibration and validation for SWAT are achieved with daily monitored information, such as USGS flow gages.
2) Simulation of in-stream reservoirs. GWLF does not consider these features.
3) Accurate representations of agricultural management practices and features for reducing agricultural load (i.e., best management practices) throughout the crop cycle. Neither HSPF nor GWLF are capable of accurate agricultural portrayals but use parameter coefficients instead.
4) In-stream processing of upland loads through nutrient kinetics model. GWLF only considers upland loads and does not route or process flow and nutrients in-stream.

The model geometry consists of one complete watershed that is composed of 15 subbasin units for the Loramie Creek watershed and 3 subbasin units for the Little Muchinippi Creek watershed. Boundaries for these subbasins were based on 12-digit USGS hydrologic unit code (HUC) borders (nested subwatersheds), to comply with TMDL reporting needs, and model

efficiency to isolate stream confluences and wastewater inputs. There are a combined eight nested subwatersheds in the study area – 7 for the Loramie Creek watershed and 1 for the Little Muchinippi Creek watershed. Within each subbasin are an array of hydrologic representative units (HRUs), one main channel (that enables connection of one subbasin to another), and one "virtual" tributary channel that connects to a main channel. HRUs are a unique combination of a soil map unit (and associated textural and physical attributes) and land use/management. Both HRUs and tributary channels exist solely by attribute in nature and possess no specific geographic location. Channel bankfull width and depth were derived from a regional curve developed for central Ohio (D. Mecklenberg, Ohio DNR Division of Soil and Water Conservation, 2008; personal communication).

SWAT watershed modeling does require a geographic distribution of land use, soils, and slope and combinations of these values comprise the HRU. Land use data were obtained from USDA NASS 2009 Cropland Data Layer (USDA 2009) having a ground resolution of 56 m. Soil boundaries and physical properties were constructed from NRCS SSURGO databases for each county (Shelby, Auglaize, Mercer, Darke, Logan, and Miami) in the study area (USDA 2010). Elevation data were used to derive channel and overland flow slope and were constructed from the USGS National Elevation Dataset (NED) 1 arc-second resolution (30 m) (Gesch et al. 2002, Gesch 2007).

Multiple point source discharges were simulated within a single basin; however, each effluent contribution was deposited into the reach at the beginning of the SWAT subbasin unit. There were 20 wastewater dischargers in the Loramie Creek SWAT model and 1 discharger in the Little Muchinippi SWAT model (Table D-5). Of the 20 dischargers in the Loramie Creek study area, 10 exist in impaired subbasin units – one facility is a major (> 1 MGD design flow), three facilities are significant minors (> 0.15 MGD), there is one new facility (Osgood, 1PB00047) that came online in 2011, two facilities no longer discharge (North Star ES and Super Stop Petroleum), and three facilities will receive an allocation of zero (Dannon Company, Minster Machine, and BP Amoco Bulk Plant). For these latter three facilities, their WLA is zero because they are indirect discharges to a POTW or have no to negligible total phosphorus loads. Loading time series for the two facilities that no longer discharge were included in the development of the model (for calibration and validation), but were not included in the baseline and allocation models. For the Little Muchinippi Creek study area, the sole discharger is a significant minor.

Most often self-monitoring by POTWs of phosphorus species (mineral phosphorus or organic phosphorus) is either non-existent or made simply for total phosphorus. The SWAT model input requires separation of total phosphorus into mineral phosphorus and organic phosphorus. Using information garnered from the Nutrient Control Design Manual (U.S. EPA 2009), there exist approximately 86 percent (50% ortho-phosphate, 36% polyphosphate) mineral phosphorus and only 14 percent organic phosphorus.

Table D-5. Inventory of NPDES facilities contributing effluent to Loramie Creek or Little Muchinippi Creek watersheds.
Note: Ohio EPA permit numbers shaded in blue contribute flow only so load contribution or allocation is zero. Nested subwatersheds all exist in the 8-digit hydrologic unit 05080001. Stn: station or outfall number. WLA (wasteload allocation) class are internal Ohio EPA guidelines and are based on average design flow (ADF, in MGD) and impairment scenario. na= class not applicable so WLA = 0. major (PL)= major facility and permit limit (PL) of 1 mg/L total P required. minor 1 (PL)= significant minor (0.15-1 MGD) and PL of 1 mg/L total P required. minor 2 (no PL)= non-significant minor (0.025-0.15 MGD) and monitoring but no PL required. minor 3 (no PL)= non-significant minor (<0.025 MGD) and monitoring but no PL required. For total P concentration and load columns, develop=concentration used to develop SWAT model (used for calibration), baseline=concentration (or load) used post-calibration and pre-allocation for determining percent responsibility, scen1= used in model scenario development (see Section D4.4.1 for discussion) for scenario 1 and all subsequent LA scenarios.

Sub #	Nested Sub-water-shed	Ohio EPA Permit #	Facility name	Stn	ADF (mgd)	WLA class	total P conc (mg/L)			total P load (kg/d)	
							develop	baseline	scen 1	baseline	scen 1
102	02 03	1PB00018	Jackson Center WWTP	001	0.370	minor 1 (PL)	1.72	1.72	1	2.41	1.40
13	06 03	1PT00068	Hardin Elem School	001	0.009	na	**2.5**	**2.5**	3	0.09	0.10
13	06 03	1PT00039	Dorothy Love Retirement Ctr	001	0.104	na	2.69	2.69	2.69	1.06	1.06
13	06 03	1IJ00046	Barrett Paving - Washington	001	2.52	na	0	0	0	0	0
11	06 04	1PG00021	Shelby Co SD Millcreek	001	0.020	na	**2.5**	**2.5**	3	0.19	0.23
11	06 04	1PG00021	Shelby Co SD Millcreek	002	0.0175	na	**2.5**	**2.5**	3	0.17	0.20
11	06 04	1IJ00053	Barrett Paving - Pence Site	001	3.60	na	0	0	0	0	0
11	06 04	1PG00099	Arrowhead WWTP	001	0.070	na	**2.5**	**2.5**	3	0.66	0.79
10	06 04	1IJ00054	Barrett Paving - Jones Site	001	3.60	na	0	0	0	0	0
15	06 01	1PS00012	Russia WWTP	001	0.075	na	2.79	2.79	2.79	0.79	0.79
15	06 01	1PT00104	Houston HS	001	0.010	na	**2.5**	**2.5**	3	0.09	0.11
7	05 01	1PB00007	Botkins STP	001	0.50	minor 1 (PL)	0.72	0.72	1	1.36	1.89
6	05 01	1PB00004	Anna STP	001	0.40	minor 1 (PL)	2.13	2.13	1	3.23	1.51
6	05 01	1PZ00007	Super Stop Petroleum Anna	001	0.005	na	**2.5**	0	0	0	0

Sub #	Nested Sub-water-shed	Ohio EPA Permit #	Facility name	Stn	ADF (mgd)	WLA class	total P conc (mg/L)			total P load (kg/d)	
							develop	baseline	scen 1	baseline	scen 1
3	05 03	2IH00004	Dannon Company Inc	001	0.020	na	0	0	0	0	0
3	05 03	2IN00173	BP Amoco Oil Plant Minster	001	0.003	minor 3 (no PL)	0.11	0.11	0.11	<0.01	<0.01
3	05 03	2PB00036	Minster WWTP	001	2.50	major (PL)	4.14	4.14	1	39.18	9.46
3	05 03	2GN00007	Minster Machine	001	0.043	na	0	0	0	0	0
3	05 03	1PH00028	Lake Loramie SSD	001	0.400	minor 1 (PL)	4.21	4.21	1	6.37	1.51
8	05 02	1PB00047	Osgood WWTP	001	0.122	minor 2 (no PL)	0	**2.5**	3	1.15	1.39
8	05 02	1PT00119	North Star Elem School	001	0.0025	na	**2.5**	0	0	0	0

impaired nested subwatershed (WLA required)

flow-only records needed

n.n estimate; also indicated by single or no decimal digit

Another primary source of direct human waste into waterways is home sewage treatment systems (HSTS). The septic system flow rate (on a per capita basis) and chemical concentrations of known constituents (e.g., BOD, nitrate, organic phosphorus, among others) in HSTS were assumed constant across the study area but estimates of the counts of people (the capita) were estimated geographically. Subsequently a determination if the system was conventional or failing was made. Values for chemical constituents and per capita flow rate were taken from field data summarized by Seigrist et al. (2005) and McCray et al. (2005). To estimate geographical variation in counts of users and type of system, various sources of county-based information was gathered. Shelby County completed a 2007 survey of systems – values were originally summarized for the entire county but subsequently divided into assessment unit at the request of this TMDL effort (Shelby County Health Department, 2011 personal communication). For Darke and Mercer counties, county health department officials estimated counts of people on HSTS within specific assessment units in those counties. Estimates of failure rate were also provided by each of the above county health officials. No recent information was available for Auglaize, Miami, and Logan counties so information was garnered from 1990 US Census Bureau block group under the parameter "type of sewage system." Then the number of people using a septic system was determined by US Census 1990 block group data on average size of household and number of households. While this information is slightly outdated, these three counties occupy a small portion of the total study area.

There was one in-stream impoundment simulated in this model version – Lake Loramie spillway at RM 22.10 on Loramie Creek. Lake water can flow over the spillway continuously when the water level is greater than 955 ft above mean sea level. There are two gated structures that discharge water near the lake bottom but they are rarely used, and when needed are used to draw down water from spring runoff. Handwritten daily records of water level over the spillway crest and gate operations were obtained from Ohio Department of Natural Resources, Loramie State Park office from the period January 1999 to the present. These records were manually transcribed to database form, errors removed, and gaps in the record estimated. The daily height of water above spillway crest was used to estimate discharge over the spillway using the following equation for estimating discharge from a suppressed, rectangular sharp-crested weir:

$$Q = C \times L \times H^{3/2}$$

Where Q is derived discharge (in ft^3/sec), C is a weir coefficient (typically 3.33 US and applied here), L is length of the weir (spillway, in ft), and H is the head above the spillway crest (ft). The weir equation (above) produced similar discharge magnitudes as that found using the Bernoulli equation for that same distribution of measured heads.

Additionally, when spillway gates were operating, the gate opening was used to estimate additional discharge using a non-linear equation based on gate opening height and total head above the gate opening based on water level of the lake surface. The latter equation was provided by Ohio DNR – Division of Dam Safety and Management. Based on anecdotal field evidence over the past few years and from the above mentioned handwritten records, the lake provides little to no downstream flow (and hence assimilative capacity) to the middle and lower reaches of Loramie Creek watershed. Stream flow below the lake is supplied by a major and significant minor POTWs and the Mile Creek drainage.

Daily precipitation data was compiled for the entire model period for five meteorological stations distributed within and beyond the watershed boundary. Station data for gauges at Fort Loramie, Lakeview, Lockington, Sidney, and Versailles (all Ohio) were obtained from the Miami Conservancy District network. Long-term records (1979-2010) were examined for wet and dry

years for which to stratify calibration periods (see also Section D4.4.1). Wet years were defined for 2003, 2005, 2007, and 2008. Dry years were defined for 2000, 2001, 2002, and 2009. Temperature data (daily minimum and maximum) were gathered from NOAA gauges at Sidney and Celina (all Ohio). Evapotranspiration (ET) was simulated using the Priestly-Taylor method (1972) which is a simpler form of the Penman-Monteith (Monteith, 1965). The selected method better reproduced average ET magnitudes expected for Ohio (shown in Brown, 1994).

The Loramie and Little Muchinippi watersheds, like most small to medium-sized agricultural watersheds in the eastern Midwest, have a complex mixture of agricultural management practices. Based on past consultation with a regional nutrient management specialist and a USDA District Conservationist for Darke County, and more recent consultation with the Loramie Valley Alliance coordinator, a detailed, realistic set of scenarios was developed for these simulations. The scenarios comprise varying crop rotation, tillage practice, fertilizer type, and fertilizer application rate. The distribution of crop rotation, tillage, and manure practice is conveyed in Table D-6. Two predominant, 5-year crop rotations were identified: CSW, which is defined as corn-soybean-corn-soybean-winter wheat, and CSWG, which is defined as corn-soybean -winter wheat-grass-grass-grass. CSW occurs entirely in the Little Muchinippi Creek study area (all 3 model subbasin units) and in the upper half of the Loramie Creek study area, but excluding subbasin 7. Regarding tillage and manure practices – no-till practice exists for 70 percent of the farms in both study areas, whereas tillage practices exist for the remaining 30 percent. Tillage practices implemented in the model include chisel plow (at 21 ft and 15 ft widths) and field cultivator. Manure application is highest in the upper portion of the Loramie Creek study area (applied to fields 70 percent of the time) and this coincides with CSWG rotations. In the Little Muchinippi Creek and the lower portion of Loramie Creek study areas, manure is applied to fields only 20 percent of the time and this coincides primarily with CSW crop rotations. Once the geography of crop rotation is defined, the resulting cross-tabulation of manure application and tillage practice yields several combinations agricultural management practices (e.g., CSW with manure and no-till) and corresponding probabilities of occurrence (Table D-6). These probabilities are honored when assigning practices to individual model HRUs, with the parameter expectation of percent of total HRU area rather than percent of total HRU count.

Table D-6. Distribution of crop rotation practice (CSW = corn, soybean, wheat; CSWG = corn, soybean, wheat, grass), manure fertilization, and tillage practice.

CSW: Little Much; Loramie S SR47 or E I-75			
	manure	not applied	applied
tillage	%	80%	20%
till	30%	24%	6%
no till	70%	56%	14%

CSWG: Loramie N SR47 and W I-75			
	manure	not applied	applied
tillage	%	30%	70%
till	30%	9%	21%
no till	70%	21%	49%

D4.4 Calibration and Validation

D4.4.1 Flow/Hydrology and Crop Yield

The Loramie Creek watershed SWAT model was calibrated for hydrology using a single US Geological Survey hydrologic gauge – Loramie Creek near Newport (03261950) – located at the outlet of model subbasin 2 (Figure D-3). The SWAT model was executed over the period January 1995 to November 2010 (about 16 years). The period 1995 to 1997 (3 years) was used for model start-up and equilibration and the results were not considered. The model calibration phase considered daily data in four years – 2000, 2001, 2002, and 2009 (dry) and 2003, 2005, 2007, and 2008 (wet). The model validation phase considered daily data for the remaining five years – 1998, 1999, 2004, 2006, and 2010. Several experiment model runs were made with the most successful flow calibration run being "Sim 24" (Table D-7). Parameters that were most sensitive to calibration are listed in Table D-7 under "Parameter Note" column. Namely the ground water recession slope, runoff curve number, soil available water capacity, evaporation rate coefficient, and crop fertilizer rate were the most important parameters for adjusting model hydrology. For calibrating hydrology, comparisons were made for:

1) *Annual:* total streamflow, surface runoff, baseflow, and baseflow ratio (baseflow divided by total streamflow) using graphical techniques (cross-plots and histogram), dimensionless statistics (E_{NS} and the average relative difference), a regression statistic (coefficient of determination or R^2), and simple univariate measures (mean, standard deviation).

2) *Seasonal:* total streamflow, surface runoff, baseflow, and baseflow ratio using graphical techniques (cross-plots and histogram), dimensionless statistics (E_{NS} and the average relative difference), and simple univariate measures (mean, standard deviation). Seasonal boundaries were defined relative to typical meteorological divisions as: winter (January, February), spring (March through June), summer (July through September), and autumn (October through December).

3) *Monthly:* surface runoff, baseflow, and baseflow ratio using graphical techniques (cross-plots and histogram), dimensionless statistics (E_{NS} and the average relative difference), and simple univariate measures (mean, standard deviation).

4) *Daily:* total streamflow (surface runoff + baseflow) using a graphical technique (percent exceedance probability curve), a dimensionless model evaluation statistic (Nash-Sutcliffe efficiency index or E_{NS}), and an error index (percent bias or PBIAS).

Baseflow separation from total streamflow was made using the USGS PART method (Rutledge 1998). Baseflow recession coefficients were computed using the filter produced by Arnold and Allen (1999). For monthly comparisons, some care should be exercised in interpreting baseflow estimates as baseflow separation algorithms are least robust at this temporal discretization.

E_{NS} and PBIAS are described in Moriasi et al. (2007) and Van Liew et al. (2007). PBIAS measures the average tendency of the simulated data to be larger or smaller than their observed counterparts (Gupta et al. 1999). Flow calibration and validation results are reported in Table D-8 through Table D-12 and Figure D-6 through Figure D-9. Performance goals for E_{NS}, PBIAS, and average relative difference statistics are included adjacent to the result reported for this study. Ranges of values reported from numerous studies for calibration and validation of total streamflow and surface runoff, among other parameters, are reported in Moriasi et al. (2007; their Table 1). In general, model simulation of streamflow can be judged as

"satisfactory" if E_{NS} > 0.50 and PBIAS ± 25 percent (Moriasi et al. 2007). In this calibration, model results for the Loramie Creek model meet or exceed these performance ratings.

Annual

Daily flow predictions summarized over an annual basis were very closely matched to observed flow (Table D-8 and Figure D-6). The following interpretations can be drawn from Table D-8:

1) When examining all years of record (13 total), surface runoff is over-predicted but baseflow is under-predicted, but not by much. Performance statistics (Nash-Sutcliffe error ratio and R-square) are very good. Total streamflow (total water yield) is slightly over-predicted by about 1 inch per year.
2) For drought events (4 years of record), the model considerably over-estimates surface runoff and baseflow, but with both being over-predicted by similar proportions, the baseflow ratio matches quite well to observed flow.
3) For wet events (4 years of record), surface runoff is over-predicted but baseflow is under-predicted. However, the Nash-Sutcliffe ratio is high for both wet and dry years (0.85 and 0.99, respectively).
4) The model validation (4 years of record) is acceptable – but confidence in baseflow prediction is much better than surface runoff based on Nash-Sutcliffe ratios.

An additional comparison of mass components of the hydrologic cycle can be made to what is expected for Ohio. Table D-12 shows the average mass balance for 10 years of SWAT model for the outlet of Loramie Creek (at the confluence with the Great Miami River) compared to those estimated for Ohio (Brown 1994). While average annual precipitation was slightly higher for the 10-year model period, actual ET and total aquifer recharge match well. Both model surface runoff and ground water flow are much higher than Brown (1994), and thus so is total stream discharge (total water yield).

Seasonal

Daily flow predictions summarized over a seasonal basis (13 years total) were very closely matched to observed flow (Table D-9 and Figure D-7). The Nash-Sutcliffe ratio is acceptable for all aggregations – all years, extreme events (both drought and wet years), and validation years.

Monthly

When considering model output and observed data aggregated by month, surface runoff is better predicted than baseflow as the latter shows a wide scatter (Figure D-8a-d). In looking at individual monthly averages (Figure D-8e-g), total streamflow (total water yield) is predicted very well. Most of the error stems from baseflow prediction where in the summer months (July-September) and spring months (March-May) this error tends to be greatest. The Nash-Sutcliffe ratio is acceptable for all aggregations – all years, extreme events (both drought and wet years), and validation years (Table D-10).

Daily

For examining the success of daily model predictions, the most efficient tool is the flow duration curve of the entire record of model and observed daily flows (Figure D-9). Predicting *individual* daily flows with success is difficult when employing a large watershed model; however, predicting the correct probability distribution of daily flows is a good measure of success. Daily predictions are fairly close to observed flow at low and high probability shown as percent exceedance (Figure D-9) but they are over-predicted in the middle range of flows. A negative percent bias (PBIAS) of -7.4 also reflects this over-estimation but overall the Nash-Sutcliffe Index is close to optimal (0.72) suggesting relatively good model fit (Table D-11). There is some slight under-estimation of very low flow (Figure D-9).

Table D-7. Evolution and description of SWAT model runs for calibration of flow/hydrology, crop yield, and nutrient chemistry.
Note: All runs refer to the Loramie Creek watershed study area with the exception of the last row in the table (Little Muchinippi Creek watershed). Model run is an arbitrary name. Description refers to adjustments in parameters made when initializing with a base model (preceding model in the evolution). Comments reflect interpretations of model result following calibration adjustment.

Model Run	Description	Base Model	Parameter Note	Comments
HydroStart	ALPHA_BF corresponding to Arnold baseflow program set for each of two sub-drainages (set in .gw for each subbasin); IPET = Priestley-Taylor.	none	ALPHA_BF (.gw); IPET (.bsn)	
Sim7	Set DEP_IMP = 1100 mm to increase tile flow for all HRUs that have existing non-zero tile parameters (e.g., DDRAIN ≠ 0; in .mgt1). Set ICN = plant ET and CN_COEFF = 0.75. Set FFCB = 0.8.	HydroStart	DEP_IMP (.hru); ICN (.bsn); CN_COEFF (.bsn); FFCB (.bsn)	
Sim8	Turn on auto-fertilization to determine N requirements for crop-growth. Current operations show about 26 kg-N/ha and 10 kg-P/ha applied. This fertilizer application appears too small to produce corn yields of 7000-8000 kg/ha (as reported by NASS).	Sim7	auto-fertilization (.mgt)	Parameter values defined as…discuss results…
Sim9	Increased fertilization rates for AGRR HRUs - increased N, P, and K application rates to meet Tri-State fertilizer recommendations. Crop yields were also calibrated using NASS data. Manure rates were especially low in previous runs (200-700 kg/ha) and they have been increased to 5000-9000 kg/ha.	Sim7	FRT_KG (.mgt2); FRT_SURFACE (.mgt2)	Crop yields are now very close to NASS results. Proceed with further hydrologic calibration and focus on CN and AWC.
Sim10	Goal is reduce to surface runoff and increase baseflow - plus overall reduce TWYLD.	Sim9	CN2 (.mgt1); SOL_AWC (.sol)	Reduced CN2 (.mgt) by 2 units for all HRUs for all land uses. Increased SOL_AWC by 0.02 (multiply by 1.02) for all layers and all land uses.

Model Run	Description	Base Model	Parameter Note	Comments
Sim11	Sim10 still produces predicted high surface RO and low baseflow.	Sim10	CN2 (.mgt1)	Reduced CN2 (.mgt) by 2 units for all HRUs for all land uses.
Sim12	Sim11 still produces predicted high surface RO and low baseflow.	Sim11	CN2 (.mgt1); ESCO (.bsn); ALPHA_BF (.gw); REVAPMN (.gw)	Reduced CN2 (.mgt) by 3 units for all HRUs for all land uses. Decreased ESCO (.bsn) from 0.95 to 0.93. Increased ALPHA_BF (.gw) from 0.0733 (from gauge data) to 0.5. Decreased REVAPMN (.gw) from 1 to 0.5.
Sim13	Sim12 still produces predicted high surface RO and low baseflow.	Sim12	CN2 (.mgt1); SOL_AWC (.sol); REVAPMN (.gw)	Reduced CN2 (.mgt) by 2 units for all HRUs for all land uses (this represents a total decrease of 9 units from default). Increased ALPHA_BF (.gw) from 0.5 to 0.6. Increased REVAPMN (.gw) from 0.5 to 2.0 (note: this is a change in direction from Sim12 - by increasing REVAPMN less water is available to revap so less is lost from the system).
Sim14	Sim14 still produces predicted high surface RO and low baseflow.	Sim13	CN2 (.mgt1); SOL_AWC (.sol)	Reduced CN2 (.mgt) by 2 units for all HRUs for all land uses (this represents a total decrease of 11 units from default - this is slightly more than the 10% max recommended). Increased SOL_AWC by 0.02 (multiply by 1.02) for all layers and all land uses.
Sim15	Adjustments to be made following phone call with R. Srinivasan.	Sim9	CN_COEFF (.bsn); ESCO (.bsn); GW_REVAP (.gw)	Decreased CN_COEFF (.bsn) from 0.75 to 0.5. Decreased ESCO (.bsn) from 0.95 to 0.85. Increased GW_REVAP (.gw) from 0.02 to 0.1.

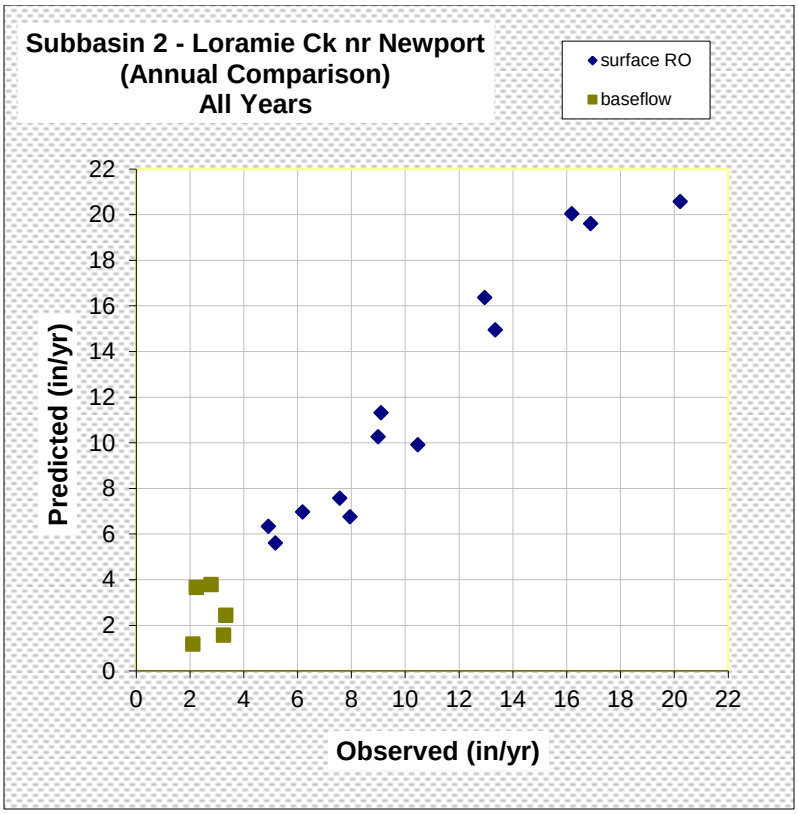
Model Run	Description	Base Model	Parameter Note	Comments
Sim16	Total water yield still high. Runoff peaks are high compared to observed.	Sim15	DEP_IMP (.hru); SURLAG (.bsn); GW_REVAP (.gw); CN2 (.mgt1); SOL_AWC (.sol)	Set DEP_IMP = 2800 mm to reduce tile drainage amount. Decrease SURLAG from 4 to 1. Reset GW_REVAP (.gw) back to default value of 0.02. Reduced CN2 (.mgt) by 4 units for all HRUs for all land uses. Increased SOL_AWC by 0.02 (multiply by 1.02) for all layers and all land uses.
Sim16_noTile	Tile flow not included in output so cannot include in baseflow term. It is included in stream flow (total water yield) so comparisons of that term (streamflow) are valid.	Sim16	DEP_IMP (.hru)	Set DEP_IMP = 0 mm to eliminate tile drainage amount.
Sim17_noTile	Improve winter and spring streamflow and surface RO match (need to increase Mar and reduce Dec/Jan/Feb.	Sim16_noTile	SMTMP (.bsn)	Increased snowmelt temperature from 0.5°C (default) to 2°C.
Sim18_noTile		Sim17_noTile	SMTMP (.bsn)	Increased snowmelt temperature from 2°C to 5°C.
Sim19		Sim16	SMTMP (.bsn)	Increased snowmelt temperature from 0.5°C (default) to 5°C.
Sim20	Increased MINP and ORGP for Minster and Fort Loramie SSD using PEQ analysis. The goal is to improve low-flow total P predictions.	Sim19		
Sim21	No improvement in low flow total P model predictions so decided to turn-off all or part of the in-stream kinetics processes.	Sim20	ISUBWQ (.bsn)	Turned-off algae/CBOD/DO algorithms.
Sim22	Still no improvement in low flow total P model prediction. Will examine uptake/production coefficients within .wwq and .swq.	Sim21	IWQ (.bsn)	Turned-off in-stream kinetics (QUAL-2E).

Model Run	Description	Base Model	Parameter Note	Comments
Sim23	Goal is to increase low-flow total P model prediction.	Sim20	AI2 (.wwq)	Increased fraction of algal biomass that is phosphorus (AI2 in .wwq) from default of 0.015 mg-P/mg-algae to a value of 0.03 (represents max permitted).
Sim24	Corrected effluent flow due to error in dimensions (translating from MGD to cmd).	Sim19		
Sim25_noTile	Corrected effluent flow due to error in dimensions (translating from MGD to cmd). Same as Sim24 but removed tile drainage.	Sim18_noTile		
Sim1_LM	For Little Muchinippi Ck study area only.			Incorporated all calibration changes found in Sim9, Sim15, Sim16, and Sim19.

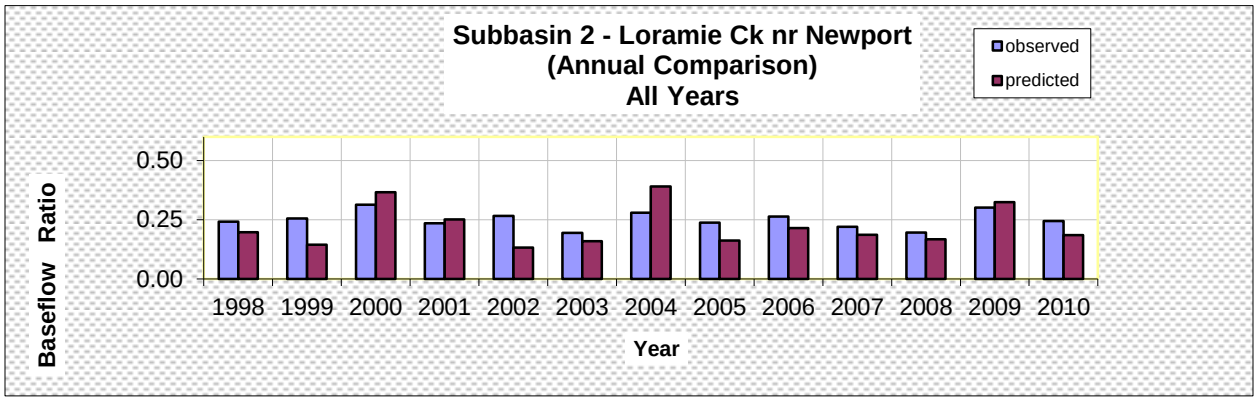
Table D-8. Calibration of flow/hydrology for annual model aggregation period for the Loramie Creek watershed SWAT model.
Note: Performance comparisons between observed and predicted (model) include mean (in/yr) and standard deviation (std dev in/yr). Performance (summary) statistics include average relative difference (in/yr), Nash-Sutcliffe efficiency index (E_{NS}, dimensionless), and coefficient of determination (R^2, dimensionless). Comparisons are made for surface runoff, baseflow, baseflow ratio, and total streamflow (total water yield [WYLD]) and then for aggregations of all years (light green), extreme events (drought [orange] and pluvial [blue] years during the calibration period), and validation (purple) (all years not used in extreme events). Performance results in red font suggest does not meet goal.

All Years (1998-2010)				
	Observed	**Predicted**	**Value**	**Goal**
Surface Runoff				
# observations	13	13		
mean (in/yr)	10.77	12.02		
std dev (in/yr)	4.82	5.60		
average relative difference (in/yr)			0.14	< 0.15
E_{NS}			0.83	> 0.5
R^2			0.94	> 0.6
Baseflow				
mean (in/yr)	3.39	3.15		
std dev (in/yr)	1.05	1.11		
average relative difference (in/yr)			0.29	< 0.15
E_{NS}			0.99	> 0.5
R^2			0.31	> 0.6
Baseflow Ratio (baseflow / total streamflow)				
mean (in/yr)	0.25	0.22		
std dev (in/yr)	0.04	0.09		
Streamflow (total water yield)				
# observations	13	13		
mean (in/yr)	14.16	15.17		
std dev (in/yr)	5.81	6.25		
R^2			0.92	> 0.6
Extreme Events: Low Flow Years (2000-2002, 2009)				
	Observed	**Predicted**	**Value**	**Goal**
Surface Runoff				
# observations	4	4		
mean (in/yr)	7.06	8.38		
std dev (in/yr)	2.31	2.83		
average relative difference (in/yr)			0.19	< 0.15
E_{NS}			0.88	> 0.5
Baseflow				
mean (in/yr)	2.64	2.93		
std dev (in/yr)	0.49	1.03		
average relative difference (in/yr)			0.43	< 0.15
E_{NS}			0.98	> 0.5
Baseflow Ratio (baseflow / total streamflow)				
mean (in/yr)	0.28	0.27		
std dev (in/yr)	0.04	0.10		

Streamflow (total water yield)				
# observations	4	4		
mean (in/yr)	9.69	11.31		
std dev (in/yr)	2.77	2.92		
Extreme Events: High Flow Years (2003, 2005, 2007, 2008)				
	Observed	**Predicted**	**Value**	**Goal**
Surface Runoff				
# observations	4	4		
mean (in/yr)	16.67	18.79		
std dev (in/yr)	2.82	2.59		
average relative difference (in/yr)			0.13	< 0.15
E_{NS}			0.85	> 0.5
Baseflow				
mean (in/yr)	4.47	3.78		
std dev (in/yr)	0.72	0.26		
average relative difference (in/yr)			0.15	< 0.15
E_{NS}			0.99	> 0.5
Baseflow Ratio (baseflow / total streamflow)				
mean (in/yr)	0.21	0.17		
std dev (in/yr)	0.02	0.01		
Streamflow (total water yield)				
# observations	4	4		
mean (in/yr)	21.14	22.57		
std dev (in/yr)	3.36	2.83		
Validation Years (1998, 1999, 2004, 2006, 2010)				
	Observed	**Predicted**	**Value**	**Goal**
Surface Runoff				
# observations	5	5		
mean (in/yr)	9.03	9.51		
std dev (in/yr)	2.69	4.03		
average relative difference (in/yr)			0.12	< 0.15
E_{NS}			0.68	> 0.5
Baseflow				
mean (in/yr)	2.64	2.93		
std dev (in/yr)	0.97	1.51		
average relative difference (in/yr)			0.29	< 0.15
E_{NS}			0.99	> 0.5
Baseflow Ratio (baseflow / total streamflow)				
mean (in/yr)	0.26	0.23		
std dev (in/yr)	0.02	0.10		
Streamflow (total water yield)				
# observations	5	5		
mean (in/yr)	12.16	12.34		
std dev (in/yr)	3.63	5.01		



(a)



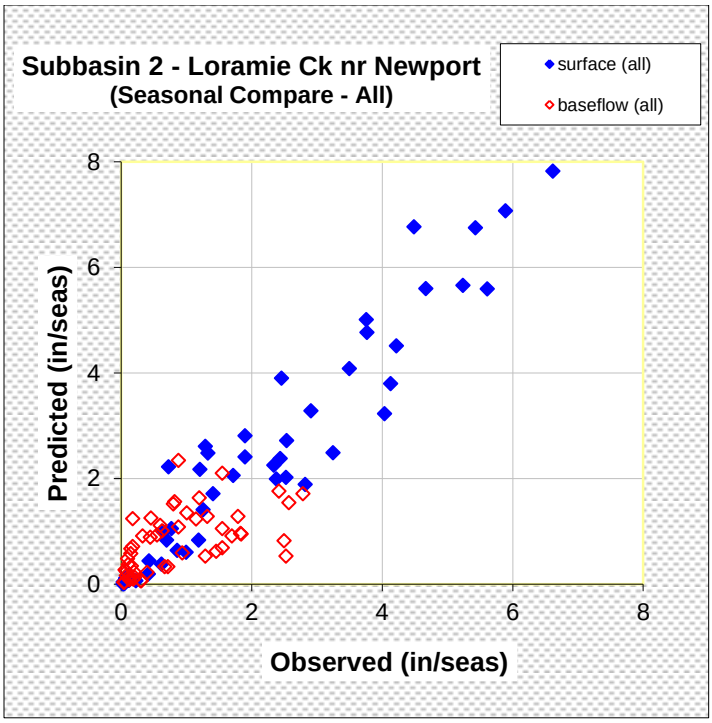
(b)

Figure D-6. Cross-plot showing comparison of predicted and observed surface runoff and baseflow (both in/yr) using <u>annual</u> totals (a) and histogram of annual baseflow ratio (baseflow/total streamflow) (b) for all years in the calibration period (1998-2010).

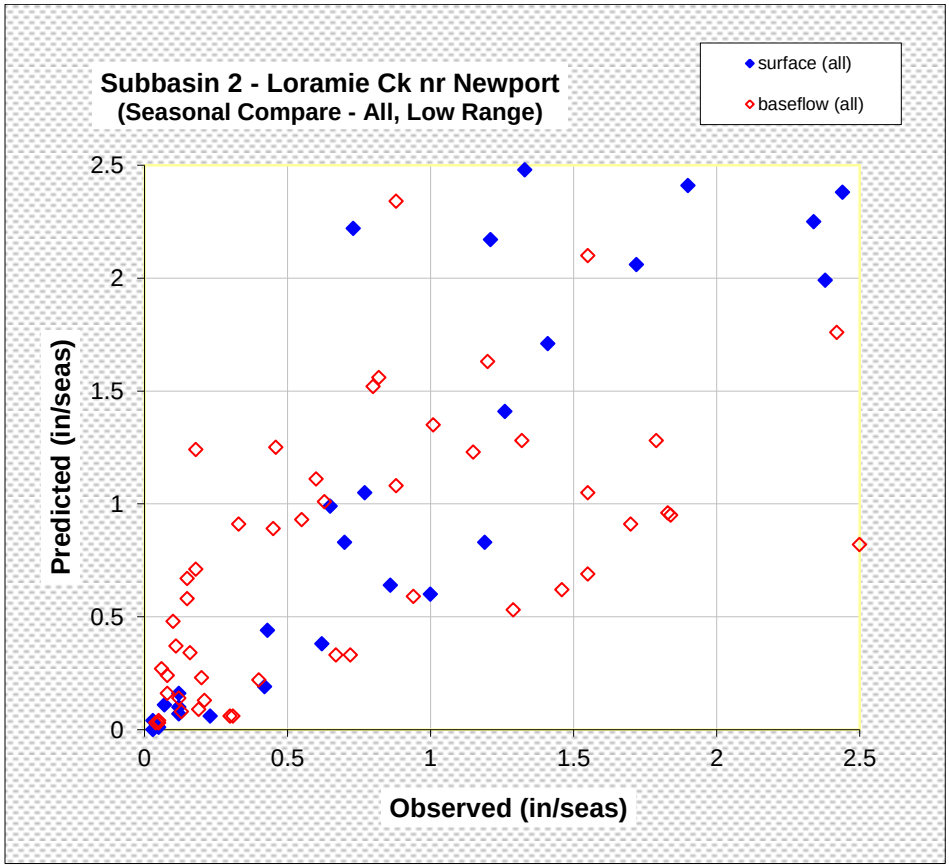
Table D-9. Calibration of flow/hydrology for seasonal model aggregation period for the Loramie Creek watershed SWAT model.
Note: Performance comparisons between observed and predicted (model) include mean (in/seas) and standard deviation (std dev in/seas). Performance (summary) statistics include average relative difference (in/seas) and Nash-Sutcliffe efficiency index (E_{NS}, dimensionless). Comparisons are made for surface runoff, baseflow, baseflow ratio, and total streamflow (total water yield [WYLD]) and then for aggregations of all years (light green), extreme events (drought [orange] and pluvial [blue] years during the calibration period), and validation (purple) (all years not used in extreme events). Performance results in red font suggest does not meet goal.

All Years (1998-2010)				
	Observed	**Predicted**	**Value**	**Goal**
Surface Runoff				
# observations	52	52		
mean (in/seas)	2.69	3.00		
std dev (in/seas)	2.52	2.73		
average relative difference (in/seas)			0.35	< 0.15
E_{NS}			0.87	> 0.5
Baseflow				
mean (in/seas)	0.85	0.79		
std dev (in/seas)	0.79	0.59		
average relative difference (in/seas)			1.01	< 0.15
E_{NS}			0.92	> 0.5
Baseflow Ratio (baseflow / total streamflow)				
mean (in/seas)	0.28	0.31		
std dev (in/seas)	0.13	0.24		
Extreme Events: Low Flow Years (2000-2002, 2009)				
	Observed	**Predicted**	**Value**	**Goal**
Surface Runoff				
# observations	16	16		
mean (in/seas)	1.76	2.09		
std dev (in/seas)	1.82	2.14		
average relative difference (in/seas)			0.50	< 0.15
E_{NS}			0.87	> 0.5
Baseflow				
mean (in/seas)	0.66	0.73		
std dev (in/seas)	0.68	0.59		
average relative difference (in/seas)			1.00	< 0.15
E_{NS}			0.93	> 0.5
Baseflow Ratio (baseflow / total streamflow)				
mean (in/seas)	0.29	0.38		
std dev (in/seas)	0.11	0.27		
Streamflow (total water yield)				
# observations	16	16		
mean (in/seas)	2.42	2.83		
std dev (in/seas)	2.46	2.44		

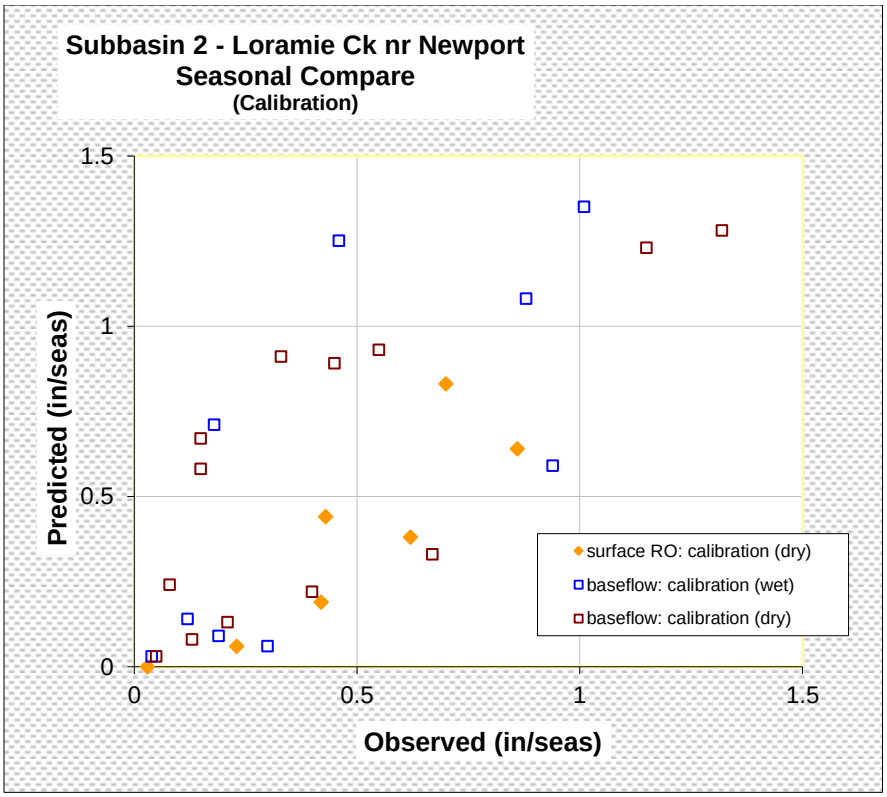
Extreme Events: High Flow Years (2003, 2005, 2007, 2008)				
	Observed	**Predicted**	**Value**	**Goal**
Surface Runoff				
# observations	16	16		
mean (in/seas)	4.17	4.70		
std dev (in/seas)	3.16	3.24		
average relative difference (in/seas)			0.31	< 0.15
E_{NS}			0.85	> 0.5
Baseflow				
mean (in/seas)	1.12	0.95		
std dev (in/seas)	0.93	0.61		
average relative difference (in/seas)			0.65	< 0.15
E_{NS}			0.92	> 0.5
Baseflow Ratio (baseflow / total streamflow)				
mean (in/seas)	0.22	0.18		
std dev (in/seas)	0.10	0.10		
Streamflow (total water yield)				
# observations	16	16		
mean (in/seas)	5.29	5.64		
std dev (in/seas)	3.76	3.74		
Validation Years (1998, 1999, 2004, 2006, 2010)				
	Observed	**Predicted**	**Value**	**Goal**
Surface Runoff				
# observations	20	20		
mean (in/seas)	2.26	2.38		
std dev (in/seas)	1.95	2.14		
average relative difference (in/seas)			0.27	< 0.15
E_{NS}			0.92	> 0.5
Baseflow				
mean (in/seas)	0.78	0.71		
std dev (in/seas)	0.73	0.57		
average relative difference (in/seas)			1.31	< 0.15
E_{NS}			0.91	> 0.5
Baseflow Ratio (baseflow / total streamflow)				
mean (in/seas)	0.32	0.35		
std dev (in/seas)	0.16	0.27		
Streamflow (total water yield)				
# observations	20	20		
mean (in/seas)	3.04	3.09		
std dev (in/seas)	2.57	2.44		


Subbasin 2 - Loramie Ck nr Newport
(Seasonal Compare - All)
surface (all)
baseflow (all)
Predicted (in/seas)
Observed (in/seas)
0
2
4
6
8

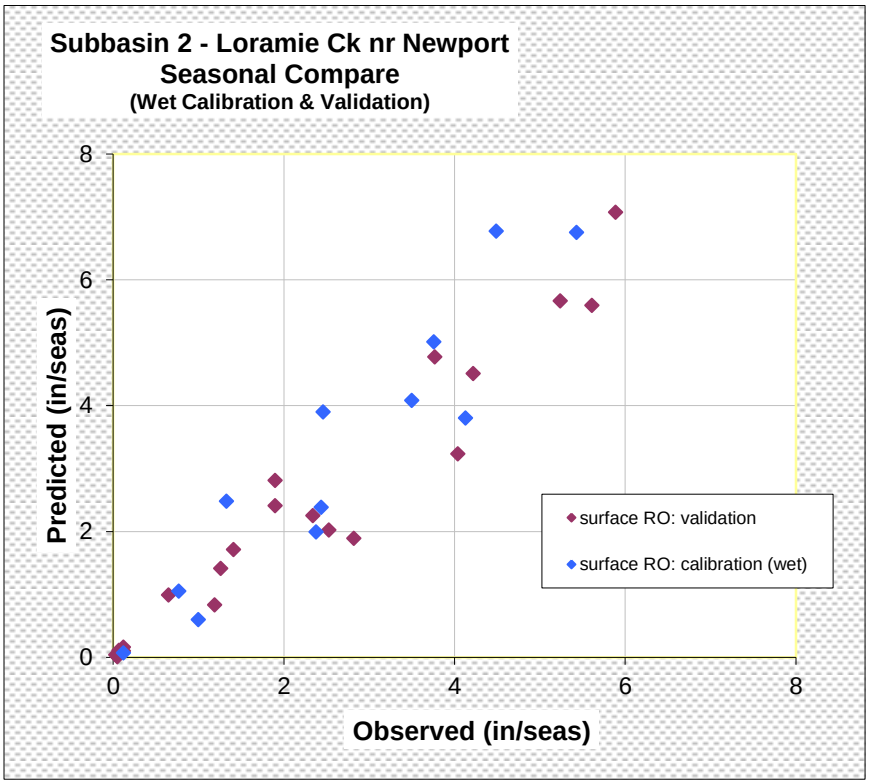
(a)


Subbasin 2 - Loramie Ck nr Newport
(Seasonal Compare - All, Low Range)
surface (all)
baseflow (all)
Predicted (in/seas)
Observed (in/seas)
0
0.5
1
1.5
2
2.5

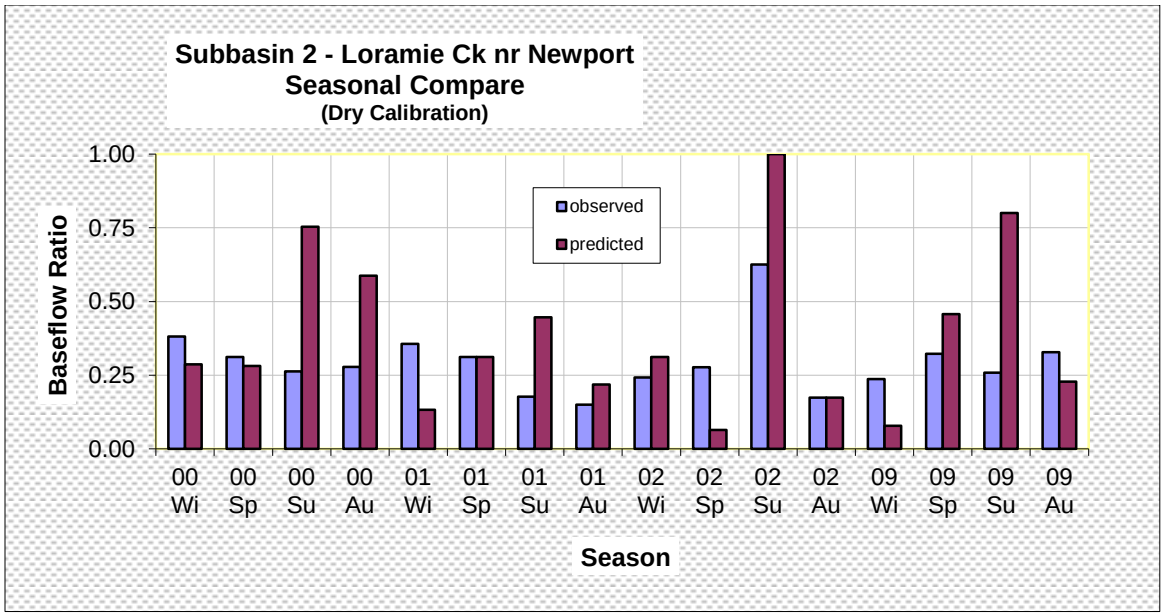
(b)


Subbasin 2 - Loramie Ck nr Newport
Seasonal Compare
(Calibration)
Predicted (in/seas)
Observed (in/seas)
0
0.5
1
1.5
surface RO: calibration (dry)
baseflow: calibration (wet)
baseflow: calibration (dry)

(c)


Subbasin 2 - Loramie Ck nr Newport
Seasonal Compare
(Wet Calibration & Validation)
Predicted (in/seas)
Observed (in/seas)
0
2
4
6
8
surface RO: validation
surface RO: calibration (wet)

(d)



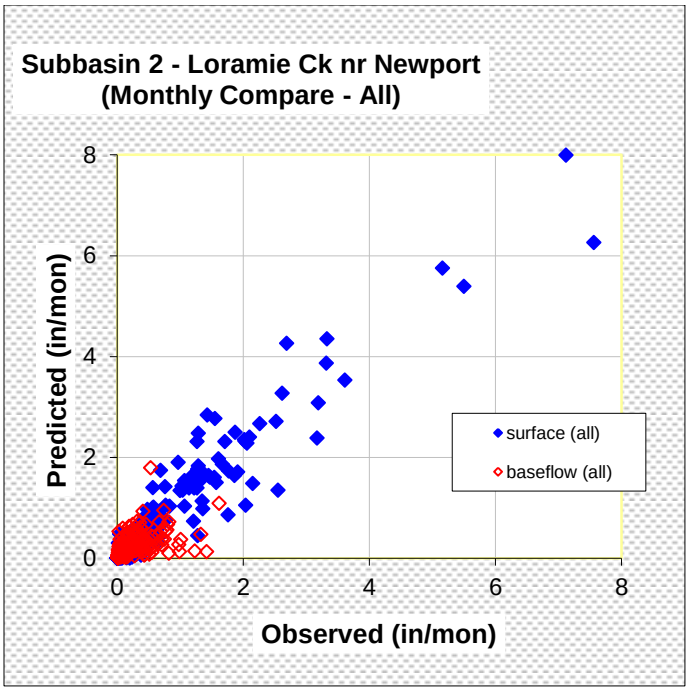
(e)

Figure D-7. Cross-plot showing comparison of predicted and observed surface runoff and baseflow (both in/seas) using <u>seasonal</u> totals (a) and low magnitude range on axes in (b) for all seasons in the calibration period (1998-2010).
Note: Cross-plot showing comparison of predicted and observed surface runoff for the dry calibration period and baseflow for both dry and wet calibration periods (all in/seas) using **seasonal** totals **(c)**. Cross-plot showing comparison of predicted and observed surface runoff for the wet calibration period and validation period (all in/seas) using **seasonal** totals **(d)**. In **(e)**, histogram of **seasonal** baseflow ratio (baseflow/total streamflow) for only the dry calibration period (selected years defined in text).

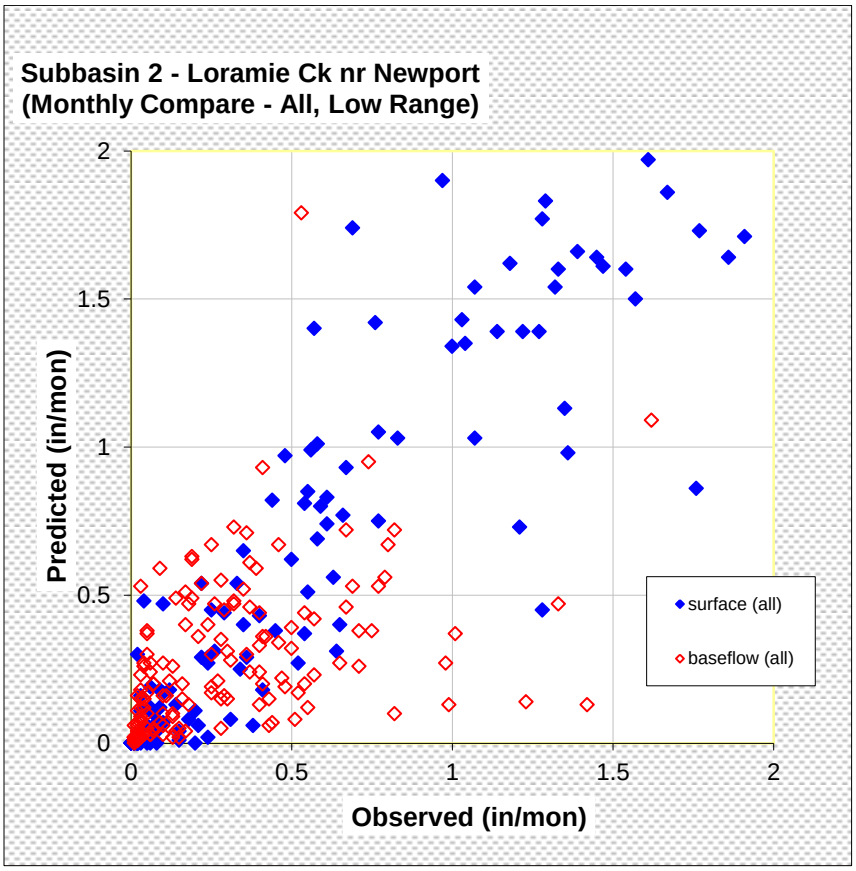
Table D-10. Calibration of flow/hydrology for monthly model aggregation period for the Loramie Creek watershed SWAT model.
Note: Performance comparisons between observed and predicted (model) include mean (in/mon) and standard deviation (std dev in/mon). Performance (summary) statistics include average relative difference (in/mon), Nash-Sutcliffe efficiency index (E_{NS}, dimensionless), and coefficient of determination (R^2, dimensionless). Comparisons are made for surface runoff, baseflow, baseflow ratio, and total streamflow (total water yield [WYLD]) and then for aggregations of all years (light green), extreme events (drought [orange] and pluvial [blue] years during the calibration period), and validation (purple) (all years not used in extreme events). Performance results in red font suggest does not meet goal.

All Years (1998-2010)				
	Observed	Predicted	Value	Goal
Surface Runoff				
# observations	155	155		
mean (in/mon)	0.90	1.01		
std dev (in/mon)	1.23	1.32		
average relative difference (in/mon)			0.71	< 0.15
E_{NS}			0.88	> 0.5
R^2			0.90	> 0.6
Baseflow				
mean (in/mon)	0.28	0.26		
std dev (in/mon)	0.31	0.26		
average relative difference (in/mon)			1.25	< 0.15
E_{NS}			0.86	> 0.5
R^2			0.21	> 0.6
Baseflow Ratio (baseflow / total streamflow)				
mean (in/mon)	0.37	0.43		
std dev (in/mon)	0.23	0.34		
Extreme Events: Low Flow Years (2000-2002, 2009)				
	Observed	Predicted	Value	Goal
Surface Runoff				
# observations	30	30		
mean (in/mon)	0.02	0.03		
std dev (in/mon)	0.02	0.09		
average relative difference (in/mon)			0.77	< 0.15
E_{NS}			0.99	> 0.5
Baseflow				
mean (in/mon)	0.02	0.07		
std dev (in/mon)	0.01	0.10		
average relative difference (in/mon)			1.82	< 0.15
E_{NS}			0.99	> 0.5
Baseflow Ratio (baseflow / total streamflow)				
mean (in/mon)	0.59	0.84		
std dev (in/mon)	0.23	0.27		
Streamflow (total water yield)				
# observations	30	30		
mean (in/mon)	0.05	0.09		
std dev (in/mon)	0.03	0.19		

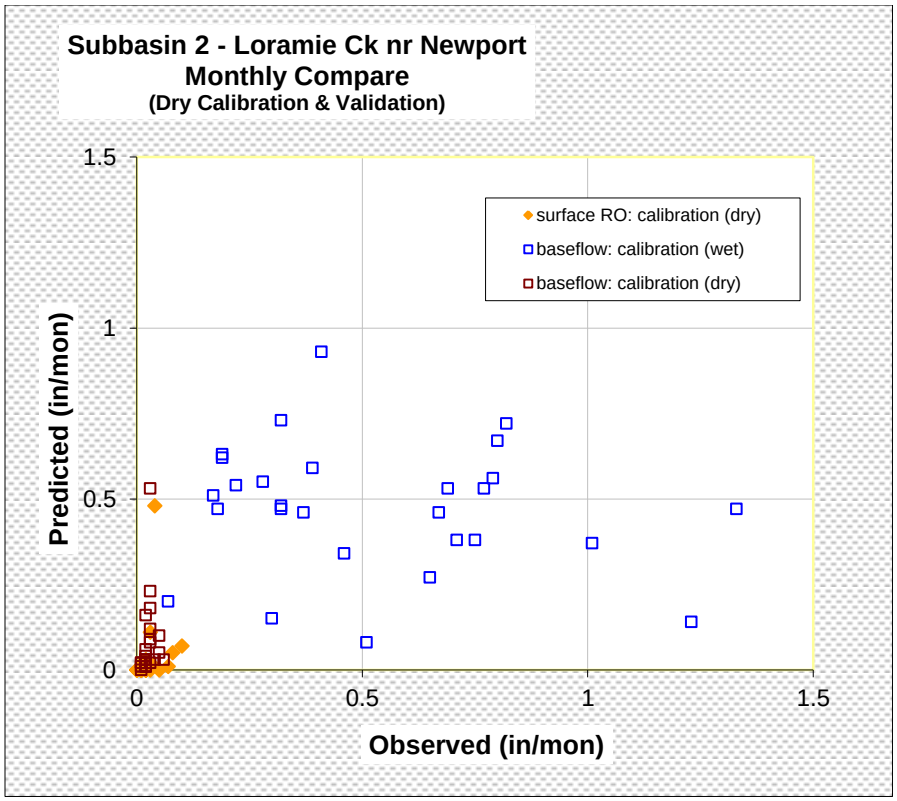
Extreme Events: High Flow Years (2003, 2005, 2007, 2008)				
	Observed	**Predicted**	**Value**	**Goal**
Surface Runoff				
# observations	30	30		
mean (in/mon)	2.24	2.46		
std dev (in/mon)	1.90	1.92		
average relative difference (in/mon)			0.36	< 0.15
E_{NS}			0.92	> 0.5
Baseflow				
mean (in/mon)	0.57	0.54		
std dev (in/mon)	0.37	0.32		
average relative difference (in/mon)			0.87	< 0.15
E_{NS}			0.34	> 0.5
Baseflow Ratio (baseflow / total streamflow)				
mean (in/mon)	0.26	0.25		
std dev (in/mon)	0.15	0.18		
Streamflow (total water yield)				
# observations	30	30		
mean (in/mon)	2.81	3.00		
std dev (in/mon)	2.10	1.98		
Validation Years (1998, 1999, 2004, 2006, 2010)				
	Observed	**Predicted**	**Value**	**Goal**
Surface Runoff				
# observations	41	41		
mean (in/mon)	0.66	0.76		
std dev (in/mon)	0.68	0.77		
average relative difference (in/mon)			0.92	< 0.15
E_{NS}			0.72	> 0.5
Baseflow				
mean (in/mon)	0.23	0.21		
std dev (in/mon)	0.24	0.18		
average relative difference (in/mon)			1.42	< 0.15
E_{NS}			0.92	> 0.5
Baseflow Ratio (baseflow / total streamflow)				
mean (in/mon)	0.33	0.41		
std dev (in/mon)	0.21	0.35		
Streamflow (total water yield)				
# observations	41	41		
mean (in/mon)	0.89	0.97		
std dev (in/mon)	0.85	0.82		


Subbasin 2 - Loramie Ck nr Newport
(Monthly Compare - All)
Predicted (in/mon)
Observed (in/mon)
0
2
4
6
8
surface (all)
baseflow (all)

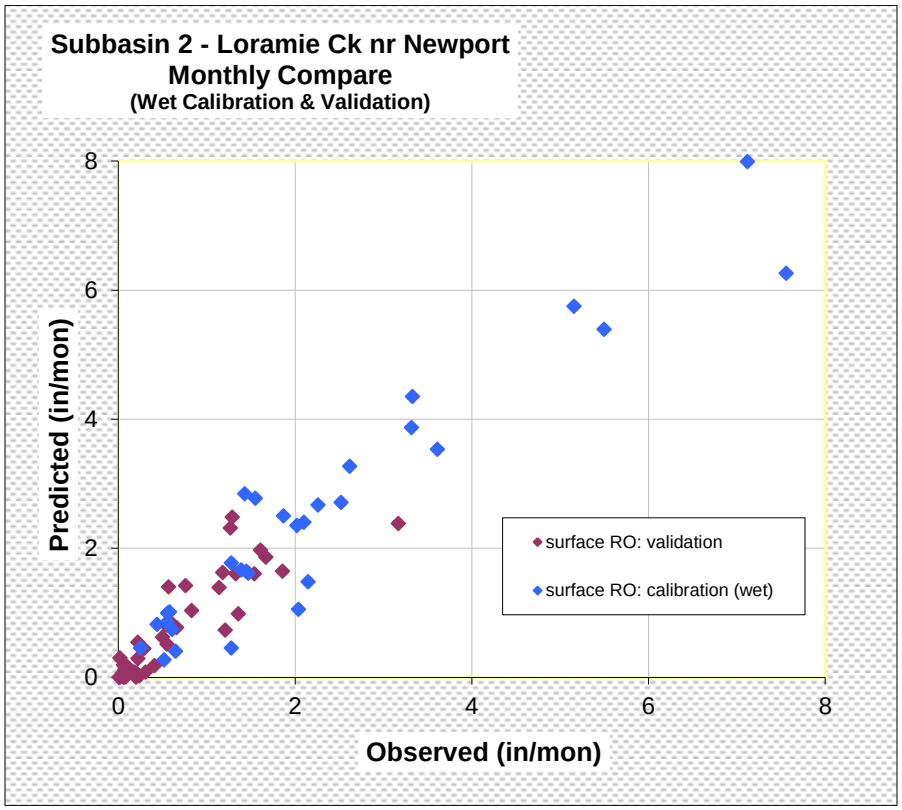
(a)


Subbasin 2 - Loramie Ck nr Newport
(Monthly Compare - All, Low Range)
Predicted (in/mon)
Observed (in/mon)
0
0.5
1
1.5
2
surface (all)
baseflow (all)

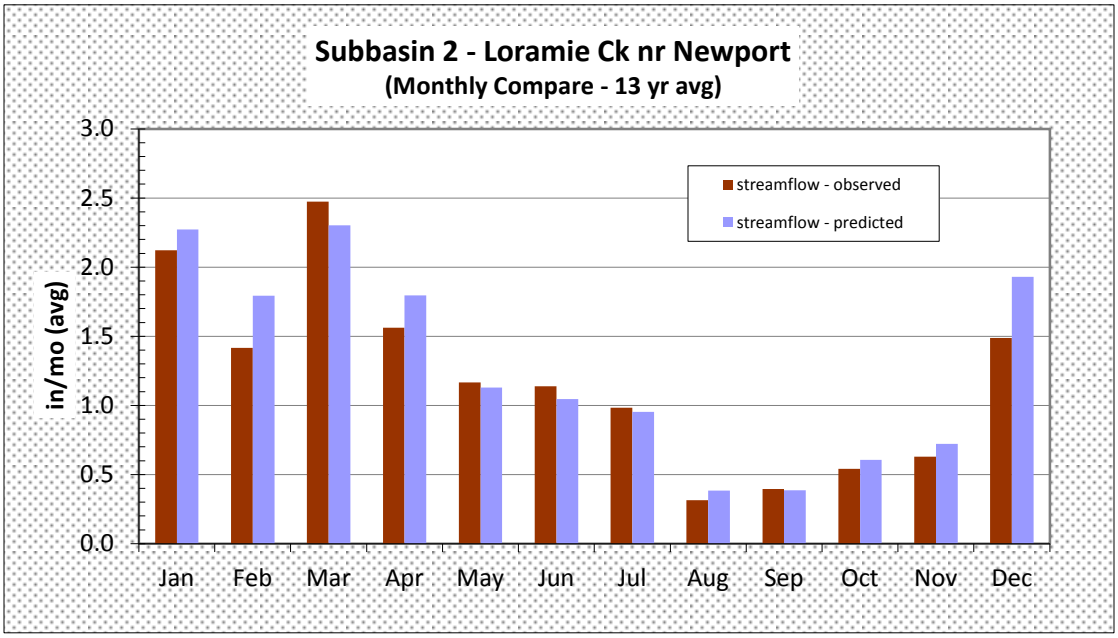
(b)


Subbasin 2 - Loramie Ck nr Newport
Monthly Compare
(Dry Calibration & Validation)
surface RO: calibration (dry)
baseflow: calibration (wet)
baseflow: calibration (dry)
Predicted (in/mon)
Observed (in/mon)
0
0.5
1
1.5

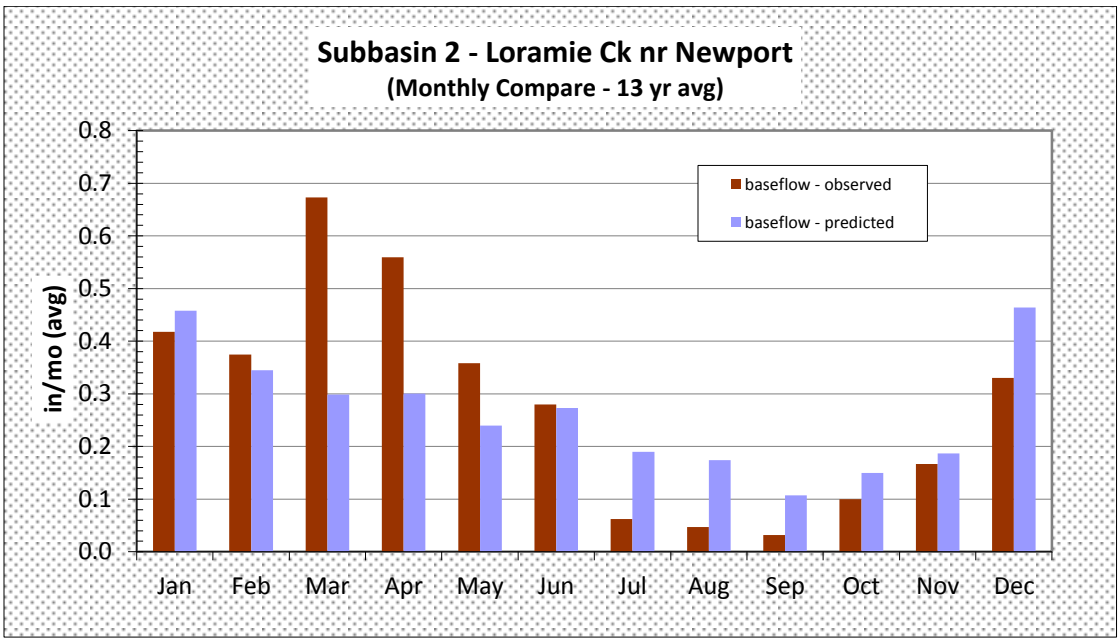
(c)


Subbasin 2 - Loramie Ck nr Newport
Monthly Compare
(Wet Calibration & Validation)
surface RO: validation
surface RO: calibration (wet)
Predicted (in/mon)
Observed (in/mon)
0
2
4
6
8

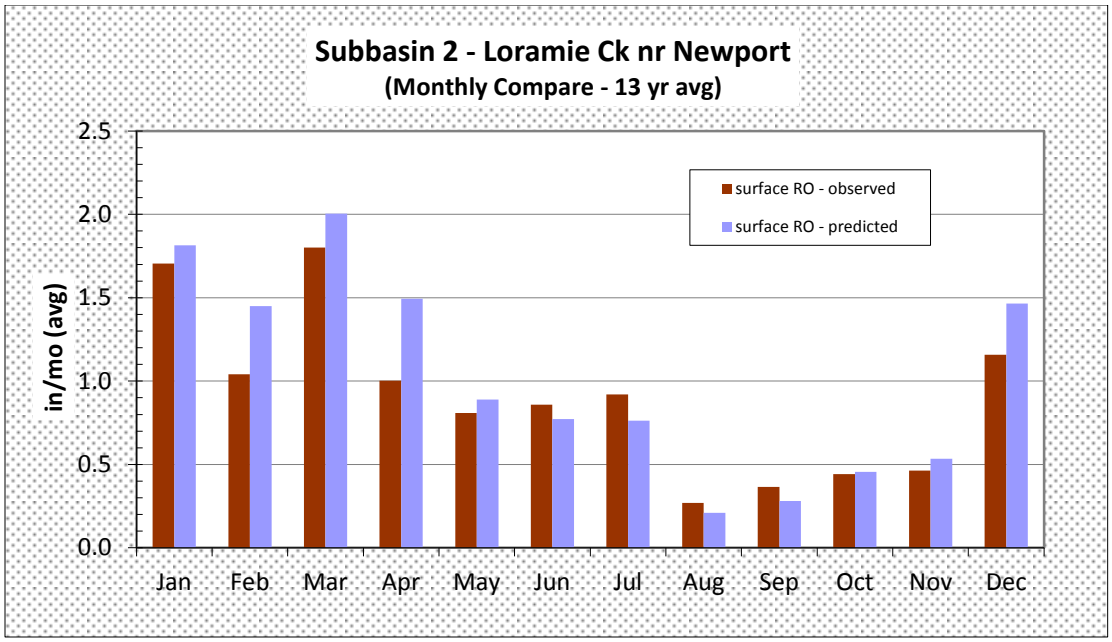
(d)


Subbasin 2 - Loramie Ck nr Newport
(Monthly Compare - 13 yr avg)
in/mo (avg)
3.0
2.5
2.0
1.5
1.0
0.5
0.0
streamflow - observed
streamflow - predicted
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec

(e)


Subbasin 2 - Loramie Ck nr Newport
(Monthly Compare - 13 yr avg)
in/mo (avg)
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
baseflow - observed
baseflow - predicted
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec

(f)



(g)

Figure D-8. Cross-plot showing comparison of predicted and observed surface runoff and baseflow (both in/mon) using <u>monthly</u> totals (a) and low magnitude range on axes in (b) for all months in the calibration period (1998-2010).
Note: Cross-plot showing comparison of predicted and observed surface runoff for the dry calibration period and baseflow for both dry and wet calibration periods (all in/mon) using monthly totals (c). Cross-plot showing comparison of predicted and observed surface runoff for the wet calibration period and validation period (all in/mon) using monthly totals (d). In (e-f-g), histograms of observed versus predicted average monthly total streamflow, baseflow, and surface runoff over the 13-year period.

Table D-11. Calibration of flow/hydrology for <u>daily</u> model aggregation period for the Loramie Creek watershed SWAT model.
Note: Performance (summary) statistics include Nash-Sutcliffe efficiency index (E_{NS}, dimensionless) and percent bias (PBIAS, dimensionless). Comparisons are made for daily streamflow for all years.

All Years (1998-2010)		
Diagnostic	**Value**	**Goal**
E_{NS}	0.72	1: optimal, range (-∞, *1)*
PBIAS	-7.40	0: optimal >0: model under-estimate <0: model over-estimate

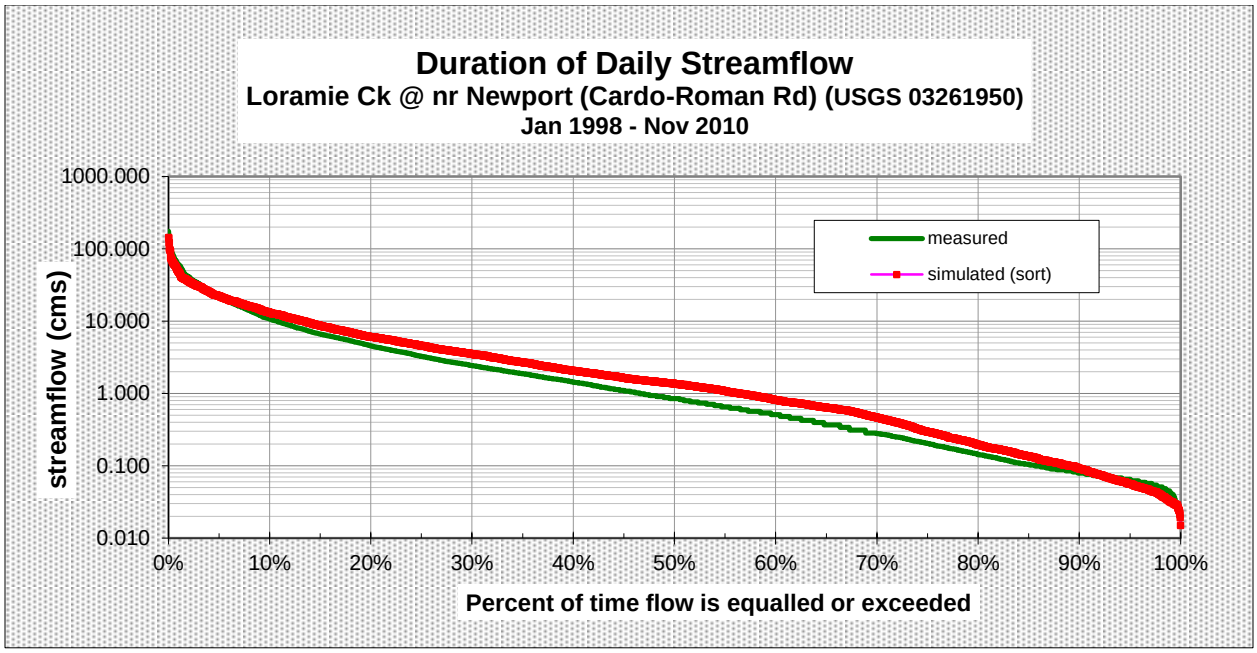


Figure D-9. Flow duration curve between SWAT-model predicted flow and observed flow for the period January 1998 to November 2010, inclusive.
Note: Observed flow taken from US Geological Survey hydrologic gauge – Loramie Creek near Newport (03261950) – located at the outlet of model subbasin 2.

Table D-12. Comparison of average annual water (mass) balance) between best flow-calibrated SWAT model for Loramie Creek watershed and Ohio averages from Brown (1994).
Note: Brown (1994) in Bulletin AEX-461-94 reported for statewide Ohio. Average for predicted balance based on 10 years of model record and for outlet of entire watershed. Values are listed in mm of depth (annual volume/watershed area).

Component of Hydrologic Cycle	Predicted Water Balance (mm)	Average Water Balance (mm)
precipitation	996	965
potential ET	803	na
actual ET	511	508
surface runoff	377	254
subsurface and lateral flow	54	na
ground water flow	101	51
total aquifer recharge	108	102
stream discharge	474	305

D4.4.2 Calibration of Phosphorus and Nitrogen Species

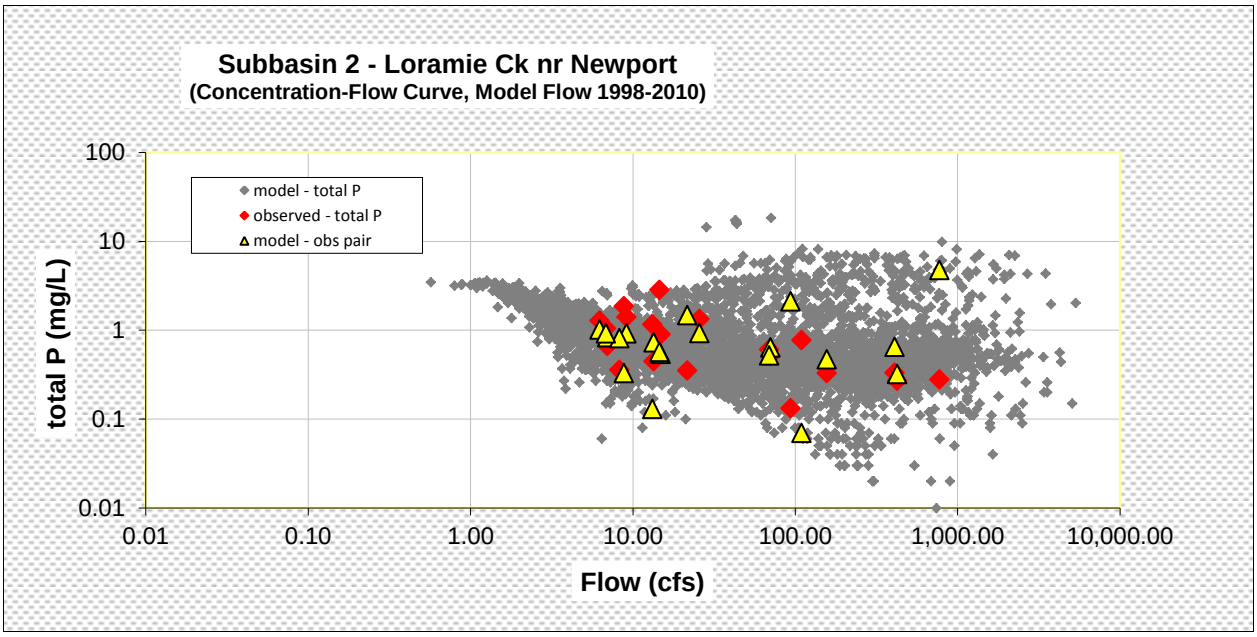
Observed chemistry data available for calibration consist of instantaneous grab samples of total phosphorus, and occasionally ortho-phosphorus, and all nitrogen species at selected locations in both study areas. Because of these single-event observations, interpreting calibration statistics is often confounded by hit/miss model predictions of daily events. The timing of concentration peaks and troughs could simply be offset by one day, between model and

observed, and wreck the success of the model. It is better to interpret model success over aggregate periods such as yearly or seasonal or monthly summaries, as shown in flow/hydrology calibration (Section D4.4.1). Thus, the model calibration results for nutrient chemistry are all demonstrated here through graphical techniques – cross-plots and time series – and conclusions on model success are based on these approaches alone. Cross-plots of observed vs. predicted concentration is made with a background of predicted concentration vs. predicted flow. The purpose of this background is to demonstrate the range of concentrations produced by the model and to determine the relative closeness of observed-predicted pairs with respect to low-flow vs. medium-flow vs. high-flow regimes. Further, time series plots of observed vs. predicted concentration pairs with a background of predicted concentration show the relative change in model success with periods of high vs. medium vs. low concentration over time. Model comparisons to observed data were made at three locations – two for the Loramie Creek watershed and one for the Little Muchinippi Creek watershed.

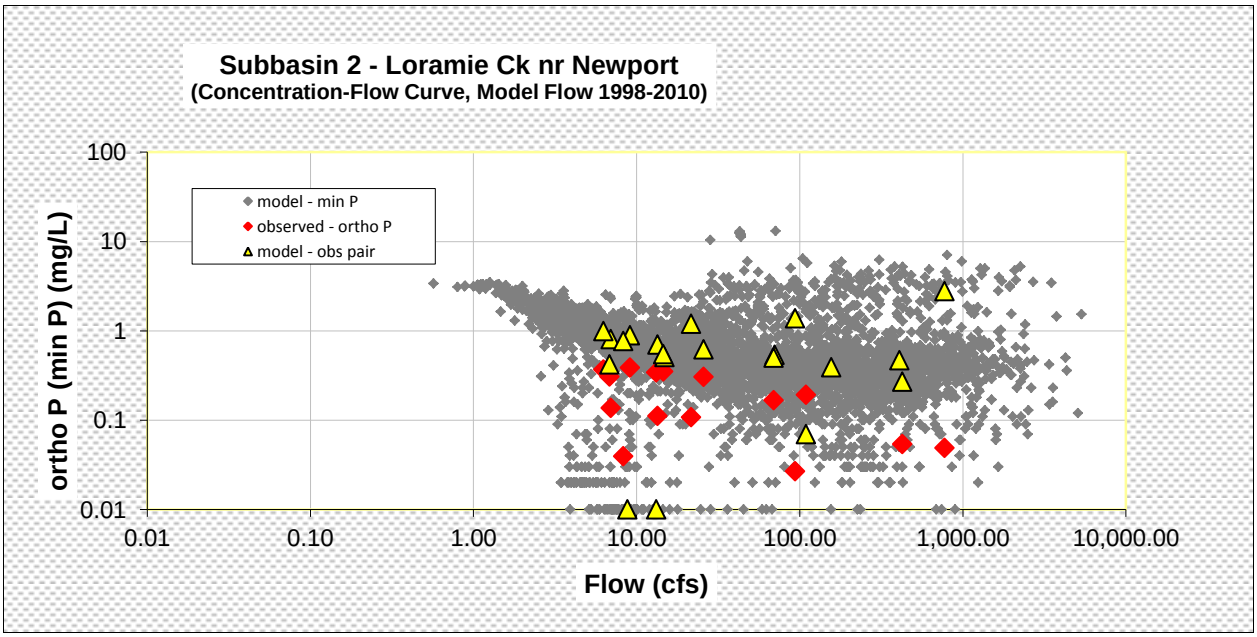
For the Loramie Creek study area, the mainstem site at the outlet of subbasin 2 (near Cardo-Roman Rd) consisted of 20 observations (Figure D-10 and Figure D-11). This site is the most downstream location of the impaired watershed zone and co-occurs with USGS daily flow measurements. Model total phosphorus and total nitrogen generally fall within the range of observed concentrations over the entire flow regime, though total nitrogen tends to be slightly under-predicted (Figure D-10a and Figure D-10c). Ortho-phosphorus concentrations appear to be over predicted at low flow events (Figure D-10b). Under-prediction of total phosphorus tends to occur at low flow events and over-prediction tends to occur at high flow events (Figure D-11).

The second Loramie Creek calibration site occurred at the outlet of subbasin 8 (Mile Creek) and consisted of 18 observations – a headwater watershed dominated by row-crop agriculture and rich in manure production. Total phosphorus and ortho-phosphorus concentrations are under-predicted at low flow regimes, whereas total nitrogen is under-predicted for all flow regimes (Figure D-12). This under-prediction is also evident on the time series plots (Figure D-13) which further indicates that its occurrence is at very low flow.

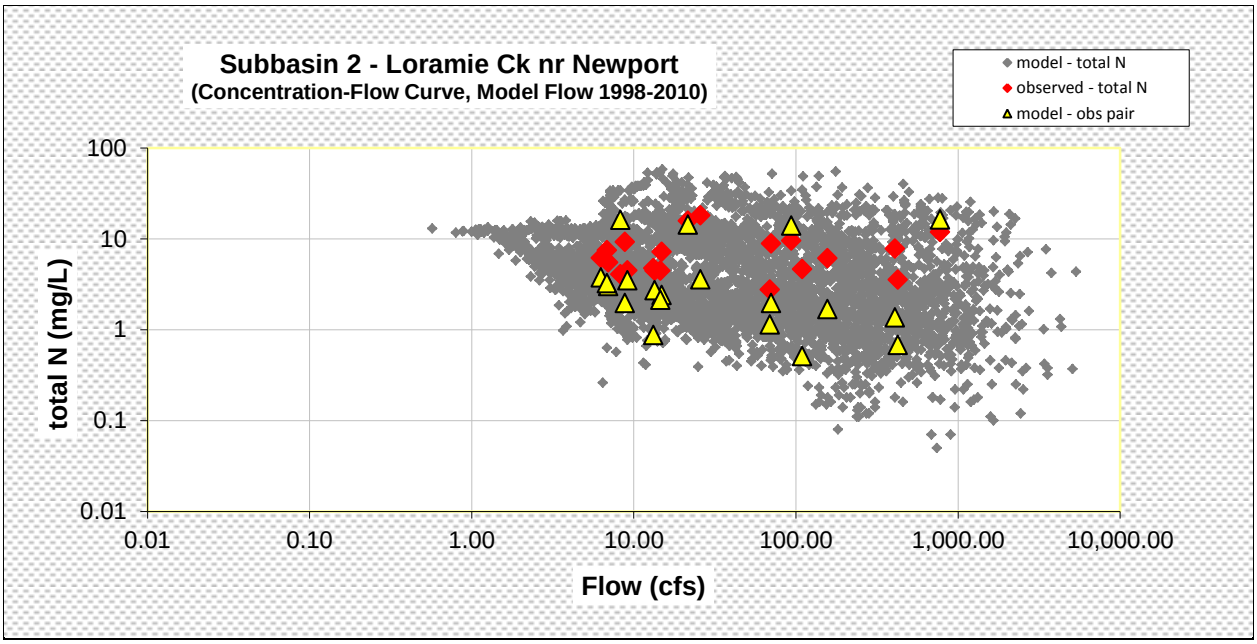
The final calibration site is for the Little Muchinippi Creek study area – located at the outlet to the watershed where six measurements were collected (Figure D-14). Little Muchinippi Creek watershed is a headwater watershed to Muchinippi Creek dominated by row-crop agriculture but with one minor point source discharge (an ADF of 0.37 MGD). Model prediction of total phosphorus concentration matches closely at low flow but does not at high flow and very low flow. For total nitrogen concentration, the model over-predicts observed values except at very high flow. But these are only rough generalizations with six plotting points to compare. When comparing the time series you observe that most of the measurements were taken at low concentration periods (Figure D-15) and that the model matches reality fairly closely when considering the range of concentrations possible in the simulation period.


Subbasin 2 - Loramie Ck nr Newport
(Concentration-Flow Curve, Model Flow 1998-2010)
model - total P
observed - total P
model - obs pair
total P (mg/L)
100
10
1
0.1
0.01
0.01
0.10
1.00
10.00
100.00
1,000.00
10,000.00
Flow (cfs)

(a)

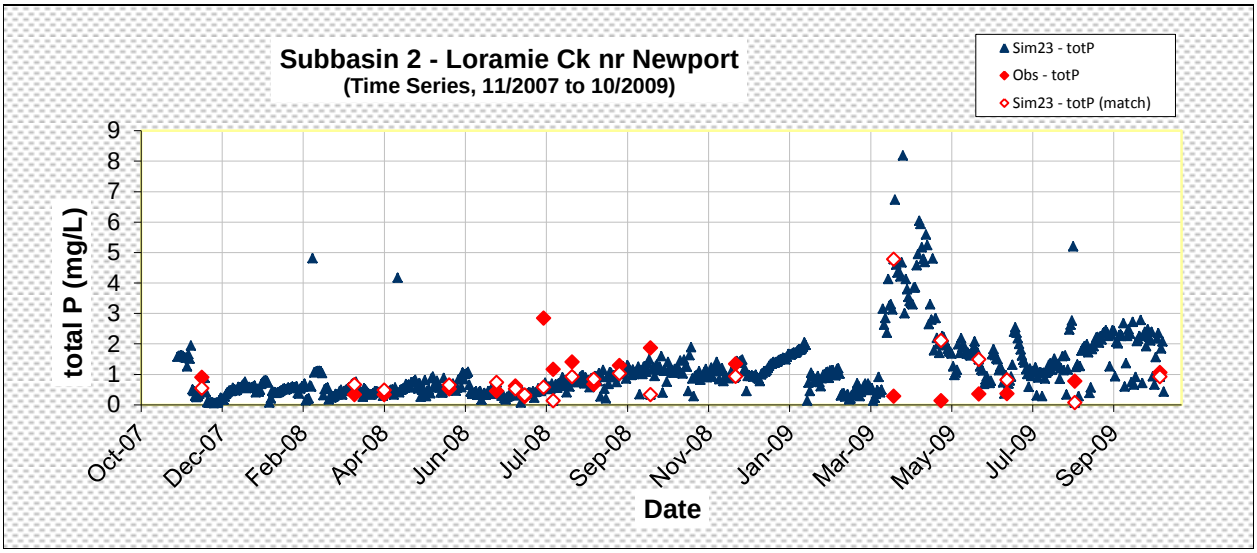

Subbasin 2 - Loramie Ck nr Newport
(Concentration-Flow Curve, Model Flow 1998-2010)
model - min P
observed - ortho P
model - obs pair
ortho P (min P) (mg/L)
100
10
1
0.1
0.01
0.01
0.10
1.00
10.00
100.00
1,000.00
10,000.00
Flow (cfs)

(b)

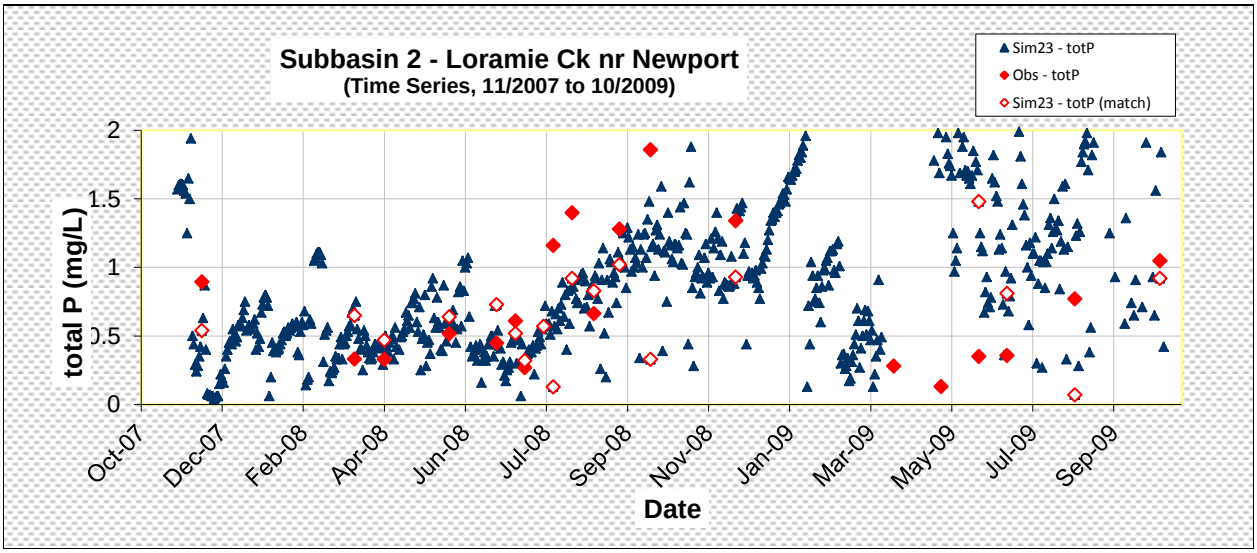


(c)

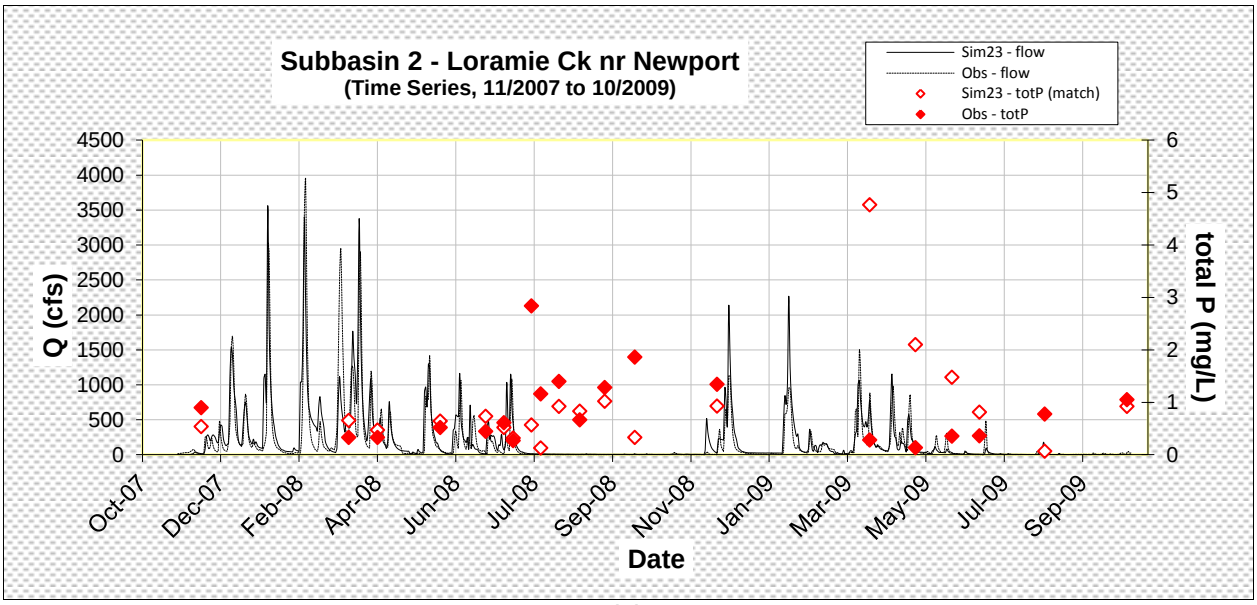
Figure D-10. Cross-plot of nutrient concentration (in mg/L) – total phosphorus (a), ortho-phosphorus (b), and total nitrogen (c) – against model flow (in cfs) measured at the time of chemistry sample.
Note: Results shown for outlet to Subbasin 2 (the downstream end of the impaired zone) for the Loramie Creek watershed SWAT model.


Subbasin 2 - Loramie Ck nr Newport
(Time Series, 11/2007 to 10/2009)
Sim23 - totP
Obs - totP
Sim23 - totP (match)
total P (mg/L)
9
8
7
6
5
4
3
2
1
0
Oct-07
Dec-07
Feb-08
Apr-08
Jun-08
Jul-08
Sep-08
Nov-08
Jan-09
Mar-09
May-09
Jul-09
Sep-09
Date

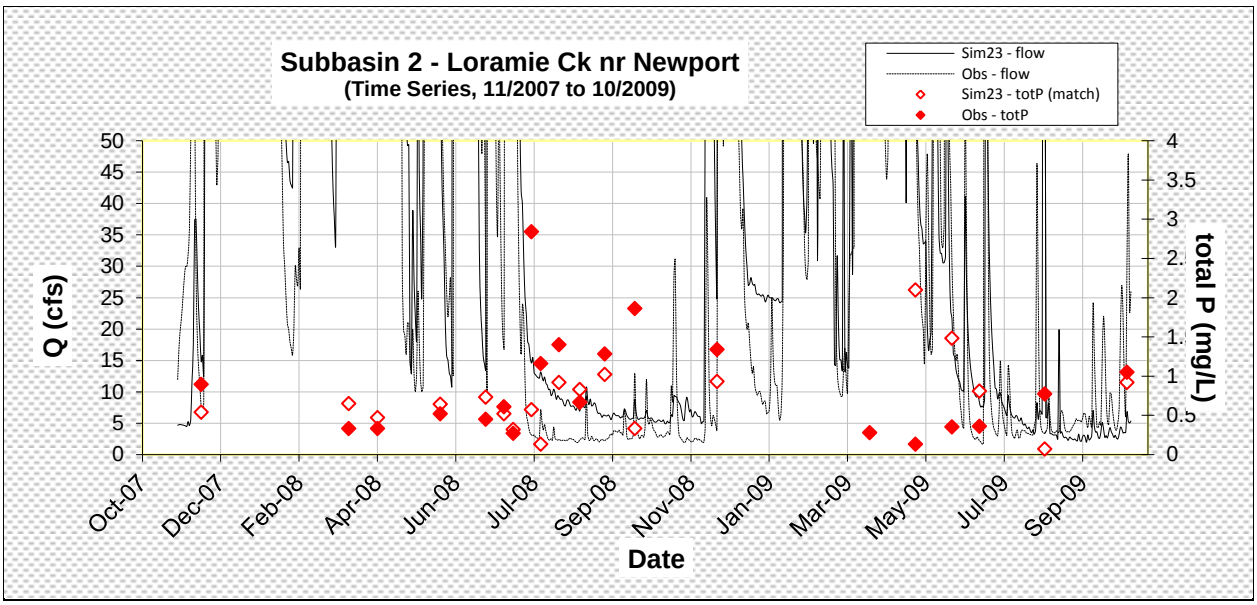
(a)


Subbasin 2 - Loramie Ck nr Newport
(Time Series, 11/2007 to 10/2009)
Sim23 - totP
Obs - totP
Sim23 - totP (match)
total P (mg/L)
2
1.5
1
0.5
0
Oct-07
Dec-07
Feb-08
Apr-08
Jun-08
Jul-08
Sep-08
Nov-08
Jan-09
Mar-09
May-09
Jul-09
Sep-09
Date

(b)

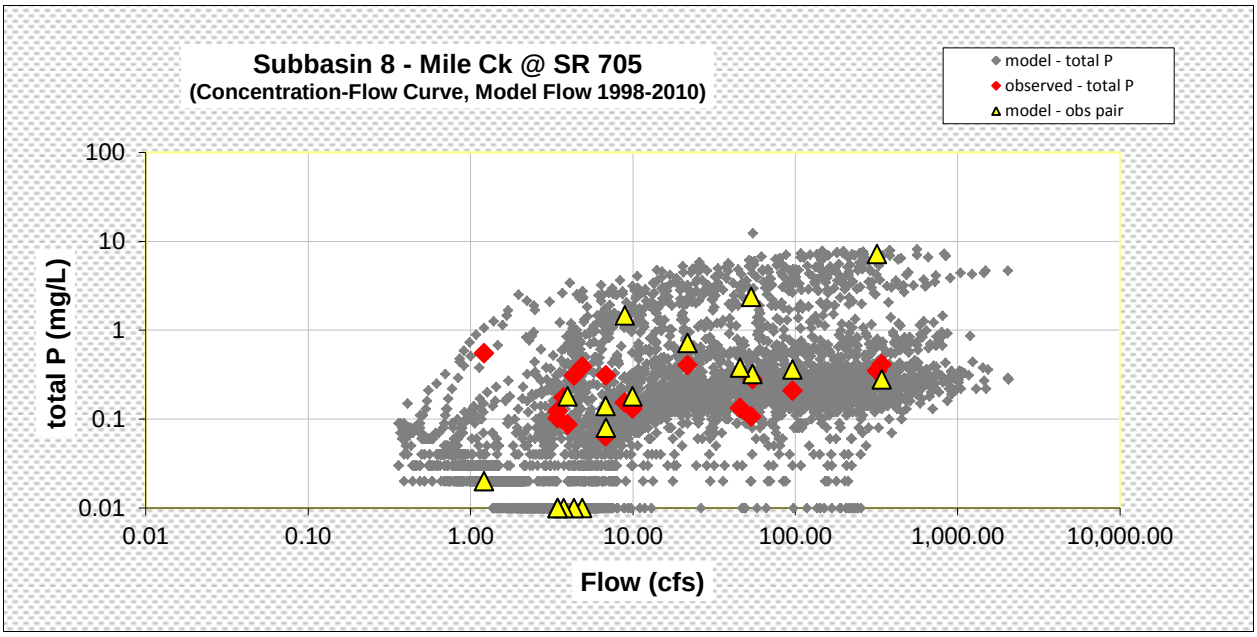


(c)

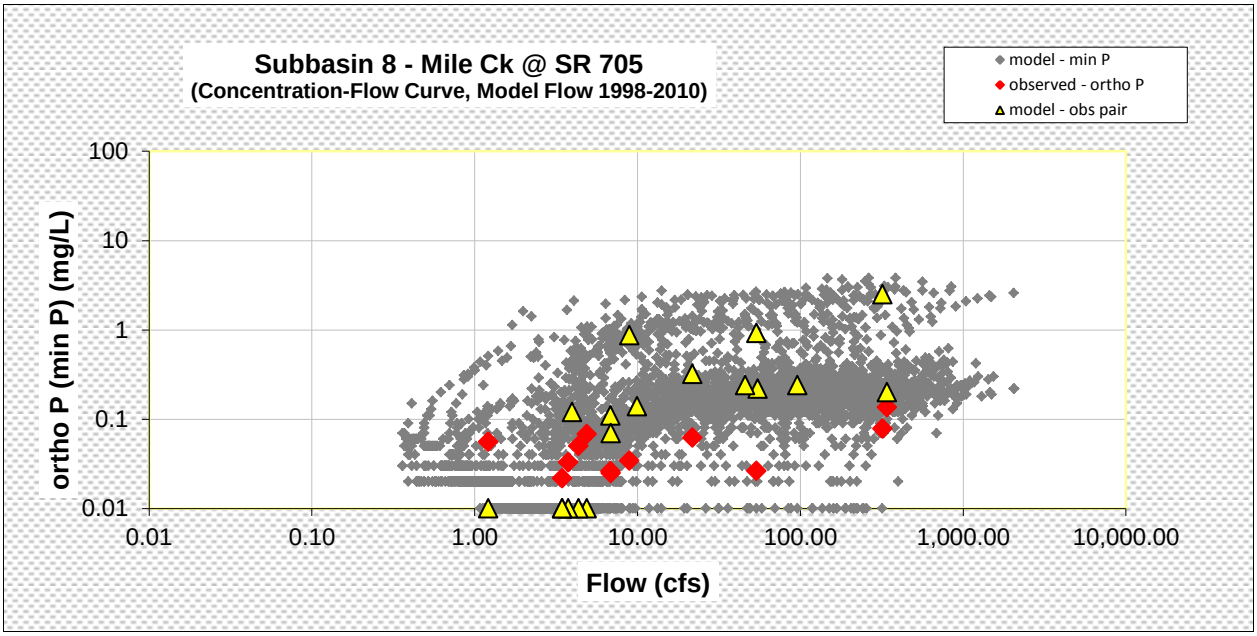


(d)

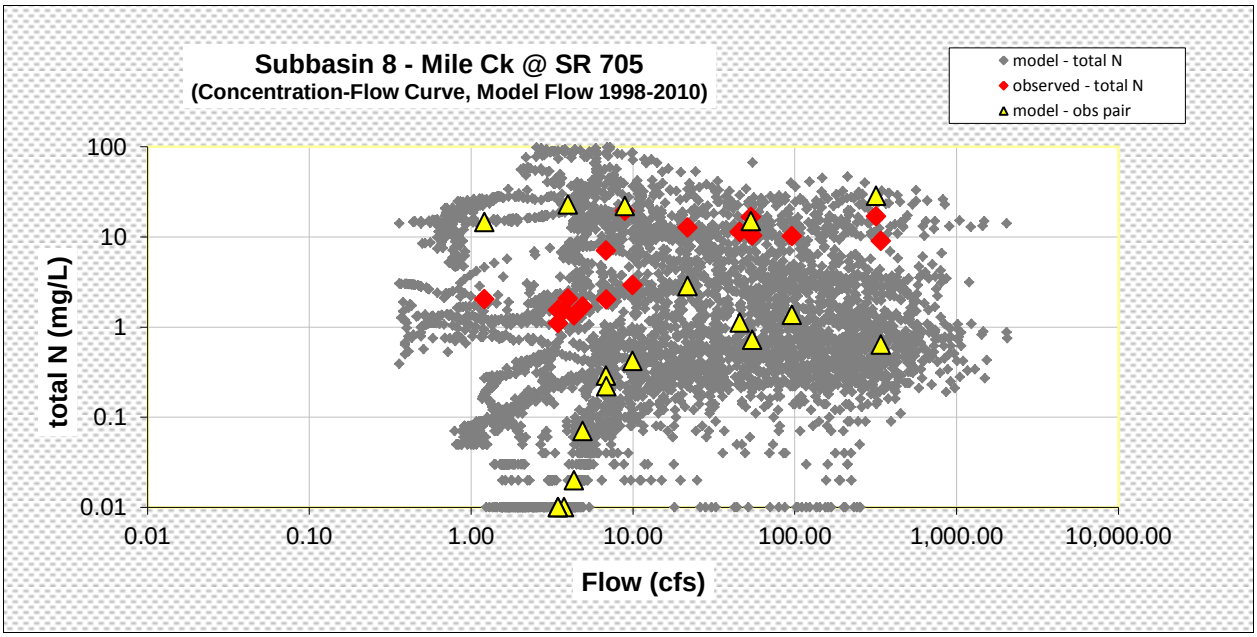
Figure D-11. Time-series plot showing subset of model record from November 2007 to October 2009 of daily total phosphorus concentration.
Note: In **(a)** and **(b)**, comparison of observed (selected sampling events) vs. predicted (model) concentration with (b) showing low magnitude axis. **(c)** and **(d)** are same as (a-b) but observed and simulated flow is included in time-series. Results shown for outlet to Subbasin 2 (the downstream end of the impaired zone).


Subbasin 8 - Mile Ck @ SR 705
(Concentration-Flow Curve, Model Flow 1998-2010)
model - total P
observed - total P
model - obs pair
total P (mg/L)
100
10
1
0.1
0.01
0.01
0.10
1.00
10.00
100.00
1,000.00
10,000.00
Flow (cfs)

(a)

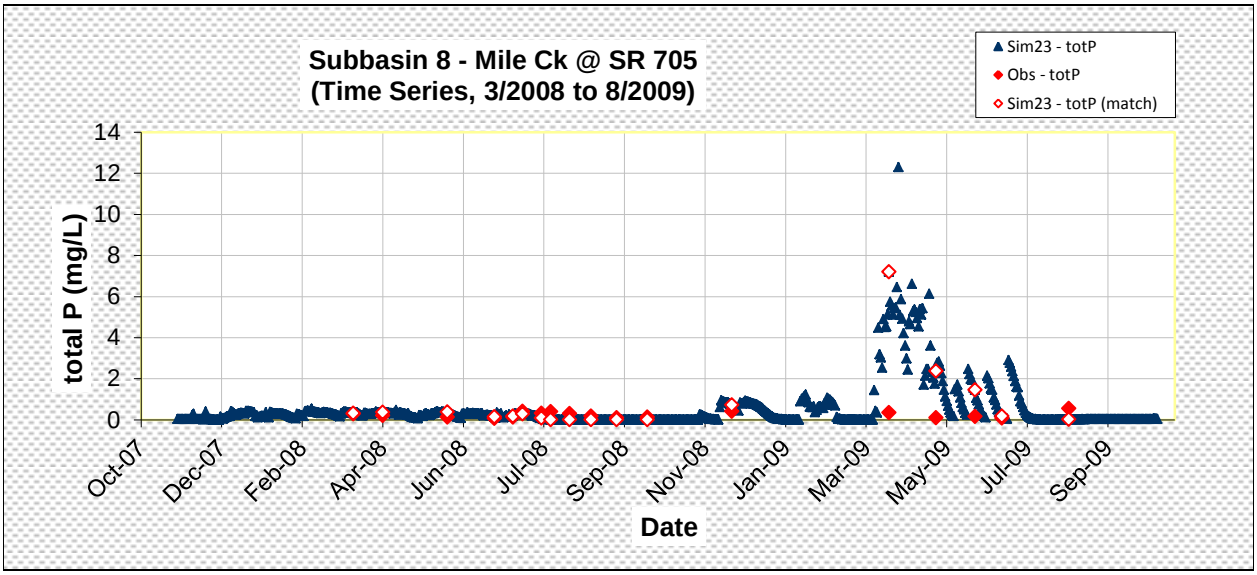

Subbasin 8 - Mile Ck @ SR 705
(Concentration-Flow Curve, Model Flow 1998-2010)
model - min P
observed - ortho P
model - obs pair
ortho P (min P) (mg/L)
100
10
1
0.1
0.01
0.01
0.10
1.00
10.00
100.00
1,000.00
10,000.00
Flow (cfs)

(b)

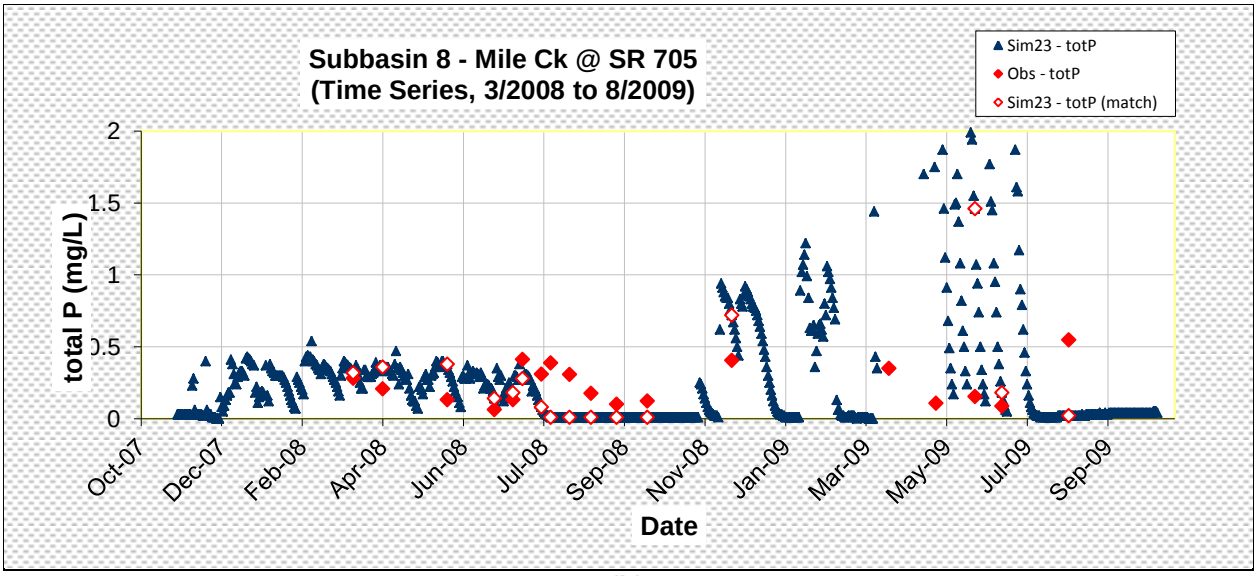


(c)

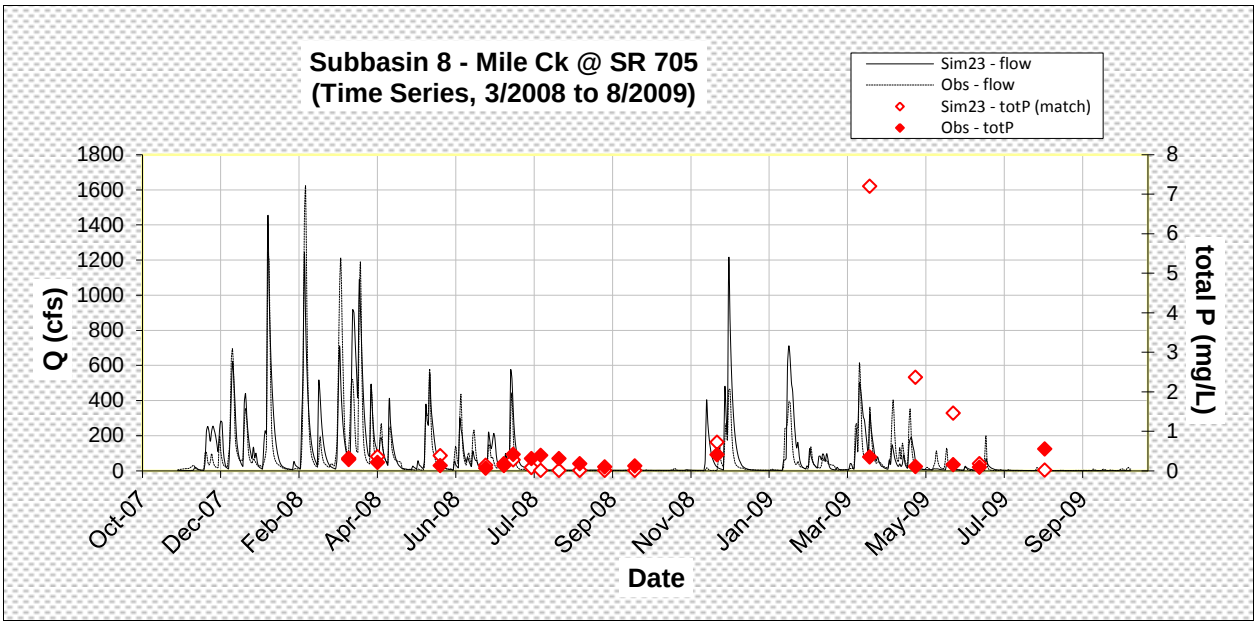
Figure D-12. Cross-plot of nutrient concentration (in mg/L) – total phosphorus (a), ortho-phosphorus (b), and total nitrogen (c) – against model flow (in cfs) measured at the time of chemistry sample.
Note: Results shown for outlet to Subbasin 8 (a headwater subbasin) for the Loramie Creek watershed SWAT model.


Subbasin 8 - Mile Ck @ SR 705
(Time Series, 3/2008 to 8/2009)
Sim23 - totP
Obs - totP
Sim23 - totP (match)
total P (mg/L)
14
12
10
8
6
4
2
0
Oct-07
Dec-07
Feb-08
Apr-08
Jun-08
Jul-08
Sep-08
Nov-08
Jan-09
Mar-09
May-09
Jul-09
Sep-09
Date

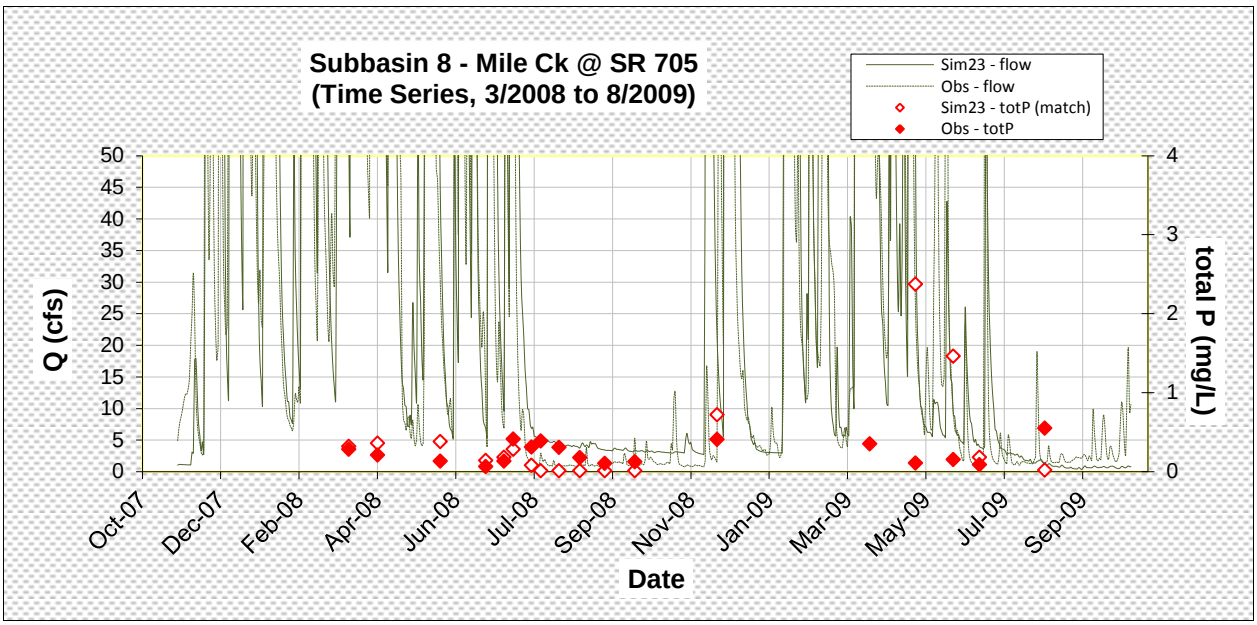
(a)


Subbasin 8 - Mile Ck @ SR 705
(Time Series, 3/2008 to 8/2009)
Sim23 - totP
Obs - totP
Sim23 - totP (match)
total P (mg/L)
2
1.5
1
0.5
0
Oct-07
Dec-07
Feb-08
Apr-08
Jun-08
Jul-08
Sep-08
Nov-08
Jan-09
Mar-09
May-09
Jul-09
Sep-09
Date

(b)

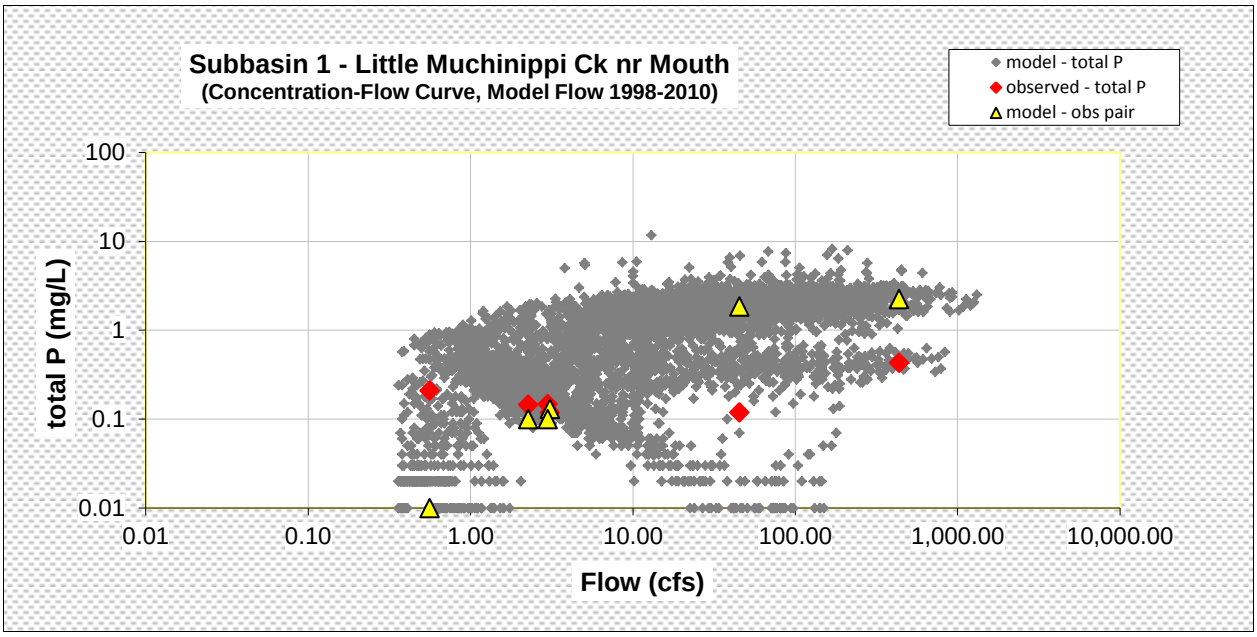


(c)

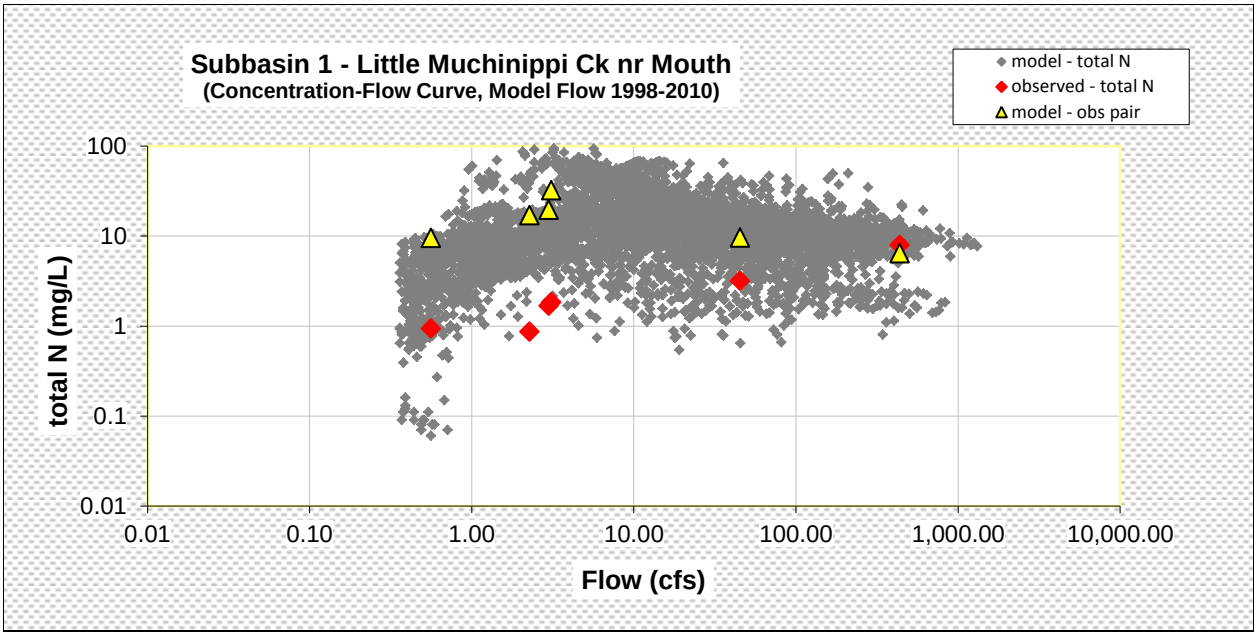


(d)

Figure D-13. Time-series plot showing subset of model record from March 2008 to August 2009 of daily total phosphorus concentration.
Note: In **(a)** and **(b)**, comparison of observed (selected sampling events) vs. predicted (model) concentration with (b) showing low magnitude axis. **(c)** and **(d)** are same as (a-b) but observed (scaled by drainage area) and simulated flow is included in time-series. Results shown for outlet to Subbasin 8 (a headwater subbasin) for the Loramie Creek watershed SWAT model.

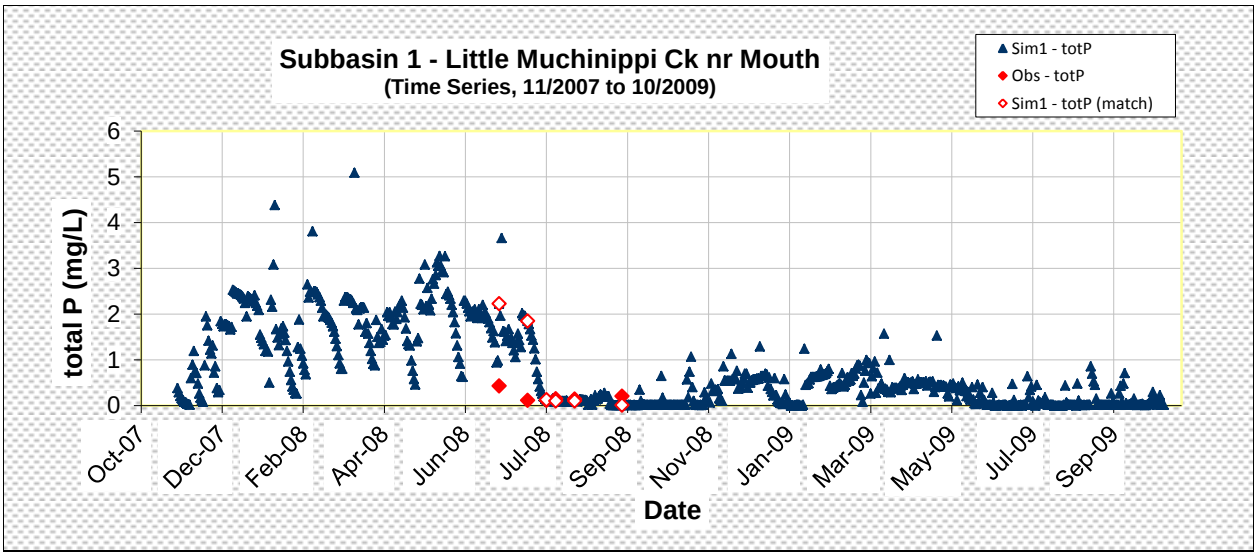


(a)

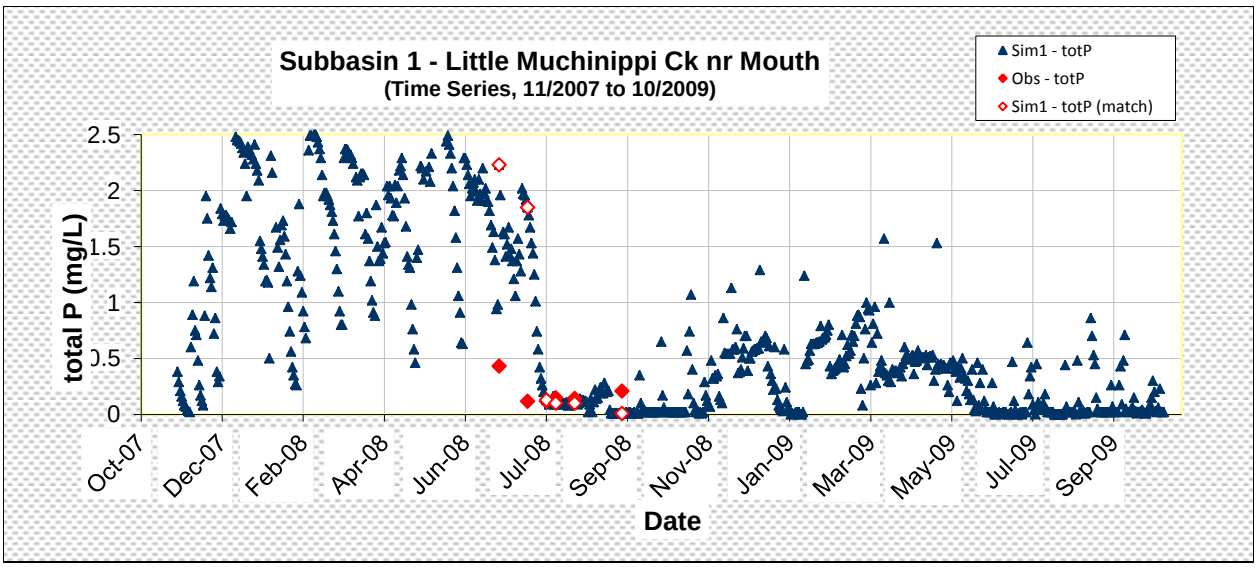


(b)

Figure D-14. Cross-plot of nutrient concentration (in mg/L) – total phosphorus (a) and (b) total nitrogen – against model flow (in cfs) measured at the time of chemistry sample.
Note: Results shown for outlet to Subbasin 1 (the outlet to the study area) for the Little Muchinippi Creek watershed SWAT model.



(a)



(b)

Figure D-15. Time-series plot showing subset of model record from November 2007 to October 2009 of daily total phosphorus concentration.
Note: In **(a)** and **(b)**, comparison of observed (selected sampling events) vs. predicted (model) concentration with (b) showing low magnitude axis. Results are shown for outlet to Subbasin 1 (the outlet to the study area) for the Little Muchinippi Creek watershed SWAT model.

There was no detailed livestock inventory to provide more accurate spatial portrayal of manure application rates. However, crop fertilization rates – both commercial synthetic and animal manure – were adjusted, typically upward, to values that would sustain crop yields that match those quantified from National Agricultural Statistics Service reports for the period 2000 to 2010 (Table D-13). Fertilization application rates (in units of mass per area) were guided by recommendations for total nitrogen, phosphate (as P_2O_5), and potash (K_2O) to support various yields (in units of mass per area) for corn, soybean, and winter wheat (Vitosh et al. 1995). Average observed yields found for Shelby County (Table D-13) were identified in Vitosh et al.

(1995) and corresponding nutrient application rates were input into the SWAT model for each study area. Adjustments to the model application rate were made until model crop yields (in kg/ha) matched observed crop yields.

Table D-13. Average crop yields (in kg/ha) for the period 2000 to 2010 (11 years total) for Shelby County OH.
Note: Shelby County occupies over 90 percent of the Loramie Creek watershed study area. Source of information is *National Agricultural Statistics Service Quick Stats 2.0.*

Crop Type	Avg Yield (kg/ha)	# years in avg
Corn Grain	9,272	11
Soybean	2,997	11
Winter Wheat	4,630	11

D4.5 TMDL Results

D4.5.1 Critical Conditions and Seasonality

The critical condition is defined as the set of environmental conditions that, if controls are designed to be protective of them, will ensure attainment of objectives for all other conditions. The argument that the critical condition for meeting a total phosphorus target applies to the entire year was established in Ohio EPA (2009) for the Stillwater River TMDL.

Here nutrient sources in the upper Loramie and Little Muchinippi watersheds arose primarily from wet weather conditions and most of the mass inputs occurred from November through June. However, the most severe eutrophic conditions were observed in the low flow (summer) period. Hence, the total P target was applied to both summer *and* winter seasons of the year. The severe eutrophic conditions were characterized by large diurnal swings in dissolved oxygen concentration, very low minimum daily dissolved oxygen concentration, and elevated in-stream total phosphorus and ortho-phosphate concentrations. While we recognize the argument made by Baker (2011) that the focus for nutrient reduction should apply to the critical low flow period – when planktonic algae are prolific and so are diurnal swings in dissolved oxygen – the plugs of particulate phosphorus during high flow (both sorbed and sediment) from upland sources must still be considered. These plugs of particulate phosphorus make their way to channel substrate and are subsequently available during low flow periods when overlying water column P concentrations are much lower.

Seasonality was addressed in the Loramie Creek and Little Muchinippi Creek TMDLs by using the calibrated SWAT model to simulate daily loadings over the period 1995 to 2010. In this model scenario, WWTP facilities were input with discharge at average design flow and total phosphorus concentrations established by self-monitored or expected levels. The daily loadings were then aggregated to two seasonal (summer, winter) average daily loads using the last six years of the simulation period and considered as the existing load for each model subunit. Seasonality in model input was produced from observed daily precipitation and minimum/ maximum temperatures, daily point source loadings, and crop management schedules. Crop management schedules included the rate and timing of synthetic dry and organic (manure) fertilizer. We propose, then, that estimated loads are therefore reflective of seasonal changes in weather, treatment facility operating practices, and agricultural management practices.

D4.5.2 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). A standard five percent explicit margin of safety (MOS) was included in this allocation strategy to account for overall uncertainty in load reduction estimation due to field sampling error, imperfect water quality targets, imperfect model calibration, and process representation in the model (e.g., less than ideal in-stream kinetics simulation by not including benthic algae interactions).

Implicit margins of safety were captured by:

1) Downstream beneficial uses are protected, in the case of nutrient impairment – aquatic life use (ALU). Protection of downstream use was operationalized at the nested subwatershed level. Even though a specific nested subwatershed was not impaired for ALU and for causes due to nutrient and/or organic enrichment, it could be assigned an allocation to protect the downstream, contiguous nested subwatershed if that downstream nested subwatershed was impaired. If both the specific nested subwatershed and downstream nested subwatershed were impaired, then the most restrictive total phosphorus target would be applied.
2) The selected nutrient targets are conservative. Total phosphorus targets obtained from Ohio EPA (1999) were taken from statewide conditions. However, background concentrations for the Eastern Cornbelt Plains ecoregion (the ecoregion home of the Loramie and Little Muchinippi watersheds), were at or near the statewide targets.
3) The modeling approach employed a detailed simulation model (SWAT) employed over a fine nested subwatershed resolution so that one can safely assume that all land surface and in-channel processes were represented.

D4.5.3 Allowance for Future Growth

Allocation for future growth was set to a minimum (1% of the TMDL) because none of the five POTWs in the impaired subbasin units have any planned facility expansions (Ohio EPA – SWDO, various permit/PTI staff; personal communication 2011). Further, the multiple county region (primarily Shelby) is expected to experience very small (less than 1%) to declining growth (Table D-14).

Table D-14. Year to year change in human population count for the six county region encompassing Loramie Creek and Little Muchinippi Creek watersheds.
Note: Values shown are in percent change from previous year, and the average and maximum for the 10 year period. Values in red font indicate negative growth rate.

	% Population Increase (Decrease) in Given Year											
County	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**Average**	**Max**
Auglaize	**-0.05**	**-0.05**	**-0.38**	**-0.17**	0.17	0.51	**-0.24**	0.00	0.51	**-0.10**	0.02	0.51
Darke	**-0.03**	**-0.49**	**-0.37**	0.08	**-0.12**	**-0.32**	**-0.56**	**-0.28**	**-0.40**	**-0.33**	-0.28	0.08
Logan	0.02	**-0.14**	0.59	0.41	0.08	**-0.31**	**-0.24**	0.71	0.03	0.10	0.13	0.71
Mercer	**-0.04**	**-0.30**	**-0.03**	**-0.15**	0.03	0.07	0.14	**-0.01**	**-0.12**	**-0.23**	-0.06	0.14
Miami	0.11	0.14	0.12	0.33	0.50	0.59	0.30	0.00	0.18	0.13	0.24	0.59
Shelby	0.16	0.60	**-0.04**	0.09	**-0.01**	0.42	0.05	0.34	0.33	0.28	0.22	0.42

D4.5.4 Load Reduction and Allocation

Following the calibration of crop yield, flow, and nutrient chemistry, a "baseline" model was established from the calibration model and then the following adjustments were subsequently added:

1) Set WWTP conduit flow to their corresponding average design flow (ADF) according to their NPDES permit;
2) Add a new facility (Osgood 1PB00047 in Subbasin 8) that came online at the end of the calibration period (2010);
3) Reduce the population (by 95 percent of the total) served by HSTS in this same subbasin as homes were moved from on-site to a public facility;
4) Eliminate facilities that no longer discharge (2010 to the present) – these are Northstar Elementary School (1PT00119) and SuperStop Petroleum Anna (1PZ00007).

Subsequent to the baseline model, a "Scenario 1" model was developed where all WLA were assigned according to internal guidance (see Table D-5 above). Further, all failed HSTS were converted to functioning conventional systems. Hence, no loading allocation (under LA) was assigned to HSTS. The allocations made in the "Scenario 1" model are presented in this section. Additional scenario models (Scenario series 2 and 3) that address reduction in the LA through indirect (e.g., crop management practices) and direct (i.e., reduced fertilization rate) are presented in the subsequent section (Section D4.5.5).

The TMDL (the load limit) and existing stressor loads were defined on a seasonal basis from daily model simulations of a 6-year period (2005 to 2010 inclusively). The seasons are winter (WI) for the months November through April, and summer (SU) as May through October. In Table D-16, distributed by nested subwatershed and then over two seasons, the existing (current) load, the allowable total phosphorus load (i.e., TMDL), and allocations to load (NPS) and corresponding NPS subdivisions, the total WLA and allocations to specific facilities are depicted. Also shown in Table D-16 are the allowance for future growth (AFG) and margin of safety (MOS), and the average daily percent reduction required. For nearly all but a few subbasins (the exception is subbasin 3 for summer season), the LA dominates the total load allowed and thus will be expected to reduce the greatest magnitude. Overall reduction rates range from 24 to 93 percent for the Loramie study area and 37 to 85 percent for the Little Muchinippi study area.

In one instance in Table D-16, the load allocation (LA) is nearly zero (below 0.01 kg/d) for the summer season – Subbasin 7 (in nested subwatershed 05080001 05 01). All of the available load capacity (TMDL less MOS and AFG) was necessarily assigned to the wasteload allocation (WLA) in order to meet internal (Ohio EPA) guidance for assigning WLAs for specific facility size and impairment scenario. However, the corresponding facility, Botkins STP (1PB00007), has been historically discharging a total phosphorus loading below the allocation (1.36 kg/d actual vs. 1.89 kg/d WLA). Further, this is the summer (lower flow) season and the expectation for nonpoint source runoff is low. Based on the WLA in Scenario 1, total phosphorus limits and allocations for POTWs in both TMDL study areas are assigned in Table D-15.

Table D-15. Proposed total phosphorus limits and/or wasteload allocations for POTWs.

Facility Name	Ohio EPA Permit #	2011 Proposed Limit (mg-P/L) or WLA	Existing Effluent Concentration (mg-P/L) – relative change
Little Muchinippi Creek Watershed			
Jackson Center	1PB00018	1.0	1.72 (decrease)
Loramie Creek Watershed			
Botkins	1PB00007	1.0	0.72 (increase)
Anna	1PB00004	1.0	2.13 (decrease)
SuperStop Anna	1PZ00007	No allocation (WLA = 0)	No longer discharging
BP Amoco Minster	2IN00173	No limit, but WLA = 0.11	ADF very low (no change – continuing discharging total P as currently is)
Minster	2PB00036	1.0	4.14 (decrease)
Minster Machine	2GN00007	No limit as WLA = 0	0 (no change)
Lake Loramie	1PH00028	1.0	4.21 (decrease)
Osgood	1PB00047	3.0	Recently came online
Northstar ES	1PT00119	No allocation (WLA = 0)	No longer discharging

Table D-16. Existing (current) total phosphorus load and subsequent load allocations for the Loramie Creek watershed.
Note: A suite of allocations exists for each nested subwatershed and SWAT model sub-basin number and for each of two seasons (summer and winter). Subcategories for LA (by land use type) and WLA (by facility) are also depicted. **Each value represents a seasonal average (summer or winter) of the distribution of daily loads in that season.** All values are shown as total phosphorus in kg/d except for average percentage reduction.

05080001 05 01 Headwaters Loramie Ck	Subbasin#: **6 Summer**
Current Load	104
TMDL = LA + WLA + AFG + MOS	8
LA (total)	6.01
LA -- cropland	6
LA -- pasture	0
LA -- residential (low density)	0
WLA (total)	1.51
WLA - facility: Anna (1PB00004) 1.51	
AFG (1%)	0.08
MOS (5%)	0.4
Average Percentage Reduction	0.74
05080001 05 01 Headwaters Loramie Ck	Subbasin#: **6 Winter**
Current Load	230
TMDL = LA + WLA + AFG + MOS	24
LA (total)	21.05
LA -- cropland	21.03
LA -- pasture	0
LA -- residential (low density)	0
WLA (total)	1.51
WLA - facility: Anna (1PB00004) 1.51	
AFG (1%)	0.24
MOS (5%)	1.2
Average Percentage Reduction	0.71

05080001 05 01 Headwaters Loramie Ck	Subbasin#: **7 Summer**
Current Load	44
TMDL = LA + WLA + AFG + MOS	2
LA (total)	<0.01
LA -- cropland	<0.01
LA -- pasture	0
LA -- residential (low density)	0
WLA (total)	1.89
WLA - facility: Botkins (1PB00007) 1.89	
AFG (1%)	0.02
MOS (5%)	0.1
Average Percentage Reduction	0.77
05080001 05 01 Headwaters Loramie Ck	Subbasin#: **7 Winter**
Current Load	114
TMDL = LA + WLA + AFG + MOS	7
LA (total)	4.69
LA -- cropland	4.68
LA -- pasture	0
LA -- residential (low density)	0
WLA (total)	1.89
WLA - facility: Botkins (1PB00007) 1.89	
AFG (1%)	0.07
MOS (5%)	0.35
Average Percentage Reduction	0.73
05080001 05 02 Mile Ck	Subbasin#: **8 Summer**
Current Load	76
TMDL = LA + WLA + AFG + MOS	9
LA (total)	7.07
LA -- cropland	7.07
LA – pasture	0
LA -- residential (low density)	0
WLA (total)	1.39
WLA - facility: Osgood (1PB00047) 1.39	
AFG (1%)	0.09
MOS (5%)	0.45
Average Percentage Reduction	0.43
05080001 05 02 Mile Ck	Subbasin#: **8 Winter**
Current Load	158
TMDL = LA + WLA + AFG + MOS	34
LA (total)	30.57
LA -- cropland	30.58
LA – pasture	0
LA -- residential (low density)	0

WLA (total)	1.39
WLA - facility: Osgood (1PB00047) 1.39	
AFG (1%)	0.34
MOS (5%)	1.7
Average Percentage Reduction	0.56
05080001 05 03 Lk Loramie-Loramie Ck	Subbasin#: **3 Summer**
Current Load	198
TMDL = LA + WLA + AFG + MOS	13
LA (total)	1.25
LA -- cropland	0.88
LA – pasture	0
LA -- residential (low density)	0.37
WLA (total)	10.97
WLA - facility: Minster (2PB00036): 9.46 Lk Loramie (1PH00028): 1.51 BP Amoco (2IN00173): 0	
AFG (1%)	0.13
MOS (5%)	0.65
Average Percentage Reduction	0.93
05080001 05 03 Lk Loramie-Loramie Ck	Subbasin#: **3 Winter**
Current Load	294
TMDL = LA + WLA + AFG + MOS	39
LA (total)	25.69
LA -- cropland	18.17
LA – pasture	0
LA -- residential (low density)	7.55
WLA (total)	10.97
WLA - facility: Minster (2PB00036): 9.46 Lk Loramie (1PH00028): 1.51 BP Amoco (2IN00173): 0	
AFG (1%)	0.39
MOS (5%)	1.95
Average Percentage Reduction	0.85
05080001 05 03 Lk Loramie-Loramie Ck	Subbasin#: **5 Summer**
Current Load	158
TMDL = LA + WLA + AFG + MOS	14
LA (total)	13.16
LA -- cropland	13.18
LA -- pasture	0
LA -- residential (low density)	0
WLA (total)	0
AFG (1%)	0.14
MOS (5%)	0.7

Average Percentage Reduction	0.65
05080001 05 03 Lk Loramie-Loramie Ck	Subbasin#: **5 Winter**
Current Load	343
TMDL = LA + WLA + AFG + MOS	43
LA (total)	40.42
LA -- cropland	40.47
LA -- pasture	0
LA -- residential (low density)	0
WLA (total)	0
AFG (1%)	0.43
MOS (5%)	2.15
Average Percentage Reduction	0.69
05080001 06 02 Painter Ck-Loramie Ck	Subbasin#: **1 Summer**
Current Load	307
TMDL = LA + WLA + AFG + MOS	27
LA (total)	25.38
LA -- cropland	16.86
LA -- pasture	8.55
LA -- residential (low density)	0
WLA (total)	0
AFG (1%)	0.27
MOS (5%)	1.35
Average Percentage Reduction	0.88
05080001 06 02 Painter Ck-Loramie Ck	Subbasin#: **1 Winter**
Current Load	598
TMDL = LA + WLA + AFG + MOS	88
LA (total)	82.72
LA -- cropland	54.95
LA -- pasture	27.85
LA -- residential (low density)	0
WLA (total)	0
AFG (1%)	0.88
MOS (5%)	4.4
Average Percentage Reduction	0.82
05080001 06 02 Painter Ck-Loramie Ck	Subbasin#: **2 Summer**
Current Load	272
TMDL = LA + WLA + AFG + MOS	23
LA (total)	21.62
LA -- cropland	13.62
LA -- pasture	8.05
LA -- residential (low density)	0
WLA (total)	0
AFG (1%)	0.23
MOS (5%)	1.15
Average Percentage Reduction	0.88

05080001 06 02 Painter Ck-Loramie Ck	Subbasin#: **2 Winter**
Current Load	468
TMDL = LA + WLA + AFG + MOS	76
LA (total)	71.44
LA -- cropland	45.01
LA -- pasture	26.61
LA -- residential (low density)	0
WLA (total)	0
AFG (1%)	0.76
MOS (5%)	3.8
Average Percentage Reduction	0.80
05080001 06 03 Turtle Ck	Subbasin#: **14 Summer**
Current Load	11
TMDL = LA + WLA + AFG + MOS	1
LA (total)	0.94
LA -- cropland	0.94
LA -- pasture	0
LA -- residential (low density)	0
WLA (total)	0
AFG (1%)	0.01
MOS (5%)	0.05
Average Percentage Reduction	0.24
05080001 06 03 Turtle Ck	Subbasin#: **14 Winter**
Current Load	23
TMDL = LA + WLA + AFG + MOS	4
LA (total)	3.76
LA -- cropland	3.76
LA -- pasture	0
LA -- residential (low density)	0
WLA (total)	0
AFG (1%)	0.04
MOS (5%)	0.2
Average Percentage Reduction	0.44

Table D-17. Existing (current) total phosphorus load and subsequent load allocations for the Little Muchinippi Creek watershed.
Note: A suite of allocations exists for each nested subwatershed and SWAT model sub-basin number and for each of two seasons (summer and winter). Subcategories for LA (by land use type) and WLA (by facility) are also depicted. **Each value represents a seasonal average (summer or winter) of the distribution of daily loads in that season.** All values are shown as total phosphorus in kg/d except for average percentage reduction.

05080001 02 03 Little Muchinippi Ck	Subbasin#: **101 Summer**
Current Load	111
TMDL = LA + WLA + AFG + MOS	6
LA (total)	5.64
LA -- cropland	5.64
LA -- pasture	0
LA -- residential (low density)	0
WLA (total)	0
AFG (1%)	0.06
MOS (5%)	0.3
Average Percentage Reduction	0.84
05080001 02 03 Little Muchinippi Ck	Subbasin#: **101 Winter**
Current Load	365
TMDL = LA + WLA + AFG + MOS	20
LA (total)	18.8
LA -- cropland	18.8
LA -- pasture	0
LA -- residential (low density)	0
WLA (total)	0
AFG (1%)	0.2
MOS (5%)	1
Average Percentage Reduction	0.85
05080001 02 03 Little Muchinippi Ck	Subbasin#: **102 Summer**
Current Load	17
TMDL = LA + WLA + AFG + MOS	4
LA (total)	2.36
LA -- cropland	2.36
LA -- pasture	0
LA -- residential (low density)	0
WLA (total)	1.4
WLA - facility: Jackson Center (1PB00018) 1.4	
AFG (1%)	0.04
MOS (5%)	0.2
Average Percentage Reduction	0.72
05080001 02 03 Little Muchinippi Ck	Subbasin#: **102 Winter**
Current Load	51
TMDL = LA + WLA + AFG + MOS	11
LA (total)	8.94
LA -- cropland	8.94

LA -- pasture	0
LA -- residential (low density)	0
WLA (total)	1.4
WLA - facility: Jackson Center (1PB00018) 1.4	
AFG (1%)	0.11
MOS (5%)	0.55
Average Percentage Reduction	0.68
05080001 02 03 Little Muchinippi Ck	Subbasin#: **103 Summer**
Current Load	35
TMDL = LA + WLA + AFG + MOS	2
LA (total)	1.88
LA -- cropland	1.88
LA -- pasture	0
LA -- residential (low density)	0
WLA (total)	0
AFG (1%)	0.02
MOS (5%)	0.1
Average Percentage Reduction	0.37
05080001 02 03 Little Muchinippi Ck	Subbasin#: **103 Winter**
Current Load	121
TMDL = LA + WLA + AFG + MOS	7
LA (total)	6.58
LA -- cropland	6.58
LA -- pasture	0
LA -- residential (low density)	0
WLA (total)	0
AFG (1%)	0.07
MOS (5%)	0.35
Average Percentage Reduction	0.64

D4.5.5 Scenarios to Address Load Reduction Goals

Smiley et al. (2011) sampled and subsequently examined headwater streams with and without herbaceous riparian buffers. Headwater streams were targeted 1) because buffer effectiveness is expected to be greater adjacent to these systems; 2) to protect larger downstream channels; and 3) because greater number of headwater streams implies more opportunity for restoration. They discovered the following:

1) While comparison of several response variables (i.e., physical habitat, water chemistry, biological communities) was made, they found no difference in nitrate+nitrite and total phosphorus concentrations between those sampled systems with and without buffer strips.
2) The study helped support existing claims that a combination of upland and riparian management improved physical habitat and water chemistry in agricultural systems.

The load reduction scenarios considered here reflect the guidance provided by the Smiley et al. (2011) study – namely *multiple* agricultural management practices are considered in one scenario. A summary of scenarios developed in this TMDL appears in Table D-18.

Table D-18. Baseline and load reduction scenarios by sector (WWTP, HSTS, and NPS).

Sector	Baseline	Scenario 1	Scenario 2	Scenario 3
WWTP (POTW)	flow set at ADF, maintain existing tot P concentration, add Osgood (new), remove no longer discharging facilities	follow guidance: 1 mg/L, 3 mg/L, or existing load	same as Scenario1	same as Scenario1
HSTS	remove 95% of population from HSTS use (both conventional and failed systems) in sub-basin 8 (Osgood collection system)	convert all failed systems to conventional systems; maintain existing conventional systems	same as Scenario1	same as Scenario1
NPS (agriculture)	same as calibrated model	same as calibrated model	Sub-scenarios :	Sub-scenarios :
			Scen2a: incorporate manure Scen2b: increase biomass residue Scen2c: eliminate all fall tillage Scen2d: add winter cover crop Scen2e: add filter strip	Scen3a: transfer all winter application of manure to April 1 Scen3b: reduce rate of April 1 manure application by 90% Scen3c: reduce rate of all manure application by 50% Scen3d: reduce rate of all P-fertilizer application by 50%
			Scen2comb: Scen1 + Scen2a + Scen2d + Scen2e	Scen3comb: Scen2comb + Scen3d

D4.5.5.1 Testing of "Soft" Agricultural Management Scenarios

Scenario 2 consists of a suite of "sub-scenarios" with each one adopting one (and only one) management practice change (Table D-18). All sub-scenarios in Scenario 2 reflect more or less physical changes in farming practices with no reduction in fertilization inputs required. Further, they are only applied to the Loramie Creek watershed for minimizing output but results can be transferred to the Little Muchinippi Creek watershed. Fertilization reduction will be considered in Scenario 3 below (Section D4.5.5.2).

An improvement in how fertilizer is incorporated into the soil is defined in Scen2a. In the Baseline and Scen1 models, 20 percent of fertilizer is retained on the surface (top 10 mm of soil) and the remaining 80 percent was incorporated into the first soil layer. In Scen2a, the amount retained on the surface decreased to 10 percent. In Scen2b, the initial residue cover was increased from a zero base amount to 1000 kg/ha. In Scen2c, all fall tillage (October and November) was eliminated to minimize soil disruption and particle transport to stream systems.

Cereal rye was selected as a winter cover crop (Scen2d) and was only planted after each corn harvest. Corn was typically harvested on October 20 and rye was planted on October 22. The end of the cover crop growing season was March 15 of the next calendar year and just prior to a spring planting of soybean. Thus, the five-year corn-soybean-wheat rotation (C-S-C-S-W) was modified for cover crop inclusion (cc) to (C-cc-S-C-cc-S-W) – adding a total of 2 cycles of cover crop. Further, the seven-year corn-soybean-wheat-hay rotation (C-S-W-H-H-H-H) was modified for cover crop inclusion to (C-cc-S-W-H-H-H-H) – adding one cycle of cover crop. Saleh et al. (2007) suggested rye as a winter cover crop and showed various levels of effectiveness in reducing nutrient loads based on adoption rate. As adoption rate increased from 15 to 100 percent of eligible drainage units (e.g., subwatershed HRUs representing landowner practices), the rate of nutrient load in each water body also decreased.

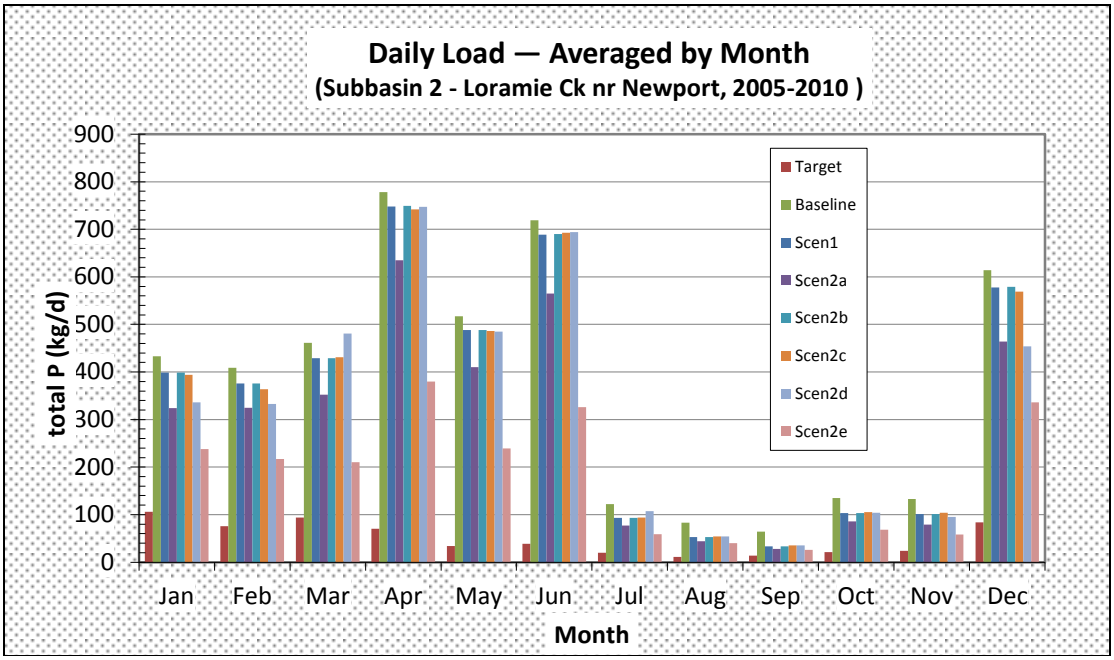
Arabi et al. (2007) reviewed conservation practice implementation in SWAT and found that filter strips and residue management were effective measures at reducing total phosphorus and nitrogen loads. Filter strips, as deployed in SWAT, are vegetated areas – those of dense vegetation – situated between streams and cropland, forestland, or disturbed land (Waidler et al. 2011).

Scen2e deploys “efficient” filter strips over the entire watershed but only to agricultural HRUs. Efficient filter strips were designed to maximally retard runoff and increase incorporation of nutrients originating from cropland and other upland activities. Efficient filter strips are characterized in this modeling application (values applied in parentheses) as one that:

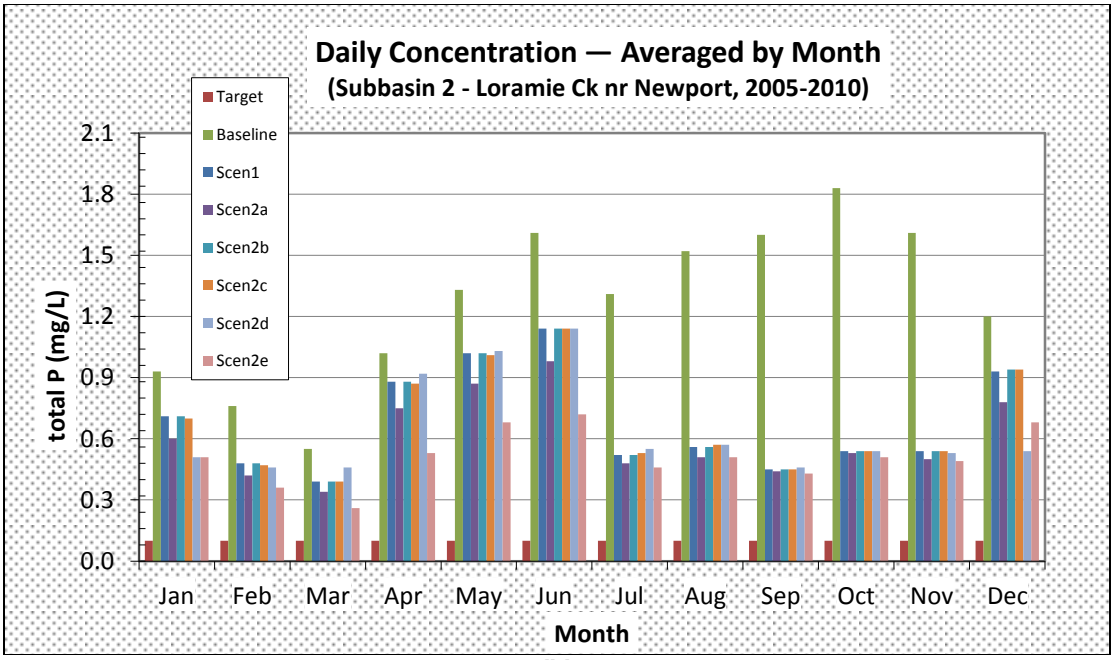
1) receives a high percentage (75 percent) of runoff from the upstream HRU into the entire length of the filter strip;
2) has a low field area to filter strip ratio (30:1 where the maximum can be ten times this ratio); and
3) has a low fraction of flow (zero percent) that is fully channelized and thus not subject to filtering or infiltration effects.

An alternative scenario Scen2e (not deployed here) could consist of a combination of efficient and inefficient filter strips; the latter system having a lower percentage of runoff entering from upstream HRUs, a higher field to strip ratio, and a higher fraction of channelized flow.

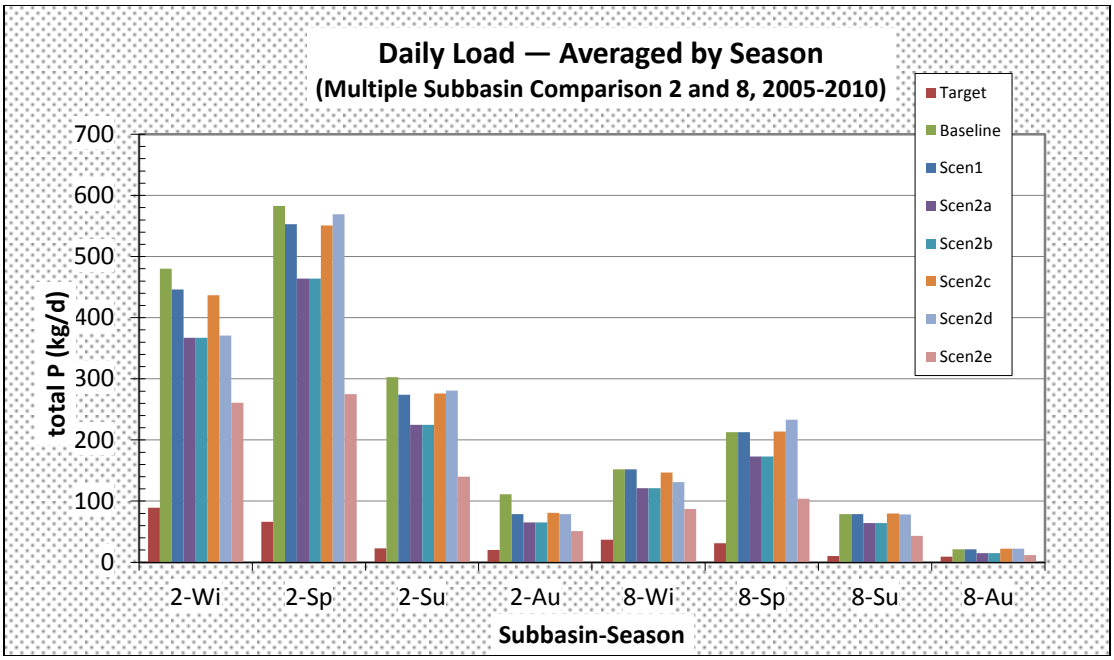
Load and concentration reductions were compared among the five sub-scenarios in Scenario 2 to determine those most effective at reducing downstream total phosphorus (Figure D-16). It should be noted that judgment here of management practice effectiveness is dependent somewhat on SWAT model characterization of a given practice and results may differ *in situ* during implementation. Three practices produced higher load reductions than the others – Scen2e (filter strip), Scen2a (manure incorporation), and Scen2d (winter cover crop), with the filter strip practice showing the most reduction in load and concentration (Figure D-16). Then, these three agricultural practices were combined into a single model run, as suggested by Smiley et.al (2011), along with Scenario 1 which considers point-source effluent reductions. The collective scenario, entitled Scen2comb, suggests significant load and concentration reductions (Figure D-17) but not enough to meet either load or concentration targets.


Daily Load — Averaged by Month
(Subbasin 2 - Loramie Ck nr Newport, 2005-2010)
total P (kg/d)
900
800
700
600
500
400
300
200
100
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Month
Target
Baseline
Scen1
Scen2a
Scen2b
Scen2c
Scen2d
Scen2e

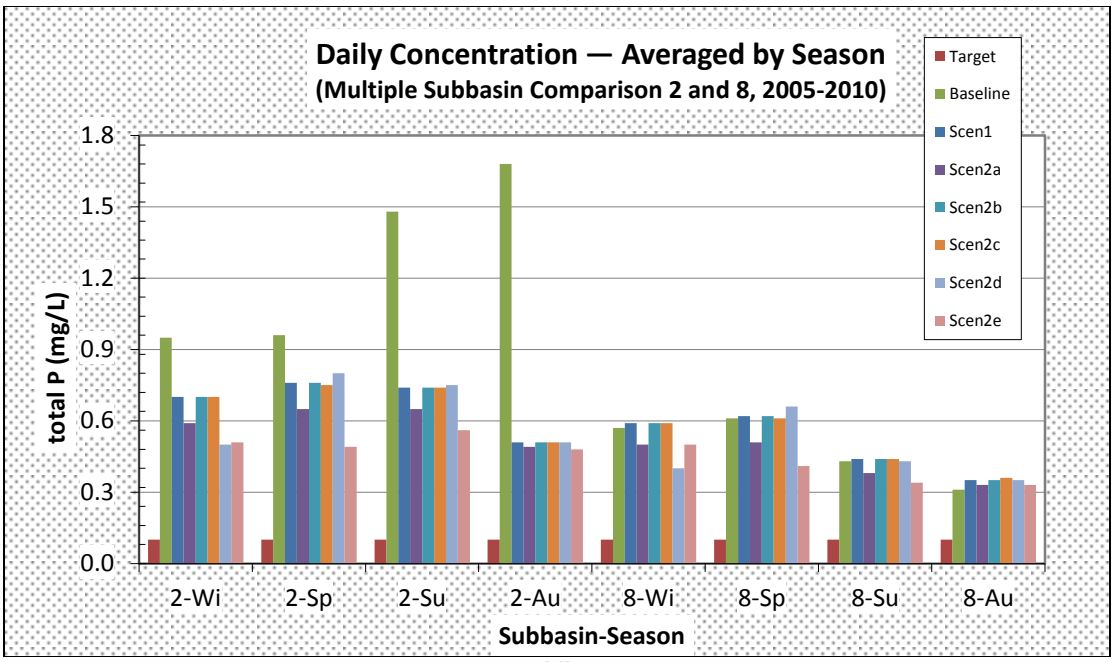
(a)


Daily Concentration — Averaged by Month
(Subbasin 2 - Loramie Ck nr Newport, 2005-2010)
total P (mg/L)
2.1
1.8
1.5
1.2
0.9
0.6
0.3
0.0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Month
Target
Baseline
Scen1
Scen2a
Scen2b
Scen2c
Scen2d
Scen2e

(b)

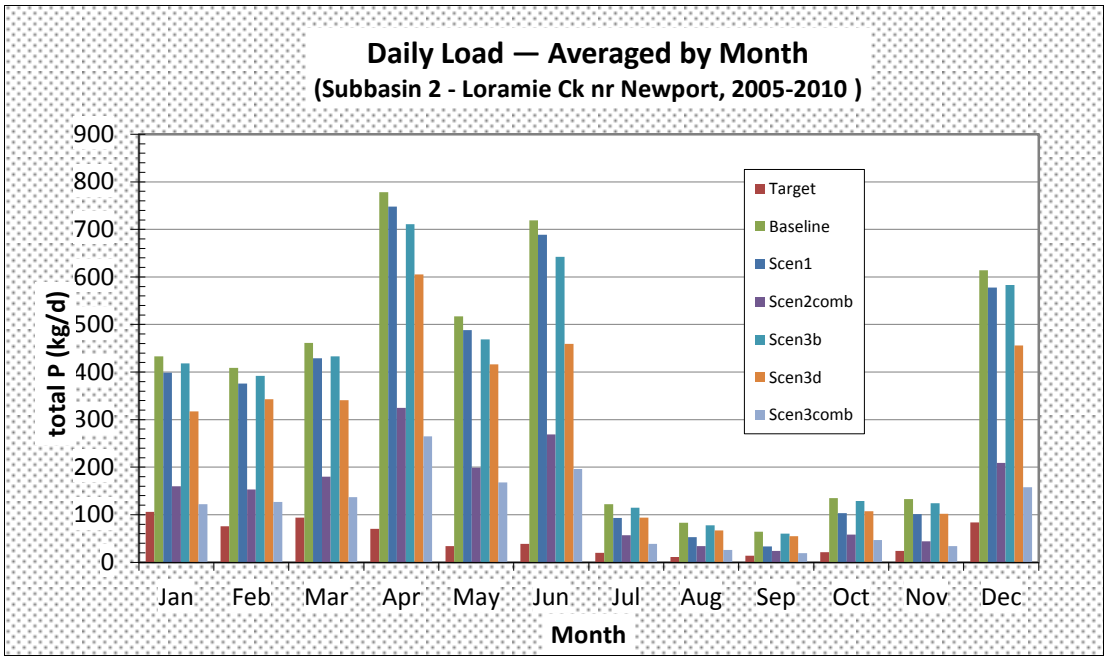


(c)

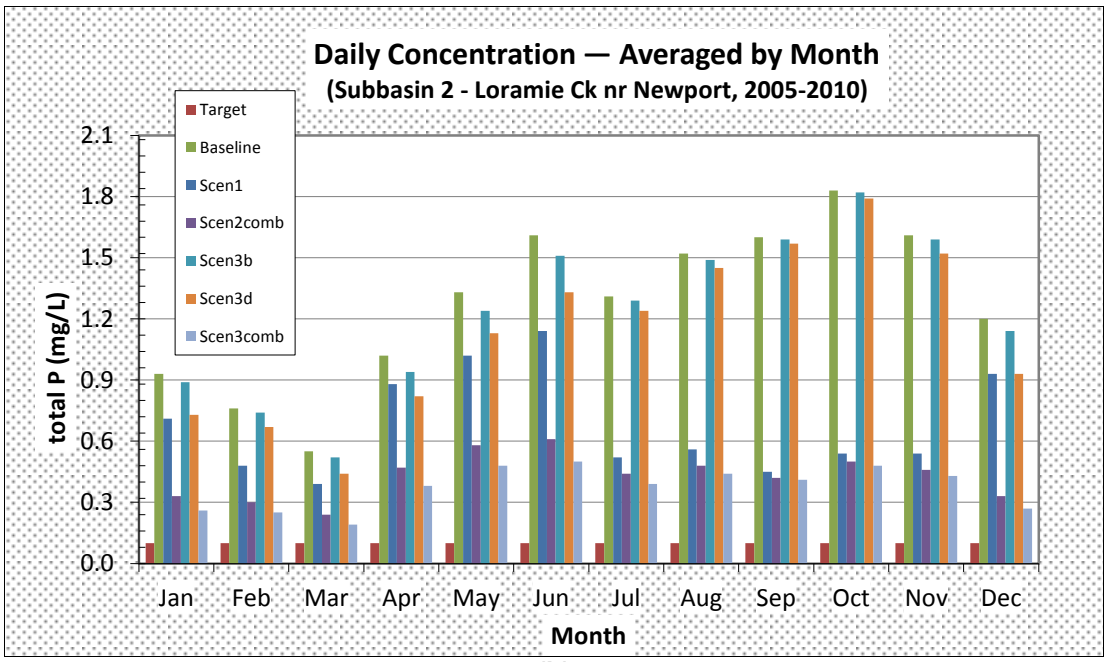


(d)

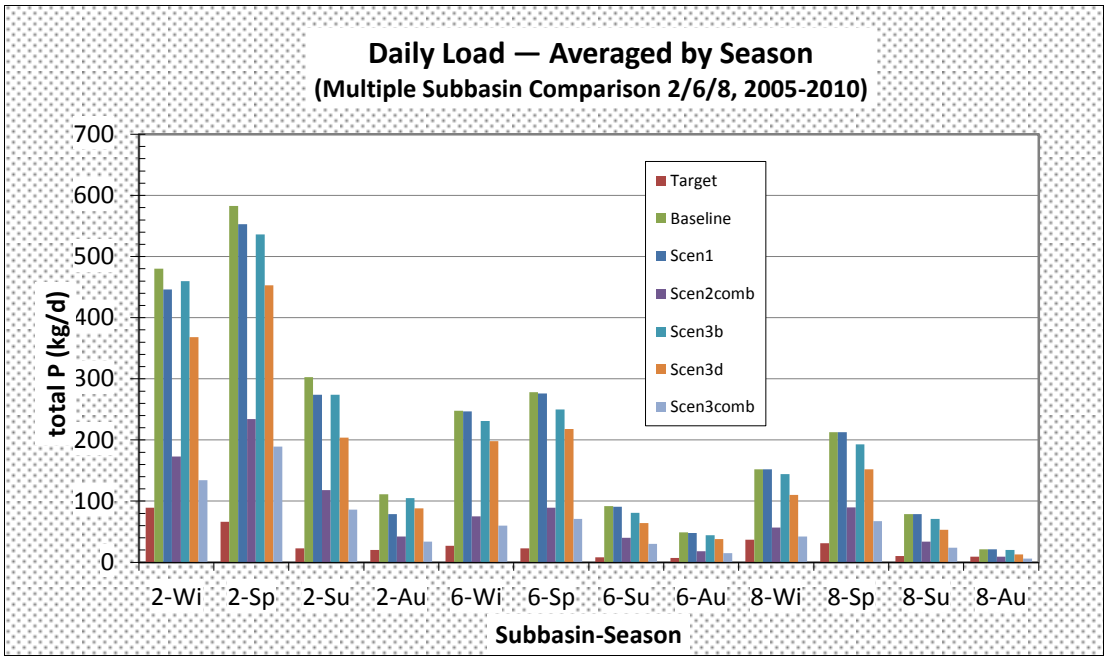
Figure D-16. For Scenario 2 subsets, comparison of in-stream total phosphorus load (kg/d) and concentration (mg/L) at selected outlet points by month (a-b) and by season (c-d).
Note: Averages computed over 6-year model run (2005-2010). Monthly results reported only for subbasin 2 whereas seasonal results reported for subbasins 2 and 8. Target load and concentration shown as a goal and referenced in Table D-4. Scenario 2 subsets are defined in text: Scen2a= manure incorporation, Scen2b= residue management, Scen2c= remove fall tillage, Scen2d= winter cover crop, and Scen2e= filter strip. Baseline model defined in Table D-18.


Daily Load — Averaged by Month
(Subbasin 2 - Loramie Ck nr Newport, 2005-2010)
total P (kg/d)
900
800
700
600
500
400
300
200
100
0
Target
Baseline
Scen1
Scen2comb
Scen3b
Scen3d
Scen3comb
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Month

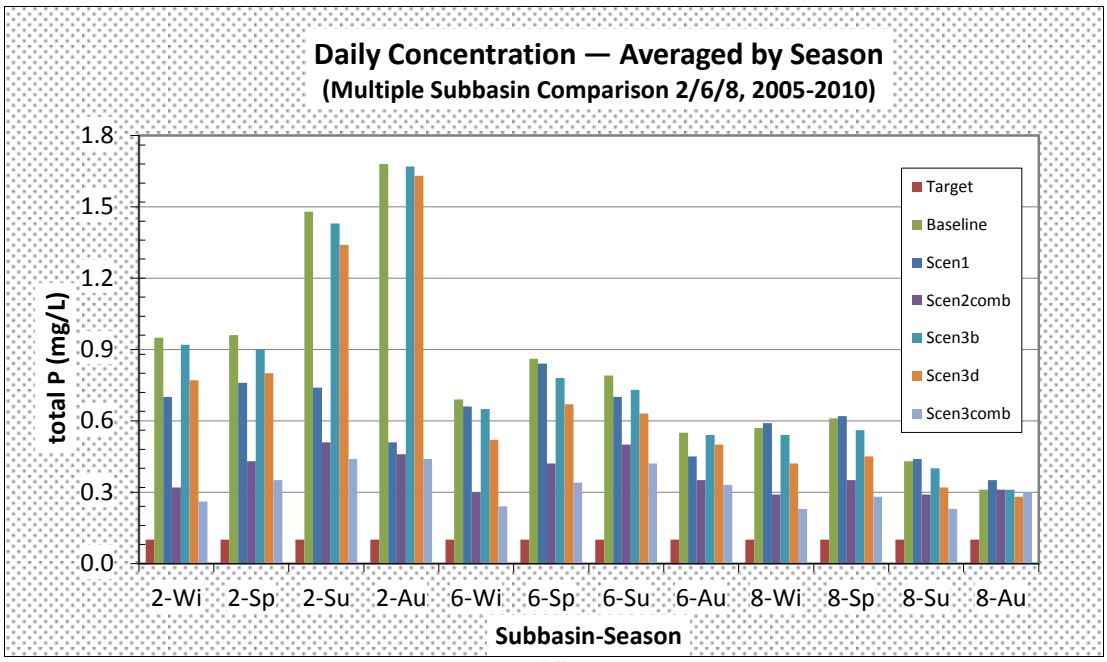
(a)


Daily Concentration — Averaged by Month
(Subbasin 2 - Loramie Ck nr Newport, 2005-2010)
total P (mg/L)
2.1
1.8
1.5
1.2
0.9
0.6
0.3
0.0
Target
Baseline
Scen1
Scen2comb
Scen3b
Scen3d
Scen3comb
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Month

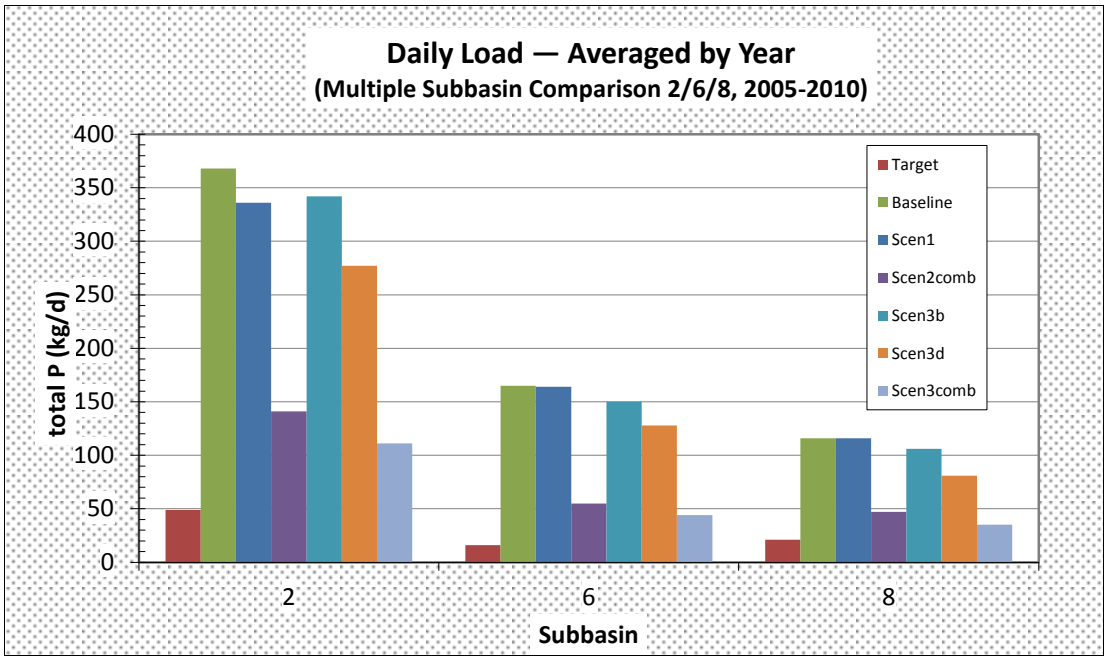
(b)


Daily Load — Averaged by Season
(Multiple Subbasin Comparison 2/6/8, 2005-2010)
total P (kg/d)
700
600
500
400
300
200
100
0
Target
Baseline
Scen1
Scen2comb
Scen3b
Scen3d
Scen3comb
2-Wi
2-Sp
2-Su
2-Au
6-Wi
6-Sp
6-Su
6-Au
8-Wi
8-Sp
8-Su
8-Au
Subbasin-Season

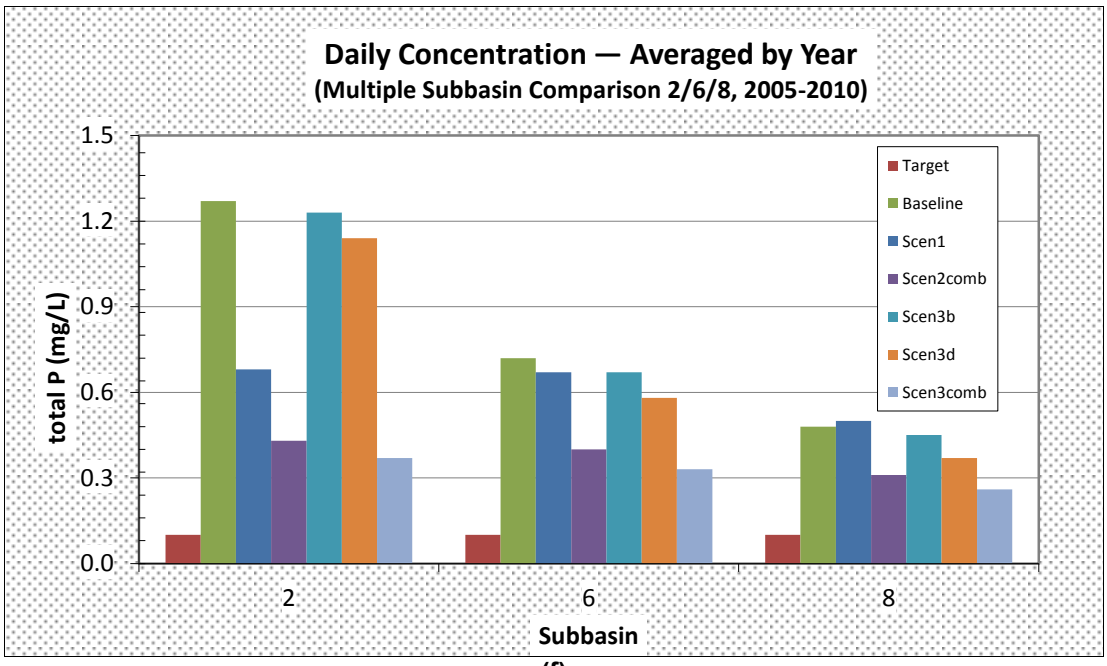
(c)


Daily Concentration — Averaged by Season
(Multiple Subbasin Comparison 2/6/8, 2005-2010)
total P (mg/L)
1.8
1.5
1.2
0.9
0.6
0.3
0.0
Target
Baseline
Scen1
Scen2comb
Scen3b
Scen3d
Scen3comb
2-Wi
2-Sp
2-Su
2-Au
6-Wi
6-Sp
6-Su
6-Au
8-Wi
8-Sp
8-Su
8-Au
Subbasin-Season

(d)



(e)



(f)

Figure D-17. Comparison of in-stream total phosphorus load (kg/d) and concentration (mg/L) at selected outlet points by month (a-b), by season (c-d), and annual (e-f).
Note: Averages computed over 6-year model run (2005-2010). Monthly results reported only for subbasin 2, seasonal and annual results reported for subbasins 2, 6, and 8. Target load and concentration shown as a goal and referenced in Table D-4. Scen2comb consists of Scen1 (point-source) reductions plus these agricultural practices: filter strips, manure incorporation, and winter cover crops. Scen3b= all winter manure moved to April 1, 90% reduction on April 1. Baseline model defined in Table D-18. Other scenarios defined in text.

D4.5.5.2 Testing of "Hard" Agricultural Management Scenarios – Fertilizer Reduction

Scenario 3 consists of a reduced fertilization scenario – the "last resort" of reducing agricultural NPS loads as it may directly affect crop yield. Any adopted reductions in fertilizer management would need to consider corresponding reductions in crop yields. Here the primary route was through elimination of winter application of manure to all fields (HRUs) in the watershed. As this SWAT model is currently calibrated and validated, future scenarios can be generated – both new styles of practices or re-distributing the existing practices to only subsets of the watershed based on innovation acceptance – with interested stakeholders (e.g., MCD, U.S. EPA, USDA, and Ohio EPA SWDO). The scenarios generated here assume 100 percent adoption in impaired watersheds. More realistic adoption rates can be decided with stakeholder meetings, such as with the Loramie Valley Alliance. As with "soft" agricultural management scenarios, the modifications are made only to the Loramie Creek watershed system.

The first approach was to move winter-time manure application to early spring. In this scenario (Scen3a, Table D-18), all HRUs with January through March application (specifically January 30 and March 1 in this model) were moved to April 1 application. Further, the same rate was applied (5000 kg/ha) so total manure applied per crop year did not change. Surprisingly, in Scen3a there was no change in load or concentration from the Baseline model (results not shown). Subsequently, a new scenario (Scen3b) was generated to reduce the rate of the April 1 manure application by 90 percent (from 5000 to 500 kg/ha). But similarly to Scen3a, Scen3b resulted in only minor load reductions – an average of 26 kg/d – though the largest reductions occurred in April through June (Figure D-17). As a solution strategy in this model application, transferring or eliminating winter-time manure application produced little total phosphorus load or concentration reduction. Scen3c was generated to produce a 50 percent reduction in manure application rate for the entire crop year but still only nominal reductions in load and concentration occurred and is insufficient to meet the TMDL target (results not shown). Still further, Scen3d was generated to include those fertilizer reductions defined in Scen3c plus additional reductions for phosphorus-based synthetic fertilizer. Namely, application rates for 10-34-00, 18-46-00, and 00-46-00 were reduced by 50 percent over the entire year. Scen3d achieved the highest reduction amounts amongst the Scenario 3 subsets (Scen3a through Scen3d) but still failed to achieve the TMDL load target alone (Figure D-17).

Given the experimental results found in the Scenario 2 and Scenario 3 subsets, the proposed overall scenario combination (Scen3comb) includes all modifications in Scen2comb plus Scen3d (Table D-18 and Figure D-17). While the load or concentration target is approached but not met, the scenario analysis shown in this section suggests a combination of approaches to reducing the source load and following the TMDL goal. It would be unfair to judge this scenario combination as inadequate to meet the TMDL goal because issues of scale – both spatial and temporal averaging – confound the direct interpretation of meeting an exact load or concentration goal. Also, any further reductions in fertilizer application rate – below the maximal 50 percent used in this investigation – would be prohibitive as they would likely reduce crop yields below economically viable quotas.

D5 Habitat and Sediment Bedload Analysis Method

D5.1 Background and Description

Habitat alteration is a significant cause of impairment throughout the upper GMR watershed. Poor habitat quality is an environmental condition, rather than a pollutant load, so development of a load-based TMDL for habitat is not possible. Nonetheless, habitat is an integral part of stream ecosystems and has a significant impact on aquatic community assemblage and consequently on the potential for a stream to meet the biocriteria within Ohio's water quality. In addition, U.S. EPA acknowledges that pollutants, conditions or other environmental stressors can be subject to the development of a TMDL to abate those stressors in order to meet water quality standards. Thus, sufficient justification for developing habitat TMDLs is established.

The Qualitative Habitat Evaluation Index (QHEI) was developed by the Ohio EPA (Ohio EPA 1989 with one of the objectives being to create a means for distinguishing impacts to the aquatic community from pollutant loading versus poor stream habitat. The design of the QHEI in conjunction with its statistically strong correlation to the biocriteria makes it an appropriate tool for developing habitat TMDLs.

The QHEI assigns a numeric value to an individual stream segment (typically 150-200 m in length) based on the quality of its habitat. The actual number values of the QHEI scores do not represent the quantity of any physical properties of the system but provide a means for comparing the relative quality of stream habitat. However, even though the numeric value is derived qualitatively, subjectivity is minimized because scores are based on the presence and absence and relative abundance of unambiguous habitat features. Reduced subjectivity was an important consideration in developing the QHEI and has since been evidenced through minimal variation between scores from various trained investigators at a given site as well as consistency with repeated evaluations (Ohio EPA 1989).

The QHEI evaluates six general aspects of physical habitat that include channel substrate, in-stream cover, riparian characteristics, channel condition, pool/riffle quality, and gradient. Within each of these categories or sub-metrics, points are assigned based on the ecological utility of specific stream features as well as their relative abundance in the system. Demerits (i.e., negative points) are also assigned if certain features or conditions are present which reduce the overall utility of the habitat (e.g., heavy siltation and embedded substrate). These points are summed within each of the six sub-metrics to give a score for that particular aspect of stream habitat. The overall QHEI score is the sum of all of the sub-metric scores.

D5.2 Habitat TMDL Targets

Since its development the QHEI has been used to evaluate habitat at most biological sampling sites and currently there is an extensive database that includes QHEI scores and other water quality variables. Strong correlations exist between QHEI scores and some its component sub-metrics and the biological indices used in Ohio's water quality standards such as the Index of Biotic Integrity (IBI). Through statistical analyses of data for the QHEI and the biological indices, target values have been established for QHEI scores with respect to the various aquatic life use designations (Ohio EPA 1999). For the aquatic life use designation of warmwater habitat (WWH) an overall QHEI score of 60 is targeted to provide reasonable certainty that habitat is not deficient to the point of precluding attainment of the biocriteria (Table D-20). An overall

score of 75 is targeted for streams designated as exceptional warmwater habitat (EWH) and a minimum score of 45 is targeted for modified warmwater habitat (MWH) streams.

One of the strongest correlations found through these statistical analyses described above is the negative relationship between the number of "modified attributes" and the IBI scores (Table D-19). Modified attributes are features or conditions that have low value in terms of habitat quality and therefore are assigned relatively fewer points or negative points in the QHEI scoring. A sub-group of the modified attributes shows a stronger impact on biological performance; these are termed "high influence modified attributes" (Table D-19).

Table D-19. Itemization of "Modified Attributes" for computing the habitat TMDL.

High Influence	Moderate Influence	
• Recent Channelization or No Recovery • Silt or Muck Substrate • Low or No Sinuosity and Drainage Area ≤ 20 sq.mi • Sparse or Nearly Absent Cover • < 40 cm Max. Pool Depth (wadeable or headwater sites)	• Recovering Channelization • Silt Heavy or Silt Moderate • Sand Substrate (boat sites) • Hardpan Substrate Origin • Fair or Poor Development • Low or No Sinuosity and Drainage Area > 20 sq.mi • Two or Less Cover Types	• Intermittent Pools and Max. Pool Depth < 40 cm • No Fast Current Velocity • Extensive or Moderate Substrate Embeddedness • Extensive or Moderate Riffle Embeddedness • No Riffle

In addition to the overall QHEI scores, targets for the maximum number of modified and high influence modified attributes have been developed. For streams designated as WWH, there should no more than 4 modified attributes of which no more than 1 should be a high influence modified attribute (Table D-19). For simplicity, a pass/fail distinction is made telling whether each of the three targets are being met. Targets are set for: 1) the total QHEI score, 2) maximum number of all modified attributes, and 3) maximum number of high influence modified attributes only. If the minimum target is satisfied, then that category is assigned a "1", if not, it is assigned a "0". To satisfy the habitat TMDL, the stream segment in question should achieve a score of three (Table D-20).

Table D-20. QHEI-based targets for the sediment and habitat TMDL.

Bedload TMDL Targets		
QHEI Category	*Target*	
	WWH	*EWH*
Substrate	≥ 13	≥ 15
Channel	≥ 14	≥ 15
Riparian	≥ 5	≥ 5
Bedload TMDL ►	≥ 32	≥ 35

Habitat TMDL Targets			
QHEI Category	*Target*		*Score*
	WWH	*EWH*	
QHEI Score	≥ 60	≥ 75	+ 1
High Influence #	≤ 1	0	+ 1
Total # Modified	≤ 4	≤ 2	+ 1
Habitat TMDL ►			+ 3

D5.3 Sediment TMDL Targets

The QHEI is also used in developing the sediment TMDL for this project. Numeric targets for sediment are based upon sub-metrics of the QHEI. Although the QHEI evaluates the overall quality of stream habitat, some of its component sub-metrics consider particular aspects of stream habitat that are closely related to and/or impacted by the sediment delivery and transport processes occurring in the system.

The QHEI sub-metrics used in the sediment TMDL are the substrate, channel morphology, and bank erosion and riparian zone. Table D-20 lists targets for each of these metrics for both WWH and EWH aquatic life use designations.

- The substrate sub-metric evaluates the dominant substrate materials (i.e., based on texture size and origin) and the functionality of coarser substrate materials in light of the amount of silt cover and degree of embeddedness. This is a qualitative evaluation of the amount of excess fine material in the system and the degree to which the channel has assimilated (i.e., sorts) the sediment loading.
- The channel morphology sub-metric considers sinuosity, riffle, and pool development, channelization, and channel stability. Except for stability each of these aspects are directly related to channel form and consequently how sediment is transported, eroded, and deposited within the channel itself (i.e., this is related to both the system's assimilative capacity and loading rate). Stability reflects the degree of channel erosion which indicates the potential of the stream as being a significant source for the sediment loading.
- The bank erosion and riparian zone sub-metric also reflects the likely degree of in-stream sediment sources. The evaluation of floodplain quality is included in this sub-metric which is related to the capacity of the system to assimilate sediment loads.

The rationale for using the QHEI for development of the sediment TMDL is largely due to the fact that other measures and/or methods of evaluating sediment loading are problematic and have limited reliability. For example, the measurement of total suspended solids (TSS) is commonly used as a loading parameter; however, gathering data that is reliable for calibration and validation is often uncertain. This uncertainty rests in the fact that TSS demonstrates a high degree of variability both over space and time and is also very sensitive to local disturbances. Additionally, models that adequately account for in-stream sediment dynamics (e.g., erosion and deposition processes) are lacking or require very high resource expenditures (e.g., much data collection) that often are not feasible.

Finally, the QHEI has a strong relationship with the biocriteria in Ohio's water quality standards, whereas TSS has a relatively weak correlation with biological performance, which is probably related to the variability and unreliability of TSS measures. The QHEI represents the end result of high sediment loading (either from the landscape of in-stream sources) as it impacts the biological community.

D5.4 TMDL Results

D5.4.1 Critical Conditions and Seasonality

The critical condition for the habitat and bedload TMDLs is the summer when environmental stress, such as increased water temperature, decreased flow, and increased pollutant

concentrations, upon aquatic organisms is greatest. It is during this period that the presence of high quality habitat features, such as deep pools and un-embedded substrate, is essential to provide refuge for aquatic life. QHEI scores, the basis of the habitat TMDLs, are assessed during the summer field season. The habitat and bedload TMDLs are therefore reflective of the critical condition.

Habitat is generally a quasi-static condition of a stream. Exceptions include major modifications made by humans (or some animals like beavers) or changes in the hydrology or sediment loading of the watershed, which is typically a human-made situation. Because habitat is relatively static, seasonality has little meaning. Specifically, absent a major disturbance, habitat quality does not change across the seasons but rather over much longer timescales (years to decades). Finally, there is no seasonal "loading" associated with habitat but instead habitat evolves through changes in morphology and riparian vegetation. However, in terms of sediment, seasonality does have meaning. For example, agricultural areas yield the highest loads when fields have minimal vegetative cover and runoff events occur. This corresponds to the spring pre-plant season. In-stream sources of sediment from bed or bank erosion are also seasonally loaded when flows are highest and banks are saturated. When stream banks are saturated, they are more susceptible to erosion through slip failure. As with upland loads, spring is an important time for this but also in mid to late fall.

D5.4.2 Margin of Safety

A margin of safety (MOS) was implicitly incorporated into the habitat and sediment TMDLs through the use of conservative target values. The target values were developed though comparison of paired IBI and QHEI evaluations. Using an IBI score of 40 as representative of the attainment of WWH, individual components of the QHEI were analyzed to determine their magnitude at which WWH attainment is probable (Ohio EPA 1999). Attainment does, however, occur at levels lower than the established targets. The difference between the habitat and sediment targets and the levels at which attainment actually occurs is an implicit MOS.

D5.4.3 Allocation for Sediment and Stream Habitat

Table D-21 and Table D-22 reflect a quantification of sediment-induced and habitat-induced cause of impairment, respectively. Sediment and habitat TMDL targets for both the WWH and EWH ALU designation are restated at the bottom of these tables.

Two sub-ecoregions – Clayey High Lime Till Plains and Loamy High Lime Till Plains – exist in the upper GMR watershed (Figure D-18). It is apparent that all habitat-related impairment occurs in the clay-dominated sub-ecoregion. In quantifying the sediment and habitat TMDLs for the upper GMR watershed, only sites with either ALU partial or non-attainment were considered. Sites having full attainment were excluded and hence do not appear in Table D-21 and Table D-22. Further, of these sites, only those with causes identified as siltation/sedimentation and/or habitat alteration were considered for a sediment TMDL (Table D-21). Correspondingly, only those sites with habitat alteration, sedimentation/siltation, turbidity, and/or flow alteration (non-natural) were considered for a habitat TMDL (Table D-22). These causes were assigned by site in Table 4 in the 2011 Technical Support Document (Ohio EPA 2011).

Most impaired sites fail the sediment target of 32 (WWH) and 35 (EWH) in the study area, though a few sites do meet the criterion (Table D-21). Some of the most severe failures, as indicated by the percent deviation from the target, include both sites in the Willow Creek (02 01) nested subwatershed, plus one site each in the Rennick Creek (03 02), Rum Creek (03 03), and

Brandywine Creek (03 06) nested subwatersheds. Notably, all sites fail the sediment criterion within the Headwaters Loramie Creek (05 01) nested subwatershed. The most frequent impairment category is the riparian metric (11 sites) followed by the channel metric (7 sites) (Table D-21).

As described earlier, the habitat TMDL considers the final QHEI score and the frequency of modified attributes for a given site. One site within the Rennick Creek (03 02) nested subwatershed meets the habitat criterion (of 3) but for the most part, many sites (14 out of 21 total) fail the criterion severely (total habitat score = 0) (Table D-22). A total habitat score of zero represents low overall QHEI and too many high and moderate influence modified attributes.

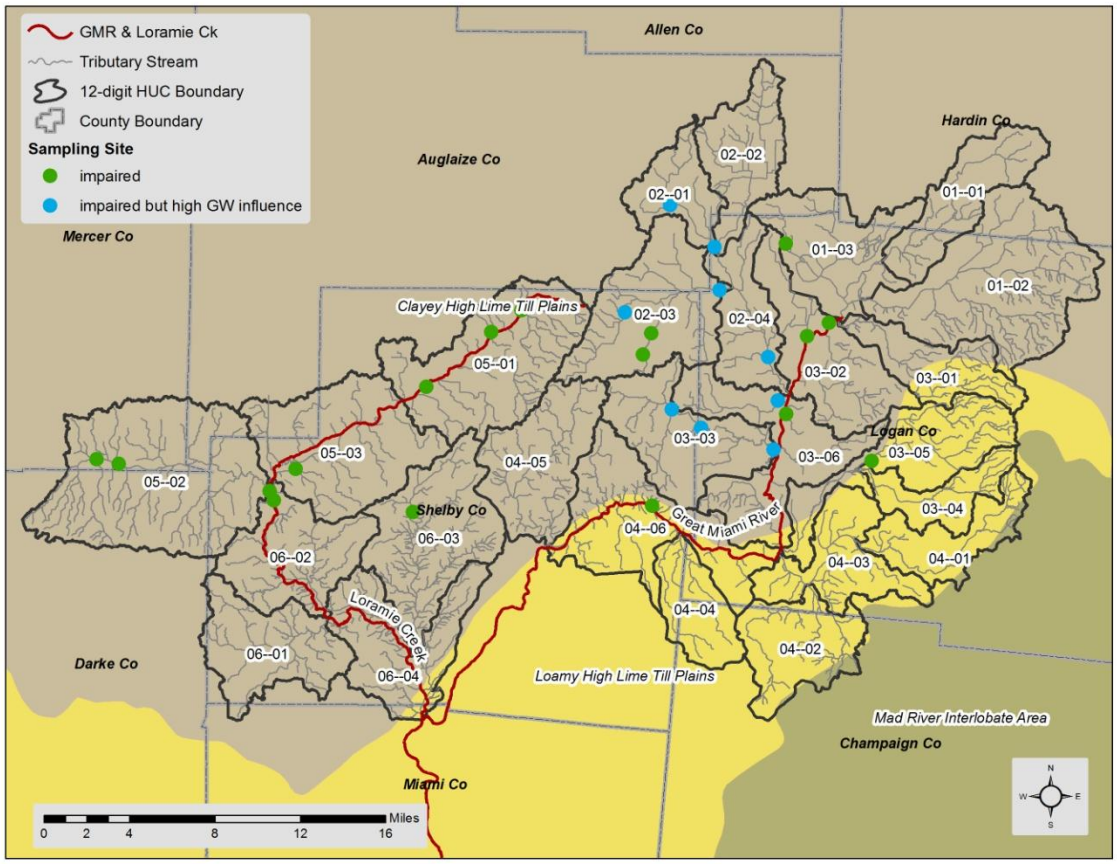


Figure D-18. Level-4 ecoregions (called subregions) in the upper GMR TMDL study area.
Note: Also shown are nested subwatershed boundaries and biological sampling sites impaired with the following causes: habitat alteration, sedimentation or siltation, flow alteration (non-natural cause) and turbidity. Sampling sites that are impaired but influenced by high ground water discharges (suggested by field notes) are also indicated.

Table D-21. The sediment TMDL using QHEI metrics for sites with impairment due to sedimentation/siltation and/or habitat alteration in the upper GMR TMDL study area.
Note: ALU designation in parentheses; if a second designation is listed the first entry is proposed. Und = previously undesignated ALU designation. Grouped by nested subwatershed; all sites are located within the 8-digit hydrologic unit 05080001. NA = not applicable as no target exists for MWH ALU designation. UNT = un-named tributary with mainstem river mile at confluence in parenthesis.

Stream/River	River Mile	QHEI Categories			Total Sediment Score	Deviation from target (%)	Main impairment category
		Subs-trate	Chan-nel	Ripa-rian			
01 03 Indian Lake – Great Miami River							
Van Horn Ck (WWH)	1.0	20	9.5	3	32.5	meets	riparian
02 01 Willow Creek							
Willow Ck (WWH)	3.7	5.5	5.5	1.5	12.5	60.9	riparian
Willow Ck (WWH)	0.5	14	4.5	1.5	20	37.5	riparian
02 03 Little Muchinippi Creek							
Jackson Center Ck (MWH-C, WWH)	2.9	2.5	6.5	2.5	11.5	NA	NA
Jackson Center Ck (MWH-C, WWH)	1.8	3	6	1.5	10.5	NA	NA
L Muchinippi Ck (WWH)	6.1	20	6	2	28	12.5	riparian
L Muchinippi Ck (WWH)	0.7	20	7.5	1.5	29	9.4	riparian
02 04 Muchinippi Creek							
Muchinippi Ck (WWH)	2.4	15	4.5	7.5	27	15.6	channel
03 02 Rennick Creek – Great Miami River							
Great Miami R (WWH)	158.9	20	16	3	39	meets	riparian
Rennick Ck (WWH, Und)	0.3	4.5	10	2.5	17	46.9	substrate
UNT Great Miami R (RM 157.34) (MWH-C, Und)	0.1	4	4	2	10	NA	NA
03 03 Rum Creek							
Rum Ck (WWH)	8.6	6	5.5	1.5	13	59.4	riparian
Rum Ck (WWH)	6.6	20	7	8.5	35.5	meets	channel
Rum Ck (WWH)	0.8	20	13	8	41	meets	channel
03 05 Bokengehalas Creek							
Bokengehalas Ck (WWH)	8.0	20	8	10	38	meets	channel
03 06 Brandywine Creek – Great Miami River							
Brandywine Ck (WWH)	0.6	6.5	8	5	19.5	39.1	substrate
Great Miami R (WWH)	153.5	15.5	8	7.5	31	3.1	channel
04 06 Turkeyfoot Creek – Great Miami River							
Great Miami R (EWH)	138.4	8	12	10	30	14.3	substrate
05 01 Headwaters Loramie Creek							
Loramie Ck (WWH)	36.9	13	7	2	22	31.3	riparian
Loramie Ck (WWH)	35	13	9	3	25	21.9	riparian
Loramie Ck (WWH)	30.4	15.5	6	1.5	23	28.1	riparian
05 02 Mile Ck							
Mile Ck (MWH-C, WWH)	9.8	20	5	2	27	NA	NA
Mile Ck (MWH-C, WWH)	8.8	13	5	2	20	NA	NA
06 02 Painter Creek – Loramie Creek							
Loramie Ck (WWH)	19.3	20	8	10	38	meets	channel
Loramie Ck (WWH)	18.9	14.5	5	7.5	27	15.6	channel
06 03 Turtle Creek							
Turtle Ck (WWH)	8.5	20	11.5	2	33.5	meets	riparian
Target (WWH)		**≥ 13**	**≥ 14**	**≥ 5**	**≥ 32**		
Target (EWH)		**≥ 15**	**≥ 15**	**≥ 5**	**≥ 35**		

Table D-22. The habitat TMDL using QHEI metrics for sites with impairment due to habitat alteration, sedimentation/siltation, turbidity, and/or flow alteration (non-natural) in the GMR (upper) TMDL study area.

Note: ALU designation in parentheses; if a second designation is listed the first entry is proposed. Und = previously undesignated ALU designation. Grouped by nested subwatershed; all sites are located within the 8-digit hydrologic unit 05080001. NA = not applicable as no target exists for MWH ALU designation. UNT = un-named tributary with mainstem river mile at confluence in parenthesis.

Stream/River	River Mile	QHEI Score	# of High Influence Attributes	Total # of Modified Attributes	Subscore			Total Habitat Score
					QHEI	High Influence	Modified	
01 03 Indian Lake – Great Miami River								
Van Horn Ck (WWH)	1.0	62.5	2	7	1	0	0	1
02 01 Willow Creek								
Willow Ck (WWH)	3.7	44	3	8	0	0	0	0
Willow Ck (WWH)	0.5	29.5	3	9	0	0	0	0
02 03 Little Muchinippi Creek								
Jackson Center Ck (MWH-C, WWH)	2.9	28.5	4	10	NA	NA	NA	NA
Jackson Center Ck (MWH-C, WWH)	1.8	25.5	4	10	NA	NA	NA	NA
L Muchinippi Ck (WWH)	6.1	47	3	8	0	0	0	0
L Muchinippi Ck (WWH)	0.7	60.5	1	7	1	1	0	2
02 04 Muchinippi Creek								
Muchinippi Ck (WWH)	2.4	55	2	8	0	0	0	0
03 02 Rennick Creek – Great Miami River								
Great Miami R (WWH)	158.9	77	0	3	1	1	1	3
Rennick Ck (WWH, Und)	0.3	43	3	10	0	0	0	0
UNT Great Miami R (RM 157.34) (MWH-C, Und)	0.1	21	4	10	NA	NA	NA	NA
03 03 Rum Creek								
Rum Ck (WWH)	8.6	24	3	9	0	0	0	0
Rum Ck (WWH)	6.6	52	3	11	0	0	0	0
Rum Ck (WWH)	0.8	68	0	5	1	1	0	2
03 05 Bokengehalas Creek								
Bokengehalas Ck (WWH)	8.0	79	1	7	1	1	0	2
03 06 Brandywine Creek – Great Miami River								
Brandywine Ck (WWH)	0.6	43	3	8	0	0	0	0
Great Miami R (WWH)	153.5	53	3	10	0	0	0	0
04 06 Turkeyfoot Creek – Great Miami River								
Great Miami R (EWH)	138.4	68.5	1	8	0	0	0	0
05 01 Headwaters Loramie Creek								
Loramie Ck (WWH)	36.9	47	2	8	0	0	0	0
Loramie Ck (WWH)	35	54	2	8	0	0	0	0
Loramie Ck (WWH)	30.4	46	3	10	0	0	0	0
05 02 Mile Ck								
Mile Ck (MWH-C, WWH)	9.8	39	4	10	NA	NA	NA	NA
Mile Ck (MWH-C, WWH)	8.8	34	5	10	NA	NA	NA	NA
06 02 Painter Creek – Loramie Creek								
Loramie Ck (WWH)	19.3	61	2	9	1	0	0	1
Loramie Ck (WWH)	18.9	43	3	10	0	0	0	0

Stream/River	River Mile	QHEI Score	# of High Influence Attributes	Total # of Modified Attributes	Subscore			Total Habitat Score
					QHEI	High Influence	Modified	
06 03 Turtle Creek								
Turtle Ck (WWH)	8.5	60.5	1	5	1	1	0	2
Target (WWH)		**≥ 60 = 1 pt**	**< 2 = 1 pt**	**< 5 = 1 pt**				**3 pts**
Target (EWH)		**≥ 75 = 1 pt**	**0 = 1 pt**	**< 3 = 1 pt**				**3 pts**

D5.4.4 Directions for Implementation based on QHEI Analysis

As mentioned above, the most frequent impairment category for the sediment TMDL is the riparian metric (11 occurrences). Streams designated with these failing metrics exist mainly in northeastern Shelby County, western Logan County, and southeaster Auglaize County (Figure D-18). Ditch maintenance practices and corresponding soil characteristics should be examined further in designing the best restoration strategy with the possible inclusion of two-stage (or self-forming channel) designs. For the habitat TMDL, the sites that fail miserably (i.e., habitat score of 0 or 1) are tributaries to the GMR in Logan County. Others include headwater portions of the Loramie Creek watershed in northeastern Shelby County. All of these failures to attain do so because they fail on all three dimensions of the summative index – total QHEI score, and large numbers of high and moderate influence attributes. Further exploration of system recoverability should be undertaken to determine likely restorability of these stream systems.

D6 *Escherichia coli* Load Duration Curve Analysis Method

D6.1 Background and Justification

Within the upper GMR watershed, numerous stream segments are impaired for recreation use due to elevated bacteria loadings. Targets to attain recreation use are promulgated water quality standards for the geometric mean of *Escherichia coli* (herein *E. coli*) bacteria (OAC 3745-1-07).

The proportion of pathogenic organisms present in assessed waters is generally small compared to non-pathogenic organisms. For this reason most pathogenic organisms are difficult to isolate and identify. Additionally, pathogenic organisms are highly varied in their characteristics and type, which also makes them difficult to measure. Non-pathogenic bacteria that are associated with pathogens transmitted by fecal contamination are more abundant and are, therefore, monitored as surrogates because of the greater ease in sampling and measuring. These bacteria, with *E. coli* being one species, are called indicator organisms.

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. The mainstem of the upper GMR throughout all of this study area is designated a Class A stream. The mainstem of Loramie Creek from the mouth to RM 30.42 is also

designated Class A PCR. All other streams assessed in this watershed are Class B PCR. Class B streams support infrequent primary contact recreation activities. For Class A 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 126 colony-forming units (cfu) per 100 mL. For Class B streams, the geometric mean of the *E. coli* sample shall not exceed 161 cfu per 100 mL.

In certain locations, a more restrictive downstream recreation use could be protected. For this TMDL, a NPDES facility that discharges to a Class B PCR stream would receive Class A standard if it is within five river miles and upstream from a Class A PCR stream.

A TMDL is generated for nested subwatersheds that drain to an assessment site found not to meet the recreation use criterion described above.

D6.2 Methods to Assess Incoming Loads and Load Reductions

Load duration curves (LDCs) using recent *E. coli* monitoring data and continuous stream flow are employed to determine TMDL loads and reductions.

To compute the required TMDL load, a flow duration curve (FDC) is generated for each impaired location with a corresponding paired grab-flow record (called a LDC assessment site). A FDC is constructed by calculating the flow (volumetric flow rate in units of cfs) expected for the full range of exceedence percentiles. The exceedence percentile is the probability that a given flow magnitude can be exceeded. This normalizes the flows to a range of natural occurrences from extremely high flows (exceedence percentile equal to 0.0) to extremely low flows (that equal to 1.0). To conform to the recreation season boundary, only flows measured between May 1 and October 31 were considered in the construction of the FDC and LDC. The FDC is converted into a LDC by taking the product of the flow magnitude (volume per time) and the *E. coli* geometric mean standard (counts per volume) for a given PCR stream class. The TMDL is this product (counts per time): the number of *E. coli* colony-forming units (CFUs or counts) per day.

The observed loads are plotted against a LDC (i.e., the TMDL) to determine the degree of exceedence or non-exceedence. Observed loads that plot above the LDC represent deviations from the water quality standard and the daily allowable load. Observed loads that fall below the LDC represent samples in compliance with standards and the daily allowable load.

Flow “regimes” are determined on the LDC for the purpose of allocating load by a finite set of classes rather than a nearly infinite number of possible loads (Figure D-19). Flow regimes are defined as:

1) Higher Flows: 0 – 5% exceedence probability
2) Wet Weather: 5 – 40% exceedence probability
3) Normal Range: 40 – 80% exceedence probability
4) Dry Weather: 80 – 95% exceedence probability
5) Low Flows: 95 – 100% exceedence probability

Flows measured during bacteria sampling events were compiled by “regime” type to determine if the sampling season was representative of flow variability (Table D-23). Most flows occur in the normal range while the dry weather and low flow regimes also contain a large number of sampling events.

Observed loads are noted with an open diamond symbol. An *E. coli* monitoring grab made when runoff flow was above 50 percent of the total flow is specially marked with a red diamond core. This flow condition is determined using the sliding-interval method for streamflow hydrograph separation contained in the USGS HYSEP program (USGS 1996). Additionally, any observations made during May or June, which are typically the high flow months of the recreation season, are marked with a "+" to separate them from mid- to late-summer observations.

Ideally, FDCs are best generated from continuous gage information and for the upper GMR study area these gages are maintained and operated by Miami Conservancy District in cooperation with the USGS-Ohio Water Science Center. There are four LDCs generated directly from site-specific gage information (highlighted in gray in Table D-26). Flows for the remaining LDC assessments (where no USGS gage is present) are generated by drainage area-weighting the flow from a representative USGS gage (its index gage). The assignments of index gages, their justification, and weights for non-gage LDCs are shown in Table D-26.

At the LDC assessment sites[1], every *E. coli* grab sample had an associated flow measured for that event; this represents an instantaneous rather than an average daily flow. The flow was either measured directly (*in situ*) or estimated from a rating curve of flows and water surface elevation (stage) for that site.

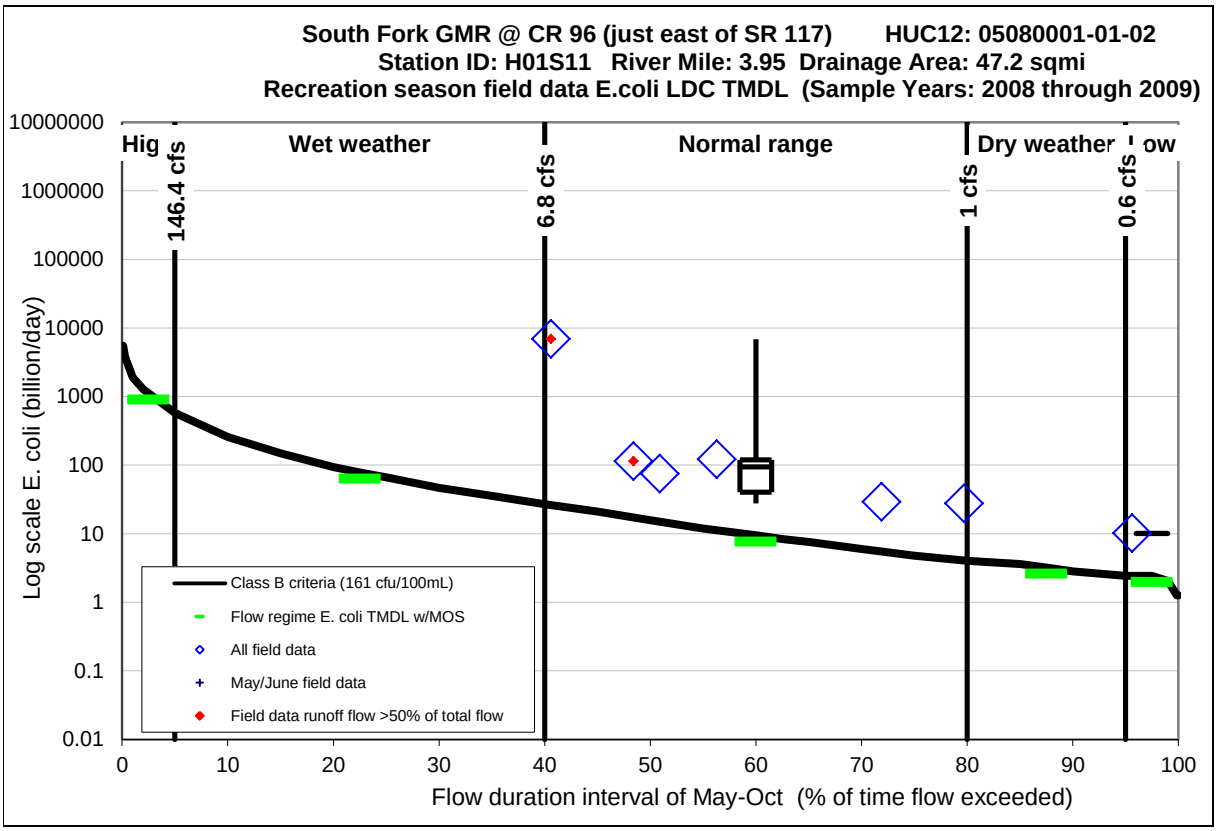


Figure D-19. Flow duration curve computed for South Fork of the GMR over the flow period of 1995-2009.

[1] The exception from Table D-26 is Loramie Creek at Hardin-Wapakoneta Rd (05080001 05 01). This site has no associated paired grab-flow measurements but a separate LDC assessment is warranted because NPDES facilities exist upstream and the next downstream, flow-based assessment site is also downstream of Lake Loramie reservoir.

Table D-23. Frequency of samples associated with LDC flow regime for the 2008 and 2009 *E. coli* sampling record. All nested subwatershed references exist in 8-digit hydrologic unit 05080001.

LDC Assessment Site (Nested Subwatershed)	Flow Range				
	High Flow	Wet Weather	Normal Range	Dry Weather	Low
South Fork GMR (01 02)	--	--	6	--	1
North Fork GMR (01 01)	--	--	4	2	1
Muchinippi Ck CR60 (02 04)	--	--	3	1	2
Mile Ck SR 705 (05 02)	--	--	2	3	1
Loramie Creek–Fessler (06 02)	--	--	3	4	2
Loramie Creek–Cardo (06 04)	--	1	7	1	--
Loramie Creek–H-W (05 01)	--	--	2	2	1
GMR SR235 (03 02)	--	--	1	2	3
GMR SR47 (07 03)	--	1	5	6	4
Bokengehalas Creek (03 05)	--	1	1	5	--

Table D-24. LDC-based TMDL allocations assigned to impaired nested subwatersheds.
Note: All nested subwatersheds exist in the 8-digit hydrologic unit 05080001. Those nested subwatersheds listed in italics have an LDC assessment at their outlet.

Nested Subwatershed	Nested Subwatershed Name	LDC Assignment
01 01	*North Fork Great Miami River*	*North Fork GMR*
01 02	*South Fork Great Miami River*	*South Fork GMR*
01 03	Indian Lake-Great Miami River	GMR SR235
02 01	Willow Creek	Muchinippi Creek CR60
02 02	Headwaters Muchinippi Creek	Muchinippi Creek CR60
02 03	Little Muchinippi Creek	Muchinippi Creek CR60
02 04	*Calico Creek-Muchinippi Creek*	*Muchinippi Creek CR60*
03 01	Cherokee Mans Run	GMR SR235
03 02	*RenniCreek Creek-Great Miami River*	*GMR SR235*
03 03	Rum Creek	GMR SR47
03 04	Blue JaCreeket Creek	Bokengehalas Creek
03 05	*Bokengehalas Creek*	*Bokengehalas Creek*
03 06	Brandywine Creek-Great Miami River	GMR SR47
04 01	MCreekees Creek	GMR SR47
04 02	Lee Creek	GMR SR47
04 03	Stoney Creek	GMR SR47
04 04	Indian Creek	GMR SR47
04 05	Plum Creek	GMR SR47
04 06	Turkeyfoot Creek-Great Miami River	GMR SR47
05 01	*Headwaters Loramie Creek*	*Loramie Hardin-Wapakoneta*
05 02	*Mile Creek*	*Mile Creek SR705*
05 03	Lake Loramie-Loramie Creek	Loramie - Cardo
06 01	Nine Mile Creek	Loramie - Fessler
06 02	*Painter Creek-Loramie Creek*	*Loramie - Fessler*
06 03	Turtle Creek	Loramie - Fessler
06 04	*Mill Creek-Loramie Creek*	*Loramie - Fessler*

D6.3 Cause and Source Determination

All of the plot area beneath the TMDL curve is considered the *E. coli* loading capacity of the stream. The difference between this area and the area representing the current loading conditions is the load that must be reduced to meet water quality standards or targets. Because loads often vary as a function of flow and differing bacteria sources may contribute loads at varying flow conditions, LDCs can directly guide TMDL implementation practices.

Analysis of the completed LDC can allude to the causes and sources of load reductions. Those exceedences seen toward the right-end of the graph occur during low flow conditions, and significant sources might include wastewater treatment plants, home sewage treatment systems, illicit sewer connections, and/or animals depositing waste directly to the stream (Table D-25). Exceedences seen on the left-end of the graph occur during higher flow events, and potential sources are manure spreading onto crop or idle land, nearby feedlots of livestock production facilities, and combined sewer overflows (Table D-25). These sources supply bacteria to streams that are washed off with storm event runoff. Analysis of the LDC helps determine which implementation practices are most effective for reducing loads.

Table D-25. Typical contributing sources as a function LDC flow zone. H: high likelihood, M: medium likelihood, L: low likelihood, and blank: no likelihood.

	Flow Zone from LDC				
Contributing Source Area	**High**	**Moist**	**Mid-Range**	**Dry**	**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)	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			

D6.4 TMDL Results

D6.4.1 Critical Conditions and Seasonality

Proliferation of bacteria (growth and metabolism) occurs during the period of warmest stream temperatures, so June through September is the most important consideration. The recreation season is defined from May 1 to October 30 so a window of time preceding this use (April through October) is important in reducing loads from all sources. Critical conditions for in-stream bacteria vary by source and can occur across the stream hydrograph from wash off of land-deposited bacteria under wet conditions to in-stream livestock and failing HSTSs in low flow conditions. Nonpoint sources to which bacteria loads are allocated in the upper GMR watershed include livestock, including wash off from land-applied manure to the presence in-stream animals, and failing HSTSs.

D6.4.1 Margin of Safety

For a definition of MOS, please refer to Section D4.5.2. 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 TMDL minus the MOS is shown in Figure D-19 as green line below the TMDL. The explicit MOS in each allocation is shown in the TMDL allocation tables throughout Section D6.4.4.

Table D-26. Stream locations for which LDCs are generated.

Note: Referenced by nested subwatershed (all in 05080001 8-digit hydrologic unit) and water quality standard classification. LDC assessment sites at USGS gages are highlighted in dark-gray. For assessment sites without a USGS gage, the index gage used to estimate flows by the drainage-area weight is listed under USGS gage reference. The justification for selecting a particular index gage and the corresponding weight is listed under headers Justification and DA (drainage area) ratio, respectively.

Nested Sub-watershed	PCR Class	Stream Name	Location	RM	DA (mi^2)	USGS Gage Reference	Justification	DA ratio
01 02	B	South Fork GMR	CR 96 (just east of SR 117)	3.95	47.2	Loramie - Newport	similar basin size	0.31
01 01	B	North Fork GMR	TR 97 (aka Dunn Rd)	6.31	14.5	Loramie - Newport	similar basin size	0.10
03 02	A	GMR	SR 235	157.22	132	GMR Sidney	mainstem site	0.24
02 04	B	Muchinippi Ck	CR 60	0.32	88.5	Loramie - Newport	similar physiography	0.58
03 05	B	Bokengehalas Ck	Miami St (in DeGraff)	1.13	40.4			
07 03	A	GMR	SR 47 (E. North St.) in Sidney	129.99	541			
05 02	B	Mile Ck	SR 705	0.5	62.4	Loramie - Newport	similar physiography	0.41
06 02	A	Loramie Ck	Cardo-Roman Road (Newport)	16.51	152			
06 04	A	Loramie Ck	Fessler-Buxton Rd (Lockington)	1.87	257			
05 01	A	Loramie Ck†	Hardin-Wapakoneta Rd	30.42	34.5	Loramie - Newport	similar physiography	0.23

†: non-sentinel site (upstream of Lake Loramie)

Table D-27. Inventory of NPDES dischargers in watersheds where LDCs have been constructed.
Note: When *E. coli* is checked the facility discharges bacteria and a fecal coliform standard applies to the NPDES permit. PCR class refers to standard for receiving water or, if 5-Mile Rule applies, the receiving water standard is enclosed in parentheses. ADF (mgd): average design flow in million gallons per day; I: industrial discharger; RM: river mile. Proximity refers to relative stream distance from outfall to assessment location.

Ohio EPA Permit #	*E. coli*	PCR class	Facility	Receiving Stream	RM	ADF (mgd)	LDC Assigned	Proximity
1PD00000	x	B	Bellefontaine WWTP	Opossum Run (BJ Ck 5.80)	0.5	4.5	Boke	far
1PP00021	x	B	ODOT Rest Area 0729	Flat Branch	2.05	0.01	Boke	far
1PK00002	x	A	Indian Lake WPCD	Great Miami River	158.05	4.6	GMR SR235	near
1II00125		--	Cherokee Run Landfill	UNT Cherokee Run (4.15)	0.7	I		
1IN00143		--	Honda of America Mfg Inc	UNT Plum Ck (3.42)	0.5	I		
1PB00036	x	A	Quincy-DeGraff STP	Great Miami River	143.1	0.495	GMR SR47	medium
2PB00036	x	A	Minster WWTP	M-E Canal	1.8	2.5	Loramie Cardo	near
1PH00028	x	A	Lake Loramie SSD	Loramie Ck	21.1	0.4	Loramie Cardo	near
2IH00004	x	A	Dannon Company Inc	M-E Canal	2	I		
2IN00173		--	BP Amoco Oil Bulk Plant – Minster	M-E Canal	2.2	I		
1PB00004	x	B	Anna STP	Clay Ck	4.5	0.4	Loramie H-W	near
1PB00007	x	A (B)	Botkins STP	Loramie Ck	35.4	0.5	Loramie H-W	near
1IJ00053		--	Barrett Paving Matls – Pence	Loramie Ck	3.3	I		
1IJ00054		--	Barrett Paving Matls – Jones	Loramie Ck	1.7	I		
1PG00099	x	A (B)	Arrowhead WWTP	Mill Ck	2.62	0.07	Loramie Fessler	near
1PS00012	x	B	Russia WWTP	UNT Ninemile Ck (5.02)	0.02	0.075	Loramie Fessler	far
1PT00039	x	B	Dorothy Love Retirement Ctr	Ernst Ditch	2.3	0.104	Loramie Fessler	far
1PT00068	x	B	Hardin Elementary School	UNT Turtle Ck (5.85)	0.1	0.009	Loramie Fessler	far
1PT00104	x	A (B)	Houston High School	Ninemile Ck	1	0.01	Loramie Fessler	medium
1PB00018	x	B	Jackson Center WWTP	Jackson Center Ck	2.3	0.37	Much CR60	far
2PB00022	x	B	Waynesfield WWTP	UNT Muchinippi Ck (12.66)	2.29	0.123	Much CR60	far
1IJ00019		--	Shelly Matls – Belle Center	UNT S Fk GMR (5.27)	3.1	I		
1PR00100	x	B	Camp Wesley	UNT to S Fk GMR (5.27)	4.2	0.012	S Fk GMR	far
1PB00047	x	B	Osgood	Brandewie Ditch	0.8	0.122	Mile Ck	far

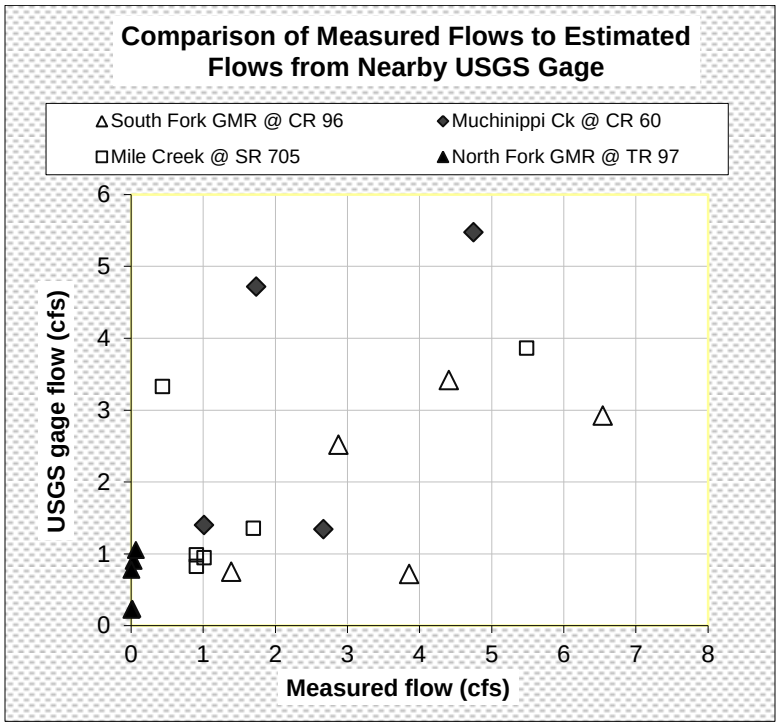
Ohio EPA Permit #	*E. coli*	PCR class	Facility	Receiving Stream	RM	ADF (mgd)	LDC Assigned	Proximity
2PR00258	x	B	Dads Drive-in	Muchinippi Ck	11.9	0.0015	Much CR60	far
1PR00052	x	B	YMCA	UNT Blue Jacket Ck (3.4)	1.1	0.015	Boke	far
2IY00003		--	Waynesfield WTP	UNT Muchinippi Ck (12.66)	2.25	I		
1IN00282		--	VE Beard Oil Co	UNT Cherokee Run (4.72)	1.2	I		
1IK00010		--	John & Susan Evans Farm	UNT Calico Ck	--	closed		
1IN00058		--	Daido Metal Bellefontaine LLC	Singley and Houck/Hankenson Ditch (BJ Ck 7.07)	1.4	I		
1IN000296		--	Advanced AGRI Solns Co-op	UNT Loramie Ck (29.15)	2.25	I		
1IJ00046		--	Barrett Paving Matls – Washington	Turtle Ck	0.1	I		
2GN00007		--	Minster Machine	M-E Canal	1.8	keep		

D6.4.2 Allowance for Future Growth

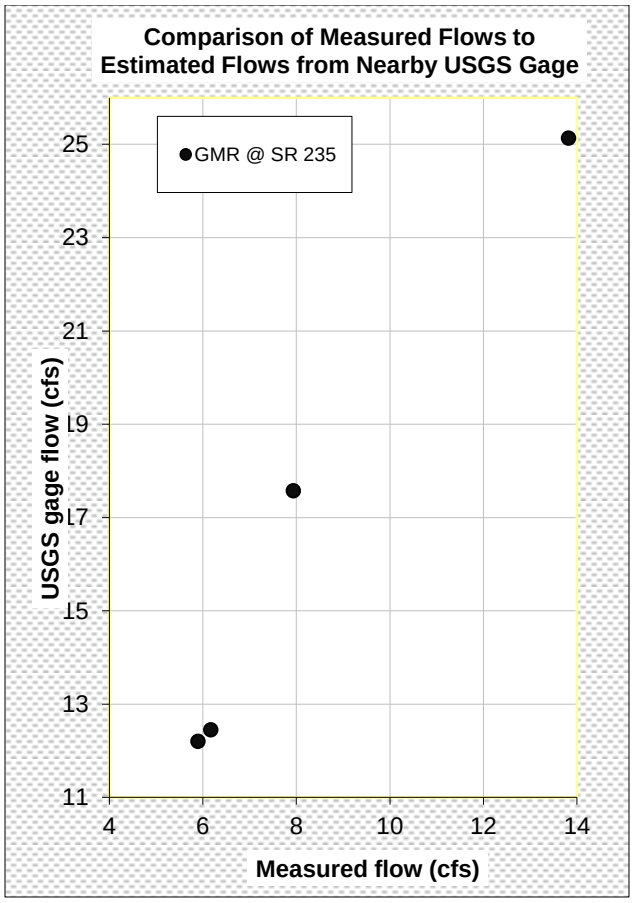
Allocation for future growth was set to a minimum (1% of the TMDL) because none of the POTWs in the impaired subbasin units have any planned facility expansions (Ohio EPA – SWDO, various permit/PTI staff; personal communication 2011). Further, the multiple county region will experience very small (less than 1%) to declining growth (Table D-14).

D6.4.3 Validation of Gage Flow Estimated from Nearby USGS Gages

As shown in Table D-26 there are four LDC sites that, with local USGS gage data, were used to compute an exact flow duration curve. For all remaining LDC sites in Table D-26, a nearby USGS gage along with drainage-area yield is employed to estimate long term flow at that site. The validity of this estimation is shown graphically in Figure D-20 where the best fit should follow a 1:1 correspondence between measured local flow and estimated long term flow. A numerical representation of validity is impractical due to the small N available for such diagnostics. The best estimations occur at South Fork GMR and Mile Ck LDC sites, whereas poor estimations occur at North Fork GMR and Muchinippi Ck (Figure D-20a). In Figure D-20b, while the measured and estimated flows are linearly related, the drainage-area yield computation overestimates the local flow, at least for these four events.



(a)



(b)

Figure D-20. Cross-plot of measured flow at LDC site vs. estimated flow from nearby USGS gage. *Note:* All sites included where both local (at LDC site) flow was measured and a long term flow was estimated from a nearby USGS gage. The flow estimation was made using a drainage-area yield relationship. Both (a) and (b) are similar plots but axes range varies depending on the site. In (a), local flow from North Fork GMR was not used in computing *E. coli* loads but is shown here to assist in recognizing the validity of using drainage-area yield as a local flow estimator.

D6.4.4 Loading Allocation for *E. coli*

LDCs are created for each impaired nested subwatershed listed in Table D-26 and the linkages to the remaining impaired assessment units are listed in Table D-24. These LDCs represent the entire watershed draining to the sampling site. TMDLs have been developed for each of the five flow regimes in each LDC. The median load in each flow regime is used as the TMDL. The MOS is established for flow regime according to the above explanation. LA and WLA are also prescribed for each flow regime. All loads (TMDLs and allocations) are determined as a daily count of *E. coli* in units of billion colonies per day.

For NPDES dischargers that currently require disinfection of their final effluent, their WLA is the product of their average design flow and the end-of-pipe numeric target for *E. coli* (see previous discussion on target development). A loading reduction analysis could not be done because end-of-pipe *E. coli* concentrations were not collected. Hence, all NPDES facilities are given a WLA equal to the product of their average design flow (ADF) and end-of-pipe allowable target concentration. However, some facilities experienced limit violations for fecal coliform and are potential violators of the *E. coli* standard (Table D-28). Because these facilities operate over the

entire range of stream flow magnitude, the WLA is constant over all of the flow regimes. The NPDES facilities located within these nested subwatersheds are listed in Table D-27 or for the specific LDC results shown in Table D-30 through Table D-39. Any NPDES facility listed in Table D-27 but not included in Table D-30 through Table D-39 has a WLA equal to zero. The entire set consists of industrial dischargers (ADF listed as I in Table D-27).

Table D-28. Summary of NPDES permit violations for Ohio EPA fecal coliform standard from the period 1/1/2005 to 12/31/2009 for all municipal facilities in the study area.

Permit #	Facility	Number of Violations	
		7-day	30-day
2PB00036	Minster WWTP	1	0
1PP00021	ODOT Rest Area 0729	5	10
1PT00039	Dorothy Love Retirement Center	5 (1-day)	2 (7-day)
1PT00068	Hardin Elementary School	4	4

After assigning the NPDES WLA and MOS, the remaining load is assigned to runoff loads as LA or MS4 loads as WLA. However, all *E. coli* loads originating from home sewage treatment systems or direct livestock waste inputs into the stream are not allocated to LA; thus, they are assigned a zero load. The LA is divided between runoff from MS4 land areas and non-MS4 land areas. Because runoff from MS4s is regulated by Ohio EPA, this allocation is considered a WLA. The non-MS4 runoff is a LA. Separation of MS4 from the LA is carried out simply by applying the land area ratio of each type (MS4 and non-MS4) to the remaining *E. coli* load (i.e., LA) allowed for each TMDL. Table D-29 shows the adjusted LA and the WLA assigned to each MS4 region by nested subwatershed.

Table D-29. Allocations assigned to storm water (MS4) TMDL based on percent land area occupied by designated MS4 zone in each LDC assessment unit.
Note: Adjusted TMDL LAs are also listed.

LDC Assessment	Area (mi^2)	% Area of LDC	LA (billion/day) – unadjusted				
			MS4-WLA (billion/day)				
			LA (billion/day) – adjusted				
Bokengehalas Ck LDC (05080001 03 05)	40.4		659	128	35	4	-4
05080001 03 04 (Bellefontaine UC)	3.255	8%	53	10	3	0	0
05080001 03 05 (Bellefontaine UC)	1.179	3%	19	4	1	0.1	0
adjusted TMDL LA (05080001 03 05)			587	114	31	3.6	-4
GMR SR47 LDC (05080001 07 03)	541		6763	979	226	134	93
05080001 04 01 (Bellefontaine UC)	0.326	0.1%	4	0.6	0.1	0.1	0.06
05080001 04 05 (Sidney UC)	0.634	0.1%	8	1	0.3	0.2	0.1
05080001 04 06 (Sidney UC)	0.020	0.0%	0	0	0	0	0
adjusted TMDL LA (05080001 07 03)			6751	977	226	133.8	92.8
Loramie Fessler (05080001 06 04)	257		3627	288	62	25	13
05080001 06 03 (Sidney UC)	0.327	0.1%	5	0.4	0.1	0.03	0
05080001 06 04 (Sidney UC)	0.261	0.1%	4	0.3	0.1	0.03	0
adjusted TMDL LA (05080001 06 04)			3619	287	61.9	24.9	13

The complete inventory of LDCs, TMDL allocations for WLA and LA, and facility-specific NPDES allocations are included in Figure D-21 through Figure D-30 and Table D-30 through Table D-39. Note, MS4 allocations are not included in Table D-30 through Table D-39 but they

and their corresponding adjusted LA should be referenced in Table D-29 above for three of the LDC assessment units.

A list of NPDES facilities, their design flow and location, and assignment to an LDC assessment unit is shown in Table D-27.

The sequence of figures and tables follow the order below (1-10). The load duration curve for each nested subwatershed (Figure D-21 through Figure D-30) is shown, followed by the load allocation table for that site (Table D-30 through Table D-39).

1. 05080001 01 02: South Fork GMR
2. 05080001 01 01: North Fork GMR
3. 05080001 03 02: GMR at State Route 235
4. 05080001 02 04: Muchinippi Creek at County Road 60
5. 05080001 03 05: Bokengehalas Creek
6. 05080001 07 03: GMR at State Route 47
7. 05080001 05 02: Mile Creek at State Route 705
8. 05080001 06 02: Loramie Creek at Cardo-Roman Road
9. 05080001 06 04: Loramie Creek at Fessler-Buxton Road
10. 05080001 05 01: Loramie Creek at Hardin-Wapakoneta Road

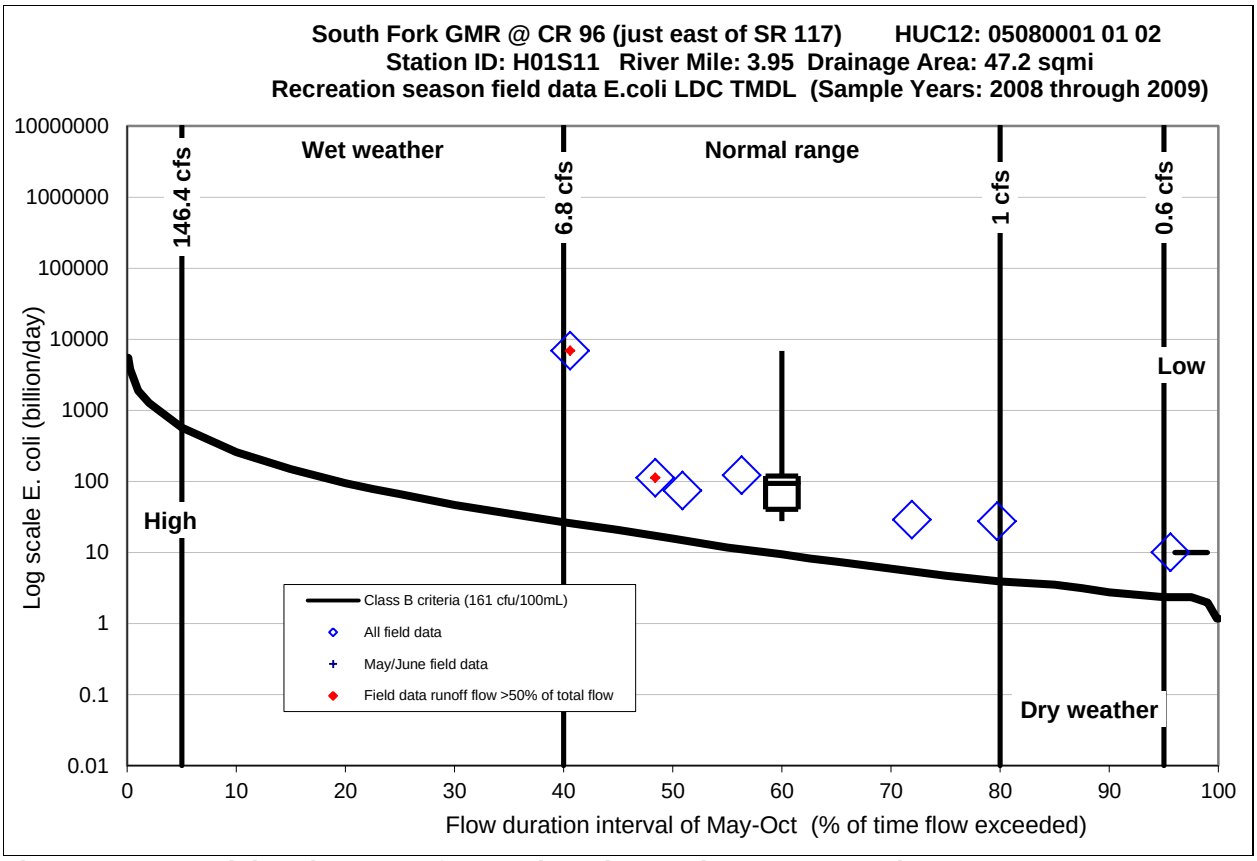


Figure D-21. Load duration curve for South Fork GMR (05080001 01 02).

Table D-30. Load allocation table for South Fork GMR (05080001 01 02).

Flow regime TMDL analysis *E. coli* **(billion organisms/day)**	**High**	**Wet weather**	**Normal range**	**Dry weather**	**Low**
Flow Duration Regime Interval	0-5%	5-40%	40-80%	80-95%	95-100%
Samples per Regime			6		1
Sample Load (median)			94		10.0
Upstream WLA	0	0	0	0	0
TMDL	1,119	78.4	9.5	3.2	2.4
MOS (explicit 20%)	224	15.7	1.9	0.6	0.5
AFG (1%)	11	1	0	0.0	0.0
WLA (total)	0.1	0.1	0.1	0.1	0.1
Camp Wesley (1PR00100)	0.1	0.1	0.1	0.1	0.1
LA	884	61.8	7.4	2.4	1.8
Total Reduction Required (%)	No Data	No Data	**89.9%**	No Data	**76.4%**

Values were adjusted for rounding.

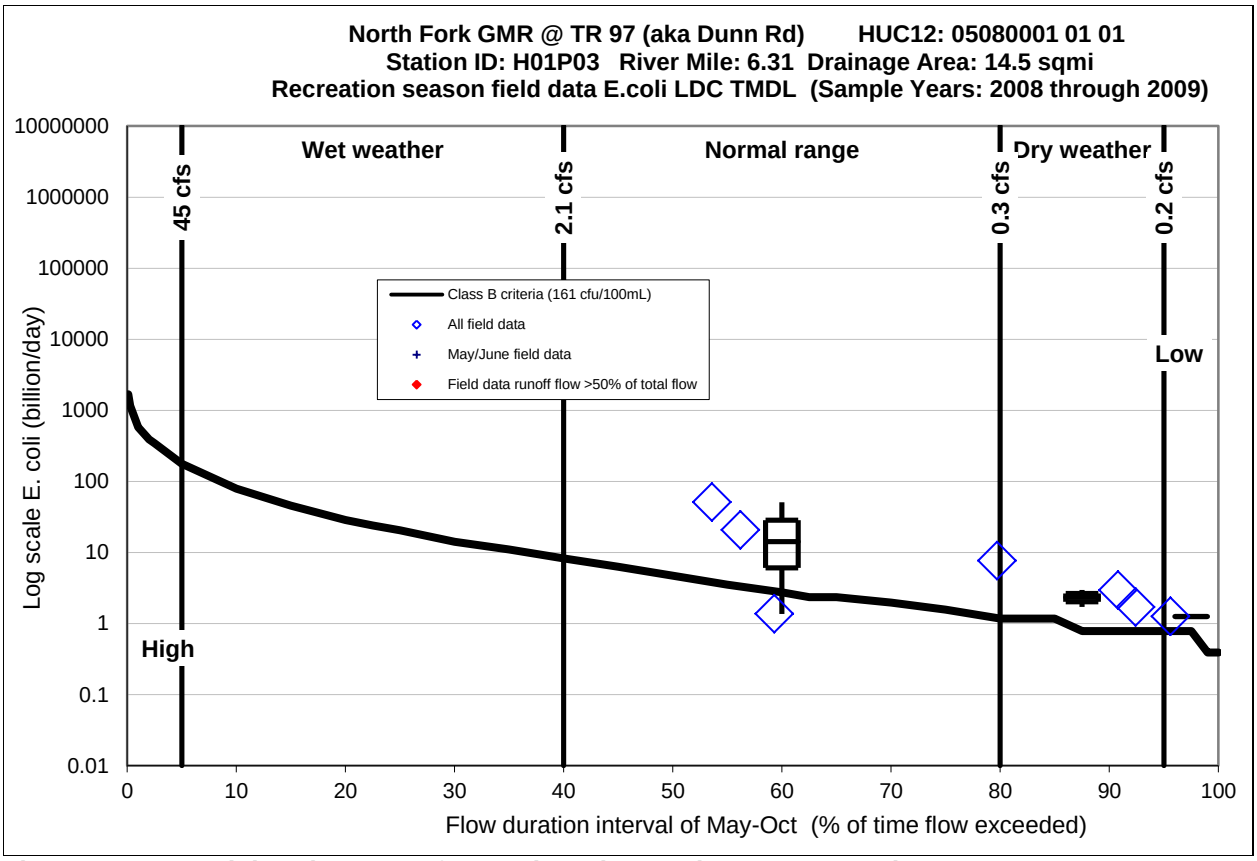


Figure D-22. Load duration curve for North Fork GMR (05080001 01 01).

Table D-31. Load allocation table for North Fork GMR (05080001 01 01).

Flow regime TMDL analysis *E. coli* **(billion organisms/day)**	**High**	**Wet weather**	**Normal range**	**Dry weather**	**Low**
Flow Duration Regime Interval	0-5%	5-40%	40-80%	80-95%	95-100%
Samples per Regime			4	2	1
Sample Load (median)			14	2.3	1.3
Upstream WLA	0	0	0	0	0
TMDL	344	24	2.8	0.8	0.8
MOS (explicit 20%)	69	4.8	0.6	0.2	0.2
AFG (1%)	3	0.2	0.0	0.0	0.0
WLA (total)	0.0	0.0	0.0	0.0	0.0
LA	272	19.0	2.2	0.6	0.6
Total Reduction Required (%)	No Data	No Data	**80.7%**	**66.4%**	**37.5%**

Values were adjusted for rounding.

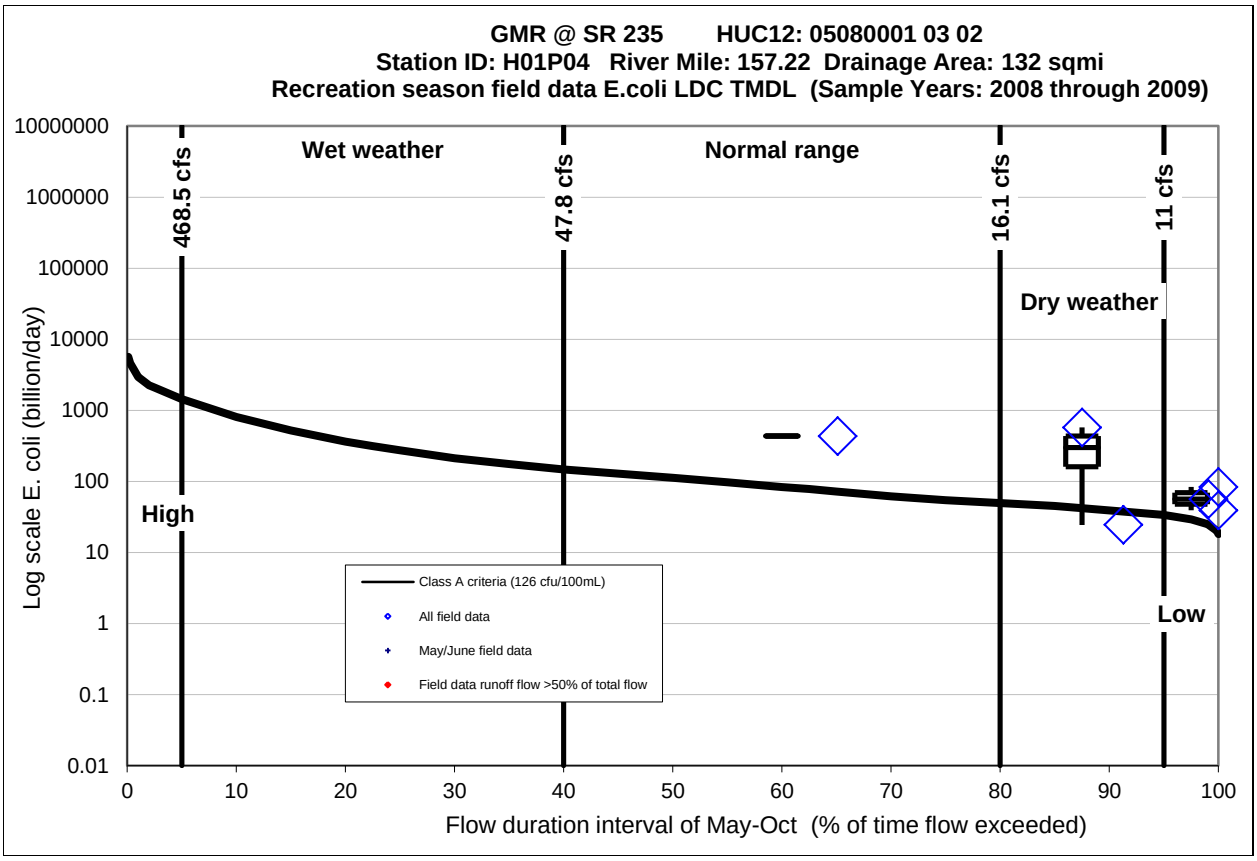


Figure D-23. Load duration curve for GMR at State Route 235 (05080001 03 02).

Table D-32. Load allocation table for GMR at State Route 235 (05080001 03 02).

Flow regime TMDL analysis *E. coli* **(billion organisms/day)**	**High**	**Wet weather**	**Normal range**	**Dry weather**	**Low**
Flow Duration Regime Interval	0-5%	5-40%	40-80%	80-95%	95-100%
Samples per Regime			1	2	3
Sample Load (median)			436	299.6	56.3
Upstream WLA	0.1	0.1	0.1	0.0	0.0
TMDL (less upstream WLA)	2102.4	315.9	83.5	42.2	29.3
MOS (explicit 20%)	420	63	17	8.4	5.9
AFG (1%)	21	3	1	0.4	0.3
WLA (total)	21.9	21.9	21.9	21.9	21.9
Indian Lake WPCD (1PK00002)	21.9	21.9	21.9	21.9	21.9
LA	1,639	228	44	11	1
Total Reduction Required (%)	No Data	No Data	**80.8%**	**85.9%**	**48.0%**

Values were adjusted for rounding.

Note: TMDL for three highest flow regimes is reduced by upstream wasteload allocation (WLA) originating from South Fork GMR (05080001 01 02) LDC. Translation of WLA from upstream assessment unit is most probable under normal-to-high flow when spillway of Indian Lake is active.

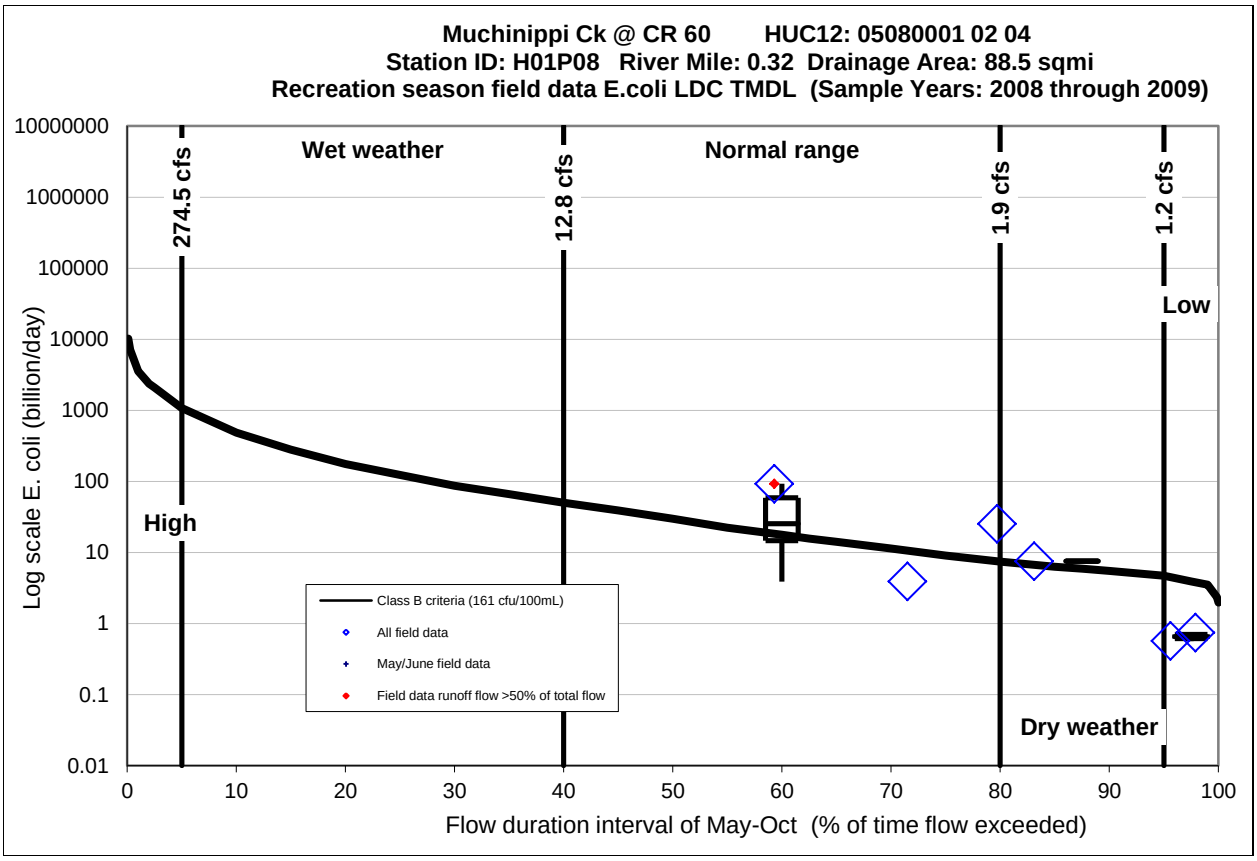


Figure D-24. Load duration curve for Muchinippi Creek at County Road 60 (05080001 02 04).

Table D-33. Load allocation table for Muchinippi Creek at County Road 60 (05080001 02 04).

Flow regime TMDL analysis *E. coli* **(billion organisms/day)**	**High**	**Wet weather**	**Normal range**	**Dry weather**	**Low**
Flow Duration Regime Interval	0-5%	5-40%	40-80%	80-95%	95-100%
Samples per Regime			3	1	2
Sample Load (median)			25	7.6	0.7
Upstream WLA	0	0	0	0	0
TMDL	2,098	147	18	5.9	3.9
MOS (explicit 20%)	420	29	4	1.2	0.8
AFG (1%)	21	1	0	0.1	0.0
WLA (total)	3.01	3.01	3.01	3.01	3.01
Jackson Center WWTP (1PB00018)	2.25	2.25	2.25	2.25	2.25
Waynesfield WWTP (2PB00022)	0.75	0.75	0.75	0.75	0.75
Dads Drive-In (2PR00258)	0.01	0.01	0.01	0.01	0.01
LA	1,654	113	11	2	0
Total Reduction Required (%)	No Data	No Data	**30.2%**	**21.8%**	**None**

Values were adjusted for rounding.

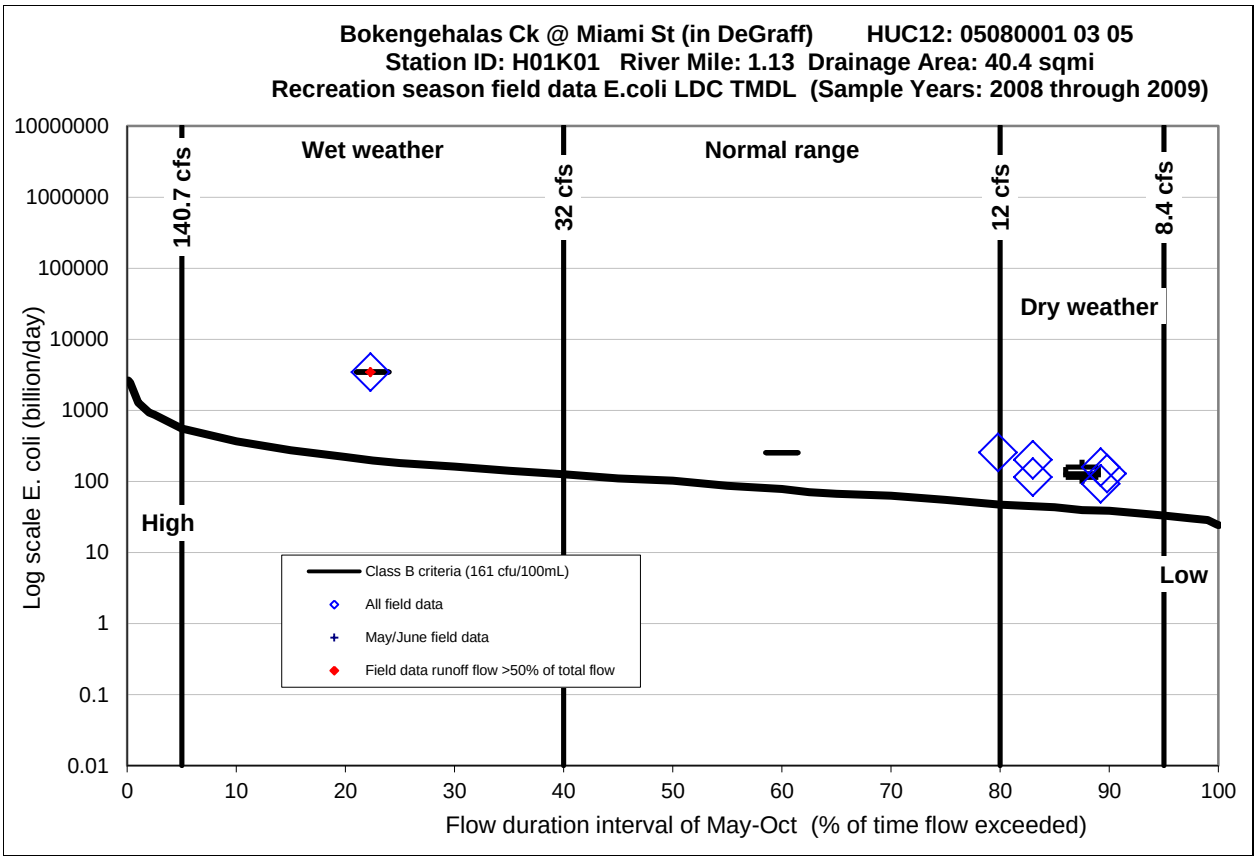


Figure D-25. Load duration curve for Bokengehalas Creek (05080001 03 05).

Table D-34. Load allocation table for Bokengehalas Creek (05080001 03 05).

Flow regime TMDL analysis ***E. coli*** **(billion organisms/day)**	**High**	**Wet weather**	**Normal range**	**Dry weather**	**Low**
Flow Duration Regime Interval	0-5%	5-40%	40-80%	80-95%	95-100%
Samples per Regime		1	1	5	
Sample Load (median)		3,459	254	128.4	
Upstream WLA	0	0	0	0	0
TMDL	870	197	79	39.4	30.3
MOS (explicit 20%)	174	39	16	7.9	6.1
AFG (1%)	9	2	1	0.4	0.3
WLA (total)	27.6	27.6	27.6	27.6	27.6
Bellefontaine WWTP (1PD00000)	27.4	27.4	27.4	27.4	27.4
ODOT Rest Area 0729 (1PP00021)	0.1	0.1	0.1	0.1	0.1
YMCA (1PR00052)	0.1	0.1	0.1	0.1	0.1
LA	659	128	35	4	-4
Total Reduction Required (%)	No Data	**94.3%**	**69.0%**	**69.3%**	No Data

Values were adjusted for rounding.

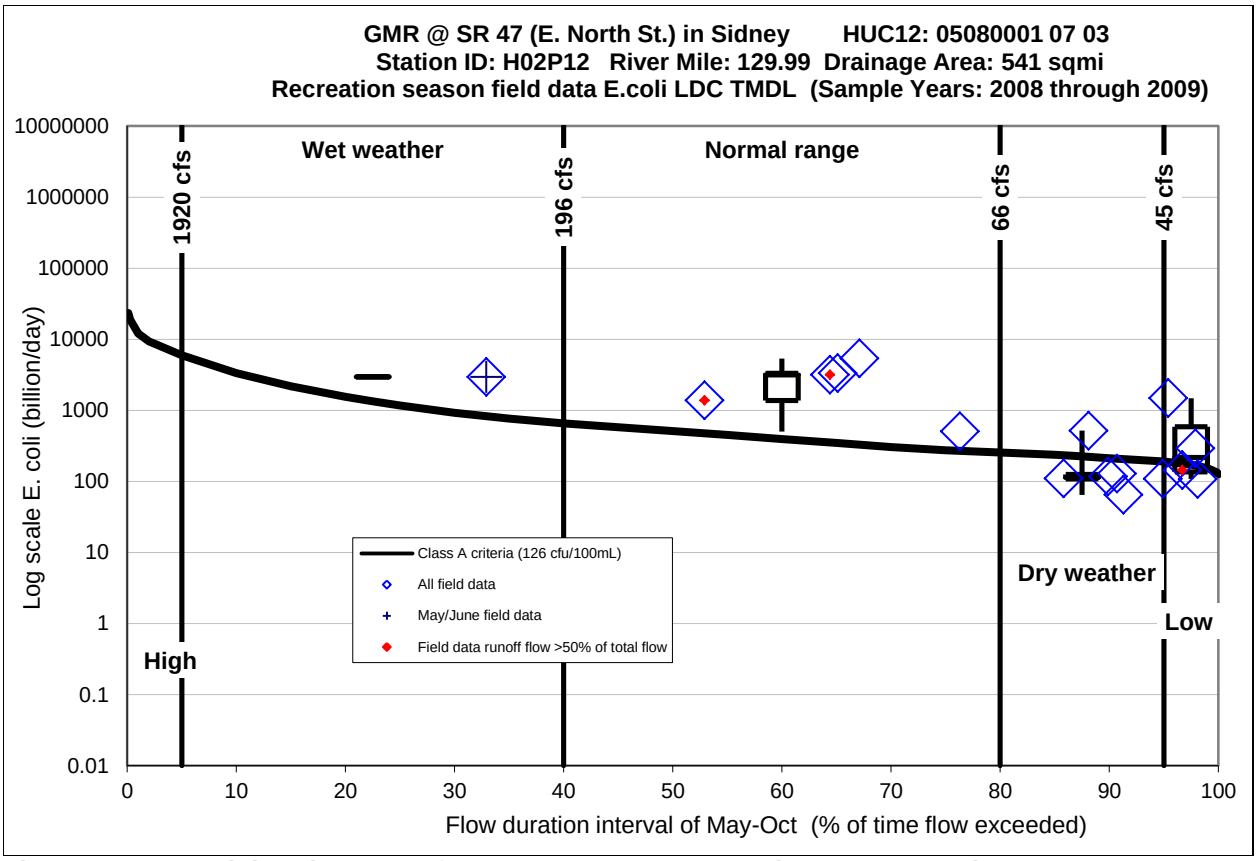


Figure D-26. Load duration curve for GMR at State Route 47 (05080001 07 03).

Table D-35. Load allocation table for GMR at State Route 47 (05080001 07 03).

Flow regime TMDL analysis *E. coli* (billion organisms/day)	High	Wet weather	Normal range	Dry weather	Low
Flow Duration Regime Interval	0-5%	5-40%	40-80%	80-95%	95-100%
Samples per Regime		1	5	6	4
Sample Load (median)		2,961	3,169	113.8	218.0
Upstream WLA	52.6	52.6	52.6	52.5	52.5
TMDL (less upstream WLA)	8564.0	1,242.0	289.5	172.6	120.2
MOS (explicit 20%)	1713	248	58	34.5	24.0
AFG (1%)	86	12	3	1.7	1.2
WLA (total)	2.4	2.4	2.4	2.4	2.4
Quincy-DeGraff STP (1PB00036)	2.4	2.4	2.4	2.4	2.4
LA	6,763	979	226	134	93
Total Reduction Required (%)	No Data	**58.1%**	**90.9%**	**None**	**44.9%**

Values were adjusted for rounding.

Note: TMDL is reduced by upstream WLAs originating from South Fork GMR (05080001 01 02)[2], Muchinippi Creek at CR 60 (05080001 02 04), GMR at SR 235 (05080001 03 02), and Bokengehalas Creek (05080001 03 05) LDCs.

[2] Reduction from this nested subwatershed occurs only in the three highest flow regimes for the GMR at SR 47 LDC.

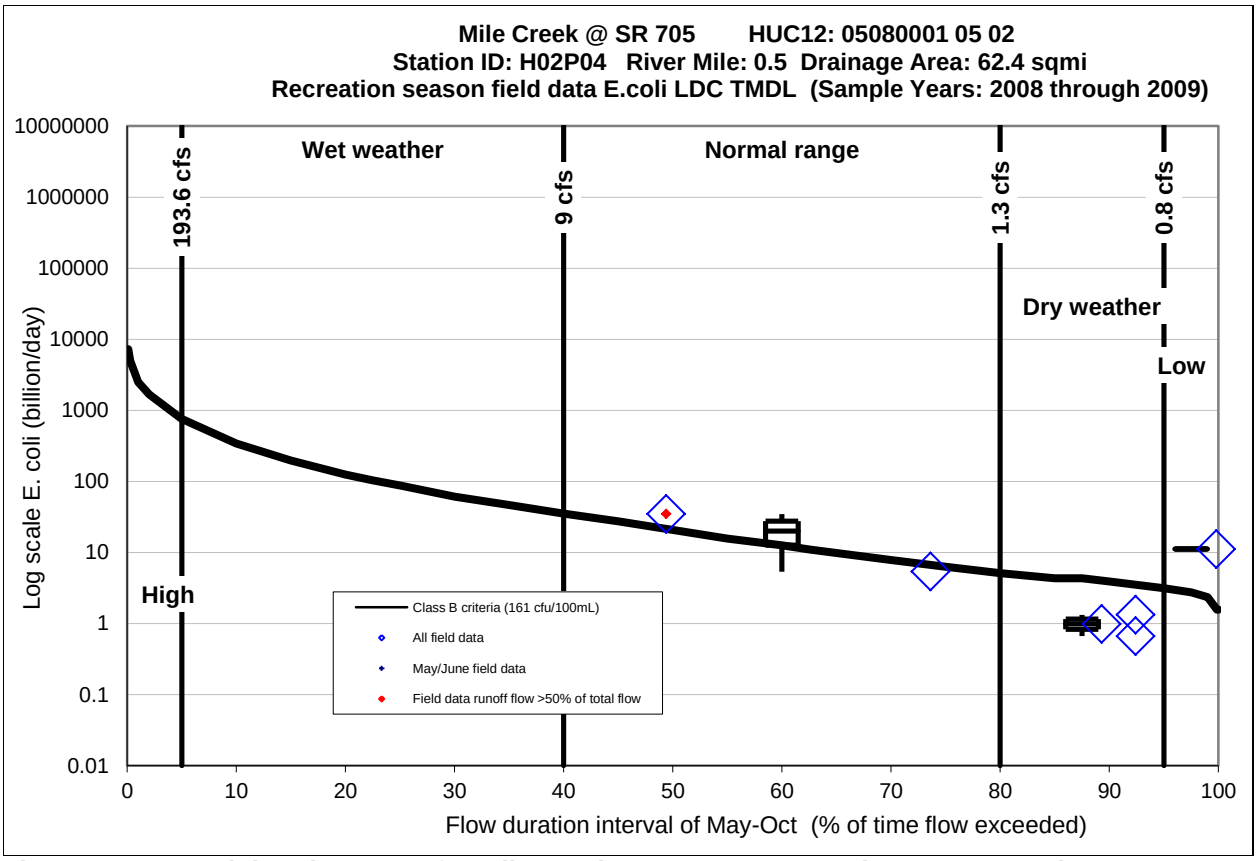


Figure D-27. Load duration curve for Mile Creek at State Route 705 (05080001 05 02).

Table D-36. Load allocation table for Mile Creek at State Route 705 (05080001 05 02).

Flow regime TMDL analysis *E. coli* (billion organisms/day)	**High**	**Wet weather**	**Normal range**	**Dry weather**	**Low**
Flow Duration Regime Interval	0-5%	5-40%	40-80%	80-95%	95-100%
Samples per Regime			2	3	1
Sample Load (median)			20	1.0	11.2
Upstream WLA	0	0	0	0	0
TMDL	1,479	104	12.6	4.3	2.8
MOS (explicit 20%)	296	21	2.5	0.9	0.6
AFG (1%)	15	1	0.1	0.0	0.0
WLA (total)	0.7	0.7	0.7	0.7	0.7
Osgood (1PB00047)	0.7	0.7	0.7	0.7	0.7
LA	1,168	81	9.2	3	1
Total Reduction Required (%)	No Data	No Data	**37.5%**	**None**	**75.4%**

Values were adjusted for rounding.

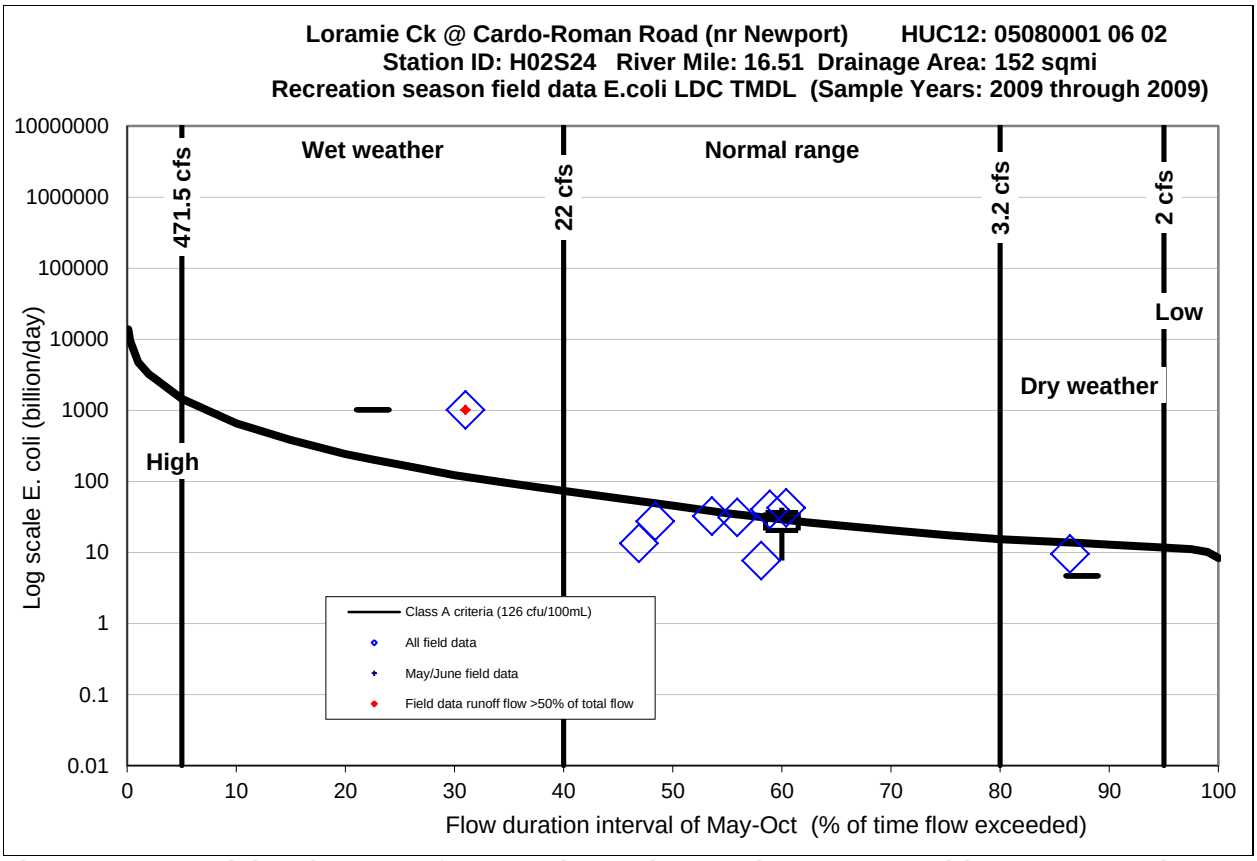


Figure D-28. Load duration curve for Loramie Creek at Cardo-Roman Road (05080001 06 02).

Table D-37. Load allocation table for Loramie Creek at Cardo-Roman Road (05080001 06 02).

Flow regime TMDL analysis *E. coli* **(billion organisms/day)**	**High**	**Wet weather**	**Normal range**	**Dry weather**	**Low**
Flow Duration Regime Interval	0-5%	5-40%	40-80%	80-95%	95-100%
Samples per Regime		1	7	1	
Sample Load (median)		1,019	31	4.7	
Upstream WLA	5.6	5.6	5.6	0.7	0.7
TMDL (less upstream WLA)	2,814	192	18	7.3	4.8
MOS (explicit 20%)	563	38	4	1.5	1.0
AFG (1%)	28	2	0	0.1	0.0
WLA (total)	13.8	13.8	13.8	13.8	13.8
Minster WWTP (2PB00036)	11.9	11.9	11.9	11.9	11.9
Lake Loramie SSD (1PH00028)	1.9	1.9	1.9	1.9	1.9
LA	2,210	138	1	-8	-10
Total Reduction Required (%)	No Data	**81.2%**	**41.6%**	**None**	No Data

Values were adjusted for rounding.

Note: TMDL is reduced by upstream WLAs originating from Loramie Creek at Hardin-Wapakoneta (05080001 05 01)[3] and Mile Creek at State Route 705 (05080001 05 02) LDCs.

[3] Reduction from this nested subwatershed occurs only in the three highest flow regimes for Loramie-Cardo LDC.

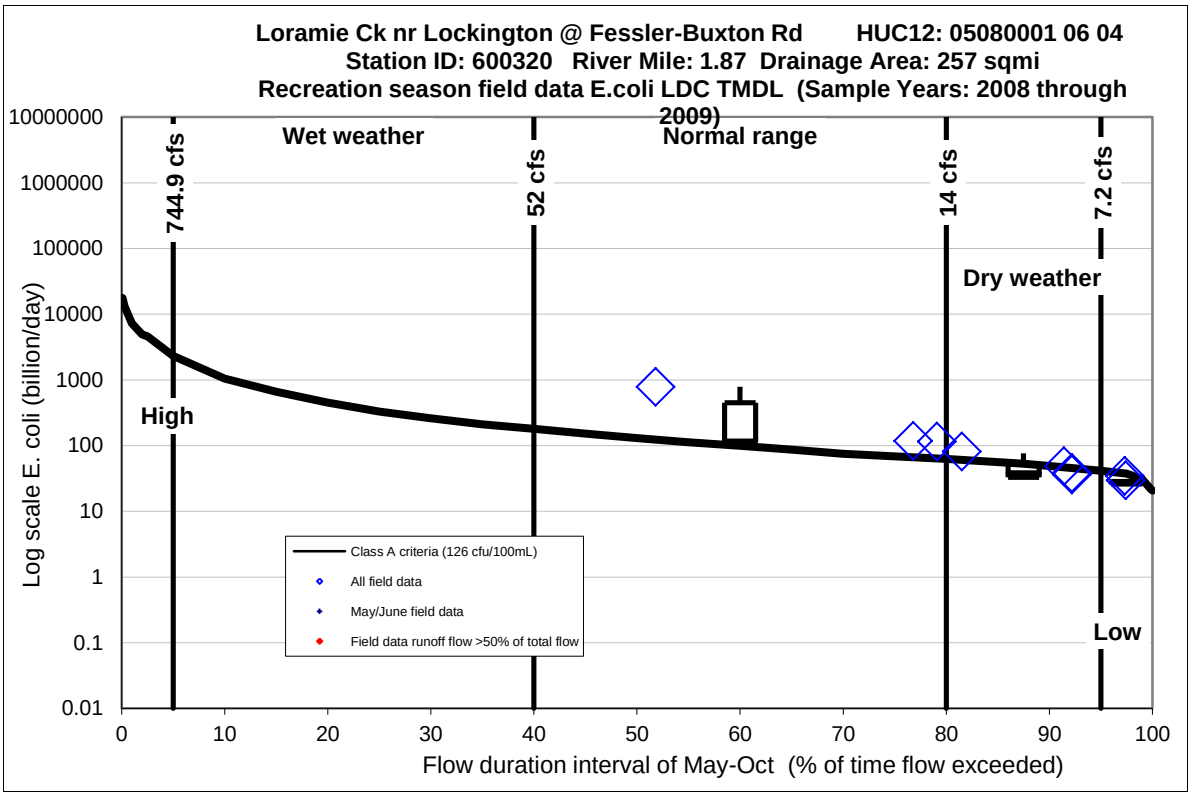


Figure D-29. Load duration curve for Loramie Creek at Fessler-Buxton Road (05080001 06 04).

Table D-38. Load allocation table for Loramie Creek at Fessler-Buxton Road (05080001 06 04).

Flow regime TMDL analysis *E. coli* **(billion organisms/day)**	**High**	**Wet weather**	**Normal range**	**Dry weather**	**Low**
Flow Duration Regime Interval	0-5%	5-40%	40-80%	80-95%	95-100%
Samples per Regime			3	4	2
Sample Load (median)			117	38.7	27.3
Upstream WLA	19	19	19	15	15
TMDL (less upstream WLA)	4,593	367	80	33.9	17.9
MOS (explicit 20%)	919	73	16	6.8	3.6
AFG (1%)	46	4	1	0.3	0.2
WLA (total)	1.5	1.5	1.5	1.5	1.5
Arrowhead WWTP (1PG00099)	0.3	0.3	0.3	0.3	0.3
Russia WWTP (1PS00012)	0.5	0.5	0.5	0.5	0.5
Dorothy Love Retirement Ctr (1PT00039)	0.6	0.6	0.6	0.6	0.6
Hardin Elementary School (1PT00068)	0.1	0.1	0.1	0.1	0.1
Houston HS (1PT00104)	0.0	0.0	0.0	0.0	0.0
LA	3,627	288	62	25	13
Total Reduction Required (%)	No Data	No Data	**31.6%**	**12.3%**	**34.5%**

Values were adjusted for rounding.

Note: TMDL is reduced by upstream WLAs originating from Loramie Creek at Hardin-Wapakoneta (05080001 05 01)[4], Loramie Creek at Cardo (05080001 06 02), and Mile Creek at SR 705 (05080001 05 02) LDCs.

[4] Reduction from this nested subwatershed occurs only in the three highest flow regimes for Loramie-Fessler LDC.

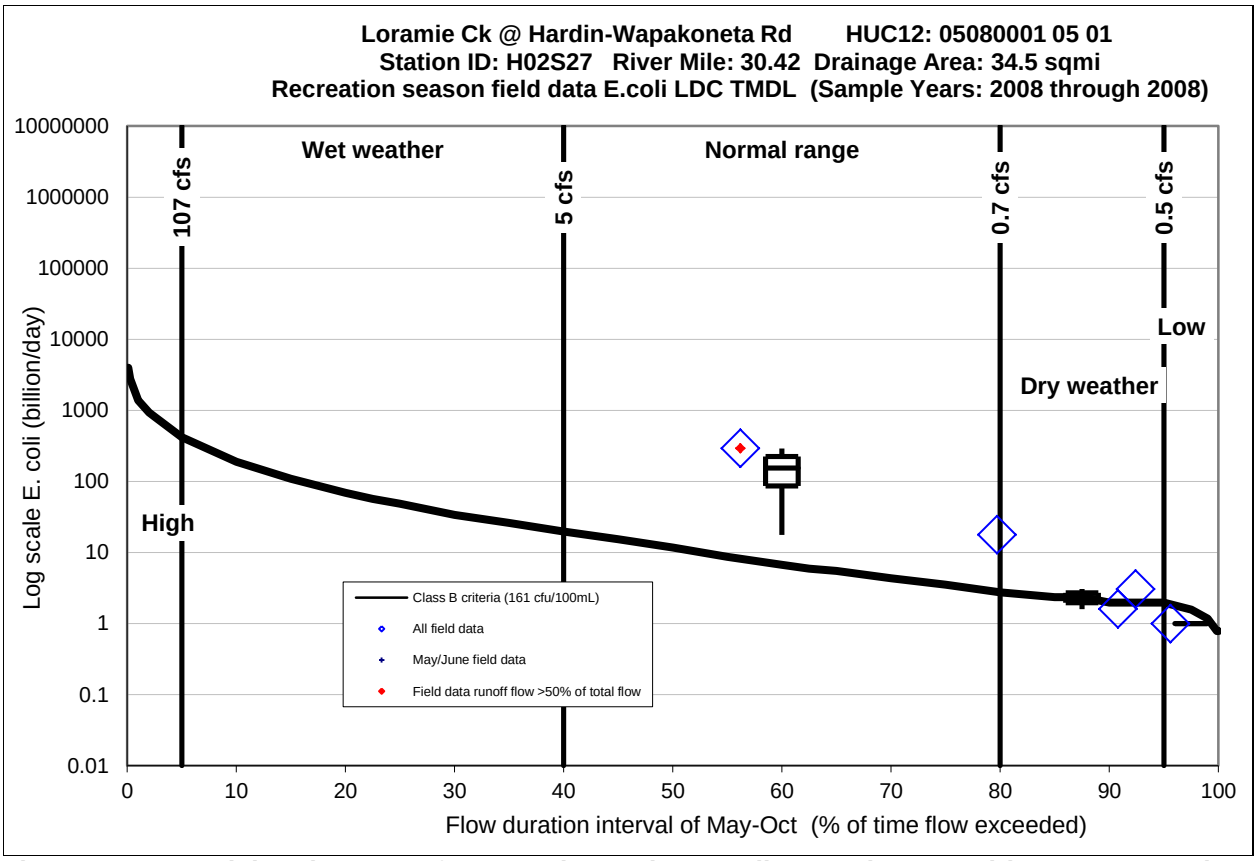


Figure D-30. Load duration curve for Loramie Creek at Hardin-Wapakoneta Rd (05080001 05 01).

Table D-39. Load allocation table for Loramie Creek at Hardin-Wapakoneta Rd (05080001 05 01).

Flow regime TMDL analysis *E. coli* **(billion organisms/day)**	**High**	**Wet weather**	**Normal range**	**Dry weather**	**Low**
Flow Duration Regime Interval	0-5%	5-40%	40-80%	80-95%	95-100%
Samples per Regime			2	2	1
Sample Load (median)			155	2.3	1.0
Upstream WLA	0	0	0	0	0
TMDL	818	57	6.7	2.4	1.6
MOS (explicit 20%)	164	11	1.3	0.5	0.3
AFG (1%)	8	1	0.1	0.0	0.0
WLA (total)	4.8	4.8	4.8	4.8	4.8
Anna STP (1PB00004)	2.4	2.4	2.4	2.4	2.4
Botkins STP (1PB00007)	2.4	2.4	2.4	2.4	2.4
LA	641	40	0.5	-3	-4
Total Reduction Required (%)	No Data	No Data	**95.7%**	**None**	**None**

Values were adjusted for rounding.

D7 Mass Balance of Total Dissolved Solids for Upper Loramie Creek

D7.1 Background and Description

Full impairment (i.e., non-attainment) of aquatic life use at RM 34.96 (Lock Two Road DST Botkins STP and WTP)[5] of Loramie Creek (nested subwatershed 05080001 03 02) is caused by nutrients, total dissolved solids (TDS), and habitat alteration. The source of TDS is fully attributed to the upstream WWTP at RM 35.42 – Village of Botkins STP (Ohio EPA 1PB00007) (Ohio EPA 2011). Development of a nutrient TMDL, which considers this facility within a wasteload allocation (WLA), is discussed in Section D4.

Nonpoint sources of TDS originate from agricultural and residential runoff and from leaching of soil that is contaminated with various inorganic constituents. In addition, certain naturally occurring total dissolved solids arise from the weathering and dissolution of rocks and soils. Here in this investigation both nonpoint sources and background loads of TDS are combined and considered under the load allocation (LA).

TDS is a measure of the combined content of all inorganic and organic substances contained in a liquid – including molecular, ionized or micro-granular (colloidal sol) suspended form. Generally the operational definition is that the solids must be small enough to survive filtration through a sieve the size of two micrometers (µm). The compounds and elements remaining after filtration are commonly calcium, magnesium, sodium, potassium, carbonate, bicarbonate, chloride, sulfate, silica, and nitrate. When a point source is the primary and/or sole source of impairment, a mass balance of pollutant load can be computed to determine the required reduction amount. Mass balance of pollutant load requires determination of stream flow (volume per time) and pollutant concentration (mass per volume). A wasteload allocation for TDS and subsequent effluent limitation is required if the pollutant has the potential to threaten or impair the designated use of receiving waters and is known or expected to occur in the discharge during the applicable permit period [OAC 3745-2-04 (A)(4)].

D7.2 Total Dissolved Solids Target

The target for TDS originates from State of Ohio laws for protection of beneficial use. A target of 1500 mg/L of TDS is assigned to this TMDL for all aquatic life use for the Outside Mixing Zone Average (or OMZA). This criterion is applied statewide and is obtained from OAC 3745-1-07 (Table 7-1, p. 10).

D7.3 Margin of Safety

Both an implicit and explicit margin of safety (MOS) is applied to the TDS TMDL. Five (5) percent of the TMDL is assigned explicitly to account for uncertainty in the relationship between attaining warmwater aquatic life use and meeting the downstream water quality target for TDS. The explicit MOS also accounts for uncertainty in the following monitoring data sources: upstream water quality from five instantaneous (grab) samples, effluent water quality from multiple samples, and stream design flow based on an area-yield from a nearby but similar watershed. Further, the explicit MOS accounts for the uncertainty in assuming steady-state flow and concentration; contrastingly, transient conditions may exist at certain times during the low-flow period. An implicit MOS also exists for the TMDL. Implicit MOS stems from 1) the use of

[5] STP=sewage treatment plant and WTP=water treatment plant

the projected effluent quality (PEQ) average instead of a less conservative simple numeric average for characterizing wastewater quality and 2) the use of conservative *in-stream* transport (i.e., no settling nor absorption) of pollutant concentration between the source (LA and WLA) and the downstream water quality target.

D7.4 Critical Condition and Seasonality

Because the primary source of the TDS-based impairment is due to WWTP effluent, the critical condition is the low-flow period of the annual streamflow cycle – the period of June through September. Nonpoint contributions and background sources of load originating from surface runoff and bank seepage would be minimal during this period.

D7.5 Allowance for Future Growth

Because the impairment cause of TDS is attributed to the Village of Botkins STP, the determination of future growth is limited to the Village of Botkins (Ohio) demographic area and characteristics of the WWTP facility. Population declined by 3.07 percent from the period April 2000, when the US Census 2000 was conducted, to July 2009 when a US Census estimation was made[6]. The current population of the village is approximately 1170 people. Further, the WWTP is not utilizing the full capacity of its design – the average design flow is 0.5 MGD but the mean daily flow is 0.287 MGD (or 57 percent of design flow) when considering all months of record for the period 2005-2011. Communication with Ohio EPA wastewater staff in the local district office confirmed that no expansion was requested by this facility in the past nor is any proposed (S. Leibfritz, personal communication 2011). Given these conditions of declining population growth, underutilization of treatment plant capacity, and no requests for expansion, the allowance for future growth (AFG) was set to zero.

D7.6 TMDL Results for Total Dissolved Solids

The complete TMDL equation is evaluated on Loramie Creek just below the mixing zone of the Botkins STP and is construed as follows:

$$\mathbf{TMDL = \sum WLA + \sum LA + AFG + MOS}$$

Where MOS and AFG are the margin of safety and allowance for future growth terms, respectively; they were discussed above. TMDL is the total maximum daily load and is calculated from the water quality target (Section D7.2 discussed above) and total downstream flow. The latter is a simple sum of flows from the LA and WLA discussed below.

The sum of LA (∑ LA) considers both nonpoint and background contributions and is estimated just upstream of the effluent discharge. The LA considers runoff from an approximately 15 square mile drainage area consisting primarily of agricultural row cropland and low-density residential land use. To compute load to address chronic aquatic life criteria, the flow estimation employs the statistical annual ${}_7Q_{10}$ design flow [OAC 3745-2-05 (A)(1)(a)]. The annual ${}_7Q_{10}$ design flow is the seven-day, ten-year low flow and means the lowest seven-consecutive-day average flow expected to occur once every ten years. While there is no streamflow gage on Loramie Creek in this vicinity, the annual ${}_7Q_{10}$ flow from a nearby gage – Muchinippi Creek near Russells Point, Ohio (USGS #03260620) (Straub 2000) – is weighted downward based on the

[6] Information obtained from US Census Bureau "American FactFinder" from http://factfinder.census.gov under the 2009 population estimates data set.

drainage area ratio of the two systems. The stream-to-discharge ratio is quite small (< 0.15) so 100 percent of the annual $_7Q_{10}$ design flow is employed. The pollutant concentration for LA is determined from an average of six instantaneous (grab) samples on Loramie Creek at RM 36.84 (STORET #H02S28). Sample dates ranged from June to September 2008.

The sum of WLA (∑WLA) only considers effluent load from Botkins STP. The STP average design flow is used to determine the WLA [OAC 3745-2-05 (A)(4)(a)] . For Botkins STP, the design flow is 0.5 MGD (or 0.774 cfs). Effluent quality is determined using the PEQ-average calculation (Method B) for summer season only (June through September) using effluent monitoring data from the summer of 2010. PEQ-average is to be employed for determining allocations with respect to chronic aquatic life use criteria [OAC 3745-2-06 (A)(1,3)]. TDS monitoring was instituted in July 2010 through a permit modification made once the potential impairment cause was identified. The summer PEQ-average concentration is made with 25 samples; one outlier (very low value) is excluded from the analysis.

After subtracting the MOS from the criterion-based TMDL, the allowable load from the WWTP is 3.87 kg/day (Table D-40). The existing contributing load from all sources is 6.35 kg/day with the predominant contribution coming from point source entities (and Botkins STP). The minor contribution of TDS from non-point sectors includes de-icing salts applied to local roadways and agro-chemicals applied to cropland. Natural sources (rock and soil) offer a small amount to this total.

This comparison suggests that a 39.1 percent reduction in TDS load is needed (Table D-40) and based on the percentage of existing load, the primary responsibility for this reduction is assigned to the WLA. The WLA is 3.77 kg/day and conveys a TDS permit limit of approximately 1597 mg/L based on the facility's design flow (Table D-40). The remaining allowance and corresponding reduction is assigned to the LA (0.1 kg/day). Installation and improvement in grassed and forested riparian buffer strips would reduce the contribution from non-point sources.

Table D-40. Existing and allocated TDS loads, expressed in kg/day, by sector (e.g., WLA vs. LA), identification of allowance for future growth (AFG) and margin-of-safety (MOS) terms.
Note: After allocation, the resulting percent reduction (from existing load) and concentration at average design flow (ADF) is also portrayed. Conc = concentration of TDS in mg/L.

	Existing Loads			Allocated Loads		
	flow (cfs)	**conc (mg/L)**	**load (kg/day)**	**load (kg/day)**	**%reduction**	**conc (mg/L) @ ADF**
AFG	0	0	0			
LA	0.116	459	0.162	0.10	39.1%	
WLA: Botkins STP (1PB00007)	0.7735	2622.5	6.19	3.77	39.1%	1596.8
total			6.35	3.87		
TMDL	0.8895	1500	4.07			
MOS	5%		0.204			
TMDL less MOS			3.87			

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