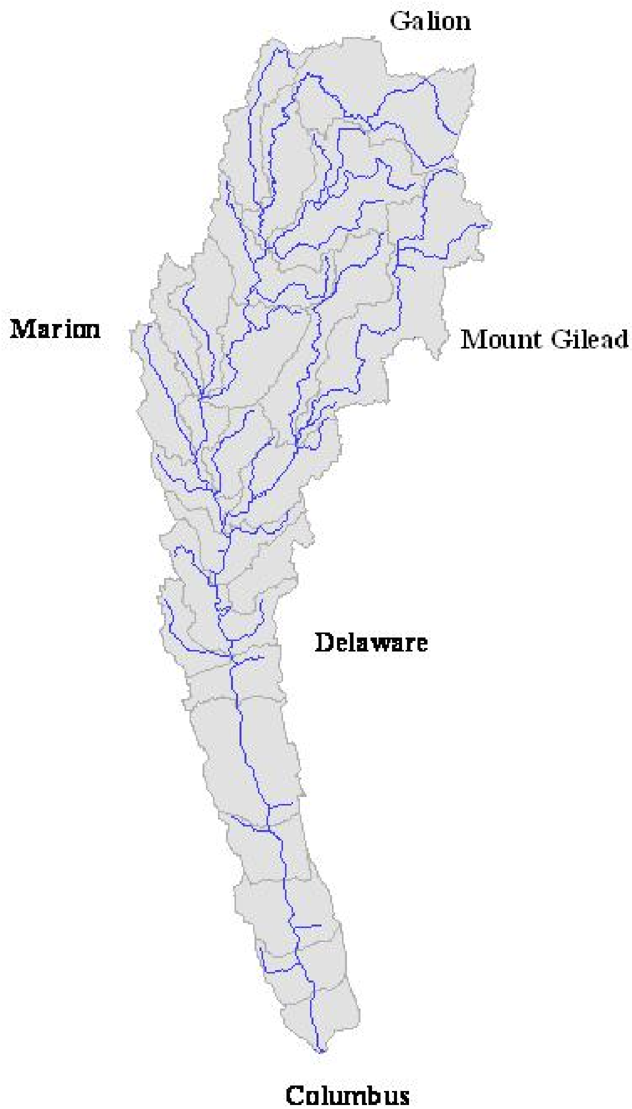
Olentangy River Watershed Total Maximum Daily Load Study

Final Report: March 2006



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Chapter 1: Introduction

1.0 Scope of Work and Objectives

The primary goal of this study was to conduct, in collaboration with Ohio Environmental Protection Agency (EPA), a research study on the Olentangy River watershed that would contribute to Total Maximum Daily Load (TMDL) development for the watershed. This collaborative effort between Ohio EPA and The Ohio State University had the following objectives:

1. Develop an informational database, identify target TMDL conditions, solicit stakeholder and Ohio EPA input throughout the process, and produce reports compliant with TMDL and United States EPA/Ohio EPA requirements.
2. Use computer simulation models to evaluate discharge and constituent transport on the landscape, within streams, and in reservoirs.
3. Statistically integrate biology, habitat, stream geomorphology, and water quality to carry out TMDL assessments.
4. Evaluate the impacts of environmental factors such as land use, habitat and, in particular, stream geomorphology on TMDLs.
5. Integrate TMDL development with research needs related to quantifying uncertainty of TMDL determinations using various watershed-related models.

Ohio is one of the few states with Water Quality Standards that considers not only water quality but also biology and the physical habitat. Integrating biology, habitat and water quality together in a quantitative manner is complex and has seen limited study. Furthermore, the role of stream processes and stream geomorphology in influencing stream health is relatively unknown and has generally not been considered in TMDL studies around the nation. One goal in having faculty and students at The Ohio State University (OSU) conduct this study was to help to address some of the research needs identified as high priority in a United States EPA report entitled, "The Twenty Needs Report: How scientific research can improve the TMDL program" (2002). Primarily, the goals of that study were to: (a) provide modeling technical support (Need 3); (b) help improve watershed and water quality modeling (Need 5); (c) perform landscape analyses to address site-specific and landscape-level issues (Need 13); and (d) strengthening the scientific basis of TMDL development to include statistical guidance for listing decisions, improving the analysis of the role of flow as ultimately affecting the designated uses, and methods for uncertainty analysis (Need 19).

The funded research proposal is presented in Appendix 1.A. A summary of the work that was performed is presented in this chapter together with an overview of the watershed, details on the development of TMDL targets (Objective 1), and an overview of agricultural best management practices (BMPs). The primary computer simulation model used to address Objective 2 was the Soil and Water Assessment Tool (SWAT; Neitsch et al., 2002a). SWAT is a river basin-scale model developed to quantify the impact of land management practices in large, complex watersheds. SWAT is a public domain model actively supported by the United States Department of Agriculture (USDA) Agricultural Research Service (ARS) at the Grassland, Soil and Water Research Laboratory in Temple, Texas.

Details on parameterization and calibration of the model are presented in Chapter 2. Results obtained with the SWAT model are presented in Chapter 3. The stream geomorphology study (parts of Objectives 3 and 4) is presented in Chapter 4. The study to statistically address relationships between biology, habitat, and stream geomorphology (Objective 3) is presented in Chapter 5. Evaluations of environmental factors that influence aquatic life use attainment, TMDLs and stream geomorphology (Objective 4) are presented in Chapters 1, 3, 4, and 5. Discussion of uncertainty (Objective 5) is presented in most chapters but primarily in Chapter 2. A summary of all 5 chapters and conclusions is provided in Chapter 6. Recommendations for implementation are presented in Chapter 7.

The work presented in this report was primarily performed by faculty, staff, and students in the College of Food Agricultural and Environmental Sciences at The Ohio State University. However, it was conducted in collaboration with personnel at the Ohio EPA. Much of the aquatic life data used in the analysis were obtained by Ohio EPA. Measured discharge data were obtained from the United State Geological Survey (USGS). Measured water quality data were obtained from several sources including Heidelberg College, the USGS, and Ohio EPA. Also, every 4 weeks to 8 weeks during much of the study, joint meetings were held with other agency personnel and stakeholders to inform them of project activities and progress, and to solicit their assistance and input into the study. Stakeholders provided valuable input and greatly helped with identifying potential sites and arranging access to those sites. Primary stakeholders included members of the Friends of the Lower Olentangy Watershed (FLOW) and the Olentangy Watershed Alliance (OWA).

1.1 Status of the Proposed Work

All of the proposed work to conduct the core TMDL study to satisfy federal requirements was performed. However, resource constraints (primarily time) prevented the OSU team from conducting some of the research aspects of the study. Specifically, we were unable to make scientific measurements of bed and bank erodibility. Also, only the primary watershed model, SWAT, was used in the analysis. Work initiated with the AGricultural NonPoint Source pollution (AGNPS) model was not completed. No work was performed with the CONservational Channel Evolution and Pollutant Transport System (CONCEPTS) model. Our inability to conduct this additional work was primarily related to problems with the SWAT model. Periodically, we discovered code errors and unexpected limitations of the model. The SWAT development team in Texas was very responsive to addressing these issues and their help was greatly appreciated. Resolving these issues caused various delays but also necessitated, on several occasions, redoing part of the analysis. In fact, several hundred simulations were performed over a period of several months before the first set of credible output was obtained. Another major problem that caused a considerable amount of additional work was significant errors in a climatic data set we had obtained from a credible source.

1.2 Overview of the Olentangy River Watershed

The Olentangy River watershed originates in Crawford County, Ohio and flows 88.5 miles south to its confluence with the Scioto River near downtown Columbus, Ohio (Figure 1.1). The total drainage area to the confluence as delineated by the SWAT model is approximately 541 mi^2.

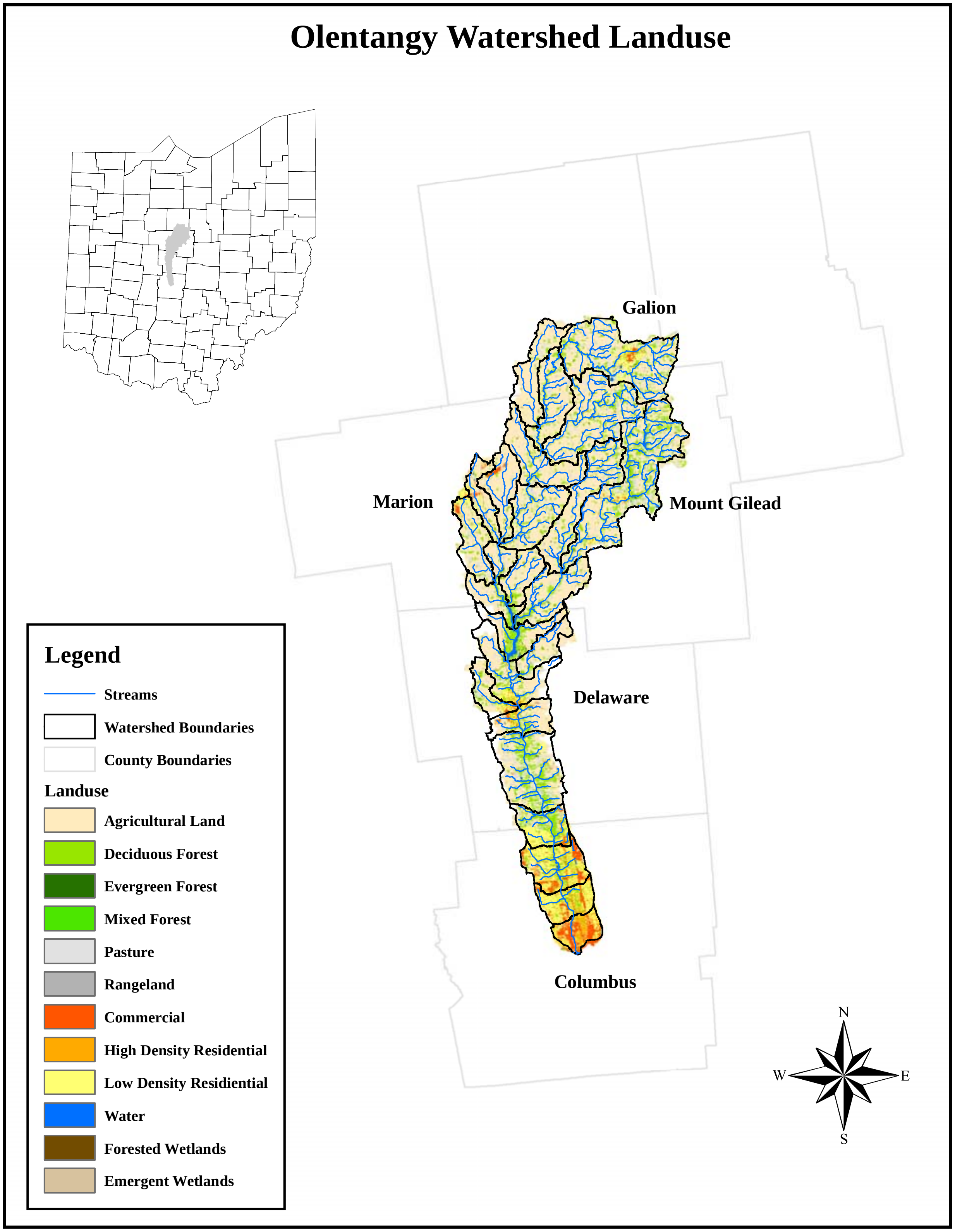


Figure 1.1 Tributaries, major cities and land uses on the Olentangy River watershed

Portions of the Olentangy River mainstem near Worthington, OH are designated as Exceptional Warmwater Habitat by the Ohio EPA. An Ohio EPA biological and water quality study of the lower Olentangy River watershed (1999; from the Delaware Dam south to Columbus, OH) found that, while most of this portion of the watershed was in attainment status, all of the nine tributaries studied were in non-attainment status. The report concluded that the urban nature of the lower watershed in and near Columbus, OH, continuing development in Delaware County, OH, and the degraded condition of the tributaries threaten the overall good water quality of the Olentangy River watershed.

Historically, land use changes between catastrophic events such as glacial movement were small, and it was easier for stream systems to remain in dynamic equilibrium. However, human activities in the last 200 years have resulted in major and often rapid changes in the landscape and receiving stream system. This has caused instability, made it difficult for streams to achieve equilibrium, and greatly reduced water quality, especially in urban areas.

The development of a soil conservation, stream stability, and sedimentation prevention strategy requires consideration of the interaction between the landscape, stream system, and the hydrologic and human inputs and outputs to this complex system. Land use changes on the landscape often increase the magnitude and volume of discharges, encroach on or eliminate the floodplain, and increase stream conveyance. Such impacts usually occur through physical changes to the channel such as lowering, widening and straightening. The influence of these changes on the stability, ecological function, and general health of the river system is very site-specific. Pollution sources in the Olentangy River watershed are diverse because the watershed spans an array of land uses from rural/agricultural to residential to urban. As a result, different parts of the runoff hydrograph will contribute different constituent loads throughout the watershed. Nutrients loads from crop production are associated with high subsurface drainage flows. Sewage discharges occur across a range of flows but are often largest during high discharge events. However, impacts to aquatic life in headwater systems might be greatest during baseflow conditions. Urban impacts are often greatest during the start of runoff and can be large even during small events. Evaluation of these factors and development of appropriate TMDL strategies in the Olentangy River watershed is, therefore, a complex process that is influenced by various spatial and temporal scales. Table 1.1 provides a summary of sites where we obtained data, were provided data, and/or conducted an analysis as part of our TMDL activities.

Table 1.1 Locations in the Olentangy River watershed where measurements were made or data were available.

Stream Name	RM	Location	DA (mi^2)	Biology		Habitat	Chem.	Morph.
				IBI	ICI	QHEI		
Rocky Fork Watershed (Olentangy River headwaters to Rocky Fork) 05060001-090-010								
Olentangy River	89.3	Olentangy @ Cummings St.	9	√	√	√	√	
	86.0/86.1	Upstream of Galion WWTP	12.2	√	√	√	√	
	85.9	Olentangy @ Hosford Rd.	12.2	√	√	√	√	
	85.2	@ Monnett New Winchester Rd.	12.4	√				x-sect
	84.5	@ Monnett New Winchester Rd.	24	√	√	√		x-sect
	79.7	Olentangy @ Shearer Rd.	39	√	√	√	√	
Rocky Fork	4.4	Rocky Fork @ CR 40	4.5					Full
	2.9	Rocky Fork @ Atkinson Rd.	8.7	√		√	√	
	0.4	Rocky Fork @Crawford Morrow Line	10.9	√		√	√	
Zimmerman Ditch	2.7	@ Iberia Rd.	0.4				√	
Trib to Olentangy River (RM 91.1)	1.5	Near Taylor Road						Full
Trib to Olentangy River (RM 84.0)	1.1	Near Taylor Road	0.4					Full
Olentangy River to Flat Run Watershed 05060001-090-020								
Olentangy River	74	Olentangy @ Monnett Chapel Rd.	50	√	√	√	√	x-sect
	70	@ Monnett New Winchester	56				√	
	68.1/68.0	@ Crawford Marion County Line Rd.	58	√	√	√	√	
	63.4/63.5	Olentangy @ Lyons Rd.	67	√	√	√	√	x-sect
Shumaker Ditch	0.5	Shumaker @ Timson Rd.	0.3				√	
Mud Run Watershed 05060001-090-030								
Mud Run	6.7	Mud Run @ Morral Kirkpatrick Rd.	7.7	√		√	√	x-sect
	2.7	Mud Run @ Monnett Chapel Rd.	17	√		√	√	x-sect

Table 1.1 Locations in the Olentangy River watershed where measurements were made or data were available (continued).

Stream Name	RM	Location	DA (mi^2)	Biology		Habitat	Chem.	Morph.
				IBI	ICI	QHEI		
Flat Run Watershed (including Thorn Run) 05060001-090-040								
Flat Run	20.3	Identified by undisclosed property owner	2	√		√		Full
	20	Identified by undisclosed property owner	2	√		√		Full
	15.5	Identified by undisclosed property owner	6.4	√		√		Full
	15.3	Identified by undisclosed property owner	6.6	√		√		Full
	15	Flat Run @SR 288	6.8	√		√		Full
	13.1	Flat Run @ SR 61	8.5	√		√		Full
	12.6	Flat Run @ SR 288 & SR 61	8.9	√		√	√	Full
	7.5	Flat Run @ Emahiser Rd.	12.6	√		√		Full
	7.3	Flat Run @ Harding Rd.	14.4	√		√		Full
	4	Flat Run @ SR 309	26.1	√		√	√	Full
	1.6	Flat Run @ Burson Rd.	29.5	√		√		Full
	0.8	@Marion Johnsonville Rd.	31.6	√		√		Full
	0.6	Flat Run @ Canaan Rd.	40.9	√		√	√	Full
	0.1	Downstream of Canaan Rd.	41.5	√		√		Full
Trib. to Flat Run	0.1	Identified by undisclosed property owner	1.9	√		√		Full
Trib. to Flat Run	0.1	@SR 288	5.1	√		√		Full
Trib. to Flat Run	0.1	Identified by undisclosed property owner	4.4	√		√		Full
Thorn Run	10	@ Mt. Gilead Iberia Galion Rd.	2	√		√		Full
	8.9	@ West Point Bellville Rd.	3.6	√		√	√	Full
	1.8	@ Cardington Denmark Martel Rd.	8.9	√		√		Full
	1.4	@ Cardington Caledonia Rd.	9	√		√		Full
	1.1	Thorn Run @ CR 61	9.3	√		√	√	Full
	1	Between Canaan, Burson, & CR 61	9.4	√		√		Full
	0.9	Between Canaan, Burson, & CR 61	9.5	√		√		Full
	0.7	Between Canaan, Burson, & CR 61	9.7	√		√		Full
	0.1	Between Canaan, Burson, & CR 61	12	√		√		Full

Table 1.1 Locations in the Olentangy River watershed where measurements were made or data were available (continued).

Stream Name	RM	Location	DA (mi^2)	Biology		Habitat	Chem.	Morph.
				IBI	ICI	QHEI		
Whetstone Creek Watershed to Shaw Creek 05060001-100-010								
Whetstone	30.5	Upstream of Candlewood Lake @ CR 40	7.5	√	√	√	√	x-sect
	29.3	Downstream of Candlewood WWTP	8.4	√	√	√	√	x-sect
	28.1	WC @ Marion Williamsport & CR 61	19	√	√	√	√	x-sect
	25.5	WC @ McKibben Rd.	26	√	√	√	√	x-sect
	23	WC @ SR 95	30				√	
	22.42	WC @ SR 61	34	√	√	√	√	x-sect
	21.7/21.8	WC @ Mt. Gilead WWTP	35	√	√	√	√	x-sect
	21.6	WC @ Loren Rd.	36	√			√	
	21.5	Downstream of Mt. Gilead WWTP	36	√	√	√	√	
	18.2/18.3	WC @ Bennett Rd.	40	√	√	√	√	Full
	13.7	@ Cardington WWTP	49	√			√	
	13.5	Downstream of Cardington WWTP	50	√		√	√	
	12.8	@ Cardington Western Rd.	52		√			
	9.2	@ Waldo-Fulton-Chesterville Rd.	62	√		√	√	x-sect
East Branch	3	EBWC @ SR 19	4.5				√	x-sect
	2.4	@ West Point Mt. Gilead Rd.	5.1					x-sect
	0.4	EBWC @ TR 76	6.3	√	√	√		Full
Sam's Creek	1.4	Sam's Creek @ Sunfish Rd.	7.8	√		√	√	x-sect
Trib to WC RM 33.71	1.4	@ SR 20	3	√		√	√	Full
Trib to Cox Ditch (Trib of WC)	0.1	@ TR 59 & TR 58	1					x-sect
Ruth's Run	0.2	@ CR 61	1					Full
Big Run	0.1	@ Cardington Western Rd.	6.1	√	√	√	√	x-sect
Shaw Creek Watershed 05060001-100-020								
Shaw Creek	13.2	@ Sexton Thatcher Rd.	11.8	√		√	√	x-sect
	10.6	@ South Canaan Rd.	14.8	√		√	√	Full
	5.2	Shaw Creek @ SR 529	21.1	√		√	√	x-sect
	1.6	Shaw Creek @ Beatty Rd.	26	√		√	√	x-sect

Table 1.1 Locations in the Olentangy River watershed where measurements were made or data were available (continued).

Stream Name	RM	Location	DA (mi^2)	Biology		Habitat	Chem.	Morph.
				IBI	ICI	QHEI		
Whetstone Creek below Shaw Creek to Delaware Reservoir 05060001-100-030								
Whetstone Creek	2.5	Near Cline Rd.	113	√		√		
	2.0	WC @ SR 229	113				√	x-sect
Claypole Run	1.2	Claypole Run @ Prospect-Mt. Vernon	3.8	√		√	√	x-sect
Mitchell Run	0.2	@ Delaware Cardington Rd.	5.4	√		√	√	Full
Trib to Whetstone Creek RM 2.3	0.7	@ Claypole Rd.						x-sect
Otter Creek Watershed (including Olentangy River) 05060001-110-010								
Olentangy River	59.5	Olentangy @ SR 746	134			√	√	
	58.8	Olentangy @ SR 95	135		√		√	
	56.6	Olentangy @ Claridon	142	√		√	√	
Otter Creek	1.1	Otter Creek @SR 95	8.3	√		√	√	x-sect
Bee Run	4.9	@ Marseilles Galion Rd.	1	√		√		x-sect
	0.3	@ Whetstone River Rd.	6.8	√		√		x-sect
Olentangy River below Otter Creek To Grave Creek 05060001-110-020								
Olentangy River	54.7	Olentangy @ SR 529	157	√	√	√	√	
	50.1/50.3	Olentangy @ River Rd.	174	√	√	√		
Riffle Creek Watershed 05060001-110-030								
Riffle Creek (MWH)	4.4	Riffle Creek @ Firstenberger Rd.	10.2	√		√	√	
	1.4	@ Marion Edison Rd.	15.8	√		√	√	
Olentangy River	45.6/45.5	Olentangy @ St. James Rd.	181	√	√	√	√	x-sect
Ulsh Ditch	2.9	Ulsh Ditch @ Roberts Rd.	1.9				√	
Grave Creek Watershed 05060001-110-040								
Grave Creek	3.21	Grave Creek @ SR 529	9.3	√		√	√	x-sect
	2.8	@ Marion WWTP, US 23	9.7				√	
	1.41	Grave Creek @ Firstenberger Rd.	11.3	√		√	√	x-sect
	0.8	Grave Creek @ SR 98	12.1	√		√		
	0.3	Grave Creek @ Whetstone River Rd.	28.5	√		√	√	

Table 1.1 Locations in the Olentangy River watershed where measurements were made or data were available (continued).

Stream Name	RM	Location	DA (mi^2)	Biology		Habitat	Chem.	Morph.
				IBI	ICI	QHEI		
Norton Run (including Olentangy River) 05060001-110-050								
Olentangy River	40.8/41.0	Olentangy @ Waldo Fulton Rd.	234	√	√	√	√	x-sect
	32.1	Olentangy @ SR 95	393	√		√	√	
Tomahawk Run		Tomahawk @ SR 23 & Ebert St.					√	
Norton Run	Not Surveyed during 2003-04							
QuaQua Creek Watershed 05060001-110-060								
Qua Qua	8	@ Sommerlot Hoffman Rd.					√	
	4.6	Qua Qua @ Owens Rd.	6.8	√		√	√	x-sect
	0.1	Qua Qua @ SR 98	17.1	√		√	√	x-sect
Brondige Run Watershed 05060001-110-070								
Brondige Run	0.7	Brondige Run @ SR 229	12			√	√	
Indian Run Watershed 05060001-110-080								
Indian Run	0.9	@ Horseshoe Rd. & Bishop Rd.	4	√		√	√	x-sect
Olentangy River from Delaware Dam to below Horseshoe Run 05060001-110-090								
Olentangy River	28.1/28.4	Olentangy @ Main Rd.	409	√	√	√	√	
	27.5	Olentangy @ Panhandle Rd.	471	√		√	√	
	27	Olentangy @ Hudson St.	470				√	
Norris Run	1.3	Norris Run @ Penry Rd.	5.8	√	√		√	x-sect
Sugar Run	1.3	Sugar Run Storage Facility	3.5	√	√		√	Full
Horseshoe Run 05060001-110-100								
Horseshoe Run	0.3	Horseshoe Rd & Kelly McMaster	10.3					x-sect
Delaware Run 05060001-110-110								
Delaware Run	1.2	@ Blue Limestone Park	8.5					Full
Mill Run	0.9	Mill Run @ North St.	1.8	√	√			x-sect

Table 1.1 Locations in the Olentangy River watershed where measurements were made or data were available (continued).

Stream Name	RM	Location	DA (mi^2)	Biology		Habitat	Chem.	Morph.
				IBI	ICI	QHEI		
Olentangy River 05060001-120-020								
Olentangy River	19.4	Olentangy @ Hyatts Rd.	455	√				
	15	Olentangy @ SR 750	483	√				
Deep Run	1.1/ 0.9	@ High Meadows Village Dr.	0.6	√				x-sect
Trib to Olentangy River (RM 20.7)	0.2	@ Chapman Rd. nr Bean Oller Rd.	2.4	√				
Big Run (Trib to OR RM 18.19)	0.1	Lewis Center @ Taggert Rd.	5.7	√				x-sect
Big Run N. Trib	0.5	Downstream of Columbus St.	3.1					x-sect
Big Run S. Trib	1.3	Downstream of Columbus St.	1.3					x-sect
	0.5	Downstream of Columbus St.	3.1					x-sect
Bartholomew Run	1	Not Surveyed in 2003-04.						
Olentangy River	12.8	@ OECC	493					
	12.1/12.4	Downstream of OECC	490					x-sect
	7.8	Olentangy @ Worthington	519					
Linworth Run	1.5	Linworth Run @ Linworth Rd.	2.5					Full
Trib to Olentangy River RM 13.3	0.2		1					x-sect
Rush Run 05060001-120-040								
Rush Run	1.5	@ Walnut Grove Cemetery	0.5					x-sect
Kempton Run	1.8	@ Don Scott/OSU Airport	2					x-sect
	1.1	@ Don Scott/OSU Airport	2.8					x-sect
Olentangy River 05060001-120-050								
Olentangy River	3.9	Olentangy @ Dodridge Rd.	535	√				
Adena Brook	0.3	@ Whetstone Park of Roses	5					x-sect
Turkey Run (WWH)	0.7	Turkey Run @ Shattuck Ave.	2.3	√				x-sect
Walhalla Ravine	0.9	Walhalla @ Gudrun Rd.	0.4	√				x-sect
Glen Echo Ravine	1	@ Glen Echo Park	0.5	√				
Olentangy River 05060001-120-060								
Olentangy River	2.1	Olentangy @ King Ave.	540	√				
	1.8	Olentangy @ 5th Ave. Dam	540	√				
	0.9	Olentangy @ Goodale Rd.	543	√				

As discussed earlier, the Olentangy River watershed is complex and possesses a number of calibration and modeling challenges. A large dam is located on the mainstem of the river and the two stream flow gages with the longest period of record are located downstream of the dam. Therefore, calibration for discharge required consideration of the release information for the dam together with routing of the discharge through the dam based on knowledge of the stage-storage-discharge rating curves available from the United States Army Corps of Engineers. Extensive watershed Geographic Information Systems (GIS) data are available for the upper portion of the Olentangy River and are currently being evaluated for other purposes by the OSU team. Similar data will be developed for the lower portion of the Olentangy River. A third stream flow gage located at Claridon (USGS OH0322300, drainage area 157 mi^2) will be particularly useful for calibration purposes and in the model comparison study. Some manipulation and additional information will be required with these data sets to provide the necessary information for the watershed model.

The structure and function of stream fish and macroinvertebrate assemblages is strongly associated with in-stream physiochemical conditions (e.g., substrate, channel morphology, and woody debris) as well as factors operating at larger scales such as land use practices within a watershed (Richards and Host, 1994; Lammert and Allan, 1999; Williams et al., 2002). Since the early 1980s, aquatic biota has been used by government agencies as a measure of water quality and watershed condition (Fausch et al., 1990). Because one of the primary objectives of the Clean Water Act (CWA) is to restore and maintain the physical, chemical, and biological integrity of United States surface waters, state and federal entities are required to establish water quality standards to meet CWA objectives. Thus, a complete assessment of stream health involves the evaluation of fish and macroinvertebrate assemblages, aquatic habitat, and adjacent riparian condition in addition to chemical analysis (Yoder and Rankin, 1998).

One of the greatest threats to stream systems is non-point source pollution, particularly sedimentation. Sediment is considered the greatest pollutant to stream systems (Waters, 1995). Straightening of stream channels and removal of riparian vegetation as a result of agricultural activities or urbanization can have strong effects on water quality and stream biota (Karr and Schlosser, 1978; Ward et al., 2002), which can lead to bank erosion and sedimentation (Mecklenburg and Ward, 2002). Removal of riparian vegetation can cause stream food webs to shift from heterotrophy to autotrophy and alter in-stream habitat, including increases in water temperature, changes in channel structure related to removal of woody debris, fewer inputs of leaf litter, and lower rates of organic matter retention (Gregory et al., 1991).

1.3 Targets for Total Phosphorus (TP), Nitrate-N and Total Suspended Solids (TSS)

In the state of Ohio, the primary objectives of water quality targets used in TMDL studies are to enhance and/or sustain attainment of aquatic life designations for lotic water systems within a watershed. Therefore, it is necessary that targets related to aquatic life attainment are consistent with constituent chemistry associations within these water systems, and are scientifically defendable. In addition, in the opinion of the TMDL team at The Ohio State University, the targets should be achievable through adoption of equitable, practical and economical treatment measures and BMPs.

1.3.1 Ohio EPA TMDL Targets for Olentangy River Watershed

Ohio EPA target TMDL concentrations for the Olentangy River watershed are reported in Table 1.2. The targets for total phosphorus (TP) and nitrate+nitrite-N are primarily based on recommendations presented in Table 1 and Table 2 of the Ohio EPA Technical Bulletin MAS/1999-1-1 (1999; pages 4-5). It is the opinion of the OSU team that the study reported in this document is one of the most comprehensive and authoritative studies of the associations between nutrients, habitat and aquatic biota. As the focus of the report is streams and rivers in Ohio it is appropriate that the results of this study are used to develop TMDL targets for the state of Ohio. However, we disagree with the recommended TMDL targets for TP and nitrate+nitrite-N reported in this study. While the report recommended TP values in the 1999 Technical Bulletin are based on levels for the Eastern Corn Belt Plain (ECBP) ecoregion, the recommended nitrate-N values are not based on any reported levels (Table 1.2).

Table 1.2 Ohio EPA recommended TMDL targets to support aquatic life in the Olentangy River Watershed (flow-weighted concentrations in mg/l).

Ohio EPA Recommendations			
Target	**TP**	**Nitrate-N**	**TSS**
Headwaters (DA<20mi^2)	0.07	1.0	9
Wadeable (20mi^2<DA<200mi^2)	0.11	1.0	31
Small Rivers (200mi^2<DA<1000mi^2)	0.16	1.5	44

Figures 1.1a and 1.1b of this report are based on Figure 18 from Ohio EPA Technical Bulletin MAS/1999-1-1 (1999; page 31). The authors of that study state *"IBI ranges (e.g., exceptional vs. good) separate rapidly with increasing TP concentration, whereas the separation with respect to nitrate-N does not occur until concentrations exceed 3 mg/l."* In several places in the Technical Bulletin the authors indicate there is little relationship between nitrate-N and aquatic biota (IBI and ICI values). For example, *"…concentrations observed in the ECBP ecoregion (<3-4 mg/l) did not appear to negatively affect the biota at such sites."* The basis for this statement is illustrated in Figure 1.3a of this report, which is taken from Figure 20 in the Ohio EPA Technical Bulletin (1999; page 28).

In a major multi-institutional study of hypoxia in the Gulf of Mexico (NOAA, 2000) it was proposed that a total nitrogen (TN) value less than 1.5 mg/l is needed to prevent eutrophic conditions (approximately 1.0 mg/l of nitrate-N in a mixed land use watershed) in lotic systems. A value of 3 mg/l of nitrate-N is consistent with standards to protect aquatic life that have been adopted in Canada (Environment Canada, 2003).

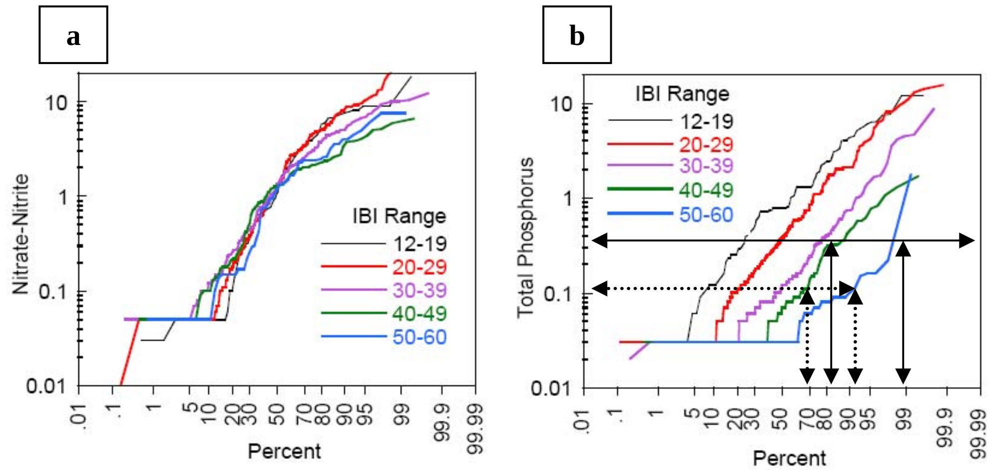


Figure 1.2a,b Cumulative frequency distributions by IBI score for (a) nitrate-N and (b) total phosphorus (*source: Figure 18; Ohio EPA, 1999*)

To a large extent, the recommended TP values can be supported by results presented in the Ohio EPA 1999 report. Also, the United States EPA (1986) recommends a TP value of <0.1 mg/l to prevent nuisance plant life in lotic systems. However, we question the statistical merit of the different targets for headwaters (drainage area < 20 mi^2), wadeable streams (drainage area 20 mi^2 < 200 mi^2), small rivers (drainage area 200 mi^2 < 1000 mi^2), and large rivers (drainage area > 1000 mi^2). First, there appears to be inconsistencies in the reported data for headwaters and wadeable streams versus small and large rivers. In Ohio, and many other parts of the ECBP ecoregion, a very large percentage of the headwaters and wadeable streams are agricultural drainage ditches or modified stream systems that exhibit higher nutrient loads than small rivers.

The data summarized in the Ohio EPA Technical Bulletin (1999) suggest that the number of agricultural systems considered was not consistent with the number of stream miles these systems represent. Figure 1.3b of this report is taken from Figure 14 in the Ohio EPA Technical Bulletin (1999; page 33). It illustrates that, in some cases, high IBI and ICI values will occur even when TP values exceed 0.2 mg/l. Figure 1.3b suggests that more than 20% of all sites with IBI values 40-49 have TP concentrations greater than 0.3 mg/l and about 2% of the sites with IBI values 50-60 exhibit TP concentrations greater than 0.3 mg/l. If a TP threshold of 0.1 mg/l is used, then about 35% of all the sites with IBI values 40-49 exceed this TP threshold and more than 10% of the sites with IBI values 50-60 exceed this TP threshold. Therefore, the results suggest that the TP concentration that is a limiting factor for aquatic life will usually be between 0.1 mg/l and 0.3 mg/l.

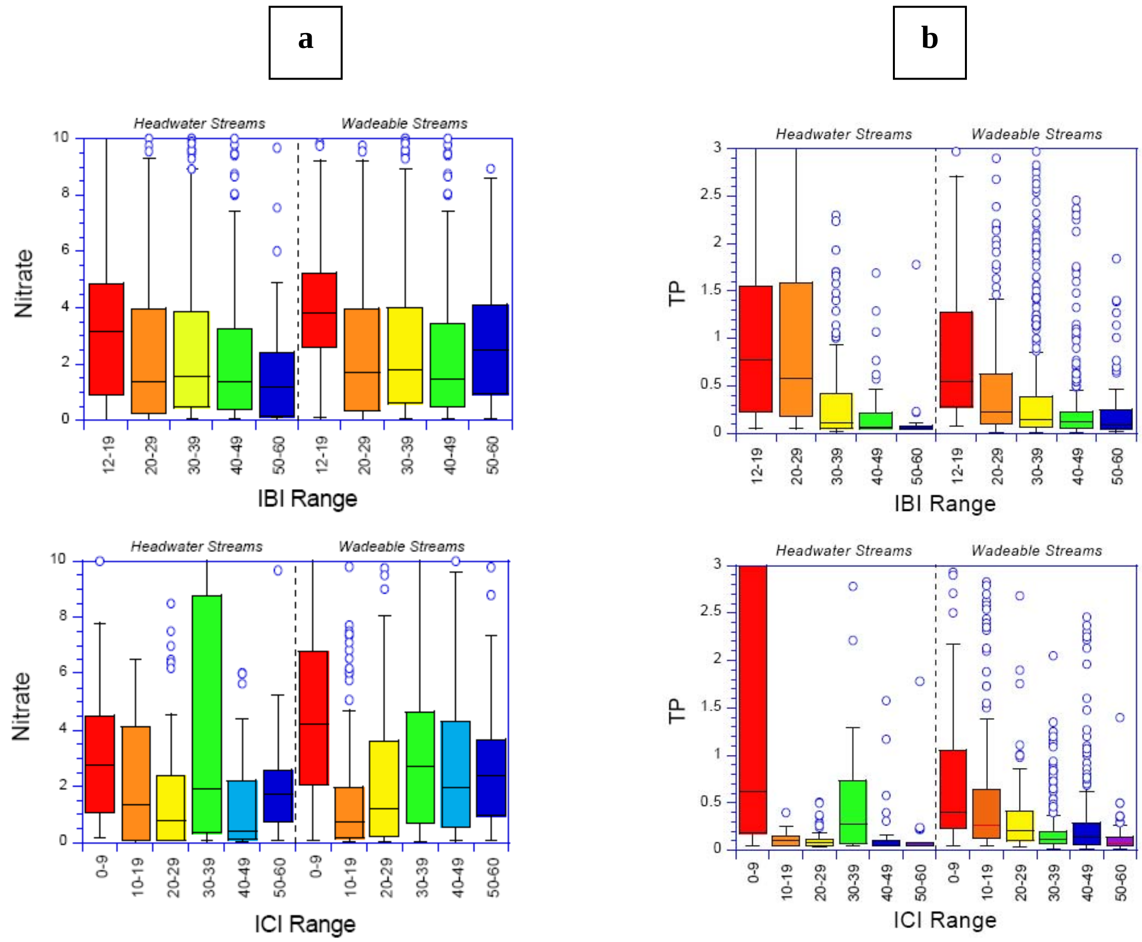


Figure 1.3a,b Background concentrations of nitrate-N (a; mg/l) and total phosphorus (b; mg/l) by IBI and ICI range (*source: Ohio EPA, 1999*)

The Ohio EPA Technical Bulletin (1999) and the literature provide little insight on appropriate targets for total suspended solids (TSS). However, as noted in the 1999 report, *"TP is often delivered to streams attached to solids particles such as sediment or suspended particles in WWTP discharges."*

Unlike TP and nitrate-N, efforts to reduce TSS loads could adversely impact stream geomorphology and the aquatic life. Agricultural BMPs such as buffers strips and conservation tillage can substantially reduce sediment discharges to receiving lotic systems. However, these practices have the potential to create "sediment hungry" stream flows that might increase bed and bank scour. In natural stream systems that are in dynamic equilibrium and have wide well-attached floodplains, it is probable that these systems will be able to adjust to changes in the sediment supply and remain in equilibrium. However, like large parts of Ohio, many of the streams in the Olentangy River watershed are incised and have limited access to a broad floodplain.

There is considerable evidence in the literature to suggest that landscape-based BMPs might have little influence on the net export of sediments from lotic systems (Trimble and Crosson, 2000; Ward and Trimble, 2004) and that the source of more than two-thirds of the sediment export is from bank and bed erosion (ASAE, 2004). Another problem with agricultural BMPs and stormwater management strategies in urbanizing areas is that they primarily remove the coarser fractions of the sediment load that are the most important in terms of both stream geomorphology and aquatic life.

1.3.2 Development of Alternative TMDL Targets

In Table 1.3, we present suggested TMDL targets we feel are scientifically defendable and consistent with constituent chemistry associations within lotic water system in the state of Ohio. All targets are based on a goal to sustain an aquatic life community with an IBI score of at least 40. A probability of risk approach commonly used in engineering design was used to identify the targets. The risk approach was then coupled with a factor of safety, knowledge of constituent thresholds reported as influencing aquatic life, and the practicality of achieving a target on a watershed where the dominant non-point sources are related to agriculture. The targets are based on: (1) consideration of constituent chemistry associations for lotic systems in the region; (2) reviews of a multi-institutional study of hypoxia in the Gulf of Mexico (NOAA, 2000), National Water Quality Assessment (NAQWA) studies by the USGS, and other literature; and to a large extent (3) an evaluation of the ALL sites data presented in Appendix 2 of the Ohio EPA Technical Bulletin (1999).

Table 1.3 TMDL recommendations to support aquatic life in Ohio's streams (average flow-weighted concentrations in mg/l)*.

Target	Total P	Nitrate-N	TSS
WWH with DA>1000 mi^2	0.20	2.5	100
WWH with DA<1000 mi^2 Factor of Safety (FS) of 1.5	0.16	2.0	80
EWH with DA>1000 mi^2	0.16	2.0	80
EWH with 20 mi^2 <DA<200 mi^2 (FS of 2.0)	0.12	1.5	60
EWH with DA<20 mi^2 (FS of 3.0)	0.08	1.0	40

* An analysis was not performed for drainage areas > 1000 mi^2.

In Table 1.4, we present a summary of water quality data obtained by Heidelberg College since 1997 for 11 small and large rivers in Ohio and Michigan (*www.heidelberg.edu*). The database includes samples obtained from the USGS gage on the Scioto River at Chillicothe, Ohio. For this data, the ratio of nitrate-N to TP is 12:1, which is slightly larger than the ratio of 10:1 used in the Ohio EPA Technical Bulletin (1999), and the ratio of TSS to TP exceeds 300 for all rivers with an average of 566. In contrast, TMDL targets that Ohio EPA has proposed for the Olentangy River watershed have ratios ranging from about 130 to less than 300.

For these streams and rivers, the mean nitrate-N, TP, and TSS concentrations are 0.34 mg/l, 4.1 mg/l, and 182 mg/l, respectively. The percent reductions needed to achieve Ohio EPA targets and targets proposed in Table 1.3 are summarized in Table 1.5. Reductions for the three small streams have been related to Exceptional Warmwater Habitat (EWH) targets. Targets for the large rivers are related to Warmwater Habitat (WWH) targets for small rivers. The rationale for doing this is that improving water quality in large rivers will be associated with the application of BMPs on the landscape drained by headwaters, wadeable streams, and small streams.

Concentrations reported in Table 1.4 for several Ohio Rivers are consistent with results obtained for gages on agricultural watersheds located throughout the Midwest and cropland throughout the United States (Table 1.6). In fact, data in Table 1.6 indicate that to meet Ohio EPA targets a high percentage of forest would be needed on most watersheds and EWH targets for headwater systems would normally only be achieved if most of the watershed was forested. The results in Table 1.5 suggest that to meet Ohio EPA targets would often require nitrate-N, TP, and TSS reductions greater than 70% and, in many cases, reductions greater than 80%. The targets we have proposed often would require reductions between about 50-70%. These reduction levels are more consistent with the ability of a combination of BMPs to reduce nutrient and sediment loads (see the next section for further detail).

Table 1.4 Water quality of Ohio Rivers for 1997-2003, with the exception of Sandusky (1197-1999; 2002-2003) and Vermilion (2001-2003) (mean flow-weighted concentrations in mg/l; *source: http://www.heidelberg.edu/WQL/index.html).*

River Name	Total P	NO_2+NO_3-N	TSS	N:TP Ratio	TSS:TP Ratio
Wadeable Stream[1]	*0.16*	*2.0*	*80*	*12.5*	*500*
Rock Creek	0.50	4.0	302	8.0	602
Honey Creek	0.42	6.1	160	14.5	379
Mean	**0.46**	**5.0**	**231**	**11.3**	**490**
Small River[2]	*0.16*	*2.0*	*60*	*12.5*	*500*
Vermilion	0.29	3.6	162	12.4	548
Grand	0.15	0.7	159	4.7	1045
Cuyahoga	0.35	1.7	323	4.9	934
Mean	**0.26**	**2.0**	**215**	**7.3**	**842**
Large River[1]	*0.20*	*2.5*	*100*	*12.5*	*500*
Raisin	0.21	5.1	109	24.3	518
Sandusky	0.43	6.7	226	15.6	520
Great Miami	0.42	4.9	146	11.7	345
Scioto	0.35	4.3	143	12.3	413
Maumee	0.42	6.5	197	15.5	473
Muskingum	0.17	1.7	78	10.0	453
Mean	**0.33**	**4.9**	**150**	**14.9**	**454**
Mean All Sites	**0.34**	**4.1**	**182**	**12.1**	**566**

[1] WWH TMDL targets recommended in Table 1.3.
[2] EWH TMDL targets recommended in Table 1.3.

Table 1.5 Estimates of reductions needed, on average, for Ohio Rivers in Table 1.4 to meet TMDL targets presented in Tables 1.2 and 1.3.

	Total P mg/L	NO2+NO3-N mg/L	TSS mg/L
Wadeable Mean	**0.46**	**5.0**	**231**
Wadeable Stream Target 1	0.11	1.0	31
Wadeable Stream Target 2	0.16	2.0	80
Reduction for Target 1	76	80	87
Reduction for Target 2	65	60	65
Small River Mean	**0.26**	**2.0**	**215**
Small River Target 1	0.07	0.5	26
Small River Target 2	0.12	1.5	60
Reduction for Target 1	73	75	88
Reduction for Target 2	54	25	72
Large River Mean	**0.33**	**4.9**	**150**
Target 1	0.16	1.5	44
Target 2	0.16	2.0	80
Reduction for Target 1	52	69	71
Reduction for Target 2	52	59	47

Table 1.6 Mean flow-weighted concentrations (mg/l) of nutrients in streams in the United States located on watersheds were the dominate land use is forest, urban, or agriculture.

Land Use	Land Use (%)	Number Of Sites	Mean Concentration (mg/L)			Concentration Ratios		
			NO_3	TN	TP	NO_3/TN	NO_3/TP	TN/TP
Forest[1]	87	36	0.2	0.4	0.08	0.45	2.4	5.4
Urban[1]	61	39	1.1	2.2	0.24	0.52	4.6	8.9
Cropland[1]	70	105	3.4	4.3	0.28	0.78	11.8	15.1
Midwest Agr.[2]	60+	12	4.2	5.7	0.30	0.74	15.7	20.9

[1]National nutrients summary for the Heinz Center report: The State of the Nation's Ecosystems, 2002. (URL:http://water.usgs.gov/nawqa/nutrients/datasets/nutconc2000/ ; Data for rivers and streams from NAWQA Study Units started in 1991 and 1994.)
[2]Hypoxia Work Group Topic 3 (NOAA, 2000).

A summary of results of the analysis conducted to develop these targets is presented in Tables 1.7 and 1.8. Additional details are provided in Appendix 1.B. In developing credible targets there is a need to ensure that the association between chemical constituents is representative of conditions that might normally occur; and, more importantly, that aquatic life is related to the target water quality constituents. Based on an evaluation of the data in Tables 1.4, 1.6, 1.7, and 1.8 we concluded that nitrate+nitrite-N to TP and TSS to TP ratios of 12.5 and 500, respectively, were representative of nutrient and sediment discharges from agricultural watersheds. The approach we used to address the issue of relatedness to aquatic life was to consider the probability that aquatic life attainment occurred even though the water quality target was exceeded. A high probability of this occurring suggests that aquatic life is unrelated to water quality. We also attempted to evaluate the condition where aquatic life attainment did not occur even though the water quality target was achieved.

For the first case, we wanted to consider the target thresholds where 5, 10, 15, 20, and 25 percent of all the sites achieved aquatic life attainment despite not achieving a water quality target threshold. In engineering design, values of 5% or 10% are often used. From Table 1.7 it can be seen that a TP of 0.32 mg/l results in about 10% (9.7%) of the sites exceeding this value but still achieving aquatic life attainment. We did not evaluate TP values greater than 0.32 mg/l so the 5% threshold was not identified.

At the opposite end of the scale, a TP threshold of 0.08 mg/l results in about 20% (20.5%) of the sites exceeding this value but still achieving aquatic life attainment. This represents 53% of all the sites with an IBI greater than 40. Nearly 60% of all the sites have a TP greater 0.08 mg/l. These results indicate that, at these levels, TP has much less influence on aquatic life as nearly half the sites that are in aquatic life attainment exhibit higher TP values; and this target value would apply to about 60% of the sites. As non-attainment can be influenced by many other factors it is hard to scientifically justify a target TP of 0.08 mg/l when a large percentage of the time good to excellent IBI scores are obtained when the mean TP value exceeds this threshold. If the influence of the many other factors that adversely impact aquatic life could be reduced or eliminated the potential exists that it might take a very high TP level to adversely impact aquatic life.

The number of samples associated with different TP values and IBI ranges is reported in Table 1.7. With the exception of exceptional headwater systems there is a distinct but inconclusive relationship between IBI and TP. While the percentage of good IBI sites increases as TP values decrease (a water quality improvement) there are large numbers of poor IBI sites with good water quality. For example, 40%-45% of the wadeable sites with IBI values of 20-29 have a TP less than 0.12 mg/l. Nearly a third of the wadeable sites with IBI values less than 20 also have a TP less than 0.12 mg/l.

As the nitrate-N values in Table 1.8 change from 0.5 mg/l to 3.0 mg/l they exhibit a statistical pattern that is similar to the TP values in Table 1.7. Nitrate-N values less than 0.5 mg/l are exhibited by only about a third of all the samples and about two-thirds of the sites that are in aquatic life attainment have poorer water quality. On the other hand, only 9.7% of all sites had an IBI greater than 40 and nitrate-N greater than 3.0 mg/l. This represents 24% of all the sites with an IBI greater than 40 and only 31% of all the sites exhibited nitrate-N greater than 3.0 mg/l.

For WWH conditions the association with drainage area is weak so we propose a target TP value of 0.16 mg/l and a nitrate-N value of 2.0 mg/l for all drainage areas smaller than 1000 mi^2. These values were obtained by applying a factor of safety of 1.5 (using $2/3^{rds}$) to the TP value of 0.24 mg/l and nitrate-N value of 3.0 mg/l. From Tables 1.7 and 1.8, about 16% (15.7%) of the TP values and 15% (14.7%) of the nitrate-N values exceed this threshold but achieve aquatic life attainment. In addition, approximately half the sites would be influenced by these targets. For large rivers, we have proposed a TP target value of 0.20 mg/l and a nitrate-N value of 2.5 mg/l. We have proposed three EWH targets that are based on results in Tables 1.7 and 1.8, and are tied to nutrient thresholds that limit the likelihood of eutrophic conditions in lotic systems. The EWH target for large rivers is based on the philosophy that some tributaries might be designated as WWH that essentially act as point sources to the main stem of the large river. Therefore, in these exceptional systems we are placing an upper limit on water quality anywhere in the system.

If the proposed targets are applied to the eleven streams and rivers reported in Table 1.4 it can be seen that only one of these lotic systems, Muskingum River, achieves the targets for all three constituents. The two wadeable streams meet none of the targets. None of the three small rivers meet the TSS target. The Grand River and the Cuyahoga River meet the nitrate+nitrite-N target. One of the six large rivers meets the proposed TP target. Two also meet the TSS target, but only the Muskingum River meets all three targets for WWH designation. However, the Muskingum River has an EWH designation and just fails to achieve the targets we have proposed for large river EWH systems.

Table 1.7 Analysis of summary TP data for ALL sites in Appendix 2 of Ohio EPA Technical Bulletin (1999)[1]

Type	Sample Total #	Sample IBI 40+ #	Percent IBI 40+ %	Sample TP Targ. #	Percent TP Targ. %	Sample IBI+TP #	Percent IBI+TP %	Prob. 1 %	Prob. 2 %
1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Target TP=0.08									
Headwater	783	113	14.4	282	36	73	9.3		36
Wadeable	1711	732	42.8	758	44	352	20.6		52
Small	762	405	53.1	274	36	157	20.6		61
All	3256	1250	38.4	1314	**40**	582	17.9	**20.5**	**53**
Target TP=0.12									
Headwater	783	113	14.4	320	41	84	10.8		25
Wadeable	1711	732	42.8	851	50	399	23.3		46
Small	762	405	53.1	331	43	189	24.7		53
All	3256	1250	38.4	1502	**46**	671	20.6	**17.8**	**46**
Target TP=0.16									
Headwater	783	113	14.4	346	44	89	11.4		21
Wadeable	1711	732	42.8	926	54	436	25.5		40
Small	762	405	53.1	382	50	216	28.3		47
All	3256	1250	38.4	1654	**51**	740	22.7	**15.7**	**41**
Target TP=0.24									
Headwater	783	113	14.4	388	49	96	12.3		15
Wadeable	1711	732	42.8	1041	61	491	28.7		33
Small	762	405	53.1	467	61	260	34.1		36
All	3256	1250	38.4	1895	**58**	848	26.0	**12.4**	**32**
Target TP=0.32									
Headwater	783	113	14.4	420	54	102	13.0		10
Wadeable	1711	732	42.8	1132	66	536	31.3		27
Small	762	405	53.1	538	71	297	39.0		27
All	3256	1250	38.4	2090	**64**	936	28.7	**9.7**	**25**

[1] Columns 3 and 4: number and percent of samples with IBI > 40.
Columns 5 and 6: number and percent of samples with TP < target value.
Columns 7 and 8: number and percent of samples with TP < target value and IBI > 40.
Column 9: percent of all sites with a TP > target value and IBI > 40.
Column 10: percent of sites in attainment with a TP > target value.

Table 1.8 Analysis of summary nitrate-N data for ALL sites in Appendix 2 of Ohio EPA Technical Bulletin (1999)[1]

Type	Sample Total #	Sample IBI 40+ #	Percent IBI 40+ %	Sample N targ. #	Percent N targ. %	Sample IBI+N #	Percent IBI+N %	Prob. 1 %	Prob. 2 %
1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Target N=0.5									
Headwater	630	114	18.1	267	42	44	7.0		61
Wadeable	1631	697	42.7	548	34	253	15.5		64
Small	703	398	56.6	180	26	130	18.5		67
All	2964	1209	40.8	995	34	427	14.4	**26.4**	**65**
Target N=1.0									
Headwater	630	114	18.1	332	53	59	9.3		48
Wadeable	1631	697	42.7	721	44	339	20.8		51
Small	703	398	56.6	253	36	176	25.1		56
All	2964	1209	40.8	1307	44	574	19.4	**21.4**	**53**
Target N=1.5									
Headwater	630	114	18.1	377	60	68	10.8		40
Wadeable	1631	697	42.7	847	52	402	24.6		42
Small	703	398	56.6	313	45	212	30.1		47
All	2964	1209	40.8	1537	52	681	23.0	**17.8**	**44**
Target N=2.0									
Headwater	630	114	18.1	415	66	79	12.6		30
Wadeable	1631	697	42.7	950	58	454	27.8		35
Small	703	398	56.6	366	52	240	34.2		40
All	2964	1209	40.8	1731	58	774	26.1	**14.7**	**36**
Target N=2.5									
Headwater	630	114	18.1	447	71	88	13.9		23
Wadeable	1631	697	42.7	1038	64	498	30.5		29
Small	703	398	56.6	415	59	266	37.8		33
All	2964	1209	40.8	1899	64	851	28.7	**12.1**	**30**
Target N=3.0									
Headwater	630	114	18.1	473	75	95	15.1		17
Wadeable	1631	697	42.7	1118	69	538	33.0		23
Small	703	398	56.6	460	65	288	41.0		28
All	2964	1209	40.8	2051	69	921	31.1	**9.7**	**24**

[1] Columns 3 and 4: number and percent of samples with IBI > 40.
Columns 5 and 6: number and percent of samples with nitrate-N < target value.
Columns 7 and 8: number and percent of samples with nitrate-N < target value and IBI > 40.
Column 9: percent of all sites with a nitrate-N > target value and IBI > 40.
Column 10: percent of sites in attainment with a nitrate-N > target value.

The difficulty with associating aquatic life to nutrient loads is illustrated in Tables 1.9 and 1.10. These tables also are based on an analysis of the ALL sites in Appendix 2 of the Ohio EPA Technical Bulletin (1999) used earlier to produce the results presented in Tables 1.7 and 1.8. Results in Table 1.9 show the weak association of TP concentration with IBI and clearly show how this association diminishes as the stream system become larger. Wadeable sites with IBI values from 20-39 have similar TP concentrations and sites with IBI values of 40-59 have only slightly lower TP concentrations. Small rivers with IBI values of 30-59 have very similar TP concentrations. The association between nitrate-N concentrations and aquatic life is even weaker. In fact, for wadeable streams the nitrate-N concentrations are very similar for sites with poor, good, or excellent aquatic life (Table 1.10).

Table 1.9 Percentage of sites in each IBI range with TP concentration below the reported values

Location	TP Value (mg/l)	Percent of samples in IBI Range and below TP value				
		12-20	20-29	30-39	40-49	50-59
Headwater	0.08	26	27	49	53	80
	0.12	29	31	54	60	100
	0.16	***32***	***34***	***57***	***65***	***100***
	0.24	36	39	62	73	100
Wadeable	0.08	28	40	45	50	54
	0.12	33	45	49	56	60
	0.16	***36***	***49***	***53***	***60***	***64***
	0.24	42	55	58	68	71
Small	0.08		25	43	44	42
	0.12		32	50	51	49
	0.16		***39***	***55***	***58***	***54***
	0.24		50	64	67	64

Table 1.10 Percentage of sites in each IBI range with nitrate-N concentration below reported values

Location	TP Value (mg/l)	Percent of samples in IBI Range and below N value				
		12-20	20-29	30-39	40-49	50-59
Headwater	0.5	43	44	42	35	62
	1	52	53	53	46	70
	1.5	***58***	***59***	***61***	***55***	***76***
	2	63	64	67	62	80
Wadeable	0.5	20	35	36	34	33
	1	28	46	46	46	44
	1.5	***35***	***53***	***52***	***54***	***52***
	2	41	59	57	61	58
Small	0.5		9	31	36	23
	1		18	42	49	33
	1.5		***27***	***50***	***57***	***40***
	2		35	56	65	46

One reason for the limited association in lotic systems of TP and nitrate-N with aquatic life is the variable association of these nutrients with chlorophyll a. Earlier, we noted that TP values of 0.1 mg/l and TN values of 1.5 mg/l have been suggested as thresholds for the establishment of eutrophic conditions in lotic systems. In Figures 1.4, 1.5, and 1.6 it can be seen that there is little relationship between chlorophyll a and TP or TN in the concentration ranges of these nutrients in most Ohio streams and rivers. For a TP range of 0.1 mg/l to 0.3 mg/l, chlorophyll a ranges from 2 µg/l to 200 µg/l (Figure 1.4). For a TN range of 0.5 mg/l to 3.0 mg/l, chlorophyll a ranges from 2 µg/l to 80 µg/l (Figure 1.5) with both the lowest and highest concentrations associated with the highest TN concentration.

1.4 Agricultural BMPs

Agricultural best management practices (BMPs) are methods, measures, or practices selected to meet the needs of non-point source control. They include structural and vegetative controls and management procedures that reduce or eliminate the transport of pollutants to receiving waters. BMPs can be selected to control a known type of pollution based on the effectiveness of controlling and reducing the pollution. BMPs for controlling sediment should be effective in controlling land and streambank erosion, routing runoff through BMPs that capture sediment, and disposing of sediment properly. Practices to control nutrients, such as nitrogen and phosphorus should be effective in: (1) minimizing sources, (2) utilizing all that is applied to the land or containing and reusing it, (3) containing animal waste, processing, and land applying, (4) minimizing soil erosion and sediment delivery, (5) and intercepting and treating runoff before it reaches the water (Novotny, 2003). A summary of practices for sediment and nutrient control are provided in Table 1.11. Effectiveness of each BMP provided is based on the results of various water quality studies.

Percent reductions are calculated by a comparison of the BMP and a conventional method or by analyzing how much pollutant was filtered from the runoff. Crop rotation is a cropping practice that is not listed in Table 1.11. This practice works by improving soil structure, which decreases soil detachment and requires fewer nutrients. The most effective rotations for water quality involve at least two years of grass or legumes in a rotation. Novotny (2003) reported that load reductions are difficult to quantify but there have been some estimated annual nitrogen and phosphorus reductions of 50% and 30%, respectively. Care should be taken in attempting to apply the reported reductions to agricultural watersheds in Ohio as it is difficult to transfer results from one region to another, and at various locations throughout our watersheds some farmers, agencies, and other stakeholders have already implemented some of these BMPs.

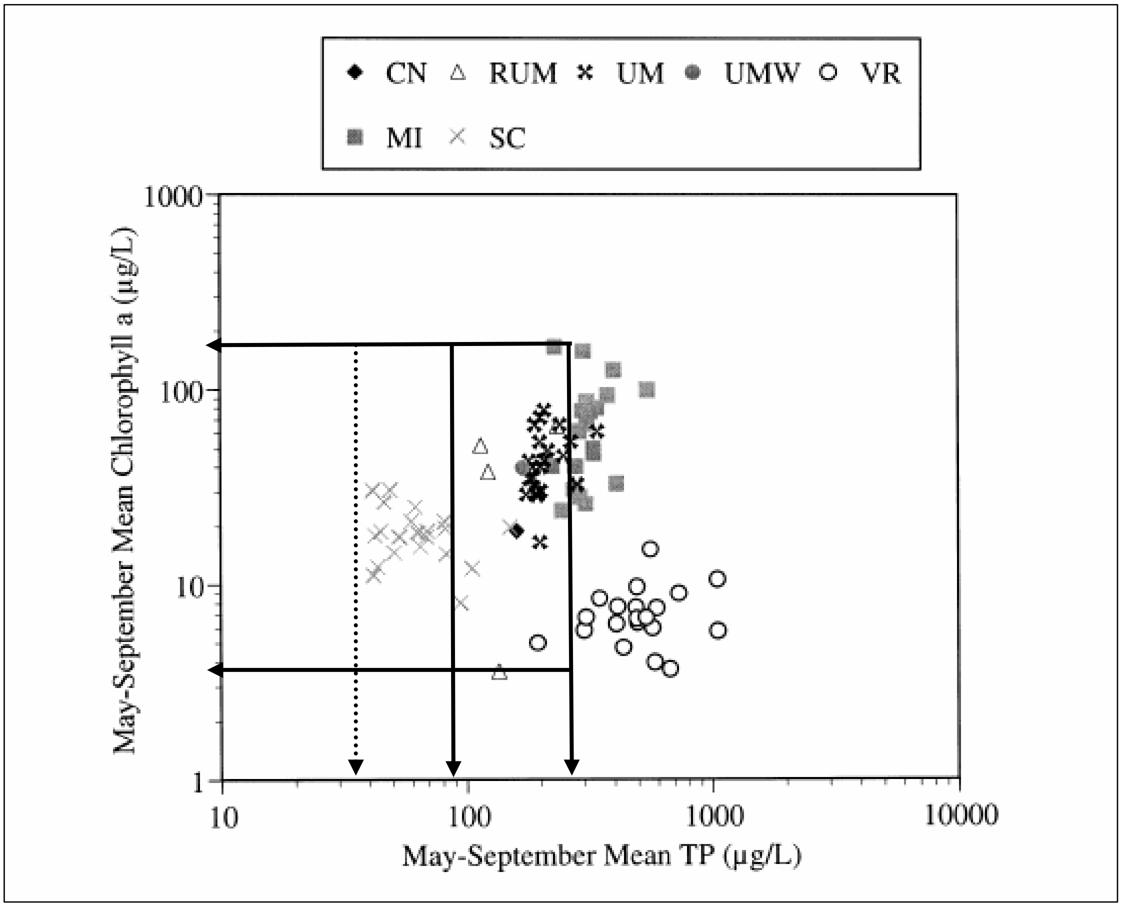


Figure 1.4 Mean chlorophyll a concentration for May-September versus mean TP concentration. (*source: Figure 3.26; NOAA, 2000*)

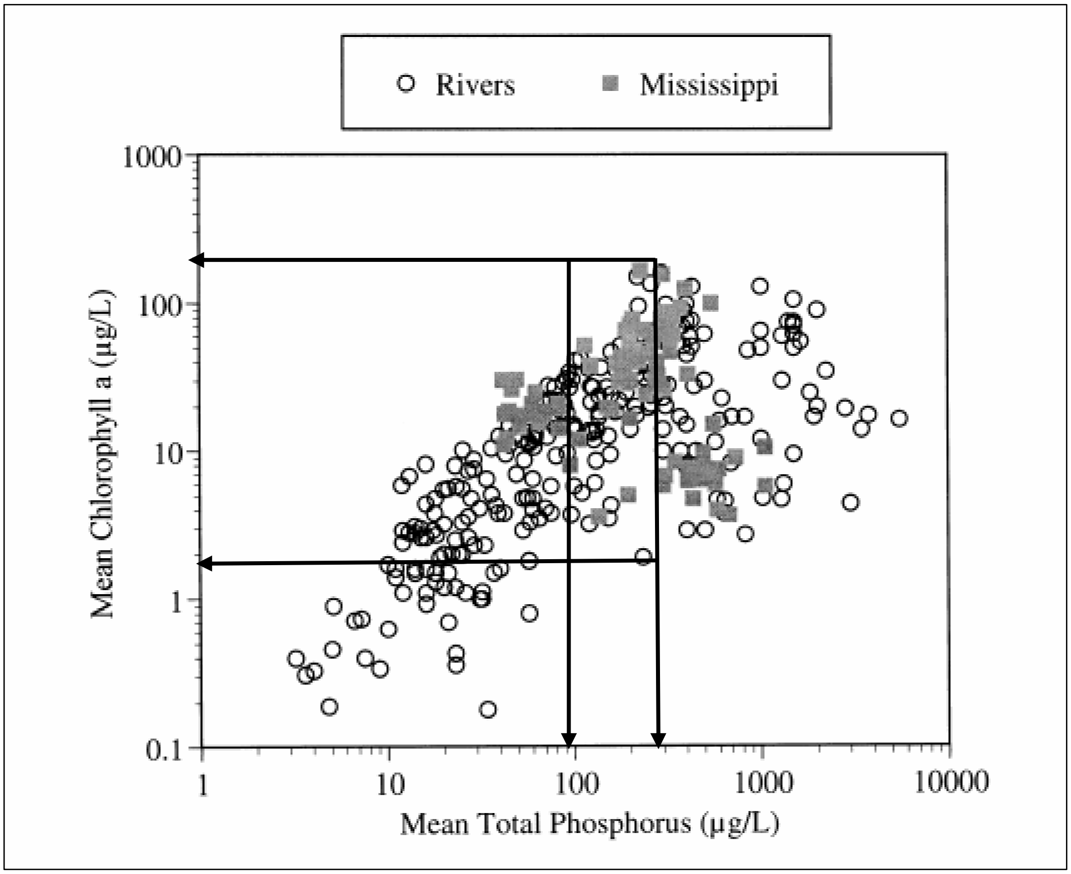


Figure 1.5 Growing season mean chlorophyll a concentration for May-September versus mean TP concentration for various rivers. (*source: Figure 3.29; NOAA, 2000*)

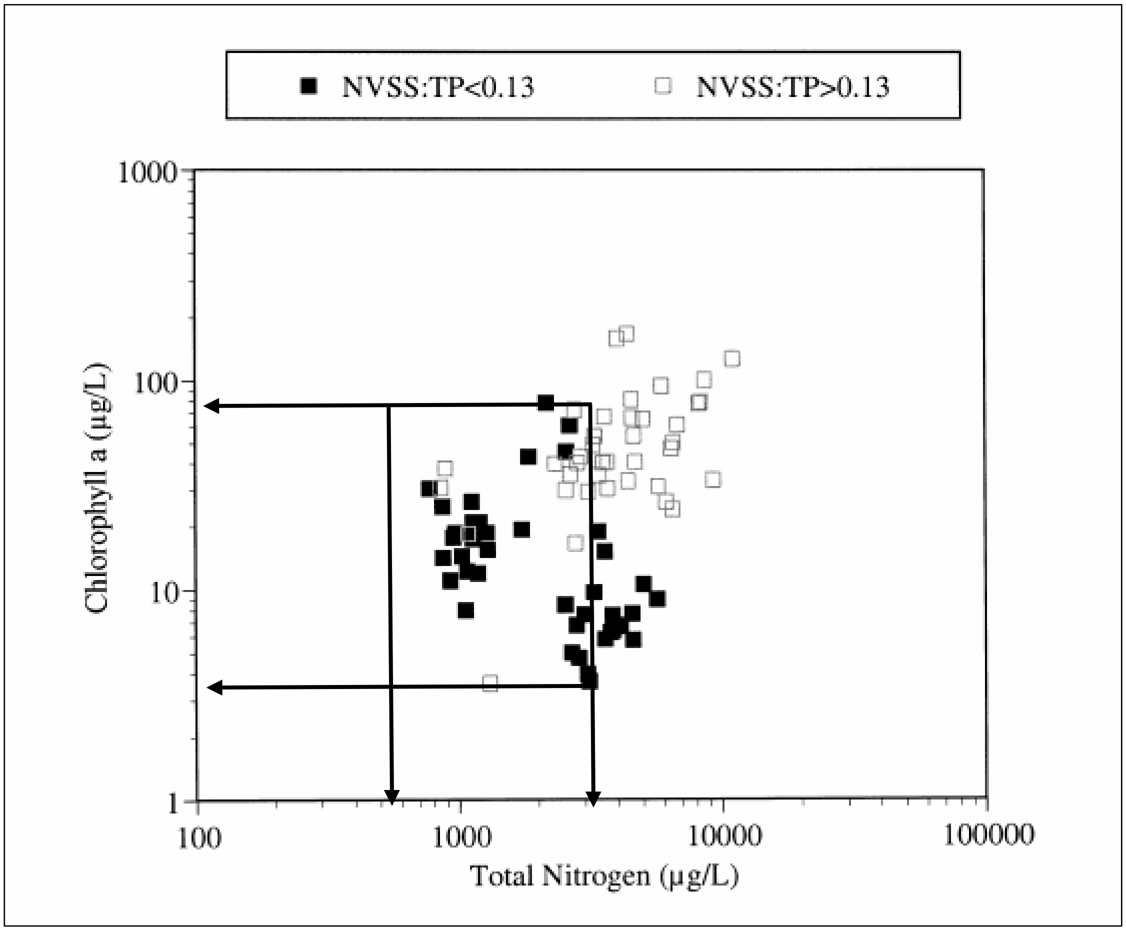


Figure 1.6 Growing season mean chlorophyll a concentration for May-September versus mean TN concentration. (*Source: Figure 3.28; NOAA, 2000*)

Table 1.11 Types of BMPs and the load reductions reported for a range of water quality studies

Reference	BMP Description	Location	Pollutant Load Reduction						
			Total Suspended Solids (TSS)	**Total Nitrogen (TN)**	**Total Kjeldahl Nitrogen (TKN)**	**Ammonium Nitrogen (NH_4^+-N)**	**Nitrate Nitrogen (NO_3^--N)**	**Total Phosphorus (TP)**	**Dissolved Phosphorus (DP)**
Cropping Practices									
Novotny, 2003*	Cover crops		40-60%	50%				30-50%	
Strock et al., 2004	A winter rye cover crop, following corn, in a corn-soybean system with tile drainage. Reductions are from comparisons with a conventional system.	MN					13%		
Novotny, 2003*	Conservation tillage		30-90%	50-80%				35-85%	
Sharpley et al., 1991	No-tillage practices of a sorghum culture. Reductions are expressed as comparisons to conventional tillage.	OK, TX	97%	90%				89%	
Conservation Reserve Program									
Davie and Lant, 1994	Two basins were studied, with 16% and 27% enrollment in CRP.	IL	0.13%, 0.27%						
Vegetated Buffers									
Dillaha et al., 1989; Dosskey, 2001	Grass buffers: Reduction is expressed as percent of the amount entering the buffer. Buffers should be mowed 2-3 times a year to promote thick vegetation and to maintain effectiveness.	VA	53-98%	43-91%		9-89%	7-78%	49-93%	(-47)-55%
Lee et al., 2000; Dosskey, 2001	Grass and woody plant mixed buffers: Reduction is expressed as percent of the amount entering the buffer.	IA	70-94%	50-90%			41-88%	46-93%	
Palone and Todd, 1997; Schultz et al., 2000	Forest buffers: Removal for 30-meter wide mature buffers. Low ranges represent larger runoff events. Trees should be harvested periodically to maintain effectiveness.	Chesapeake Bay	40-64%; 85-95%	15-45%; 68-92%				24-50%; 70-81%	
Streambank Stabilization									
Novotny, 2003*	Vegetative stabilization, in conjunction with riparian restoration and planted grass filter strips.		80-90%	60-90%				30-90%	

Table 1.11 Types of BMPs and the load reductions reported for a range of water quality studies continued

Reference	BMP Description	Location	Pollutant Load Reduction: Total Suspended Solids (TSS)	Total Nitrogen (TN)	Total Kjeldahl Nitrogen (TKN)	Ammonium Nitrogen (NH_4^+-N)	Nitrate Nitrogen (NO_3^--N)	Total Phosphorus (TP)	Dissolved Phosphorus (DP)
Livestock Exclusion									
Novotny, 2003*	Includes fences, stream crossings, and an off-stream water source		50-90%					50-90%	
Line et al., 2000		NC	77-82%		69-79%			69-76%	
Galeone, 2000	Streambank fences, stream crossings	PA	10-25%	no statistical significance					
Sheffield et al., 1997	Off-stream water source	VA	96%	56%		77%	(-13)%	98%	
Animal Waste Management									
Novotny, 2003*	Combination of liquid manure storage basins, anaerobic digesters and composters, nutrient management, and landscape BMPs to divert runoff from feedlot and barnyard			62%				21%	
Brannan et al., 2000	Manure storage structures, nutrient management, stream fencing, watering troughs, stream crossings, cover crops, field strip cropping and grassed waterways	Virginia	19%	35%				54%	

*Novotny (2003) percent reductions are summarized from multiple reports.

Chapter 2: SWAT Parameterization and Calibration

2.0 Introduction

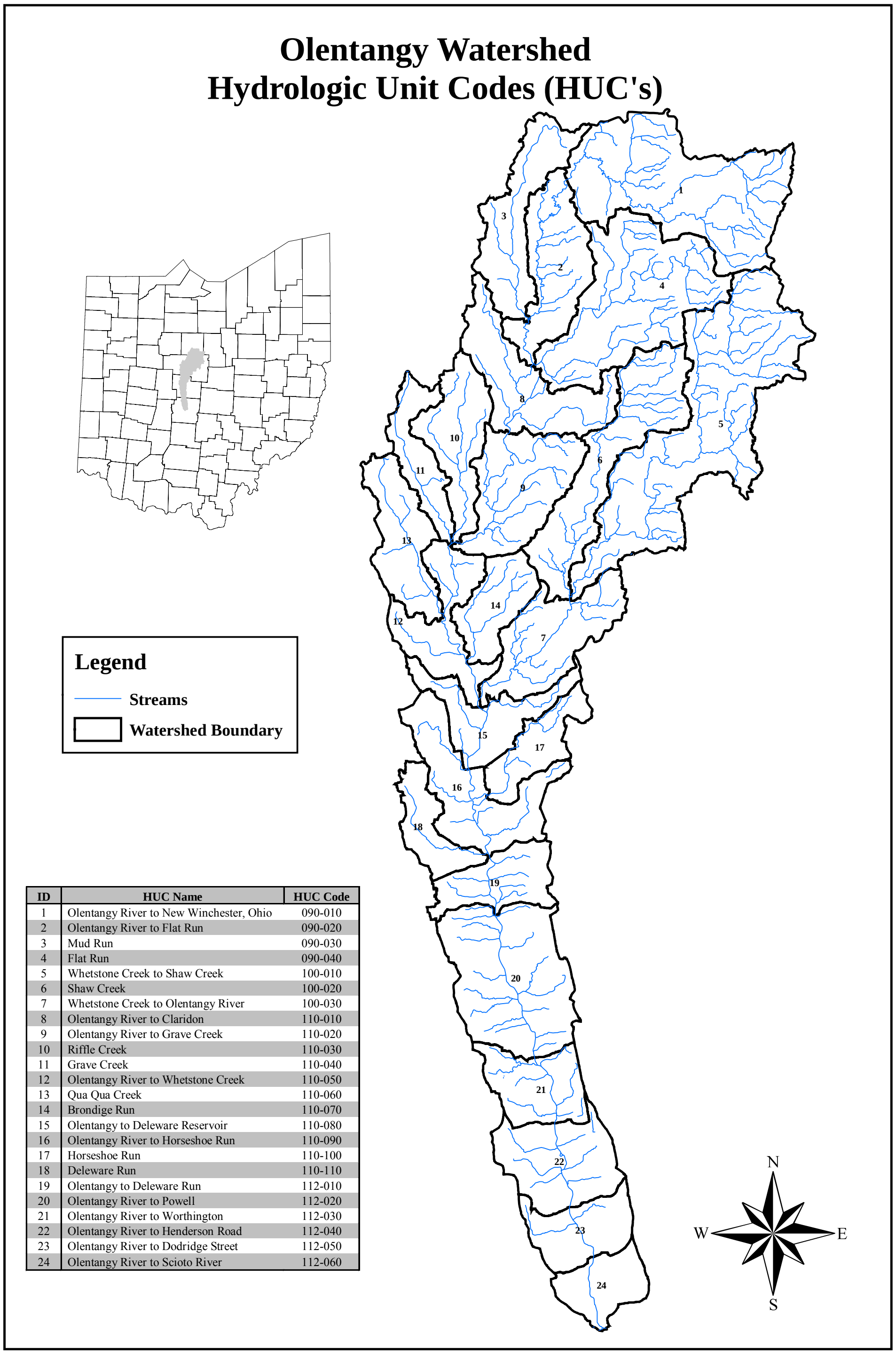
The Soil and Water Assessment Tool (SWAT) was used to model the Olentangy River watershed. SWAT is a daily time step, watershed-scale model developed and supported by the United States Department of Agriculture-Agricultural Research Service (USDA-ARS) at the Blackland Research Center in Temple, Texas. SWAT was developed to predict the impact of land management practices on water, sediment, and nutrient yields in large complex watersheds with varying soils, topography, land use and land management practices.

The model used in this study was a customized version of SWAT 2005. This version is capable of simulating a restrictive layer of material in the soil profile and its impact on subsurface drainage, watershed hydrology, and pollutant transport. The SWAT development team in Texas provided extensive assistance in resolving modeling and model code difficulties. A thorough description, evaluation, and sensitivity analysis of SWAT is provided in Neitsch et al. (2002a) and at *www.brc.tamus.edu/swat/*. A GIS interface AVSWATX (Di Luzio, 2002) was used to generate input files required by the SWAT model. This chapter presents details on SWAT, parameterization of model inputs, studies performed to calibrate the model, and a discussion on uncertainties associated with modeling results. Further details are presented in Appendix 2.A and 2.B. Results of the analysis conducted with SWAT are presented in Chapter 3.

The simulation period for the SWAT modeling began on January 1, 1985 and ended on December 31, 2002. Calendar year 1985 was used as a “warm up” year to account for any errors in initializing the model. Subsequently, all model predictions for 1985 were excluded in model evaluation, calibration, and reporting. The model has hundreds of input parameters together with suggested default values, or ranges of values, for many of these parameters. We used default values for any parameters not discussed in this chapter or in Appendix 2.A.

2.1 Model Structure

TMDL reporting is often related to 11-digit or 14-digit Hydrologic Unit Codes (HUCs, Figure 2.1). However, SWAT divides a watershed into sub-basins (see Appendix 2.A) and hydrologic response units (HRUs). Sub-basins can be delineated to represent HUCs, but generally it is desirable to use even smaller drainage areas to more accurately represent variations in the watershed that impact hydrology and nutrient transport. Specifically, it is possible to assign land uses, soil types and land management practices to areas where they actually occur in the watershed giving the model greater spatial resolution. Assignment of land use and soil combinations was completed using the AVSWATX interface.



ID	HUC Name	HUC Code
1	Olentangy River to New Winchester, Ohio	090-010
2	Olentangy River to Flat Run	090-020
3	Mud Run	090-030
4	Flat Run	090-040
5	Whetstone Creek to Shaw Creek	100-010
6	Shaw Creek	100-020
7	Whetstone Creek to Olentangy River	100-030
8	Olentangy River to Claridon	110-010
9	Olentangy River to Grave Creek	110-020
10	Riffle Creek	110-030
11	Grave Creek	110-040
12	Olentangy River to Whetstone Creek	110-050
13	Qua Qua Creek	110-060
14	Brondige Run	110-070
15	Olentangy to Deleware Reservoir	110-080
16	Olentangy River to Horseshoe Run	110-090
17	Horseshoe Run	110-100
18	Deleware Run	110-110
19	Olentangy to Deleware Run	112-010
20	Olentangy River to Powell	112-020
21	Olentangy River to Worthington	112-030
22	Olentangy River to Henderson Road	112-040
23	Olentangy River to Dodridge Street	112-050
24	Olentangy River to Scioto River	112-060

Figure 2.1 14-digit HUCs in the Olentangy River Watershed.

Each sub-basin has a specific geographic location in the watershed and outputs from sub-basins are routed through the stream network. Within a sub-basin the landscape is further divided into HRUs. HRUs do not posses a spatial location within the sub-basin and all calculations of hydrology and pollutant transport on the landscape are performed at the HRU level. All HRU outputs are then lumped (i.e., summed up) and routed through the model at the sub-basin scale.

To divide the watershed into sub-basins and HRUs the AVSWATX interface uses a Digital Elevation Model (DEM) and a stream layer with standard Geographical Information Systems (GIS) procedures to perform the delineation. The model user has the option to set the minimum area required to initiate a stream. In other words, once a certain amount of area drains to a point SWAT considers that point the beginning of a stream. For the Olentangy River project, the minimum area selected to initiate a stream was 1,483 acres (2.32 mi^2). SWAT algorithms then create a sub-basin outlet at stream intersections. We delineated 147 sub-basins for the Olentangy River watershed (Figure 2.2).

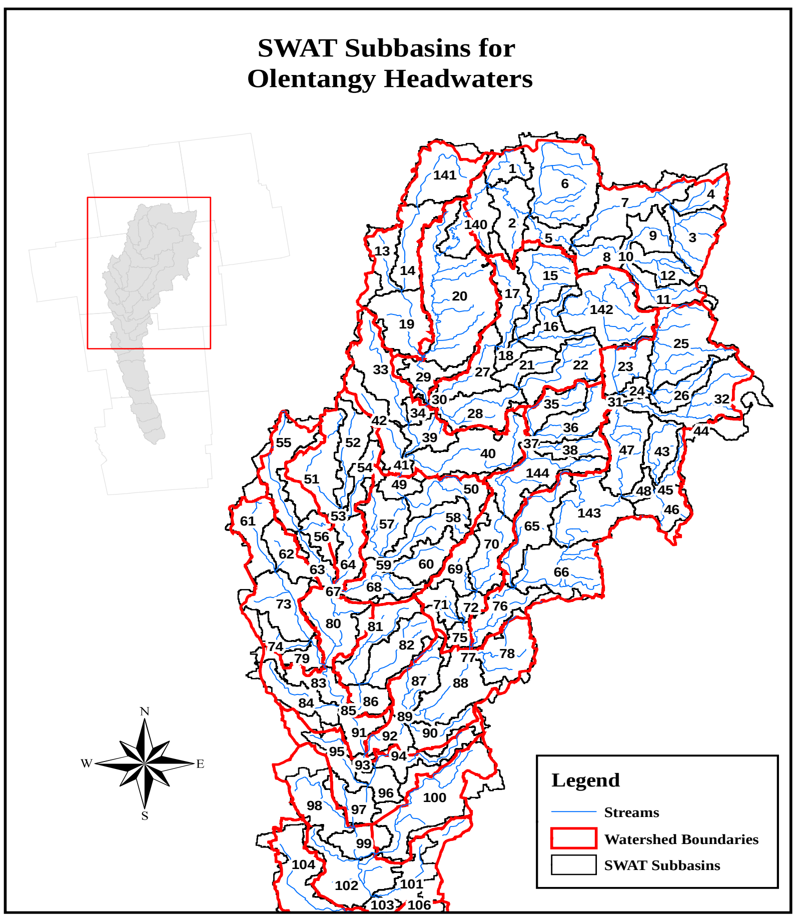


Figure 2.2a SWAT sub-basin delineation for upper reaches of the Olentangy.

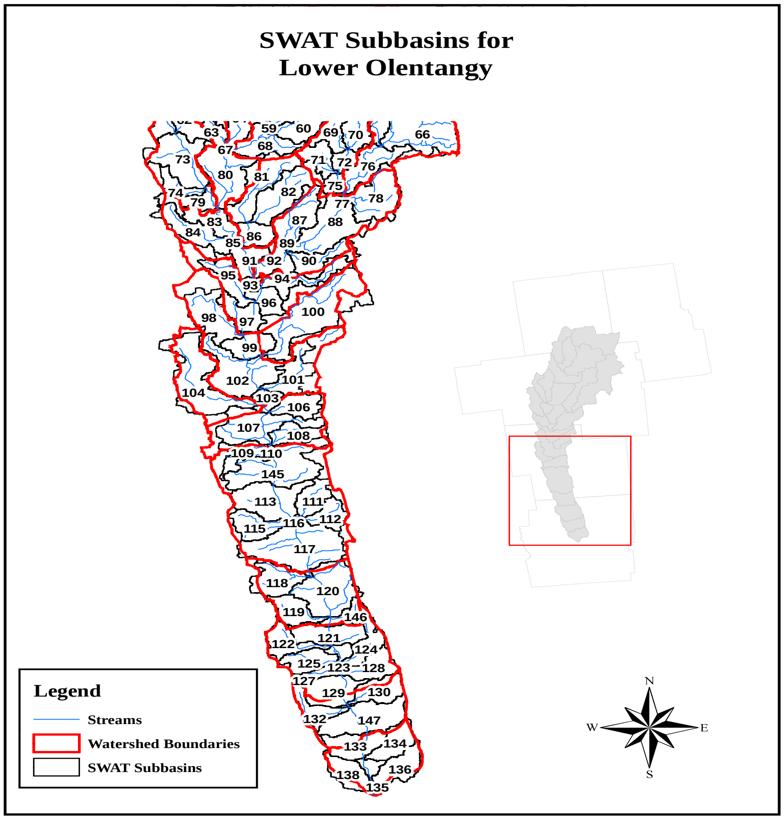


Figure 2.2b SWAT sub-basin delineation for lower reaches of the Olentangy.

To further subdivide the sub-basins into HRUs the AVSWATX interface requires the user to set minimum thresholds for the amount of a land use type and soil type required to form an HRU. Multiple thresholds were tried and it was determined that a 20% threshold for both land use and soil type created enough HRUs (342) to adequately represent the watershed, but not so many as to become overly cumbersome to manage and manipulate input files for modeling management alternatives. Typically, using a lower threshold and creating more HRUs is necessary if land use activity distributions are not adequate and/or there is poor correlation between one of the target outputs and measured data. The "actual" and modeled land use distributions are summarized in Table 2.1. While there is not exact agreement we felt that the uncertainty inherent in "actual" estimates did not warrant using a lower threshold to obtain better agreement. Also, loads from agricultural and urban areas are the main concern so the slight overestimation of these land uses provides more conservative results.

Table 2.1 Actual and Modeled Land Use (%) for the Olentangy River Watershed

Land Use	Actual (%)	Modeled (%)
Agriculture	57	64
Urban	9	11
Forest	16	13
Pasture	14	12
Water	<1	<1

Past studies have shown that selection of sub-basin size should depend, in part, on: 1) the constituent being studied (Jha et al., 2004); 2) complexity of watershed topography (Bingner et al., 1997; Fitzhugh and Mackay, 2000); and 3) land use homogeneity (Bingner et al., 1997). Jha et al. (2004) found that sub-basin sizes approximately 2%, 3%, and 5% of the watershed area were required for accurate predictions of sediment, nitrate-N, and organic phosphorus, respectively. In this study, the average size sub-basin is 0.7% of the watershed area. Several studies have shown the simulation of flows is not sensitive to the number of sub-basins (Bingner et al., 1997; Fitzhugh and Mackay, 2000); however, results indicated that sediment generation decreased with decreases in sub-watershed and HRU size. Initially, sediment generation was greatly overestimated in the Olentangy River TMDL study. We adjusted slope and slope length to address this issue. A better strategy might have been to increase the number of HRUs. However, because of resource constraints that also limited our ability to adequately consider in-stream sediment transport processes no adjustment was made to the number of HRUs.

2.2 SWAT Theory

In SWAT, the driving force behind modeling hydrologic response of a watershed is calculating daily water balance. SWAT algorithms simulate or account for many physical processes associated with the movement of water and nutrients in a watershed. Simulation of these processes can be separated into two phases: land phase and routing phase. A schematic representation of the hydrologic cycle simulated by SWAT is shown in Figure 2.3.

A schematic outlining the major pathways of water movement in SWAT is provided in Figure 2.4. The land phase controls the amount of water, sediment, and nutrient loading to the channel in each sub-basin. This allows the model to reflect differences in calculations of physical processes associated with heterogeneous HRUs. The most important physical processes modeled in the land phase include: climate, surface runoff, infiltration, evapotranspiration, lateral flow, percolation, seepage, and return flow. After calculating water, sediment, and nutrient loadings from the landscape SWAT routes loadings through the stream network. During the routing phase flow and nutrients from point source discharges are added to the channel. Parameters associated with mathematical models used to estimate these processes were used in model calibration. A more detailed discussion of those processes and parameters is presented later in this chapter.

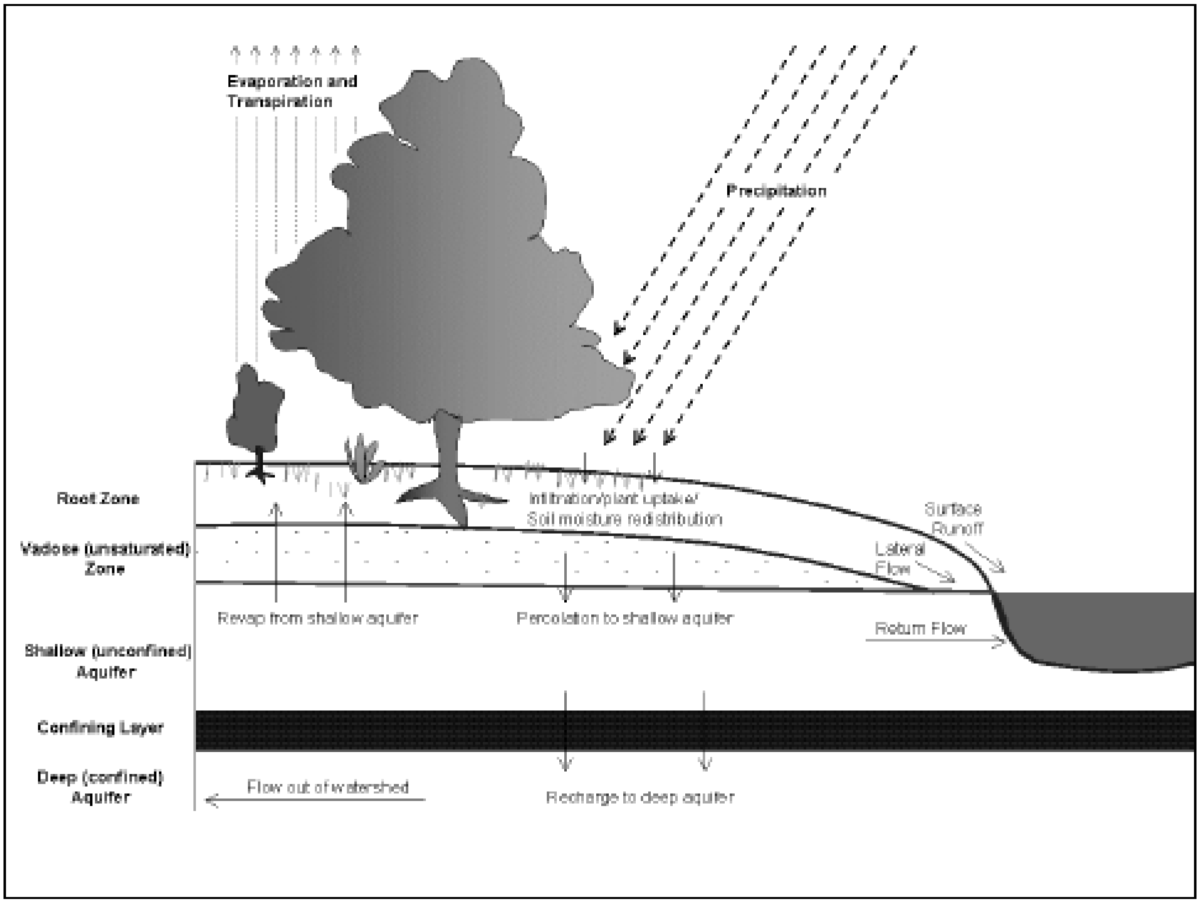


Figure 2.3 The Hydrologic Cycle (*Source: Figure 1.3 from Neitsch et al., 2002a*)

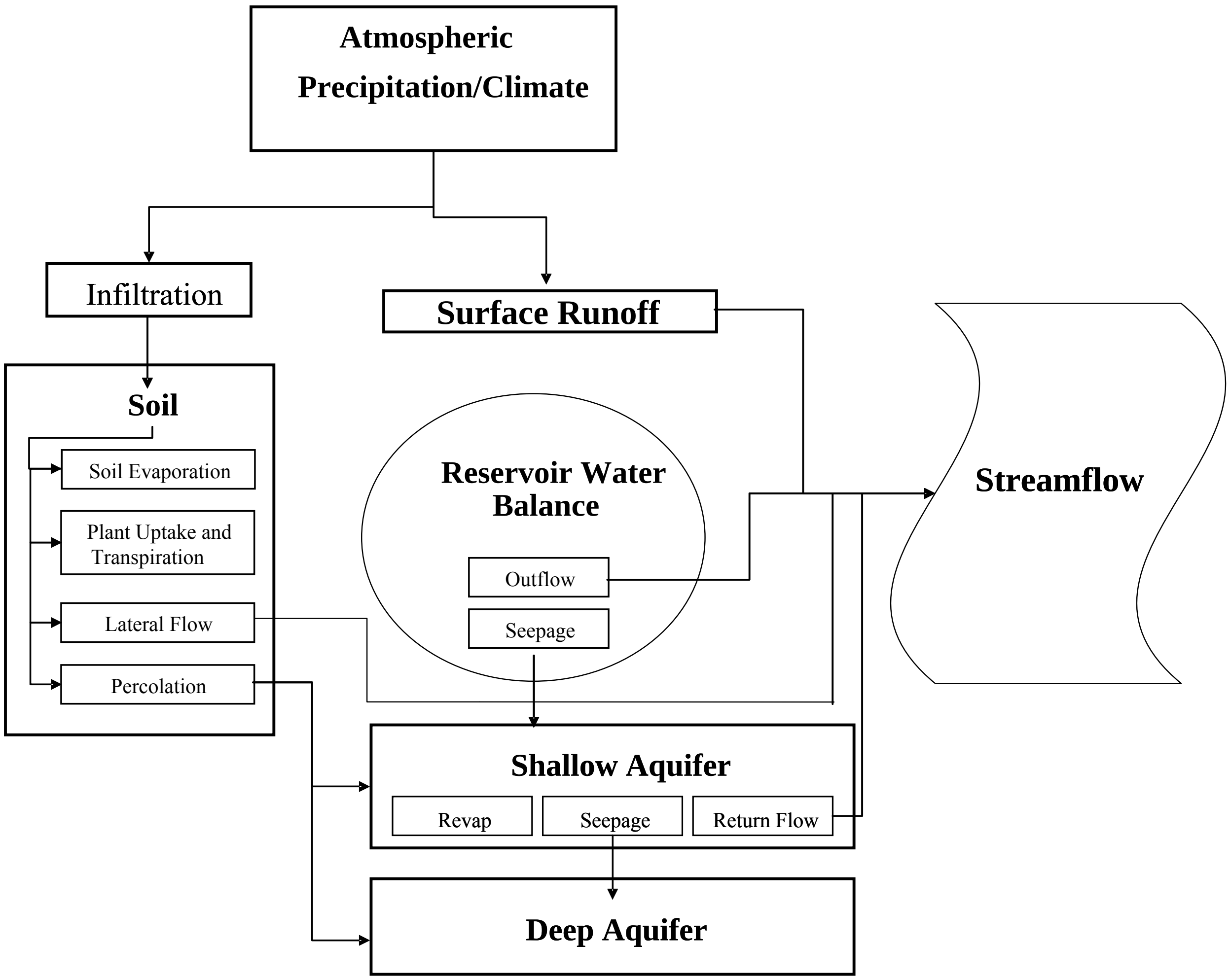


Figure 2.4 Schematic of water pathways in SWAT (*Source: simplified reproduction of Figure 1.5 from Neitsch et al., 2002a*).

2.3 GIS Inputs to AVSWATX

2.3.1 Digital Elevation Model (DEM)

The AVSWATX interface requires topographic information to delineate the Olentangy River watershed into sub-basins. These data are used to determine surface drainage patterns, stream slopes, and overland slopes. Overland slopes derived from the DEM can be seen in Figure 2.5. For the Olentangy River TMDL study we used the National Elevation Dataset (NED) from the USGS Seamless Data Distribution System (data and details available at *http://seamless.usgs.gov/website/seamless/index.asp*). Elevation data are in raster format and have a resolution of 30 meters.

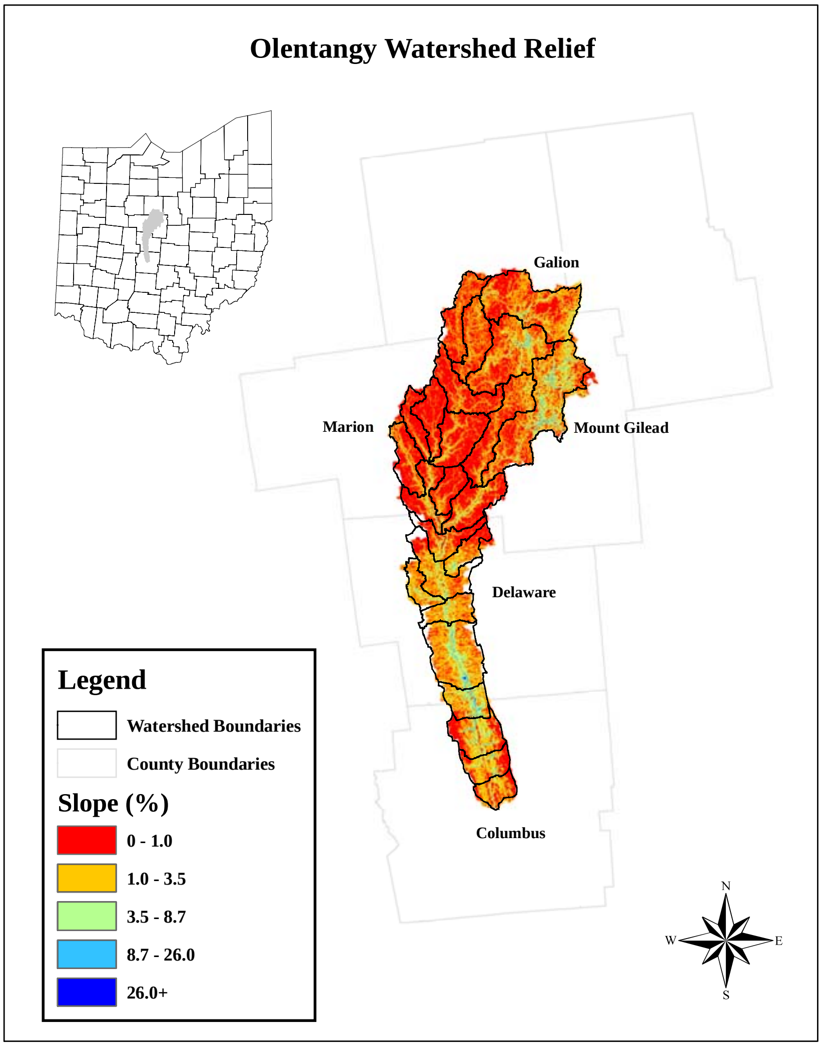


Figure 2.5 Overland slopes in the Olentangy River watershed.

2.3.2 Stream Network

The stream network used in this study was the USGS National Hydrology Dataset (NHD; available at *http://nhd.usgs.gov.html*). The NHD is a medium resolution dataset (1:100,000 scale) with 90% of definable features within 167 feet of their true geographic position. This data layer was used in the AVSWATX interface in a "stream burning" procedure (Di Luzio et al., 2002) to ensure that the DEM is hydrologically correct (i.e., water flows the correct direction). This step is necessary because low relief areas of the Olentangy River watershed, and the manner in which they are represented in the medium resolution DEM, can create incorrect drainage networks.

2.3.3 Land Use

Land use data were acquired from the USGS Seamless Data Distribution System (*http://seamless.usgs.gov/website/seamless/index.asp*). The National Land Cover Data 1992 (NLCD 92) is a 21-catergory land cover classification scheme based on an unsupervised classification of Landsat thematic mapper (TM) imagery. Spatial resolution of the raster dataset is 30 meters. NLCD 92 and equivalent SWAT land use categories were determined by the SWAT development team through their experience with various research projects utilizing the NLCD 92 data. A field reconnaissance, discussions with watershed stakeholders, and examination of National Agricultural Statistics Service (NASS) data for Ohio counties confirmed that no large-scale change in land use has occurred during the simulation period. A map of land use in the Olentangy River watershed is provided in Figure 2.6.

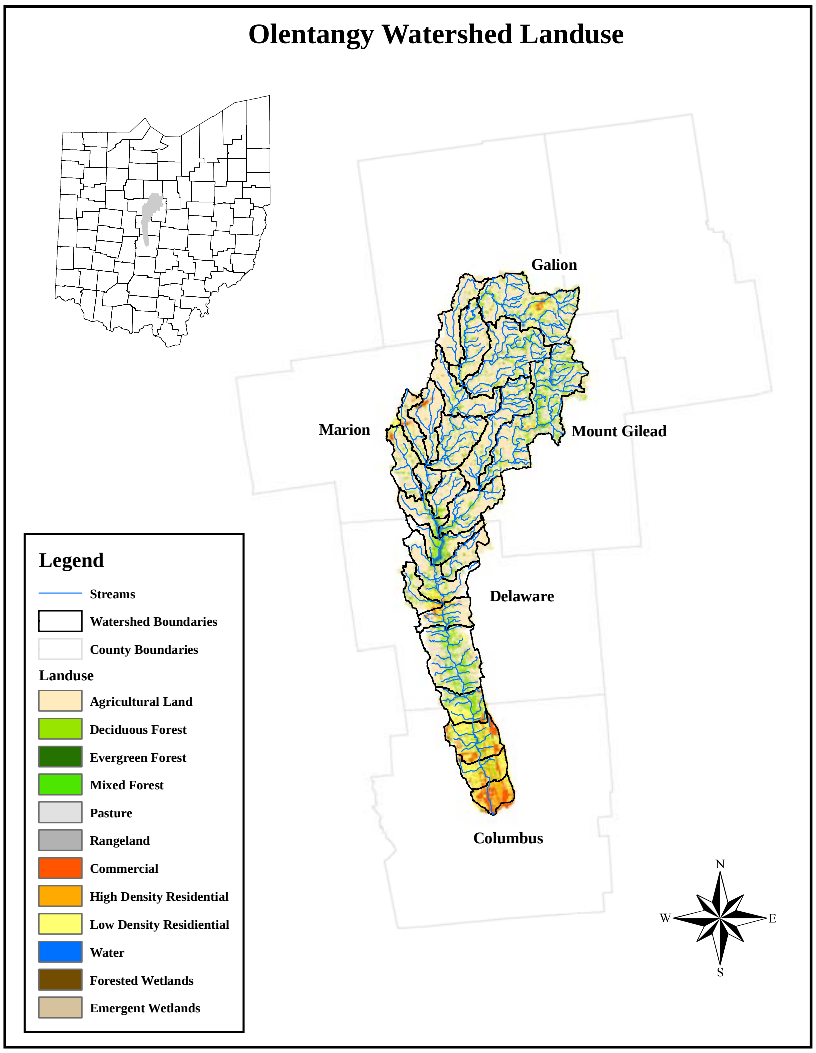


Figure 2.6 Land Use Classifications of the Olentangy River Watershed.

2.3.4 Soils

State Soil Geographic (STATSGO) data were used to characterize soils in the Olentangy River TMDL study (data and details available at *http://soildatamart.nrcs.usda.gov/*). STATSGO is a medium resolution (1:250,000 scale) dataset and generally is appropriate for watershed-scale modeling. Fifteen soil types were identified in the STATSGO dataset covering the Olentangy River watershed. A map of soils types and table of soils properties can be seen in Figure 2.7 and Table 2.2.

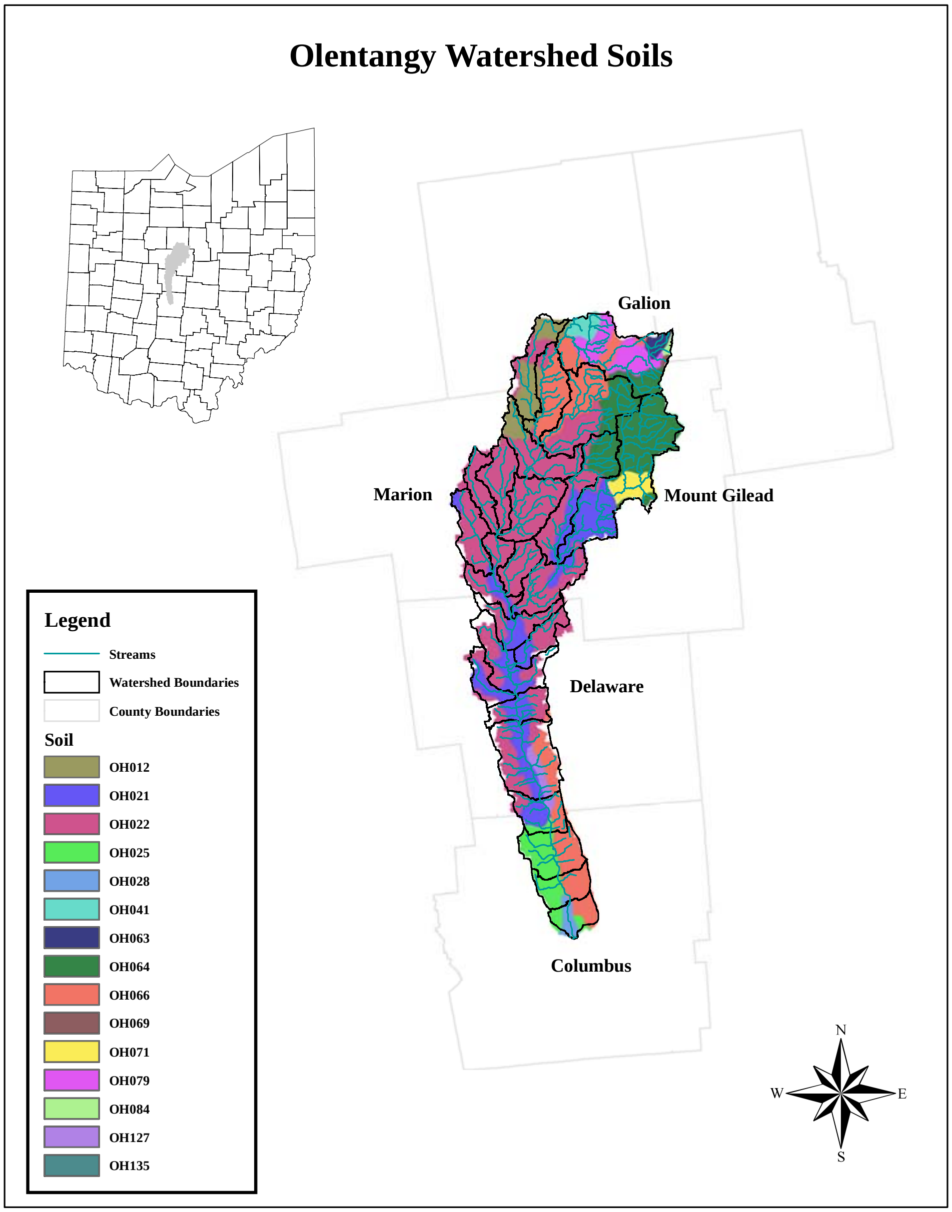


Figure 2.7 Soil Types in the Olentangy River Watershed (*source: NRCS State Soil Geographic (STATSGO) data, http://soildatamart.nrcs.usda.gov/*)

Table 2.2 Names and properties of soils found in the Olentangy River Watershed (to be used with Figure 2.7).

Soil ID	Soil Name	Texture	k-value	Hydrologic Soil Group
OH012	Milford	Silty-Clay-Loam	0.28	B
OH021	Glynwood	Silt Loam	0.43	C
OH022	Pewamo	Silty-Clay-Loam	0.28	C
OH025	Crosby	Silt Loam	0.37	C
OH028	Eldean	Loam	0.37	B
OH041	Tiro	Silt Loam	0.37	C
OH063	Bennington	Silt Loam	0.43	C
OH064	Centerburg	Silt Loam	0.37	C
OH066	Bennington	Silt Loam	0.43	C
OH071	Centerburg	Silt Loam	0.37	C
OH079	Bennington	Silt Loam	0.43	C
OH084	Rittman	Silt Loam	0.43	C
OH127	Cardington	Silt Loam	0.37	C

2.4 Climate Inputs

Precipitation data that accurately represent the quantity and spatial distribution of rainfall in the modeled area are critical. SWAT allows input for multiple precipitation stations. All precipitation stations near the watershed were input into the AVSWATX interface. The interface then calculated the distance from each precipitation station to the centroid of each SWAT sub-basin. Sub-basins are assigned data from the nearest precipitation station. Four precipitation stations in Ohio, located near the cities of Galion, Marion, Delaware and Columbus, were used in model development (Figure 2.8; Table 2.3).

Results from initial SWAT runs revealed problems with precipitation data for the upper region of the Olentangy River sub-watershed. At times, predicted discharges at the USGS Claridon, Ohio stream gauge did not compare well with observed discharges for certain storm events. Plots of daily precipitation at the Galion and Marion gages showed several instances of heavy localized storms. Therefore, the Galion and Marion gauges were averaged, and the averaged values were used for both the Galion and Marion stations. The Delaware and Columbus stations were used in their original format.

Another climatic input required by SWAT is the daily maximum and daily minimum temperature in degrees Celsius. Temperature is required in SWAT to: 1) determine when precipitation is in the form of snowfall; 2) track snow accumulation and snowmelt; 3) determine when soils are frozen for proper partitioning of hydrology; 4) simulate plant growth; and 5) initiate management activities based on the number of accumulated heat units. Temperature data is less sensitive and variable to spatial location; and therefore, one climatic station at Delaware, Ohio was used as input to the model (Figure 2.6; Table 2.3).

Additional climate data were required for certain methods of estimating potential evapotranspiration (PET), which included solar radiation, wind speed, and relative humidity in addition to the temperature data described above. All of these variables were input into the model as measured data collected at the Delaware, Ohio station.

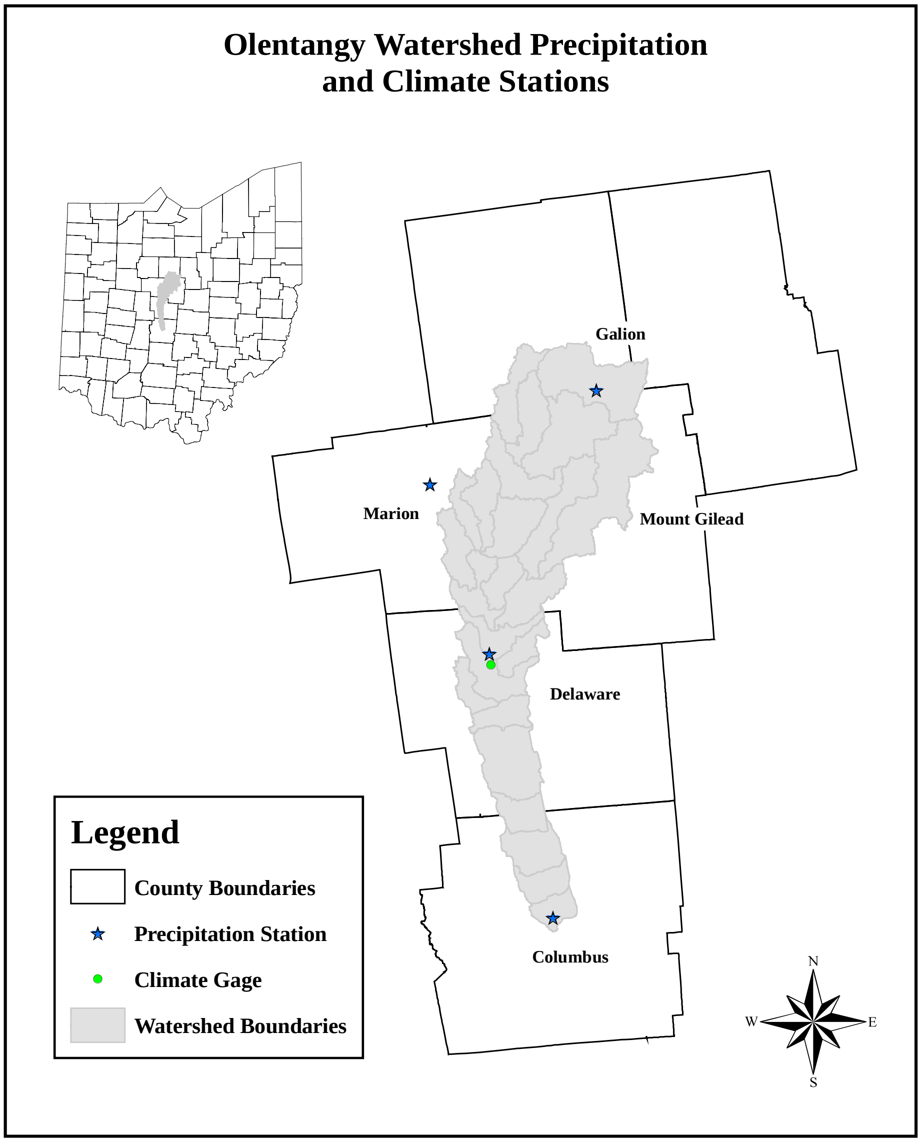


Figure 2.8 Precipitation and climate station locations in the Olentangy River watershed.

Table 2.3 Precipitation and climate station identification and sources.

Station Name	Station ID	Collected By	Distributed By
Galion_Water_Works	333021	NCDC[1]; NOAA[2]	MRCC[3,5]
Marion_2_N	334942	NCDC[1]; NOAA[2]	MRCC[3,5]
Delaware, OH	332119	NCDC[1]; NOAA[2]	MRCC[3,5]
Columbus, OH	None	OARDC[4]	OARDC[4,6]

[1]National Climatic Data Center
[2]National Oceanic and Atmospheric Administration
[3]Midwest Regional Climate Center
[4]Ohio Agricultural Research and Development Center
[5]http://sisyphus.sws.uiuc.edu/index.jsp
[6]www.oardc.ohio-state.edu/centernet/weather.htm

2.5 Point Source Dischargers

SWAT is capable of incorporating point source discharges into stream reaches at the outlet of the sub-basin in which they are located. For the Olentangy River TMDL study, the input used was the average daily point source loads for each individual month of the simulation period. Within the Olentangy River watershed, six point sources are considered major dischargers by the Ohio EPA (Table 2.4). Because of high volumes of treated effluent discharged to receiving streams we felt it was necessary to accurately represent those loads in the model. Monthly Operating Reports (MOR) were obtained from Ohio EPA and used to calculate point source loadings to the receiving stream.

Table 2.4 Discharge-weighted average concentrations for point source pollutant dischargers over the simulation period (developed from Ohio EPA MOR data).

Facility Name	Ohio EPA Permit	Discharge (MGD)	Total P (mg/l)	NO_3-N (mg/l)	Sediment (mg/l)
Galion WWTP	2PD00030	2.57	2.57	11.5	6
Marion WWTP	2PJ00002	0.88	2.02	12.3	12
Mt. Gilead WWTP	4PB00102	0.53	5.03	6.0	12
Cardington WWTP	4PA00100	0.27	2.98	6.2	12
Delaware WWTP	4PD0004	3.51	2.22	8.9	7
Ohio Environmental Control Center (OECC)	4PK00001	1.92	1.02	8.5	3

Using MOR data created two major problems. The first problem encountered was that EPA sampling data for phosphorus and the format necessary for SWAT input were not directly equivalent. MOR data only included measurements of total phosphorus whereas SWAT requires phosphorus inputs in mineral and organic form. Both types are required because of the manner in which the various forms are routed through the stream network. We attempted to find data from Ohio that measured mineral and organic phosphorus as well as total phosphorus to determine the appropriate partitioning of mineral to organic phosphorus. These data were not readily available; therefore, we used data from an unpublished study in Iowa to determine these ratios (personal communication, SWAT development team). The Iowa data exhibited a 9:1 ratio of mineral phosphorus to organic phosphorus. Results from the Stillwater River TMDL indicated a ratio of 8.5:1.5 for mineral phosphorus to organic phosphorus. While the ratios are not identical we decided there was insufficient evidence to change the 9:1 ratio we had selected. A discussion of MOR results for constituents and their SWAT equivalents is available in the Stillwater TMDL report (*www.epa.state.oh.us/dsw/tmdl/*).

The second problem encountered was that many treatment plants had several months of missing data. To determine loadings for months with missing data, statistics for data of the same month in other years during the simulation were calculated. In most cases, the average concentration of a nutrient was very similar to median concentration. Ultimately, we chose to replace missing values with median concentrations to avoid any impacts of a few large outliers in the dataset. Details on design flows and permit limits for minor point source dischargers are available in Tables 2.5 and 2.6. Minor point source dischargers were included in the model to determine their impact on nutrient loads in the Olentangy River watershed. Minor dischargers (Table 2.6) typically have fewer permit limits and are monitored less intensely than major dischargers. Therefore, we developed a strategy to lump all minor dischargers into groups based on their proximity to a major discharger. This facilitated the comparison of non-point source and major and minor point source loads. Because of the small amount of data available at these sites we determined, in conjunction with Ohio EPA staff, that design flows and permit limits would be used to calculate loads for minor dischargers. Permit limits existed for total suspended solids (TSS) and ammonia (summer and winter limits). Only nutrients with permit limits were input into the model.

Table 2.5 Minor Discharger Permit Concentration Limits (Minor dischargers listed in Table 2.6).

Code	Ammonia (mg/l) Summer	Ammonia (mg/l) Winter	TSS (mg/l)
a	--	--	12
b	--	--	30
c	1.0	--	--
d	1.5	--	--
e	1.7	--	--
f	2.0	--	--
g	3.27	--	--
h	3.3	--	--
i	5.0	--	--
j	--	1.7	--
k	--	2.0	--
l	--	3.0	--
m	--	5.2	--
n	--	6.8	--
o	--	8.5	--
p	--	14.3	--

Table 2.6 Minor Point Source Dischargers in the Olentangy River Watershed.

Facility Name	Ohio EPA Permit	Group[1]	Flow Limit (GPD)	Constituent Limit[2]
USDA Experiment Station	4PN00001	Delaware	12,000	a, c, l
Crystal Lake MHP	4PV00010	Delaware	24,000	a, f, k
Buckeye Valley School	4PT00107	Delaware	35,000	a, c, l
Chef Is In Inc.	4PX00001	Delaware	3,500	a, c, l
Delaware MHP	4PV00106	Delaware	10,000	a, c, l
Shroyers MHP	4PV00095	Delaware	20,000	a, f, k
Swiss Village MHP	2PR00099	Galion	8,000	a, d, l
Spring Valley MHP	2PY0023	Marion	10,000	a, c, l
General Mills	2IH00106	Marion	1,500	a, d, l
Specialty Fertilizer Products	4IF00100	Marion	2,000	a, c, l
Glen Gary Corp.	2IJ00074	Marion	2,000	a, c, l
United Mobile Homes	2PY00015	Marion	30,000	a, e, j
River Bend Corp.	2PR00189 001	Marion	5,000	a, c, l
River Bend Corp.	2PR00189 002	Marion	7,000	a, c, l
Blue Willow MHP	2PR00039	Marion	15,000	a, c, l
Verizon North	2PR00115	Marion	25,000	a, d, l
Caledonia WWTP	2PA00035	Marion	120,000	a, c, l
Marion County 5A	2PG00035	Marion	100,000	a, d, o
Waldo Dutchess	2PR00062	Marion	1,500	a, c, l
Northmoor Local Schools	4PT00110	MG/Card[3]	7,500	a, c, l
Candlewood Lake WWTP	4PU00005	MG/Card[3]	15,000-60,000[4]	a, c, m
Olentangy Local Schools	4PT00002	OECC	35,000	a, c, l
Nissan North	4PX00012	OECC	2,000	a, h, n
Adrian Subdivision	4PW00005	OECC	30,000	a, c, l
Delaware JVS	4IM00006	OECC	10,000	b, i, p
Worthington Arms MHP	4PV00093	OECC	39,000	a, g, n
Speedway/Super America	4PX00024	OECC	1,500	a, c, l

[1]Minor dischargers were grouped (i.e., summed up) and input into the model near the major discharger in this column.

[2]See Table 2.6 for a list of permit limits.

[3]Because of the close proximity of Mt. Gilead and Cardington, all minor dischargers were grouped and placed in a sub-basin on the Whetstone Creek between Mt. Gilead WWTP and Cardington WWTP.

[4]We varied the amount of flow discharged from Candlewood Lake WWTP during the simulation period based on Ohio EPA recommendations. From 1985-1995 flow was assigned to be 15,000 gallons/day. From 1995-2000 flow was assigned 30,000 gallons/day. For the remainder of the simulation period a value of 60,000 gallons/day was assigned.

2.6 Land Use Management

The primary goal of modeling hydrology of the Olentangy River watershed was to determine the impact of anthropogenic activities on water quality. The Olentangy River watershed supports a wide variety of land uses and activities. Accurate representation of these uses and management activities was an important component of the modeling process. To develop representative management scenarios we used government-collected statistical data on agriculture, sources of literature applicable to Ohio, and the judgment of experts, extension personnel, local agencies, and producers.

2.6.1 Agriculture Management and Non-Point Source Dischargers

Row Crops

Statistical agricultural data from Ohio were used extensively to develop management scenarios that were representative of agricultural practices in the watershed. Reports from the Ohio Agricultural Statistics Service (*www.nas.usda.gov/oh*) provided information on planted crop types, fertilizer use, planting/harvesting progress, and crop yields by county for each year of the simulation period. Information on tillage practices was taken from results of a state-wide survey conducted by the Conservation Tillage Information Center (*www.ctic.purdue.edu/CTIC/*). The following discussion is presented to describe how that information was used to develop management scenarios.

Twenty agricultural management scenarios were developed to represent variation in crop types, management strategies, and timing of management activities from year to year. Each of the twenty scenarios was then applied to 5% (1/20) of the agricultural land in the watershed. One benefit to developing so many scenarios is the ability to have multiple days with tillage, planting, fertilization, and harvesting operations occurring because, in reality, not all farming operations occur on one particular day throughout the watershed.

To select multiple planting days we created cumulative density functions (CDFs) from the agricultural statistics data. A CDF for a crop shows the amount (%) of planting completed at different points in the year. For example, Figure 2.9 shows a CDF of corn planting for each year during the model simulation period. Several days were selected that gave a good distribution throughout the planting season (represented by dashed vertical lines). To determine the amount of planting associated with one of those days, midpoints between that planting date and the prior and/ or following planting date were estimated (represented by horizontal lines with arrows). The amount planted was determined by taking the difference between the percent planted at the midpoints.

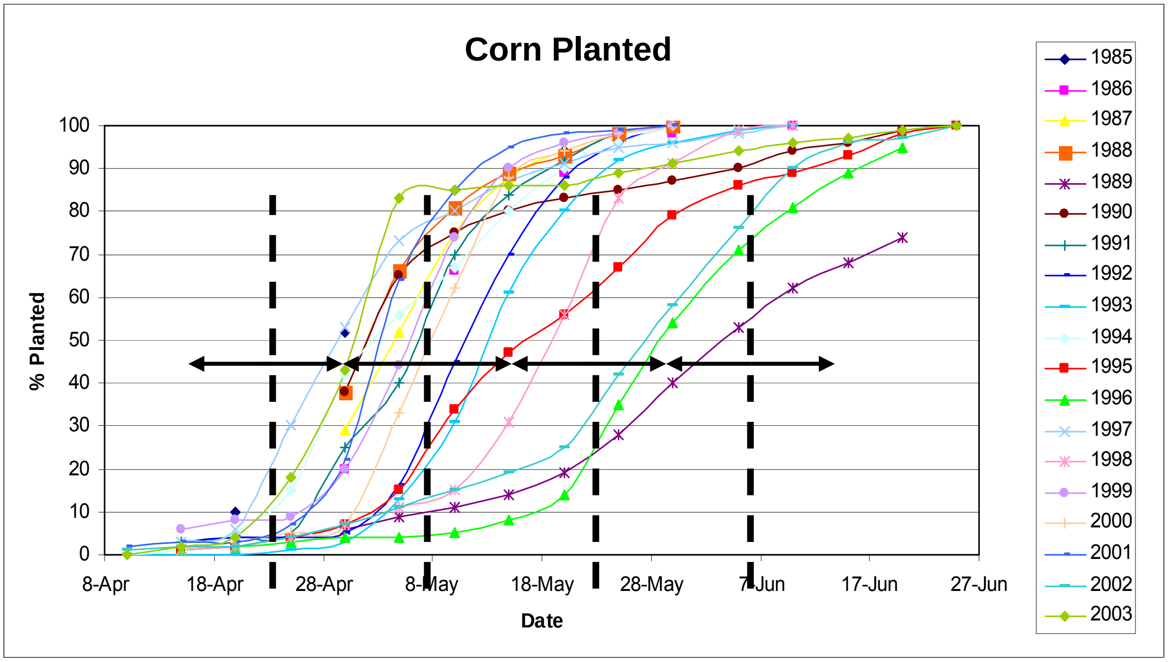


Figure 2.9 Cumulative density functions (CDF) of corn planting progress derived for each year during the simulation period.

The overriding goal of this task was to include enough detail so management scenarios were representative of practices used during the simulation period. It was impossible to represent all of the variation in management practices so we made several simplifying assumptions, which are listed below:

1) Spring tillage occurred one week prior to planting.
2) Spring no-till operations occurred on the planting date.
3) Crops with fertilizer applied at planting occurred on the planting date.
4) Forty percent of agricultural land had phosphorus applied in fall. Application occurred from one day after harvest to one month after harvest depending on time of the year.
5) Soybean ground with fall fertilizer application the previous year also received a small amount of nitrogen.
6) Forty percent of corn acreage received split application of nitrogen. The second application occurred one month after the crop was planted. One hundred pounds per acre was applied at planting followed by 50 pounds per acre for side dressing.
7) All row crop rotations followed a corn-soybean, corn-soybean-soybean, or corn-soybean-wheat rotation. Any combination of these may occur in any particular management scenario.
8) Subsurface drainage was simulated on a portion of the agricultural land. We used estimates from local agency and extension personnel to assign percentages of agricultural land with subsurface drainage. The percentage of agricultural land

with subsurface drainage was estimated to be 70%, 70%, 20%, 40%, and 0% for Crawford, Marion, Morrow, Delaware, and Franklin counties, respectively.

9) Harvesting of row crops was determined using the CDF method procedure described earlier. Crops with earlier planting dates also received earlier harvest dates. All other management operations were adjusted based on planting date to better represent when those activities would take place during the growing season.
10) Hay crops were harvested 3 or 4 times annually based on their harvesting CDFs. Hay ground with earlier first cutting was followed by earlier subsequent cuttings.
11) Nitrogen fertilization of winter wheat occurred at planting (19 lbs/acre) and on March 15 (56 lbs/acre) of the following spring.
12) Fertilizer application rates (Table 2.7) were based on a combination of sources including Tri-State Fertilizer Recommendations (Vitosh et al., 1995), the agricultural statistics data, and personal communication with local experts.
13) Wheat was the only small grain crop considered in the analysis. All other small grains or specialty crops account for a small percentage of land use and were not considered.
14) Crop growth and cover factors used in the simulations are reported in Table 2.8.

Table 2.7 Fertilizer application rates for the Olentangy River Watershed.

Crop	Nutrient	Time Applied	Rate (lbs/acre)
Corn	Nitrogen	Spring[1]	150
	Phosphate	Fall or Spring	60
Soybeans	Nitrogen	Fall or Spring	15
	Phosphate	Fall or Spring	50
Wheat	Nitrogen	At Planting	19
	Nitrogen	Spring	56
	Phosphate	At Planting	50

[1]Nitrogen has been applied in two ways: 1) prior to or at planting, and 2) a split application of 100 lbs/acre at planting and 50 lbs/acre side dressed one month after planting.

Table 2.8 Crop growth parameters used in the SWAT model analysis.

Crop	Biomass Energy Ratio[1]	Max Root Depth (ft)	Optimal Growth Temp (°F)	Minimum Base Growth Temperature	USLE C
Hay	35	6.6	77	54	0.003
Mixed Forest	15	11.5	86	50	0.001
Deciduous Forest	15	11.5	86	50	0.001
Pasture	35	6.6	77	54	0.003
Corn	39	6.6	77	46	0.200
Winter Wheat	30	4.3	64	32	0.030
Bermuda Grass	35	6.6	77	54	0.003
Soybeans	25	5.6	77	50	0.200

[1]Biomass Energy Ratio is the amount of dry biomass produced per unit of intercepted solar energy (kg/ha)/(MJ/m^2)

Livestock and Manure Management

Animal manure was applied to agricultural land based on the assumption that all animal manure produced in a watershed (for this case a watershed is considered to be the Ohio EPA 14-digit HUC) was applied in that particular watershed. This assumption is generally acceptable because high costs to transport manures typically limit the area to which those manures can be applied. Animal types and numbers (Table 2.9) were obtained from the Upper Olentangy Watershed Management Plan (UOWAPT, 2004) and used to estimate manure amounts. The same number of different types of animals was used throughout the simulation period. These data were based on animal estimates for the last 4-5 years. Because specific data on livestock were not available for earlier years these numbers were used to ensure that pollutants from animal waste were incorporated into the water quality signatures.

Table 2.9 Number and type of livestock for the Olentangy River HUC sub-watersheds.

HUC[1]	Animal Type	No. of Animals
090-010	Beef Cattle Swine	300 2,500
090-020	Beef Cattle Swine	200 7,400
090-030	Dairy Swine	350 6,800
090-040	Beef Cattle	100
100-010	Beef Cattle Swine Chicken	1,600 1,500 12,000
100-020	Beef Cattle Swine	500 2,500
100-030	None Reported	None Reported
110-010	Beef Cattle	200
110-020	Beef Cattle	150
110-030	Dairy	200
110-040	None Reported	None Reported
110-050	Dairy Swine	1000 2000
110-060	Dairy Swine	1000 2000
110-070	Beef Cattle	100
110-080	None Reported	None Reported

[1]See Figure 2.1 for HUC locations

Manure production per unit animal weight was determined from Johnson and Eckert (1995) and Lorimor et al. (2000) and is summarized in Table 2.10. The number of livestock in production below the area covered by the Upper Olentangy Management Plan is considered to be negligible and, therefore, no livestock waste was applied in those sub-watersheds.

Table 2.10 Annual manure amounts for different type of animals

Animal Type	Manure[2](tons/year)
Cattle	13.0[1]
Dairy	15.0
Swine (Feeder)	11.9
Layer Chickens	9.7

[1]Deviates by +15% from value in Johnson and Eckert (1995).
[2]Manure per 1,000 pounds animal weight. Average animal size estimated at 125, 800, 1200, and 4 pounds for swine, beef cattle, dairy cattle, and chickens, respectively. (*source: Table 6 of Lorimor et al. (2000*).

Animal manure was applied at multiple rates and throughout the calendar year. Manure application rates varied from less than crop needs to "disposal rates". Disposal rates of manure application are commonly used to "get rid" of animal waste on an amount of land that a producer has available. Often, this rate is several times the crop requirement. No simulated manure application rates exceeded 270 lbs-N/acre.

Timing of manure application was guided by unpublished survey results provided by Ohio State University Extension personnel that suggested most beef/dairy manure is disposed of from October-March and most swine manure is disposed of from July-December. Only three types of manure were applied including beef/dairy, swine, and chicken manure. When other animals such as sheep or horses were present their estimated weight was converted to an equivalent weight of cattle and added to the cattle manure estimates. The small number other animal types and similar nutrient content of their manures make errors in this approach negligible. Also, this simplified development of management scenarios.

A small amount of beef/dairy manure also was applied to pasture lands through grazing operations. The grazing season was assumed to begin June 1 of each year and continue for 120 days. Pasture fields for grazing were selected by size to maintain about one animal grazing/two acres/season. Manure was applied at a rate of 30 pounds/acre/day based on manure production rate per day (approximately 60 pounds manure/day/animal) and a density of one animal/two acres.

2.6.2 Urban Land Use Management

The main inputs used to simulate urban conditions are reported in Table 2.11. Fertilizer application rates and recommended application dates for urban grasses were taken from an Ohio State University fact sheet (Street and White). An exact match for the recommended fertilizer types was not available in the SWAT database so the closest match (28-3-0 NPK) was selected. Applications of 5 pounds, 5 pounds, and 10 pounds per 1,000 square feet of 28-3-0 were applied on May 1, September 1, and November 1, respectively. This amount converts to approximately 244 lbs-N/acre and 26 lbs-P/acre. SWAT algorithms only apply fertilizers to pervious areas within an urban land use, thereby taking into account various amounts of open space at different levels of urbanization.

Table 2.11 Urban inputs: parameters for urban land uses.

Urban Land Use	Impervious Area (fraction)	Directly Connected Impervious Area (fraction)	Curb Density (miles/acre)
High Density Residential	0.60	0.44	0.06
Medium Density Residential	0.38	0.30	0.06
Medium/Low Density Residential	0.20	0.17	0.06
Low Density Residential	0.12	0.10	0.06
Commercial	0.67	0.62	0.07
Industrial	0.84	0.79	0.04
Transportation	0.98	0.95	0.03
Institutional	0.51	0.47	0.03

2.6.3 Other Land Use Management

Other types of land use, including forests and wetlands, occur in smaller amounts in the Olentangy River watershed and were modeled with SWAT default scenarios. Management practices for these land uses include initiating plant growth in spring and ending plant growth in fall. Timing of these operations is scheduled by the amount of heat units accumulated in the watershed in a particular year. Depending on the type of plant growing, a percentage of biomass is returned to the land as residue and increases organic nutrient pools.

2.7 Hydrology Parameters and Model Calibration

To accurately predict the movement of pollutants through the watershed the hydrologic cycle, simulated by the SWAT model, must conform to what is happening in the watershed (Nietsch et al., 2002a). The first phase of the cycle, the landscape phase, depends on climatic inputs (discussed previously), physical properties of the land, and management activities on the landscape. The second stage of the cycle includes routing water through the stream system and is impacted by physical properties of the stream channel and anthropogenic manipulation of stream flow through control structures as well as the addition of point source discharges. Several parameters used to model landscape and channel processes were changed from SWAT default values for calibration purposes because we had better values based on knowledge of the system, and/or because we developed alternative values based on analysis of a dataset. The following section briefly presents calibration results for hydrology, highlights SWAT parameters changed from default values, and discusses the rationale for such changes. Knowledge of the quantity of water through various flow paths for water provided a valuable starting point for evaluating and calibrating the model.

2.7.1 Surface Runoff and Infiltration

Surface runoff is simulated in SWAT using the NRCS Curve Number procedure (Ward and Trimble, 2003). SWAT initially selects curve numbers from NRCS standard tables based on land cover and soil type. These curve numbers are then adjusted based on the slope of the HRU with a procedure developed by Williams (1995). Standard NRCS curve numbers are appropriate for slopes less than 5%. SWAT curve numbers are then adjusted on a daily time step depending on antecedent moisture conditions and soil temperature, which is used to determine when soils are frozen.

Soils in the Olentangy River watershed are in hydrologic soil groups B and C. SWAT automatically selects NRCS curve numbers based on hydrologic soil group and land use. Curve number ranges for common land use types are included in Table 2.12. A more detailed listing of the curve numbers used in the calibrated model are presented in Appendix 2. For the baseline model, the initial curve numbers were not altered. It is probable that they over-predicted runoff from forested areas and under-predicted runoff from low density urban areas. However, a reasonable calibration was obtained without needing to modify the curve number.

Table 2.12 Assigned NRCS curve numbers from the SWAT model.

Land Use	NRCS Curve Number[1]
Agricultural Row Crops	75-85
Forest	66-77
Pasture	69-79
Grasses	59-83
Urban (various densities)	65-94

[1]Ranges assigned to SWAT land uses for hydrologic soil groups B and C.

Infiltration is the movement of water into the soil profile from the soil surface. Infiltration rates are dependent upon soil properties, antecedent moisture condition, and soil temperature. In SWAT, the amount of water available for infiltration is the difference between the amount of rainfall and the amount of surface runoff.

2.7.2 Evapotranspiration and Soil-Water Retention

Evapotranspiration includes all processes by which water on or in the earth's surface is transformed to water vapor. Potential Evapotranspiration (PET) is the rate that evapotranspiration occurs from growing vegetation when soil-water is not limited. The following PET methods have been incorporated into SWAT: (1) the Penman-Monteith method that requires solar radiation, air temperature, relative humidity and wind speed data (Monteith, 1965; Allen, 1986; Allen et al., 1989); (2) the Hargreaves method that only requires air temperature data (Hargreaves et al., 1985); and (3) the Priestley-Taylor method that requires solar radiation, air temperature and relative humidity (Priestley and Taylor, 1972).

The Soil Evaporation Compensation Factor (ESCO) variable allows the model user to modify the depth distribution used to meet the soil evaporative demand to account for the effect of capillary action, crusting, and cracks. ESCO can vary between 0.01 and 1.0; a lower value allows the model to extract more evaporative demand from greater depths in the soil profile. Further discussion and graphical information on the ESCO variable can be found in the SWAT Users Manual (Nietsch et al., 2002b). This variable was used as a calibration parameter with values ranging from 0.7-0.95. The original SWAT default value of 0.95 was determined to be most appropriate for the baseline model.

To initialize the amount of water in the soil profile at the beginning of the simulation SWAT has incorporated Initial Soil Water Storage Fraction (FFCB) parameter. This parameter sets initial soil water content at a fraction of field capacity. Based on the timing of the start of simulation, the SWAT development team suggested a value of 0.8 or 80% of field capacity would be appropriate. Furthermore, because the first year of simulation was discarded from evaluation exact knowledge of FFCB is not necessary. In fact, during model simulations where FFCB was set to 0.0 soil water storage stabilized after 8-9 months of simulations, well within the first year of the simulation predictions eliminated from evaluation.

In SWAT, water may also move from the shallow aquifer into the overlying unsaturated zone. In periods when material overlying the aquifer is dry, water in the capillary fringe that separates the saturated and unsaturated zones will evaporate and diffuse upward (Neitsch et al., 2002a). As water is removed, it is replaced by water from the underlying shallow aquifer. Removal of water from the saturated zone also can be accomplished by deep rooted plants. A parameter used to estimate these up-fluxes is the ground water revap coefficient (GW_REVAP), which we used as a calibration parameter that was varied within a suggested range of 0.02 and 0.20. Lower values of groundwater revap restrict movement of water from the saturated to unsaturated zone. A GW_REVAP value of 0.20 gave the best results. This value seems appropriate as the process is more important in watersheds with a low depth to the saturated zone, which is affected by the impeding layer simulated in many sub-basins.

2.7.3 Subsurface Drainage and Groundwater Recharge

The subsurface drainage component of SWAT is simple compared to other field-scale models capable of simulating subsurface drainage, but has shown good agreement with measured results in studies at the watershed scale (Du et al., 2005). SWAT has four variables specific to subsurface drainage. Two were altered from default values to more accurately represent conditions in the Olentangy River watershed.

In the modified version of SWAT 2005, movement of water through the soil profile is impacted by a user-defined depth to an impeding layer (DEPIMP). Soil water routing algorithms calculate a water table height by allowing the soil profile above the impeding layer to fill to field capacity. After all soil layers reach field capacity additional soil-water is allowed to fill the soil profile from the impeding layer upwards. A water table height is then calculated. To develop a relationship between the water table and subsurface drains, SWAT requires a user-defined depth to drain parameter (DDRAIN). When the water table height exceeds the tile height subsurface drainage will occur. The rate at which excess water is removed is determined by a user-defined time required to drain the soil from saturation to field capacity and a drain tile lag time controls the amount of time between transfers of water from the soil to the drain outlet.

Parameters changed from SWAT defaults include depth to subsurface drain (DDRAIN) and depth to an impeding layer (DEPIMP). More detailed information regarding these parameters and results of a sensitivity analysis are available in Arnold et al. (2005). The depth of subsurface drains parameter was set to 3.3 feet (39 inches) based on discussions with farmers, drainage contractors, Ohio State University Extension personnel, and NRCS personnel. Recommendations typically varied between 36 inches and 42 inches. The depth to a restrictive layer was set at 4 feet based on discussions with NRCS soil scientists. Depth to a restrictive layer of glacial till can be quite variable in the Olentangy River watershed where depths ranging from 2 feet to 6 feet or more are common. In this version of SWAT, the impeding layer is simulated only on sub-basins where subsurface drainage occurred.

SWAT also models the amount of ground water recharge in the watershed. For the calibrated baseline simulation ground water recharge was estimated as 4 inches. This amount is in agreement with an Ohio Department of Natural Resources report that estimates recharge rates between 4 inches and 6 inches for the Olentangy River watershed (Dumouchell and Schiefer, 2002).

2.7.4 Baseflow versus Surface Runoff

We used the Baseflow Filter program to determine the portion of streamflow derived from baseflow versus surface runoff (Arnold et al., 1995; Arnold and Allen, 1999). This program was used to analyze USGS streamflow data at 13 gage stations throughout the watershed with a record of at least 2 years. Several stations had records in excess of 50 years providing for a more thorough analysis. Gage information and length of stream flow record are presented in Table 2.13. According to Arnold et al. (1995), the fraction of baseflow estimated by the program falls within a range of values. The upper and lower limits of baseflow at each station also are provided in Table 2.13. The authors' experience in other studies suggests the actual value generally is closer to the upper end of the calculated range (Jeff Arnold, personal communication). Results from analyses of the 13 gages suggest that baseflow comprises between 0.29-0.44 (29-44%) of total stream flow. Results were consistent throughout the watershed area.

Table 2.13 Results from Analysis of Streamflow Data with the Baseflow Filter Program.

Site Name	USGS Gage	Drainage Area (mi^2)	Upper Limit	Lower Limit	Begin Record	End Record
Olentangy Trib. at Bethel Rd.	3226875	0.22	0.45	0.32	Oct-78	Oct-81
Olentangy River at Claridon	3223000	157	0.46	0.29	Oct-46	Sep-98
Olentangy River at Delaware	3225500	393	0.43	0.26	24-Oct	3-Sep
Olentangy Trib. at Linworth Rd.	3226870	2.03	0.41	0.26	Oct-78	Oct-81
Olentangy River at Henderson Rd.	3226885	518	0.44	0.27	Aug-78	Oct-81
Olentangy River at New Winchester	3222500	49.4	0.4	0.25	Oct-46	Sep-49
Olentangy River at Stratford	3226500	445	0.45	0.29	Aug-34	Sep-58
Olentangy Trib. at SR315	3226872	2.5	0.39	0.24	Jul-79	Sep-81
Rush Run at Worthington	3226865	1.65	0.52	0.37	Oct-78	Oct-81
Shaw Creek at Shawtown	3224000	25.4	0.43	0.27	Oct-46	Sep-55
Whetstone Creek at Ashley	3224500	98.7	0.45	0.29	Oct-54	Sep-74
Whetstone Creek at Mt. Gilead	3223425	37.9	0.43	0.28	Oct-96	3-Sep
Olentangy River at Worthington	3226800	497	0.45	0.28	Oct-55	3-Sep

Baseflow in SWAT includes subsurface drainage discharge, ground water flow, and lateral flow. Percentage of baseflow is calculated with the following equation:

$$BaseflowPercentage = \left(\frac{TileFlow + GroundWaterFlow + LateralFlow}{TotalWaterYield} \right) * 100 \qquad (2.1)$$

where tile flow, ground water flow, lateral flow, and total water yield are average annual flow volumes expressed as a depth of flow across the watershed area in inches. For the calibrated Olentangy River TMDL baseline model the percentage of baseflow is:

$$BaseflowPercentage = \left(\frac{2.53 inches + 2.69 inches + 0.04 inches}{12.75 inches} \right) * 100 = 41\% \qquad (2.2)$$

The Baseflow Recession Constant is an index of the ground water response to changes in recharge (Nietsch et al., 2002a; Smedema and Rycroft, 1983). Estimates of this variable can be made by analyzing stream flow data during periods of no recharge. The Baseflow Filter Program discussed previously also analyzes stream flow data for this variable and provides estimates in the output. All gages analyzed showed good agreement when a value of 0.02 days was used for all sub-basins.

2.7.5 Routing Flow in Channels

In SWAT, channels are approximated as the two-stage system illustrated in Figure 2.10. The first (lower) stage is the main fluvial channel and the second stage is the floodplain. SWAT uses Manning's equation and Manning's *n* values to calculate flow velocities for water routing. Default values for Manning's *n* are set at 0.014 for main and tributary channel flow, which is appropriate for concrete channels. Manning's *n* values can be input into the model at the sub-basin scale, but not enough information or resources were available to adequately determine appropriate values for individual reaches. Also, results of a sensitivity analysis suggested the model was not particularly sensitive to these variables. Therefore, Manning's *n* values of 0.044 and 0.050 were assigned globally to tributary and main channels, respectively.

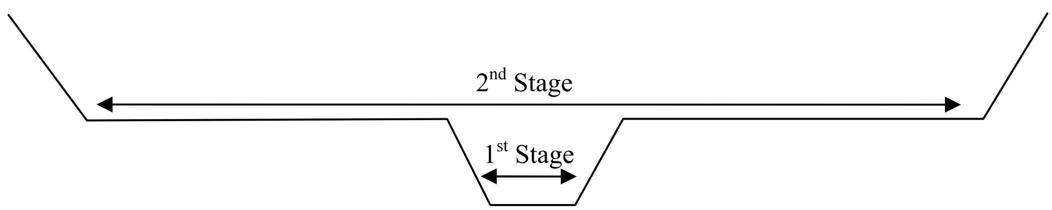


Figure 2.10 Two-stage channel system modeled by SWAT.

The main fluvial channel is approximated as a trapezoid that is sized based on bankfull dimensions that are a function of a regional curve. SWAT calculates and assigns channel dimensions using a known relationship between drainage areas and channel widths and depths. The AVSWATX interface calculates drainage areas to each sub-basin outlet and that information is then used with a default regional curve to calculate channel dimensions. Comparison of the SWAT default regional curve to the regional curve developed for the Olentangy River and Upper Scioto River watersheds showed vast differences in channel geometries. Therefore, SWAT channel dimensions were replaced with dimensions based on the Upper Scioto River regional curve discussed in Chapter 1. Channel width to depth ratios also were updated based on the new dimensions.

Flow can be routed through the channel network using a variable storage routing method or the Muskingum River Routing method (Chow et al., 1988). The variable storage routing method used for the Olentangy River TMDL model was developed by Williams (1969) and used in the HYMO (Williams and Hann, 1973) and ROTO (Arnold et al., 1995) models.

2.7.6 Scale Issues

Several issues may arise when attempting to model watershed hydrology using a daily time step. One issue is related to the timing of precipitation events and how those data are input into the model. Rainfall on a particular day is summed up and input as a single value. There is no knowledge regarding the timing of the event (i.e., sub-daily scale) other than the amount and day that it occurred. Therefore, a storm that occurs in the late evening may show a large response in SWAT on the day it occurred when, in reality, stream flow was not measured until the following day.

Another problem arises in sub-basins/watersheds that are particularly large. In the Olentangy River TMDL model hydrology was evaluated at the Claridon, Ohio gage (drainage area 157 mi^2), the Delaware, Ohio gage (drainage area 393 mi^2), and the Worthington, Ohio gage (drainage area 497 mi^2). Times of concentration to these points could be quite large and an input parameter called the surface runoff lag coefficient (SURLAG) can be used to smooth peaks of the hydrograph by lagging a fraction of the flow to the following days. For the Olentangy River TMDL the SURLAG has been set to 2 days. Alternative values of SURLAG ranging from 1 day to 4 days were used in the manual calibration. Values of 1 day and 3 days produced similar statistical results for hydrology when compared to a SURLAG of 2 days. Ultimately, 2 days was selected because it appeared to preserve hydrograph peaks more consistently than other values.

2.8 Calibrating Stream Flow

We used the standard procedure outlined in the SWAT User's Manual (Neitsch et al., 2002b) to calibrate the Olentangy River TMDL model. The following outlines the steps of the procedures that were useful in this study:

- Total Flow Calibration
    1) Match surface runoff estimates from baseflow separation program
        - Adjust curve numbers at antecedent soil moisture condition two (CN2) to increase or reduce surface runoff
        - Adjust soil evaporation compensation factor (ESCO) to account for crusting and cracking affects on surface runoff
- Calibrate Subsurface Flow
    1) Baseflow recession
        - Change baseflow recession constant (Alpha_BF) to estimated value in baseflow filter program
    2) Match subsurface flow volume estimates from baseflow separation program
        - Adjust ground water revap coefficient (GW_Revap) to control the amount of water removed from the soil profile through evaporation
        - Adjust subsurface drain parameters
- Adjust Timing of Peaks
    1) Lag a portion of the surface runoff lag coefficient (SURLAG)
- Repeat the process as needed until hydrology is correct

SWAT-predicted stream flow was evaluated against measured results for USGS gages at Claridon, Delaware, and Worthington (Table 2.14). The position of the gages and the Delaware Dam within the watershed (Figure 2.11) diminished the value of the gage at Delaware because records of outflow from the dam were an input into SWAT. The Olentangy at Delaware USGS gage is about 0.5 miles downstream of the dam outfall. Therefore, most of the flows at the gage would simply be the flows that were inputs into SWAT – correlation would be almost perfect as measured values would essentially be compared with the same measured values. Some files contained missing data. Whenever possible stage measurements and stage-discharge relationships were obtained from the Ohio USGS and used to fill gaps in data. Where data did not exist values were omitted from analysis of SWAT-predicted flows.

Table 2.14 Results of regression analysis of observed versus predicted flow (ft^3/s) at USGS gage stations in the Olentangy River watershed.

USGS Gage	Time	Slope	Intercept	R^2
Claridon	Annual	0.92	5.5	0.84
Claridon	Monthly	0.83	17.7	0.80
Claridon	Daily	0.57	60.2	0.51
Delaware	Annual	1.05	4.8	0.97
Delaware	Monthly	1.06	-0.1	0.98
Worthington	Annual	0.86	67.9	0.92
Worthington	Monthly	1.01	30.9	0.95

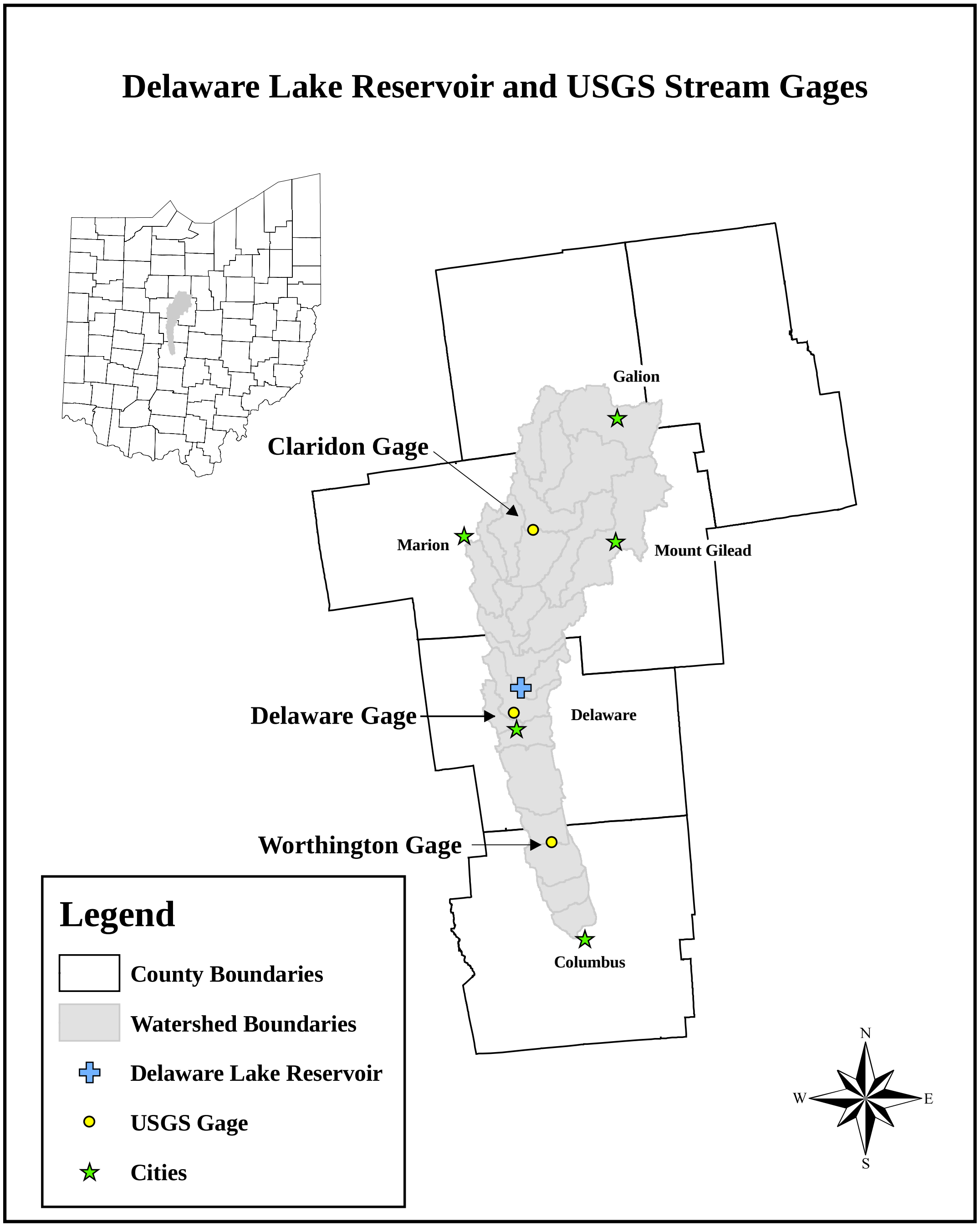


Figure 2.11 Map of Olentangy River watershed showing Delaware Dam and USGS stream gages.

By default, regression analysis results of observed versus predicted flows at the Delaware gage were in good agreement (Figure 2.12) and evaluation at this point in the system was not useful in the calibration.

To a lesser degree, the same problem occurs when evaluating SWAT stream flow in the Olentangy River watershed at the USGS gage in Worthington. Flow at this gage is also dependent on the controlled flows from Delaware Dam (that are directly read into the model), and results of the regression analysis were once again, by default, in good agreement (Figure 2.13).

Any model developed for the watershed area below the dam would benefit from additional sources of data for calibration. For example, flow data on several larger tributary systems in the lower Olentangy River sub-watershed would have been useful.

Several gages were in operation during the late 1970's and early 1980's, but these data did not fall within same timeframe as this study; therefore, we were unable to make a direct comparison of observed versus predicted stream flow on several tributaries that would have been particularly useful for model calibration.

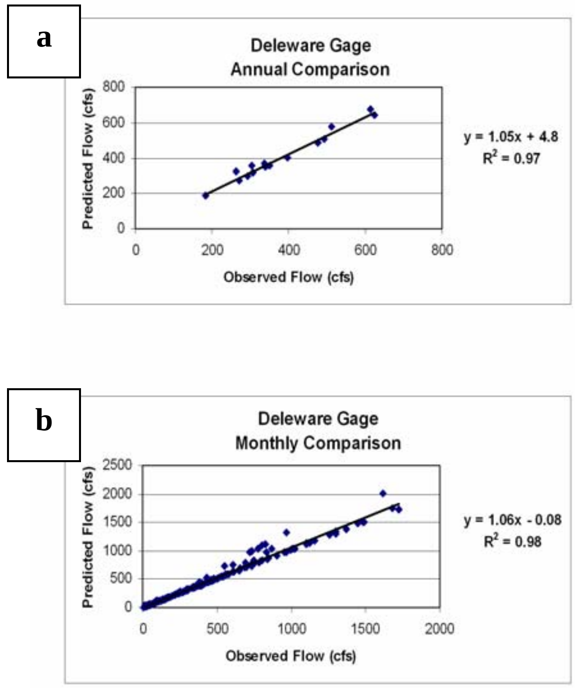


Figure 2.12 Observed vs. predicted a) mean annual discharge and b) mean monthly discharge at the Delaware gage.

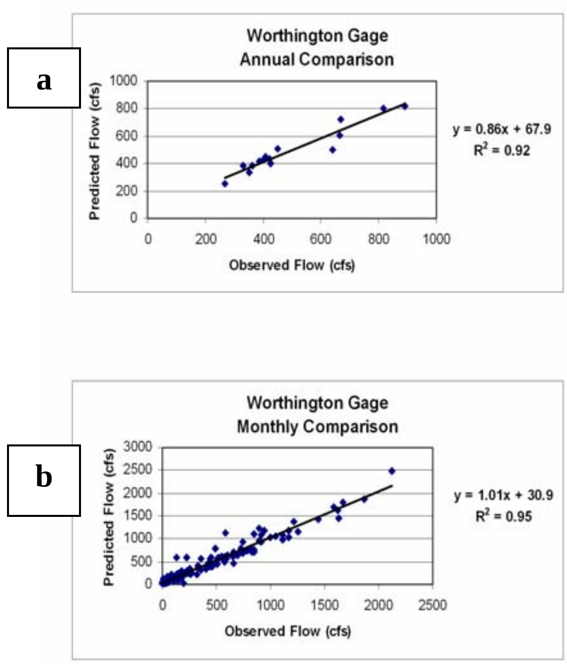


Figure 2.13 Observed vs. predicted a) mean annual discharge and b) mean monthly discharge at the Worthington Gage.

The most useful point in the watershed for calibration is at the Olentangy at Claridon USGS gage. The watershed area above this point (drainage area 157 mi^2) is predominantly agricultural or forested and flows are not significantly altered by control structures.

One major point source, the City of Galion, discharges into the headwaters of the Olentangy River but has little influence on flows at the Claridon gage. Results from a regression analysis of observed versus predicted flow at the Claridon gage can be seen in Figure 2.14 and Table 2.14.

To further aid in the calibration we examined observed versus predicted flows for individual months during the simulation period (Table 2.15 and Figures 2.15a and 2.15b).

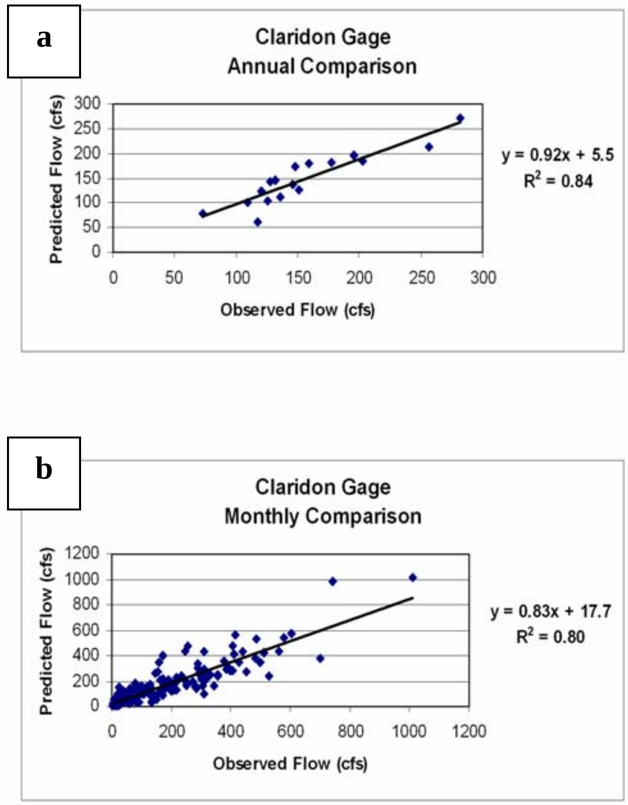


Figure 2.14 Observed versus predicted a) mean annual discharge; and b) mean monthly discharge at the Claridon Gage

This evaluation allowed us to determine if there were problems during any individual month or season of the year. Examination of regression results for individual months of flow suggested that additional calibration or better data inputs, such as temperature, might have improved prediction of flows during winter months.

Table 2.15 Monthly Regression Analysis Statistics

Month	Slope	Intercept	R^2
January	0.55	126.1	0.46
February	0.57	67.8	0.77
March	0.82	-12.6	0.90
April	0.63	-5.5	0.75
May	0.80	13.2	0.93
June	0.61	45.4	0.50
July	0.99	18.5	0.98
August	0.92	23.7	0.95
September	0.84	9.4	0.63
October	0.93	6.0	0.96
November	0.92	22.7	0.74
December	1.13	32.2	0.95

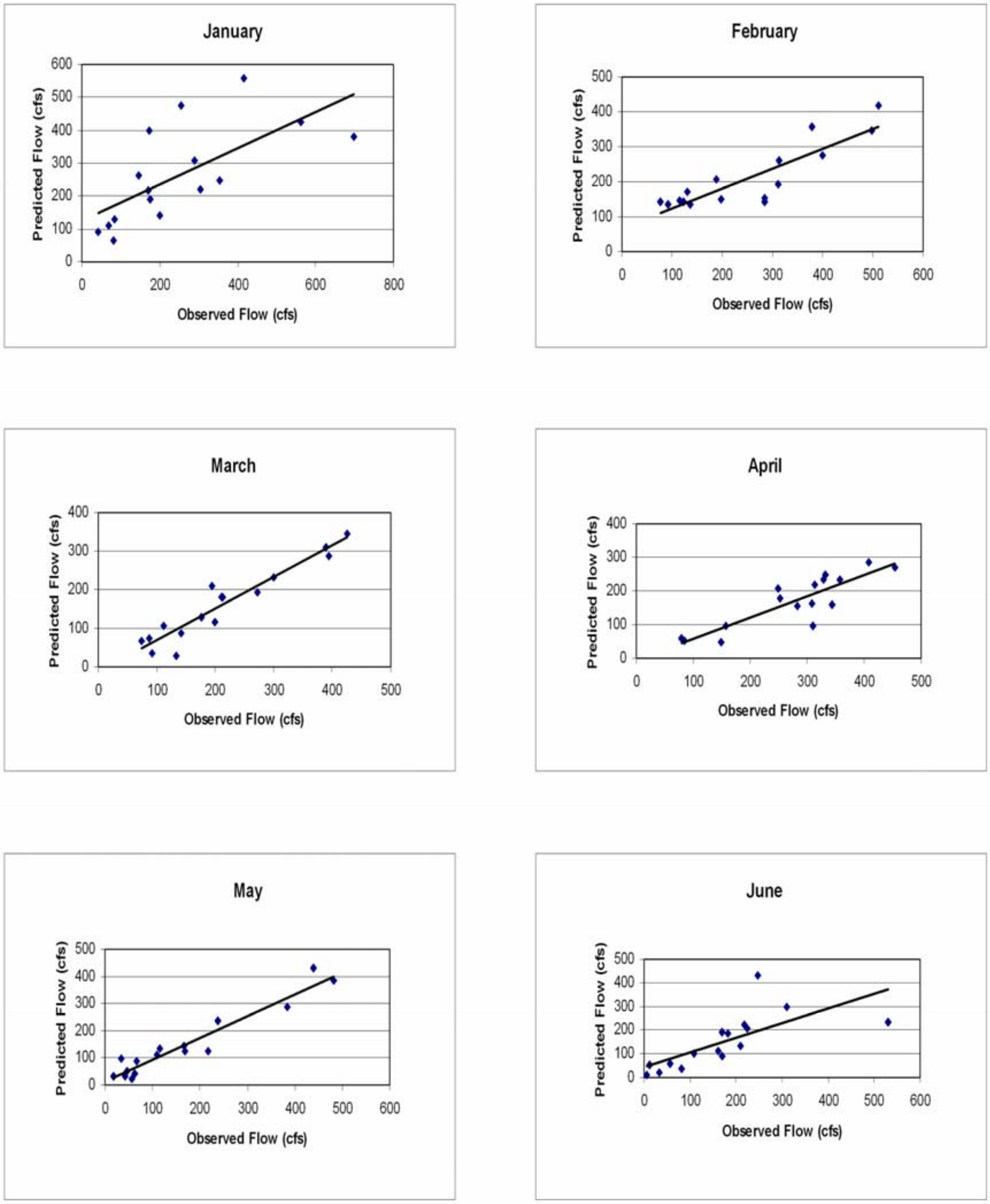


Figure 2.15a Observed versus predicted flows at the Claridon gage for individual months – January to June.

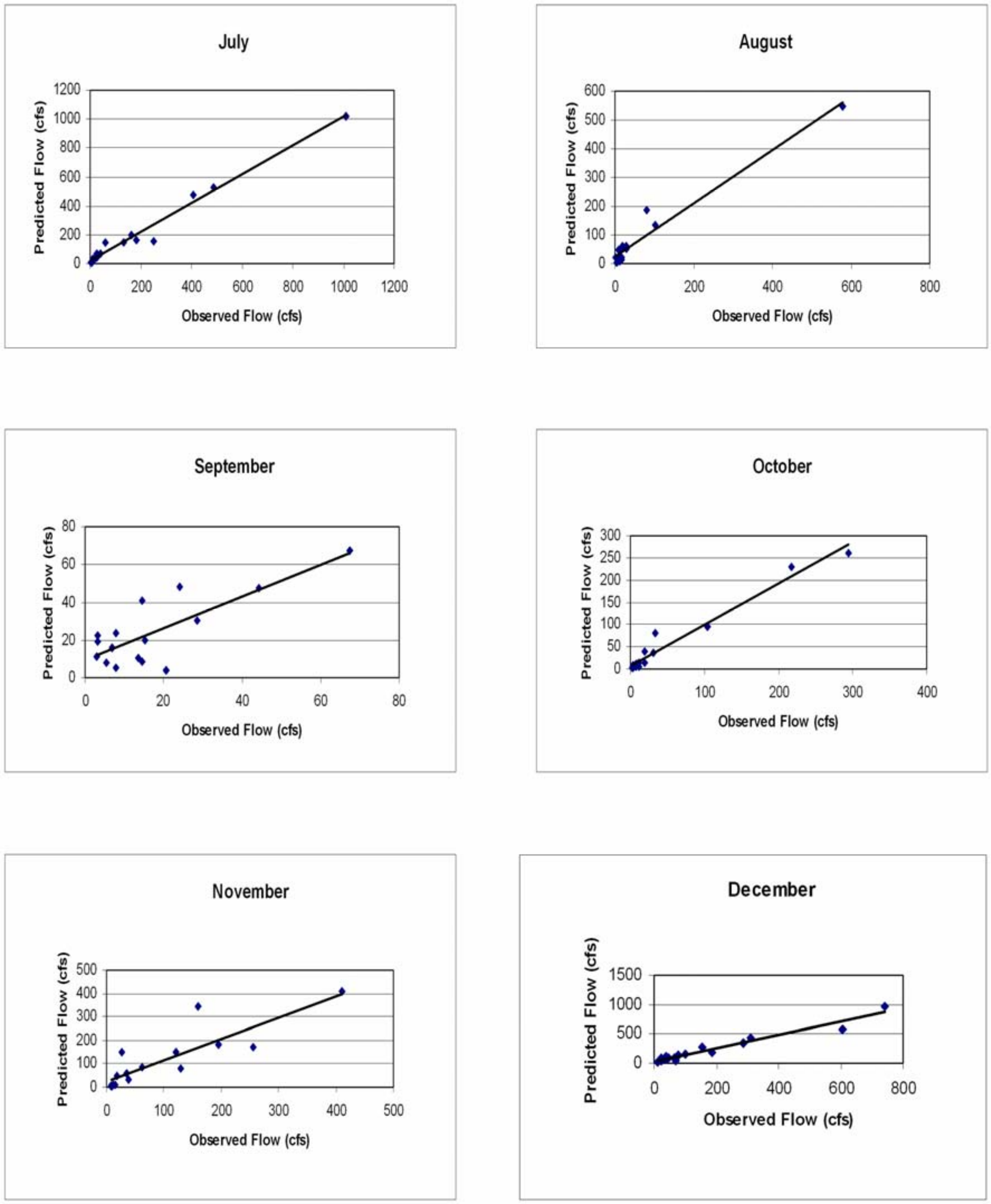


Figure 2.15b Observed versus predicted flows at the Claridon gage for individual months – July to December.

A summary of the average annual water balance for the calibrated model is reported in Table 2.16

Table 2.16 Average annual mass water balance.

Component of Hydrologic Cycle	Water Depth[1](inches)
Precipitation	39.1
Potential Evapotranspiration	42.7
Actual Evapotranspiration	24.6
Surface Runoff	7.6
Tile and Lateral Flow	2.6
Groundwater Flow	2.7
Total Aquifer Recharge	4.1
Water Yield	12.8[2]

[1]Water Depth is depth of water (inches) across the watershed area and is the sum of the surface runoff, tile and lateral flow and groundwater flow.
[2]Watershed area is approximately 540 square miles at the confluence.

Arguably, results from one study cannot be compared to results from another study because of different temporal and spatial scales, different levels of available measured input data such as climatic data, and different levels of measured data used to compare predicted and observed outputs. However, difficulties with accurately modeling monthly flows at various times of the year, particularly the winter months, have been reported in the literature. When SWAT was applied to the Sandusky River watershed, Qi and Grunwald (2005) noted "*the model had problems dealing with snow accumulation and melting processes ...*" For the five sub-watersheds in the Sandusky River they report correlation coefficients for monthly flow of 0.62 to 0.87.

At various locations in the Rock River Basin in Wisconsin, a comparison of measured and annual flows predicted using SWAT gave correlation coefficient values ranging from 0.28 to 0.98 (Kirsch et al., 2002). Near the outlet of this 9,708 km^2 watershed the correlation coefficient was 0.78. Wang (2005), in a study of the Wild Rice River watershed in Minnesota, found that SWAT had difficulty in predicting monthly flows in January, February, March, September, October, and November. In that study, correlation coefficient value for mean daily flows varied from 0.52 to 0.73, correlation coefficient values for mean monthly flows varied from 0.20 to 0.98, while correlation coefficient values for mean annual flows varied from 0.73 to 0.93.

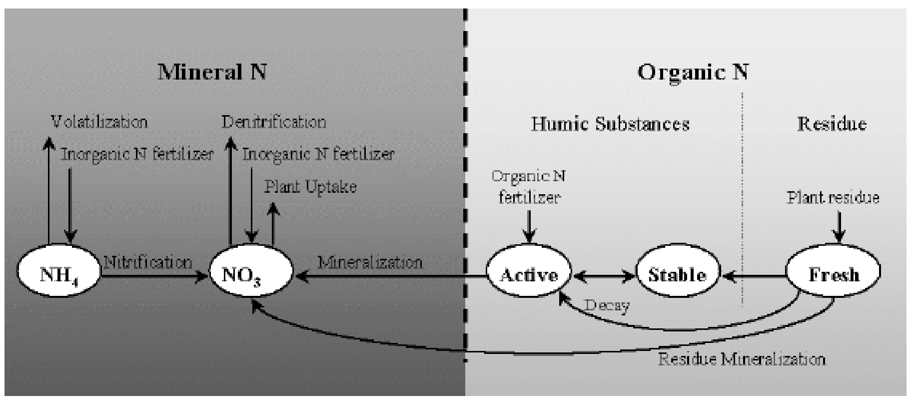
2.9 Sediment and Nutrient Parameters

Transport of sediments and nutrients from the landscape into streams is a normal result of soil weathering and erosion processes (Neitsch et al., 2002a). In highly managed agricultural and urban watersheds excess nutrients can be delivered to stream systems and potentially cause impairments. The following sections discuss some of the parameters used to calibrate nutrient loadings in the Olentangy River TMDL model. Because phosphorus is primarily transported by attachment to sediment particles the calibration for sediment impacted phosphorus calibration.

2.9.1 Nutrient Cycling

Based on many factors, SWAT simulates the transformation of nutrients into other phases of the nutrient cycle. For a complete discussion of nutrient pools and transformations simulated by SWAT consult Neitsch et al. (2002a). A schematic illustrating the processes modeled in SWAT is shown in Figure 2.16. SWAT does have the capability of simulating in-stream nutrient transformations, but that option was not utilized because of the difficulty and uncertainty in parameter estimation. Therefore, SWAT routed dissolved nutrients based on water movement and organic or sorbed nutrients with sediment transport.

a) Nitrogen Process Partitioning



b) Phosphorus Process Partitioning

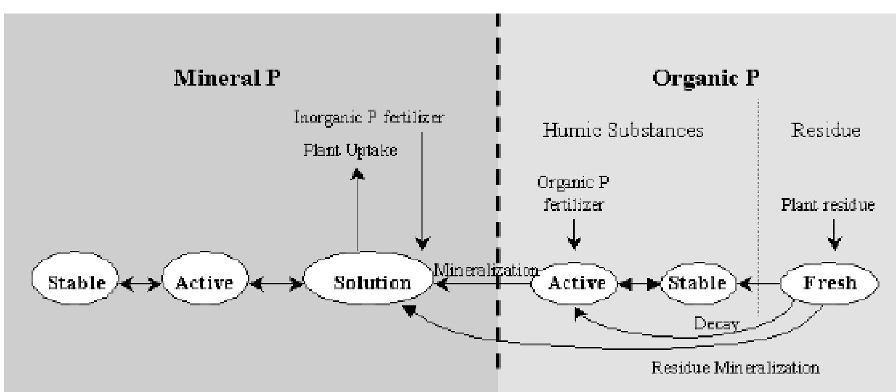


Figure 2.16 Partitioning of a) Nitrogen and b) Phosphorus in SWAT (*source: Neitsch et al., 2002a*).

The following description of nutrient cycling in SWAT was obtained from Neitsch et al. (2002a). SWAT tracks the movement and transformation of several forms of nitrogen and phosphorus in the watershed. In the soil, transformation of nitrogen from one form to another is governed by the nitrogen cycle (Figure 2.17). Nutrients may be introduced to the main channel and transported downstream through surface runoff and lateral subsurface flow. Plant use of nitrogen was estimated using a supply and demand approach. In addition to plant use, nitrate-N and organic N may be removed from the soil via mass flow of water.

Amounts of nitrate-N contained in runoff, lateral flow and percolation were estimated as products of the volume of water and the average concentration of nitrate-N in the layer. Organic N transport with sediment was calculated with a loading function developed by McElroy et al. (1976) and modified by Williams and Hann (1978) for application to individual runoff events. The loading function estimates the daily organic N runoff loss based on the concentration of organic N in the top soil layer, the sediment yield, and the enrichment ratio. The enrichment ratio is the concentration of organic N in the sediment divided by the concentration in the soil.

Plant use of phosphorus was estimated using the supply and demand approach. In addition to plant use, soluble P and organic P may be removed from the soil via mass flow of water. Phosphorus is not a mobile nutrient and interaction between surface runoff with solution P in the top 10 mm of soil will not be complete. The amount of soluble P removed in runoff was predicted using the solution P concentration in the top 10 mm of soil, the runoff volume, and a partitioning factor. Sediment transport of P was simulated with a loading function as described in organic N transport.

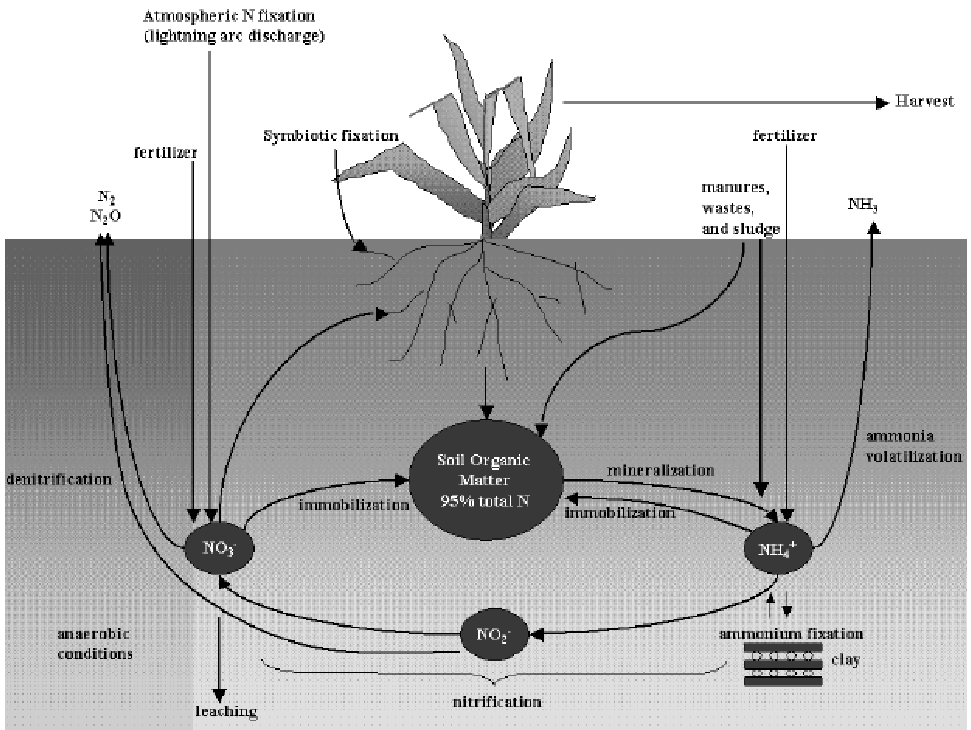


Figure 2.17 The nitrogen cycle and its processes (*Source: Neitsch et al., 2002a*).

To estimate the amount of nitrate-N removed in surface runoff SWAT uses a nitrogen percolation coefficient (NPERCO). SWAT allows surface runoff to interact and transport nutrients from a near surface soil layer. The concentration of nitrate-N in the mobile water at the near surface layer is expressed as a fraction of the percolation concentration NPERCO ranges from 0.01 to 1.0. As NPERCO approaches 1.0 the concentration of nitrate-N in the surface runoff approaches the concentration of nitrate-N in percolated water. NPERCO was set to 1.0 for the Olentangy River TMDL model.

SWAT simulated nitrogen and phosphorus transport through the Delaware Dam using a settling rate model (Chapra, 1997) for each constituent. The settling rate is an apparent rate and represents the combined affect of all nutrient settling processes. Positive settling rates suggest the reservoir is a sink for nutrients while negative settling rates suggest the reservoir is a source of nutrients. For the Olentangy River TMDL model these parameters were set to zero, therefore the reservoir was not considered a source or a sink for nitrogen and phosphorus.

2.9.2 Sediment Parameters

Sediment routing was simulated with two major processes: deposition and degradation. SWAT uses a simplified version of William's (1980) modification of Bagnold's stream power equation to determine the maximum amount of sediment that can be transported as a function of peak channel velocity (Nietsch et al., 2002a). To model sediment loadings from the landscape to streams SWAT uses the Modified Universal Soil Loss Equation (MUSLE; Williams, 1975; Williams, 1995). Calibration of sediment in the Olentangy River watershed included adjustment of the topographic factor of the MUSLE, HRU slopes, and a sediment routing/re-entrainment coefficient. The modified universal soil loss equation is:

$$sed = 11.8 * \left(Q_{surf} * q_{peak} * area_{hru}\right)^{0.56} * K_{USLE} * C_{USLE} * P_{USLE} * LS_{USLE} * CFRG \qquad (2.3)$$

where *sed* is sediment yield on a given day (metric tons), Q_{surf} is the surface runoff volume (mm H_2O/ha), q_{peak} is the peak runoff rate (m^3/s), $area_{hru}$ is the area of the HRU (ha), K_{USLE} is the USLE soil erodibility factor (0.013 metric ton m^2 hr/(m^3-metric ton cm)), C_{USLE} is the USLE cover and management factor, P_{USLE} is the USLE support practice factor, LS_{USLE} is the USLE topographic factor and *CFRG* is the coarse fragment factor. The topographic factor (LS) is the expected ratio of soil loss per unit area from a field slope to that from a 22.1 meter length at 9% uniform slope. This value was automatically assigned by the AVSWATX interface and appeared to over-predict LS factors, which ranged from 60 meters to 120 meters. Therefore, the LS factors were reduced to 30 meters. Slopes of the sub-basins were adjusted by multiplying by a factor of 0.3048. The AVSWATX interface-derived slopes seemed to be systematically over-predicting landscape slopes by a factor of about 3. Actual slopes were taken from the State of Ohio Gazetteer (DeLorme, 2000). We suspect an error in the GIS projection and a conversion error of 0.3048 (number of meters in 1 foot) to be consistent for all sub-basins. Once adjusted, all sub-basin slopes appeared reasonable.

In the sediment routing component of SWAT an equation was added to limit the maximum amount of sediment that could be transported. The maximum concentration of sediment transported is limited by a power function relationship based on peak velocity of channel flow. Sediment transport in the channel network is a function of deposition and degradation. SWAT computes deposition and degradation by using either the same channel dimensions for the entire simulation or by estimating down-cutting and widening of the stream channel and then updating channel dimensions throughout the simulation. In version 2005 of SWAT the algorithms for these processes were modified and simplified. The maximum amount of sediment transported from a reach segment is a function of the peak channel velocity and two user-defined parameters. The exponential component of the equation was set at the default value of 1.0 making it a linear relationship with a slope based on the parameter SPCON. SPCON was set at 0.0005 (default value = 0.0001) and essentially used as a calibration parameter. Values for SPCON and the exponential component of the equation could be refined with further information on channel flow velocities and corresponding sediment concentrations.

Degradation is a function of a user-defined channel erodibility factor and a channel cover factor. The channel erodibility factor is conceptually similar to the soil erodibility factor used in the USLE equation. Channel erodibility is a function of properties of bed or bank materials and can be measured with a submerged vertical jet device (Hanson, 1990).

In general, values for channel erodibility are an order of magnitude smaller than values for soil erodibility. The channel cover factor is defined as the ratio of degradation from a channel with a specified vegetative cover to the corresponding degradation from a channel with no vegetative cover. Vegetation affects degradation by reducing stream velocity and, consequently, its erosive power near the bed surface. Measurements of channel erodibility were not made because of resource constraints. No method is currently available to quantify the channel cover factor. Therefore, in the main Olentangy River TMDL analysis we did not simulate degradation. However, sensitivity of TSS loads to degradation was evaluated for one sub-basin, Horseshoe Run.

SWAT also has parameters to deal with sediment transport through reservoirs. This involves setting an equilibrium concentration of sediment in the reservoir. When inflow to the reservoir exceeds that concentration settling is allowed to occur. We set this variable to 100 mg/l based on analysis of outflow data collected by the City of Delaware in 2003 and 2004 at the dam. Results of a sensitivity analysis suggested that water quality predictions downstream from the dam were not very sensitive to this parameter. We varied this parameter between 50 mg/l and 200 mg/l with little variation in sediment concentration predictions at the watershed outlet.

2.10 Calibration of Water Chemistry Loads

Compared to hydrology, there was substantially less information on which to calibrate nutrient loadings. It was not possible to perform a statistical evaluation of observed and predicted loads because of the unavailability of long-term measurements at the same locations that SWAT was predicting loads. We were able to use results from several other studies to determine appropriate loadings and to guide nutrient calibration. The following datasets were used in model calibration of sediment and nutrients: 1) grab samples from the Ohio EPA chemical and biological assessment of the Olentangy River watershed 2003; 2) results from a City of Delaware 319 Project; 3) a report to the Great Lakes Commission (Whiting, 2003); and 4) data from Heidelberg College's Water Quality Lab long-term monitoring station on the Scioto River at Chillicothe, Ohio (*http://wql-data.heidelberg.edu/*).

Ohio EPA grab samples were taken at about 35 locations in the upper Olentangy River watershed from April 2003 to October 2003. During that time, each location was typically sampled 6 times. Samples were analyzed for a suite of pollutants including TP, nitrate-N, and TSS. Results from this study were used to determine general water quality trends and signatures throughout the watershed. Because samples were collected during a limited sampling season they were not used for additional calibration.

As part of a 319 project to develop a management plan for the upper Olentangy River watershed, the City of Delaware (COD) collected water samples monthly or bimonthly depending on time of year at 8 locations. Two of those sites included the Olentangy River at Claridon and the Olentangy River near Worthington. Because of their proximity to USGS stream gages, these two sites were used for the reason that we could combine flow data and pollutant concentrations and determine flow-weighted averages. Results are available in Table 2.17.

Table 2.17 Comparison of modeled nutrient concentrations and sampling results in the Olentangy River and Scioto River watersheds.

Location	Source	Average TP (mg/l)	Average NO_3-N (mg/l)	Average TSS (mg/l)	FW TP (mg/l)	FW NO_3-N (mg/l)	FW TSS (mg/l)	TSS:TP
Claridon	SWAT	0.50	5.9	56	0.37	3.6	172	464
Outlet[1]	SWAT	0.35	5.4	70	0.32	3.8	114	356
Scioto[2]	Heidelberg	0.30	3.7	69	0.34	4.4	145	426
Claridon	COD	-	-	-	0.49	3.6	126	257
Worthington	COD	-	-	-	0.23	3.7	47	204
Scioto[3]	Heidelberg	-	-	-	0.37	3.3	170	459

[1]Outlet is the confluence of the Olentangy to the Scioto River – downstream of Worthington.
[2]Scioto River at Chillicothe.
[3]Results from this row are taken from the Heidelberg database but include only samples taken on the same days as the City of Delaware (COD) samples.

A study conducted by Whiting (2003) analyzed stream gages in the Great Lakes Basin with multiple years of suspended sediment data. These data were used to determine sediment loading rates per unit watershed area. A summary of Ohio streams in that study is presented in Table 2.18. Average sediment loading per unit watershed area was also calculated for SWAT results and is included in Table 2.18.

Since 1997, as part of a study of tributaries to the Ohio River, Heidelberg College has obtained water quality data on the Scioto River at Chillicothe. Typically 1 to 3 samples were taken daily and flow data were available to calculate flow weighted averages for TP, nitrate-N, and TSS. A summary of this data was presented in Chapter 1 and is shown again in Table 2.19. Results in Tables 2.17, 2.18, and 2.19 show that predicted TP, nitrate-N, and TSS loads or concentrations are similar to measured values at various locations in the Olentangy River and Upper Scioto River.

Table 2.18 Comparison of SWAT prediction of sediment loading per unit area to a study of gages in the Great Lakes (Whiting, 2003).

River	Sediment Loading (tons/acre/yr)
St. Mary's near Fort Wayne	0.30
Maumee River at Waterville	0.27
Portage River at Woodville	0.16
Sandusky River near Fremont	0.41
Huron River	0.22
Scioto River at Higby	0.37
Olentangy River (SWAT prediction)	0.31[1]

[1]Average predicted sediment loading for SWAT sub-basins.

Table 2.19 Water quality of Ohio Rivers for 1997-2003, with the exception of Sandusky (1997-1999; 2002-2003) and Vermilion (2001-2003). Mean flow-weighted concentrations in mg/l (*Source: http://www.heidelberg.edu*).

River Name	Total P	NO_2+NO_3-N	TSS	N:TP	TSS:TP
Wadeable Stream					
Rock Creek	0.50	4.0	302	8.0	602
Honey Creek	0.42	6.1	160	14.5	379
Small River					
Vermilion	0.29	3.6	162	12.4	548
Grand	0.15	0.7	159	4.7	1045
Cuyahoga	0.35	1.7	323	4.9	934
Large River					
Raisin	0.21	5.1	109	24.3	518
Sandusky	0.43	6.7	226	15.6	520
Great Miami	0.42	4.9	146	11.7	345
Scioto	0.35	4.3	143	12.3	413
Maumee	0.42	6.5	197	15.5	473
Muskingum	0.17	1.7	78	10.0	453
Mean All Sites	**0.34**	**4.1**	**182**	**12.1**	**566**

2.11 Calibration of Crop Yields

An important component of SWAT is the plant growth model. To simulate plant growth SWAT uses a simplified version of EPIC (Erosion-Productivity Impact Calculator; Williams et al., 1995). For SWAT to give reasonable predictions of hydrology and nutrient transport this component must work well because water and nutrient uptake and nutrient transformations into various pools will affect loadings to the stream system. One way to determine if crop growth appears to be simulated properly is to compare predicted crop yields to actual reported crop yields. Information on actual crop yields was determined from the National Agricultural Statistics data. A comparison of actual and predicted crop yields indicated that predicted yields were lower than actual yields (Table 2.20).

Table 2.20 Comparison of Actual and Predicted Crop Yields

Crop	Actual Yield[1] (bushels/acre)	Predicted Yield[2] (bushels/acre)	% of Actual
Corn	120	87	73
Soybeans	38	28	74
Wheat	58	42	72

[1]Actual Yield Data was calculated with Ohio's National Agricultural Statistics Service data for Crawford, Marion, Morrow, and Delaware counties.
[2]Predicted Yield data was calculated from SWAT results.

We determined that, while further modification of parameters that influenced the water balance improved yields they decreased the correlation between observed and predicted flow and water quality. Higher fertilizer applications increased yields but also modified water quality results. Predicted plant biomass seemed reasonable, but adjustments in how biomass is converted to yields would probably improve the yield predictions. As these changes would not influence the other results, and we had no scientific knowledge on what to change, we decided to make no further calibration for yields.

2.12 Scale Issues and Uncertainty

2.12.1 Temporal and Spatial Scale Issues

The SWAT model we developed for this TMDL project includes the entire Olentangy River watershed (approximately 540 mi^2). It is not feasible and/or practical to model actual land use activities and practices at the scale they occur. For example, individual fields and subdivisions were not modeled. The timing of every activity that might generate a load also was not modeled. The watershed was subdivided into 147 sub-basins (average size 3.7 mi^2) and 342 HRUs (average size 1.6 mi^2). In general, each HRU consisted of a grouping of similar activities that are likely to occur at some location, or locations, within a sub-basin. Calibration of the model occurred primarily at the Claridon (drainage area 157 mi^2) and Worthington (drainage area 450 mi^2) gages. SWAT results are reported at the 14-digit HUC outlets (approximately 10 mi^2 to 63 mi^2). Because the model was developed and calibrated at a different scale than reality, and at a slightly different scale than the reporting of results, it is important to understand how results at a particular point (such as a HUC outlet) could be affected by scale issues.

An example of a model development decision that could have created scale issues was the assignment of tile drainage to agricultural sub-basins. As described earlier, this version of SWAT requires tile drainage to be assigned to entire sub-basins. Therefore, it was necessary to select sub-basins with agricultural land HRUs to assign subsurface drainage. Otherwise, SWAT will simulate drainage on land uses that are not typically drained. In certain cases it was necessary to “swap” HRUs with other sub-basins in the HUC to create enough completely agricultural sub-basins. In areas like Crawford and Marion counties that have a high percentage of agricultural land with subsurface drainage (70%) many sub-basins will simulate tile flow. It is possible that all sub-basins with agricultural land use in a 14-digit HUC could be simulating tile drainage when in reality the percentage is much less. Therefore, an overestimation of the percentage of subsurface drained agricultural land could provide biased results at the HUC scale. We attempted to minimize these issues whenever possible and have identified HUCs with potential errors due to scale issues (Chapter 3).

Other modeling strategies that might influence the results include: (1) strategies used to represent the timing of different farming practices and the application of nutrients in agricultural and urban areas; (2) allocation of animal waste to various fields and pastures; (3) inadequate consideration of the specific location of various non-point source activities; (4) inadequate consideration of urban storm water management strategies; (5) inadequate consideration of septic systems; and (7) and insufficient knowledge to model each minor point discharger. In developing our strategies that relate to these seven issues, our primary goal was to obtain representative water quality signatures at an 11-digit HUC scale and reasonable signatures at a 14-digit HUC scale. We use the term “inadequate consideration” for situations where we believe the impact on the result would be small and there was insufficient knowledge, a SWAT modeling limitation, and/or addressing that issue in more detail would overwhelm the resources available for the study. Specific input and modeling factors that might cause the most uncertainty are discussed in the next sections.

2.12.2 Input Data Uncertainty Issues

Any parameter or dataset used in SWAT modeling has some degree of uncertainty associated with it. We used literature values, or a range of values suggested by the model developers, that may or may not be appropriate for a particular watershed. Often we must accept these values because data were not available or could not be collected to support making changes in a parameter value. Digital datasets at different resolutions might impact everything from basin delineation to parameterization of physical properties. We did not specifically calculate error propagation through the model, but our approach is consistent with other studies.

Care should be taken in attempting to compare our results with results for other watersheds reported in the literature or in published TMDL studies. In most cases, simulation models like SWAT are only calibrated to minimize the differences between measured and predicted stream flow. Less often, calibration is also performed for one or more water chemistry constituents. Rarely does the calibration also consider crop yields. Our calibration study addressed stream flow, water quality, and crop yields in that order. The best calibration for stream flow did not provide adequate results for water quality and yield. The best calibration for stream flow and water quality did not provide the best yield estimates. Therefore, input parameter adjustments and even changes in how processes, such as PET, were modeled were made in order to obtain reasonable signatures for stream flow, water quality, and crop yields. At the end of this process we still underestimated crop yields. Further adjustments to crop growth variables that have little influence on stream flow and water quality might have increase yields. However, we suspect that actual fertilizer applications might be somewhat higher than reported. Increasing these applications would increase yields but would also change the water quality. These changes might then necessitate some changes in other input variables.

When using a simulation model it is almost impossible to obtain a “correct” answer. Also, there is a reasonable probability that an acceptable answer might be obtained based on a wrong modeling strategy, an incorrect model input, or in adequate consideration of important processes. For example, consideration of in-stream processes, such as bed and bank scour, was inadequate because of inadequate knowledge of model inputs to simulate these processes. Although we have reasonable water quality signatures, these “good” results are to some extent based on the "wrong" reasons. It is our belief that the main value of the modeling results is to provide information on general trends and relative differences or changes associated with representative combinations of human activities, climatic variables, and landscape attributes. On a day-to-day, week-to-week, or month-to-month basis the error might be large. In the long term (several years) there is probably at least a 25% error in any of the stream flow, water quality, and crop yield estimates at the outlet of an 11-digit HUC. The error for any specific location in a sub-basin could be 100% or more.

Care needs to be taken in interpreting the benefits of a management practice such as the use of a grass buffer. The SWAT model is unable to consider situations were surface runoff combines before reaching the buffer and then discharges through only a small portion of the buffer. Also, the model is unable to exclude treating tile flow that passes underneath a buffer.

2.12.3 Uncertainty Issues Related to Watershed Descritization

The AVSWATX interface facilitates rapid subdivision of a watershed into sub-basins and HRUs. However, evaluation of the effect of watershed descritization on the quality of model predictions has not been widely studied. Research has shown that SWAT predictions can be significantly influenced by these choices (Chaubey et al., 2004). Some studies have shown there is a threshold beyond which further division of the watershed has a negligible impact on model predictions. Other studies show that certain nutrients are not as sensitive as others with regards to discretization. Impacts of sub-basin and HRU size were not specifically evaluated in this project, but our sub-basin and HRU size compared to overall watershed size is consistent with other studies reported in the literature and other published TMDL reports. In general, we had more sub-basins than is often used but larger HRUs. However, as shown earlier the statistical relationships between measured and predicted stream flows were similar or better than most recent studies with SWAT.

2.12.4 Uncertainty Issues Related to ET Method or Model Choices

To examine some of the issues of model uncertainty we developed an alternative SWAT model of the Olentangy River watershed using the Penman-Monteith method for PET. This model used the same parameters as the Hargreaves model except for Initial SCS Curve Number (CN2) and the Soil Evaporation Coefficient (ESCO). Differences for those values can be seen in Table 2.21.

Table 2.21 Parameter differences in Olentangy River models.

Parameter	Penman-Monteith	Hargreaves
CN2	CN2 reduced by 2	CN2
ESCO	0.8	0.95

Results of a regression analysis (Tables 2.22 and 2.23) of observed versus predicted flows (ft^3/s) appear to be slightly better for the Penman-Monteith Olentangy model. Our selection of the Hargreaves model was based on better estimation of baseflow (Hargreaves - 41%; Penman-Monteith - 28%), better estimates of ground water recharge (Hargreaves - 4 inches; Penman-Monteith – 3 inches), and better comparison of nutrient predictions to measured data (Table 2.23). The Hargreaves model also modeled crop yields slightly better than the Penman model (5-7% depending on crop type).

Table 2.22 Annual, monthly, and daily regression results for Olentangy River models.

USGS Gage	Time	ET Method	Slope	Intercept	R^2
Claridon	Annual	Penman-Monteith	0.98	1.1	0.87
Claridon	Monthly	Penman-Monteith	0.93	8.6	0.83
Claridon	Daily	Penman-Monteith	0.64	55.0	0.56
Claridon	Annual	Hargreaves	0.92	5.5	0.84
Claridon	Monthly	Hargreaves	0.83	17.7	0.80
Claridon	Daily	Hargreaves	0.57	60.2	0.51

Table 2.23 Individual month regression results for Olentangy River models.

	Penman-Monteith			Hargreaves		
Month	Slope	Intercep	R^2	Slope	Intercept	R^2
January	0.66	107.0	0.60	0.55	126.1	0.46
February	0.60	65.5	0.86	0.57	67.8	0.77
March	0.98	-26.3	0.86	0.82	-12.6	0.90
April	0.74	-28.4	0.66	0.63	-5.5	0.75
May	0.96	1.3	0.87	0.80	13.2	0.93
June	0.88	20.0	0.63	0.61	45.4	0.50
July	1.09	11.7	0.96	0.99	18.5	0.98
August	1.24	13.9	0.98	0.92	23.7	0.95
September	0.72	6.9	0.69	0.84	9.4	0.63
October	1.01	2.5	0.94	0.93	6.0	0.96
November	0.98	13.4	0.73	0.92	22.7	0.74
December	1.20	19.9	0.97	1.13	32.2	0.95

2.13 Conclusions and Recommendations

Statistically, the correlation between observed and predicted flow, water quality, and crop yields in this study are comparable to or better than most published manuscripts or applications of SWAT in TMDL studies. For model calibration, we used a procedure outlined in the SWAT User's Manual and changed SWAT parameters within suggested ranges. The SWAT model is an approximation of a complex system and is not able to simulate all processes at the exact spatial and temporal scales that they occur. Also, many processes are approximated by empirical algorithms that sometime contain parameters that are difficult to quantify and/or cannot be determined based on actual measurements. The potential exists that other modeling assumptions might have resulted in improved results. However, the SWAT model literally has hundreds of variables that could be used for calibration. Also, measured data are never exact and some of the unexplained variability between observed and predicted outputs is due to uncertainties and/or errors in the measured inputs and outputs.

Results of the SWAT modeling are presented in Chapter 3. The results provide useful information on general watershed responses to various management practices and combinations of soil and landscape attributes, but application of these results should be used with caution. They are not intended to provide absolute values or specific results for locations within a sub-basin. Because of limited knowledge in some cases, such as specific fertilizer and manure application, it was necessary to "randomly" assign applications to some HRUs. The potential exists that some sub-basins have simulated applications that are inconsistent (too high or two low) with actual applications.

Appendix 2

Table A.1 Properties for land use and soils combinations in SWAT.

Land Use	Soil Association Name	Map Unit ID	Hydrologic Group	Overland Manning's	Curve Number (AMCII)
Agriculture	Milford-Laurey-Tiro	OH012	B	0.14	75
Pasture/Hay	Milford-Laurey-Tiro	OH012	B	0.14	75
Forest	Milford-Laurey-Tiro	OH012	B	0.10	66
Agriculture	Glynwood-Blount-Morley	OH021	C	0.14	81
Low Density Residential[1]	Glynwood-Blount-Morley	OH021	C	0.10	79.3
Pasture/Hay	Glynwood-Blount-Morley	OH021	C	0.15	79
Forest	Glynwood-Blount-Morley	OH021	C	0.10	77
Agriculture	Pewamo-Blount-Glynwood	OH022	C	0.14	81
Low Density Residential[1]	Pewamo-Blount-Glynwood	OH022	C	0.10	79.3
Pasture/Hay	Pewamo-Blount-Glynwood	OH022	C	0.15	79
Forest	Pewamo-Blount-Glynwood	OH022	C	0.10	77
High Density Residential[1]	Crosby-Brookston-Miamian	OH025	C	0.10	92
Commercial[1]	Crosby-Brookston-Miamian	OH025	C	0.10	89.4
Low Density Residential[1]	Crosby-Brookston-Miamian	OH025	C	0.10	79.3
Forest	Crosby-Brookston-Miamian	OH025	C	0.10	77
High Density Residential[1]	Eldean-Ockley-Sleeth	OH028	B	0.10	89.6
Commercial[1]	Eldean-Ockley-Sleeth	OH028	B	0.10	85.1
Low Density Residential[1]	Eldean-Ockley-Sleeth	OH028	B	0.10	69.5
Agriculture	Tiro-Pandora-Bennington	OH041	C	0.14	81
Pasture/Hay	Tiro-Pandora-Bennington	OH041	C	0.15	79
Agriculture	Bennington-Cardington-Orrville	OH063	C	0.14	81
Agriculture	Centerburg-Bennington-Marengo	OH064	C	0.14	81
Low Density Residential[1]	Centerburg-Bennington-Marengo	OH064	C	0.14	79.3
Pasture/Hay	Centerburg-Bennington-Marengo	OH064	C	0.15	79
Forest	Centerburg-Bennington-Marengo	OH064	C	0.10	77
Commercial[1]	Bennington-Pewamo-Cardington	OH066	C	0.10	89.4
Agriculture	Bennington-Pewamo-Cardington	OH066	C	0.14	81
Low Density Residential[1]	Bennington-Pewamo-Cardington	OH066	C	0.10	80.2
Pasture/Hay	Bennington-Pewamo-Cardington	OH066	C	0.15	79
Agriculture	Centerburg-Amanda-Bennington	OH071	C	0.14	81
Pasture/Hay	Centerburg-Amanda-Bennington	OH071	C	0.15	79
Forest	Centerburg-Amanda-Bennington	OH071	C	0.10	77
Agriculture	Bennington-Condit-Cardington	OH079	C	0.14	81
Low Density Residential[1]	Bennington-Condit-Cardington	OH079	C	0.10	79.3
Pasture/Hay	Bennington-Condit-Cardington	OH079	C	0.15	79
Forest	Bennington-Condit-Cardington	OH079	C	0.10	76
Pasture/Hay	Cardington-Bennington-Sloan	OH0127	C	0.15	79
Forest	Cardington-Bennington-Sloan	OH0127	C	0.10	77

[1]In urban areas, surface runoff is calculated separately for directly connected impervious area. For directly connected impervious area a curve number of 98 is used. Otherwise, a composite curve number is calculated using a procedure outlined in Soil Conservation Service Engineering Division (1986).

Table A.2 Properties for land use and soils combinations in SWAT.

Land Use	Soil Association Name	Map Unit ID	Hydrologic Group	Wiling Point	Field Capacity	Saturation
Agriculture	Milford-Laurey-Tiro	OH012	B	269	295	400
Pasture/Hay	Milford-Laurey-Tiro	OH012	B	269	295	400
Forest	Milford-Laurey-Tiro	OH012	B	269	295	400
Agriculture	Glynwood-Blount-Morley	OH021	C	227	241	345
Low Density Residential	Glynwood-Blount-Morley	OH021	C	227	241	345
Pasture/Hay	Glynwood-Blount-Morley	OH021	C	227	241	345
Forest	Glynwood-Blount-Morley	OH021	C	227	241	345
Agriculture	Pewamo-Blount-Glynwood	OH022	C	308	257	326
Low Density Residential	Pewamo-Blount-Glynwood	OH022	C	308	257	326
Pasture/Hay	Pewamo-Blount-Glynwood	OH022	C	308	257	326
Forest	Pewamo-Blount-Glynwood	OH022	C	308	257	326
High Density Residential	Crosby-Brookston-Miamian	OH025	C	242	221	284
Commercial	Crosby-Brookston-Miamian	OH025	C	242	221	284
Low Density Residential	Crosby-Brookston-Miamian	OH025	C	242	221	284
Forest	Crosby-Brookston-Miamian	OH025	C	242	221	284
High Density Residential	Eldean-Ockley-Sleeth	OH028	B	165	139	474
Commercial	Eldean-Ockley-Sleeth	OH028	B	165	139	474
Low Density Residential	Eldean-Ockley-Sleeth	OH028	B	165	139	474
Agriculture	Tiro-Pandora-Bennington	OH041	C	217	288	402
Pasture/Hay	Tiro-Pandora-Bennington	OH041	C	217	288	402
Agriculture	Bennington-Cardington-Orrville	OH063	C	245	261	359
Agriculture	Centerburg-Bennington-Marengo	OH064	C	232	224	372
Low Density Residential	Centerburg-Bennington-Marengo	OH064	C	232	224	372
Pasture/Hay	Centerburg-Bennington-Marengo	OH064	C	232	224	372
Forest	Centerburg-Bennington-Marengo	OH064	C	232	224	372
Commercial	Bennington-Pewamo-Cardington	OH066	C	245	261	359
Agriculture	Bennington-Pewamo-Cardington	OH066	C	245	261	359
Low Density Residential	Bennington-Pewamo-Cardington	OH066	C	245	261	359
Pasture/Hay	Bennington-Pewamo-Cardington	OH066	C	245	261	359
Agriculture	Centerburg-Amanda-Bennington	OH071	C	232	224	372
Pasture/Hay	Centerburg-Amanda-Bennington	OH071	C	232	224	372
Forest	Centerburg-Amanda-Bennington	OH071	C	232	224	372
Agriculture	Bennington-Condit-Cardington	OH079	C	245	261	359
Low Density Residential	Bennington-Condit-Cardington	OH079	C	245	261	359
Pasture/Hay	Bennington-Condit-Cardington	OH079	C	245	261	359
Forest	Bennington-Condit-Cardington	OH079	C	245	261	359
Pasture/Hay	Cardington-Bennington-Sloan	OH0127	C	235	260	361
Forest	Cardington-Bennington-Sloan	OH0127	C	235	260	361

[1]measured in millimeters H_20.

Chapter 3: SWAT Modeling Results and Discussion

3.0 Introduction

A TMDL is the maximum amount of a flow constituent, such as a nutrient or total suspended solid (TSS), that can be discharged into a stream and still allow the stream to meet its use designation. Designated uses may include agricultural or public water supply, recreational uses, or aquatic life uses. Designated uses are assigned to stream reaches by Ohio EPA. Further discussion on use designations and use attainment is available at *http:// http://ohioline.osu.edu/b873/*. In a TMDL study, loads are allocated to point and non-point sources. Also included, either explicitly or implicitly, is a margin of safety. A TMDL is generally expressed as:

$$TMDL = WLA + LA + MOS \qquad (3.1)$$

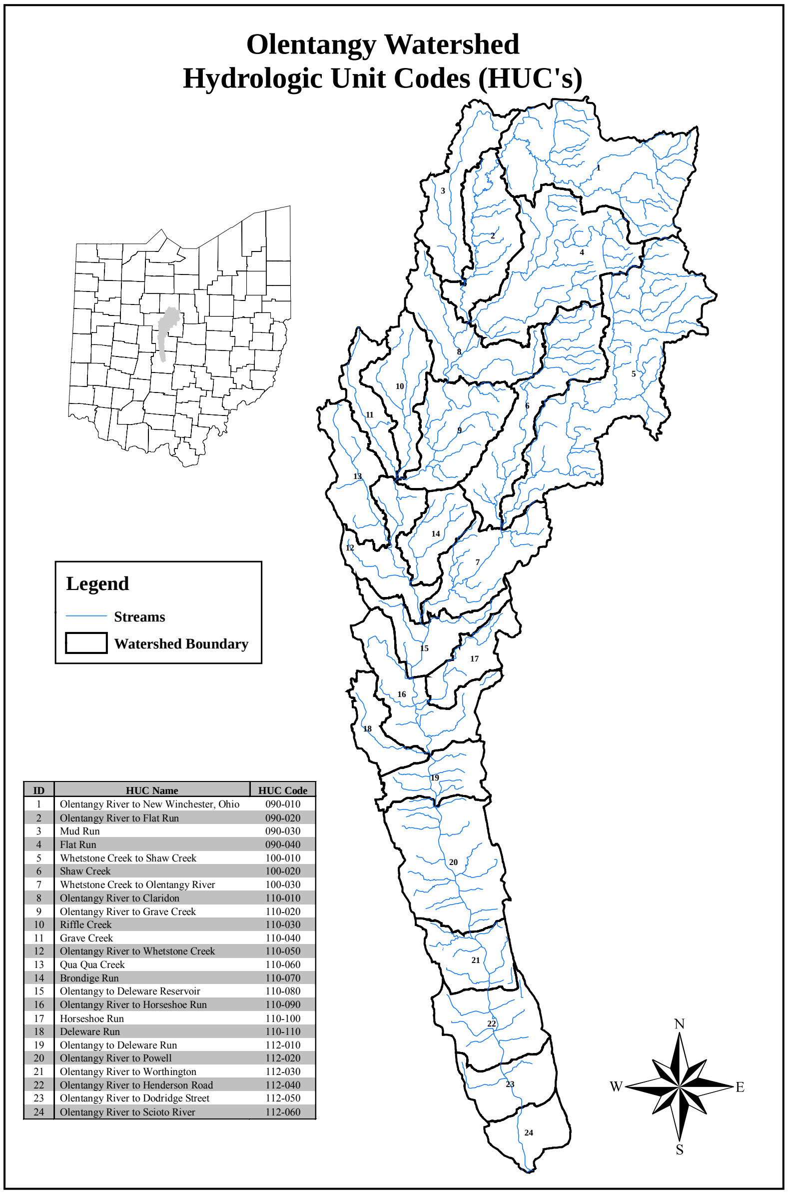
where *WLA* is a Waste Load Allocation from point source dischargers (National Pollutant Discharge Elimination System (NPDES) Permitting Program), *LA* is a load allocation for non-point discharges, and *MOS* is the margin of safety.

TMDL load reductions are determined by comparing simulated or measured loads, or concentrations, at a particular point in the system (i.e., 11-digit or 14-digit HUC, entire watershed outlet, USGS gage station, etc.) with a target load or concentration (see Chapter 1). Simulation models like SWAT are used to estimate loads because measured data often are inadequate or unavailable. The use of simulation models also aids in evaluating the benefits of alternative management practices that might be adopted to help reduce loads. Useful insight can be obtained by comparing existing loads to background loads. For the Olentangy River watershed, background loads are estimates of the amount of total phosphorus (TP), nitrate-N (NO_3-N) and total suspended solids (TSS) that would be transported to the stream if land use was natural with no additional human inputs. Prior to European settlement natural conditions in the watershed would have been a mixture of forests, grasses, and wetlands. For ease of analysis it was assumed in determining background conditions that each of these three land uses occurred throughout the entire watershed.

This chapter outlines results from various SWAT simulations. Section 3.1 outlines how loads were calculated, the rationale for using flow-weighted concentrations as the main method for reporting loads, and why various scales have been used to report results. Sections 3.2 and 3.3 describe basic TMDL terminology and provide more details on how loads and load reductions were calculated. The remainder of the chapter presents estimates of load reductions associated with various TMDL targets and land use practices, and describes alternative management practices that might be considered to meet the targets. A margin of safety was not applied in the analysis as there are no adequate methods for estimating uncertainty in the predictions or in determining the likelihood of success or failure in achieving aquatic life use attainment if a target is not achieved. A more detailed discussion on uncertainty was presented in Chapter 2.

3.1 Reporting SWAT Results

Several types of output are reported in this chapter to facilitate evaluation and understanding of the model outputs, management scenarios, and the stream system. They include landscape-level values and reach-level values. Values reported at the landscape level are specific to a watershed area and flow, nutrients and TSS generated from that area. In this study, landscape-level results are reported by 14-digit HUC (Figure 3.1).



ID	HUC Name	HUC Code
1	Olentangy River to New Winchester, Ohio	090-010
2	Olentangy River to Flat Run	090-020
3	Mud Run	090-030
4	Flat Run	090-040
5	Whetstone Creek to Shaw Creek	100-010
6	Shaw Creek	100-020
7	Whetstone Creek to Olentangy River	100-030
8	Olentangy River to Claridon	110-010
9	Olentangy River to Grave Creek	110-020
10	Riffle Creek	110-030
11	Grave Creek	110-040
12	Olentangy River to Whetstone Creek	110-050
13	Qua Qua Creek	110-060
14	Brondige Run	110-070
15	Olentangy to Deleware Reservoir	110-080
16	Olentangy River to Horseshoe Run	110-090
17	Horseshoe Run	110-100
18	Deleware Run	110-110
19	Olentangy to Deleware Run	112-010
20	Olentangy River to Powell	112-020
21	Olentangy River to Worthington	112-030
22	Olentangy River to Henderson Road	112-040
23	Olentangy River to Dodridge Street	112-050
24	Olentangy River to Scioto River	112-060

Figure 3.1 Map showing the 14-digit HUCs in the Olentangy River Watershed.

Values reported at the reach-level are associated with the entire contributing drainage area to that point in the stream system. For example, the nutrient and TSS concentrations at the outlet reach of the 14-digit HUC 090-020 (Olentangy River to Flat Run) would include all flow, nutrients and TSS transported from HUC 090-010 (Olentangy Headwaters to New Winchester, OH), HUC 090-030 (Mud Run) and HUC 090-020.

3.1.1 Concentrations

We used several types of values to report nutrient and TSS levels. Concentration is a common way to express amount of pollution per unit volume of water that can be calculated by several methods. We reported the following types of results:

> **Average annual concentrations** – predictions of nutrient and TSS loadings from the landscape to the stream channel are output from SWAT as a mass quantity. SWAT also provides the amount of flow generated on the landscape and delivered to the stream channel. Average annual concentration reported in this study is the amount of nutrient or TSS transported to the stream per year divided by the volume of water delivered to the stream in that same year. Average annual concentrations are reported in landscape-level loading tables for nutrients and TSS (Tables 3A.1 through 3A.11 in Appendix 3A).
>
> **Time-weighted average concentrations** – time-weighted averages are based on the sampling or prediction interval of the data. In this case, SWAT outputs flow, nutrients and TSS concentrations in a stream reach on a daily interval. Time interval is consistent throughout the study and time-weighted average concentration is simply the average daily nutrient and TSS concentration. Time-weighted concentrations for stream reaches at the outlet of each 14-digit HUC are reported in reach-level loading tables for nutrient and TSS (Tables 3B.1 through 3B.12 in Appendix 3B).
>
> **Flow-weighted average concentrations** – flow-weighted concentrations can be thought of as a normalized yield taking into account not only the concentration during a particular time interval, but also the amount of flow during that interval. Nutrient and TSS concentrations during times of high flow will be weighted more heavily than nutrient and TSS concentrations during low flow. Conceptually, a flow-weighted concentration would be the same as routing all the flow that passed by a point into a big, well-mixed pool and collecting and analyzing one sample from the pool to obtain an average nutrient and TSS concentration.

Arguably, high flow conditions and extreme events can have a large influence on flow-weighted concentrations but less influence on aquatic life; therefore, we also analyzed the influence of excluding flows that exceeded various thresholds. Results of this analysis were inconclusive (Table 3.1). There was little difference between flow-weighted TP values for the following conditions: (1) excluding no flows; (2) excluding all flows above 1000 ft^3/s; or (3) excluding all flows above half the mean daily flow for the period of record.

In contrast, nitrate-N concentrations increased while TSS concentrations decreased as smaller and smaller flows were excluded. We decided to not exclude any flows in this analysis because using different flow thresholds for different constituents would greatly increase the complexity of the analysis, our ability to interpret the results, and our ability to then use the results in the development of strategies to enhance aquatic life and water quality. Also, there is no clear evidence in the literature regarding what flows should be excluded.

Table 3.1 SWAT-predicted flows at Claridon, OH excluding flows above a threshold value and their corresponding nutrient and TSS loads.

Flows Excluded	Average Total P (mg/l)	Average NO_3-N (mg/l)	Average TSS (mg/l)	Flow Weight. Total P (mg/l)	Flow Weight. NO_3-N (mg/l)	Flow Weight. TSS (mg/l)
None	0.50	5.9	56	0.37	3.6	172
>2500 ft^3/s	0.51	5.9	55	0.40	3.7	159
>1000 ft^3/s	0.51	6.0	50	0.36	4.2	120
>Mean Daily Flow	0.55	6.7	24	0.27	5.9	42
>50% Mean Daily Flow	0.68	6.9	13	0.35	6.0	19

3.1.2 Loadings

A nutrient or TSS load is the mass of the constituent transported to a channel or past a certain point in the stream. Different types of loadings reported in this study include:

> **Landscape-level loading rates** – a landscape-level loading rate is the amount of nutrient or TSS delivered to a stream channel divided by the area that generated the load. Inherent in reporting a loading rate is a time period. We have reported landscape-level loadings for TSS as tons per acre per year (t/ac/yr) and TP and nitrate-N as pounds per acre per year (lbs/ac/yr). Landscape-level loading rates are reported in loading tables for nutrients and TSS (Tables 3A.1 through 3A.11 in Appendix 3A).
>
> **Reach level loading rates** – a reach level loading rate is the amount of load transported past a certain point in the stream divided by the amount of landscape area that generated the load within a specified time period. This value is similar to landscape-level loading except SWAT models in-stream transport/routing of TSS and nutrients (see Chapter 2). Therefore, the amount, timing and delivery of nutrient and TSS loads to a downstream point do not necessarily coincide with the time or amount of load delivered to the stream channel. Reach level loadings also are reported as tons per acre per year and pounds per acre per year for TSS and nutrients, respectively. Reach-level loading rates are reported in loading tables for nutrients and TSS (Tables 3B.1 through 3B.12 in Appendix 3B).

Results at the landscape and reach scales are expressed as concentrations (mg/l) and as loads per unit watershed area per unit time. Concentrations were reported for two reasons. First, results expressed as concentrations are more likely to be meaningful to the general public. Second, to facilitate comparison of SWAT results to Ohio EPA targets and alternative targets recommended by the OSU TMDL team (see Chapter 1).

Results should be expressed at scales and in units that have meaning to a broad audience. Values such as total loads of nutrient and TSS (lbs, kgs, or tons) in a watershed have little meaning to most people. Using total loads makes comparisons between differently sized areas on the landscape difficult; therefore, we have expressed load per unit area per unit time (pounds or tons/acre/year. These reporting units can easily be compared to fertilizer application rates on agricultural crops and urban grasses. Reporting concentrations and loads per unit area should facilitate relating land management decisions that help reduce loads and impacts to water quality. There is little scientific difference between any of the reporting methods. If flow-weighted concentration is multiplied by volume of flow, the total load is determined. If load per unit area is multiplied by area, the total load also is determined.

3.2 TMDL Load Reductions for 11-digit and 14-digit HUCs

While SWAT provides information at a reach scale that is a function of sub-basin delineation, relating this information to some HUCs was not possible. Often, in-stream transformations resulted in misleading estimates when inflows from upstream HUCs were subtracted from discharges from the outlet of the HUC of interest. Therefore, we based load reductions on discharges directly from the landscape. Point loads were not included in this analysis but if it is desirable to use a pollution trading approach (non-point reductions versus point load reductions) data that would be needed are presented in Appendix 3C. For each HUC and each targeted water quality constituent, load reductions were determined to satisfy the recommended Ohio EPA headwater and small river warmwater habitat (WWH) target. Alternative WWH targets are provided in this report (see Chapter 1). Selection of the appropriate target for a specific HUC should be made by Ohio EPA.

3.3 SWAT Land Management Scenarios

Extensive efforts were spent developing input databases and then calibrating the SWAT model to existing conditions in the Olentangy River watershed. Based on good agreement between observed versus predicted flows, and nutrients and TSS loads (see Chapter 2), the Olentangy River TMDL model has the potential to predict impacts of alternative management scenarios provided adequate consideration is given to model limitations as well as scale and uncertainty issues (Chapter 2).

Management scenarios modeled as part of this study fall into the following four groups: 1) baseline conditions; 2) background loads; 3) buffer strips; and 4) crop rotation and fertilizer application scenarios.

3.3.1 Baseline Condition

As stated earlier, the baseline scenario was developed to represent actual "average" conditions in the watershed during the simulation period. The baseline condition includes point source discharges as well as estimates of no-point source pollution. To evaluate the impact of point source pollution, an alternative scenario that excluded point source discharges of flow, nutrients and TSS was developed.

3.3.2 Background Condition

Three SWAT simulations were made to estimate the background load contribution to the TMDL with the same parameter values used in the baseline scenario except changes were made to land use and management operations. In each SWAT simulation we changed all land use to prairie, wetlands, or forest. For each land use and soil type we assigned the appropriate NRCS curve number and a default SWAT management strategy. The default SWAT management strategy included starting and ending a growing season based on accumulated heat units in the watershed. No additional nutrients were applied and all subsurface drainage was removed from the watershed.

Because of the manner in which SWAT files were created with the AVSWATX interface we were unable to remove the Delaware Dam so flows in the lower reaches of the Olentangy River watershed were still controlled by the dam for the simulated baseline conditions. This does not impact the delivery of nutrients to the stream channel from the landscape and, therefore, direct comparison of landscape loading results is appropriate. Background reach level results below the Delaware Dam are impacted however, and should be interpreted with caution.

3.3.3 Buffer Strip Scenarios

Installation of buffer/filter strips along stream and ditch banks is a common practice to reduce sediment delivery to streams and mitigate erosion from fields. SWAT simulates the effects of a buffer strip by estimating the trapping efficiency of a buffer for sediment and nutrients based on the width of the filter strip. We developed three scenarios to determine the relative potential of buffer strips to reduce nutrient and TSS loading to stream channels. Those scenarios include: 1) an additional 33-foot buffer on all cropland; 2) an additional 100-foot buffer on all cropland; and 3) an additional 100-foot buffer on un-drained cropland only. The baseline scenario without flows and nutrient and TSS loads from point sources was used to develop the buffer strip scenarios. Therefore, it is not appropriate to compare reach level outputs from the baseline scenario that includes point source discharges. Landscape level loading to the stream system is directly comparable for all scenarios.

During the development and evaluation of the Olentangy River watershed baseline scenario we determined that SWAT reduced nutrient and TSS loads delivered to the stream through subsurface drainage systems when buffer strips were modeled. In reality, the influence of buffer strips on subsurface drainage flows might be small, but we speculated that the type of reductions that SWAT predicted might be in the range that could occur when subsurface drainage systems are fitted with head control structures. Therefore, buffer strip scenarios 1 and 2 described above were included to approximate the benefits of a buffer strip for all fields in conjunction with head control structures on any subsurface drainage outlets. Scenario 3 only applied buffer strips to cropland without subsurface drains so nutrient and TSS loads delivered from subsurface drainage flow were not reduced by a management strategy such as a buffer strip or head control structure.

3.3.4 Crop Rotation and Fertilizer Application Scenarios

In the Olentangy River watershed, as well as much of the Midwest, row crop agriculture typically follows one of three crop rotations: 1) corn-soybean; 2) corn-soybean-soybean; or 3) corn-soybean-winter wheat. According to agricultural statistics, the corn-soybean-wheat rotation is least common, as wheat accounts for about 5% to 15% of planted cropland in this watershed in a given year. Inclusion of small grains into crop rotations usually has water quality benefits. Therefore, a SWAT input scenario was developed to predict potential impacts of including wheat into all crop rotations. Each scenario was developed by taking the baseline scenario without point source discharges and changing land management practices to a default corn-soybean-winter wheat rotation.

When developing scenarios outlined in this chapter several assumptions were made to simplify parameterization of SWAT land management files. These assumptions include: 1) no animal manure applied to the landscape; 2) crop production was limited to one crop throughout the entire watershed at a given time; and 3) timing of operations was the same for all cropland. SWAT datasets were also developed to determine potential water quality impacts from increased and decreased rates of fertilizer application to cropland. In these scenarios we increased or decreased baseline fertilizer application rates by 25% for the corn-soybean rotation described above.

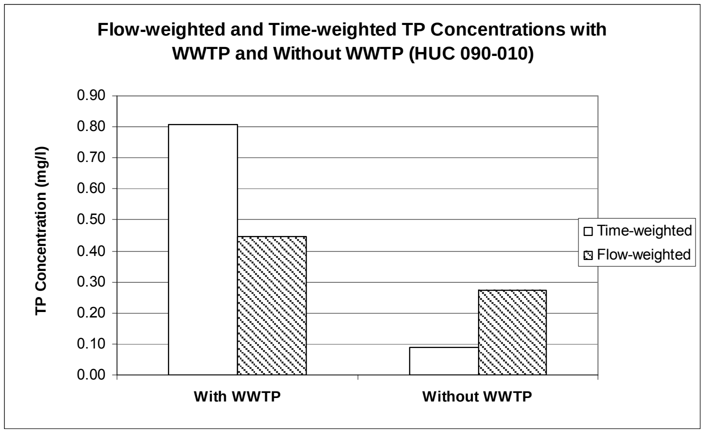
These simplifying assumptions could increase uncertainty and complicate interpretation of model results relative to baseline conditions and other alternative scenarios. Elimination of animal manures would impact results from watersheds with extensive animal agriculture, while more urban/forested watersheds might not be impacted at all. Assumption 2 outlined above states that one crop is in production in the entire watershed at any particular time. For example, in the corn-soybean rotation scenario corn would be planted in the entire watershed on odd numbered years while soybeans would be planted in even numbered years. In this type of scenario with a simulation period of 17 years, one or two extreme weather years could impact averaged model results. Finally, the timing of each field operation including tillage, planting, fertilizer application, and crop harvest was scheduled to occur on a single day. In reality, field operations for different percentages of the total cropland occur daily across a period of many weeks at various points in the year. An example of a problem caused by the aforementioned assumption is described in Section 3.6. More comprehensive management scenarios, similar to those used for the baseline analysis, could have been developed but this would have greatly increased the complexity and the resources needed to conduct this part of the study.

3.4 Point Source Influences

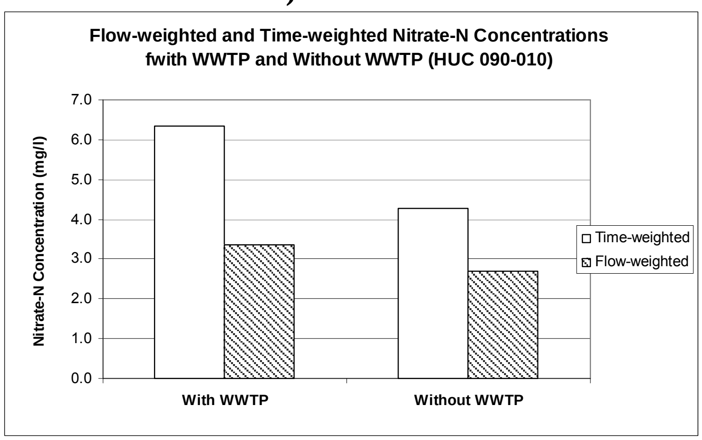
Reach results by 14-digit HUC for the baseline scenarios, with and without point sources, can be seen in Figures 3B.1 and 3B.2 in Appendix 3B. As an example, results for HUC 090-010 (Olentangy headwaters to New Winchester, OH) are presented in Figure 3.2. This HUC includes one of six major point source dischargers located within the watershed.

It is evident by comparing time-weighted versus flow-weighted concentrations that TP concentrations (Figure3.2a) in stream flow at the HUC outlet are highly influenced by point source discharges. Nitrate-N concentrations are adversely impacted during low flow (Figure 3.2b). Alternatively, point source discharges have little impact on TSS concentrations (Figure 3.2c).

a) Total Phosphorus



b) Nitrate-N



c) Total Suspended Solids

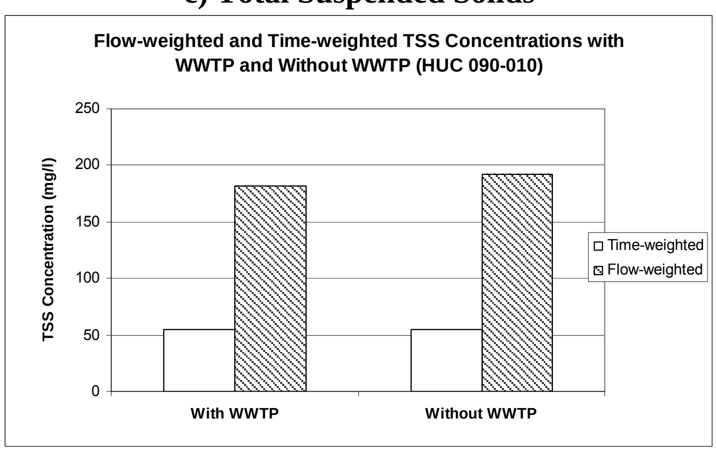


Figure 3.2 Comparison of nutrient and TSS concentrations for a) total phosphorus, b) nitrate-N, and c) total suspended sediment at the outlet of HUC 090-010.

3.5 Load Reductions

Loads and load reductions for the 11-digit HUCs are reported in Table 3C.1 in Appendix 3C and below in Tables 3.2 to 3.4. Within each HUC, load reductions vary from 11% to 97% depending on the constituent, source of the constituent, and target applied. Septic systems were not modeled as their contribution will typically be less than 5% of the load, and there was insufficient available data to provide meaningful simulations for these systems. Estimated non-point source reductions will need to be greater than reported if allowable discharges from point sources exceed target values. Further discussion on agricultural BMPs is presented in Chapter 1. Based on our knowledge of agricultural BMPs it is probable that target reductions greater than 50% will be very difficult to achieve at a watershed scale and often difficult to achieve at a field scale.

Table 3.2 Total phosphorus reductions (%) needed to meet various target limits.

11-digit HUC	TP (mg/l)	Headwaters Target[1]	Wadeable Target[1]	Small River Target[1]	Alternative Target[2]
5060001090	0.31	77	65	48	48
5060001100	0.24	71	54	33	33
5060001110	0.37	81	70	57	57
5060001120	0.18	61	39	11	11

[1]Ohio EPA TP target limits for headwater, wadeable, and small rivers are 0.07, 0.11, and 0.16 mg/l, respectively.
[2]OSU TMDL team recommended TP target for all drainage areas is 0.16 mg/l.

Table 3.3 Nitrate-nitrogen reductions (%) needed to meet various target limits.

11-digit HUC	NO_3-N (mg/l)	Headwaters Target[1]	Wadeable Target[1]	Small River Target[1]	Alternative Target[2]
5060001090	3.5	71	71	57	43
5060001100	4.1	76	76	63	51
5060001110	4.8	79	79	69	58
5060001120	4.5	78	78	67	56

[1]Ohio EPA NO_3-N target limits for headwater, wadeable, and small rivers are 1.0, 1.0, and 1.5 mg/l, respectively.
[2]OSU TMDL team recommended NO_3-N target for all drainage areas is 2.0 mg/l.

Table 3.4 Total suspended solids reductions (%) needed to meet various target limits.

11-digit HUC	TSS (mg/l)	Headwaters Target[1]	Wadeable Target[1]	Small River Target[1]	Alternative Target[2]
5060001090	318	97	90	86	75
5060001100	268	97	88	84	70
5060001110	233	96	87	81	66
5060001120	141	94	78	69	43

[1]Ohio EPA TSS target limits for headwater, wadeable, and small rivers are 9, 31, and 44 mg/l, respectively.
[2]OSU TMDL recommended TSS target for all drainage areas is 80 mg/l.

Load and load reductions for the 14-digit HUCs are reported in Tables 3.5 to 3.7. Generally, reductions of more than 40% will be needed to satisfy any of the targets. In many cases, and particularly for TSS, reductions of more than 60% will be needed. Further discussion on each constituent and how the reductions might be achieved is presented in the next section.

Table 3.5 Load reductions to meet the recommended Ohio EPA headwater target for the Olentangy River.

14-digit HUC	Non-point Source Reduction (%)		
	TP	**NO3-N**	**TSS**
5060001090010	74	65	98
5060001090020	53	65	83
5060001090030	86	83	97
5060001090040	79	70	97
5060001100010	63	75	97
5060001100020	77	81	97
5060001100030	76	67	96
5060001110010	77	76	95
5060001110020	81	69	96
5060001110030	80	81	96
5060001110040	83	82	96
5060001110050	87	88	96
5060001110060	85	88	96
5060001110070	77	73	95
5060001110080	62	51	93
5060001110090	83	76	98
5060001110100	85	80	97
5060001110110	60	30	96
5060001120010	90	82	99
5060001120020	60	13	95
5060001120030	20	63	82
5060001120040	26	88	63
5060001120050	2	85	53
5060001120060	47	79	75
Min	**2**	**13**	**53**
Max	**90**	**88**	**99**
Ave	**67**	**71**	**91**

Table 3.6 Load reductions to meet the recommended Ohio EPA small river target for the Olentangy River.

14-digit HUC	Non-Point Source Reduction (%)		
	TP	NO_3-N	TSS
5060001090010	60	65	92
5060001090020	27	65	41
5060001090030	77	83	89
5060001090040	67	70	91
5060001100010	42	75	88
5060001100020	64	81	89
5060001100030	63	67	88
5060001110010	65	76	84
5060001110020	69	69	86
5060001110030	68	81	85
5060001110040	74	82	87
5060001110050	79	88	87
5060001110060	77	88	86
5060001110070	64	73	83
5060001110080	40	51	76
5060001110090	74	76	92
5060001110100	76	80	89
5060001110110	37	30	85
5060001120010	84	82	95
5060001120020	38	13	83
5060001120030	0	63	37
5060001120040	0	88	0
5060001120050	0	85	0
5060001120060	16	79	16
Min	**0**	**13**	**0**
Max	**84**	**88**	**95**
Ave	**52**	**71**	**73**

Table 3.7 Load reductions to meet the alternative targets for the Olentangy River watershed (presented in Chapter 1).

14-digit HUC	Non-Point Source Reduction (%)		
	TP	NO_3-N	TSS
5060001090010	41	31	79
5060001090020	0	30	0
5060001090030	67	67	72
5060001090040	52	40	77
5060001100010	16	49	69
5060001100020	47	62	72
5060001100030	46	35	69
5060001110010	49	51	60
5060001110020	56	38	64
5060001110030	54	62	61
5060001110040	61	64	67
5060001110050	69	77	68
5060001110060	66	76	64
5060001110070	47	47	55
5060001110080	13	2	38
5060001110090	62	52	79
5060001110100	66	60	73
5060001110110	8	0	60
5060001120010	76	65	87
5060001120020	10	0	57
5060001120030	0	26	0
5060001120040	0	75	0
5060001120050	0	70	0
5060001120060	0	59	0
Min	**0**	**0**	**0**
Max	**76**	**77**	**87**
Ave	**38**	**47**	**53**

3.6 Landscape Management Scenarios

Predicted results for landscape-level and reach-level concentrations and loadings are available in Appendices 3A and 3B. Each Appendix contains results for all management scenarios. Landscape results for the baseline with and without point sources are identical because point sources were added into the channel and do not impact what is coming off the landscape. Presenting the results in their entirety in graphical form would generate an overwhelming number of figures; therefore, we selected landscape-level and reach-level results from individual HUCs with the highest and lowest concentrations for each constituent

3.6.1 Total Phosphorus

For current (baseline) conditions, predicted TP concentrations generated from the landscape ranged from 0.07 mg/l to 0.67 mg/l. The highest TP values occurred in HUC 120-010 (Olentangy River below Delaware Run; Figure 3.3a and 3.3b). This HUC is near the City of Delaware, which still has some areas in agricultural production. In this HUC, overland slopes are greater than other areas of the Olentangy River watershed. These areas have flat headwaters, where much of the agriculture is located, and then transition to ravine settings near the confluence with the Olentangy River. Given this, SWAT estimates of landscape erosion based on the average overland slope might have over-predicted erosion from agricultural fields. The lowest TP value occurred in HUC 120-050 (Olentangy River to Dodridge St., Figure 3.4a and 3.4b), which is highly urbanized and contains no agriculture. For the entire Olentangy River watershed it was not practical to use SWAT to account for landscape disturbance during urban construction. Therefore, TP and TSS are probably underestimated in urban watersheds and, in particular, watersheds undergoing rapid development.

At the reach-level, the impact of point source discharges is evident by comparison of the baseline scenarios with and without waste water treatment plants (WWTP). TP loads at this point in the stream system also do not appear to be sensitive to fertilizer application rates. This would be expected, though, as phosphorus transport to the system is highly dependent upon erosion processes that are not altered by fertilizer application.

The best management strategies to reduce TP loadings appear to be the use of grass buffers adjacent to agricultural fields. It is probable that SWAT overestimates the efficiency of these systems as surface runoff often collects in rills and then bypasses much of the buffer. Also, subsurface tile flow often discharges through buried pipes located below the buffer. In some circumstances, a head control structure could be added into subsurface drainage systems – a practice that is part of the current CREP program and has been shown to be very effective in reducing nutrient discharges. SWAT does not directly simulate this approach, but to provide an indication of the potential benefit we have approximated the practice as a *"10 meter or 33 meter buffer with all discharge going through the buffer"* (see Section 3.3.3). Results indicate that discharge of all the flow through very efficient buffers will be needed to meet any of the targets TP.

Inclusion of a winter wheat or a cover crop in the rotation would be beneficial, and would be more effective than simply reducing fertilizer applications. It should be noted that the 100% (baseline) fertilizer rates used in the analysis might be lower than actual rates and are probably close to the threshold where further reductions would impact on the economic viability of the cropping systems.

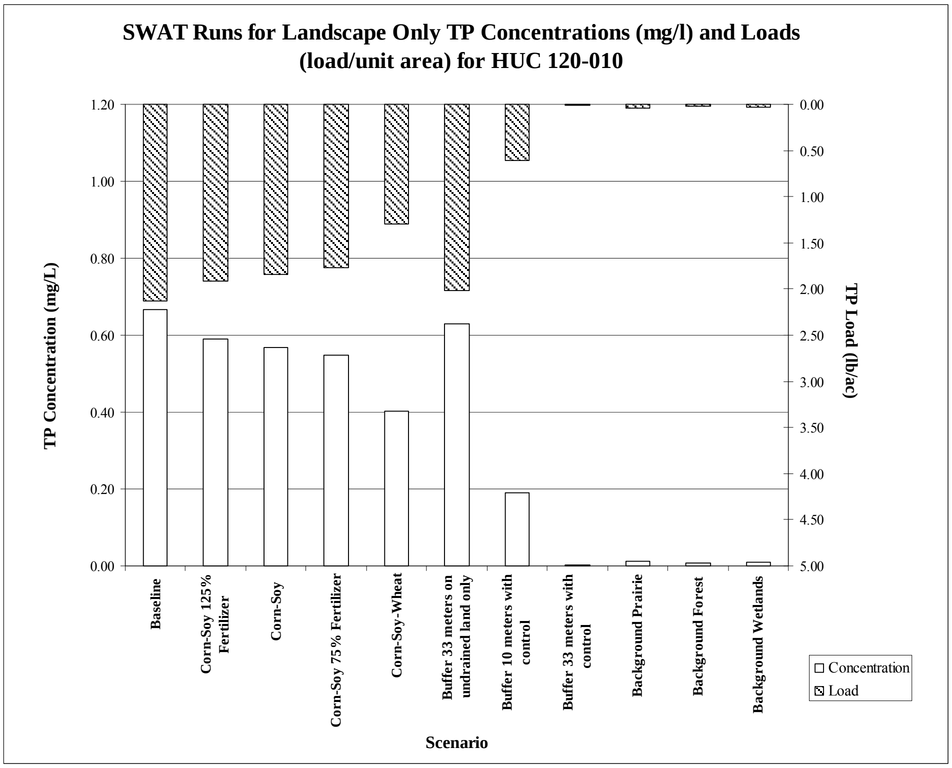


Figure 3.3a 11-digit HUC with highest TP landscape loads.

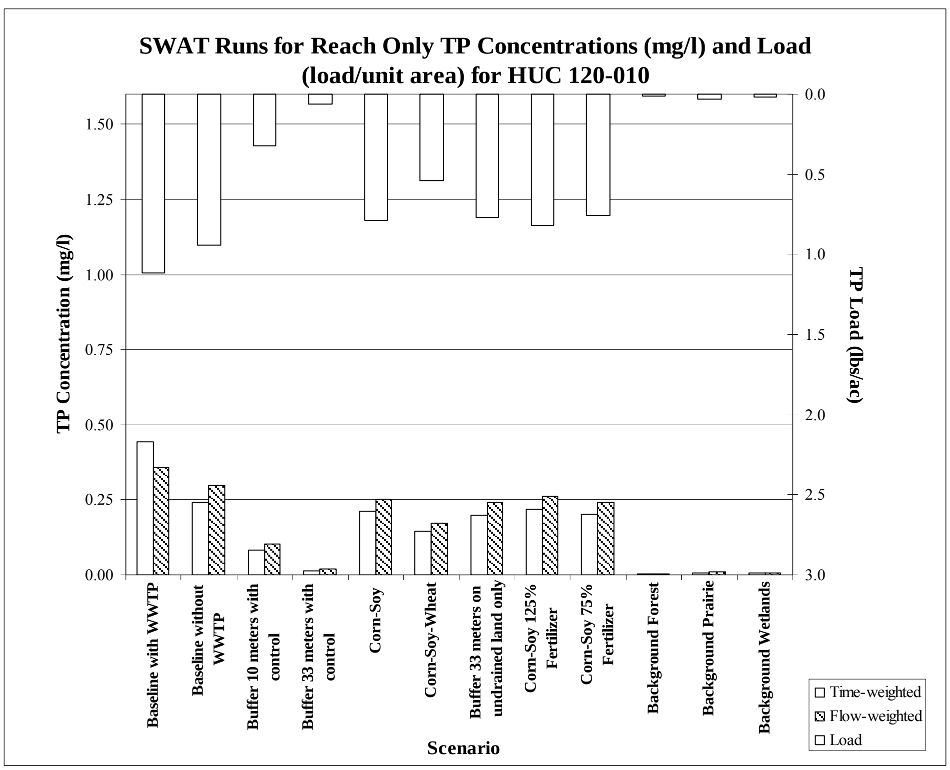


Figure 3.3b 11-digit HUC with highest TP loads in a reach.

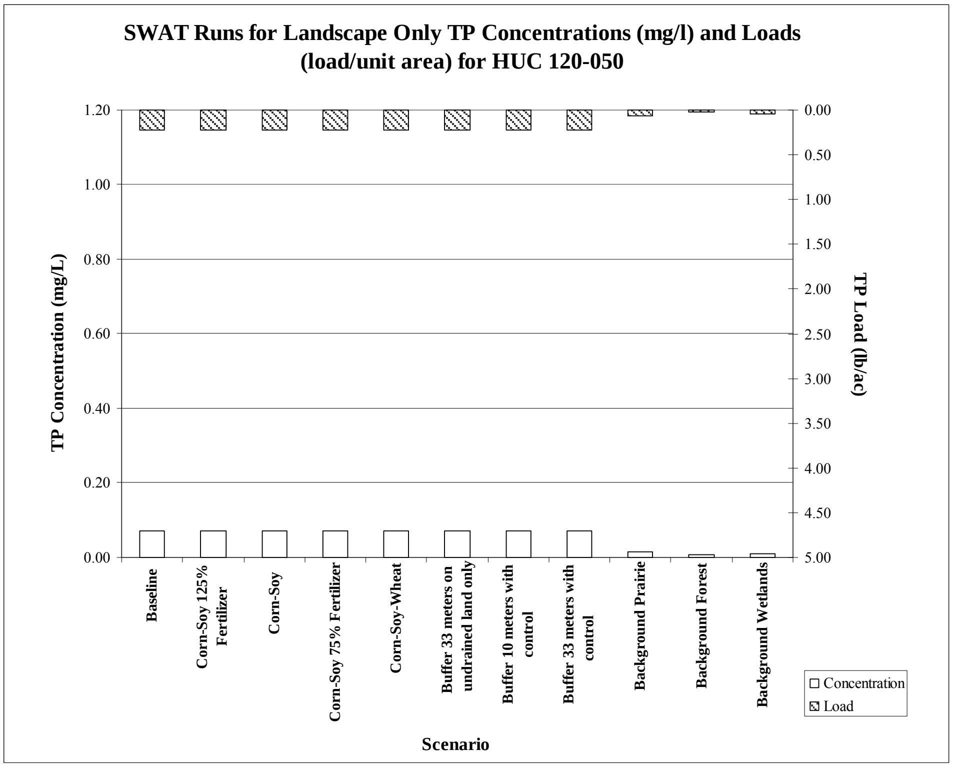


Figure 3.4a 11-digit HUC with lowest TP landscape loads.

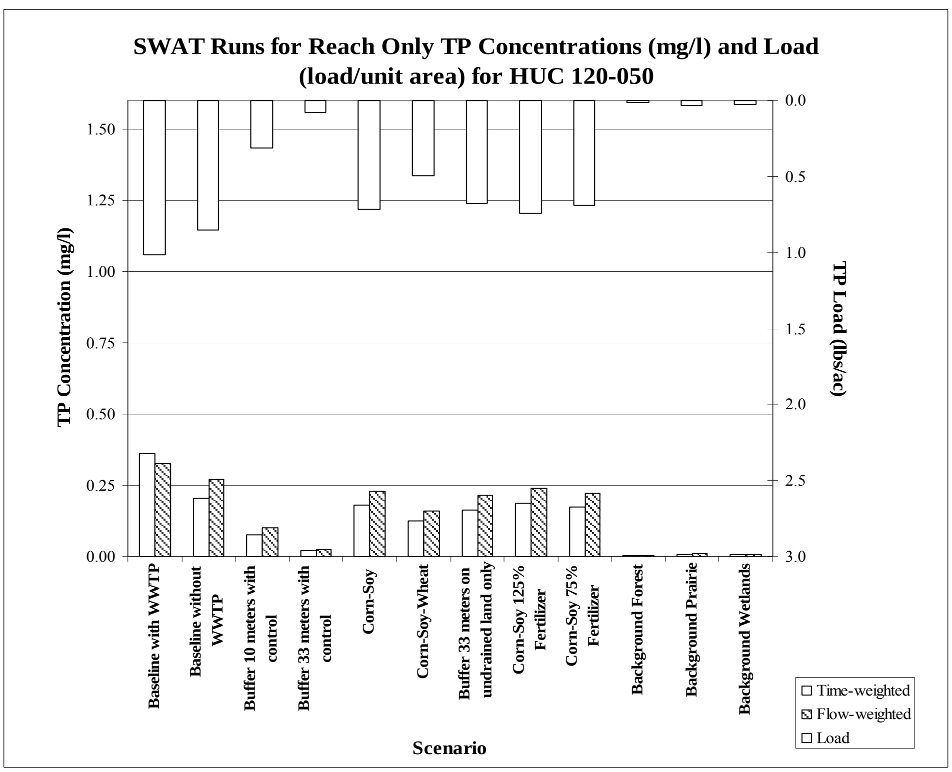


Figure 3.4b 11-digit HUC with lowest TP loads in a reach.

3.6.2 Nitrate-Nitrogen

Predicted nitrate-N concentrations from the landscape varied from 1.1 mg/l to 8.7 mg/l. HUC 110-050 (Olentangy to Whetstone Creek) exhibited the highest nitrate-N concentrations (Figure 3.5a and 3.5b). This watershed is predominately agricultural with significant amounts of subsurface drainage. HUC 120-020 (Olentangy River near Powell, OH) had the lowest predicted nitrate-N loading rate to the channel (Figure 3.6a and 3.6b). This is because of the high percentage of forest and pasture land use in the watershed at the time the land use data was developed. This area along the Olentangy River in Delaware and Franklin counties is developing quickly and infrastructure is being constructed to support additional growth.

Evaluation of alternative management scenarios suggest that a combination of buffer strips and head control structures on subsurface drained agricultural land would be needed to satisfy any of the targets. Other strategies to reduce nitrate-N from agricultural land would be similar to those for TP. Nitrate-N discharges from urban areas are often high and educational programs to promote the use of less fertilizer on lawns and other grassed areas might be the best strategy to reduce these loads.

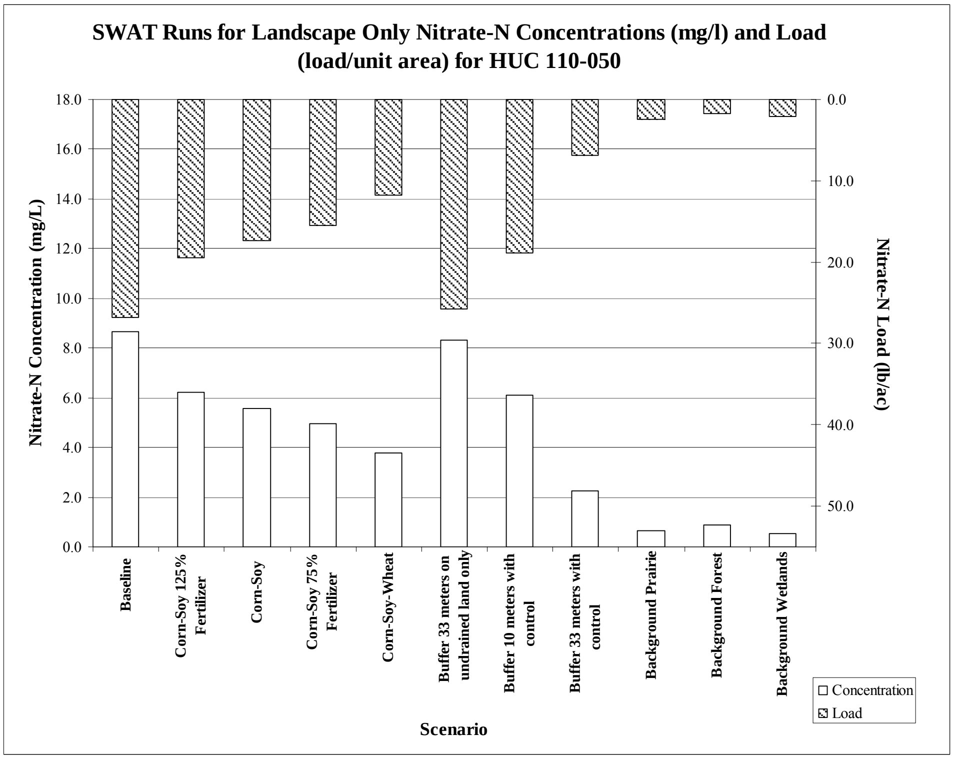


Figure 3.5a 11-digit HUC with highest nitrate-N landscape loads.

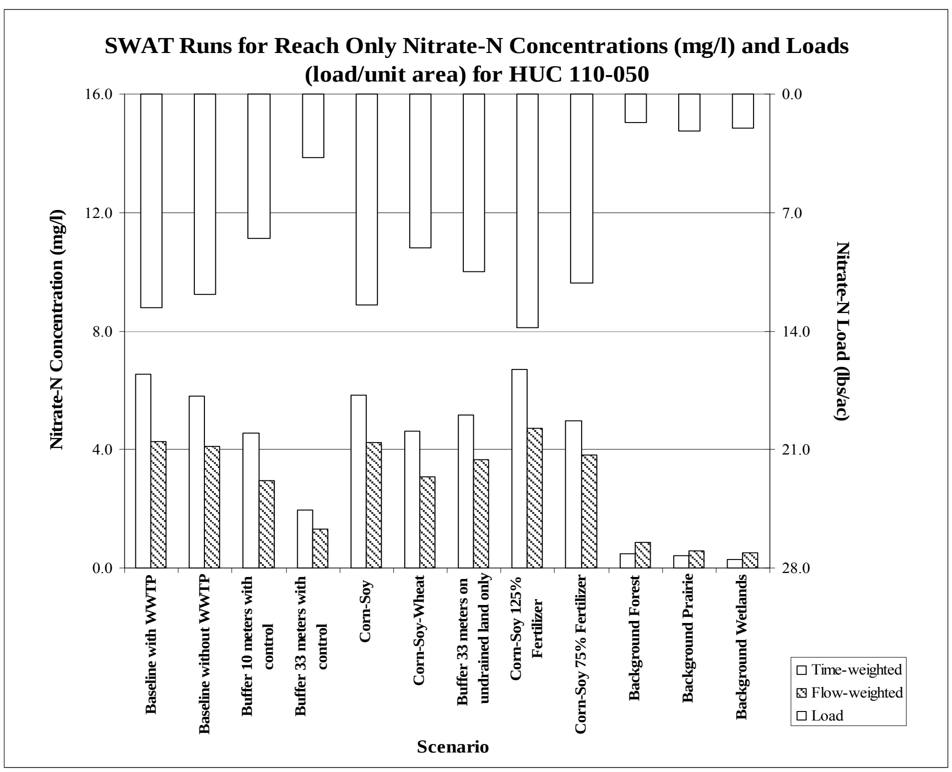


Figure 3.5b 11-digit HUC with highest nitrate-N loads in a reach.

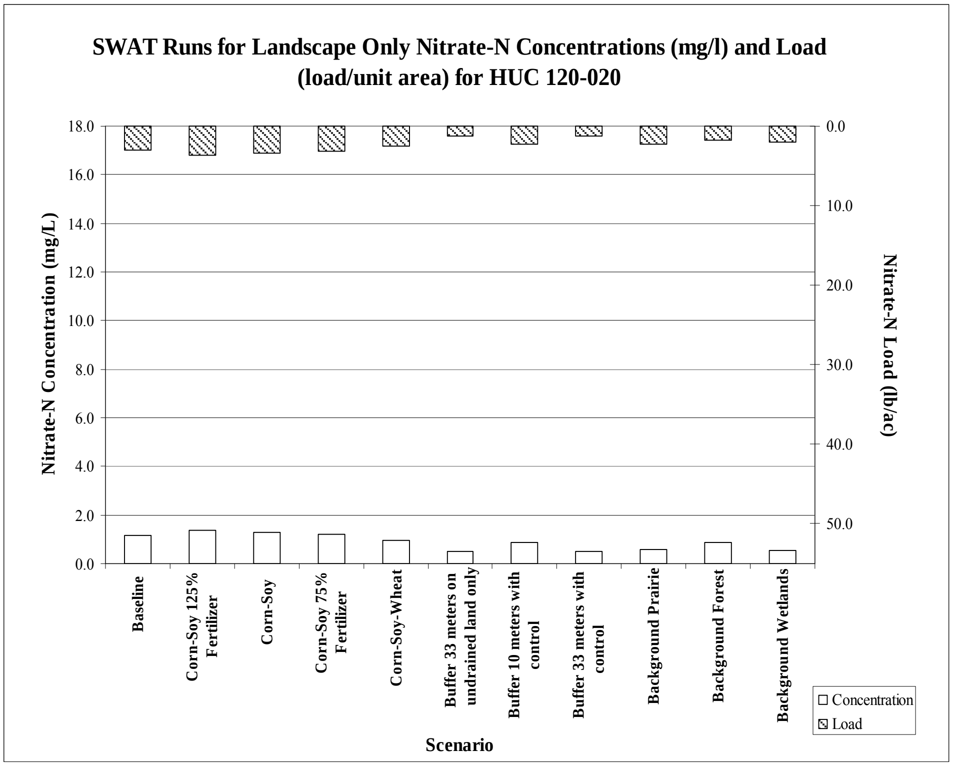


Figure 3.6a 11-digit HUC with lowest nitrate-N landscape loads.

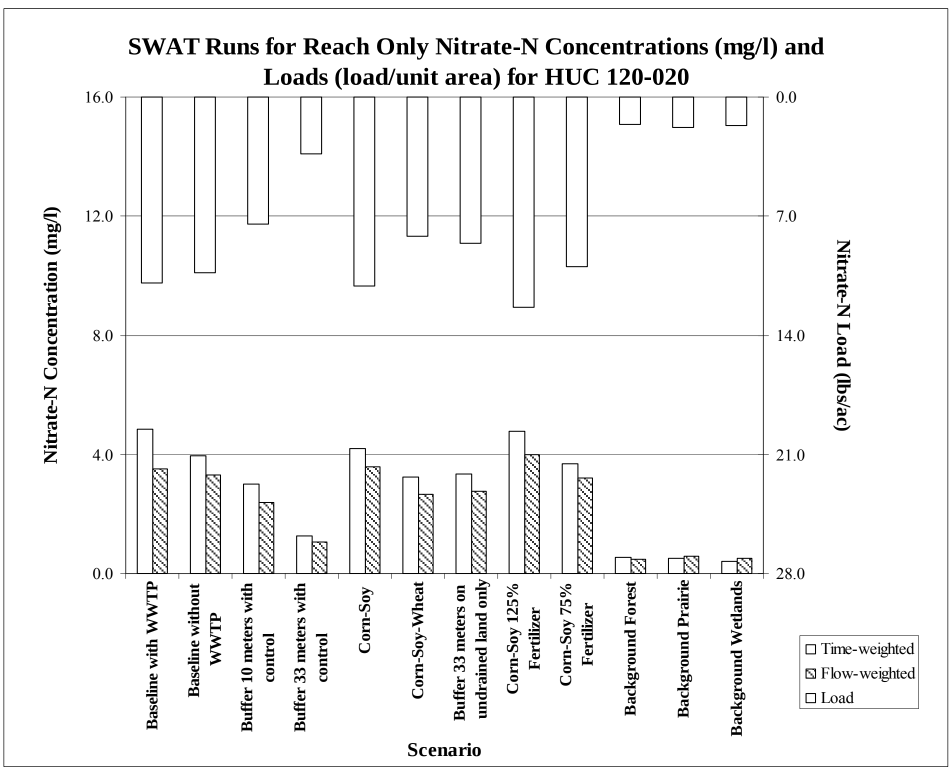


Figure 3.6b 11-digit HUC with lowest nitrate-N loads in a reach.

3.6.3 Total Suspended Sediment

Predicted TSS concentrations generated from the landscape ranged from 19 mg/l to 636 mg/l. The highest TSS concentration was predicted in HUC 120-010 (Olentangy River below Delaware Run, Figure 3.7a and 3.7b), which is the same HUC that had the highest TP loads. This result may be an over-prediction because of poorly estimated overland slopes generated by the AVSWATX interface (see Section 3.6.1). In this HUC, buffer/filter strips seem to have the most potential to reduce sediment delivery to the stream system. The corn-soybean-wheat rotation also showed reductions in TSS when compared to the baseline condition. Winter wheat serves as a cover crop and can potentially reduced erosion during winter months.

The lowest value for TSS occurred in HUC 120-050 (Olentangy to Dodridge St., Figure 3.8a and 3.8b), which is highly urbanized and contains no agriculture. As discussed in section 3.6.1, SWAT might be underestimating TSS in urban watersheds and, in particular, watersheds that are undergoing rapid development. Model predictions could be improved by simulating channel degradation, but it was not possible to collect field data to support parameterization of SWAT for individual sub-basins. Therefore, channel degradation and impacts on TSS loads are discussed based on a sensitivity analysis presented in Section 3.7.1.

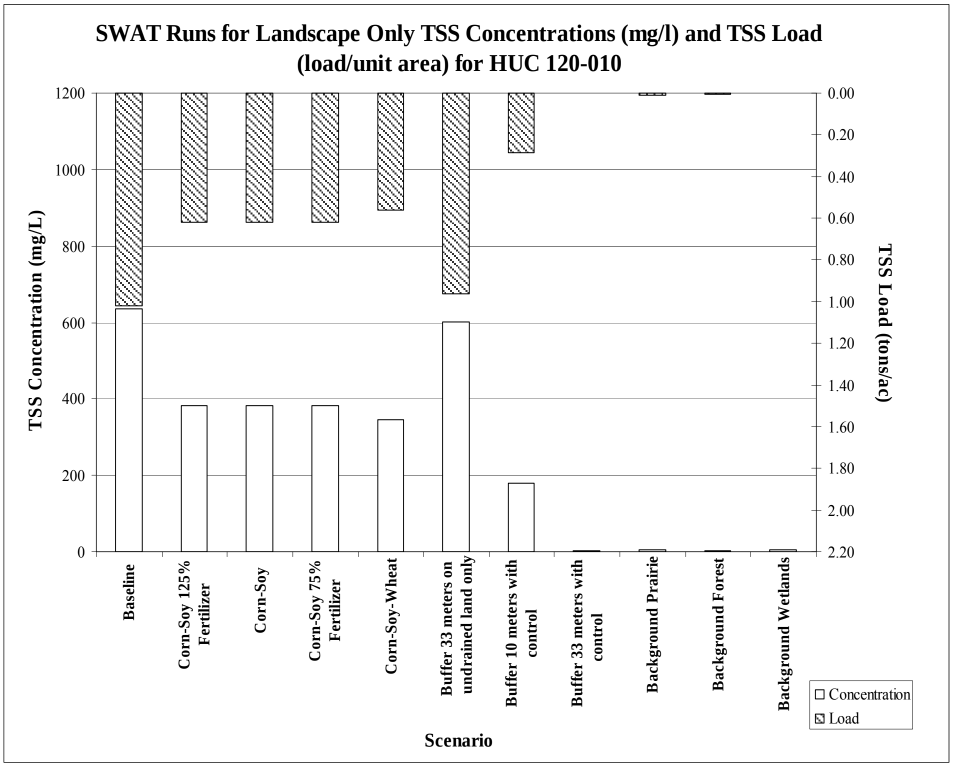


Figure 3.7a 11-digit HUC with highest TSS landscape loads.

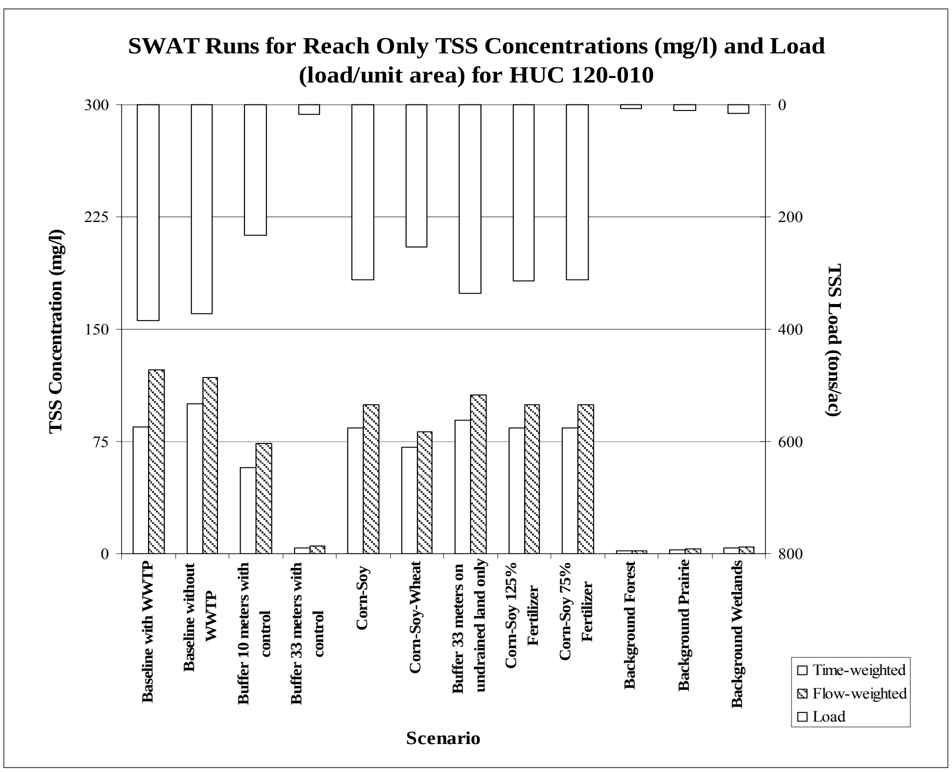


Figure 3.7b 11-digit HUC with highest TSS loads in a reach.

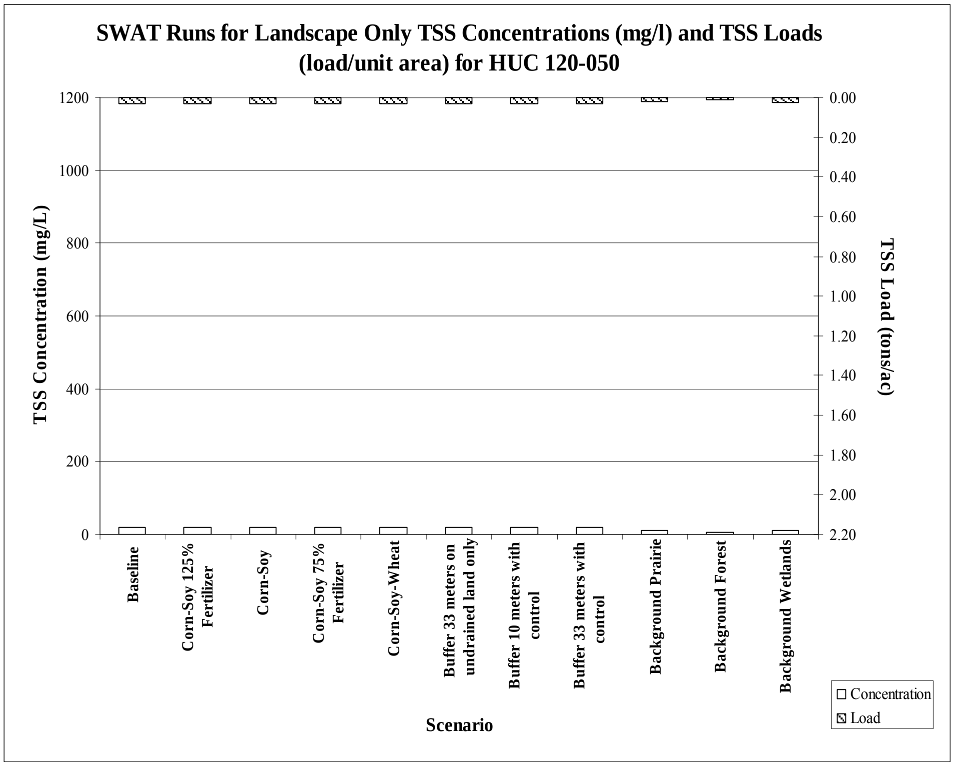


Figure 3.8a 11-digit HUC with lowest TSS landscape loads.

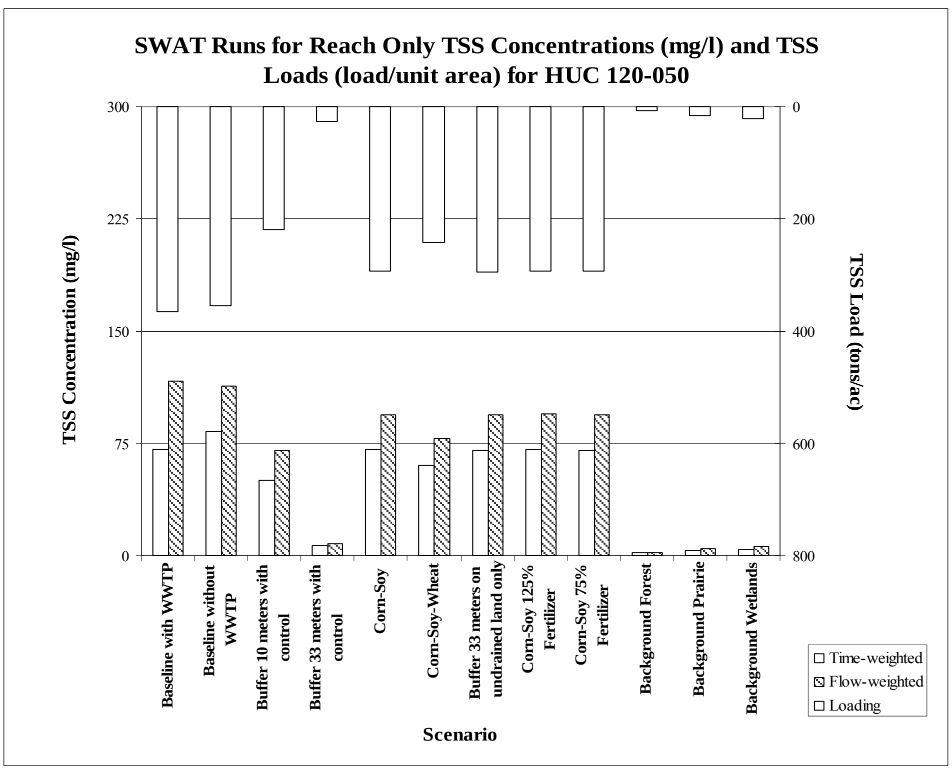


Figure 3.8b 11-digit HUC with lowest TSS loads in a reach.

3.7 Discussion

3.7.1 Channel Degradation

SWAT can simulate deposition and degradation in stream channels. Deposition and re-entrainment of deposited sediment is discussed in Chapter 2. Degradation and down-cutting of the streambed can be modeled in SWAT with knowledge of the erodibility of channel materials and a channel cover factor. Channel erodibility is similar to the USLE K-value, but K-values for the landscape are not appropriate to use for the streambed and banks because the environment of channel and floodplain soils is very different than the same soil on the landscape. Because of time and resource constraints we were unable to collect data to support parameterization of this component of SWAT.

A channel cover factor is also used to model degradation, down-cutting and widening in SWAT. The channel cover factor is defined as the ratio of degradation from a channel with a specified vegetative cover to the degradation of a channel with no vegetative cover. Values for channel cover can vary from 0.0-1.0. Review of available literature provided no insight into methods or procedures to estimate the channel cover factor.

Because we were unable to collect field data for these parameters, we conducted a sensitivity analysis to determine to what degree SWAT predictions were impacted by simulating channel degradation. The SWAT User Manual notes that channel erodibility values are typically an order of magnitude less than USLE K-factors for the same soil (Neitsch et al., 2002b). Based on values for soil K-factors in the Olentangy River watershed, we set typical channel erodibility at 0.04 cm/hr/Pa. We also set a higher value at 0.12 cm/hr/Pa as an upper range to see how SWAT reacted to various values for erodibility. Because a procedure to estimate channel cover was not available we varied its value across a broad range (0.0, 0.1, 0.3, and 0.6). Reach concentration values were then evaluated at Claridon, OH and at the outlet of the Olentangy River watershed to the Scioto River.

Upon evaluation of SWAT output at Claridon (Table 3.8) it was evident that, under the worst case scenario, time-weighted and flow-weighted predicted concentrations of TSS increased by a factor of 2 to 3. This could suggest that a portion of the TSS predicted at Claridon is generated from the stream system itself and current modeling results of landscape erosion are over-predicted. Careful consideration must be given to this as it is possible that water quality targets may not be met by addressing landscape erosion only.

Evaluating the same SWAT simulations at the confluence of the Scioto River (Table 3.8) shows the immense potential for TSS derived from channel erosion below Claridon and, in particular, below the Delaware Dam. Using the same channel erodibility and cover factors, SWAT predicted increases in TSS concentrations that were 8 to 10 times higher than baseline conditions. SWAT predictions of changes in channel size suggested that the cross-sectional area of a channel could increase by a multiple of two or more in many of the tributary systems below Delaware, OH; a finding consistent with observations made in geomorphology changes associated with urbanization and field surveys done between the Delaware Dam and the confluence with the Scioto River.

Table 3.8 Evaluation of the sensitivity of TSS loads to channel degradation parameters.

Scenario	Channel Erodibility	Channel Cover	Claridon TW TSS	Claridon FW TSS	Confluence TW TSS	Confluence FW TSS
BUFFER 33	0.04	0.3	21	50	267	434
BUFFER 33	0.12	0.3	56	127	489	882
BUFFER 33	0.12	0.6	99	224	599	1079
BUFFER 33	0.04	0.6	39	90	411	707
BUFFER 33	0.04	0.1	9	23	107	171
BUFFER 33	0.12	0.1	21	50	267	434
BUFFER 33	0.06	0.6	56	127	489	882
BUFFER 33	0	0	3	8	7	9
FOREST	0.04	0.3	15	47	253	458
FOREST	0.12	0.3	40	126	471	969
FOREST	0.12	0.6	72	226	578	1217
FOREST	0.04	0.6	28	87	395	767
FOREST	0.04	0.1	6	18	98	173
FOREST	0.12	0.1	15	47	253	458
FOREST	0.06	0.6	40	126	471	969
FOREST	0	0	1	3	2	2
BASELINE	0.04	0.3	72	200	282	475
BASELINE	0.12	0.3	100	252	490	909
BASELINE	0.12	0.6	136	320	597	1103
BASELINE	0.04	0.6	86	227	413	736
BASELINE	0.04	0.1	61	182	148	246
BASELINE	0.12	0.1	72	200	282	475
BASELINE	0.06	0.6	100	252	490	909
BASELINE	0	0	56	172	70	114
Double Urban Area	0.04	0.6	86	225	415	732
Double Urban Area	0.04	0.1	61	180	149	244
Double Urban Area	0.12	0.3	100	250	492	905
Double Urban Area	0.12	0.1	71	198	283	472

To predict the impact that increased urbanization might have on TSS loads in the watershed we doubled the amount of urban land use simulated in the SWAT model. This *double urban area* scenario was simulated with a range of channel erodibility and channel cover factors (Table 3.8). Comparing these values to the baseline condition shows very little difference between average and flow-weighted concentrations for the baseline and double urban area scenarios. Essentially, the TSS load has remained more or less constant even though other land uses that typically produce more erosion from the landscape have been replaced by an urban land use. Therefore, the additional TSS is being generated from the stream channel through degradation resulting from changes in hydrology. Comparison of average annual water yield for the baseline and double urban area scenarios shows a small increase in surface runoff and overall water yield with an increase in urban land use (Table 3.9). This scenario represents urban areas with good stormwater control measures and could be much worse without proper BMP's.

Table 3.9 Comparison of water yields for the baseline scenario and the baseline with double the amount of urban area.

	Baseline Water Yield Depth[1](mm)	Double Urban Area Water Yield Depth[1](mm)
Surface Runoff	193.7	200.6
Tile and Lateral Flow	65.3	65.2
Groundwater Flow	68.2	65.7
Transmission Losses	-3.3	-3.4
Total Water Yield	323.9	328.1

[1]Volume of water is expressed as a depth of water across the watershed area. Watershed area is 1,400 km^2

Relatively few modeling studies conducted with SWAT have utilized the channel degradation component. Additional time and resources would be needed to complete this activity for the Olentangy River TMDL model. As an alternative, we can evaluate model predictions based on our measurements and knowledge of stream geomorphology. Field surveys conducted at many locations throughout the watershed provided insight into areas where channel erosion was a significant source of TSS and enabled us to identify areas where landscape BMP's, in-stream BMP's, or a combination of both would be needed to meet water quality targets.

3.7.2 Tillage

As previously stated, caution must be exercised if trying to make direct comparisons between groups of scenarios. Assumptions made in the development of management scenarios could produce results that do not seem consistent with expected results if compared to a scenario that does not make the same assumptions. As an example, we evaluated sediment loadings to the stream channel for Horseshoe Run (HUC 110-100). Under the baseline condition, the landscape load to the channel was predicted to be 0.47 tons per acre per year. In the corn-soybean rotation scenario, which would typically be the most intensive and highest input agricultural system, the predicted sediment yields were much less at 0.26 tons per acre per year. Taken at face value, this result seemed erroneous, but a closer look at assumptions related to the timing of tillage operations provided useful insight on the problem.

In the baseline scenario for Horseshoe Run (Figure 3.9) much of the cropland received fall tillage. Fall tillage operations leave soils bare and unprotected during winter months. Furthermore, combinations of large precipitation events and frozen soils with little capability for infiltration can create conditions conducive to excessive erosion. In the corn-soybean rotation scenario all tillage operations were completed in the spring prior to planting. In this scenario, crop residue remained on the land during the winter months thus reducing overland flow and erosion.

To illustrate the impact of timing of tillage operations on sediment yields we altered the corn-soybean rotation (with spring tillage) scenario so that all tillage operations occurred during the fall. We also evaluated a conservation tillage practice. Figure 3.9 shows the baseline condition together with results for the three tillage scenarios with a corn-soybean rotation. Results are reported as average sediment yield per month. It is apparent that tillage practice can greatly impact annual sediment yields and it is probable that conservation tillage benefits might be greater than predicted.

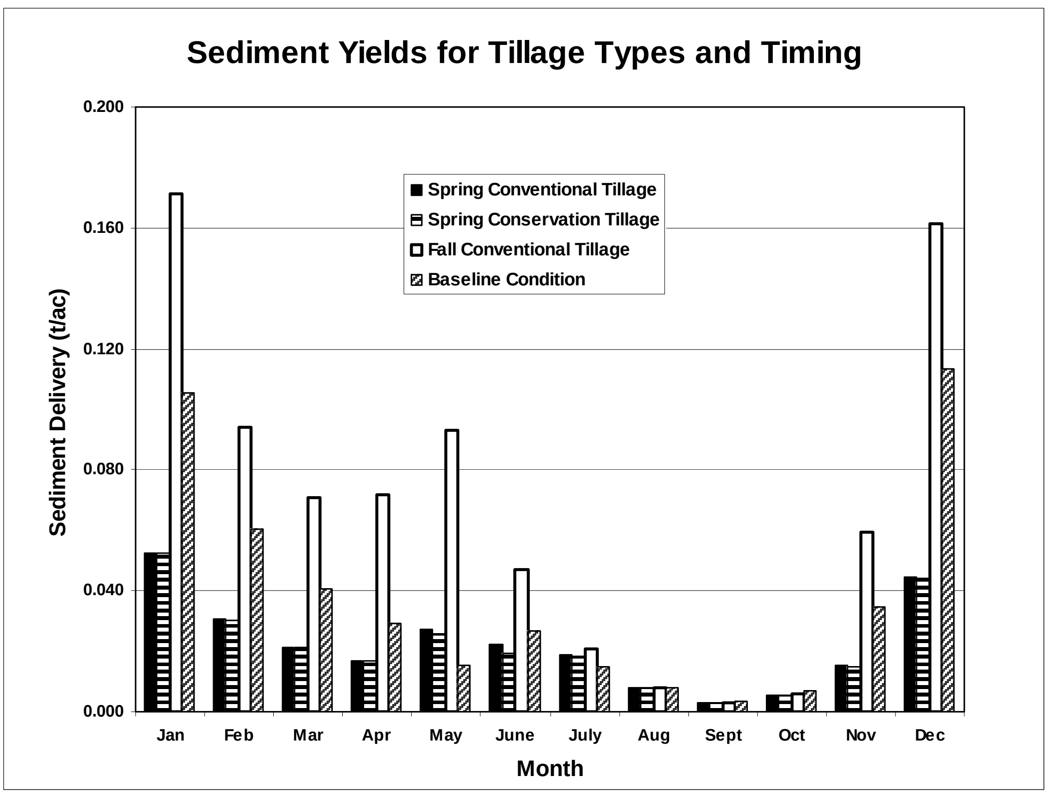


Figure 3.9 Comparison of sediment yields for four SWAT management scenarios in Horseshoe Run: 1) conventional tillage in spring, 2) conservation tillage in spring, 3) conventional tillage in fall, and 4) the baseline condition.

3.7.3 Crop Yields

In calibrating the SWAT model, efforts were made to minimize differences between observed and predicted flows, water quality concentrations, and crop yields. Yield predictions received the least focus, and it is probable that to closely approximate reported yields flow and/or water quality agreement with reality would have been worse. In Table 3.10 we show that, on average, we predicted about 70% of the reported yields. This could be because ET was underestimated, the applied fertilizer levels we used were too low, or one of the crop input parameters was incorrect.

Table 3.10 Actual crop yields (bushels/acre) and average predicted yields (bushels/acre and % of actual) for SWAT scenarios. Percentage of predicted yield versus actual yield follows in parenthesis.

			Corn Soybean Rotation		
		Baseline Scenario[1]	Baseline Fertilizer Scenario[2]	25% More Fertilizer Scenario[3]	25% Less Fertilizer Scenario[4]
Crop	Actual Yield[5]	Predicted Yield	Predicted Yield	Predicted Yield	Predicted Yield
Corn	120	86 (71%)	86 (72%)	91 (76%)	79 (66%)
Soybeans[6]	38	28 (72%)[7]	26 (68%)	26 (68%)	26 (68%)
Wheat	58	42 (72%)	-	-	-

[1]Fertilizer application rates: corn-nitrogen 150 lbs/acre, phosphate-60 lbs/acre; soybeans – nitrogen 15 lbs/acre, phosphate 50 lbs/acre; wheat - nitrogen 75 lbs/acre, phosphate-50 lbs/acre.
[2]Fertilizer application rates: corn-nitrogen 150 lbs/acre, phosphate-60 lbs/acre; soybeans – nitrogen 15 lbs/acre, phosphate 50 lbs/acre.
[3]Fertilizer application rates: corn-nitrogen 187 lbs/acre, phosphate-75 lbs/acre; soybeans – nitrogen 19 lbs/acre, phosphate 62 lbs/acre.
[4]Fertilizer application rates: corn-nitrogen 112 lbs/acre, phosphate-45 lbs/acre; soybeans – nitrogen 11 lbs/acre, phosphate 37 lbs/acre.
[5]Actual yields calculated by taking average reported yields of corn, soybeans and wheat for Crawford, Marion, Morrow, and Delaware counties from National Agricultural Statistics Service Data. Averages computed for the entire simulation period (1985-2002).
[6]Predicted yields for soybeans did not change because adequate nutrients were available for growth. Over the simulation period a slight build up in soil phosphorus suggests that crop growth was not limited by availability of phosphorus. A small amount of nitrogen was applied at planting, but soybeans are nitrogen-fixing legumes and are not likely to be impacted by a addition/small reduction in nitrogen at planting.

A 25% increase in fertilizer applications still predicted yields lower than reported values. Adjusting ET would adversely impact calibrated flows. In SWAT, yields are a fraction of the total plant biomass "grown" by the model. Therefore, adjustments to parameters that control the amount of biomass that is a harvestable yield should provide a better match between observed and predicted yields. However, no knowledge was available on what adjustments might be appropriate. The main value in presenting the results is to evaluate relative change in yield associated with increases or decreases in fertilizers. At fertilizer levels used in the simulations, 25% increases or decreases in application resulted in about a 10% change in corn yield. For soybeans, there is no apparent response to increases in applied fertilizers because the applied amounts are very small and much of the nitrogen needs are provided by plant nitrogen fixation.

3.8 Conclusions

A comprehensive summary of the TMDL results is presented in Chapter 6. This chapter has primarily reported water quality results predicted by SWAT. On a field-by-field or HRU-by-HRU basis, there would be considerable uncertainty associated with these results. However, they provide a useful signature of the relative nutrient and TSS loads associated with different management practices. They also illustrate the difficulty in achieving TMDL targets associated with aquatic life use attainment. In general, load reductions of 50% or more would be desirable for TP, nitrate-N and TSS.

Limited consideration was given to urbanization. It has the potential to greatly increase channel degradation and, hence, TSS loads. Also, nitrate-N loads from urban areas can be high. Combined stormwater and sewage overflow cannot be directly modeled by SWAT. As Ohio EPA is conducting a major study of this issue for Columbus, OH we assume that solutions to that type of problem should not be considered in the TMDL study. Similar problems might occur for other towns and cities. However, as this type of problems falls between a non-point and a point source problem it could not be adequately addressed with the resources available for this TMDL study. Loads associated with Municipal Separate Storm and Sewage Systems (MS4s) are tabulated in Appendix 3.C.

Appendix 3A
Landscape-level Loading Tables

Table 3A.1: Baseline

HUC #	Total P (mg/l)	NO3-N (mg/l)	Sediment (mg/l)	Tot P (lbs/ac)	NO3-N (lbs/ac)	Sediment (t/ac)
5060001090010	0.27	2.9	384	0.8	8.0	0.53
5060001090020	0.15	2.8	52	0.4	6.8	0.06
5060001090030	0.49	6.0	287	1.4	17.1	0.41
5060001090040	0.33	3.3	347	1.0	9.5	0.50
5060001100010	0.19	4.0	262	0.5	10.3	0.34
5060001100020	0.30	5.2	289	0.9	15.5	0.43
5060001100030	0.29	3.1	257	0.8	8.6	0.36
5060001110010	0.31	4.1	200	0.9	12.0	0.29
5060001110020	0.36	3.2	224	1.1	9.8	0.34
5060001110030	0.35	5.2	204	1.1	16.8	0.33
5060001110040	0.42	5.6	241	1.4	18.6	0.40
5060001110050	0.52	8.7	248	1.6	26.8	0.38
5060001110060	0.48	8.2	225	1.5	25.0	0.34
5060001110070	0.30	3.8	178	0.9	11.3	0.27
5060001110080	0.18	2.0	129	0.5	5.7	0.18
5060001110090	0.42	4.2	374	1.2	12.4	0.56
5060001110100	0.47	5.0	292	1.5	16.1	0.47
5060001110110	0.17	1.4	202	0.5	4.1	0.29
5060001120010	0.67	5.7	636	2.1	18.2	1.02
5060001120020	0.18	1.1	187	0.5	3.0	0.25
5060001120030	0.09	2.7	50	0.3	8.2	0.08
5060001120040	0.09	8.1	24	0.3	27.5	0.04
5060001120050	0.07	6.8	19	0.2	21.5	0.03
5060001120060	0.13	4.8	37	0.5	19.1	0.07

Table 3A.2: Corn Soy Wheat

HUC #	Total P (mg/l)	NO3-N (mg/l)	Sediment (mg/l)	Tot P (lbs/ac)	NO3-N (lbs/ac)	Sediment (t/ac)
5060001090010	0.15	2.3	213	0.4	6.4	0.30
5060001090020	0.07	1.1	51	0.2	2.6	0.06
5060001090030	0.23	4.6	153	0.7	13.3	0.22
5060001090040	0.19	3.2	182	0.6	9.3	0.27
5060001100010	0.11	3.2	152	0.3	8.4	0.20
5060001100020	0.17	4.1	155	0.5	12.3	0.23
5060001100030	0.18	2.7	144	0.5	7.6	0.21
5060001110010	0.17	3.8	105	0.5	11.4	0.16
5060001110020	0.19	3.4	112	0.6	10.7	0.18
5060001110030	0.20	4.7	113	0.7	15.9	0.19
5060001110040	0.23	4.7	130	0.8	15.9	0.22
5060001110050	0.24	3.8	148	0.8	11.7	0.23
5060001110060	0.25	4.5	127	0.8	14.0	0.20
5060001110070	0.16	2.8	91	0.5	8.5	0.14
5060001110080	0.12	2.1	69	0.3	5.9	0.10
5060001110090	0.23	3.3	185	0.7	10.0	0.28
5060001110100	0.26	4.8	146	0.9	16.3	0.25
5060001110110	0.10	1.3	99	0.3	3.7	0.14
5060001120010	0.40	4.9	346	1.3	15.7	0.56
5060001120020	0.12	1.0	117	0.3	2.6	0.16
5060001120030	0.06	2.7	30	0.2	8.2	0.05
5060001120040	0.09	8.1	24	0.3	27.5	0.04
5060001120050	0.07	6.8	19	0.2	21.5	0.03
5060001120060	0.13	4.8	37	0.5	19.1	0.07

Table 3A.3: Corn Soy More Fert

HUC #	Total P (mg/l)	NO3-N (mg/l)	Sediment (mg/l)	Tot P (lbs/ac)	NO3-N (lbs/ac)	Sediment (t/ac)
5060001090010	0.28	3.5	251	0.8	9.8	0.35
5060001090020	0.08	1.1	54	0.2	2.8	0.07
5060001090030	0.36	6.9	188	1.0	19.9	0.27
5060001090040	0.32	5.1	210	0.9	14.9	0.31
5060001100010	0.19	4.7	177	0.5	12.2	0.23
5060001100020	0.27	6.4	178	0.8	19.1	0.27
5060001100030	0.27	4.3	161	0.8	12.3	0.23
5060001110010	0.27	5.7	126	0.8	17.0	0.19
5060001110020	0.29	5.3	126	0.9	16.6	0.20
5060001110030	0.31	7.4	126	1.0	24.7	0.21
5060001110040	0.35	7.4	147	1.2	24.9	0.25
5060001110050	0.35	6.2	160	1.1	19.5	0.25
5060001110060	0.35	6.5	141	1.1	20.2	0.22
5060001110070	0.23	4.7	99	0.7	14.2	0.15
5060001110080	0.16	3.2	75	0.5	9.1	0.11
5060001110090	0.34	5.3	204	1.0	15.9	0.31
5060001110100	0.37	8.0	155	1.3	27.4	0.27
5060001110110	0.16	2.1	112	0.5	5.9	0.16
5060001120010	0.59	7.8	382	1.9	25.2	0.62
5060001120020	0.17	1.4	130	0.4	3.6	0.17
5060001120030	0.08	2.7	34	0.2	8.4	0.05
5060001120040	0.09	8.1	24	0.3	27.5	0.04
5060001120050	0.07	6.8	19	0.2	21.5	0.03
5060001120060	0.13	4.8	37	0.5	19.1	0.07

Table 3A.4: Corn Soy Less Fert

HUC #	Total P (mg/l)	NO3-N (mg/l)	Sediment (mg/l)	Tot P (lbs/ac)	NO3-N (lbs/ac)	Sediment (t/ac)
5060001090010	0.25	2.7	249	0.7	7.6	0.35
5060001090020	0.07	1.1	54	0.2	2.7	0.07
5060001090030	0.34	6.0	190	1.0	17.1	0.27
5060001090040	0.29	3.8	207	0.8	11.0	0.30
5060001100010	0.17	3.5	171	0.5	9.2	0.23
5060001100020	0.25	4.9	174	0.7	14.6	0.26
5060001100030	0.25	3.5	162	0.7	10.0	0.23
5060001110010	0.26	4.9	127	0.8	14.5	0.19
5060001110020	0.27	4.2	125	0.9	13.0	0.20
5060001110030	0.29	5.8	126	1.0	19.4	0.21
5060001110040	0.33	5.9	146	1.1	19.6	0.24
5060001110050	0.32	5.0	159	1.0	15.5	0.25
5060001110060	0.33	5.3	141	1.0	16.6	0.22
5060001110070	0.22	3.7	99	0.7	11.4	0.15
5060001110080	0.15	2.7	75	0.4	7.5	0.10
5060001110090	0.32	4.3	205	1.0	12.9	0.31
5060001110100	0.34	6.3	154	1.2	21.6	0.26
5060001110110	0.15	1.7	113	0.4	4.9	0.16
5060001120010	0.55	6.3	383	1.8	20.3	0.62
5060001120020	0.16	1.2	130	0.4	3.2	0.17
5060001120030	0.07	2.7	34	0.2	8.2	0.05
5060001120040	0.09	8.1	24	0.3	27.5	0.04
5060001120050	0.07	6.8	19	0.2	21.5	0.03
5060001120060	0.13	4.8	37	0.5	19.1	0.07

Table 3A.5: Corn Soy

HUC #	Total P (mg/l)	NO3-N (mg/l)	Sediment (mg/l)	Tot P (lbs/ac)	NO3-N (lbs/ac)	Sediment (t/ac)
5060001090010	0.26	3.1	250	0.7	8.7	0.35
5060001090020	0.08	1.1	54	0.2	2.7	0.07
5060001090030	0.35	6.5	189	1.0	18.7	0.27
5060001090040	0.30	4.4	208	0.9	12.9	0.30
5060001100010	0.18	4.1	173	0.5	10.7	0.23
5060001100020	0.26	5.6	175	0.8	16.7	0.26
5060001100030	0.26	3.9	161	0.7	11.2	0.23
5060001110010	0.26	5.4	126	0.8	15.9	0.19
5060001110020	0.28	4.7	125	0.9	14.7	0.20
5060001110030	0.30	6.6	126	1.0	21.9	0.21
5060001110040	0.34	6.6	146	1.1	22.3	0.25
5060001110050	0.33	5.6	159	1.0	17.4	0.25
5060001110060	0.34	5.9	141	1.0	18.3	0.22
5060001110070	0.23	4.2	99	0.7	12.7	0.15
5060001110080	0.16	2.9	74	0.4	8.2	0.10
5060001110090	0.33	4.7	204	1.0	14.4	0.31
5060001110100	0.36	7.1	154	1.2	24.4	0.26
5060001110110	0.16	1.9	112	0.4	5.4	0.16
5060001120010	0.57	7.0	381	1.8	22.8	0.62
5060001120020	0.16	1.3	130	0.4	3.4	0.17
5060001120030	0.08	2.7	34	0.2	8.3	0.05
5060001120040	0.09	8.1	24	0.3	27.5	0.04
5060001120050	0.07	6.8	19	0.2	21.5	0.03
5060001120060	0.13	4.8	37	0.5	19.1	0.07

Table 3A.6: Buffer 10 meters

HUC #	Total P (mg/l)	NO3-N (mg/l)	Sediment (mg/l)	Tot P (lbs/ac)	NO3-N (lbs/ac)	Sediment (t/ac)
5060001090010	0.10	2.1	134	0.3	5.7	0.19
5060001090020	0.14	2.8	37	0.3	6.7	0.04
5060001090030	0.22	4.8	102	0.6	13.7	0.15
5060001090040	0.10	2.3	109	0.3	6.5	0.16
5060001100010	0.09	3.2	98	0.2	8.3	0.13
5060001100020	0.10	4.0	90	0.3	11.8	0.13
5060001100030	0.09	2.2	77	0.3	6.1	0.11
5060001110010	0.11	3.1	59	0.3	9.0	0.09
5060001110020	0.10	2.2	65	0.3	6.8	0.10
5060001110030	0.10	3.6	56	0.3	11.7	0.09
5060001110040	0.11	3.8	66	0.4	12.6	0.11
5060001110050	0.15	6.1	73	0.5	18.9	0.11
5060001110060	0.16	6.1	67	0.5	18.7	0.10
5060001110070	0.09	2.4	54	0.3	7.3	0.08
5060001110080	0.07	1.5	42	0.2	4.3	0.06
5060001110090	0.13	3.0	119	0.4	8.8	0.18
5060001110100	0.13	3.5	80	0.4	11.2	0.13
5060001110110	0.07	1.0	79	0.2	2.7	0.11
5060001120010	0.19	4.2	179	0.6	13.3	0.29
5060001120020	0.09	0.9	93	0.2	2.3	0.12
5060001120030	0.06	2.6	29	0.2	8.1	0.04
5060001120040	0.09	8.1	24	0.3	27.5	0.04
5060001120050	0.07	6.8	19	0.2	21.5	0.03
5060001120060	0.13	4.8	37	0.5	19.1	0.07

Table 3A.7: Buffer 33 meters

HUC #	Total P (mg/l)	NO3-N (mg/l)	Sediment (mg/l)	Tot P (lbs/ac)	NO3-N (lbs/ac)	Sediment (t/ac)
5060001090010	0.02	0.8	12	0.1	2.3	0.02
5060001090020	0.13	2.7	27	0.3	6.5	0.03
5060001090030	0.09	2.4	7	0.2	6.9	0.01
5060001090040	0.00	0.8	1	0.0	2.2	0.00
5060001100010	0.04	1.7	17	0.1	4.3	0.02
5060001100020	0.01	1.7	1	0.0	5.0	0.00
5060001100030	0.00	0.8	0	0.0	2.3	0.00
5060001110010	0.03	1.4	4	0.1	4.2	0.01
5060001110020	0.00	0.8	0	0.0	2.3	0.00
5060001110030	0.00	1.3	0	0.0	4.3	0.00
5060001110040	0.00	1.4	0	0.0	4.5	0.00
5060001110050	0.00	2.2	0	0.0	6.9	0.00
5060001110060	0.04	3.0	6	0.1	9.0	0.01
5060001110070	0.00	0.8	0	0.0	2.3	0.00
5060001110080	0.02	0.8	1	0.0	2.2	0.00
5060001110090	0.00	1.2	2	0.0	3.6	0.00
5060001110100	0.00	1.3	0	0.0	4.0	0.00
5060001110110	0.00	0.2	0	0.0	0.5	0.00
5060001120010	0.00	1.7	1	0.0	5.5	0.00
5060001120020	0.03	0.5	33	0.1	1.3	0.04
5060001120030	0.04	2.6	16	0.1	7.8	0.02
5060001120040	0.09	8.1	24	0.3	27.5	0.04
5060001120050	0.07	6.8	19	0.2	21.5	0.03
5060001120060	0.13	4.8	37	0.5	19.1	0.07

Table 3A.8: Buffer 33 meters Alt

HUC #	Total P (mg/l)	NO3-N (mg/l)	Sediment (mg/l)	Tot P (lbs/ac)	NO3-N (lbs/ac)	Sediment (t/ac)
5060001090010	0.16	1.8	214	0.4	4.9	0.30
5060001090020	0.13	2.7	27	0.3	6.5	0.03
5060001090030	0.49	6.0	287	1.4	17.1	0.41
5060001090040	0.25	2.5	231	0.7	7.1	0.33
5060001100010	0.11	2.7	144	0.3	7.0	0.19
5060001100020	0.20	4.0	206	0.6	12.0	0.31
5060001100030	0.22	2.5	203	0.6	7.0	0.29
5060001110010	0.29	4.0	189	0.9	11.8	0.28
5060001110020	0.31	2.8	194	0.9	8.5	0.29
5060001110030	0.35	5.2	203	1.1	16.7	0.33
5060001110040	0.42	5.6	241	1.4	18.6	0.40
5060001110050	0.47	8.3	203	1.5	25.7	0.31
5060001110060	0.46	8.1	213	1.4	24.8	0.33
5060001110070	0.22	3.1	131	0.7	9.2	0.20
5060001110080	0.15	1.9	85	0.4	5.2	0.12
5060001110090	0.33	3.7	248	1.0	11.0	0.37
5060001110100	0.47	5.0	292	1.5	16.1	0.47
5060001110110	0.00	0.2	0	0.0	0.5	0.00
5060001120010	0.63	5.5	600	2.0	17.6	0.96
5060001120020	0.03	0.5	33	0.1	1.3	0.04
5060001120030	0.04	2.6	16	0.1	7.8	0.02
5060001120040	0.09	8.1	24	0.3	27.5	0.04
5060001120050	0.07	6.8	19	0.2	21.5	0.03
5060001120060	0.13	4.8	37	0.5	19.1	0.07

Table 3A.9: Background Forest

HUC #	Total P (mg/l)	NO3-N (mg/l)	Sediment (mg/l)	Tot P (lbs/ac)	NO3-N (lbs/ac)	Sediment (t/ac)
5060001090010	0.01	0.9	4	0.0	1.6	0.00
5060001090020	0.01	0.9	3	0.0	1.7	0.00
5060001090030	0.01	0.8	2	0.0	1.6	0.00
5060001090040	0.01	0.9	3	0.0	1.7	0.00
5060001100010	0.01	0.9	4	0.0	1.8	0.00
5060001100020	0.01	0.9	2	0.0	1.7	0.00
5060001100030	0.01	0.9	2	0.0	1.8	0.00
5060001110010	0.01	0.9	1	0.0	1.7	0.00
5060001110020	0.01	0.9	1	0.0	1.7	0.00
5060001110030	0.01	0.9	1	0.0	1.7	0.00
5060001110040	0.01	0.9	1	0.0	1.7	0.00
5060001110050	0.01	0.9	2	0.0	1.8	0.00
5060001110060	0.01	0.9	1	0.0	1.7	0.00
5060001110070	0.01	0.9	1	0.0	1.8	0.00
5060001110080	0.01	0.9	2	0.0	1.8	0.00
5060001110090	0.01	0.9	3	0.0	1.8	0.00
5060001110100	0.01	0.9	1	0.0	1.8	0.00
5060001110110	0.01	0.9	2	0.0	1.9	0.00
5060001120010	0.01	0.9	3	0.0	1.8	0.00
5060001120020	0.01	0.9	5	0.0	1.7	0.01
5060001120030	0.01	0.9	8	0.0	2.4	0.01
5060001120040	0.01	0.9	6	0.0	2.5	0.01
5060001120050	0.01	0.9	6	0.0	2.4	0.01
5060001120060	0.01	0.9	5	0.0	2.4	0.01

Table 3A.10: Background Prairie

HUC #	Total P (mg/l)	NO3-N (mg/l)	Sediment (mg/l)	Tot P (lbs/ac)	NO3-N (lbs/ac)	Sediment (t/ac)
5060001090010	0.01	0.5	5	0.0	1.8	0.01
5060001090020	0.01	0.6	5	0.0	2.1	0.01
5060001090030	0.01	0.6	3	0.0	2.1	0.00
5060001090040	0.01	0.6	4	0.0	2.0	0.01
5060001100010	0.01	0.5	6	0.0	2.0	0.01
5060001100020	0.01	0.6	3	0.0	2.2	0.01
5060001100030	0.01	0.7	2	0.0	2.5	0.00
5060001110010	0.01	0.6	2	0.0	2.3	0.00
5060001110020	0.01	0.6	1	0.0	2.4	0.00
5060001110030	0.01	0.6	1	0.0	2.4	0.00
5060001110040	0.01	0.6	1	0.0	2.4	0.00
5060001110050	0.01	0.7	2	0.0	2.5	0.00
5060001110060	0.01	0.6	2	0.0	2.4	0.00
5060001110070	0.01	0.7	1	0.0	2.6	0.00
5060001110080	0.01	0.6	3	0.0	2.4	0.01
5060001110090	0.01	0.6	4	0.0	2.4	0.01
5060001110100	0.01	0.7	1	0.0	2.6	0.00
5060001110110	0.01	0.6	3	0.0	2.4	0.01
5060001120010	0.01	0.6	4	0.0	2.4	0.01
5060001120020	0.01	0.6	7	0.0	2.2	0.01
5060001120030	0.02	0.7	14	0.1	2.8	0.03
5060001120040	0.01	0.7	10	0.1	3.1	0.02
5060001120050	0.01	0.7	10	0.1	2.9	0.02
5060001120060	0.01	0.7	9	0.1	3.0	0.02

Table 3A.11: Background Wetland

HUC #	Total P (mg/l)	NO3-N (mg/l)	Sediment (mg/l)	Tot P (lbs/ac)	NO3-N (lbs/ac)	Sediment (t/ac)
5060001090010	0.01	0.5	7	0.0	2.0	0.01
5060001090020	0.01	0.5	5	0.0	2.0	0.01
5060001090030	0.01	0.5	3	0.0	1.9	0.01
5060001090040	0.01	0.5	5	0.0	2.0	0.01
5060001100010	0.01	0.5	8	0.0	2.0	0.02
5060001100020	0.01	0.5	4	0.0	2.0	0.01
5060001100030	0.01	0.5	3	0.0	2.1	0.01
5060001110010	0.01	0.5	2	0.0	2.0	0.00
5060001110020	0.01	0.5	2	0.0	2.0	0.00
5060001110030	0.01	0.5	1	0.0	2.1	0.00
5060001110040	0.01	0.5	2	0.0	2.1	0.00
5060001110050	0.01	0.5	4	0.0	2.1	0.01
5060001110060	0.01	0.5	3	0.0	2.0	0.01
5060001110070	0.01	0.5	2	0.0	2.1	0.00
5060001110080	0.01	0.5	5	0.0	2.1	0.01
5060001110090	0.01	0.5	6	0.0	2.1	0.01
5060001110100	0.01	0.6	2	0.0	2.1	0.00
5060001110110	0.01	0.5	4	0.0	2.1	0.01
5060001120010	0.01	0.5	6	0.0	2.1	0.01
5060001120020	0.01	0.5	9	0.0	2.0	0.02
5060001120030	0.01	0.6	16	0.1	2.7	0.04
5060001120040	0.01	0.6	12	0.0	2.7	0.03
5060001120050	0.01	0.6	12	0.0	2.7	0.03
5060001120060	0.01	0.6	11	0.0	2.7	0.02

Appendix 3B
Reach-level Loading Tables

Table 3B.1: Baseline with WWTP

HUC #	TW Total P (mg/l)	TW NO3-N (mg/l)	TW TSS (mg/l)	FW Total P (mg/l)	FW NO3-N (mg/l)	FW TSS (mg/l)	Total P (lbs/acre/yr)	NO3-N (lbs/acre/yr)	Sediment (lbs/acre/yr)
090-010	0.81	6.3	54	0.44	3.4	182	1.3	10.0	544
090-020	0.66	6.5	45	0.40	3.8	152	1.1	10.8	428
090-030	0.17	9.3	46	0.49	5.8	143	1.4	16.4	401
090-040	0.12	4.7	68	0.33	3.0	201	0.9	8.7	572
100-010	0.46	4.3	50	0.28	3.5	194	0.7	9.3	515
100-020	0.11	5.5	48	0.30	4.4	135	0.9	13.0	397
100-030	0.29	4.9	56	0.29	3.7	188	0.8	10.1	518
110-010	0.50	5.9	56	0.37	3.6	172	1.1	10.2	489
110-020	0.46	5.7	58	0.37	3.5	177	1.1	10.1	506
110-030	0.17	7.5	48	0.35	4.5	114	1.1	14.5	362
110-040	1.07	8.0	56	0.57	5.6	132	2.2	21.4	503
110-050	0.44	6.5	49	0.39	4.3	150	1.2	12.6	442
110-060	0.20	11.5	59	0.48	7.7	148	1.4	23.5	448
110-070	0.11	3.3	56	0.30	3.4	165	0.9	10.0	492
110-080	0.31	4.6	72	0.32	3.5	89	1.0	10.9	277
110-090	0.29	4.7	83	0.33	3.5	108	1.0	11.0	334
110-100	0.23	9.6	127	0.47	4.4	290	1.5	14.1	927
110-110	0.06	1.8	64	0.18	1.4	203	0.5	4.0	573
112-010	0.44	5.3	85	0.36	3.6	123	1.1	11.4	384
112-020	0.41	4.9	78	0.35	3.5	126	1.1	10.9	392
112-030	0.39	4.8	76	0.34	3.5	123	1.1	10.8	384
112-040	0.37	5.2	72	0.33	3.7	119	1.0	11.5	372
112-050	0.36	5.3	71	0.32	3.8	117	1.0	11.7	365
112-060	0.35	5.4	70	0.32	3.8	114	1.0	11.9	359

Table 3B.2: Baseline without WWTP

HUC #	TW Total P (mg/l)	TW NO3-N (mg/l)	TW TSS (mg/l)	FW Total P (mg/l)	FW NO3-N (mg/l)	FW TSS (mg/l)	Total P (lbs/acre/yr)	NO3-N (lbs/acre/yr)	Sediment (lbs/acre/yr)
090-010	0.09	4.3	55	0.27	2.7	192	0.8	7.4	531
090-020	0.10	4.8	44	0.30	3.4	156	0.8	9.3	420
090-030	0.17	9.3	46	0.49	5.8	143	1.4	16.4	401
090-040	0.12	4.7	68	0.33	3.0	201	0.9	8.7	572
100-010	0.05	4.0	50	0.19	3.4	198	0.5	8.9	514
100-020	0.11	5.5	48	0.30	4.4	135	0.9	13.0	397
100-030	0.08	4.8	56	0.24	3.6	190	0.7	9.9	517
110-010	0.11	4.7	56	0.31	3.4	175	0.9	9.4	484
110-020	0.11	4.6	58	0.32	3.3	179	0.9	9.3	501
110-030	0.17	7.5	48	0.35	4.5	114	1.1	14.5	362
110-040	0.21	7.1	60	0.42	4.9	149	1.4	15.9	489
110-050	0.14	5.8	48	0.35	4.1	152	1.0	11.9	437
110-060	0.20	11.5	59	0.48	7.7	148	1.4	23.5	448
110-070	0.11	3.3	56	0.30	3.4	165	0.9	10.0	492
110-080	0.24	3.8	74	0.28	3.4	84	0.9	10.7	267
110-090	0.24	4.1	93	0.29	3.4	102	0.9	10.8	324
110-100	0.23	9.6	127	0.47	4.4	290	1.5	14.1	927
110-110	0.06	1.8	64	0.18	1.4	203	0.5	4.0	573
112-010	0.24	4.3	100	0.30	3.4	118	0.9	10.9	372
112-020	0.22	3.9	93	0.29	3.3	122	0.9	10.3	381
112-030	0.21	3.9	90	0.28	3.3	120	0.9	10.2	373
112-040	0.21	4.4	85	0.28	3.5	115	0.9	10.9	361
112-050	0.20	4.6	83	0.27	3.6	113	0.8	11.2	354
112-060	0.20	4.7	81	0.27	3.6	110	0.8	11.4	348

Table 3B.3: Buffer Add 10 Meters

HUC #	TW Total P (mg/l)	TW NO3-N (mg/l)	TW TSS (mg/l)	FW Total P (mg/l)	FW NO3-N (mg/l)	FW TSS (mg/l)	Total P (lbs/acre/yr)	NO3-N (lbs/acre/yr)	Sediment (lbs/acre/yr)
090-010	0.03	3.4	35	0.10	1.9	123	0.3	5.2	341
090-020	0.05	4.0	28	0.14	2.7	100	0.4	7.3	269
090-030	0.08	7.9	28	0.22	4.7	88	0.6	13.1	246
090-040	0.04	3.5	36	0.10	2.0	104	0.3	5.8	296
100-010	0.03	3.3	27	0.09	2.7	97	0.2	7.1	251
100-020	0.04	4.3	27	0.10	3.3	77	0.3	9.7	225
100-030	0.03	3.8	27	0.09	2.8	88	0.3	7.5	238
110-010	0.04	3.8	30	0.12	2.5	94	0.3	7.0	260
110-020	0.04	3.7	29	0.12	2.5	91	0.3	6.9	253
110-030	0.05	5.7	25	0.10	3.1	53	0.3	9.9	170
110-040	0.06	5.1	29	0.11	3.2	63	0.4	10.5	206
110-050	0.05	4.6	28	0.12	3.0	80	0.4	8.5	231
110-060	0.07	9.3	26	0.16	5.8	64	0.5	17.5	193
110-070	0.03	2.3	20	0.09	2.1	54	0.3	6.3	163
110-080	0.08	2.9	56	0.10	2.5	68	0.3	7.8	216
110-090	0.08	3.1	57	0.10	2.5	71	0.3	7.8	224
110-100	0.06	7.0	35	0.13	3.0	79	0.4	9.5	253
110-110	0.02	1.3	25	0.07	0.9	80	0.2	2.7	225
112-010	0.08	3.3	58	0.10	2.5	74	0.3	7.9	233
112-020	0.08	3.0	55	0.10	2.4	75	0.3	7.5	234
112-030	0.08	3.0	53	0.10	2.4	73	0.3	7.5	229
112-040	0.08	3.6	51	0.10	2.6	71	0.3	8.3	223
112-050	0.08	3.7	50	0.10	2.7	70	0.3	8.6	220
112-060	0.08	3.9	50	0.10	2.8	69	0.3	8.8	218

Table 3B.4: Buffer Add 33 Meters

HUC #	TW Total P (mg/l)	TW NO3-N (mg/l)	TW TSS (mg/l)	FW Total P (mg/l)	FW NO3-N (mg/l)	FW TSS (mg/l)	Total P (lbs/acre/yr)	NO3-N (lbs/acre/yr)	Sediment (lbs/acre/yr)
090-010	0.01	1.3	3	0.02	0.8	12	0.1	2.2	32
090-020	0.02	1.9	4	0.06	1.5	13	0.2	4.0	35
090-030	0.03	3.5	2	0.09	2.4	7	0.2	6.7	20
090-040	0.00	1.2	0	0.00	0.7	1	0.0	1.9	2
100-010	0.01	1.5	5	0.04	1.5	17	0.1	3.8	43
100-020	0.00	1.8	1	0.01	1.4	1	0.0	4.2	3
100-030	0.01	1.6	3	0.02	1.3	9	0.1	3.6	25
110-010	0.01	1.7	3	0.04	1.2	8	0.1	3.4	23
110-020	0.01	1.6	2	0.03	1.2	7	0.1	3.2	20
110-030	0.00	2.2	0	0.00	1.1	0	0.0	3.5	0
110-040	0.00	1.9	0	0.00	1.1	0	0.0	3.7	0
110-050	0.01	1.9	2	0.03	1.3	5	0.1	3.7	16
110-060	0.02	4.4	3	0.04	2.8	6	0.1	8.5	19
110-070	0.00	0.8	0	0.00	0.6	0	0.0	1.9	0
110-080	0.02	1.3	5	0.02	1.1	6	0.1	3.5	19
110-090	0.02	1.3	4	0.02	1.1	6	0.1	3.5	18
110-100	0.00	2.7	0	0.00	1.1	0	0.0	3.4	0
110-110	0.00	0.2	0	0.00	0.2	0	0.0	0.4	0
112-010	0.01	1.4	4	0.02	1.1	5	0.1	3.5	17
112-020	0.01	1.3	5	0.02	1.1	7	0.1	3.3	22
112-030	0.02	1.4	5	0.02	1.1	7	0.1	3.5	23
112-040	0.02	2.0	6	0.02	1.4	8	0.1	4.5	25
112-050	0.02	2.2	6	0.02	1.5	8	0.1	4.8	26
112-060	0.02	2.4	7	0.03	1.6	9	0.1	5.2	29

Table 3B.5: Corn Soy

HUC #	TW Total P (mg/l)	TW NO3-N (mg/l)	TW TSS (mg/l)	FW Total P (mg/l)	FW NO3-N (mg/l)	FW TSS (mg/l)	Total P (lbs/acre/yr)	NO3-N (lbs/acre/yr)	Sediment (lbs/acre/yr)
090-010	0.09	4.9	49	0.26	2.7	177	0.7	7.6	495
090-020	0.08	5.0	40	0.25	3.3	145	0.7	8.9	398
090-030	0.13	11.3	42	0.35	6.2	134	1.0	17.8	384
090-040	0.12	6.6	59	0.30	4.0	177	0.9	11.7	513
100-010	0.05	3.6	41	0.18	3.4	157	0.5	8.9	410
100-020	0.10	5.5	41	0.26	4.7	119	0.8	14.0	355
100-030	0.08	5.0	45	0.22	3.9	148	0.6	10.6	405
110-010	0.10	5.5	46	0.27	3.7	151	0.8	10.5	424
110-020	0.10	5.5	46	0.27	3.8	147	0.8	10.8	419
110-030	0.16	8.9	45	0.30	5.7	104	1.0	18.8	344
110-040	0.17	8.2	52	0.34	5.7	126	1.1	18.9	417
110-050	0.11	5.8	43	0.28	4.2	132	0.8	12.5	389
110-060	0.14	7.5	47	0.34	5.4	119	1.0	16.8	367
110-070	0.08	3.3	36	0.23	3.7	99	0.7	11.3	301
110-080	0.21	4.0	74	0.23	3.6	83	0.7	11.2	262
110-090	0.21	4.4	81	0.24	3.7	91	0.8	11.6	286
110-100	0.20	11.6	77	0.36	6.2	153	1.2	21.2	517
110-110	0.06	2.2	39	0.16	1.9	113	0.4	5.3	320
112-010	0.21	4.6	84	0.25	3.7	100	0.8	11.7	313
112-020	0.19	4.2	79	0.24	3.6	101	0.8	11.1	315
112-030	0.19	4.2	76	0.24	3.6	99	0.7	11.0	308
112-040	0.18	4.6	72	0.23	3.8	96	0.7	11.7	299
112-050	0.18	4.8	71	0.23	3.8	94	0.7	11.9	294
112-060	0.18	4.9	70	0.23	3.9	92	0.7	12.1	290

Table 3B.6: Corn Soy Wheat

HUC #	TW Total P (mg/l)	TW NO3-N (mg/l)	TW TSS (mg/l)	FW Total P (mg/l)	FW NO3-N (mg/l)	FW TSS (mg/l)	Total P (lbs/acre/yr)	NO3-N (lbs/acre/yr)	Sediment (lbs/acre/yr)
090-010	0.06	3.8	37	0.15	2.0	119	0.4	5.7	338
090-020	0.06	3.9	31	0.16	2.4	100	0.4	6.6	276
090-030	0.09	8.2	31	0.23	4.4	87	0.7	12.6	251
090-040	0.08	4.9	44	0.19	2.9	119	0.6	8.5	347
100-010	0.03	3.1	32	0.12	2.7	120	0.3	7.1	314
100-020	0.07	4.6	32	0.17	3.5	86	0.5	10.4	256
100-030	0.05	4.0	36	0.14	2.9	115	0.4	8.0	316
110-010	0.07	4.2	36	0.17	2.7	105	0.5	7.7	299
110-020	0.07	4.3	37	0.17	2.8	105	0.5	8.0	302
110-030	0.11	7.2	33	0.20	4.1	70	0.7	13.6	231
110-040	0.12	6.4	39	0.23	4.1	84	0.8	13.5	280
110-050	0.08	4.6	32	0.19	3.1	91	0.6	9.1	270
110-060	0.11	6.4	38	0.25	4.2	89	0.8	12.9	275
110-070	0.06	2.7	34	0.16	2.5	88	0.5	7.5	268
110-080	0.14	3.0	59	0.16	2.7	66	0.5	8.4	206
110-090	0.14	3.4	68	0.17	2.7	74	0.5	8.6	231
110-100	0.16	9.6	80	0.26	4.2	144	0.9	14.2	485
110-110	0.04	1.6	38	0.10	1.3	99	0.3	3.6	283
112-010	0.14	3.6	71	0.17	2.8	81	0.5	8.6	254
112-020	0.13	3.2	67	0.17	2.7	84	0.5	8.2	258
112-030	0.13	3.2	64	0.17	2.7	82	0.5	8.2	253
112-040	0.13	3.8	62	0.16	2.9	79	0.5	9.0	246
112-050	0.13	3.9	60	0.16	3.0	78	0.5	9.3	241
112-060	0.13	4.1	59	0.16	3.0	76	0.5	9.5	238

Table 3B.7: Buffer 33 Meters Alternative

HUC #	TW Total P (mg/l)	TW NO3-N (mg/l)	TW TSS (mg/l)	FW Total P (mg/l)	FW NO3-N (mg/l)	FW TSS (mg/l)	Total P (lbs/acre/yr)	NO3-N (lbs/acre/yr)	Sediment (lbs/acre/yr)
090-010	0.06	2.9	45	0.16	1.6	150	0.4	4.4	414
090-020	0.08	3.9	38	0.23	2.8	127	0.6	7.5	341
090-030	0.17	9.3	46	0.49	5.8	143	1.4	16.4	401
090-040	0.10	3.6	58	0.25	2.2	166	0.7	6.3	472
100-010	0.03	2.3	28	0.11	2.2	128	0.3	5.6	331
100-020	0.08	4.0	28	0.20	3.3	82	0.6	9.6	241
100-030	0.06	3.4	37	0.16	2.5	130	0.4	6.9	352
110-010	0.09	3.9	49	0.25	2.8	148	0.7	7.7	408
110-020	0.09	3.8	51	0.26	2.7	152	0.7	7.6	425
110-030	0.17	7.5	48	0.35	4.5	113	1.1	14.4	361
110-040	0.21	7.1	60	0.42	4.9	149	1.4	15.9	489
110-050	0.12	5.2	45	0.30	3.6	135	0.9	10.5	389
110-060	0.20	11.4	55	0.47	7.7	137	1.4	23.3	415
110-070	0.08	2.5	42	0.22	2.7	124	0.7	8.0	371
110-080	0.19	3.2	70	0.22	2.8	81	0.7	9.0	258
110-090	0.20	3.6	84	0.24	2.9	95	0.7	9.1	300
110-100	0.23	9.6	127	0.47	4.4	290	1.5	14.1	927
110-110	0.00	0.2	0	0.00	0.2	0	0.0	0.4	0
112-010	0.20	3.8	89	0.24	2.9	106	0.8	9.2	336
112-020	0.18	3.4	78	0.23	2.7	102	0.7	8.6	318
112-030	0.17	3.3	75	0.22	2.7	99	0.7	8.6	310
112-040	0.17	3.9	72	0.22	3.0	96	0.7	9.3	300
112-050	0.16	4.0	70	0.22	3.1	94	0.7	9.6	295
112-060	0.16	4.2	69	0.21	3.1	92	0.7	9.8	291

Table 3B.8: Corn Soy More Fertilizer

HUC #	TW Total P (mg/l)	TW NO3-N (mg/l)	TW TSS (mg/l)	FW Total P (mg/l)	FW NO3-N (mg/l)	FW TSS (mg/l)	Total P (lbs/acre/yr)	NO3-N (lbs/acre/yr)	Sediment (lbs/acre/yr)
090-010	0.10	5.7	49	0.28	3.1	178	0.8	8.6	495
090-020	0.09	5.7	40	0.26	3.5	145	0.7	9.7	397
090-030	0.13	12.4	42	0.36	6.6	134	1.0	18.8	384
090-040	0.12	7.8	59	0.32	4.7	178	0.9	13.5	515
100-010	0.05	4.1	41	0.19	3.9	159	0.5	10.2	413
100-020	0.11	6.4	41	0.27	5.3	120	0.8	15.9	355
100-030	0.08	5.7	45	0.23	4.4	149	0.6	12.0	407
110-010	0.10	6.3	46	0.28	4.1	151	0.8	11.6	424
110-020	0.10	6.3	46	0.28	4.2	148	0.8	12.0	419
110-030	0.16	10.3	45	0.31	6.4	104	1.0	21.1	345
110-040	0.18	9.2	53	0.35	6.3	126	1.2	21.0	418
110-050	0.12	6.7	43	0.29	4.7	133	0.9	13.8	389
110-060	0.15	8.5	47	0.35	6.0	119	1.1	18.5	367
110-070	0.09	3.7	36	0.24	4.1	99	0.7	12.5	302
110-080	0.22	4.5	74	0.24	4.0	84	0.8	12.5	262
110-090	0.22	5.0	81	0.25	4.1	91	0.8	12.9	287
110-100	0.20	13.3	78	0.37	7.0	154	1.3	23.6	520
110-110	0.06	2.4	39	0.16	2.1	113	0.5	5.8	319
112-010	0.22	5.2	84	0.26	4.2	100	0.8	13.0	313
112-020	0.20	4.8	79	0.25	4.0	102	0.8	12.4	315
112-030	0.20	4.7	76	0.25	3.9	100	0.8	12.2	309
112-040	0.19	5.1	72	0.24	4.1	96	0.8	12.9	299
112-050	0.19	5.3	71	0.24	4.2	94	0.7	13.0	294
112-060	0.19	5.3	70	0.23	4.2	92	0.7	13.2	290

Table 3B.9: Corn Soy Less Fertilizer

HUC #	TW Total P (mg/l)	TW NO3-N (mg/l)	TW TSS (mg/l)	FW Total P (mg/l)	FW NO3-N (mg/l)	FW TSS (mg/l)	Total P (lbs/acre/yr)	NO3-N (lbs/acre/yr)	Sediment (lbs/acre/yr)
090-010	0.09	4.1	49	0.25	2.4	177	0.7	6.7	495
090-020	0.08	4.3	40	0.24	2.9	146	0.7	8.0	398
090-030	0.12	10.0	42	0.35	5.7	135	1.0	16.3	384
090-040	0.11	5.4	59	0.29	3.5	176	0.8	10.1	511
100-010	0.05	3.0	41	0.17	3.0	157	0.5	7.7	409
100-020	0.10	4.8	41	0.25	4.1	119	0.7	12.3	355
100-030	0.07	4.3	45	0.21	3.4	147	0.6	9.3	404
110-010	0.09	4.7	46	0.26	3.3	151	0.7	9.4	424
110-020	0.09	4.7	46	0.26	3.4	147	0.7	9.7	419
110-030	0.15	7.7	44	0.29	5.1	103	1.0	16.8	343
110-040	0.16	7.0	52	0.33	5.1	125	1.1	16.9	416
110-050	0.11	5.0	43	0.27	3.8	132	0.8	11.2	388
110-060	0.14	6.6	47	0.33	5.0	118	1.0	15.3	366
110-070	0.08	2.9	36	0.22	3.4	99	0.7	10.2	301
110-080	0.20	3.5	73	0.23	3.2	83	0.7	10.0	261
110-090	0.20	3.8	80	0.23	3.3	91	0.7	10.4	286
110-100	0.19	10.2	77	0.34	5.6	153	1.2	19.0	517
110-110	0.05	1.9	39	0.15	1.7	114	0.4	4.8	321
112-010	0.20	4.0	84	0.24	3.3	99	0.8	10.5	312
112-020	0.19	3.7	79	0.24	3.2	101	0.7	10.0	315
112-030	0.18	3.7	76	0.23	3.2	99	0.7	9.9	308
112-040	0.18	4.2	72	0.22	3.4	96	0.7	10.6	299
112-050	0.17	4.3	70	0.22	3.5	94	0.7	10.8	293
112-060	0.17	4.4	69	0.22	3.5	92	0.7	11.1	289

Table 3B.10: Background Forest

HUC #	TW Total P (mg/l)	TW NO3-N (mg/l)	TW TSS (mg/l)	FW Total P (mg/l)	FW NO3-N (mg/l)	FW TSS (mg/l)	Total P (lbs/acre/yr)	NO3-N (lbs/acre/yr)	Sediment (lbs/acre/yr)
090-010	0.00	0.4	1	0.01	0.9	4	0.0	1.6	8
090-020	0.00	0.4	1	0.01	0.9	4	0.0	1.6	7
090-030	0.00	0.3	1	0.01	0.8	2	0.0	1.5	4
090-040	0.00	0.5	1	0.01	0.9	3	0.0	1.7	6
100-010	0.00	0.4	1	0.01	0.9	4	0.0	1.7	9
100-020	0.00	0.4	1	0.01	0.9	2	0.0	1.7	4
100-030	0.00	0.4	1	0.01	0.9	3	0.0	1.7	7
110-010	0.00	0.4	1	0.01	0.9	3	0.0	1.6	6
110-020	0.00	0.5	1	0.01	0.9	3	0.0	1.6	5
110-030	0.00	0.5	0	0.01	0.9	1	0.0	1.7	2
110-040	0.00	0.4	0	0.01	0.9	1	0.0	1.7	2
110-050	0.00	0.5	1	0.01	0.9	2	0.0	1.7	4
110-060	0.00	0.4	1	0.01	0.9	1	0.0	1.7	3
110-070	0.00	0.5	0	0.01	0.9	1	0.0	1.8	2
110-080	0.00	0.6	2	0.00	0.4	2	0.0	1.6	6
110-090	0.00	0.6	2	0.00	0.4	2	0.0	1.6	6
110-100	0.00	0.5	0	0.01	0.9	1	0.0	1.8	2
110-110	0.00	0.5	1	0.01	0.9	2	0.0	1.9	5
112-010	0.00	0.6	2	0.00	0.4	2	0.0	1.6	6
112-020	0.00	0.5	2	0.00	0.5	2	0.0	1.6	6
112-030	0.00	0.5	2	0.00	0.5	2	0.0	1.6	7
112-040	0.00	0.6	2	0.00	0.5	2	0.0	1.7	7
112-050	0.00	0.6	2	0.00	0.5	2	0.0	1.7	8
112-060	0.00	0.5	2	0.00	0.5	2	0.0	1.7	8

Table 3B.11: Background Prairie

HUC #	TW Total P (mg/l)	TW NO3-N (mg/l)	TW TSS (mg/l)	FW Total P (mg/l)	FW NO3-N (mg/l)	FW TSS (mg/l)	Total P (lbs/acre/yr)	NO3-N (lbs/acre/yr)	Sediment (lbs/acre/yr)
090-010	0.00	0.3	2	0.01	0.5	5	0.0	1.8	20
090-020	0.00	0.3	2	0.01	0.5	5	0.0	1.9	17
090-030	0.00	0.4	1	0.01	0.6	3	0.0	2.1	10
090-040	0.00	0.4	1	0.01	0.6	4	0.0	2.0	14
100-010	0.00	0.4	2	0.01	0.5	6	0.0	2.0	21
100-020	0.00	0.4	1	0.01	0.6	3	0.0	2.2	11
100-030	0.00	0.4	2	0.01	0.6	4	0.0	2.1	16
110-010	0.00	0.4	1	0.01	0.6	4	0.0	2.0	14
110-020	0.00	0.4	1	0.01	0.6	4	0.0	2.1	13
110-030	0.00	0.5	0	0.01	0.6	1	0.0	2.4	4
110-040	0.00	0.5	0	0.01	0.6	1	0.0	2.4	4
110-050	0.00	0.4	1	0.01	0.6	3	0.0	2.2	11
110-060	0.00	0.5	1	0.01	0.6	2	0.0	2.4	7
110-070	0.00	0.5	1	0.01	0.7	1	0.0	2.5	5
110-080	0.01	0.5	3	0.01	0.5	4	0.0	1.6	11
110-090	0.01	0.5	3	0.01	0.6	4	0.0	1.7	11
110-100	0.00	0.5	1	0.01	0.7	1	0.0	2.6	5
110-110	0.00	0.5	1	0.01	0.6	3	0.0	2.4	11
112-010	0.01	0.5	3	0.01	0.6	4	0.0	1.7	11
112-020	0.01	0.5	3	0.01	0.6	4	0.0	1.8	12
112-030	0.01	0.5	3	0.01	0.6	4	0.0	1.8	13
112-040	0.01	0.5	3	0.01	0.6	5	0.0	1.9	15
112-050	0.01	0.5	3	0.01	0.6	5	0.0	1.9	15
112-060	0.01	0.5	3	0.01	0.6	5	0.0	1.9	16

Table 3B.12: Background Wetlands

HUC #	TW Total P (mg/l)	TW NO3-N (mg/l)	TW TSS (mg/l)	FW Total P (mg/l)	FW NO3-N (mg/l)	FW TSS (mg/l)	Total P (lbs/acre/yr)	NO3-N (lbs/acre/yr)	Sediment (lbs/acre/yr)
090-010	0.00	0.3	2	0.01	0.5	7	0.0	1.9	28
090-020	0.00	0.3	2	0.01	0.5	6	0.0	1.9	23
090-030	0.00	0.3	1	0.01	0.5	3	0.0	1.9	12
090-040	0.00	0.3	2	0.01	0.5	5	0.0	2.0	20
100-010	0.00	0.3	3	0.01	0.5	8	0.0	2.0	31
100-020	0.00	0.3	2	0.01	0.5	4	0.0	2.0	15
100-030	0.00	0.3	2	0.01	0.5	6	0.0	2.0	23
110-010	0.00	0.3	2	0.01	0.5	5	0.0	2.0	20
110-020	0.00	0.3	2	0.01	0.5	5	0.0	2.0	18
110-030	0.00	0.3	1	0.01	0.5	1	0.0	2.0	6
110-040	0.00	0.3	1	0.01	0.5	2	0.0	2.0	6
110-050	0.00	0.3	2	0.01	0.5	4	0.0	2.0	15
110-060	0.00	0.3	1	0.01	0.5	3	0.0	2.0	10
110-070	0.00	0.3	1	0.01	0.5	2	0.0	2.1	8
110-080	0.01	0.5	4	0.01	0.5	5	0.0	1.6	14
110-090	0.01	0.5	4	0.01	0.5	5	0.0	1.6	15
110-100	0.00	0.3	1	0.01	0.6	2	0.0	2.1	7
110-110	0.00	0.3	2	0.01	0.5	4	0.0	2.1	16
112-010	0.01	0.4	4	0.01	0.5	5	0.0	1.6	15
112-020	0.01	0.4	4	0.01	0.5	5	0.0	1.7	16
112-030	0.01	0.4	4	0.01	0.5	6	0.0	1.7	18
112-040	0.01	0.4	4	0.01	0.5	6	0.0	1.7	20
112-050	0.01	0.4	4	0.01	0.5	6	0.0	1.7	20
112-060	0.01	0.4	4	0.01	0.5	6	0.0	1.8	21

Appendix 3C

Point Source and Non-point Source Load Tables

Table 3C.1: Point source and non-point source load tables for 11-digit HUC's.

	NPS							PS						
HUC #	Total P (mg/l)	NO3-N (mg/l)	TSS (mg/l)	Flow (10^6 l/yr)	Total P (mt/yr)	NO3-N (mt/yr)	TSS (mt/yr)	Total P (mg/l)	NO3-N (mg/l)	TSS (mg/l)	Flow (10^6 l/yr)	Total P (mt/yr)	NO3-N (mt/yr)	TSS (mt/yr)
5060001090	0.31	3.5	318	108548	33.7	381.7	34563.3	2.57	11.5	6	3564	9.2	41.0	21.4
5060001100	0.24	4.1	268	94442	22.7	388.9	25335.2	4.30	6.1	12	1106	4.8	6.7	13.3
5060001110	0.37	4.8	233	158046	58.8	765.1	36761.5	2.02	12.3	12	1658	3.3	20.4	19.9
5060001120	0.18	4.5	141	99032	18.1	451.0	13961.6	1.79	8.8	6	7815	14.0	68.4	43.4

mt = metric tons = 1000 kg
l=liters; 10^6 = 1,000,000 liters

Table 3C.2: Point source and non-point source load tables for 14-digit HUC's.

	NPS							PS						
HUC #	Total P (mg/l)	NO3-N (mg/l)	TSS (mg/l)	Flow (10^6 l/yr)	Total P (mt/yr)	NO3-N (mt/yr)	TSS (mt/yr)	Total P (mg/l)	NO3-N (mg/l)	TSS (mg/l)	Flow (10^6 l/yr)	Total P (mt/yr)	NO3-N (mt/yr)	TSS (mt/yr)
5060001090010	0.27	2.9	384	43386	11.8	125.5	16668.6	2.57	11.5	6	3564	9	41	21
5060001090020	0.15	2.8	52	12604	1.9	35.8	660.8	0.00	0.0	0	0	0	0	0
5060001090030	0.49	6.0	287	16895	8.2	101.8	4855.0	0.00	0.0	0	0	0	0	0
5060001090040	0.33	3.3	347	35663	11.8	118.6	12378.9	0.00	0.0	0	0	0	0	0
5060001100010	0.19	4.0	262	50179	9.5	198.4	13141.9	4.30	6.1	12	1106	5	7	13
5060001100020	0.3	5.2	289	25451	7.7	133.0	7362.1	0.00	0.0	0	0	0	0	0
5060001100030	0.29	3.1	257	18812	5.5	57.5	4831.2	0.00	0.0	0	0	0	0	0
5060001110010	0.31	4.1	200	22133	6.9	91.0	4419.5	0.00	0.0	0	0	0	0	0
5060001110020	0.36	3.2	224	19292	6.9	62.5	4315.0	0.00	0.0	0	0	0	0	0
5060001110030	0.35	5.2	204	17387	6.1	90.8	3548.7	0.00	0.0	0	0	0	0	0
5060001110040	0.42	5.6	241	9878	4.1	55.5	2384.0	2.02	12.3	12	1658	3	20	20
5060001110050	0.52	8.7	248	14157	7.4	122.6	3506.9	0.00	0.0	0	0	0	0	0
5060001110060	0.48	8.2	225	16333	7.8	134.0	3669.6	0.00	0.0	0	0	0	0	0
5060001110070	0.3	3.8	178	12133	3.7	45.6	2155.8	0.00	0.0	0	0	0	0	0
5060001110080	0.18	2.0	129	9859	1.8	20.2	1271.1	0.00	0.0	0	0	0	0	0
5060001110090	0.42	4.2	374	17104	7.1	71.0	6399.0	0.00	0.0	0	0	0	0	0
5060001110100	0.47	5.0	292	12233	5.7	61.0	3569.4	0.00	0.0	0	0	0	0	0
5060001110110	0.17	1.4	202	7537	1.3	10.8	1522.6	0.00	0.0	0	0	0	0	0
5060001120010	0.67	5.7	636	11064	7.4	62.9	7038.3	2.22	8.9	7	4997	11	44	35
5060001120020	0.18	1.1	187	26369	4.7	30.2	4942.1	1.02	8.5	3	2817	3	24	8
5060001120030	0.09	2.7	50	13749	1.2	37.1	680.9	0.00	0.0	0	0	0	0	0
5060001120040	0.09	8.1	24	21161	2.0	171.0	509.6	0.00	0.0	0	0	0	0	0
5060001120050	0.07	6.8	19	10740	0.8	72.5	204.8	0.00	0.0	0	0	0	0	0
5060001120060	0.13	4.8	37	15949	2.1	77.3	585.8	0.00	0.0	0	0	0	0	0

mt = metric tons = 1000 kg
l=liters; 10^6 = 1,000,000 liters

Chapter 4: Stream Geomorphology and Watershed Hydrology

4.0 Introduction

Knowledge of stream geomorphology was obtained for the following purposes: (1) to determine if aquatic life use attainment and biological indicators are related to stream geomorphology; (2) to aid in evaluating if the stream is in dynamic equilibrium; (3) to help identify and diagnose stream bed and bank scour or instability problems; (4) to help identify and diagnose sediment deposition (aggradation) problems; to (5) aid in evaluating potential land use change impacts and to help identify measures to minimize potential adverse impacts; and (6) to provide representative channel dimension geometry information for use with the SWAT simulation model.

Understanding the geomorphology and ecology of a stream system requires a diagnosis of numerous factors and a "weight of evidence" approach. Little knowledge is available on how stream geomorphology influences aquatic life. The limited consideration in the QHEI of factors that influence habitat might well be the best practical approach that has been adopted to relate stream health to geomorphology.

Factors useful in helping diagnose stream systems include: (1) the development and application of a set of regional curves that are specific to the system being evaluated; (2) ratios that relate the out of bank or flooded width to the bankfull width; (3) ratios that relate the top of bank depth to a measure of the bankfull depth; and (4) relating the bed material to shear stresses associated with bankfull discharge. Regional curves are empirical by nature and usually are constructed from bankfull discharge-stage observations and measurements of stable riffle cross-sections. Regional curves are regression equations that express mathematical relationships between contributing drainage area and channel dimensions - cross sectional area, top of bank width, and mean depth, corresponding to the effective or bankfull discharge.

Regional curves can provide estimations of bankfull channel dimensions and bankfull discharges for both gaged and ungaged rivers and streams within a region; however, there is considerable uncertainty associated with their use. The common use of the word "regional" is unfortunate as the spatial scale associated with a specific set of regional curves can vary from a few hundred acres to large river basins or physiographic regions that straddle several states. Local sub-watershed attributes, topography, soil and bedrock properties, vegetation on the banks and adjacent riparian zone, and size and characteristics of the active floodplain will result in a variety of different "stable" channel dimensions for similar size drainage areas within a watershed or region.

The term *effective discharge* is based on concepts proposed by Wolman and Miller (1960) and is the streamflow that transports the most sediment over the long term. Inherent in the use of the term *effective discharge* is the collection and/or analysis of suspended and/or bedload sediment data (Andrews, 1980; Nash, 1994; Andrews and Nankervis, 1995; Orndorff and Whiting, 1999; Whiting et al., 1999; Biedenharn and Copeland; 2000; Emmett and Wolman, 2001). *Bankfull discharge* is often related to the streamflow that fills the main channel and begins to spill onto the active floodplain (Wolman and Leopold, 1956; Wolman and Miller, 1960). It is a range of flows that is most effective in forming a channel, benches (floodplains), banks, and bars (Williams, 1978). The bankfull discharge is "*considered to be the channel-forming or effective discharge*" (Leopold, 1994). Inherent in the use of the term bankfull discharge is the collection and/or analysis of channel dimension data (Andrews, 1980; Nolan et al, 1987; Rosgen, 1994; Johnson and Heil, 1996). The term *bankfull* causes some confusion because in some constructed channels, such as agricultural ditches, the size of the ditch is unrelated to dimensions associated with fluvial processes. In entrenched or incised streams that are common in urban and many rural settings, the bankfull stage is lower than the top of the bank and is identified as a bench, a change in bank material and vegetation, the top of a point bar, or a scour line.

Typically, knowledge of stream geomorphology is acquired by conducting detailed surveys along a reach of interest, conducting a detailed survey on a "reference" reach along the same or a similar nearby stream system, and/or developing regional curves that relate channel dimensions and discharges to watershed drainage area. Regional curves are often developed by conducting stream surveys at locations where there are long-term records of stream flows. Like most parts of the nation, however, the Olentangy River watershed has a limited number of gages on small sub-watersheds and, typically, these gages have short records or have been discontinued. At most sites that were evaluated in this study it was necessary to use Manning's equation to estimate discharge (Ward and Trimble, 2003). Also, to provide additional information from stream gages, the regional curve analysis was expanded to include the whole Upper Scioto River watershed to the USGS gage at Higby, Ohio.

Other difficulties associated with developing regional curves for the Olentangy River watershed were: (1) most gages were located along the main tributaries of the Upper Scioto River on reaches that often were not wadeable and were modified by human activities; (2) finding "reference" reaches was a time consuming, costly, and difficulty activity that depended on access being provided by stakeholders; and (3) to be useful for some aspects of the TMDL study it was desirable to obtain stream geomorphology information for a range of equilibrium conditions not just locations that were in dynamic equilibrium.

Stream geomorphology measurements ranged from: (1) making bankfull stage measurements at USGS gages; (2) obtaining cross-section dimensions at a representative riffle or run; (3) conducting pebble counts at some sites where cross-section data were obtained; and (4) conducting a comprehensive reach survey. Sites were primarily selected to obtain stream geomorphology information at or near locations where Ohio EPA had made IBI, ICI, and QHEI determinations. In addition, we obtained detailed geomorphology, fish biology and habitat data for the Thorn Run and Flat Run watersheds.

4.1 Methods

To consider the influence of stream geomorphology on the TMDL analysis the following tasks were performed:

- Site selection.
- Measuring stream geomorphology characteristics at most of those sites.
- Determining bankfull geometry, and other geomorphology values at each location, and developing a regional curve for the Upper Scioto River; developing discharge versus recurrence interval relationships at each gage; then determining, at each gage, the bankfull and/or effective discharge and its recurrence interval; using the gage results to calibrate the USGS rural or urban empirical discharge equations.
- Using spreadsheet tools to determine the stage associated with predicted 0.8-year, 1.6-year, and 50-year discharge; then determining floodplain width and bank height ratios associated with these discharges; also, developing a qualitative index to assess the geomorphology status at each of the sites selected for evaluation.
- Relating geomorphology indicators to spatial location, habitat and IBI scores.

The last task is reported in Chapter 5. All the other tasks listed above and the results of these tasks are presented in this chapter. A discussion is then presented on the uncertainty associated with the results.

4.1.1 Site Selection Strategy

Potential sites were marked on a State of Ohio Gazetteer (Delorme, 2000). Provisional sites were selected based on consultation with Ohio EPA personnel, discussions with personnel from other agencies, and discussions with stakeholders within the watershed. Orthophotos contained in a GIS database also were used. Many sites were selected to correspond to sites used by Ohio EPA to obtain aquatic life information. Additional sites were identified to obtain good spatial distribution across the watershed – with several sites having similar drainage areas within each log cycle. Initially, many more sites were marked on the Gazetteer than we anticipated actually measuring. A drive-through reconnaissance was then made of the watershed. Additional observations were made by canoeing several miles of the main stem of the upper Olentangy River from Claridon, Ohio, to near the Delaware Dam. Sites with and without instability problems were then selected and property owners were contacted to obtain permission to conduct studies on their properties. The size of the study area was expanded to include more sites with USGS gages.

4.1.2 Stream Geomorphology Measurements

For each reach survey information was obtained on the channel materials, dimension, pattern and profile. Procedures used were generally consistent with the guidelines presented by Harrelson et al. (1994). The survey was conducted with a laser level, 100-foot measuring tape, and a telescoping rod with a laser receiver. The approach used is suitable only for streams that are wadeable and was usually performed by a team of three people.

For each reach, a longitudinal survey was conducted over a stream length equal to at least 20 channel widths so that the survey encompassed at least two bends. Occasionally, it was only possible to survey one bend. Features typically measured included: channel cross-sections at 2-3 points along the reach; bed profile along the thalweg; water surface profile; azimuths of the banks from each feature to the next reach; the bankfull discharge elevation at points along the reach where it was easily identified, the top of the bank; and bed material particle size distribution. Each survey included at least one representative cross-section in a riffle feature that also had distinct bankfull features.

The most common method for characterizing the bed material of a stream is to conduct a Wolman Pebble Count (1954). Wolman pebble counts were conducted in riffle sections because:

- Collecting particle size distributions associated with bankfull dimensions aid in properly classifying the stream or river based on the dominant bed material size.
- The calculated particle size at the threshold of motion (based on average tractive force at bankfull) relates the streams' transport capacity to move the dominant particle size (D_{50}) measured in the bed. This knowledge aids in determining if bankfull stage was correctly identified and in identifying the equilibrium state of the stream.
- Particle sizes and substrate materials are also useful for fish habitat studies and assessing the riparian ecosystem.

At each gage location, bankfull discharge was determined by identifying and measuring the stage of a bankfull fluvial feature, computing the channel cross-sectional area associated with the measured stage, and then calculating the discharge conveyed by the cross-sectional area. Many of the streams were entrenched, so the dominant bankfull feature was typically a narrow floodplain or bench located below the top of the bank. These features exhibited a combination of changes in the bank material, slope, particle size distribution, and vegetation. Using the gage as a point of reference, the bankfull stage was measured at the most prominent observed bankfull feature using a laser level, a telescoping rod, and a laser receiver. Time was recorded and used to obtain the water stage elevation (at the time of measurement) from the real-time USGS gage. Determination of the cross-sectional area and bankfull discharge was based on published USGS measurements at the gage, a USGS gage rating curve, and our measurement of the bankfull stage.

4.1.3 Determining Geomorphology Relationships

Stream geomorphology measurements were entered into one or more of a suite of spreadsheets called STREAM (Spreadsheet Tools for River Evaluation, Assessment and Monitoring). The STREAM modules were developed by Dan Mecklenburg, at the Ohio Department of Natural Resources (ODNR), with input from Andy Ward at The Ohio State University (Mecklenburg and Ward, 2005). In developing these tools we had the following objectives: (1) to help facilitate the activities listed in the acronym by being consistent with standard or commonly used techniques; (2) to "crunch" numbers and draw plots that at times can be laborious; (3) to present some rather challenging techniques in a way some may find more understandable; and (4) as educational tools. Embedded in the tools are details on the equations and theory that are used to generate the reported outputs.

The *Reference Reach Spreadsheet* (RRSS) was used for reducing channel survey data and calculating basic bankfull hydraulic characteristics. Cross-sections were plotted and various bankfull channel dimensions were calculated including area, width, mean and maximum depth, etc. Determining bankfull location is one of the most challenging tasks in geomorphology. The RRSS facilitates the determination of bankfull by using cross-sections in conjunction with the channel profile. The stage at which a bankfull-trend line from the profile intersects each cross section provides a first iteration of the bankfull stage. Refinement of these values was based on local trends in the profile and details of the cross-section.

Bankfull flow characteristics were calculated using Manning's Equation (Ward and Trimble, 2003). The RRSS also calculates other resistance, force, and power factors. To manage the information obtained from each channel survey values were reduced to dimensionless ratios. This facilitated comparisons between channels. The RRSS provided a summary of all data including an average and range of all values.

Pattern is the dimension least well defined by a site survey. Often, better information can be obtained by aerial photographs, GIS, and even topographic maps that can be entered in the RRSS. All of which allow a greater length of stream to be assessed. Also, while surveying the profile with a tape and level, if an azimuth is obtained and entered with each corresponding distance that information will be reduced and presented in plan form. In addition, water depth information is represented on the plan view allowing an interesting perspective of pool and riffle location throughout the meander pattern. In the RRSS, pebble count data were plotted as a cumulative percent versus particle size and the D_{50} and D_{84} were calculated.

Another approach to determining bankfull that is utilized in the RRSS is based on the idea that in gravel bed channels the particle at the threshold of motion at bankfull flow is often near the measured D_{50}. Using Shield's parameter, the RRSS computes particle size at the threshold of motion and presents it with the D_{50} and D_{84} values for comparison. External from the RRSS we also used "Andy's 1x1=1" rule to estimate the particle at incipient motion. This rule states that the mean particle size in inches that will be moved at incipient motion is the product of the bed slope in percent and the flow depth in feet (a 1 inch particle will be moved by 1 foot of flow across a bed slope of 1 percent).

The *Contrasting Channel* and *Two-Stage Channel* modules in the STREAM suite of spreadsheets were also used in the analysis. The hydrology features in the *Contrasting Channel* spreadsheet were used to estimate the 0.8-year, 1.6-year, and 50-year recurrence interval (RI). In the spreadsheet, the stage associated with these discharges was then plotted on an estimate of the channel cross-section based on regional curves for the Upper Scioto River. These stages were then transferred to a version of the *Two-Stage Channel* spreadsheet customized to provide some of the output presented in this chapter. Hydrology models developed by USGS (Koltun and Roberts, 1990; Koltun, 2003; Sherwood, 1986; 1993) are built into the spreadsheet and calibration of these models is discussed in Section 4.2.

Two factors that provide useful indicators of equilibrium conditions are the *flooded width ratio* and the *bank height ratio*. The *flooded width ratio* is the width of flow when the bankfull discharge is just exceeded divided by the bankfull width. The *bank height ratio* is the height to the top of the bank divided by the bankfull discharge stage height. Ward and Mecklenburg (2004) suggest that for natural streams the *flooded width ratio* should be at least 8 times the bankfull width and the *bank height ratio* needs to be much less than 1.5 to sustain dynamic equilibrium. Recently, Dan Mecklenburg at ODNR has proposed a *3:5:10 Rule* where, in agricultural settings, the flooded width ratio should be at least 3; in urbanizing setting a minimum ratio of 5 is desirable; and in more natural settings a ratio of at least 10 should be sustained. Estimating these ratios requires considerable judgment. In order to provide a constant point of reference we determined width and depth ratios associated with the 0.8-year, 1.6-year, and 50-year RI discharge. For the Olentangy River watershed most bankfull dimensions are associated with a discharge less than the predicted 1.6-year RI discharge and, in some cases, a discharge less than the 0.8-year RI discharge.

Many studies have related bankfull channel dimensions and discharge to drainage area (DA; Ward and Trimble, 2003). Channel width, depth, and cross-sectional area usually can be related to discharge or drainage area as power functions:

$$W = a\ DA^{b} \qquad (4.1)$$

$$D = c\ DA^{d} \qquad (4.2)$$

$$A = e\ DA^{f} \qquad (4.3)$$

These relationships are called regional curves. Bankfull channel width, depth and cross-sectional area, reported in the RRSS, together with the drainage area at each location surveyed were entered into a spreadsheet. A log-log plot was then made of each bankfull dimension versus drainage area. Least squares analysis was then used to fit a regression line through each set of data, and the equation of the line and correlation coefficient (r^2) were recorded. Typically, only data from studies on reaches that are in dynamic equilibrium are used to develop a regional curve (Ward and Trimble, 2003). For the

Olentangy River watershed much of the geomorphology data consisted of a single set of measurements at a cross-section and, in many cases, the stream was somewhat incised or exhibited signs of instability.

In some cases, data collection specifically focused on making assessments at locations where instability might adversely influence aquatic life. Therefore, in developing the regional curves it was necessary to exclude from the analysis sites with poor geomorphology and use an expert knowledge approach to decide whether signs of instability and incision warranted exclusion of sites. Where possible, a *weight of evidence* approach was used and factors such as the relationship between the measured substrate sizes and estimates of the size of particle moved at incipient motion were helpful. At some of our sites no measurements were made of the bed material because it was too deep or material size was too fine to be discernable.

4.1.4 Discharge Relationships

Annual peak discharge data for the USGS gages in the Upper Scioto River watershed were sorted, ranked, and plotted using the Weibull Method (Ward and Trimble, 2003). The data typically yield a linear relationship for the less frequent events (RI > 2 years) and produce an “elbow” tailing down towards zero for the more frequent events (RI < 2 years). Log regression equations were fitted to the data to best represent discharge versus recurrence interval relationships. Regression equations were used to estimate discharge recurrence intervals for bankfull flows at each gage.

Effective discharge at the Higby, Ohio gage was determined based on USGS daily measurements of sediment and discharge. A spreadsheet tool was used to develop a Wolman-Miller model of the geomorphic work (Mecklenburg and Ward, 2004; Ward and Mecklenburg, 2005). Calculating effective discharge values using the Wolman-Miller model requires that bins are comprised of discharges that represent similar flows. The discharge range of each bin was determined using the USGS rating curve for each gage site. A stage interval was set, and all discharges from the rating curve that fell within the first stage interval were grouped by the spreadsheet tool into the first bin. The next bin incorporated all the discharges for the next stage interval. This process was repeated until all discharges were considered. With discharge data divided into bins of similar flows, sediment load data were examined to determine the best representation of sediment transport by discharge. Sediment and discharge data were divided into three groups that were each fitted with a separate regression equation. This technique provides a more accurate functional representation of sediment transport data during the most influential discharges. Because data in the low discharge range had little influence on the effective discharge calculation, the regression equation through low discharge values was eliminated and the middle sediment transport function was extended to create estimates for low discharge conditions. Discharge breakpoints for each range were selected based on visual breaks in the slope of the discharge versus sediment scatter-plot (Simon et al., 2004). The visually-selected breakpoints were then evaluated to provide the best correlation between measured and predicted sediment transport load.

4.1.5 Qualitative Geomorphology Index

To aid in assessing the sites in this study we developed a qualitative geomorphology index based on the factors presented in Table 4.1, which included flooded width ratio associated with the predicted 1.6-year recurrence interval event, relative difference between the measured bankfull cross-sectional area and the area predicted by the regional curve; a measure of the calculated mean particle size at incipient motion and measured D_{50} and D_{84}; stage discharge ratio of the 1.6-year recurrence interval discharge and the bankfull discharge; and a visual assessment of the site. The minimum index score for a site is -3 and the maximum score is a 10.

Table 4.1 Factors used in developing a qualitative geomorphology index for sites in the Olentangy River watershed

Factor	Excellent	Good	Fair	Poor
Flooded width				
Ratio	>3.0	2.5-2.9	2.0-2.4	<2.0
Score	2	1	0	-1
Regional Curve				
Difference from 1.0	<0.2	0.2-0.4	0.4-0.6	>0.6
Score	2	1	0	-1
Shear Stresses				
D_{50} –D_{84}	Similar to D_{50}	Between D_{50} and D_{84}	$<D_{50}$ or $>D_{84}$	n/a
Score	2	1	0	
Stage Discharge				
Ratio	1.0-1.1	1.2-1.3	1.4-1.5	>1.5
Score	2	1	0	-1
Visual Observation				
Score	2	1	0	n/a

4.2 Results

Sites where geomorphology, aquatic life, habitat, or hydrology measurements were made in the Olentangy River watershed are reported in Table 1.1. Geomorphology cross-section or reach measurements were made at a total of 84 sites, which included 28 sites on Thorn Run and Flat Run watersheds. The remaining 58 sites were distributed across the entire watershed. To avoid biasing the results, only 5 of the sites for Flat Run and 2 of the sites for Thorn Run were used in the analysis. Bankfull measurements were made at 8 USGS gages in the Upper Scioto River Basin (the total watershed draining to the gage at Higby, Ohio). A summary of the data for sites used in developing a regional curve are presented in Appendix 4.A.

A regional curve for the Upper Scioto River Basin is shown in Figure 4.2. Data for the two sites (at Chillicothe, Ohio and Higby, Ohio) with drainage areas larger than 1,000 mi^2 are not shown on the plot. We evaluated excluding those two sites from the analysis and found there was an insignificant change in the regional curves. The regional curve is based on 48 of the geomorphology sites and all 8 USGS gages. Sites that appeared to be close to an equilibrium state or had distinct fluvial features associated with recovery were used in the analysis.

Coefficients of determinations (r^2) greater than 0.9 for regional curves are consistent with results commonly obtained from detailed geomorphology studies on high quality reference reaches. Because the regional curve relationships are a power function, this high correlation provides a misleading indicator of how closely the bankfull dimensions at each site fit the regional curve. The mean difference in the observed and predicted bankfull cross-sectional area, width, and depth was 22%, 19%, and 17%, respectively. However, at 7 sites the difference between measured and predicted cross-sectional area was more than 40% - with the biggest difference being 69%. At 3 sites, the difference between measured and predicted bankfull width was more than 40% - with the biggest difference being 76%. At 4 sites, the difference between measured and predicted bankfull depth was more than 40% - with the biggest difference being 49%.

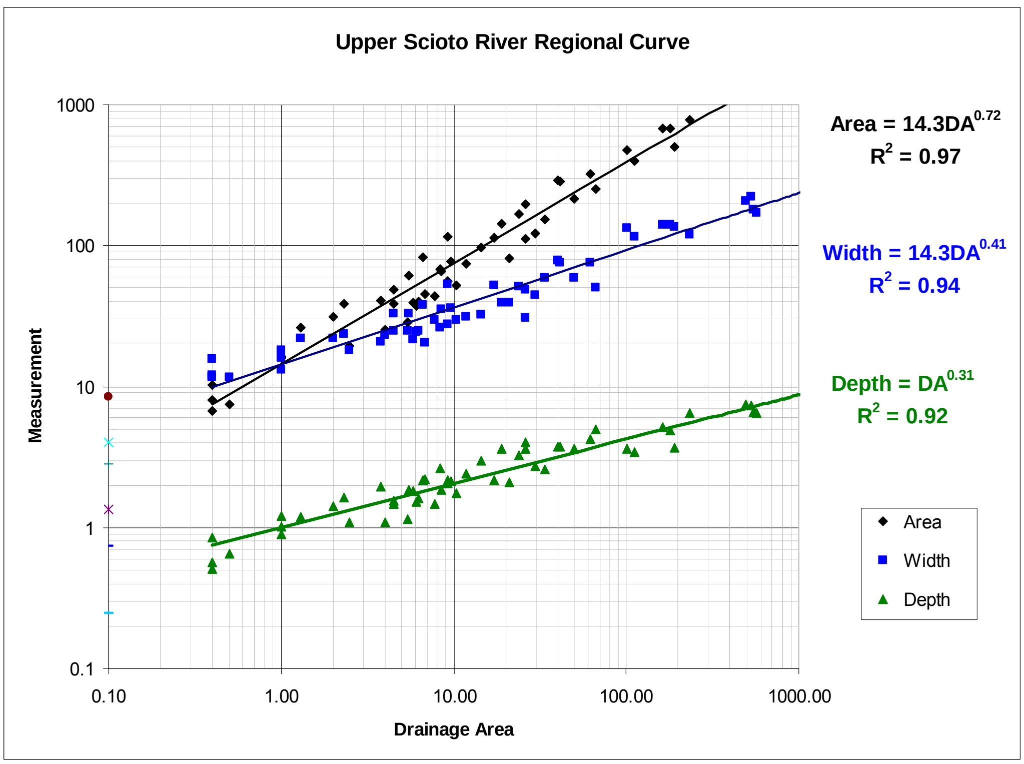


Figure 4.1 Regional curve for the Upper Scioto River basin

Results of the annual peaks series analysis to determine a relationship between bankfull discharge and recurrence interval are presented in Table 4.2. Also reported in Table 4.2 is the effective discharge at the Higby, Ohio gage on the Scioto River (Powell et al., 2005). Gages on the Olentangy River itself were not included in the analysis for a variety of reasons. Discharges at Worthington, Ohio are greatly influenced by the Delaware

Dam. Also, during 2004 a bike path and a bridge were constructed in the vicinity of this gage. The gage at Delaware, Ohio is just downstream of the dam and does not provide representative information on natural flow regimes. The gage at Claridon, Ohio was used to calibrate the USGS peak discharge equations; however, at this location there is a weir and it is unknown what influence it has on bankfull stage.

Table 4.2 Recurrence interval of bankfull discharges at gages in the Upper Scioto River basin

Site	Gage	Drainage Area (mi^2)	Bankfull Discharge (cfs)	Recurrence Interval (years)
Little Darby @ West Jefferson	03230310	162	1500	0.9
Big Walnut @ Central College	03228500	190	1000	0.8
Big Walnut @ Sunbury	03228300	501	2220	0.8
Big Walnut @ Reese	03229500	544	4000	0.9
Big Darby @ Darbyville	03230500	534	4180	1.1
Scioto @ Prospect	03219500	567	3300	0.9
Scioto @ Chillicothe	03231500	3849	14700	1.1
Scioto @ Higby	03234500	5131	27000	1.3
Scioto @ Higby	03234500	5131	18000[1]	1.0

[1] Effective discharge at the USGS gage on the Scioto River at Higby.

Results show that, based on the method used, the recurrence interval of bankfull discharge is 0.8 to 1.3 years. This is consistent with the results reported by Powell et al. (2005) for other rivers in Ohio. Based on other studies we have conducted in Ohio it is probable that low building features, such as benches in agricultural ditches, are associated with more frequent discharges than the 0.8-year RI flows. Care should be taken in interpreting these results as a recent study by the USGS to develop regional curves for Ohio (personal communication, USGS) reported locations where regional curves were related to discharges greater than the 1.3-year RI events. Also, we have made measurements in Ohio on streams where the bankfull discharge is greater than the 1.3-year RI event. However, the results presented in Table 4.2 provide a useful indicator of the probable RI of bankfull discharges in the Olentangy River watershed.

The USGS peak discharge equations for rural areas in Ohio (Koltun and Roberts, 1990; Koltun, 2003) were calibrated against measured discharges at the Claridon, Ohio gage (Table 4.3). There is close agreement between discharges predicted with the USGS Rural Equation and discharges determined based on long-term historic measurements. While there is a trend for the over-prediction to increase as the recurrence interval decreases we did not use the ratios to adjust any predicted values. The reasons for this decision were: (1) the reported mean error in using this method is more than 30%; (2) the method does not consider urbanization; and (3) no information is available on whether the ratios should be adjusted as drainage area changes. For highly urbanized watersheds we used the USGS Urban Equation (Sherwood et al., 1993). Lack of measured data on urban watersheds prevented calibration of that method.

Table 4.3 Measured and predicted discharges for different recurrence intervals at the Claridon, Ohio gage.

Recurrence Interval (years)	Measured Discharge (cfs)	Predicted Discharge (cfs)	Ratio Measured:Predicted
2	3039	4176	0.73
5	5471	6518	0.84
10	7312	8203	0.89
25	9744	10393	0.94
50	11585	12039	0.96
100	13425	13771	0.98

The main purpose in obtaining information on hydrology and stream geomorphology of ditches and streams in the Olentangy River watershed was to identify problem areas and to ascertain if aquatic life and habitat were associated with geomorphology. Results of that analysis are presented in Chapter 5. In order to conduct that analysis, sites were selected in HUCs located on the main tributaries and at several locations along the main stem of the Olentangy River. At each of these sites we identified the stage of the 0.8-year, 1.6-year, and 50-year RI discharges, flooded width and depth ratios were determined, and a qualitative geomorphology index was estimated (Table 4.4).

Detailed summaries for the 36 sites in Table 4.4 are presented in Appendix 4.C. In general, the geomorphology of the watershed is fairly good as many streams have some connection with wooded active floodplains. For all but a few of the sites there were bankfull features associated with predicted discharge having a recurrence interval less than 1.6 years and often less than or similar to 0.8 years. This result is consistent with the recurrence interval of bankfull and effective discharge at the USGS gages (see Table 4.3). At most locations the particle size at incipient motion, calculated based on bankfull depth and bed slopes estimated from the GIS data from the SWAT model, was similar to the measured D_{50} or D_{84}. However, there is evidence of incision at many locations. The frequency of out of bank flows associated with the bankfull discharge is probably declining and, in most locations, the flooded width is much less than desirable for natural stream systems and often less than three times the bankfull width.

Table 4.4 Qualitative assessment of geomorphology of primary sites in the Olentangy River watershed

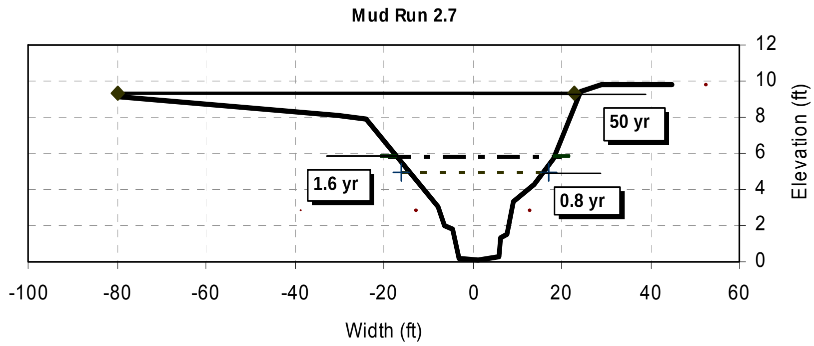
Site	River Mile	Shear Stresses	Regional Curve Ratio	Stage Discharge Ratio	Flooded Ratio	Visual Obs.	Index Score
Adena Brook	0.3	between	2.3	1.2	0.9	good	1
Big Run N Trib	0.5	between	1.8	1.1	1.0	good	2
Big Run S. Trib	1.3	same	1.5	1.4	1.0	good	2
Walhalla Ravine	0.9	larger	1.4	1.2	5.8	good	5
Bee Run	0.1	between	0.8	1.1	9.6	poor	7
Deep Run	0.9	smaller	1.15	1.3	1.8	good	3
Delaware Run	1.2	same	0.9	1.1	2.5	poor	7
E.Br. WC	2.4	same	1.3	1.3	1.0	good	4
Grave Creek	1.4	same	0.7	1.1	1.9	poor	3
Flat Run	0.1	larger	1.5	1.2	1.3	excellent	2
Horseshoe Run	0.9	smaller	0.7	1.1	4.4	good	6
Indian Run	0.9	same	0.7	1.1	4.3	poor	6
Kempton Run	1.1	same	1.7	1.3	1.0	good	2
Fisher Run	1.5	larger	0.7	1.5	1.7	poor	-1
Mill Run	0.9	between	0.5	1.4	1.5	poor	0
Mud Run	2.7	larger	0.6	1.2	1.5	good	1
Norris Run	1.3	between	1.2	1.2	5.2	good	7
Otter Creek	1.1	larger	1.1	1.2	6.8	poor	5
Olentangy River	12.1	larger	1.4	1.3	1.4	good	2
Olentangy River	40.8	same	1.2	1.3	3.9	excellent	9
Olentangy River	45.5	same	1.2	1.3	2.3	good	6
Olentangy River	63.4	larger	0.9	1.2	4.2	good	6
Olentangy River	74.0	--	0.8	1.3	1.2	poor	1*
Olentangy River	84.5	same	1.2	1.3	1.3	excellent	6
Olentangy River	85.2	same	1.5	1.1	4.6	excellent	8
QuaQua Creek	0.1	same	1.1	1.2	2.0	excellent	7
Rocky Fork	4.4	same	1.0	1.2	3.4	excellent	9
Rush Run	1.5	--	0.9	1.2	2.2	poor	3*
Shaw Creek	1.6	larger	0.8	1.6	5.3	good	4
Sugar Run	1.3	smaller	0.9	1.4	2.9	excellent	5
Thorn Run	1.3	same	1.6	1.3	2.7	good	5
Turkey Run	0.7	between	1.5	1.4	1.0	poor	0
Trib to OR 13.3	0.1	between	1.2	1.3	1.0	good	4
Whetstone Creek	2.0	same	0.9	1.4	1.2	good	4
Whetstone Creek	9.2	between	1.2	1.2	1.1	good	4
Whetstone Creek	29.3	between	1.1	1.2	1.2	poor	3

*Does not reflect a score for shear stresses. Index score may actually be higher or lower than what is indicated.

An example of how the data were used is shown in Figure 4.2. Figure 4.2a shows a fairly stable agricultural ditch that is building benches and has a grass buffer. However, the system is much incised, straight, and needs a narrower channel and slightly higher benches to prevent aggradation. Figure 4.2b shows a stream that is well attached to a broad, wooded active floodplain. Bed material size is very consistent with shear stresses associated with the bankfull discharge. Incision is small and bankfull dimensions are similar to those predicted by the regional curve.

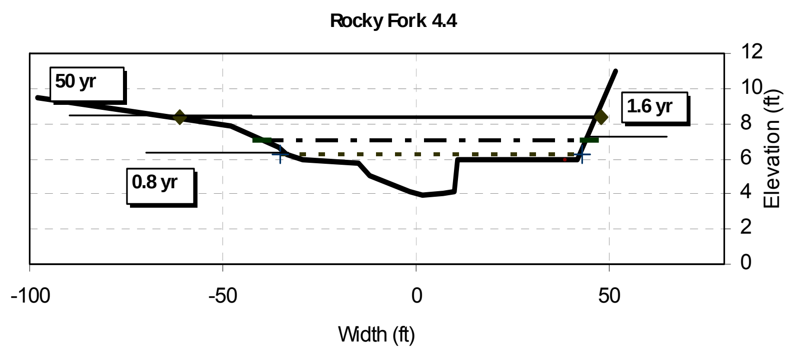
Aggradation occurs in many locations primarily because of structures in the channel such as low rise weirs, bridges and log jams. Most of the small headwater systems are modified channels or agricultural ditches. These systems have a mosaic of small wooded areas with attachment to the floodplain; straight deep ditches flanked by grass buffer strips or row crops that are building benches in the lower half of the ditches; un-maintained ditches, or ditch reaches, that are attempting to recover; and maintained sections with various levels of aggradation depending on the frequency of maintenance. At a few locations cattle grazing caused localized bank instability problems. Periodically within this mosaic, there is evidence of urbanization and commercial activities adversely impacting dynamic equilibrium. At several locations and, in particular, from a few miles north of Delaware, Ohio to the confluence with the Scioto River in the center of Columbus, Ohio, urbanization is the main threat to sustaining equilibrium.

a) Mud Run at river mile 2.7, with poor geomorphology



Site	Shear Stresses	Regional Curve (Fraction)	Stage Discharge Ratio	Floodplain Ratio	Visual Observation	Index Score
Mud Run	larger	0.6	1.2	1.5	good	1

b) Rocky Fork at river mile 4.4, with excellent geomorphology



Site	Shear Stresses	Regional Curve (Fraction)	Stage Discharge Ratio	Floodplain Ratio	Visual Observation	Index Score
Rocky Fork	same	1	1.2	3.4	excellent	9

Figure 4.2 Example of: a) an agricultural ditch with relative poor geomorphology (Geomorphology Index = 1); and b) a stream with excellent geomorphology (Geomorphology Index = 9).

4.3 Uncertainty Associated with Stream Geomorphology and Hydrology Analyses

It is important to understand the limitations and uncertainties associated with regional curves and bankfull discharge estimates. Regional curves are: (1) only useful for streams where dynamic equilibrium is associated with bankfull/effective discharge concepts; (2) a “snapshot in time” and provide little or no information on the evolution state of a reach; (3) on their own, providing no information on how land use change will influence bankfull discharge and dimension; (4) often encompassing several stream types in a single set of curves; (5) at best only providing limited information related to the supply and transport of sediment; (6) providing no information on the floodplain; and (7) in most practical applications, only providing general information on bankfull width and mean depth.

It is perhaps easiest to understand some of the main limitations of regional curves if we consider hydrology, channel hydraulics, and stream geomorphology concepts. Although one of the main factors that influences runoff is land use it is not considered in regional curves. Therefore, we should not expect that bankfull discharge and dimensions would be highly correlated only to drainage area unless land use distributions are similar across the region. Flow velocity and discharge are related to channel bed slope, another factor not considered in regional curves. In cases where regional curve concepts might be useful geomorphology of the stream system is primarily a function of sediment supply and sediment transport. These factors are a function of: (1) shear stresses on the bed and bank; (2) the availability of sufficient attached floodplain to sustain bankfull geometry, pattern and profile; and (3) local and system-wide factors that influence sediment supply and sediment transport. Again, none of these issues are directly considered in regional curves. If we consider stream classification methods, such as the Rosgen stream classification (Ward and Trimble, 2003; Rosgen, 1996), we find that headwater systems often will transition into a different stream type as drainage area increases. For example, in many regions of the United States headwater systems that are an “A”, “B”, or “E” stream type might transition into a “C” stream type. In fact, within a single region we might find the whole alphabet soup of stream types. Most natural systems in the Olentangy River watershed that are near equilibrium are Rosgen type E and C streams.

In addition to the process-related limitations of regional curves a serious problem is the quantitative uncertainty associated with information provided by regional curves. For the Olentangy River watershed, data were obtained at a large number of sites and much of the regional curve development was determined with data from the same sites. Therefore, we were able to directly evaluate differences between measured bankfull dimensions and estimates based on regional curves. However, at some of these sites, and the sites not used in developing the regional curves, data available from the curves only provide general information on problems such as widening and incision. The regional curves provide no information on whether land use change or channel modifications will result in the system moving out of equilibrium or recovering.

Discharge estimates based on the USGS peak discharge methods for Ohio also have much uncertainty associated with them. The methods were developed for watersheds with drainage areas smaller than a few square miles, and the developers of these methods report a mean standard error in the estimate of more than 30%. This is not uncommon for hydrology methods. In this study, we related estimated discharges at the Claridon, Ohio gage to measured values and found good agreement. Also, the consistency of the relationship between bankfull features and predicted 0.8-year to 1.6-year recurrence interval discharges suggest that the hydrology methods are providing useful information. These estimates were closely related to the recurrence interval of channel forming discharges at gages in the region thus providing further evidence of their usefulness.

At each location misleading or incorrect interpretations could occur due to several uncertainties including: (1) incorrect identification of the bankfull feature; (2) an incorrect estimate of the bed slope; (3) an incorrect estimate of the channel roughness; (4) an inability to adequately consider land use differences in each sub-watershed; and (5) an inability to estimate probable impacts of future land use changes. We recommend, therefore, that little importance be placed on the quantitative data and that the results primarily are used to guide future strategies to sustain and enhance these lotic systems.

Appendix 4A
Regional Curve Data Summary

Site Name	Watershed	Survey Type	Drain Area (mi^2)	Area (ft^2)	Width (ft)	Depth (ft)
Trib. to Olentangy River (RM 84.1) 0.6	UO	F	0.4	8.0	15.8	0.5
Walhalla Run 0.9	LO	CS	0.4	10.3	12.0	0.9
Rush Run 1.5	LO	CS	0.5	7.5	11.6	0.7
Trib. to Cox Ditch (RM 0.5) 0.1	WC	CS	1.0	15.9	13.2	1.2
Trib to Olentangy River (RM 13.3) 0.2	LO	CS	1.0	16.2	18.0	0.9
Trib. To Whetstone Creek (RM 28.1) 0.2	WC	F	1.0	16.2	15.9	1.0
Big Run South Trib. 1.3	LO	CS	1.3	26.2	22.0	1.2
Flat Run 20.0	UO	F	2.0	31.2	22.1	1.4
Turkey Run 0.7	LO	CS	2.3	38.5	23.6	1.6
Fisher Run 1.5	LO	CS	2.5	19.5	18.1	1.1
Claypole Run 1.2	WC	CS	3.8	40.5	20.7	2.0
Indian Run 0.9	MO	CS	4.0	25.1	23.0	1.1
East Branch Whetstone Creek 3.0	WC	CS	4.5	48.5	32.8	1.5
Rocky Fork 4.4	UO	CS	4.5	38.5	24.9	1.5
Mitchell Run 0.2	WC	F	5.4	28.4	25.0	1.1
East Branch Whetstone Creek 2.4	WC	CS	5.5	61.7	33.3	1.9
Norris Run 1.3	MO	CS	5.8	60.7	25.3	2.4
Big Run 0.1 (Trib. to Whetstone Creek)	WC	CS	6.1	37.4	24.6	1.5
East Branch Whetstone Creek 0.4	WC	F	6.3	40.1	24.9	1.6
Flat Run 15.5	UO	F	6.6	82.3	37.7	2.2
Bee Run 0.3	MO	CS	6.8	45.1	20.6	2.2
Sams Creek 1.4	WC	CS	7.8	43.4	29.7	1.5
Otter Creek 1.1	MO	CS	8.3	68.6	26.3	2.6
Delaware Run 1.2	MO	CS	8.5	66.3	35.6	1.9
Grave Creek 3.2	MO	CS	9.3	56.0	27.4	2.0
Thorn 1.1	UO	CS	9.3	109.6	48.3	2.3
Thorne Run 0.7	UO	F	9.7	76.9	36.0	2.1
Horseshoe Run 0.9	MO	CS	10.3	52.0	29.6	1.8
Shaw Creek 13.2	WC	CS	11.8	74.8	31.1	2.4
Flat Run 7.3	UO	F	14.4	96.5	32.4	3.0
Qua Qua Creek 0.1	MO	CS	17.1	112.7	52.1	2.2
Whetstone Creek 28.1	WC	CS	19.0	142.3	39.2	3.6
Shaw Creek 5.2	WC	CS	21.1	81.4	39.2	2.1
Olentangy River 84.5	UO	CS	24.0	167.0	51.7	3.2
Shaw Creek 1.6	WC	CS	26.0	111.5	30.6	3.6
Whetstone Creek 25.5	WC	CS	26.0	196.9	48.9	4.0
Flat Run 1.6	UO	F	29.5	122.9	44.7	2.7
Whetstone Creek 22.4	WC	CS	34.0	152.6	59.4	2.6
Whetstone Creek 18.2	WC	CS	40.0	291.3	78.1	3.7
Flat Run 0.1	UO	CS	41.5	286.7	75.9	3.8
Olentangy River 74.0	UO	CS	50.0	173.0	49.2	3.5
Whetstone Creek 9.2	WC	CS	62.0	320.4	75.7	4.2
Olentangy River 63.4	UO	CS	67.0	252.0	50.8	5.0
Big Walnut at Sunbury, Ohio	US	G	101.0	478.8	133.9	3.6
Whetstone Creek 2.0	WC	CS	112.5	397.1	116.0	3.4
Little Darby at West Jefferson, Ohio	US	G	162.0	676.9	140.2	5.1
Olentangy River 45.5	MO	CS	181.0	682.2	140.1	4.9
Big Walnut At Central College, Ohio	US	G	190.0	500.2	135.7	3.7
Olentangy River 40.8	MO	CS	234.0	783.1	119.8	6.5
Olentangy River 12.1	LO	CS	490.0	1538.5	206.6	7.4
Big Darby at Darbyville, Ohio	US	G	534.0	1707.6	224.1	7.3
Big Walnut at Rees, Ohio	US	G	544.0	1264.9	152.2	8.3
Scioto River near Prospect, Ohio	US	G	567.0	1085.2	169.4	6.5
Scioto River at Chillicothe, Ohio	S	G	3849.0	5238.2	462.7	11.8
Scioto River at Higby, Ohio	S	G	5131.0	6877.0	586.6	11.9

Appendix 4B
One-page Summary Tables

Adena Brook 0.3 5060001-120-050

Location: Whetstone Park of Roses northeast of lower parking lot

Major Impairments:
- **Urbanization**
- Point Sources

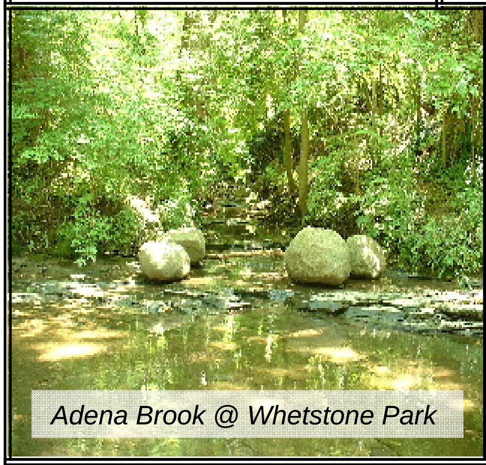
Use Designation: WWH

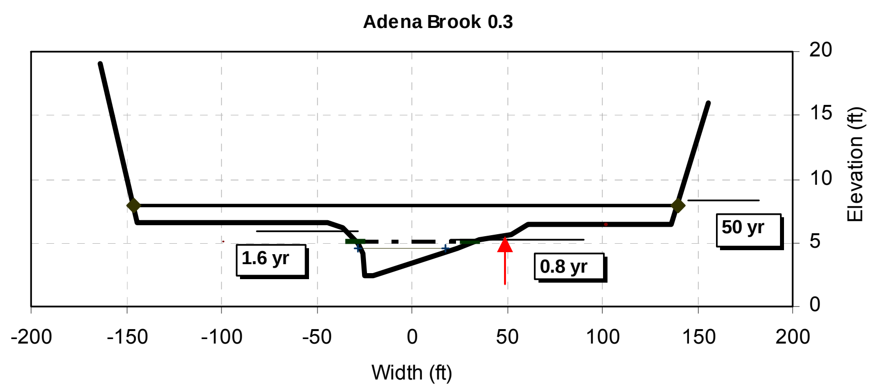
Attainment Status: Unknown

Geomorphology Score: 1

Adena Brook is a high gradient, bedrock controlled stream in a wooded ravine-like landscape bound on both banks by high density residential housing in Columbus, OH. Urbanization and channelization are the primary causes of instability in this sub-watershed.

Adena Brook is 2.3 times larger than the regional channel size. The particle at incipient motion (predicted D50) was calculated to be 42 mm, which is between the measured D50 and D84. The floodplain is much less than the minimum recommended 3 times the bankfull width (1.6 yr RI width ratio). Access to a larger wooded floodplain occurs only during high flows. Adena Brook is over-wide, but there is evidence of a small floodplain building within the channel to regain stability. The bankfull feature indicated by the arrow below has a small functional fluvial influence on equilibrium and is consistent with visual observations. Predicted water quality is good but lack specific details on urban impacts so actual concentrations might be higher.





Channel Dimensions		Flood Dimensions		Materials	
102.8	*X-section area (ft.sq.)*	286.4	*W flood prone area (ft)*	28	*D50 Riffle (mm)*
66.6	*Width (ft)*	4.3	*Entrenchment ratio*	87	*D84 Riffle (mm)*
1.5	*Mean depth (ft)*	4.6	*0.8 yr RI Elevation (ft)*	**Regional Channel Size**	
2.9	*Max depth (ft)*	0.7	*0.8 yr RI width ratio*	2.3	*Size ratio*
67.9	*Wetted perimeter (ft)*	5.1	*1.6 yr RI Elevation (ft)*	2.4	*W-D Proportion*
1.5	*Hyd radi (ft)*	0.9	*1.6 yr RI width ratio*	1.1	*Slope (%, SWAT)*
43.2	*Width-depth ratio*	7.9	*50 yr RI Elevation (ft)*	**Stage Discharge Ratios**	
		4.3	*50 yr RI width ratio*	1.2	*$Q_{1.6}$ ratio*
				2.5	*Q_{50} ratio*

(1.6 yr RI assumed to be upper limit of bankfull elevation; based on bench below right bank, see arrow)

Numeric Estimates and Target Reductions for biological, habitat, and water quality parameters

Current Estimate/ Target Reduction	*DA (mi^2)*	*ICI[a]*	*IBI[b]*	*QHEI[c]*	*Water Quality (flow weighted average)* TP (mg/L) NP[d]	TP (mg/L) Total[e]	Nitrate (mg/L) NP	Nitrate (mg/L) Total	TSS (mg/L) NP	TSS (mg/L) Total
Current	5.0	Not surveyed in 2003-04			0.06	0.06	3.0	3.0	18	18
Target 1[f] Reduction/Improvement					--	--	2.0	2.0	9	9
Target 2[g] Reduction					--	--	1.0	1.0	--	--

[a] OEPA target ICI scores: EWH ≥ 42; WWH ≥ 32
[b] OEPA target IBI scores: EWH ≥ 46; WWH ≥ 36
[c] OEPA target QHEI scores: EWH ≥ 75; WWH ≥ 60
[d] NP reduction only needed if point sources are meeting the target
[e] Total is required if it's a collective reduction strategy.
[f] Target 1= OEPA less than 20 sq. mi.
[g] Target 2= WWH less than 200 sq. mi.

Bee Run 0.3 5060001-110-010

Location: Whetstone River Road

Major Impairments:

- Siltation
- **Habitat Alteration**
- Nutrient Enrichment

Use Designation: WWH

Attainment Status: Partial

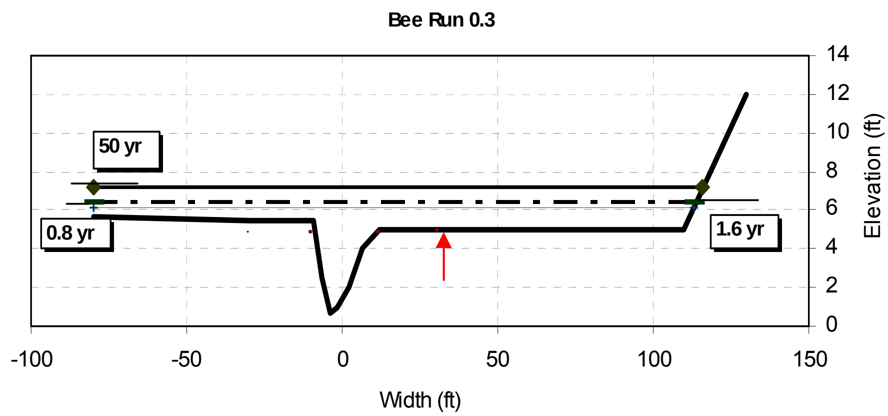
Geomorphology Score: 7

Bee Run is an agricultural ditch bound on both sides by row crops.

Bee Run is 0.8 times the regional channel size. The particle at incipient motion (predicted D50) was calculated to be 5.6 mm, which is between the measured D50 and D84. The floodplain at this location is much larger than the minimum recommended 3 times the bankfull width (1.6 yr RI width ratio).

The bankfull feature indicated by the arrow below has a functional fluvial influence on equilibrium and is consistent with visual observations. Bee Run is more sinuous than the photo below would suggest. The location evaluated is in a pasture just before the confluence. This location is not representative of the whole ditch. The ditch has siltation problems in the headwaters, is incised, and has built low benches in places. A more representative geomorphology score would be close to 4.

Bee Run @ Whetstone River Rd.



Channel Dimensions		Flood Dimensions		Materials	
45.1	*X-section area (ft.sq.)*	--	*W flood prone area (ft)*	1.6	*D50 Riffle (mm)*
20.6	*Width (ft)*	--	*Entrenchment ratio*	7.6	*D84 Riffle (mm)*
2.2	*Mean depth (ft)*	6.1	*0.8 yr RI Elevation (ft)*	**Regional Channel Size**	
4.3	*Max depth (ft)*	9.6	*0.8 yr RI width ratio*	0.8	*Size ratio*
23.0	*Wetted perimeter (ft)*	6.4	*1.6 yr RI Elevation (ft)*	0.5	*W-D Proportion*
2.0	*Hyd radi (ft)*	9.6	*1.6 yr RI width ratio*	0.1	*Slope (%)*
9.4	*Width-depth ratio*	7.2	*50 yr RI Elevation (ft)*	**Stage Discharge Ratios**	
		9.7	*50 yr RI width ratio*	1.1	$Q_{1.6}$ *ratio*
				1.2	Q_{50} *ratio*
(based on floodplain on right bank, indicated by arrow)					

Numeric Estimates and Target Reductions for biological, habitat, and water quality parameters										
Current Estimate/ Target Reduction	***DA (mi^2)***	***ICI[a]***	***IBI[b]***	***QHEI[c]***	***Water Quality (flow weighted average)***					
					TP (mg/L)		***Nitrate (mg/L)***		***TSS (mg/L)***	
					NP[d]	**Total[e]**	**NP**	**Total**	**NP**	**Total**
Current	6.8	--	38	59	0.39	0.39	6.0	6.0	292	292
Target 1[f] Reduction/Improvement		--	--	1	0.32	0.32	5.0	5.0	283	283
Target 2[g] Reduction					0.23	0.23	4.0	4.0	212	212

[a] OEPA target ICI scores: EWH ≥ 42; WWH ≥ 32
[b] OEPA target IBI scores: EWH ≥ 46; WWH ≥ 36
[c] OEPA target QHEI scores: EWH ≥ 75; WWH ≥ 60
[d] NP reduction only needed if point sources are meeting the target.
[e] Total is required if it's a collective reduction strategy.
[f] Target 1= OEPA less than 20 sq. mi.
[g] Target 2= WWH less than 200 sq. mi.

Big Run North Tributary 0.5 5060001-120-020

Location: Upstream of confluence with Olentangy River at river mile 18.19

Major Impairments:

- Siltation
- **Urbanization**
- Nutrient Enrichment

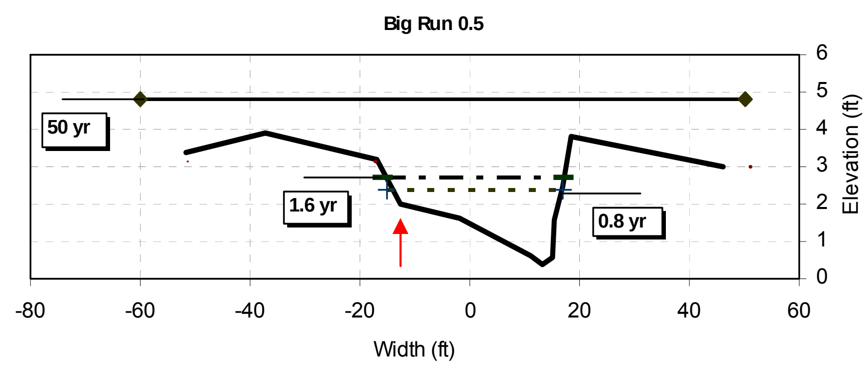
Use Designation: WWH

Attainment Status: Unknown

Geomorphology Score: 2

Big Run North Tributary (NT) is located south of Delaware, OH in a rapidly urbanizing landscape. This high gradient, bedrock controlled stream in a wooded ravine-like landscape currently is slated for medium-density residential development. Urbanization is the primary causes of instability in this sub-watershed.

Big Run NT is 1.8 times larger than the regional channel size. The particle at incipient motion (predicted D50) was calculated to be 34.5mm, which is between the measured D50 and D84. The floodplain is much smaller than the minimum recommended 3 times the bankfull width (1.6 yr RI width ratio). Big Run NT is incised and over-wide, and does not have an attached floodplain. Instability is likely to increase because of pending development. The bankfull feature indicated by the vertical arrow below has a small functional fluvial influence on equilibrium and is consistent with visual observations. The black horizontal arrow might be the location at which the bank should be located.



Channel Dimensions		Flood Dimensions		Materials	
57.9	*X-section area (ft.sq.)*	95.8	*W flood prone area (ft)*	27	*D50 Riffle (mm)*
34.8	*Width (ft)*	4.3	*Entrenchment ratio*	80	*D84 Riffle (mm)*
1.7	*Mean depth (ft)*	2.4	*0.8 yr RI Elevation (ft)*	**Regional Channel Size**	
2.8	*Max depth (ft)*	0.9	*0.8 yr RI width ratio*	1.8	*Size ratio*
36.3	*Wetted perimeter (ft)*	2.7	*1.6 yr RI Elevation (ft)*	1.2	*W-D Proportion*
1.6	*Hyd radi (ft)*	1.0	*1.6 yr RI width ratio*	0.8	*Slope (%, measured)*
20.9	*Width-depth ratio*	4.8	*50 yr RI Elevation (ft)*	**Stage Discharge Ratios**	
		3.2	*50 yr RI width ratio*	1.1	*$Q_{1.6}$ ratio*
				2.2	*Q_{50} ratio*

(1.6 yr RI assumed to be upper limit of bankfull elevation; based on grade break below top of left bank, indicated by the vertical arrow)

Numeric Estimates and Target Reductions for biological, habitat, and water quality parameters

Current Estimate/ Target Reduction	*DA (mi^2)*	*ICI[a]*	*IBI[b]*	*QHEI[c]*	*Water Quality (flow weighted average)*					
					TP (mg/L)		*Nitrate (mg/L)*		*TSS (mg/L)*	
					NP[d]	**Total[e]**	**NP**	**Total**	**NP**	**Total**
Current	3.1	Not surveyed in 2003-04			0.20	0.20	1.2	1.2	263	263
Target 1[f] Reduction/Improvement					0.13	0.13	0.2	0.2	254	254
Target 2[g] Reduction					0.04	0.04	--	--	83	83

[a] OEPA target ICI scores: EWH ≥ 42; WWH ≥ 32
[b] OEPA target IBI scores: EWH ≥ 46; WWH ≥ 36
[c] OEPA target QHEI scores: EWH ≥ 75; WWH ≥ 60
[d] NP reduction only needed if point sources are meeting the target.
[e] Total is required if it's a collective reduction strategy.
[f] Target 1= OEPA less than 20 sq. mi.
[g] Target 2= WWH less than 200 sq. mi.

Big Run South Tributary 1.3 5060001-120-020

Location: Upstream of Taggert Road

Major Impairments:

- Siltation
- **Urbanization**
- Nutrient Enrichment

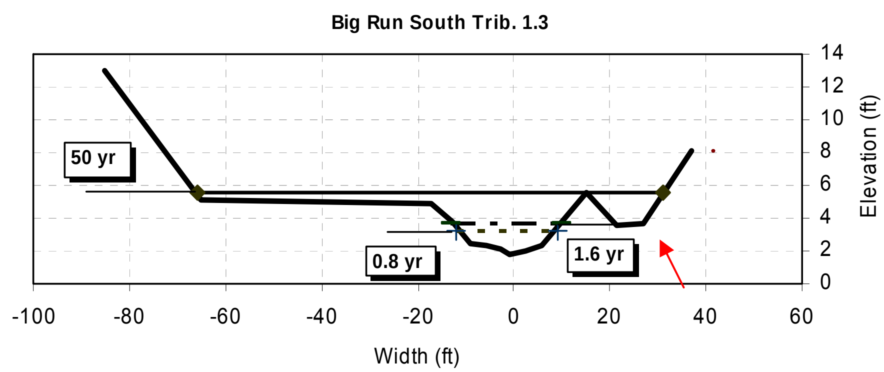
Use Designation: WWH

Attainment Status: Unknown

Geomorphology Score: 2

Big Run South Tributary (ST) is located south of Delaware, OH in a rapidly urbanizing landscape. This high gradient, bedrock controlled stream in a wooded ravine-like landscape currently is slated for medium-density residential development. Urbanization is the primary causes of instability in this sub-watershed.

Big Run ST is 1.5 times larger than the regional channel size. The particle at incipient motion (predicted D50) was calculated to be 24.4 mm, which is similar to the measured D50. The floodplain is much smaller than the minimum recommended 3 times the bankfull width (1.6 yr RI width ratio). Access to the floodplain only occurs during high flows. Big Run is incised and over-wide, and does not have an attached floodplain. Instability is likely to increase because of urbanization, and biology is threatened as Big Run ST becomes more detached from the main channel. The bankfull feature indicated by the arrow below has a small functional fluvial influence on equilibrium and is consistent with visual observations. Actual water quality concentrations are unlikely to represent current conditions because of the ongoing urbanization.



Channel Dimensions		Flood Dimensions		Materials	
26.2	*X-section area (ft.sq.)*	95.8	*W flood prone area (ft)*	27	*D50 Riffle (mm)*
22.0	*Width (ft)*	4.3	*Entrenchment ratio*	80	*D84 Riffle (mm)*
1.2	*Mean depth (ft)*	3.2	*0.8 yr RI Elevation (ft)*	**Regional Channel Size**	
1.8	*Max depth (ft)*	1.0	*0.8 yr RI width ratio*	1.5	*Size ratio*
22.5	*Wetted perimeter (ft)*	3.7	*1.6 yr RI Elevation (ft)*	1.2	*W-D Proportion*
1.2	*Hyd radi (ft)*	1.0	*1.6 yr RI width ratio*	0.8	*Slope (%, measured)*
18.5	*Width-depth ratio*	5.6	*50 yr RI Elevation (ft)*	**Stage Discharge Ratios**	
		4.4	*50 yr RI width ratio*	1.4	*$Q_{1.6}$ ratio*
				2.7	*Q_{50} ratio*

(1.6 yr RI assumed to be upper limit of bankfull elevation; based on right bank floodplain, indicated by arrow)

Numeric Estimates and Target Reductions for biological, habitat, and water quality parameters

Current Estimate/ Target Reduction	*DA (mi^2)*	*ICI[a]*	*IBI[b]*	*QHEI[c]*	*Water Quality (flow weighted average)*					
					TP (mg/L)		*Nitrate (mg/L)*		*TSS (mg/L)*	
					NP[d]	Total[e]	NP	Total	NP	Total
Current	1.3	Not surveyed in 2003-04			0.19	0.19	1.3	1.3	258	258
Target 1[f] Reduction/Improvement					0.12	0.12	0.3	0.3	249	249
Target 2[g] Reduction					0.03	0.03	--	--	178	178

[a] OEPA target ICI scores: EWH ≥ 42; WWH ≥ 32
[b] OEPA target IBI scores: EWH ≥ 46; WWH ≥ 36
[c] OEPA target QHEI scores: EWH ≥ 75; WWH ≥ 60

[e] Total is required if it's a collective reduction strategy.
[f] Target 1=OEPA less than 20 sq. mi.
[g] Target 2= WWH less than 200 sq. mi.

Deep Run 1.1/0.9 5060001-120-020

Location: West of State Route 23 near Orange Road

Major Impairments:

- Habitat Alteration
- Urbanization
- Nutrient Enrichment

Use Designation: WWH

Attainment Status: Non

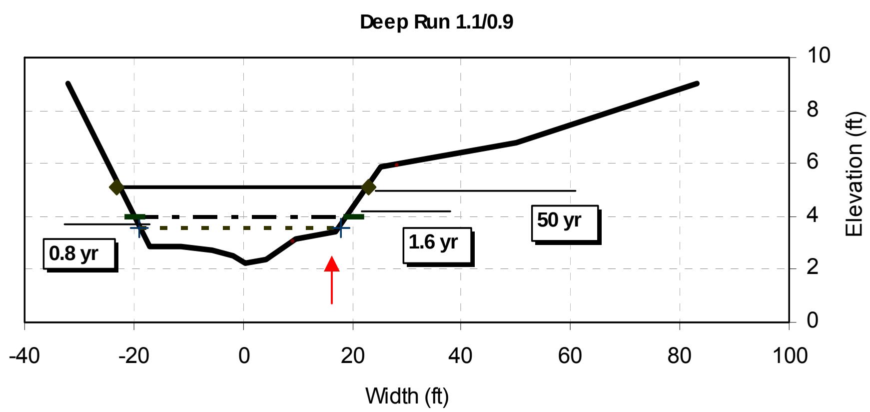
Geomorphology Score: 3

Deep Run is a high gradient, bedrock controlled stream in a wooded ravine-like landscape located south of Delaware, OH in a medium density residential landscape that is rapidly urbanizing.

Deep Run is 0.9 times the regional channel size. The particle at incipient motion (predicted D50) was calculated to be 9.1 mm, which is much smaller than the measured D50. It has an extensive, well-attached floodplain that is nearly 3 times greater than the recommended 3 times the bankfull width (1.6 yr RI width ratio)

The bankfull feature indicated by the arrow below does not have a large functional fluvial influence on equilibrium but is consistent with visual observations. The possible reasons for this include: the benches are trying to build up to regain stability; the stream wants to establish floodplain between the lower bench and the top of the floodplain; or the slope given by the SWAT model is inaccurate.

Deep Run @ Sweetwater Ct.



Channel Dimensions		Flood Dimensions		Materials	
9.2	*X-section area (ft.sq.)*	38.9	*W flood prone area (ft)*	26	*D50 Riffle (mm)*
15.1	*Width (ft)*	2.6	*Entrenchment ratio*	79	*D84 Riffle (mm)*
0.6	*Mean depth (ft)*	3.6	*0.8 yr RI Elevation (ft)*	**Regional Channel Size**	
0.9	*Max depth (ft)*	2.5	*0.8 yr RI width ratio*	0.9	*Size ratio*
15.2	*Wetted perimeter (ft)*	4.0	*1.6 yr RI Elevation (ft)*	1.7	*W-D Proportion*
0.6	*Hyd radi (ft)*	2.7	*1.6 yr RI width ratio*	0.6	*Slope (%, SWAT)*
24.9	*Width-depth ratio*	5.1	*50 yr RI Elevation (ft)*	**Stage Discharge Ratios**	
		3.1	*50 yr RI width ratio*	1.3	*$Q_{1.6}$ ratio*
				1.9	*Q_{50} ratio*

(1.6 yr RI assumed to be upper limit of bankfull elevation; based lower bench indicated by arrow)

Numeric Estimates and Target Reductions for biological, habitat, and water quality parameters

Current Estimate/ Target Reduction	*DA (mi^2)*	*ICI[a]*	*IBI[b]*	*QHEI[c]*	*Water Quality (flow weighted average)* Nitrate (mg/L) NP[d]	Nitrate (mg/L) Total[e]	TP (mg/L) NP	TP (mg/L) Total	TSS (mg/L) NP	TSS (mg/L) Total
Current	0.6	0	22	48	n/a	n/a	n/a	n/a	n/a	n/a
Target 1[f] Reduction/Improvement		32	14	12						
Target 2[g] Reduction										

[a] OEPA target ICI scores: EWH ≥ 42; WWH ≥ 32
[b] OEPA target IBI scores: EWH ≥ 46; WWH ≥ 36
[c] OEPA target QHEI scores: EWH ≥ 75; WWH ≥ 60
[d] NP reduction only needed if point sources are meeting the target
[e] Total is required if it's a collective reduction strategy.
[f] Target 1= OEPA less than 20 sq. mi.
[g] Target 2= WWH less than 200 sq. mi.

Delaware Run 1.2 5060001-110-110

Location: Blue Limestone Park in Delaware, OH

Major Impairments:

- Habitat Alteration
- **Urbanization**
- Nutrient Enrichment

Use Designation: WWH
Attainment Status: Unknown
Geomorphology Score: 7

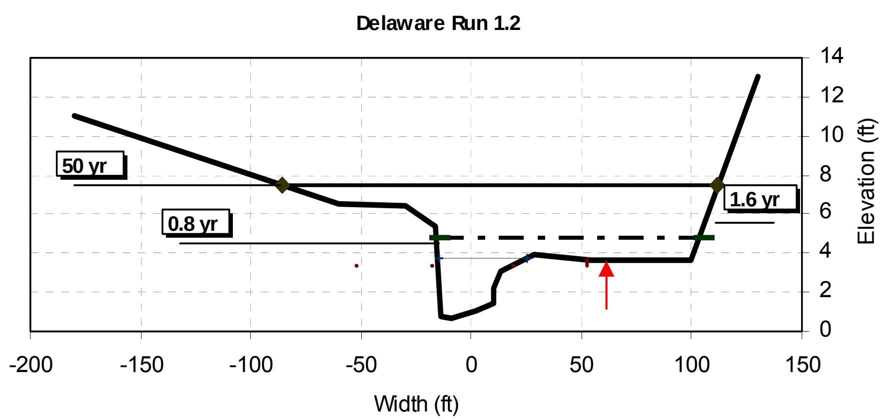
Management Strategies:

Delaware Run joins the Olentangy River at river mile 25.7 and runs through the city of Delaware, OH, which is rapidly urbanizing. Small rock dam and a log jam downstream backing up water as it flows from the tunnel. In this section, the banks are straightened and hardened.

Delaware Run is 0.9 times smaller than the regional channel size. The particle at incipient motion (predicted D50) was calculated to be 33.7 mm, which is similar to the measured D50. It has a well-attached floodplain that is less than the minimum recommended 3 times the bankfull width (1.6 yr RI width ratio).

The bankfull feature indicated by the arrow below has a functional fluvial influence on equilibrium and is consistent with visual observations.
However, the stability of Delaware Run will likely diminish rapidly as urbanization increases.

Delaware Run @ Blue Limestone Park



Channel Dimensions		Flood Dimensions		Materials	
66.3	*X-section area (ft.sq.)*	135.6	*W flood prone area (ft)*	30	*D50 Riffle (mm)*
35.6	*Width (ft)*	3.8	*Entrenchment ratio*	70	*D84 Riffle (mm)*
1.9	*Mean depth (ft)*	2.9	*0.8 yr RI Elevation (ft)*	**Regional Channel Size**	
2.8	*Max depth (ft)*	1.1	*0.8 yr RI width ratio*	0.9	*Size ratio*
38.1	*Wetted perimeter (ft)*	3.2	*1.6 yr RI Elevation (ft)*	1.7	*W-D Proportion*
1.7	*Hyd radi (ft)*	2.5	*1.6 yr RI width ratio*	0.7	*Slope (%, measured)*
19.1	*Width-depth ratio*	4.1	*50 yr RI Elevation (ft)*	**Stage Discharge Ratios**	
		2.6	50 yr RI width ratio	1.1	*$Q_{1.6}$ ratio*
				1.5	*Q_{50} ratio*

(1.6 yr RI assumed to be upper limit of bankfull elevation; based on right bank floodplain, indicated by arrow)

Numeric Estimates and Target Reductions for biological, habitat, and water quality parameters

Current Estimate/ Target Reduction	*DA (mi^2)*	*ICI[a]*	*IBI[b]*	*QHEI[c]*	*TP (mg/L)* NP[d]	*TP (mg/L)* Total[e]	*Nitrate (mg/L)* NP	*Nitrate (mg/L)* Total	*TSS (mg/L)* NP	*TSS (mg/L)* Total
Current	8.5	Not surveyed in 2003-04			0.20	0.20	1.4	1.4	195	195
Target 1[f] Reduction/Improvement					0.13	0.13	0.4	0.4	186	186
Target 2[g] Reduction					0.04	0.04	--	--	115	115

Water Quality (flow weighted average) applies to TP, Nitrate and TSS columns.

[a] OEPA target ICI scores: EWH ≥ 42; WWH ≥ 32
[b] OEPA target IBI scores: EWH ≥ 46; WWH ≥ 36
[c] OEPA target QHEI scores: EWH ≥ 75; WWH ≥ 60
[d] NP reduction only needed if point sources are meeting the target.
[e] Total is required if it's a collective reduction strategy.
[f] Target 1=OEPA less than 20 sq. mi.
[g] Target 2=OSU WWH less than 200 sq. mi.

East Branch of Whetstone Creek 2.4 5060001-100-010

Location: North side of Marion Williamsport Road at State Route 19

Major Impairments:

- Habitat Alteration
- Siltation
- Nutrient Enrichment

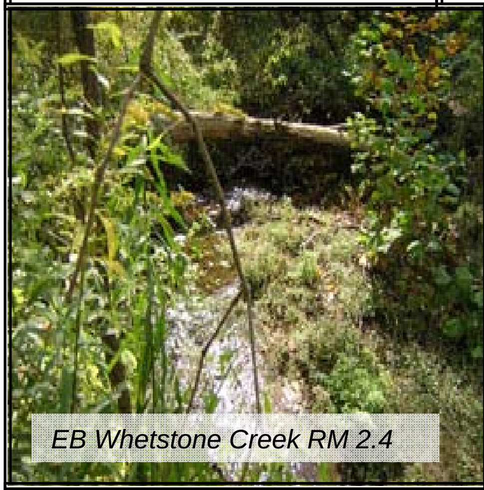
Use Designation: WWH

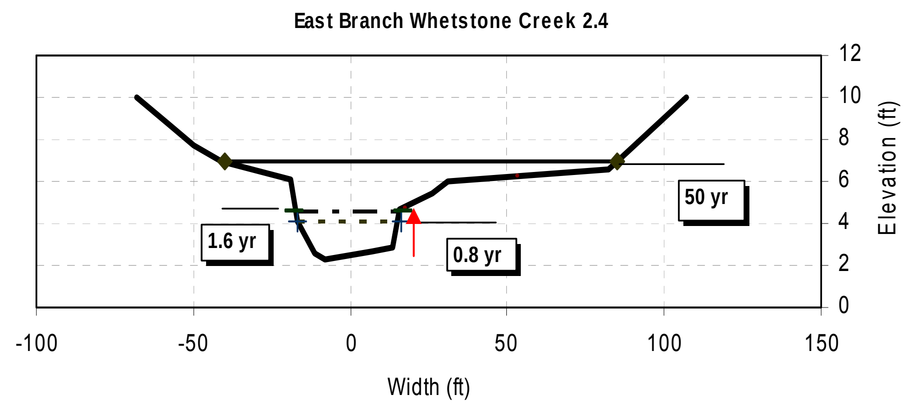
Attainment Status: Unknown

Geomorphology Score: 4

East Branch of Whetstone Creek (EBWC) at river mile 2.4 is 1.3 times larger than the regional channel size. The particle at incipient motion (predicted D50) was calculated to be 29 mm, which is similar to the measured D50. The floodplain is much less than the minimum recommended 3 times the bankfull width (1.6 yr RI width ratio). Access to a larger wooded floodplain occurs only during high flows.

EBWC is incised and slightly over-wide. The bankfull feature indicated by the arrow below has a small functional fluvial influence on equilibrium and is consistent with visual observations. Upstream of this location, the stream becomes narrower as it winds through a wooded area. Water quality concentrations might be higher than predicted.





Channel Dimensions		Flood Dimensions		Materials	
61.7	*X-section area (ft.sq.)*	127.3	*W flood prone area (ft)*	25	*D50 Riffle (mm)*
33.3	*Width (ft)*	3.8	*Entrenchment ratio*	120	*D84 Riffle (mm)*
1.9	*Mean depth (ft)*	4.1	*0.8 yr RI Elevation (ft)*	**Regional Channel Size**	
2.4	*Max depth (ft)*	1.0	*0.8 yr RI width ratio*	1.3	*Size ratio*
34.3	*Wetted perimeter (ft)*	4.6	*1.6 yr RI Elevation (ft)*	1	*W-D Proportion*
1.8	*Hyd radi (ft)*	1.0	*1.6 yr RI width ratio*	0.6	*Slope (%, SWAT)*
17.9	*Width-depth ratio*	7.0	*50 yr RI Elevation (ft)*	**Stage Discharge Ratios**	
		3.7	*50 yr RI width ratio*	1.3	*$Q_{1.6}$ ratio*
				2.6	*Q_{50} ratio*

(1.6 yr RI assumed to be upper limit of bankfull elevation; based on lower grade break below top of right bank, indicated by arrow)

Numeric Estimates and Target Reductions for biological, habitat, and water quality parameters

Current Estimate/ Target Reduction	*DA (mi^2)*	*ICI[a]*	*IBI[b]*	*QHEI[c]*	*Water Quality (flow weighted average)* TP (mg/L) NP[d]	TP (mg/L) Total[e]	Nitrate (mg/L) NP	Nitrate (mg/L) Total	TSS (mg/L) NP	TSS (mg/L) Total
Current	5.5	Not surveyed in 2003-04			0.09	0.09	1.7	1.7	118	118
Target 1[f] Reduction/Improvement					0.02	0.02	0.7	0.7	109	109
Target 2[g] Reduction					--	--	--	--	38	38

[a] OEPA target ICI scores: EWH ≥ 42; WWH ≥ 32
[b] OEPA target IBI scores: EWH ≥ 46; WWH ≥ 36
[c] OEPA target QHEI scores: EWH ≥ 75; WWH ≥ 60
[d] NP reduction only needed if point sources are meeting the target.
[e] Total is required if it's a collective reduction strategy.
[f] Target 1= OEPA less than 20 sq. mi.
[g] Target 2= WWH less than 200 sq. mi.

Fisher Run 1.5 5060001-120-030

Location: East side of Worthington Kilbourne High School

Major Impairments:

- Siltation
- Habitat Alteration
- **Urbanization**
- Nutrient Enrichment

Use Designation: WWH

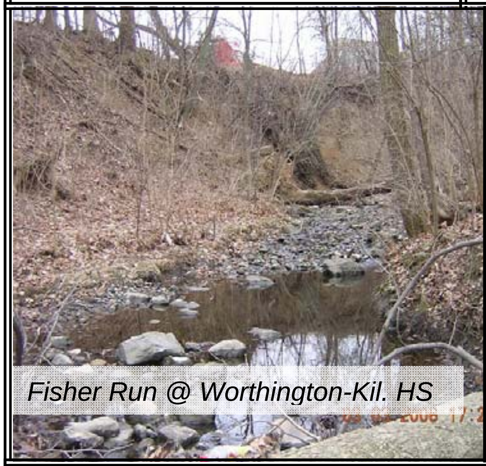
Attainment Status: Unknown

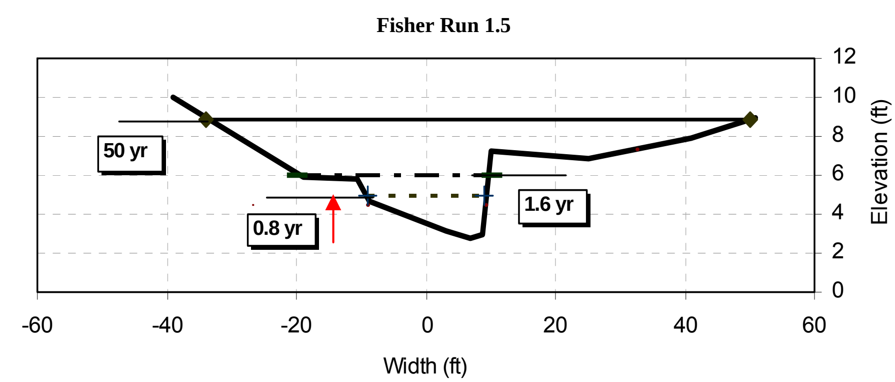
Geomorphology Score: -1

Fisher Run is located in Worthington, OH in a medium/high density residential area. This high gradient stream in a wooded ravine-like runs through several new and existing subdivisions before it enters the Olentangy River. Urbanization is the primary threat to this stream.

Fisher Run is 0.7 times smaller than the regional channel size. The particle at incipient motion (predicted D50) was calculated to be 53 mm, which is larger than the measured D50 and D84. The available floodplain is half the minimum recommended 3 times the bankfull width (1.6 yr RI width ratio), but has access to a larger floodplain during high flows.

Fisher Run is incised. There is evidence of building small floodplains within the channel to re-establish equilibrium. The bankfull feature indicated by the arrow below does not have functional fluvial influence on equilibrium but is consistent with visual observations.





Channel Dimensions		Flood Dimensions		Materials	
19.5	*X-section area (ft.sq.)*	31.9	*W flood prone area (ft)*	17	*D50 Riffle (mm)*
18.1	*Width (ft)*	1.8	*Entrenchment ratio*	43	*D84 Riffle (mm)*
1.1	*Mean depth (ft)*	5.0	*0.8 yr RI Elevation (ft)*	**Regional Channel Size**	
1.9	*Max depth (ft)*	1.0	*0.8 yr RI width ratio*	0.7	*Size ratio*
19.4	*Wetted perimeter (ft)*	6.0	*1.6 yr RI Elevation (ft)*	1	*W-D Proportion*
1.0	*Hyd radi (ft)*	1.7	*1.6 yr RI width ratio*	1.9	*Slope (%, measured)*
16.8	*Width-depth ratio*	8.9	*50 yr RI Elevation (ft)*	**Stage Discharge Ratios**	
		4.7	*50 yr RI width ratio*	1.5	*$Q_{1.6}$ ratio*
				2.8	*Q_{50} ratio*

(1.6 yr RI assumed to be upper limit of bankfull elevation; based on left bank, indicated by arrow)

Numeric Estimates and Target Reductions for biological, habitat, and water quality parameters										
Current Estimate/ Target Reduction	***DA (mi^2)***	***ICI[a]***	***IBI[b]***	***QHEI[c]***	***Water Quality (flow weighted average)***					
					TP (mg/L)		***Nitrate (mg/L)***		***TSS (mg/L)***	
					NP[d]	**Total[e]**	**NP**	**Total**	**NP**	**Total**
Current	2.5	Not surveyed in 2003-04			0.07	0.07	7.2	7.2	19	19
Target 1[f] Reduction/Improvement					--	--	6.2	6.2	10	10
Target 2[g] Reduction					--	--	5.2	5.2	--	--

[a] OEPA target ICI scores: EWH ≥ 42; WWH ≥ 32
[b] OEPA target IBI scores: EWH ≥ 46; WWH ≥ 36
[c] OEPA target QHEI scores: EWH ≥ 75; WWH ≥ 60
[d] NP reduction only needed if point sources are meeting the target.
[e] Total is required if it's a collective reduction strategy.
[f] Target 1= OEPA less than 20 sq. mi.
[g] Target 2= WWH less than 200 sq. mi.

Flat Run 0.1 **5060001-090-040**

Location: Downstream of West Canaan Road

Major Impairments:

- **Habitat Alteration**
- Siltation
- Nutrient Enrichment

Use Designation: WWH

Attainment Status: Full

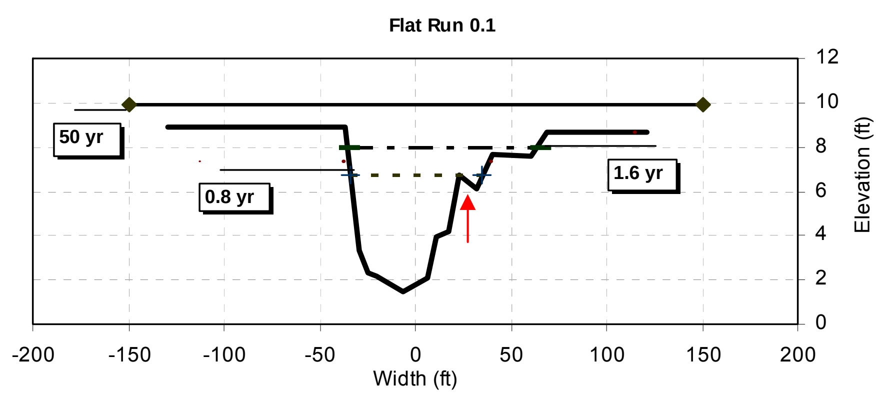
Geomorphology Score: 2

Flat Run at river mile 0.1 is essentially an un-maintained agricultural ditch flanked on both sides by row crops.

Flat Run is 1.5 times larger than the regional channel size. The particle at incipient motion (predicted D50) was calculated to be 58 mm, which is much larger than the measured D50 and D84. It has access to a floodplain that is less than half of the minimum recommended 3 times as wide as the bankfull width (1.6 yr RI width ratio). Flat Run is deeply incised, but there is evidence of floodplain building within the existing channel as indicated by the arrow below.

Though it is difficult to predict with certainty given that Flat Run is a ditch and is highly unstable, it is trying to become more shallow and wider than it is now. The bankfull feature indicated by the arrow below does not have a functional fluvial influence on equilibrium but is consistent with visual observations. Water quality estimates seem reasonable but could be higher.

No Photo Available



Channel Dimensions		Flood Dimensions		Materials	
286.7	*X-section area (ft.sq.)*	660.4	*W flood prone area (ft)*	16	*D50 Riffle (mm)*
75.9	*Width (ft)*	2.9	*Entrenchment ratio*	31	*D84 Riffle (mm)*
3.8	*Mean depth (ft)*	6.7	*0.8 yr RI Elevation (ft)*	**Regional Channel Size**	
6.2	*Max depth (ft)*	0.9	*0.8 yr RI width ratio*	1.5	*Size ratio*
78.5	*Wetted perimeter (ft)*	8.0	*1.6 yr RI Elevation (ft)*	0.9	*W-D Proportion*
3.7	*Hyd radi (ft)*	1.3	*1.6 yr RI width ratio*	0.6	*Slope (%, measured)*
20.1	*Width-depth ratio*	9.9	*50 yr RI Elevation (ft)*	**Stage Discharge Ratios**	
		4.0	*50 yr RI width ratio*	1.2	*$Q_{1.6}$ ratio*
				1.6	*Q_{50} ratio*

(1.6 yr RI assumed to be upper limit of bankfull elevation; based on lower bench on right bank, indicated by arrow)

Numeric Estimates and Target Reductions for biological, habitat, and water quality parameters

Current Estimate/ Target Reduction	*DA (mi^2)*	*ICI*[a]	*IBI*[b]	*QHEI*[c]	*Water Quality (flow weighted average)*					
					TP (mg/L)		*Nitrate (mg/L)*		*TSS (mg/L)*	
					NP[d]	Total[e]	NP	Total	NP	Total
Current	41.5	--	46	77.5	0.37	0.37	2.9	2.9	192	192
Target 1[f] Reduction/Improvement		--	--	--	0.26	0.26	1.9	1.9	161	161
Target 2[g] Reduction					0.21	0.21	0.9	0.9	112	112

[a] OEPA target ICI scores: EWH ≥ 42; WWH ≥ 32
[b] OEPA target IBI scores: EWH ≥ 46; WWH ≥ 36
[c] OEPA target QHEI scores: EWH ≥ 75; WWH ≥ 60
[d] NP reduction only needed if point sources are meeting the target.
[e] Total is required if it's a collective reduction strategy.
[f] Target 1= OEPA 20 sq. mi. to 200 sq. mi.
[g] Target 2= WWH less than 200 sq. mi.

Grave Creek 1.4 5060001-110-040

Location: South Side of Firstenberger Road at State Route 98

Major Impairments:

- Habitat Alteration
- Siltation
- Nutrient Enrichment
- *Point Sources*

Use Designation: WWH

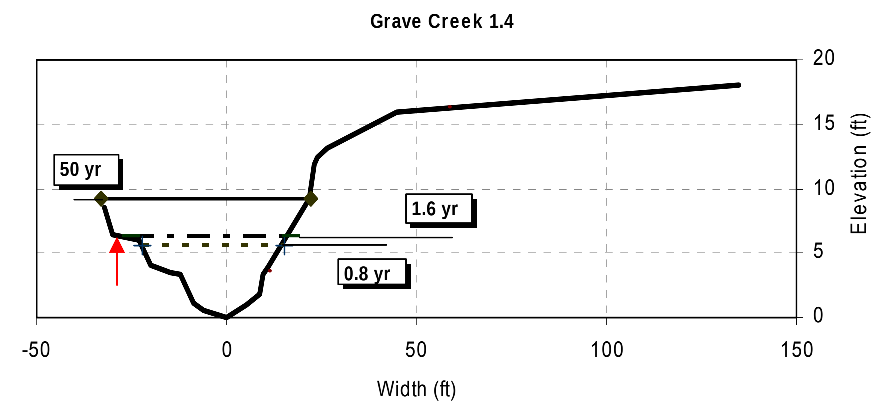
Attainment Status: Non

Geomorphology Score: 3

Grave Creek at river mile 1.4 currently is an un-maintained agricultural ditch confined by Firstenberger Road on the right bank and a valley wall on the left bank.

Grave Creek is 0.65 times the regional channel size. The particle at incipient motion (predicted D50) was calculated to be 11.7 mm, which is similar to the measured D50. The floodplain is much less than the minimum recommended 3 times the bankfull width (1.6 yr RI width ratio).

This site is not representative of the stream system and has poorer bankfull features. At this location, Grave Creek is narrower and deeper than it should be. The bankfull feature indicated by the arrow below has a functional fluvial influence on equilibrium and is consistent with visual observations of the right bank downstream of the survey site.



Channel Dimensions		Flood Dimensions		Materials	
51.0	*X-section area (ft.sq.)*	46.9	*W flood prone area (ft)*	8.5	*D50 Riffle (mm)*
21.7	*Width (ft)*	2.2	*Entrenchment ratio*	39	*D84 Riffle (mm)*
2.3	*Mean depth (ft)*	5.6	*0.8 yr RI Elevation (ft)*	**Regional Channel Size**	
3.4	*Max depth (ft)*	1.7	*0.8 yr RI width ratio*	0.65	*Size ratio*
23.4	*Wetted perimeter (ft)*	6.3	*1.6 yr RI Elevation (ft)*	0.5	*W-D Proportion*
2.2	*Hyd radi (ft)*	1.9	*1.6 yr RI width ratio*	0.2	*Slope (%, SWAT)*
9.2	*Width-depth ratio*	9.3	*50 yr RI Elevation (ft)*	**Stage Discharge Ratios**	
		2.5	*50 yr RI width ratio*	1.1	*$Q_{1.6}$ ratio*
				1.7	*Q_{50} ratio*

(1.6 yr RI assumed to be upper limit of bankfull elevation; based on low left bench, indicated by arrow)

Numeric Estimates and Target Reductions for biological, habitat, and water quality parameters

Current Estimate/ Target Reduction	*DA (mi^2)*	*ICI[a]*	*IBI[b]*	*QHEI[c]*	*Water Quality (flow weighted average)*					
					TP (mg/L)		*Nitrate (mg/L)*		*TSS (mg/L)*	
					NP[d]	Total[e]	NP	Total	NP	Total
Current	11.3	--	26	44.5	0.43	0.57	4.6	4.7	142	125
Target 1[f] Reduction/Improvement		--	10	5.5	0.36	0.50	3.6	3.7	133	116
Target 2[g] Reduction					0.27	0.41	2.6	2.7	62	65

[a] OEPA target ICI scores: EWH ≥ 42; WWH ≥ 32
[b] OEPA target IBI scores: EWH ≥ 46; WWH ≥ 36
[c] OEPA target QHEI scores: EWH ≥ 75; WWH ≥ 60
[d] NP reduction only needed if point sources are meeting the target.
[e] Total is required if it's a collective reduction strategy.
[f] Target 1= OEPA less than 20 sq. mi.
[g] Target 2= WWH less than 200 sq. mi.

Horseshoe Run 0.9 5060001-110-100

Location: Horseshoe Road at Kelly McMaster Road

Major Impairments:
- **Habitat Alteration**
- Urbanization
- Nutrient Enrichment

Use Designation: WWH

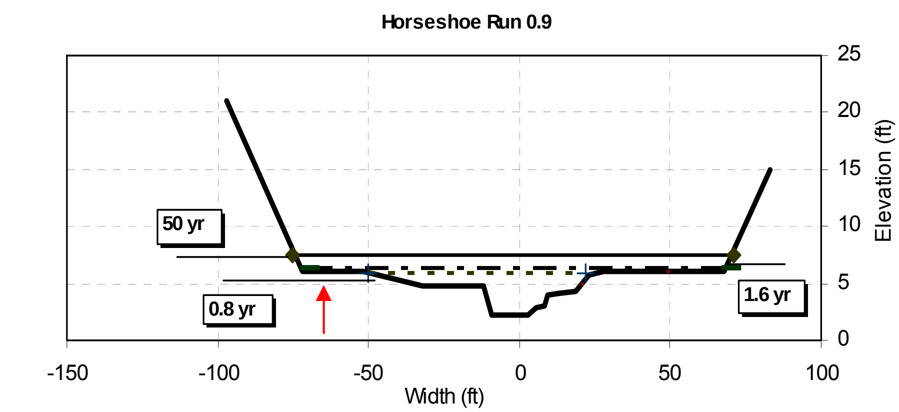
Attainment Status: Unknown

Geomorphology Score: 6

Horseshoe Run is located in an urbanizing landscape and is bound by pastures, row crops, roads and houses causes many changes along its length. Horseshoe Run is highly susceptible to changes in flows or removal of floodplain vegetation that could cause erosion.

Horseshoe Run is 0.7 times the regional channel size. The particle at incipient motion (predicted D50) was calculated to be 9.1 mm, which is smaller than the measured D50. It is well connected to a floodplain that is larger than the minimum recommended 3 times the bankfull width (1.6 yr RI width ratio).

The bankfull feature indicated by the arrow below has a functional fluvial influence on equilibrium and is consistent with visual observations.
There is evidence of the lower benches continuing to build to a more stable elevation. The primary cause of instability is a 4 ft tall weir located upstream of the survey site.



Channel Dimensions		Flood Dimensions		Materials	
52.0	*X-section area (ft.sq.)*	145.2	*W flood prone area (ft)*	17	*D50 Riffle (mm)*
29.6	*Width (ft)*	4.9	*Entrenchment ratio*	63	*D84 Riffle (mm)*
1.8	*Mean depth (ft)*	5.9	*0.8 yr RI Elevation (ft)*	**Regional Channel Size**	
2.7	*Max depth (ft)*	2.3	*0.8 yr RI width ratio*	0.7	*Size ratio*
30.1	*Wetted perimeter (ft)*	6.4	*1.6 yr RI Elevation (ft)*	1	*W-D Proportion*
1.7	*Hyd radi (ft)*	4.4	*1.6 yr RI width ratio*	0.2	*Slope (%, SWAT)*
16.9	*Width-depth ratio*	7.5	*50 yr RI Elevation (ft)*	**Stage Discharge Ratios**	
		4.6	*50 yr RI width ratio*	1.1	*$Q_{1.6}$ ratio*
				1.4	*Q_{50} ratio*

(1.6 yr RI assumed to be upper limit of bankfull elevation; based on left bank floodplain, indicated by arrow)

Numeric Estimates and Target Reductions for biological, habitat, and water quality parameters

Current Estimate/ Target Reduction	*DA (mi^2)*	*ICI[a]*	*IBI[b]*	*QHEI[c]*	*Water Quality (flow weighted average)*					
					TP (mg/L)		*Nitrate (mg/L)*		*TSS (mg/L)*	
					NP[d]	Total[e]	NP	Total	NP	Total
Current	10.3	Not surveyed in 2003-04			0.51	0.51	4.2	4.2	275	275
Target 1[f] Reduction/Improvement					0.44	0.44	3.2	3.2	266	266
Target 2[g] Reduction					0.35	0.35	2.2	2.2	95	95

[a] OEPA target ICI scores: EWH ≥ 42; WWH ≥ 32
[b] OEPA target IBI scores: EWH ≥ 46; WWH ≥ 36
[c] OEPA target QHEI scores: EWH ≥ 75; WWH ≥ 60
[d] NP reduction only needed if point sources are meeting the target.
[e] Total is required if it's a collective reduction strategy.
[f] Target 1= OEPA less than 20 sq. mi.
[g] Target 2= WWH less than 200 sq. mi.

Indian Run 0.9 5060001-110-080

Location: Intersection of Bishop Road and Horseshoe Road

Major Impairments:

- Siltation
- **Habitat Alteration**
- Nutrient Enrichment

Use Designation: WWH

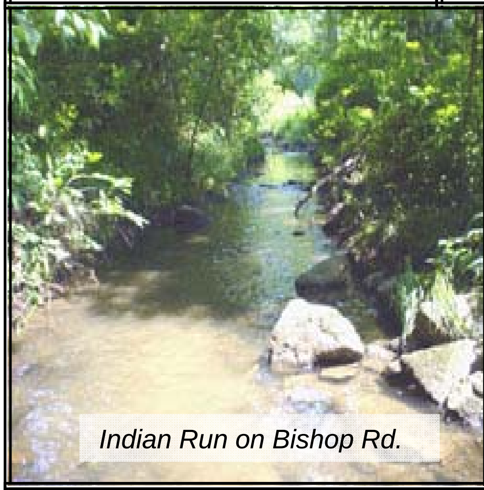
Attainment Status: Full

Geomorphology Score: 6

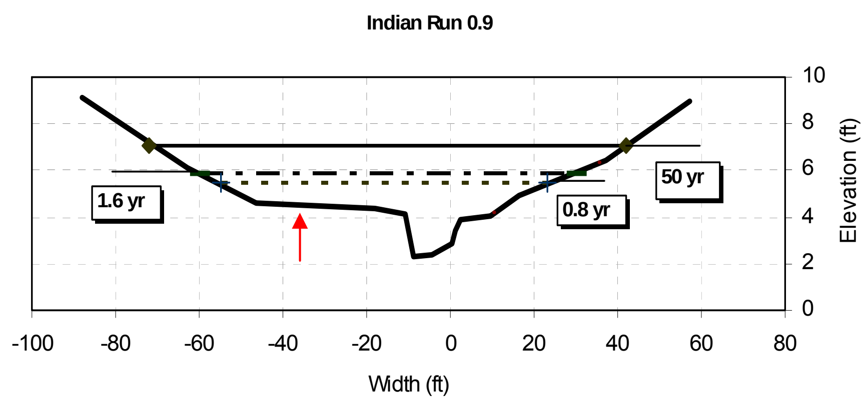
Indian Run is located in Delaware County, a rapidly urbanizing area, and appears to be a recovered agricultural ditch.

Indian Run is 0.65 times the regional channel size. The particle at incipient motion (predicted D50) was calculated to be 13.4 mm, which is similar to the measured D50. A small weir is located near the survey site. Downstream of this weir there is an extensive wooded floodplain that is larger than the minimum recommended 3 times the bankfull width (1.6 yr RI width ratio).

The bankfull feature indicated by the arrow below has a functional fluvial influence on equilibrium. Indian Run changes quite a bit moving downstream through the watershed. Indian Run starts as a narrow E-channel, then becomes over-wide with a wooded floodplain, and returns to a small E-channel with a grassed floodplain. Water quality is probably worse than predicted.



Indian Run on Bishop Rd.



Channel Dimensions		Flood Dimensions		Materials	
25.1	*X-section area (ft.sq.)*	103.7	*W flood prone area (ft)*	15	*D50 Riffle (mm)*
23.0	*Width (ft)*	4.5	*Entrenchment ratio*	100	*D84 Riffle (mm)*
1.1	*Mean depth (ft)*	5.5	*0.8 yr RI Elevation (ft)*	**Regional Channel Size**	
2.1	*Max depth (ft)*	3.8	*0.8 yr RI width ratio*	0.65	*Size ratio*
24.1	*Wetted perimeter (ft)*	5.9	*1.6 yr RI Elevation (ft)*	1	*W-D Proportion*
1.0	*Hyd radi (ft)*	4.3	*1.6 yr RI width ratio*	0.5	*Slope (%, SWAT)*
21.1	*Width-depth ratio*	7.1	*50 yr RI Elevation (ft)*	**Stage Discharge Ratios**	
		5.5	*50 yr RI width ratio*	1.1	*$Q_{1.6}$ ratio*
				1.5	*Q_{50} ratio*

(1.6 yr RI assumed to be upper limit of bankfull elevation; based on floodplain on left bank, indicated by arrow)

Numeric Estimates and Target Reductions for biological, habitat, and water quality parameters

Current Estimate/ Target Reduction	*DA (mi^2)*	*ICI[a]*	*IBI[b]*	*QHEI[c]*	*Water Quality (flow weighted average)*					
					TP (mg/L)		*Nitrate (mg/L)*		*TSS (mg/L)*	
					NP[d]	Total[e]	NP	Total	NP	Total
Current	4.0	--	36	69	0.04	0.04	0.70	0.70	2	2
Target 1[f] Reduction/Improvement		--	--	--	--	--	--	--	--	--
Target 2[g] Reduction					--	--	--	--	--	--

[a] OEPA target ICI scores: EWH ≥ 42; WWH ≥ 32
[b] OEPA target IBI scores: EWH ≥ 46; WWH ≥ 36
[c] OEPA target QHEI scores: EWH ≥ 75; WWH ≥ 60
[d] NP reduction only needed if point sources are meeting the target.
[e] Total is required if it's a collective reduction strategy.
[f] Target 1= OEPA less than 20 sq. mi.
[g] Target 2= WWH less than 200 sq. mi.

Kempton Run 1.1 5060001-120-040

Location: Downstream of the OSU Airport, near Abby Church Road

Major Impairments:

- Siltation
- Habitat Alteration
- **Urbanization**
- Nutrient Enrichment

Use Designation: WWH

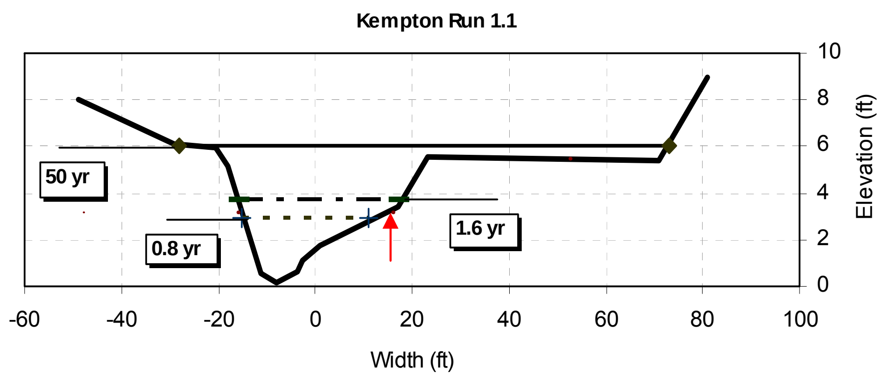
Attainment Status: Unknown

Geomorphology Score: 2

Kempton Run is a high gradient stream in a wooded ravine-like setting located in Worthington, OH in a medium/high density residential area. Urbanization is the primary threat to this stream.

Kempton Run is 1.7 times larger than the regional channel size. The particle at incipient motion (predicted D50) was calculated to be 36.5 mm, which is between the measured D50 and D84. The floodplain is much less than the minimum recommended 3 times the bankfull width (1.6 yr RI width ratio). Access to a larger wooded floodplain occurs only during high flows. Kempton Run is incised, but there is evidence of building small floodplains within the channel to re-establish equilibrium. The bankfull feature indicated by the arrow below has a functional fluvial influence on equilibrium and is consistent with visual observations. Water quality is probably worse than predicted as livestock are located on the upper reaches.

No Photo Available



Channel Dimensions		Flood Dimensions		Materials	
51.4	*X-section area (ft.sq.)*	109.0	*W flood prone area (ft)*	8.5	*D50 Riffle (mm)*
32.4	*Width (ft)*	3.4	*Entrenchment ratio*	39	*D84 Riffle (mm)*
1.6	*Mean depth (ft)*	2.9	*0.8 yr RI Elevation (ft)*	**Regional Channel Size**	
3.2	*Max depth (ft)*	0.8	*0.8 yr RI width ratio*	1.7	*Size ratio*
33.5	*Wetted perimeter (ft)*	3.7	*1.6 yr RI Elevation (ft)*	1.2	*W-D Proportion*
1.5	*Hyd radi (ft)*	1.0	*1.6 yr RI width ratio*	0.9	*Slope (%, SWAT)*
20.4	*Width-depth ratio*	6.0	*50 yr RI Elevation (ft)*	**Stage Discharge Ratios**	
		3.2	*50 yr RI width ratio*	1.3	*$Q_{1.6}$ ratio*
				2.1	*Q_{50} ratio*

(1.6 yr RI assumed to be upper limit of bankfull elevation; based on lower bench on right bank, indicated by arrow)

Numeric Estimates and Target Reductions for biological, habitat, and water quality parameters

Current Estimate/ Target Reduction	*DA (mi^2)*	*ICI[a]*	*IBI[b]*	*QHEI[c]*	*Water Quality (flow weighted average)* TP (mg/L) NP[d]	TP (mg/L) Total[e]	Nitrate (mg/L) NP	Nitrate (mg/L) Total	TSS (mg/L) NP	TSS (mg/L) Total
Current	2.8	Not surveyed in 2003-04			0.08	0.08	11.9	11.9	16	16
Target 1[f] Reduction/Improvement					0.01	0.01	10.9	10.9	7	7
Target 2[g] Reduction					--	--	9.9	9.9	--	--

[a] OEPA target ICI scores: EWH ≥ 42; WWH ≥ 32
[b] OEPA target IBI scores: EWH ≥ 46; WWH ≥ 36
[c] OEPA target QHEI scores: EWH ≥ 75; WWH ≥ 60
[d] NP reduction only needed if point sources are meeting the target.
[e] Total is required if it's a collective reduction strategy.
[f] Target 1= OEPA less than 20 sq. mi.
[g] Target 2= WWH less than 200 sq. mi.

Mill Run 0.9 5060001-120-010

Location: E. Williams Street near North Street

Major Impairments:

- Habitat Alteration
- **Urbanization**
- Nutrient Enrichment

Use Designation: WWH

Attainment Status: Full

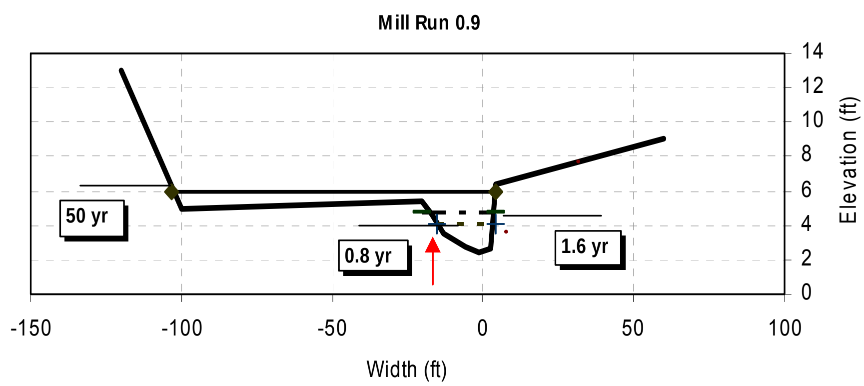
Geomorphology Score: 0

Mill run runs through the city of Delaware, OH, a rapidly urbanizing area. The primary threat to this stream is urbanization and industrial pollution discharging directly into the stream.

Mill run is 0.5 times the regional channel size. The particle at incipient motion (predicted D50) was calculated to be 72.6 mm, which is between the measured D50 and D84. The floodplain is smaller than the minimum recommended 3 times the bankfull width (1.6 yr RI width ratio) except for flows higher than the 1.6 year RI.

Mill Run is over-wide, but there is evidence of building small floodplains within the channel to re-establish equilibrium. The bankfull feature indicated by the arrow below has a functional fluvial influence on equilibrium and is consistent with visual observations.

No Photo Available



Channel Dimensions		Flood Dimensions		Materials	
10.5	*X-section area (ft.sq.)*	20.4	*W flood prone area (ft)*	12	*D50 Riffle (mm)*
15.9	*Width (ft)*	1.3	*Entrenchment ratio*	110	*D84 Riffle (mm)*
0.7	*Mean depth (ft)*	4.1	*0.8 yr RI Elevation (ft)*	**Regional Channel Size**	
1.1	*Max depth (ft)*	1.2	*0.8 yr RI width ratio*	0.5	*Size ratio*
16.5	*Wetted perimeter (ft)*	4.7	*1.6 yr RI Elevation (ft)*	1.4	*W-D Proportion*
0.6	*Hyd radi (ft)*	1.5	*1.6 yr RI width ratio*	1.3	*Slope (%, SWAT)*
24.1	*Width-depth ratio*	6.0	*50 yr RI Elevation (ft)*	**Stage Discharge Ratios**	
		6.8	*50 yr RI width ratio*	1.4	*$Q_{1.6}$ ratio*
				2.1	*Q_{50} ratio*
(1.6 yr RI assumed to be upper limit of bankfull elevation; based on left bank lower grade break, indicated by arrow)					

Numeric Estimates and Target Reductions for biological, habitat, and water quality parameters

Current Estimate/ Target Reduction	*DA (mi^2)*	*ICI[a]*	*IBI[b]*	*QHEI[c]*	*Water Quality (flow weighted average)*					
					TP (mg/L)		*Nitrate (mg/L)*		*TSS (mg/L)*	
					NP[d]	Total[e]	NP	Total	NP	Total
Current	1.8	--	37	68	0.73	0.73	4.7	4.7	426	426
Target 1[f] Reduction/Improvement		--	--	--	0.66	0.66	3.7	3.7	417	417
Target 2[g] Reduction					0.57	0.57	2.7	2.7	346	346

[a] OEPA target ICI scores: EWH ≥ 42; WWH ≥ 32
[b] OEPA target IBI scores: EWH ≥ 46; WWH ≥ 36
[c] OEPA target QHEI scores: EWH ≥ 75; WWH ≥ 60
[d] NP reduction only needed if point sources are meeting the target.
[e] Total is required if it's a collective reduction strategy.
[f] Target 1= OEPA less than 20 sq. mi.
[g] Target 2= WWH less than 200 sq. mi.

Mud Run 2.7 5060001-090-030

Location: East side of Monnett Chapel Road

Major Impairments:
- **Habitat Alteration**
- Siltation
- Nutrient Enrichment

Use Designation: WWH

Attainment Status: Partial

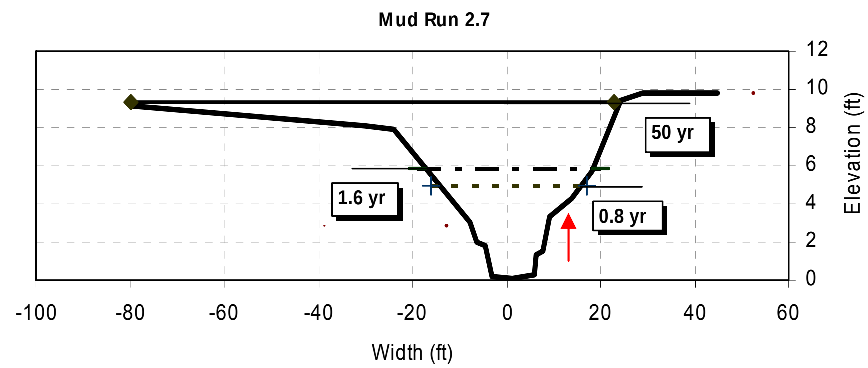
Geomorphology Score: 1

Mud Run is an un-maintained agricultural drainage ditch bound on both sides by row crops and a grassed buffer strip.

Mud Run is 0.58 times the regional channel size. The particle at incipient motion (predicted D50) was calculated to be 6 mm, which is much larger than the measured D50 and D84. The floodplain is less than the minimum recommended 3 times the bankfull width (1.6 yr RI width ratio), however, there is access to larger floodplain for flows greater than the 1.6 year RI.

The bankfull feature indicated by the arrow below has some functional fluvial influence on equilibrium and are consistent with visual observations. However, aggradation is a problem even though there is adequate stream power to move large particles. The sediment source needs to be identified and addressed – perhaps it is tile blow outs in some fields.

Mud Run @ Monnett Chapel Rd.



Channel Dimensions		Flood Dimensions		Materials	
62.1	*X-section area (ft.sq.)*	75.5	*W flood prone area (ft)*	0.062	*D50 Riffle (mm)*
25.8	*Width (ft)*	2.9	*Entrenchment ratio*	5.5	*D84 Riffle (mm)*
2.4	*Mean depth (ft)*	5.0	*0.8 yr RI Elevation (ft)*	**Regional Channel Size**	
4.3	*Max depth (ft)*	1.3	*0.8 yr RI width ratio*	0.58	*Size ratio*
28.8	*Wetted perimeter (ft)*	5.8	*1.6 yr RI Elevation (ft)*	0.54	*W-D Proportion*
2.2	*Hyd radi (ft)*	1.5	*1.6 yr RI width ratio*	0.1	*Slope (%, SWAT)*
10.8	*Width-depth ratio*	9.3	*50 yr RI Elevation (ft)*	**Stage Discharge Ratios**	
		5.5	*50 yr RI width ratio*	1.2	*$Q_{1.6}$ ratio*
				1.9	*Q_{50} ratio*

(benches on one or both sides of the ditch are the bankfull elevation as indicated by arrow)

Numeric Estimates and Target Reductions for biological, habitat, and water quality parameters

Current Estimate/ Target Reduction	*DA (mi²)*	*ICI[a]*	*IBI[b]*	*QHEI[c]*	*Water Quality (flow weighted average)*					
					TP (mg/L)		*Nitrate (mg/L)*		*TSS (mg/L)*	
					NP[d]	Total[e]	NP	Total	NP	Total
Current	17.0	--	40	38	0.50	0.50	5.6	5.6	137	137
Target 1[f] Reduction/Improvement		--	--	22	0.43	0.43	4.6	4.6	128	128
Target 2[g] Reduction					0.34	0.34	3.6	3.6	57	57

[a] OEPA target ICI scores: EWH ≥ 42; WWH ≥ 32
[b] OEPA target IBI scores: EWH ≥ 46; WWH ≥ 36
[c] OEPA target QHEI scores: EWH ≥ 75; WWH ≥ 60
[d] NP reduction only needed if point sources are meeting the target.
[e] Total is required if it's a collective reduction strategy.
[f] Target 1= OEPA less than 20 sq. mi.
[g] Target 2= WWH less than 200 sq. mi.

Norris Run 1.3 5060001-110-090

Location: South side of Penry Road

Major Impairments:

- Habitat Alteration
- **Urbanization**
- Nutrient Enrichment

Use Designation: WWH

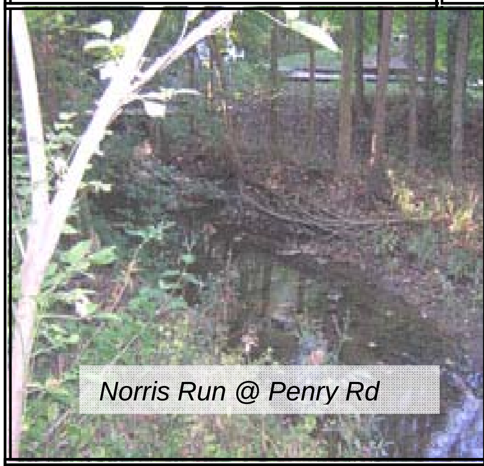
Attainment Status: Partial

Geomorphology Score: 7

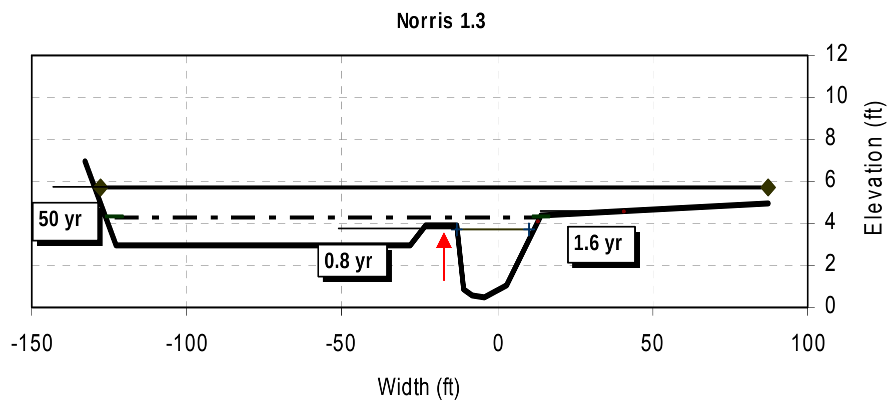
Norris Run runs through moderate density residential landscape in Delaware County, which is rapidly urbanizing. Large residential lots (1+ acres) occur on both sides of the stream.

Norris Run is 1.2 times larger than the regional channel size. The particle at incipient motion (predicted D50) was calculated to be 54.8 mm, which is between the measured D50 and D84. The floodplain, consisting of woods and lawn grass, is more than the minimum recommended 3 times the bankfull width (1.6 yr RI width ratio).

Major impacts to Norris Run include the construction by landowners of small rock weirs in multiple locations, and roads, bridges, etc. allowing access from Penry Road to adjacent houses. The bankfull feature indicated by the arrow below has a functional fluvial influence on equilibrium and is consistent with visual observations. Water quality might be better than predicted.



Norris Run @ Penry Rd



Channel Dimensions		Flood Dimensions		Materials	
60.7	*X-section area (ft.sq.)*	--	*W flood prone area (ft)*	1.9	*D50 Riffle (mm)*
25.3	*Width (ft)*	--	*Entrenchment ratio*	83	*D84 Riffle (mm)*
2.4	*Mean depth (ft)*	3.7	*0.8 yr RI Elevation (ft)*	**Regional Channel Size**	
3.4	*Max depth (ft)*	0.9	*0.8 yr RI width ratio*	1.2	*Size ratio*
27.3	*Wetted perimeter (ft)*	4.3	*1.6 yr RI Elevation (ft)*	0.65	*W-D Proportion*
2.2	*Hyd radi (ft)*	5.2	*1.6 yr RI width ratio*	0.9	*Slope (%, SWAT)*
10.6	*Width-depth ratio*	5.7	*50 yr RI Elevation (ft)*	**Stage Discharge Ratios**	
		8.1	*50 yr RI width ratio*	1.2	$Q_{1.6}$ *ratio*
				1.6	Q_{50} *ratio*

(1.6 yr RI assumed to be upper limit of bankfull elevation; based on left bank, indicated by arrow)

Numeric Estimates and Target Reductions for biological, habitat, and water quality parameters

Current Estimate/ Target Reduction	*DA (mi²)*	*ICI[a]*	*IBI[b]*	*QHEI[c]*	*Water Quality (flow weighted average)*					
					TP (mg/L)		*Nitrate (mg/L)*		*TSS (mg/L)*	
					NP[d]	**Total[e]**	**NP**	**Total**	**NP**	**Total**
Current	5.8	0	23	62	0.66	0.66	5.3	5.3	363	363
Target 1[f] Reduction/Improvement		32	13	--	0.59	0.59	4.3	4.3	354	354
Target 2[g] Reduction					0.50	0.50	3.3	3.3	83	83

[a] OEPA target ICI scores: EWH ≥ 42; WWH ≥ 32
[b] OEPA target IBI scores: EWH ≥ 46; WWH ≥ 36
[c] OEPA target QHEI scores: EWH ≥ 75; WWH ≥ 60
[d] NP reduction only needed if point sources are meeting the target.
[e] Total is required if it's a collective reduction strategy.
[f] Target 1= OEPA less than 20 sq. mi.
[g] Target 2= WWH less than 200 sq. mi.

Olentangy River 12.1 5060001-120-030

Location: East of State Route 315 near Hard Road

Major Impairments:

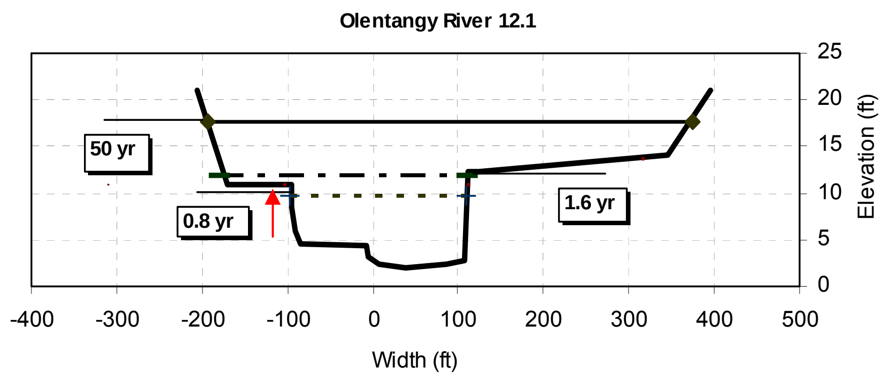
- Siltation
- **Urbanization**
- Nutrient Enrichment
- Point Sources

Use Designation: WWH

Attainment Status: Full

Geomorphology Score: 2

Olentangy River 12.1 is south of Delaware Dam and is part of the scenic river section of the watershed. This part of the watershed is rapidly urbanizing and in close proximity to OECC. At this location, the Olentangy River is 1.4 times larger than the regional channel size. The particle at incipient motion (predicted D50) is 94 mm, which is larger than the measured D50 and D84. The floodplain is much less than the minimum recommended 3 times the bankfull width (1.6 yr RI width ratio). The bankfull feature indicated by the arrow below does not have much functional fluvial influence on equilibrium but is consistent with visual observations. Possible reasons for this include: The floodplain is too narrow, even during high flows; aggradation is occurring resulting in an inaccurate slope and finer than expected substrate; the slope provided by SWAT is inaccurate (too large) – the most probable reason. Also, no adjustment to account for the influence of Delaware Dam has been to the discharge estimates.



Channel Dimensions		Flood Dimensions		Materials	
1538.5	*X-section area (ft.sq.)*	587.8	*W flood prone area (ft)*	10	*D50 Riffle (mm)*
206.6	*Width (ft)*	2.8	*Entrenchment ratio*	82	*D84 Riffle (mm)*
7.4	*Mean depth (ft)*	9.8	*0.8 yr RI Elevation (ft)*	**Regional Channel Size**	
9.0	*Max depth (ft)*	1.0	*0.8 yr RI width ratio*	1.4	*Size ratio*
214.8	*Wetted perimeter (ft)*	12.0	*1.6 yr RI Elevation (ft)*	1.05	*W-D Proportion*
7.2	*Hyd radi (ft)*	1.4	*1.6 yr RI width ratio*	0.5	*Slope (%, SWAT)*
27.7	*Width-depth ratio*	17.6	*50 yr RI Elevation (ft)*	**Stage Discharge Ratios**	
		2.7	*50 yr RI width ratio*	1.3	*$Q_{1.6}$ ratio*
				2.0	*Q_{50} ratio*

(1.6 yr RI assumed to be upper limit of bankfull elevation; based on left upper bank, indicated by arrow)

Numeric Estimates and Target Reductions for biological, habitat, and water quality parameters

Current Estimate/ Target Reduction	*DA (mi^2)*	*ICI[a]*	*IBI[b]*	*QHEI[c]*	*Water Quality (flow weighted average)* TP (mg/L) NP[d]	TP (mg/L) Total[e]	Nitrate (mg/L) NP	Nitrate (mg/L) Total	TSS (mg/L) NP	TSS (mg/L) Total
Current	490	--	50	71	0.30	0.35	3.2	3.0	114	116
Target 1[f] Reduction/Improvement		--	--	--	0.14	0.19	1.7	1.5	70	72
Target 2[g] Reduction					0.06	0.11	0.2	--	--	--

[a] OEPA target ICI scores: EWH ≥ 42; WWH ≥ 32
[b] OEPA target IBI scores: EWH ≥ 46; WWH ≥ 36
[c] OEPA target QHEI scores: EWH ≥ 75; WWH ≥ 60
[d] NP reduction only needed if point sources are meeting the target.
[e] Total is required if it's a collective reduction strategy.
[f] Target 1= OEPA greater than 200 sq. mi.
[g] Target 2= WWH greater than 200 sq. mi.

Olentangy River 40.8 5060001-110-050

Location: Waldo Fulton Road near State Route 98

Major Impairments:

- Siltation
- Habitat Alteration
- Nutrient Enrichment
- Point Sources

Use Designation: WWH

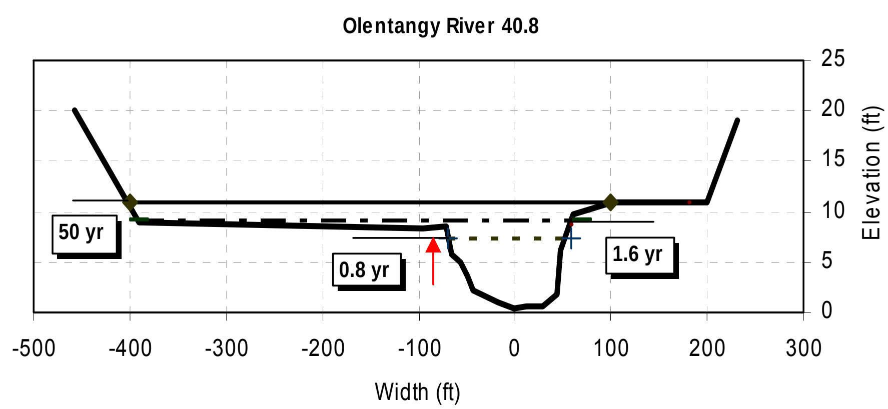
Attainment Status: Partial

Geomorphology Score: 9

At this location, the Olentangy River runs though a predominantly rural landscape and has an extensive wooded riparian zone.

The Olentangy River is 1.15 times larger than the regional channel size. The particle at incipient motion (predicted D50) was calculated to be 33 mm, which is which is the same as the measured D50. The floodplain is larger than the minimum recommended 3 times the bankfull width (1.6 yr RI width ratio). Access to a larger wooded floodplain occurs only during high flows due to some incision.

The bankfull feature indicated by the arrow below has a functional fluvial influence on equilibrium and is consistent with visual observations. However, further disturbance to the system will likely result in instability and reduce the quality of in-stream habitat.



Channel Dimensions		Flood Dimensions		Materials	
783.1	*X-section area (ft.sq.)*	660.4	*W flood prone area (ft)*	33	*D50 Riffle (mm)*
119.8	*Width (ft)*	5.5	*Entrenchment ratio*	97	*D84 Riffle (mm)*
6.5	*Mean depth (ft)*	7.3	*0.8 yr RI Elevation (ft)*	**Regional Channel Size**	
8.2	*Max depth (ft)*	1.1	*0.8 yr RI width ratio*	1.15	*Size ratio*
122.6	*Wetted perimeter (ft)*	9.1	*1.6 yr RI Elevation (ft)*	0.7	*W-D Proportion*
6.4	*Hyd radi (ft)*	3.9	*1.6 yr RI width ratio*	0.2	*Slope (%, SWAT)*
18.3	*Width-depth ratio*	10.9	*50 yr RI Elevation (ft)*	**Stage Discharge Ratios**	
		4.2	*50 yr RI width ratio*	1.3	*$Q_{1.6}$ ratio*
				1.5	*Q_{50} ratio*

(1.6 yr RI assumed to be upper limit of bankfull elevation; based on left bank floodplain, indicated by arrow)

Numeric Estimates and Target Reductions for biological, habitat, and water quality parameters

Current Estimate/ Target Reduction	*DA (mi²)*	*ICI[a]*	*IBI[b]*	*QHEI[c]*	*Water Quality (flow weighted average)*					
					TP (mg/L)		*Nitrate (mg/L)*		*TSS (mg/L)*	
					NP[d]	Total[e]	NP	Total	NP	Total
Current	234	46	34	60	0.37	0.41	3.5	3.9	165	162
Target 1[f] Reduction/Improvement		--	2	--	0.21	0.25	2.0	2.4	121	118
Target 2[g] Reduction					0.13	0.17	0.5	0.9	45	42

[a] OEPA target ICI scores: EWH ≥ 42; WWH ≥ 32
[b] OEPA target IBI scores: EWH ≥ 46; WWH ≥ 36
[c] OEPA target QHEI scores: EWH ≥ 75; WWH ≥ 60
[d] NP reduction only needed if point sources are meeting the target.
[e] Total is required if it's a collective reduction strategy.
[f] Target 1= OEPA greater than 200 sq. mi.
[g] Target 2= WWH greater than 200 sq. mi.

Olentangy River 45.5 5060001-110-020

Location: East of St. James Road and south of Whetstone River Road

Major Impairments:

- Siltation
- **Habitat Alteration**
- Nutrient Enrichment

Use Designation: WWH

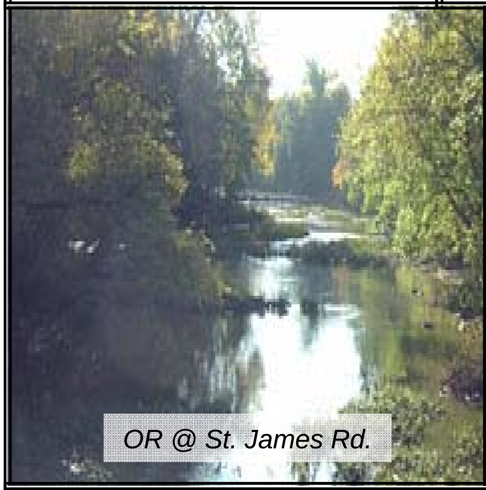
Attainment Status: Full

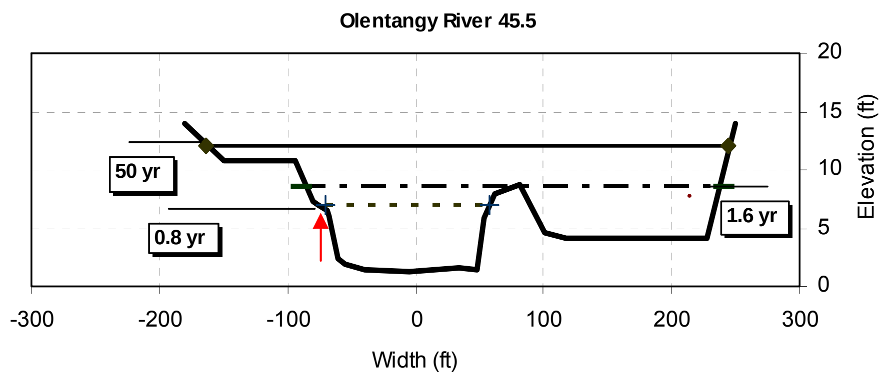
Geomorphology Score: 6

The Olentangy River at river mile 45.5 runs along a golf course in a predominantly rural area. There is nice riffle/pool development in this section of the river. The golf course constructed a low rise weir for irrigation.

At this location, the Olentangy River is 1.2 times larger than the regional channel size. The particle at incipient motion (predicted D50) was calculated to be 12.4 mm, which is which is similar to the measured D50. The floodplain is less than the minimum recommended 3 times the bankfull width (1.6 yr RI width ratio) even during high flows.

The bankfull feature indicated by the arrow below has a functional fluvial influence on equilibrium and is consistent with visual observations. Major impacts to this section of river are the low rise weir, the golf course, and the St. James Road bridge.





Channel Dimensions		Flood Dimensions		Materials	
682.2	*X-section area (ft.sq.)*	421.7	*W flood prone area (ft)*	9.4	*D50 Riffle (mm)*
140.1	*Width (ft)*	3.0	*Entrenchment ratio*	60	*D84 Riffle (mm)*
4.9	*Mean depth (ft)*	7.0	*0.8 yr RI Elevation (ft)*	**Regional Channel Size**	
6.0	*Max depth (ft)*	0.9	*0.8 yr RI width ratio*	1.2	*Size ratio*
142.9	*Wetted perimeter (ft)*	8.6	*1.6 yr RI Elevation (ft)*	1.2	*W-D Proportion*
4.8	*Hyd radi (ft)*	2.3	*1.6 yr RI width ratio*	0.1	*Slope (%, SWAT)*
28.8	*Width-depth ratio*	12.0	*50 yr RI Elevation (ft)*	**Stage Discharge Ratios**	
		2.9	*50 yr RI width ratio*	1.3	*$Q_{1.6}$ ratio*
				1.9	*Q_{50} ratio*

(based on grade break below floodplain on left bank, indicated by arrow)

Numeric Estimates and Target Reductions for biological, habitat, and water quality parameters

Current Estimate/ Target Reduction	*DA (mi²)*	*ICI[a]*	*IBI[b]*	*QHEI[c]*	*Water Quality (flow weighted average)*					
					TP (mg/L)		*Nitrate (mg/L)*		*TSS (mg/L)*	
					NP[d]	Total[e]	NP	Total	NP	Total
Current	181	52	40	84.5	0.34	0.39	3.2	3.2	172	169
Target 1[f] Reduction/Improvement		--	--	--	0.23	0.28	2.2	2.2	141	138
Target 2[g] Reduction					0.18	0.23	1.2	1.2	92	89

[a] OEPA target ICI scores: EWH ≥ 42; WWH ≥ 32
[b] OEPA target IBI scores: EWH ≥ 46; WWH ≥ 36
[c] OEPA target QHEI scores: EWH ≥ 75; WWH ≥ 60
[d] NP reduction only needed if point sources are meeting the target.
[e] Total is required if it's a collective reduction strategy.
[f] Target 1= OEPA 20 sq. mi. to 200 sq. mi.
[g] Target 2= WWH less than 200 sq. mi.

Olentangy River 63.4 5060001-090-020

Location: Along Lyons Road

Major Impairments:

- **Siltation**
- Habitat Alteration
- Nutrient Enrichment
- Point Sources

Use Designation: WWH

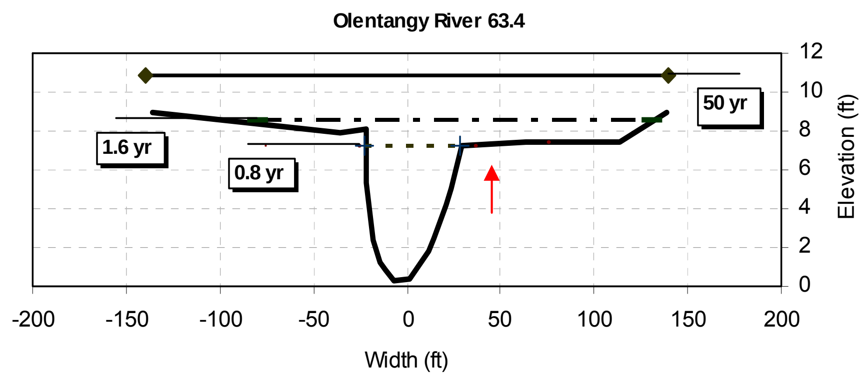
Attainment Status: Partial

Geomorphology Score: 6

Olentangy River at river mile 63.4 is located in a predominantly rural landscape.

At this location, the Olentangy River is 0.89 times the regional channel size. The particle at incipient motion (predicted D50) was calculated to be 12.7 mm, which is much larger than the measured D50 and D84. The floodplain is more than the minimum recommended 3 times the bankfull width (1.6 yr RI width ratio).

The bankfull feature indicated by the arrow below has some functional fluvial influence on equilibrium and is consistent with visual observations.
The primary problem along this reach is the presence of several large log jams backing up water creating long, slow-flowing runs. Fine sediments are dropping out of suspension and depositing on the bed and banks. The log jams and aggradation cause temporary bed slope reductions and finer than expected substrate. Upstream of this location, there is good attachment to a large wooded floodplain on both banks where we anticipate the QHEI scores to be higher.



Channel Dimensions		Flood Dimensions		Materials	
252.0	*X-section area (ft.sq.)*	--	*W flood prone area (ft)*	0.06	*D50 Riffle (mm)*
50.8	*Width (ft)*	--	*Entrenchment ratio*	0.16	*D84 Riffle (mm)*
5.0	*Mean depth (ft)*	7.2	*0.8 yr RI Elevation (ft)*	**Regional Channel Size**	
7.0	*Max depth (ft)*	1.0	*0.8 yr RI width ratio*	0.89	*Size ratio*
54.7	*Wetted perimeter (ft)*	8.6	*1.6 yr RI Elevation (ft)*	0.45	*W-D Proportion*
4.6	*Hyd radi (ft)*	4.2	*1.6 yr RI width ratio*	0.1	*Slope (%, SWAT)*
10.2	*Width-depth ratio*	10.9	*50 yr RI Elevation (ft)*	**Stage Discharge Ratios**	
		5.6	*50 yr RI width ratio*	1.2	*$Q_{1.6}$ ratio*
				1.5	*Q_{50} ratio*
(1.6 yr RI assumed to be upper limit of bankfull elevation; based on right bank floodplain, indicated by arrow)					

Numeric Estimates and Target Reductions for biological, habitat, and water quality parameters										
Current Estimate/ Target Reduction	***DA (mi^2)***	***ICI[a]***	***IBI[b]***	***QHEI[c]***	***Water Quality (flow weighted average)***					
					TP (mg/L)		***Nitrate (mg/L)***		***TSS (mg/L)***	
					NP[d]	**Total[e]**	**NP**	**Total**	**NP**	**Total**
Current	67.0	40	45	57.5	0.28	0.41	2.7	2.8	153	147
Target 1[f] Reduction/Improvement		--	--	2.5	0.17	0.30	1.7	1.8	122	116
Target 2[g] Reduction					0.12	0.25	0.7	0.8	73	67

[a] OEPA target ICI scores: EWH ≥ 42; WWH ≥ 32
[b] OEPA target IBI scores: EWH ≥ 46; WWH ≥ 36
[c] OEPA target QHEI scores: EWH ≥ 75; WWH ≥ 60
[d] NP reduction only needed if point sources are meeting the target.
[e] Total is required if it's a collective reduction strategy.
[f] Target 1= OEPA 20 sq. mi. to 200 sq. mi.
[g] Target 2= WWH less than 200 sq. mi.

Olentangy River 74.0 5060001-090-020

Location: East side of Poe Road at Monnett Chapel Road

Major Impairments:

- **Siltation**
- Habitat Alteration
- Nutrient Enrichment

Use Designation: WWH

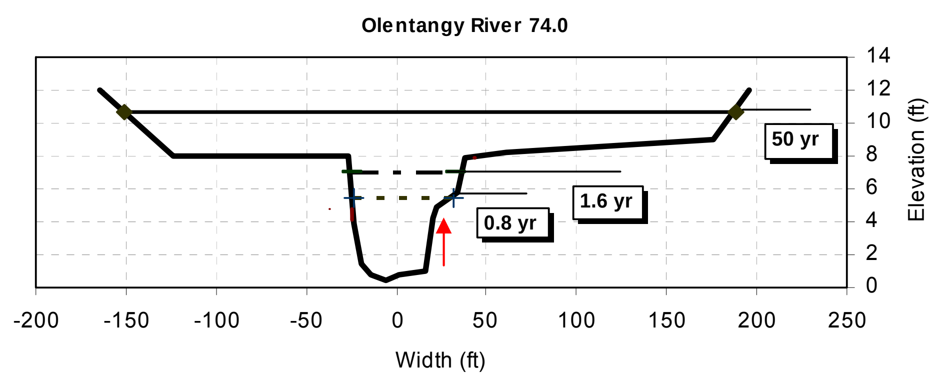
Attainment Status: Partial

Geomorphology Score: 1*

Olentangy River at river mile 74.0 is upstream of a golf course in a predominantly rural area.

At this location, the Olentangy River is 0.76 times the regional channel size. The particle at incipient motion (predicted D50) was calculated to be 9.1 mm. The substrate is fine sand and silt. The floodplain is much less than the minimum recommended 3 times the bankfull width (1.6 yr RI width ratio). This location is not representative of the rest of the river where it is less incised and less impacted from log jams.

The bankfull feature indicated by the arrow below likely has no functional fluvial influence on equilibrium. Possible reasons for this include: the stream is incised and wants to be wider and shallower than it is now; aggradation is occurring resulting in an inaccurate slope and finer than expected substrate; and the slope provided by SWAT is inaccurate.



Channel Dimensions		Flood Dimensions		Materials	
173.0	*X-section area (ft.sq.)*	320.0	*W flood prone area (ft)*	--	*D50 Riffle (mm)*
49.2	*Width (ft)*	6.5	*Entrenchment ratio*	--	*D84 Riffle (mm)*
3.5	*Mean depth (ft)*	5.5	*0.8 yr RI Elevation (ft)*	**Regional Channel Size**	
4.6	*Max depth (ft)*	1.1	*0.8 yr RI width ratio*	0.76	*Size ratio*
51.6	*Wetted perimeter (ft)*	7.0	*1.6 yr RI Elevation (ft)*	0.65	*W-D Proportion*
3.3	*Hyd radi (ft)*	1.2	*1.6 yr RI width ratio*	0.1	*Slope (%, SWAT)*
14.0	*Width-depth ratio*	10.7	*50 yr RI Elevation (ft)*	**Stage Discharge Ratios**	
		6.8	*50 yr RI width ratio*	1.3	*$Q_{1.6}$ ratio*
				2.0	*Q_{50} ratio*

(1.6 yr RI assumed to be upper limit of bankfull elevation; based on right bank grade break, indicated by arrow)

Numeric Estimates and Target Reductions for biological, habitat, and water quality parameters

Current Estimate/ Target Reduction	*DA (mi^2)*	*ICI[a]*	*IBI[b]*	*QHEI[c]*	*Water Quality (flow weighted average)* TP (mg/L) NP[d]	TP (mg/L) Total[e]	Nitrate (mg/L) NP	Nitrate (mg/L) Total	TSS (mg/L) NP	TSS (mg/L) Total
Current	50.0	0	40	57.5	0.31	0.47	2.9	3.1	184	174
Target 1[f] Reduction/Improvement		32	--	2.5	0.20	0.36	1.9	2.1	153	143
Target 2[g] Reduction					0.15	0.31	0.9	1.1	104	94

[a] OEPA target ICI scores: EWH ≥ 42; WWH ≥ 32
[b] OEPA target IBI scores: EWH ≥ 46; WWH ≥ 36
[c] OEPA target QHEI scores: EWH ≥ 75; WWH ≥ 60
[d] NP reduction only needed if point sources are meeting the target.
[e] Total is required if it's a collective reduction strategy.
[f] Target 1= OEPA 20 sq. mi. to 200 sq. mi.
[g] Target 2= WWH less than 200 sq. mi.

Olentangy River 84.5 5060001-090-010

Location: At Monnett New Winchester Road

Major Impairments:

- Siltation
- Habitat Alteration
- Nutrient Enrichment
- Point Sources

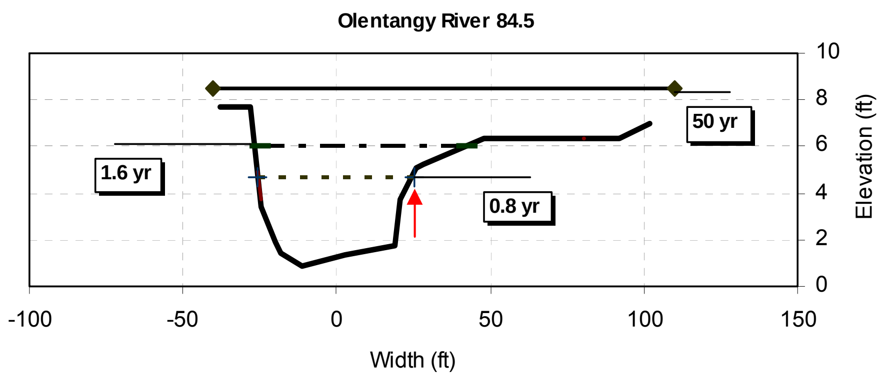
Use Designation: WWH

Attainment Status: Full

Geomorphology Score: 6

At this location, the Olentangy River is 1.2 times larger than the regional channel size. The particle at incipient motion (predicted D50) was calculated to be 32.5 mm, which is similar to the measured D50. The floodplain is less than the minimum recommended 3 times the bankfull width (1.6 yr RI width ratio) except during high flows.

The bankfull feature indicated by the arrow below likely has a functional fluvial influence on equilibrium. However, the floodplain located 0.5-1.0 ft above the elevation is currently the most important fluvial feature. Further incision could result in a substantial decline in both the geomorphology and aquatic life.



Channel Dimensions		Flood Dimensions		Materials	
167.0	*X-section area (ft.sq.)*	--	*W flood prone area (ft)*	35	*D50 Riffle (mm)*
51.7	*Width (ft)*	--	*Entrenchment ratio*	85	*D84 Riffle (mm)*
3.2	*Mean depth (ft)*	4.7	*0.8 yr RI Elevation (ft)*	**Regional Channel Size**	
4.3	*Max depth (ft)*	1.0	*0.8 yr RI width ratio*	1.2	*Size ratio*
54.1	*Wetted perimeter (ft)*	6.0	*1.6 yr RI Elevation (ft)*	0.8	*W-D Proportion*
3.1	*Hyd radi (ft)*	1.3	*1.6 yr RI width ratio*	0.4	*Slope (%, SWAT)*
16.0	*Width-depth ratio*	8.5	*50 yr RI Elevation (ft)*	**Stage Discharge Ratios**	
		2.9	*50 yr RI width ratio*	1.5	*$Q_{1.6}$ ratio*
				2.0	*Q_{50} ratio*

(1.6 yr RI assumed to be upper limit of bankfull elevation; based on grade break below right bank floodplain)

Numeric Estimates and Target Reductions for biological, habitat, and water quality parameters

Current Estimate/ Target Reduction	*DA (mi^2)*	*ICI[a]*	*IBI[b]*	*QHEI[c]*	*Water Quality (flow weighted average)*					
					TP (mg/L)		*Nitrate (mg/L)*		*TSS (mg/L)*	
					NP[d]	Total[e]	NP	Total	NP	Total
Current	24.0	46	32	82.5	0.31	0.58	2.8	3.1	229	202
Target 1[f] Reduction/Improvement		--	--	--	0.20	0.47	1.8	2.1	198	171
Target 2[g] Reduction					0.15	0.42	0.8	1.1	149	122

[a] OEPA target ICI scores: EWH ≥ 42; WWH ≥ 32
[b] OEPA target IBI scores: EWH ≥ 46; WWH ≥ 36
[c] OEPA target QHEI scores: EWH ≥ 75; WWH ≥ 60
[d] NP reduction only needed if point sources are meeting the target.
[e] Total is required if it's a collective reduction strategy.
[f] Target 1= OEPA 20 sq. mi. to 200 sq. mi.
[g] Target 2= WWH less than 200 sq. mi.

Olentangy River 85.2 5060001-010-010

Location: Along Monnett New Winchester Road

Major Impairments:
- Siltation
- Habitat Alteration
- Nutrient Enrichment
- Point Sources

Use Designation: WWH

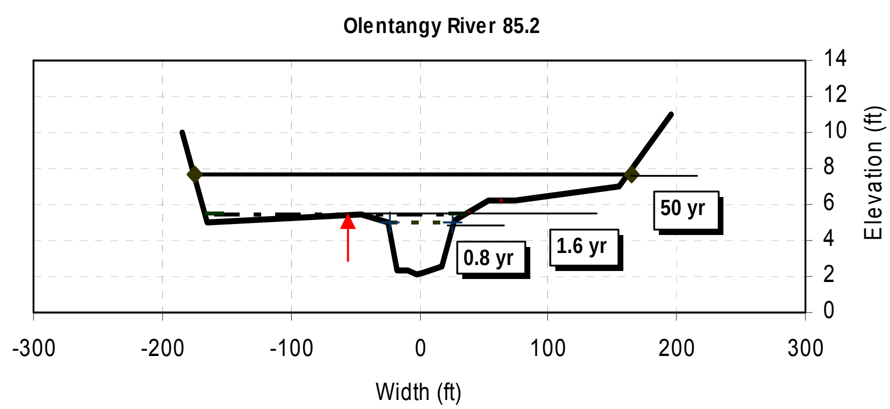
Attainment Status: Partial

Geomorphology Score: 8

The Olentangy River at river mile 85.2 is located upstream of the confluence with Rocky Fork in a predominantly rural landscape.

At this location, the Olentangy River is 1.5 times larger than the regional channel size. The particle at incipient motion (predicted D50) was calculated to be 15.2 mm, which is similar to the measured D50. The floodplain is more than the minimum recommended 3 times the bankfull width (1.6 yr RI width ratio).

The bankfull feature indicated by the arrow below has a functional fluvial influence on equilibrium and is consistent with visual observations. At this location, the Olentangy River is slightly incised. Further disturbance to the site likely will cause instability.



Channel Dimensions		Flood Dimensions		Materials	
125.7	*X-section area (ft.sq.)*	345.5	*W flood prone area (ft)*	18	*D50 Riffle (mm)*
62.8	*Width (ft)*	5.5	*Entrenchment ratio*	58	*D84 Riffle (mm)*
2.0	*Mean depth (ft)*	5.0	*0.8 yr RI Elevation (ft)*	**Regional Channel Size**	
3.1	*Max depth (ft)*	1.2	*0.8 yr RI width ratio*	1.5	*Size ratio*
63.6	*Wetted perimeter (ft)*	5.5	*1.6 yr RI Elevation (ft)*	0.7	*W-D Proportion*
2.0	*Hyd radi (ft)*	4.6	*1.6 yr RI width ratio*	0.3	*Slope (%, SWAT)*
31.3	*Width-depth ratio*	7.7	*50 yr RI Elevation (ft)*	**Stage Discharge Ratios**	
		8.2	*50 yr RI width ratio*	1.1	*$Q_{1.6}$ ratio*
				1.8	*Q_{50} ratio*

(1.6 yr RI assumed to be upper limit of bankfull elevation; based on right bank, indicated by arrow)

Numeric Estimates and Target Reductions for biological, habitat, and water quality parameters

Current Estimate/ Target Reduction	*DA (mi^2)*	*ICI[a]*	*IBI[b]*	*QHEI[c]*	*Water Quality (flow weighted average)*					
					TP (mg/L)		*Nitrate (mg/L)*		*TSS (mg/L)*	
					NP[d]	Total[e]	NP	Total	NP	Total
Current	12.4	--	38	--	0.33	0.80	2.1	2.8	202	163
Target 1[f] Reduction/Improvement		--	--	--	0.26	0.73	1.1	1.8	193	154
Target 2[g] Reduction					0.17	0.64	0.1	0.8	122	83

[a] OEPA target ICI scores: EWH ≥ 42; WWH ≥ 32
[b] OEPA target IBI scores: EWH ≥ 46; WWH ≥ 36
[c] OEPA target QHEI scores: EWH ≥ 75; WWH ≥ 60
[d] NP reduction only needed if point sources are meeting the target.
[e] Total is required if it's a collective reduction strategy.
[f] Target 1= OEPA less than 20 sq. mi.
[g] Target 2= WWH less than 200 sq. mi.

Otter Creek 1.1 5060001-110-010

Location: Along State Route 95

Major Impairments:
- Siltation
- **Habitat Alteration**

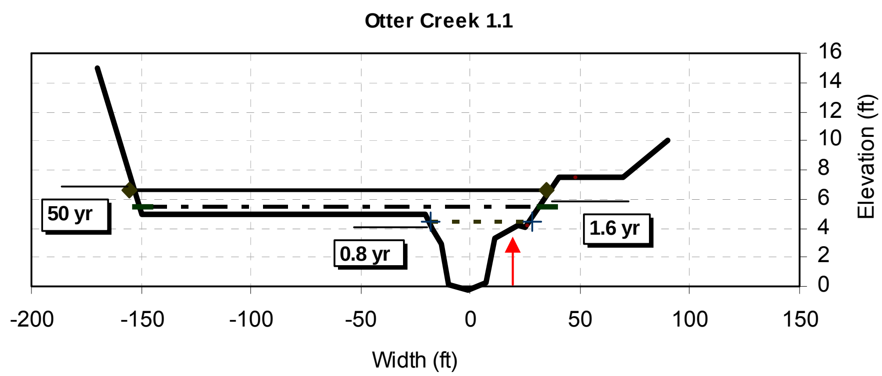
Use Designation: WWH

Attainment Status: Partial

Geomorphology Score: 5

Otter Creek is an agricultural ditch located in a predominantly rural landscape flanked on both sides by row crops. Major impacts are localized influences such as a bridge, a new house construction, maintained lawn up to the stream banks, and rip-rapping. Otter Creek is 1.05 times larger than the regional channel size. The particle at incipient motion (predicted D50) was calculated to be 6.6 mm, which is much larger than the measured D50 and D84. The floodplain is more than twice the minimum recommended 3 times the bankfull width (1.6 yr RI width ratio). The bankfull feature indicated by the arrow below does not have a functional fluvial influence on equilibrium but is consistent with visual observations.

Otter Creek is more incised than the data and the cross-section would suggest. The floodplain indicated below is poorly attached and acts more like a terrace than a functional active floodplain. Aggradation is a problem despite sufficient stream power to move large particles. The water quality is not correctly predicted at this location and is probably much worse – particularly for TP and TSS.



Channel Dimensions		Flood Dimensions		Materials	
68.6	*X-section area (ft.sq.)*	189.9	*W flood prone area (ft)*	0.06	*D50 Riffle (mm)*
26.3	*Width (ft)*	7.2	*Entrenchment ratio*	0.16	*D84 Riffle (mm)*
2.6	*Mean depth (ft)*	4.5	*0.8 yr RI Elevation (ft)*	**Regional Channel Size**	
3.5	*Max depth (ft)*	1.7	*0.8 yr RI width ratio*	1.05	*Size ratio*
28.3	*Wetted perimeter (ft)*	5.5	*1.6 yr RI Elevation (ft)*	0.6	*W-D Proportion*
2.4	*Hyd radi (ft)*	6.8	*1.6 yr RI width ratio*	0.1	*Slope (%, SWAT)*
10.1	*Width-depth ratio*	6.6	*50 yr RI Elevation (ft)*	**Stage Discharge Ratios**	
		6.9	*50 yr RI width ratio*	1.2	*$Q_{1.6}$ ratio*
				1.4	*Q_{50} ratio*

(1.6 yr RI assumed to be upper limit of bankfull elevation; based on right bank lower bench, indicated by arrow)

Numeric Estimates and Target Reductions for biological, habitat, and water quality parameters

Current Estimate/ Target Reduction	*DA (mi^2)*	*ICI[a]*	*IBI[b]*	*QHEI[c]*	*Water Quality (flow weighted average)*					
					TP (mg/L)		*Nitrate (mg/L)*		*TSS (mg/L)*	
					NP[d]	Total[e]	NP	Total	NP	Total
Current	8.3	--	38	44	0.07	0.07	1.1	1.1	13	13
Target 1[f] Reduction/Improvement		--	--	16	--	--	0.1	0.1	4	4
Target 2[g] Reduction					--	--	--	--	--	--

[a] OEPA target ICI scores: EWH ≥ 42; WWH ≥ 32
[b] OEPA target IBI scores: EWH ≥ 46; WWH ≥ 36
[c] OEPA target QHEI scores: EWH ≥ 75; WWH ≥ 60
[d] NP reduction only needed if point sources are meeting the target.
[e] Total is required if it's a collective reduction strategy.
[f] Target 1= OEPA less than 20 sq. mi.
[g] Target 2= WWH less than 200 sq. mi.

Qua Qua Creek 0.1 5060001-110-060

Location: East side of State Route 98

Major Impairments:

- Siltation
- Urbanization
- Nutrient Enrichment
- Point Sources

Use Designation: WWH

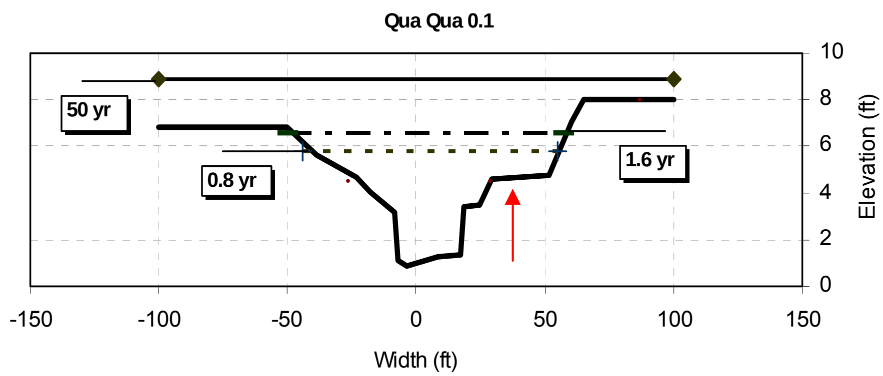
Attainment Status: Full

Geomorphology Score: 7

Qua Qua Creek flows though agricultural fields, a wooded corridor and under state route 98 before entering the Olentangy River.

Qua Qua Creek is 1.1 times larger than the regional channel size. The particle at incipient motion (predicted D50) was calculated to be 27.9 mm, which is similar to the measured D50 and D84. The floodplain is less than the minimum recommended 3 times the bankfull width (1.6 yr RI width ratio) but a nice wooded flood plain is located just above the predicted stage for the 1.6 year RI discharge.

The bankfull feature indicated by the arrow below has a functional fluvial influence on equilibrium and is consistent with visual observations. Qua Qua Creek is slightly incised but has accesses to large wooded floodplain during flows higher than the 1.6 year RI. There are multiple impacts to this stream and it is difficult to ascertain the primary impacts.



Channel Dimensions		Flood Dimensions		Materials	
112.7	*X-section area (ft.sq.)*	--	*W flood prone area (ft)*	26	*D50 Riffle (mm)*
52.1	*Width (ft)*	--	*Entrenchment ratio*	64	*D84 Riffle (mm)*
2.2	*Mean depth (ft)*	5.8	*0.8 yr RI Elevation (ft)*	**Regional Channel Size**	
3.8	*Max depth (ft)*	1.9	*0.8 yr RI width ratio*	1.1	*Size ratio*
54.6	*Wetted perimeter (ft)*	6.6	*1.6 yr RI Elevation (ft)*	1.2	*W-D Proportion*
2.1	*Hyd radi (ft)*	2.0	*1.6 yr RI width ratio*	0.5	*Slope (%, SWAT)*
24.1	*Width-depth ratio*	8.9	*50 yr RI Elevation (ft)*	**Stage Discharge Ratios**	
		3.8	*50 yr RI width ratio*	1.2	*$Q_{1.6}$ ratio*
				1.6	*Q_{50} ratio*

(1.6 yr RI assumed to be upper limit of bankfull elevation; based on right bank bench, indicated by arrow)

Numeric Estimates and Target Reductions for biological, habitat, and water quality parameters

Current Estimate/ Target Reduction	*DA (mi^2)*	*ICI*[a]	*IBI*[b]	*QHEI*[c]	*Water Quality (flow weighted average)*					
					TP (mg/L)		*Nitrate (mg/L)*		*TSS (mg/L)*	
					NP[d]	Total[e]	NP	Total	NP	Total
Current	17.1	--	44	75	0.49	0.49	3.8	7.4	141	141
Target 1[f] Reduction/Improvement		--	--	--	0.42	0.42	2.8	6.4	132	132
Target 2[g] Reduction					0.33	0.33	1.8	5.4	61	61

[a] OEPA target ICI scores: EWH ≥ 42; WWH ≥ 32
[b] OEPA target IBI scores: EWH ≥ 46; WWH ≥ 36
[c] OEPA target QHEI scores: EWH ≥ 75; WWH ≥ 60
[d] NP reduction only needed if point sources are meeting the target.
[e] Total is required if it's a collective reduction strategy.
[f] Target 1= OEPA less than 20 sq. mi.
[g] Target 2= WWH less than 200 sq. mi.

Rocky Fork 4.4 5060001-090-010

Location: East side of County Road 40

Major Impairments:

- Siltation
- Nutrient Enrichment
- Point Sources

Use Designation: WWH

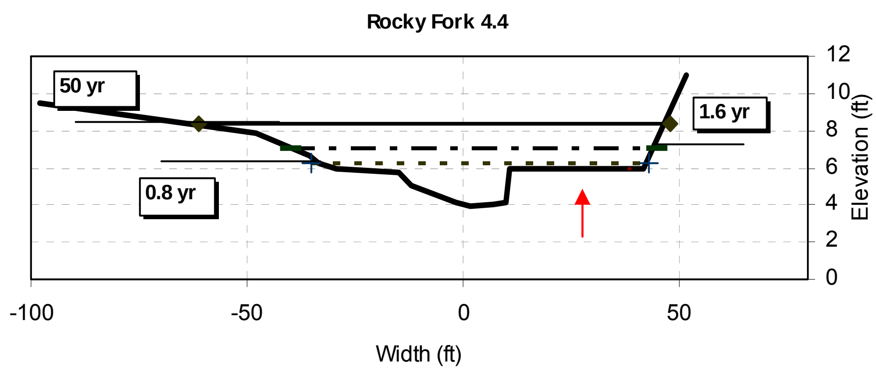
Attainment Status: Unknown

Geomorphology Score: 9

Rocky Fork at river mile 4.4 is located near the headwaters of the Olentangy River in a predominantly rural watershed.

Rocky Fork is similar to the regional channel size. The particle at incipient motion (predicted D50) is 11.4 mm, which is similar to the measured D50 and D84. The wooded floodplain is more than the minimum recommended 3 times the bankfull width (1.6 yr RI width ratio).

The bankfull feature indicated by the arrow below has a functional fluvial influence on equilibrium that is consistent with visual observations.



Channel Dimensions		Flood Dimensions		Materials	
38.5	*X-section area (ft.sq.)*	119.4	*W flood prone area (ft)*	9.4	*D50 Riffle (mm)*
24.9	*Width (ft)*	4.8	*entrenchment ratio*	37	*D84 Riffle (mm)*
1.5	*Mean depth (ft)*	6.8	*0.8 yr RI Elevation (ft)*	**Regional Channel Size**	
2.1	*Max depth (ft)*	3.1	*0.8 yr RI width ratio*	1	*Size ratio*
25.0	*Wetted perimeter (ft)*	7.4	*1.6 yr RI Elevation (ft)*	0.9	*W-D Proportion*
1.5	*Hyd radi (ft)*	3.4	*1.6 yr RI width ratio*	0.3	*Slope (%, measured)*
16.1	*Width-depth ratio*	8.7	*50 yr RI Elevation (ft)*	**Stage Discharge Ratios**	
		4.6	*50 yr RI width ratio*	1.2	*$Q_{1.6}$ ratio*
				1.7	*Q_{50} ratio*

(1.6 yr RI assumed to be upper limit of bankfull elevation; based on floodplain on both banks, indicated by arrow)

Numeric Estimates and Target Reductions for biological, habitat, and water quality parameters

Current Estimate/ Target Reduction	*DA (mi^2)*	*ICI[a]*	*IBI[b]*	*QHEI[c]*	*Water Quality (flow weighted average)*					
					TP (mg/L)		*Nitrate (mg/L)*		*TSS (mg/L)*	
					NP[d]	Total[e]	NP	Total	NP	Total
Current	4.5	Not surveyed in 2003-04			0.25	0.25	4.6	4.6	209	209
Target 1[f] Reduction/Improvement					0.18	0.18	3.6	3.6	200	200
Target 2[g] Reduction					0.09	0.09	2.6	2.6	129	129

[a] OEPA target ICI scores: EWH ≥ 42; WWH ≥ 32
[b] OEPA target IBI scores: EWH ≥ 46; WWH ≥ 36
[c] OEPA target QHEI scores: EWH ≥ 75; WWH ≥ 60
[d] NP reduction only needed if point sources are meeting the target.
[e] Total is required if it's a collective reduction strategy.
[f] Target 1= OEPA less than 20 sq. mi.
[g] Target 2= WWH less than 200 sq. mi.

Rush Run 1.5 5060001-120-040

Location: Walnut Grove Cemetery

Major Impairments:

- Siltation
- **Urbanization**
- Nutrient Enrichment

Use Designation: WWH

Attainment Status: Unknown

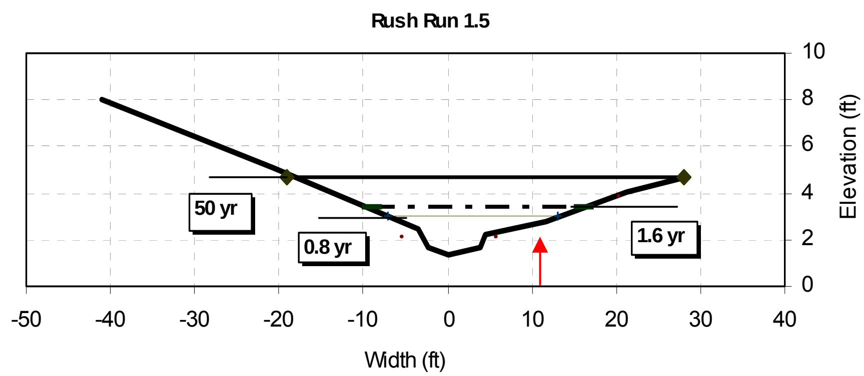
Geomorphology Score: 3*

Rush Run is a small, high gradient first order tributary in an urban watershed.

At this location, the Olentangy River is 0.9 times the regional channel size. The particle at incipient motion (predicted D50) is 12.4 mm. Substrate was not measured in this location, but consists of fine sands and silts. The floodplain is less than the minimum recommended 3 times the bankfull width (1.6 yr RI width ratio).

The bankfull feature indicated by the arrow below has a functional fluvial influence on equilibrium but is consistent with visual observations. Rush Run is likely building to re establish a stable geometry.

No Photo Available



Channel Dimensions		Flood Dimensions		Materials	
7.5	*X-section area (ft.sq.)*	29.9	*W flood prone area (ft)*	--	*D50 Riffle (mm)*
11.6	*Width (ft)*	2.6	*Entrenchment ratio*	--	*D84 Riffle (mm)*
0.7	*Mean depth (ft)*	3.0	*0.8 yr RI Elevation (ft)*	**Regional Channel Size**	
1.2	*Max depth (ft)*	1.8	*0.8 yr RI width ratio*	0.9	*Size ratio*
12.1	*Wetted perimeter (ft)*	3.4	*1.6 yr RI Elevation (ft)*	1.1	*W-D Proportion*
0.6	*Hyd radi (ft)*	2.2	*1.6 yr RI width ratio*	0.7	*Slope (%, SWAT)*
17.7	*Width-depth ratio*	4.7	*50 yr RI Elevation (ft)*	**Stage Discharge Ratios**	
		4.2	*50 yr RI width ratio*	1.2	*$Q_{1.6}$ ratio*
				2.0	*Q_{50} ratio*

(1.6 yr RI assumed to be upper limit of bankfull elevation; based on right bank grade break, indicated by arrow)

Numeric Estimates and Target Reductions for biological, habitat, and water quality parameters

Current Estimate/ Target Reduction	*DA (mi^2)*	*ICI[a]*	*IBI[b]*	*QHEI[c]*	*Water Quality (flow weighted average)*					
					TP (mg/L)		*Nitrate (mg/L)*		*TSS (mg/L)*	
					NP[d]	**Total[e]**	**NP**	**Total**	**NP**	**Total**
Current	0.5	Not surveyed in 2003-04			0.11	0.11	2.6	2.6	29	29
Target 1[f] Reduction/Improvement					0.04	0.04	1.6	1.6	20	20
Target 2[g] Reduction					0.03	0.03	1.6	1.6	--	--

[a] OEPA target ICI scores: EWH ≥ 42; WWH ≥ 32
[b] OEPA target IBI scores: EWH ≥ 46; WWH ≥ 36
[c] OEPA target QHEI scores: EWH ≥ 75; WWH ≥ 60
[d] NP reduction only needed if point sources are meeting the target.
[e] Total is required if it's a collective reduction strategy.
[f] Target 1= OEPA less than 20 sq. mi.
[g] Target 2= WWH less than 200 sq. mi.

Shaw Creek 1.6 5060001-100-020

Location: Near Beatty Road

Major Impairments:

- **Siltation**
- Nutrient Enrichment
- Point Sources

Use Designation: EWH

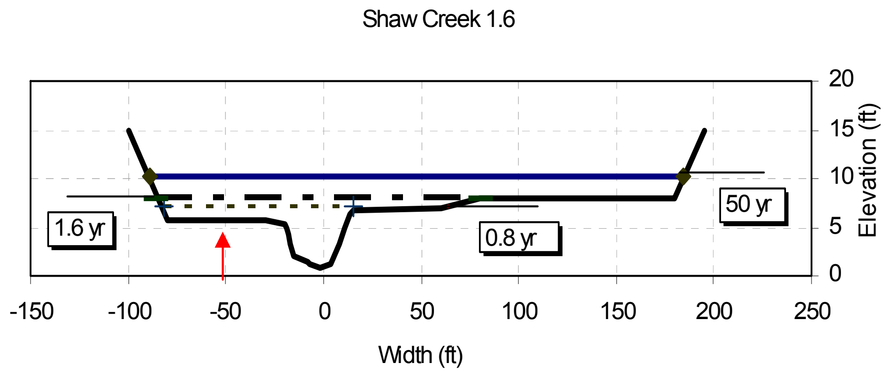
Attainment Status: Non

Geomorphology Score: 4

Shaw Creek is a recovering agricultural ditch that runs though a pig farm, row crops, pasture, and maintained lawn areas.

Shaw Creek is 0.8 times the regional channel size. The particle at incipient motion (predicted D50) is 18.3 mm, which is much larger than the measured D50 and D84. The floodplain is more than the minimum recommended 3 times the bankfull width (1.6 yr RI width ratio).

The bankfull feature indicated by the arrow below does not have a large functional fluvial influence on equilibrium but is consistent with visual observations. Possible reasons for this include: the presence of a rock weir backing up water creating long, slow-flowing runs as pictured below. Fine sediments are dropping out of suspension and depositing on the bed and banks. This aggradation results in a temporary reduction in bed slope and finer than expected substrate.



Channel Dimensions		Flood Dimensions		Materials	
111.5	*X-section area (ft.sq.)*	274.9	*W flood prone area (ft)*	1.6	*D50 Riffle (mm)*
30.6	*Width (ft)*	9.0	*entrenchment ratio*	7.6	*D84 Riffle (mm)*
3.6	*Mean depth (ft)*	5.3	*0.8 yr RI Elevation (ft)*	**Regional Channel Size**	
4.9	*Max depth (ft)*	7.3	*0.8 yr RI width ratio*	0.8	*Size ratio*
32.1	*Wetted perimeter (ft)*	7.9	*1.6 yr RI Elevation (ft)*	0.4	*W-D Proportion*
3.5	*Hyd radi (ft)*	5.3	*1.6 yr RI width ratio*	0.2	*Slope (%, SWAT)*
8.4	*Width-depth ratio*	9.7	*50 yr RI Elevation (ft)*	**Stage Discharge Ratios**	
		8.7	*50 yr RI width ratio*	1.6	*$Q_{1.6}$ ratio*
				2.0	*Q_{50} ratio*
(based on left bank floodplain, indicated by arrow)					

Numeric Estimates and Target Reductions for biological, habitat, and water quality parameters

Current Estimate/ Target Reduction	*DA (mi^2)*	*ICI[a]*	*IBI[b]*	*QHEI[c]*	*Water Quality (flow weighted average)*					
					TP (mg/L)		*Nitrate (mg/L)*		*TSS (mg/L)*	
					NP[d]	Total[e]	NP	Total	NP	Total
Current	26.0	--	38	69.5	0.33	0.33	4.4	4.4	126	126
Target 1[f] Reduction/Improvement		--	8	5.5	0.22	0.22	3.4	3.4	95	95
Target 2[g] Reduction					0.21	0.21	2.9	2.9	66	66

[a] OEPA target ICI scores: EWH ≥ 42; WWH ≥ 32
[b] OEPA target IBI scores: EWH ≥ 46; WWH ≥ 36
[c] OEPA target QHEI scores: EWH ≥ 75; WWH ≥ 60
[d] NP reduction only needed if point sources are meeting the target.
[e] Total is required if it's a collective reduction strategy.
[f] Target 1=OEPA 20 sq. mi. to 200 sq. mi.
[g] Target 2= EWH 20 sq. mi. to 200 sq. mi.

Sugar Run 1.3 5060001-110-090

Location: Upstream of Sugar Run Storage Facility on State Route 42

Major Impairments:

- Siltation
- Nutrient Enrichment
- Point Sources

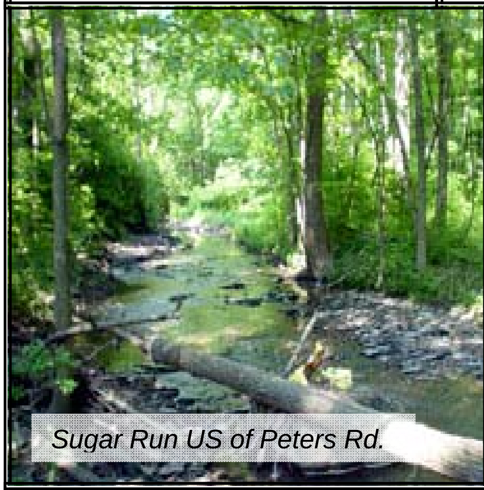
Use Designation: WWH

Attainment Status: Partial

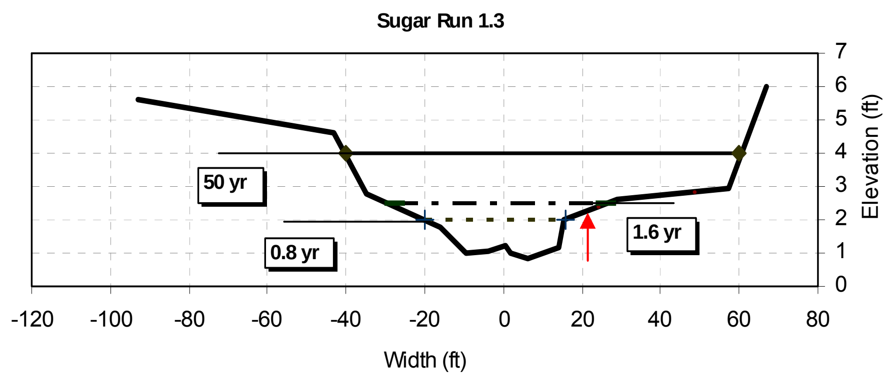
Geomorphology Score: 5

Sugar Run is a higher gradient, predominantly bedrock controlled stream located in a rural landscape bound on both sides by an extensive wooded riparian zone.

Sugar Run is 0.85 times the regional channel size. The particle at incipient motion (predicted D50) is 12.2 mm, which is smaller than the measured D50. The floodplain is slightly less than the minimum recommended 3 times the bankfull width (1.6 yr RI width ratio). The bankfull feature indicated by the arrow below does not have a large functional fluvial influence on equilibrium but is consistent with visual observations. The primary reason for this is that the stream is over-wide at this location and the bankfull feature is probably slightly higher than estimated. Downstream, Sugar Run becomes more narrow and deeper, which is likely more representative of what the system should look like. Stream health at other locations might be slightly better than is indicated by the SWAT predictions and the geomorphology at this location.



Sugar Run US of Peters Rd.



Channel Dimensions		Flood Dimensions		Materials	
28.8	*X-section area (ft.sq.)*	94.8	*W flood prone area (ft)*	22	*D50 Riffle (mm)*
35.5	*Width (ft)*	2.7	*entrenchment ratio*	120	*D84 Riffle (mm)*
0.8	*Mean depth (ft)*	2.5	*0.8 yr RI Elevation (ft)*	**Regional Channel Size**	
1.2	*Max depth (ft)*	1.7	*0.8 yr RI width ratio*	0.85	*Size ratio*
35.9	*Wetted perimeter (ft)*	3.1	*1.6 yr RI Elevation (ft)*	2	*W-D Proportion*
0.8	*Hyd radi (ft)*	2.9	*1.6 yr RI width ratio*	0.6	*Slope (%, measured)*
43.8	*Width-depth ratio*	4.4	*50 yr RI Elevation (ft)*	**Stage Discharge Ratios**	
		3.3	*50 yr RI width ratio*	1.3	*$Q_{1.6}$ ratio*
				2.1	*Q_{50} ratio*

(1.6 yr RI assumed to be upper limit of bankfull elevation; based on right bank grade break, indicated by arrow)

Numeric Estimates and Target Reductions for biological, habitat, and water quality parameters

Current Estimate/ Target Reduction	*DA (mi^2)*	*ICI[a]*	*IBI[b]*	*QHEI[c]*	*Water Quality (flow weighted average)*					
					TP (mg/L)		*Nitrate (mg/L)*		*TSS (mg/L)*	
					NP[d]	**Total[e]**	**NP**	**Total**	**NP**	**Total**
Current	3.5	0	29	60	0.78	0.78	5.2	5.2	640	640
Target 1[f] Reduction/Improvement		32	7	--	0.71	0.71	4.2	4.2	631	631
Target 2[g] Reduction					0.62	0.62	3.2	3.2	560	560

[a] OEPA target ICI scores: EWH ≥ 42; WWH ≥ 32
[b] OEPA target IBI scores: EWH ≥ 46; WWH ≥ 36
[c] OEPA target QHEI scores: EWH ≥ 75; WWH ≥ 60
[d] NP reduction only needed if point sources are meeting the target.
[e] Total is required if it's a collective reduction strategy.
[f] Target 1= OEPA less than 20 sq. mi.
[g] Target 2= WWH less than 20 sq. mi.

Thorn Run 1.1/1.3 5060001-090-040

Location: County Road 61

Major Impairments:

- Siltation
- Nutrient Enrichment
- **Habitat Alteration**

Use Designation: WWH

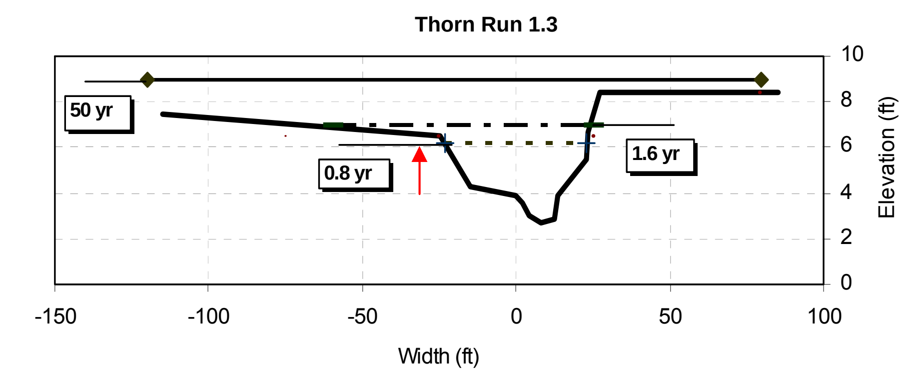
Attainment Status: Partial

Geomorphology Score: 5

Thorn Run is located in a rural landscape bound by row crops and pasture. Biology and habitat were sampled at river mile 1.1. Geomorphology was surveyed at river mile 1.3 because this location had better bankfull features.

At this location, Thorn Run is 1.6 times the regional channel size. The particle at incipient motion (predicted D50) is 11.7 mm, which is similar to the measured D50. The floodplain is slightly less than the minimum recommended 3 times the bankfull width (1.6 yr RI width ratio).

The bankfull feature indicated by the arrow below has a functional fluvial influence on equilibrium and is consistent with visual observations. The geomorphology is very variable along this agricultural stream but generally the aquatic life is good.



Channel Dimensions		Flood Dimensions		Materials	
109.6	*X-section area (ft.sq.)*	--	*W flood prone area (ft)*	14	*D50 Riffle (mm)*
48.3	*Width (ft)*	--	*Entrenchment ratio*	30	*D84 Riffle (mm)*
2.3	*Mean depth (ft)*	6.5	*0.8 yr RI Elevation (ft)*	**Regional Channel Size**	
3.8	*Max depth (ft)*	1.0	*0.8 yr RI width ratio*	1.6	*Size ratio*
49.7	*Wetted perimeter (ft)*	7.5	*1.6 yr RI Elevation (ft)*	1.2	*W-D Proportion*
2.2	*Hyd radi (ft)*	2.7	*1.6 yr RI width ratio*	0.2	*Slope (%, measured)*
21.3	*Width-depth ratio*	9.0	*50 yr RI Elevation (ft)*	**Stage Discharge Ratios**	
		4.0	*50 yr RI width ratio*	1.3	*$Q_{1.6}$ ratio*
				1.7	*Q_{50} ratio*
(based on left bank, indicated by arrow)					

Numeric Estimates and Target Reductions for biological, habitat, and water quality parameters

Current Estimate/ Target Reduction	*DA (mi²)*	*ICI*[a]	*IBI*[b]	*QHEI*[c]	*Water Quality (flow weighted average)*					
					TP (mg/L)		*Nitrate (mg/L)*		*TSS (mg/L)*	
					NP[d]	Total[e]	NP	Total	NP	Total
Current	9.3	--	42	56	0.44	0.44	3.4	3.4	145	145
Target 1[f] Reduction/Improvement		--	--	4	0.37	0.37	2.4	2.4	136	136
Target 2[g] Reduction					0.28	0.28	1.4	1.4	65	65

[a] OEPA target ICI scores: EWH ≥ 42; WWH ≥ 32
[b] OEPA target IBI scores: EWH ≥ 46; WWH ≥ 36
[c] OEPA target QHEI scores: EWH ≥ 75; WWH ≥ 60
[d] NP reduction only needed if point sources are meeting the target.
[e] Total is required if it's a collective reduction strategy.
[f] Target 1= OEPA less than 20 sq. mi.
[g] Target 2= WWH less than 20 sq. mi.

Tributary to Olentangy River 13.3 5060001-010-010

Location: Highbanks Metro Park

Major Impairments:

- Siltation
- Urbanization
- Nutrient Enrichment
- Point Sources

Use Designation: WWH

Attainment Status: Unknown

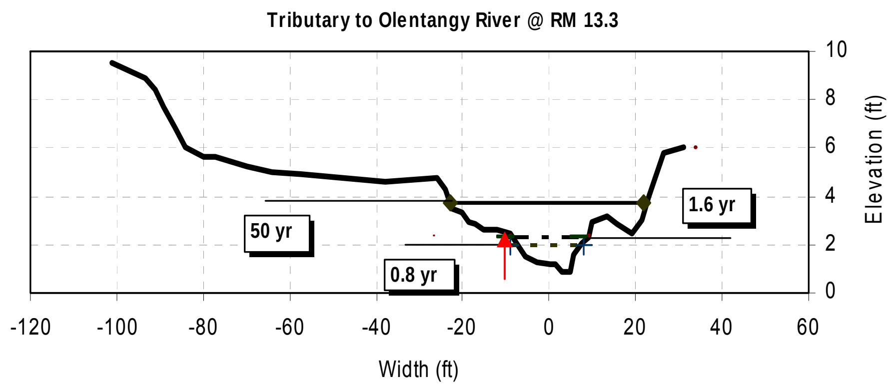
Geomorphology Score: 4

This unnamed tributary to Olentangy River at river mile 13.3 is a first order tributary in the scenic river section of the watershed. Urbanization poses the greatest threat to this tributary.

This tributary is 1.15 times the regional channel size. The particle at incipient motion (predicted D50) was 13.7mm, which is between the measured D50 and D84. The floodplain is much less than the recommended 3 times the bankfull width (1.6 yr RI width ratio).

The stream is incised but there is evidence of building floodplain within the existing channel. The bankfull feature indicated by the arrow below has a functional fluvial influence on equilibrium but is consistent with visual observations. Further disturbance to the system will likely reduce stability.

No Photo Available



Channel Dimensions		Flood Dimensions		Materials	
16.2	*X-section area (ft.sq.)*	46.1	*W flood prone area (ft)*	8.5	*D50 Riffle (mm)*
18.0	*Width (ft)*	2.6	*Entrenchment ratio*	39	*D84 Riffle (mm)*
0.9	*Mean depth (ft)*	2.0	*0.8 yr RI Elevation (ft)*	**Regional Channel Size**	
1.5	*Max depth (ft)*	1.0	*0.8 yr RI width ratio*	1.15	*Size ratio*
18.6	*Wetted perimeter (ft)*	2.3	*1.6 yr RI Elevation (ft)*	1.25	*W-D Proportion*
0.9	*Hyd radi (ft)*	1.0	*1.6 yr RI width ratio*	0.6	*Slope (%, SWAT)*
20.0	*Width-depth ratio*	3.7	*50 yr RI Elevation (ft)*	**Stage Discharge Ratios**	
		2.5	*50 yr RI width ratio*	1.3	*$Q_{1.6}$ ratio*
				2.5	*Q_{50} ratio*

(1.6 yr RI assumed to be upper limit of bankfull elevation; based on low bench on left bank, indicated by arrow)

Numeric Estimates and Target Reductions for biological, habitat, and water quality parameters

Current Estimate/ Target Reduction	*DA (mi^2)*	*ICI[a]*	*IBI[b]*	*QHEI[c]*	*Water Quality (flow weighted average)*					
					Nitrate (mg/L)		*TP (mg/L)*		*TSS (mg/L)*	
					NP[d]	**Total[e]**	**NP**	**Total**	**NP**	**Total**
Current	1.0	Not surveyed in 2003-04			n/a	n/a	n/a	n/a	n/a	n/a
Target 1[f] Reduction/Improvement										
Target 2[g] Reduction										

[a] OEPA target ICI scores: EWH ≥ 42; WWH ≥ 32
[b] OEPA target IBI scores: EWH ≥ 46; WWH ≥ 36
[c] OEPA target QHEI scores: EWH ≥ 75; WWH ≥ 60
[d] NP reduction only needed if point sources are meeting the target.
[e] Total is required if it's a collective reduction strategy.
[f] Target 1= OEPA less than 20 sq. mi.
[g] Target 2= WWH less than 200 sq. mi.

Turkey Run 0.7 5060001-120-050

Location: Along Shattuck Avenue upstream of Tillbury Road

Major Impairments:

- Urbanization
- Nutrient Enrichment
- Point Sources

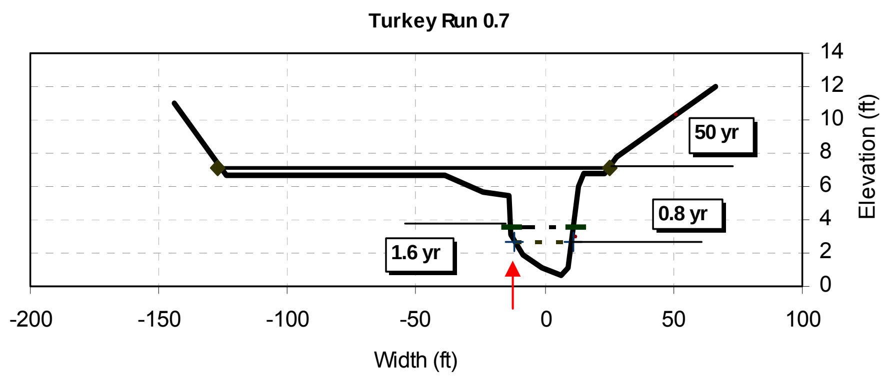
Use Designation: WWH

Attainment Status: Non

Geomorphology Score: 0

Turkey Run is located north of Columbus, OH. It is a first order stream that flows through a moderate/high residential landscape.

Turkey Run is 1.5 times the regional channel size. The particle at incipient motion (predicted D50) was calculated to be 28.4mm, which is between the measured D50 and D84. The floodplain is much less than the minimum recommended 3 times the bankfull width (1.6 yr RI width ratio). But has access to extensive floodplain during high flows. Turkey Run is incised and unattached to a floodplain except during high flow, but may be showing signs of re-establishing equilibrium by building a floodplain within the channel. The bankfull feature indicated by the arrow below has a small functional fluvial influence on equilibrium and is consistent with visual observations. Further disturbances are likely to reduce stability of the sub-watershed. Water quality might be worse than predicted.



Channel Dimensions		Flood Dimensions		Materials	
38.5	*X-section area (ft.sq.)*	31.8	*W flood prone area (ft)*	17	*D50 Riffle (mm)*
23.6	*Width (ft)*	1.3	*entrenchment ratio*	87	*D84 Riffle (mm)*
1.6	*Mean depth (ft)*	2.7	*0.8 yr RI Elevation (ft)*	**Regional Channel Size**	
2.5	*Max depth (ft)*	1.0	*0.8 yr RI width ratio*	1.5	*Size ratio*
24.8	*Wetted perimeter (ft)*	3.6	*1.6 yr RI Elevation (ft)*	0.9	*W-D Proportion*
1.6	*Hyd radi (ft)*	1.0	*1.6 yr RI width ratio*	0.7	*Slope (%, SWAT)*
14.5	*Width-depth ratio*	7.1	*50 yr RI Elevation (ft)*	**Stage Discharge Ratios**	
		6.3	*50 yr RI width ratio*	1.4	*$Q_{1.6}$ ratio*
				3.1	*Q_{50} ratio*

(1.6 yr RI assumed to be upper limit of bankfull elevation; based on low grade break, indicated by arrow)

Numeric Estimates and Target Reductions for biological, habitat, and water quality parameters

Current Estimate/ Target Reduction	*DA (mi²)*	*ICI[a]*	*IBI[b]*	*QHEI[c]*	*Water Quality (flow weighted average)*					
					TP (mg/L)		*Nitrate (mg/L)*		*TSS (mg/L)*	
					NP[d]	Total[e]	NP	Total	NP	Total
Current	2.3	0	20	55	0.08	0.08	11.5	11.5	13	13
Target 1[f] Reduction/Improvement		32	16	5	0.01	0.01	10.5	10.5	4	4
Target 2[g] Reduction					--	--	9.5	9.5	--	--

[a] OEPA target ICI scores: EWH ≥ 42; WWH ≥ 32
[b] OEPA target IBI scores: EWH ≥ 46; WWH ≥ 36
[c] OEPA target QHEI scores: EWH ≥ 75; WWH ≥ 60
[d] NP reduction only needed if point sources are meeting the target.

[e] Total is required if it's a collective reduction strategy.
[f] Target 1= OEPA less than 20 sq. mi.
[g] Target 2= WWH less than 200 sq. mi.

Walhalla Ravine 0.9 5060001-120-050

Location: Intersection of Walhalla Ravine Road and Gudrun Road

Major Impairments:

- Habitat Alteration
- **Urbanization**
- Point Sources

Use Designation: WWH

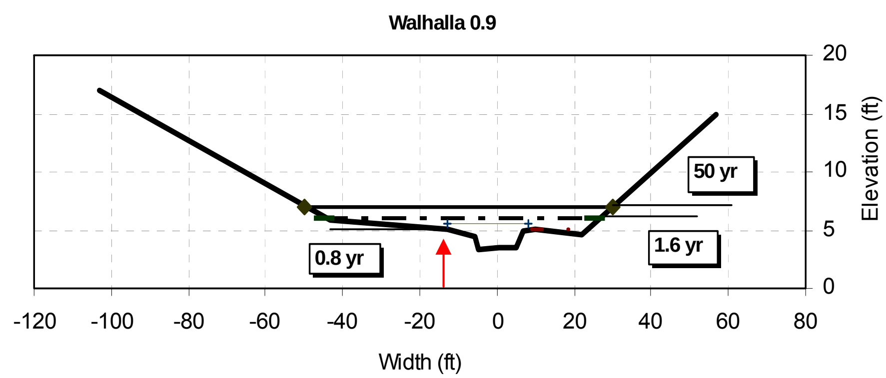
Attainment Status: Non

Geomorphology Score: 5

Walhalla Ravine is a high gradient, bedrock controlled stream in a wooded ravine-like landscape bound on both banks by high density residential housing in Columbus, OH.

Walhalla Ravine is 1.4 times larger than the regional channel size. The particle at incipient motion (predicted D50) was calculated to be 16 mm, which is larger than the measured D50 and D84. It has an extensive, well-attached floodplain that is nearly twice as big as the minimum recommended 3 times the 1.6 year bankfull width.

The bankfull feature indicated by the arrow below has some functional fluvial influence on equilibrium and is consistent with visual observations and an adequate floodplain size. The ability to move larger particles suggests that the benches may be trying to build up to regain stability; and/or the slope given by the SWAT model is inaccurate.



Channel Dimensions		Flood Dimensions		Materials	
10.3	*X-section area (ft.sq.)*	53.8	*W flood prone area (ft)*	4.7	*D50 Riffle (mm)*
12.0	*Width (ft)*	4.5	*Entrenchment ratio*	11	*D84 Riffle (mm)*
0.9	*Mean depth (ft)*	5.6	*0.8 yr RI Elevation (ft)*	**Regional Channel Size**	
1.7	*Max depth (ft)*	1.7	*0.8 yr RI width ratio*	1.4	*Size ratio*
23.8	*Wetted perimeter (ft)*	6.0	*1.6 yr RI Elevation (ft)*	1	*W-D Proportion*
0.9	*Hyd radi (ft)*	5.8	*1.6 yr RI width ratio*	0.7	*Slope (%, SWAT)*
25.1	*Width-depth ratio*	7.0	*50 yr RI Elevation (ft)*	**Stage Discharge Ratios**	
		6.6	*50 yr RI width ratio*	1.2	*$Q_{1.6}$ ratio*
				1.6	*Q_{50} ratio*

(1.6 yr RI assumed to be upper limit of bankfull elevation; based on floodplain on both banks, indicated by arrow)

Numeric Estimates and Target Reductions for biological, habitat, and water quality parameters

Current Estimate/ Target Reduction	*DA (mi²)*	*ICI[a]*	*IBI[b]*	*QHEI[c]*	*Water Quality (flow weighted average)*					
					TP (mg/L)		*Nitrate (mg/L)*		*TSS (mg/L)*	
					NP[d]	Total[e]	NP	Total	NP	Total
Current	0.4	0	12	57.5	n/a	n/a	n/a	n/a	n/a	n/a
Target 1[f] Reduction/Improvement		32	24	2.5						
Target 2[g] Reduction										

[a] OEPA target ICI scores: EWH ≥ 42; WWH ≥ 32
[b] OEPA target IBI scores: EWH ≥ 46; WWH ≥ 36
[c] OEPA target QHEI scores: EWH ≥ 75; WWH ≥ 60
[d] NP reduction only needed if point sources are meeting the target.
[e] Total is required if it's a collective reduction strategy.
[f] Target 1= OEPA 20 sq. mi. to 200 sq. mi.
[g] Target 2= WWH less than 200 sq. mi.

Whetstone Creek 2.0 5060001-100-030

Location: Cline Road and State Route 229

Major Impairments:

- Siltation
- Nutrient Enrichment
- Point Sources

Use Designation: EWH

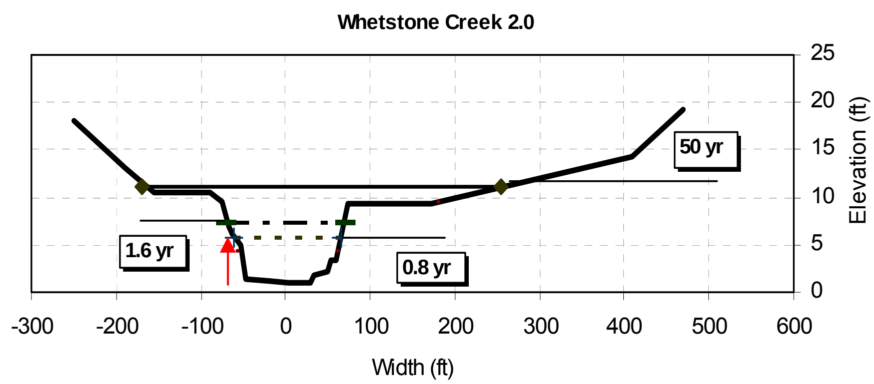
Attainment Status: Non

Geomorphology Score: 4

Whetstone Creek at river mile 2.0 is located in a predominantly rural landscape.

At this location, Whetstone Creek is 0.9 times the regional channel size. The particle at incipient motion (predicted D50) is 17.2 mm, which is similar to the measured D50. The floodplain is much less than the minimum recommended 3 times the bankfull width (1.6 yr RI width ratio).

The bankfull feature indicated by the arrow below has a functional fluvial influence on equilibrium and is consistent with visual observations. At this location Whetstone Creek is somewhat incised and further disturbance to the system likely will reduce stability.



Channel Dimensions		Flood Dimensions		Materials	
397.1	*X-section area (ft.sq.)*	147.6	*W flood prone area (ft)*	14	*D50 Riffle (mm)*
116.0	*Width (ft)*	1.3	*Entrenchment ratio*	150	*D84 Riffle (mm)*
3.4	*Mean depth (ft)*	5.7	*0.8 yr RI Elevation (ft)*	**Regional Channel Size**	
4.1	*Max depth (ft)*	1.1	*0.8 yr RI width ratio*	0.9	*Size ratio*
117.6	*Wetted perimeter (ft)*	7.4	*1.6 yr RI Elevation (ft)*	1.5	*W-D Proportion*
3.4	*Hyd radi (ft)*	1.2	*1.6 yr RI width ratio*	0.2	*Slope (%, SWAT)*
33.9	*Width-depth ratio*	11.2	*50 yr RI Elevation (ft)*	**Stage Discharge Ratios**	
		3.7	*50 yr RI width ratio*	1.4	*$Q_{1.6}$ ratio*
				2.2	*Q_{50} ratio*

(1.6 yr RI assumed to be upper limit of bankfull elevation; based on left bank grade break, indicated by arrow)

Numeric Estimates and Target Reductions for biological, habitat, and water quality parameters

Current Estimate/ Target Reduction	*DA (mi^2)*	*ICI[a]*	*IBI[b]*	*QHEI[c]*	*Water Quality (flow weighted average)* TP (mg/L) NP[d]	TP Total[e]	Nitrate (mg/L) NP	Nitrate Total	TSS (mg/L) NP	TSS Total
Current	113	--	36	61.5	0.27	0.31	3.5	3.5	182	180
Target 1[f] Reduction/Improvement		--	10	13.5	0.16	0.20	2.5	2.5	151	149
Target 2[g] Reduction					0.15	0.19	2.0	2.0	122	120

[a] OEPA target ICI scores: EWH ≥ 42; WWH ≥ 32
[b] OEPA target IBI scores: EWH ≥ 46; WWH ≥ 36
[c] OEPA target QHEI scores: EWH ≥ 75; WWH ≥ 60
[d] NP reduction only needed if point sources are meeting the target.
[e] Total is required if it's a collective reduction strategy.
[f] Target 1= OEPA 20 sq. mi. to 200 sq. mi.
[g] Target 2= EWH 20 sq. mi. to 200 sq. mi.

Whetstone Creek 9.2 5060001-100-010

Location: Waldo-Fulton-Chesterville Road

Major Impairments:
- Siltation
- Nutrient Enrichment
- Point Sources

Use Designation: EWH

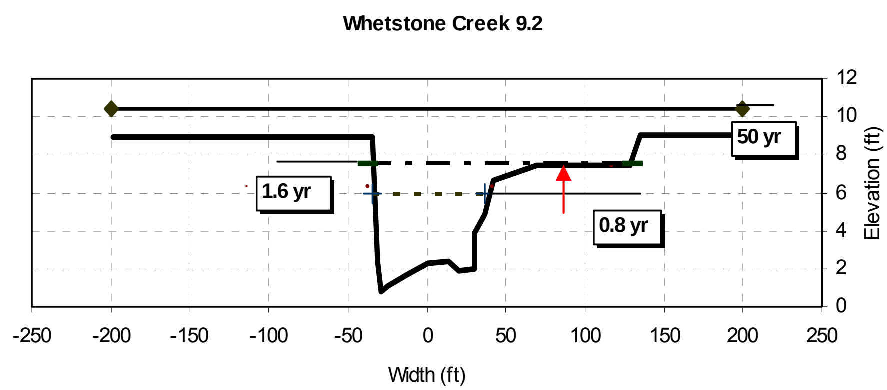
Attainment Status: Non

Geomorphology Score: 4

Whetstone Creek at river mile 9.2 is located just below the confluence with Shaw Creek in a predominantly rural landscape.

At this location, Whetstone Creek is 1.15 times the regional channel size. The particle at incipient motion (predicted D50) is 21 mm, which is between the measured D50 and D84. The floodplain is much less than the minimum recommended 3 times the bankfull width (1.6 yr RI width ratio). However, it has access to a more extensive floodplain during flows slight greater than the predicted 1.6 year RI.

The bankfull feature indicated by the arrow below has a functional fluvial influence on equilibrium and is consistent with visual observations. Further disturbance to the system will likely reduce stability.



Channel Dimensions		Flood Dimensions		Materials	
320.4	*X-section area (ft.sq.)*	734.5	*W flood prone area (ft)*	9.1	*D50 Riffle (mm)*
75.7	*Width (ft)*	9.7	*entrenchment ratio*	42	*D84 Riffle (mm)*
4.2	*Mean depth (ft)*	3.8	*0.8 yr RI Elevation (ft)*	**Regional Channel Size**	
5.9	*Max depth (ft)*	0.9	*0.8 yr RI width ratio*	1.15	*Size ratio*
80.5	*Wetted perimeter (ft)*	4.5	*1.6 yr RI Elevation (ft)*	0.85	*W-D Proportion*
4.0	*Hyd radi (ft)*	1.1	*1.6 yr RI width ratio*	0.2	*Slope (%, SWAT)*
17.9	*Width-depth ratio*	6.3	*50 yr RI Elevation (ft)*	**Stage Discharge Ratios**	
		4.9	*50 yr RI width ratio*	1.2	*$Q_{1.6}$ ratio*
				1.8	*Q_{50} ratio*

(1.6 yr RI assumed to be upper limit of bankfull elevation; based on right bank top grade break, indicated by arrow)

Numeric Estimates and Target Reductions for biological, habitat, and water quality parameters

Current Estimate/ Target Reduction	*DA (mi^2)*	*ICI[a]*	*IBI[b]*	*QHEI[c]*	*Water Quality (flow weighted average)*					
					TP (mg/L)		*Nitrate (mg/L)*		*TSS (mg/L)*	
					NP[d]	Total[e]	NP	Total	NP	Total
Current	62.0	--	40	68.5	0.22	0.30	3.3	3.3	140	186
Target 1[f] Reduction/Improvement		--	6	6.5	0.11	0.19	2.3	2.3	109	155
Target 2[g] Reduction					0.10	0.18	1.8	1.8	80	126

[a] OEPA target ICI scores: EWH ≥ 42; WWH ≥ 32
[b] OEPA target IBI scores: EWH ≥ 46; WWH ≥ 36
[c] OEPA target QHEI scores: EWH ≥ 75; WWH ≥ 60
[d] NP reduction only needed if point sources are meeting the target.
[e] Total is required if it's a collective reduction strategy.
[f] Target 1= OEPA 20 sq. mi. to 200 sq. mi.
[g] Target 2= EWH 20 sq. mi. to 200 sq. mi.

Whetstone Creek 29.3 5060001-100-010

Location: West side of County Road 59 near Candlewood Lake

Major Impairments:

- Siltation
- **Habitat Alteration**
- Nutrient Enrichment
- Point Sources

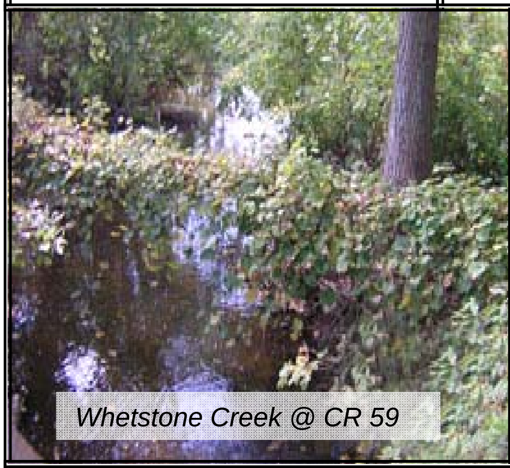
Use Designation: EWH

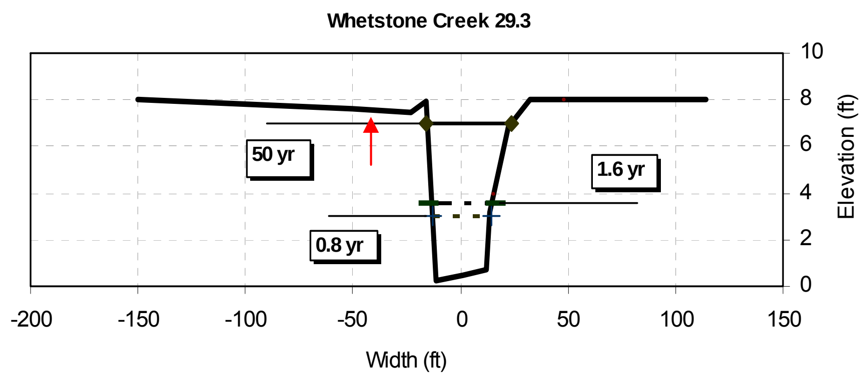
Attainment Status: Non

Geomorphology Score: 3

Whetstone Creek at river mile 29.3 is located in a predominantly rural landscape bordered by pasture on both sides, and is downstream of Candlewood Lake WWTP.

At this location, Whetstone Creek is 1.05 times the regional channel size. The particle at incipient motion (predicted D50) is 53 mm, which is between the measured D50 and D84. The floodplain is much less than the minimum recommended 3 times the bankfull width (1.6 yr RI width ratio). The bankfull feature indicated by the arrow below has limited functional fluvial influence on equilibrium and is consistent with visual observations. The stream is heavily incised with no predicted attachment to the floodplain. There are signs near the County Road 59 bridge that bankfull is consistent with the 0.8 yr and 1.6 yr RI shown below. This system is dam controlled; therefore, it is difficult to match the hydrology. It is possible that bankfull occurs at a lower elevation than what is indicated in the cross-section but the more likely inconsistency in the results is due to an over-prediction of the bed slope that has placed each of the reported discharges lower in the channel than what occurs.





Channel Dimensions		Flood Dimensions		Materials	
68.6	*X-section area (ft.sq.)*	35.4	*W flood prone area (ft)*	30	*D50 Riffle (mm)*
26.8	*Width (ft)*	1.3	*Entrenchment ratio*	81	*D84 Riffle (mm)*
2.6	*Mean depth (ft)*	3.0	*0.8 yr RI Elevation (ft)*	**Regional Channel Size**	
3.0	*Max depth (ft)*	1.0	*0.8 yr RI width ratio*	1.05	*Size ratio*
29.9	*Wetted perimeter (ft)*	3.6	*1.6 yr RI Elevation (ft)*	0.55	*W-D Proportion*
2.3	*Hyd radi (ft)*	1.2	*1.6 yr RI width ratio*	0.8	*Slope (%, SWAT)*
10.4	*Width-depth ratio*	7.0	*50 yr RI Elevation (ft)*	**Stage Discharge Ratios**	
		1.5	*50 yr RI width ratio*	1.2	*$Q_{1.6}$ ratio*
				1.9	*Q_{50} ratio*

(1.6 yr RI assumed to be upper limit of bankfull elevation; based on incised top of bank, indicated by arrow)

Numeric Estimates and Target Reductions for biological, habitat, and water quality parameters

Current Estimate/ Target Reduction	*DA (mi^2)*	*ICI[a]*	*IBI[b]*	*QHEI[c]*	*Water Quality (flow weighted average)*					
					TP (mg/L)		*Nitrate (mg/L)*		*TSS (mg/L)*	
					NP[d]	Total[e]	NP	Total	NP	Total
Current	8.4	0	41	73	0.38	0.38	4.7	4.7	405	405
Target 1[f] Reduction/Improvement		42	5	2	0.31	0.31	3.7	3.7	396	396
Target 2[g] Reduction					0.30	0.30	3.7	3.7	365	365

[a] OEPA target ICI scores: EWH ≥ 42; WWH ≥ 32
[b] OEPA target IBI scores: EWH ≥ 46; WWH ≥ 36
[c] OEPA target QHEI scores: EWH ≥ 75; WWH ≥ 60
[d] NP reduction only needed if point sources are meeting the target.
[e] Total is required if it's a collective reduction strategy.
[f] Target 1= OEPA less than 20 sq. mi.
[g] Target 2= EWH less than 20 sq. mi.

Chapter 5: Statistical Analysis of Biological and Environmental Variables

5.0 Introduction

The structure and function of aquatic communities is influenced by a number of spatial and temporal factors. At the watershed scale, factors like climate, geomorphology, and zoogeography influence regional species pools (Williams et al., 2002). Regional pools, in turn, are influenced by biotic interactions and abiotic factors producing local species assemblages (Tonn et al., 1990). The structure of local fish assemblages has been linked to factors including geography, geology and climate, richness of regional species pools (Angermeier and Winston, 1998), stream order and network position (Pusey et al., 1995; Williams et al., 2005), local stream habitat, water quality, and flow characteristics (Matthews et al., 1994).

There is adequate evidence that single-factor explanations for fish assemblage structure are inadequate, and recent work has focused on determining the relative importance of factors acting at different spatial scales, with particular emphasis on large-scale versus local effects (Osborne et al., 1992; Kelso and Minns, 1996; Wang et al., 2003; Williams et al., 2005). It is difficult to distinguish among natural inherent variability, variability associated with past disturbance events, or variation related to events triggered by anthropogenic activities because there are so many processes across the watershed that are not easily quantified. Knowing which and how different spatial scale factors affect stream communities increases our ability to detect anthropogenic influences, identify biological response signatures to human-induced stress and ultimately improve river structure and function (Weigel, 2003).

Because streams are intimately linked to terrestrial landscape-level and local processes, aquatic biota such as fishes and macroinvertebrates are useful environmental indicators for explaining impacts of disturbances on streams. Ohio is one of the few states that incorporate biology and physical habitat into Water Quality Standards (Yoder and Rankin, 1998). The Ohio Environmental Protection Agency (EPA) uses a variety of multi-metric indices to assess stream structure and function, including the Index of Biotic Integrity (IBI; Karr, 1981; 1986; Fausch et al., 1984), the Invertebrate Community Index (ICI; DeShon, 1995), and the Qualitative Habitat Evaluation Index (QHEI; Rankin, 1989; 1995) among others. While these indices are useful for revealing water quality problems and potential correlative sources, the ecological relationships among biota and habitat are not easily elucidated. Integrating biology, habitat, and water quality in a quantitative manner is complex and has seen limited study. Furthermore, the role of stream processes and stream geomorphology in influencing stream function is relatively unknown and generally has not been considered in Total Maximum Daily Load (TMDL) studies around the nation.

Our first objective was to identify key environmental variables within the watershed and reach scales that structure stream fish assemblages. Our second objective was to evaluate the relative influence of environmental variables from different spatial scales in determining fish assemblages. Our third objective was to compare geomorphology and water chemistry variables measured in the field with estimates from computer models. Physical habitat, geomorphology, spatial location, and water quality variables were assessed by site with multiple regression techniques to detect spatial and temporal differences in IBI score.

Wang et al. (2003) used multivariate statistical techniques to evaluate the relative importance of watershed-scale and reach-scale habitat conditions in structuring stream fish assemblages. They concluded that reach-scale factors were the primary determinant of stream-fish assemblages in relatively undisturbed stream ecosystems but that watershed-scale factors became increasingly important as the degree of landscape modifications increased. Examining the relationships between local species assemblages and environmental variables at multiple spatial scales, from local- to landscape-level, will ultimately assist state regulatory agencies in prioritizing the scale at which to revitalize, manage and derive policies for stream ecosystem integrity in the Olentangy River watershed and throughout the region.

5.1 Methods

To conduct this study, we had the benefit of access to Ohio EPA's extensive database for the Olentangy River watershed. We collected geomorphology, spatial location, and computer model-generated water chemistry at many locations throughout the watershed based on places that had existing Ohio EPA biological data. The first task presented to us was how to manage the large data sets to organize them and match them up by site and year to ensure that statistical analysis would be valid using the most data available to us. A major challenge simply was interpreting the data as it was collected, at multiple sites and over multiple years. A second major challenge was matching data by site and handling missing values in the data analysis. A third major challenge was presenting the data in a formal, but succinct way.

To aid in this endeavor, the OSU team created a flow chart showing all of the data sets used in this study, year(s) they were collected, and how many locations within the watershed were represented by each category of data (Figure 5.1). The flow chart also shows how we moved from the baseline data sets to reduced versions to create the statistical models. Because we were analyzing the influence of environmental factors on fish assemblages, it was necessary that all environmental data had corresponding IBI data for a particular site. Implications of using reduced data sets will be discussed later in the chapter.

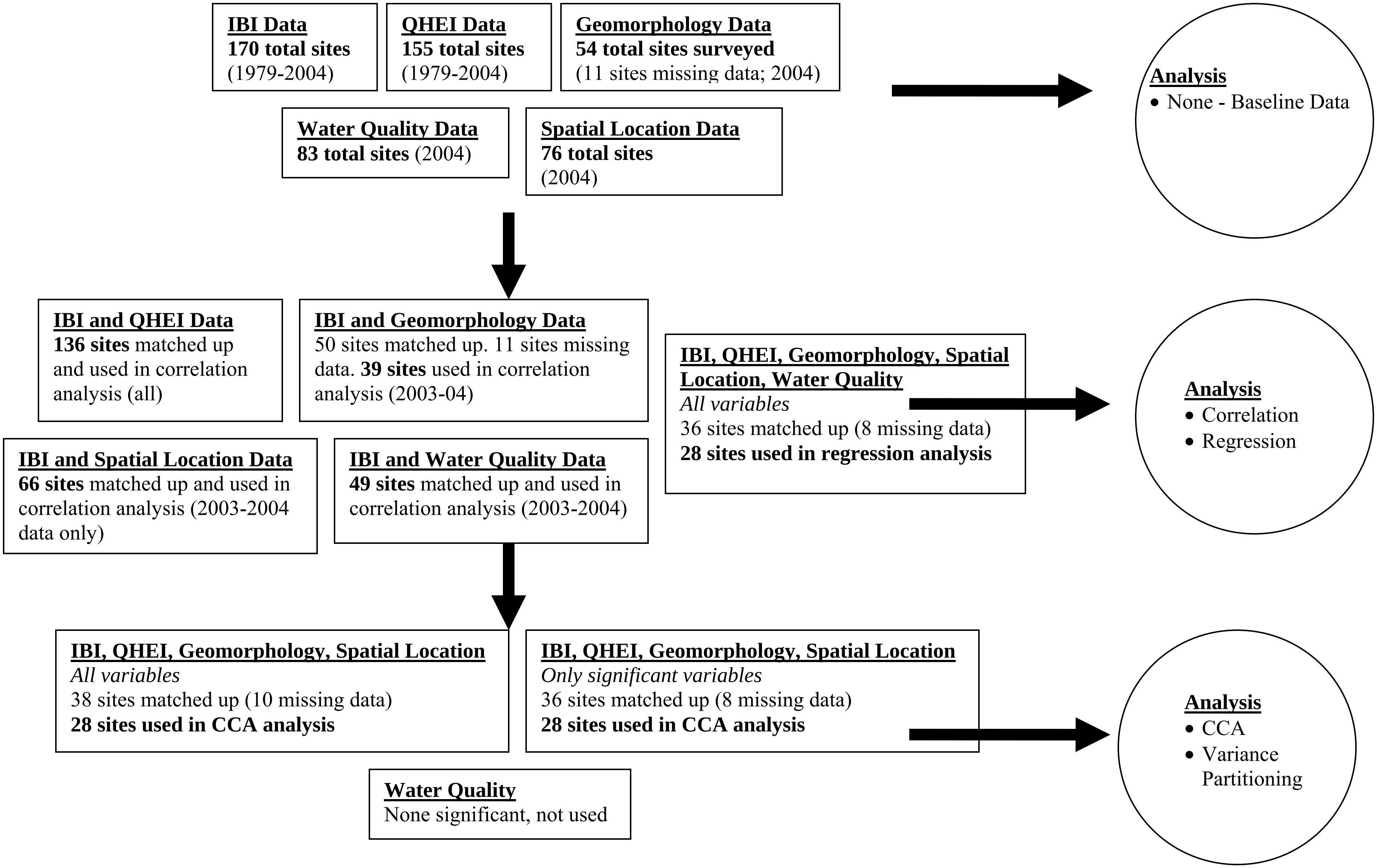


Figure 5.1 Data derivation flow chart for statistical analysis relating fish assemblages (IBI score) to environmental variables in the Olentangy River watershed. Each box on the left indicates the type of data, how many total sites from that data set were available and from what year(s), and how many total sites were used and from what year(s) in subsequent analyses. Moving from top to bottom, datasets become smaller because of incompleteness and/or inconsistent data collection across the range of sites available. The type of analysis that the data was used for is indicated by the circles.

5.1.1 IBI and Environmental Variables

Fish can be one of the most sensitive indicators of the quality of the aquatic environment for multiple reasons including (Ohio EPA, 1987):

- Fish, as end products of most food webs, are integrators of community response to environmental disturbance.
- Fish are highly recognizable and valued by the public.
- Fish reproduce and complete their entire life cycle in an aquatic environment.
- Fish are highly sensitive to a variety of substances and physical disturbances.
- Fish are readily identifiable, and abundant information on their life histories is available.

IBI relies on 12 community metrics within three broad categories (species richness and composition, trophic composition, and fish abundance and condition) to assess fish community attributes that are presumed to correlate with biotic integrity. Although no one metric alone can indicate this consistently, all of the IBI metrics combined include the redundancy needed to obtain a consistent measure of biotic integrity (Angermeier and Karr, 1986). Therefore, we analyzed the influence of environmental variables on the aggregate IBI score for each site. Ohio EPA collected IBI data for a total 170 sites in the Olentangy River watershed from 1979 to 2004. Seventy-nine of those sites were surveyed in 2003 and 2004. Where more than one IBI score was calculated for one site in the same sampling year, the IBI scores were averaged. Where IBI score was calculated for both 2003 and 2004, the most recent data were used.

5.1.2 Physical Habitat

The IBI-type assessments often use ecoregions (Omernik and Gallant, 1988) as the basic classification unit. In this case, all streams within an ecoregion are assumed to be similar, and test sites are compared with reference sites within the ecoregion. Frequently, however, streams are not homogeneous at the ecoregion scale (Wang et al., 2003), and finer-scale classifications have been developed based on physical attributes that are important in structuring biological assemblages. In these cases, test sites are compared with reference sites having similar characteristics such as stream size or use designation (Ohio EPA, 1987).

The QHEI was developed based on knowledge of fish habitat and is intended to be both positively and negatively correlated with IBI scores. While we test the correlation of the QHEI and its metrics to IBI scores in this study, of greater importance is how the QHEI compares to other environmental variables such as geomorphology, water quality, and spatial location within the watershed in affecting IBI scores. In our study, stream habitat is represented by QHEI metrics: substrate quality, channel morphology, pool/glide quality, riffle/run quality, in-stream cover, riparian zone quality and gradient (ft/mi). Ohio EPA has QHEI data for a total of 155 sites in the Olentangy River watershed from

1979 to 2004. Data on QHEI were collected by Ohio EPA during 2003 and 2004 at 77 of those locations. Where data were available for both 2003 and 2004, the most recent data were used.

5.1.3 Geomorphology

Linking stream geomorphology to physical habitat characteristics may partially explain differing channel responses to effects of land use change on stream communities. Measured geomorphology variables were: slope (ft/ft, reach surveys; slope from cross-section surveys was estimated using the SWAT model), bankfull width (feet), mean depth (feet), cross sectional area (square feet), sinuosity, entrenchment ratio, width of the flood prone area (feet), hydraulic radius (feet), width to depth ratio, and bed material size (D_{50} and D_{84}; millimeters). Measured data, including both entire reach surveys and cross-sectional surveys, were collected at 54 sites throughout the Olentangy River watershed by the OSU team in 2004. Fifty of those sites contained corresponding IBI data to analyze geomorphologic influence on 2003 and 2004 IBI scores.

5.1.4 Spatial Location

Numerous studies have led to the development of models that emphasize the linkage between downstream community structure and function to upstream processes (e.g., Vannote et al., 1980; Minshall, 1988). Empirical evidence also suggests that basin characteristics influence processing rates of nutrients, such as nitrogen and phosphorus, and the distribution and abundance of aquatic organisms in stream channels (Wiley et al., 1990; Covich, 1988). Large-scale watershed investigations suggest that fish species richness generally increases with increasing drainage area in low to mid order streams although it is not clear whether this is a result of increasing habitat diversity, differential immigration and extinction rates, or simply a sampling trend because larger areas generally support more individuals (Power et al., 1988).

Because the location of stream channels within a drainage network appears to influence IBI scores causing resource manager to underestimate biotic integrity in headwater tributary streams or over estimate the quality of main channel tributary streams (Osborne et al., 1992), we described the relationship of a given stream reach to upstream and downstream influences within the Olentangy River watershed. Spatial location in reference to the Olentangy River mainstem was represented by stream order (as described by Strahler, 1952), drainage area (mi^2), river mile, distance downstream to next order stream (feet), distance upstream to a wooded riparian zone (feet), and percent wooded riparian zone within one square mile of the survey site. Spatial location variables were created by the OSU team as a way to express connectivity of the Olentangy watershed for a total of 76 sites using visual observation and ArcGIS 1:24,000 scale topographic maps, Digital Elevation Models and aerial photographs. Sixty-six of those sites had corresponding IBI information and were used to determine spatial location influence on IBI scores.

5.1.5 Water Quality

Traditionally, TMDLs are based on watershed-scale water quality modeling, which attempts to integrate non-point and point source inputs to the watershed. This modeling approach, however, is confounded when factors such as natural constituents (e.g., sediment) are considered, and when habitat must be included (Yoder and Smith, 1999). Uncertainty becomes extremely high when results are extrapolated across a watershed. Often, the targeted water quality end-points are indirect substitutes for more direct biological indicators.

Measured water chemistry, represented by the mean and median values of the following constituents analyzed from Ohio EPA grab samples collected in 2004, include: nitrate-N, ammonia-N, nitrite-N, total phosphorus, total suspended solids, fecal coliform, total Kjeldahl nitrogen, and biological oxygen demand (BOD). Eighty-three sites were sampled in the Olentangy River watershed during 2003-2004. Forty-nine of those sites contained corresponding 2003-2004 IBI data and were used to analyze measured water chemistry influence on IBI score. However, the grab samples only provide a snapshot in time of the water quality signature of the watershed.

5.1.6 Species–Environment Statistical Methods

Distinguishing the environmental variables important in explaining fish distribution and abundance from those of less importance is a multivariate problem. To understand how a fish assemblage responds to a multitude of external factors, aquatic ecologists have used a variety of methods including multiple regression analysis, multivariate analysis of variance, factor analysis, correspondence analysis, principal components analysis, and canonical correspondence analysis for systems in the United States and elsewhere (Matthews et al., 1994; Taylor et al., 1993; Pusey et al., 1995, Williams et al., 2003 and 2005).

In assessing the response of fish assemblages to physical, chemical and spatial factors, we sought a statistically succinct way of handling large amounts of information available to us through our own investigations and data provided by Ohio EPA. For complex, large-scale questions in community ecology, standard parametric multivariate tools (i.e., MANOVA) often are inappropriate for testing hypotheses and data rarely meet the assumptions of these tests (Williams et al., 2005). Typical univariate analyses usually are inappropriate because intercorrelated response variables do not adequately express the complexity of the relationship between independent and dependent variables (McCune and Grace, 2002; Williams et al., 2005).

In order to employ multivariate statistical techniques to shorten a long list of variables containing somewhat redundant information about the watershed, the information must be uncorrelated linear combinations of variables derived from the original data set. To reduce the data set from seven to nine variables per category to three to five variables per category, for example, we first assessed the correlation of the variables to each other and to IBI score. First, we created a correlation matrix for each of the four categories of variables: habitat represented by QHEI, geomorphology, spatial location, and water quality. We began by setting our minimum correlation threshold to 0.3, and eliminated any variables below this threshold. Then, we assessed the variables against each other to determine which variables grouped together. Finally, we assessed the grouped variables for correlation to IBI score. For example, river mile, stream order and drainage area are highly correlated with each other and with IBI score within the spatial location category. Stream order showed the strongest correlation to IBI score, followed by drainage area, therefore, river mile was eliminated from the list of variables describing spatial location.

We then conducted linear and stepwise multiple regression analyses to determine which of the remaining variables were significant ($p < 0.05$, except water quality variables where $p < 0.1$) to further reduce the data set. To ensure that significant variables were not inadvertently eliminated during the correlation analysis, we also conducted linear and stepwise multiple regression analyses using all the variables of the original data set. In our study, correlation and simple linear regression analyses were done using the Systat v.11 statistical software package (SSI, 2004).

We used canonical correspondence analysis (CCA; ter Braak, 1986) to determine the relationship of total fish assemblage (IBI metrics; dependent variables) to the environmental factors which are most important in contributing to spatial segregation in the Olentangy River watershed: stream habitat, geomorphology, water quality and spatial location (independent variables). CCA is a direct gradient analysis widely utilized in ecology for ordinating species and environmental data simultaneously where an ordination of one multivariate matrix is constrained by multiple linear regressions on variables in a second matrix (McCune and Grace, 2002). The underlying assumption of CCA is that species exhibit Gaussian-type (unimodal) responses to environmental gradients; or, that within their range species will be most abundant around their environmental optima for survival (ter Braak and Verdonschot, 1995). Recent authors have used similar multivariate techniques to test hypotheses about species-environment relationships at different spatial and temporal scales or the effects on aquatic assemblages (ter Braak and Verdonschot, 1995; Jongman et al., 1995; Wang et al., 2003; Williams et al., 2003; Williams et al., 2005). We applied CCA using the computer program Canoco (ter Braak and Smilauer, 2002). Variables with a p-value less than 0.05, using Monte Carlo tests (1,000 permutations), were retained in the analysis. We then inferred the nature of the species–environment relationship from intraset canonical correlation coefficients of environmental variables with CCA axes.

We used a variance partitioning technique to relate variation in fish assemblage to the explanatory variables for each category (as described in Williams et al., 2005). Variance partitioning is accomplished by a series of partial CCAs. For each of the three categories (geomorphology, habitat, and spatial location), we used the other two categories as covariates in the analysis to assess the pure effects of each. We computed the percent variance in IBI metrics that were explained by each independent variable set. For each partial CCA, we used Monte Carlo tests (1,000 permutations) to estimate the significance of each variable ($p < 0.05$).

5.2 Results

5.2.1 Correlation Analysis

Nine environmental variables out of 32 from the four categories habitat, geomorphology, spatial location, and water quality were retained following correlation (Table 5.1). None of the water quality constituents were significant, and thus were not retained for regression analysis.

Table 5.1 Correlation analysis results from SYSTAT showing environmental variables retained for regression analysis (bold variables have r^2 = *0.3* or greater).

Environmental Categories			
Habitat		**Geomorphology**	
Original Variables	*Reduced Data Set*	*Original Variables*	*Reduced Data Set*
• QHEI Score • In-stream Cover • Channel Quality • Riparian Quality • Pool/Glide Quality • Riffle/Run Quality • Gradient (ft/mi)	• **Pool Quality** • **Gradient (ft/mi)**	• Stream Length (mi) • Elevation (source, ft) • Elevation (mouth, m) • Average Fall (ft/ft) • D_{50} (mm) • D_{84} (mm) • Width of the flood prone area • Cross sectional area (ft^2) • W:D ratio • Entrenchment Ratio • Hydraulic Radius (ft)	• **Elevation (mouth, ft)** • **Average Fall (ft/ft)** • **Cross sectional area (ft^2)** • **W:D ratio**
Spatial Location		**Water Quality**	
Original Variables	*Reduced Data Set*	*Original Variables*	*Reduced Data Set*
• Stream Order • Distance upstream to wooded riparian zone (m) • Riparian zone percentage • Distance downstream to next higher order stream (m) • River Mile • Drainage Area (km^2)	• **Drainage Area (mi^2)** • **Stream Order** • **Riparian zone percentage**	• Nitrate (median, mean) • Ammonia (median, mean) • Nitrite (median, mean) • Total phosphorus (median, mean) • Total Suspended Solids (median, mean) • Fecal coliform (median, mean) • Total Kjeldahl Nitrogen (median, mean) • Biological Oxygen Demand (BOD; median, mean)	• **None significant**

5.2.2 Regression Analysis for Significance

When regression analysis was conducted on all variables of the data set, results were similar to the reduced data set analysis as in the example below using spatial location variables (Table 5.2); therefore, we had confidence that our initial correlation analysis was correct. The most significant environmental variables influencing IBI score in the Olentangy River watershed were pool quality (p = 0.005), gradient (p = 0.041), stream order (p < 0.000), and elevation at the mouth (p = 0.023).

Table 5.2 Systat linear regression results for (a) all variables of the spatial location category (independent variables) and IBI score (dependent variable), and (b) reduced set of significant variables from the correlation analysis (*p < 0.05*).

(a) All Spatial Location Variables

Dep Var: IBI N: 66 Multiple R: 0.796 Squared multiple R: 0.634
Adjusted squared multiple R: 0.597 Standard error of estimate: 6.264

Effect	Coefficient	Std Error	Std Coef	Tolerance	t	P(2 Tail)
CONSTANT	17.019	2.600	0.000	.	6.545	0.000
RM	0.811	0.880	0.726	0.010	0.921	0.361
DRNAREA	-0.159	0.066	-0.330	0.328	-2.398	0.020
STREAMORDER	7.803	1.311	0.912	0.264	5.952	0.000
DISTTORIP	0.001	0.000	0.122	0.802	1.391	0.169
RIPZONEPCT	0.170	0.062	0.251	0.748	2.753	0.008
DISTNXTORDR	-0.000	0.001	-0.663	0.010	-0.842	0.403

(b) Reduced Spatial Location Data Set

Dep Var: IBI N: 66 Multiple R: 0.793 Squared multiple R: 0.629
Adjusted squared multiple R: 0.598 Standard error of estimate: 6.257

Effect	Coefficient	Std Error	Std Coef	Tolerance	t	P(2 Tail)
CONSTANT	17.309	2.578	0.000	.	6.715	0.000
DRNAREA	-0.149	0.065	-0.308	0.338	-2.276	0.026
STREAMORDER	7.777	1.309	0.909	0.265	5.941	0.000
DISTTORIP	0.001	0.000	0.111	0.818	1.277	0.207
RIPZONEPCT	0.164	0.061	0.242	0.757	2.671	0.010
DISTNXTORDR	0.000	0.000	0.057	0.618	0.568	0.572

5.2.4 Canonical Correspondence Analysis

The environmental variables most important in explaining IBI metrics and scores were determined by examining correlation with CCA ordination axes. The correlation of an environmental variable with each axis indicates the strength of its relationship with a particular stream and/or fish assemblage attributes. Arrows indicating relative importance and direction of environmental variables were placed on the axes by Canoco. Each arrow points in the direction of maximum variation in value of the corresponding variables. The most important environmental variables (in terms of explaining fish assemblage) have longer arrows than less important variables. Only significant variables from the regression analysis were used for the CCA (Table 5.3).

Table 5.3 Environmental variable data set available for the Olentangy River watershed. Items in bold were found to be significant (*p<0.05*) after correlation and regression analyses and were retained for CCA analyses.

Spatial Location	Habitat	Geomorphology	Water Quality
• **Drainage Area (mi^2)** • **Stream Order** • **Riparian zone percentage** • River Mile • Distance upstream to wooded riparian zone (ft) • Distance downstream to next higher order stream (ft)	• **Pool Quality** • **Gradient (ft/mi)** • QHEI Score • In-stream Cover • Channel Quality • Riparian Quality • Riffle/Run Quality	• **Elevation (mouth, ft)** • **Average Fall (ft/ft)** • **Cross sectional area (ft^2)** • **W:D ratio** • Stream Length (mi) • Elevation (source, ft) • D_{50} (mm) • D_{84} (mm) • Width of the flood prone area (ft) • Entrenchment Ratio • Hydraulic Radius (ft)	• None

Canonical correspondence analysis of IBI metrics and environmental variables reflected spatial differences (Figure 5.2) within the Olentangy River watershed and between fish assemblage attributes represented by metrics of the IBI score (Figure 5.3). The first and second axes explained 90% of variance.

The lower portion of the Olentangy River watershed is distinctly different from the Whetstone Creek watershed streams and only similar to the upper portion of the watershed near the Delaware Reservoir. The upper portion of the watershed is distinctly different from the Whetstone Creek watershed except for streams closest to the boundary between the two watersheds including Flat Run, Claypool Run, and Mitchell Run.

Stream reaches within the lower Olentangy watershed tend to be higher gradient and wider than they are deep most likely because they are predominantly bedrock controlled and located in ravine-like settings. Streams located in the upper Olentangy watershed tend to be low gradient agricultural streams with relatively poor riparian zones and in-stream habitat. Streams within the Whetstone Creek watershed tend to be higher gradient with relatively good in-stream habitat and riparian zones.

Individual metrics of the IBI were superimposed on the ordination diagram of the environmental arrows to interpret fish assemblage variation (Figure 5.3). Cyprinids and sunfish species are closest to the centroid indicating they are more associated with average stream quality and can be found almost anywhere within the watershed. Headwater species, darters, and simple lithophilic species tend to need higher stream quality in the form of amount of riparian zone and better pool quality. Insectivores are associated with stream gradient and width-to-depth ratio. Not surprisingly, more intolerant species and top carnivores are found in larger streams, and omnivores are associated with poor stream quality.

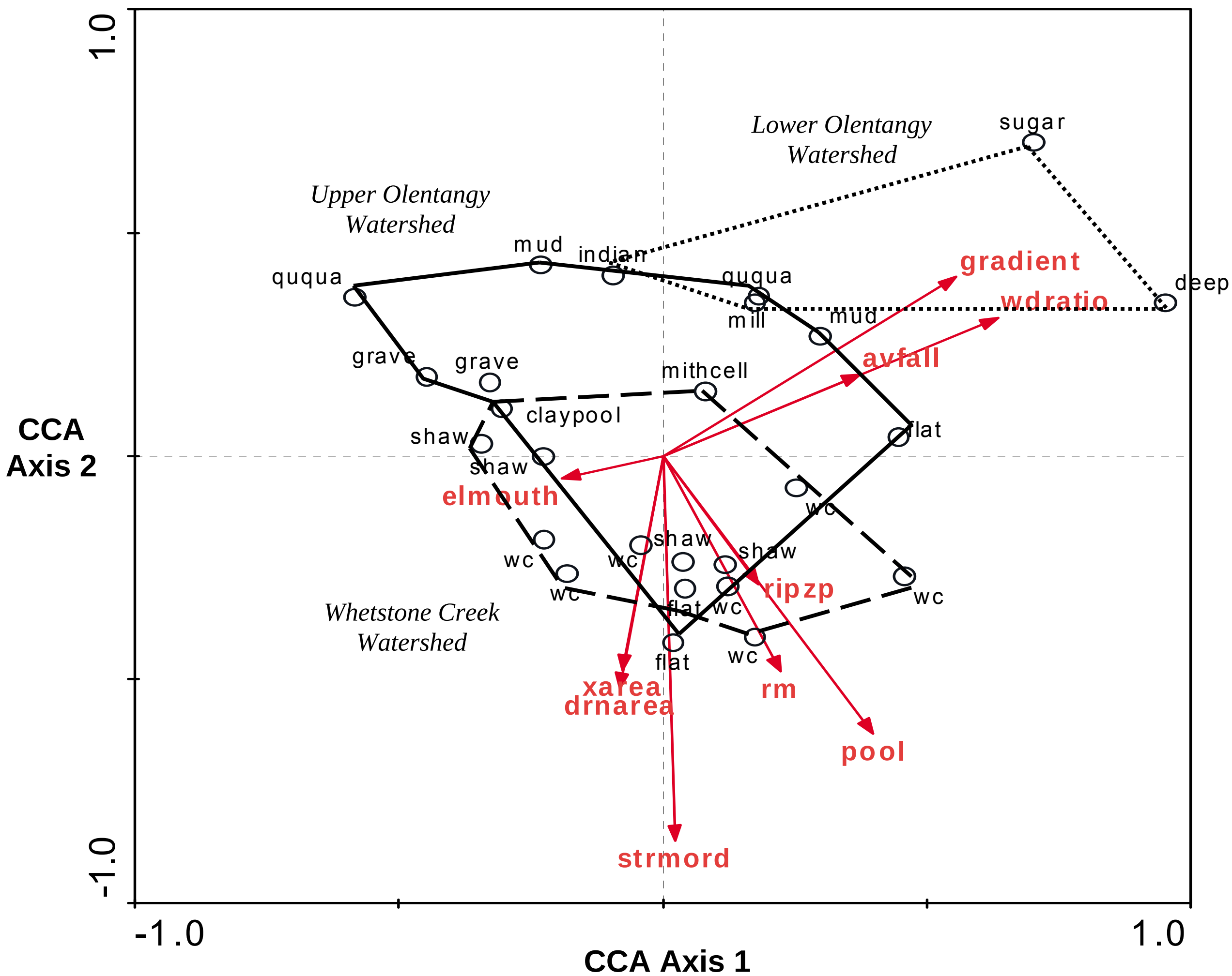


Figure 5.2 CCA ordination diagram showing stream reaches superimposed on significant environmental variables (arrows; *p<0.05*) most closely associated with axes CCA1 and CCA2 using Canoco. *Variables include: Stream order (strmord), pool quality (pool), river mile (rm), drainage area (drnarea), cross sectional area (xarea), riparian zone percentage (ripzp), elevation at the mouth (elmouth), gradient, average fall (avfall), and width to depth ratio (wdratio). Regions of the watershed are identified and partitioned by dashed line boundary (Whetstone Creek Watershed), dotted line boundary (Lower Olentangy Watershed below Delaware Reservoir), and solid line boundary (Upper Olentangy Watershed above Delaware Reservoir). Overlap of boundaries indicates similarity between sites and regions of the watershed.*

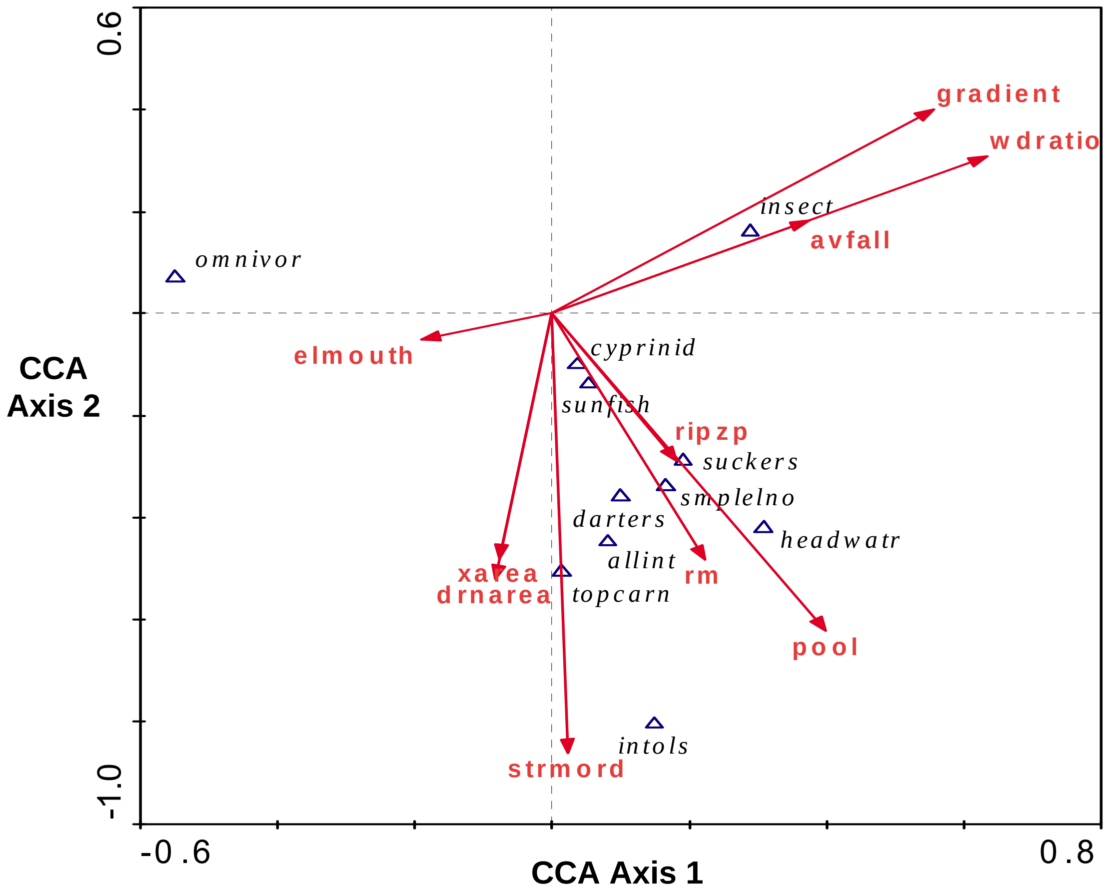


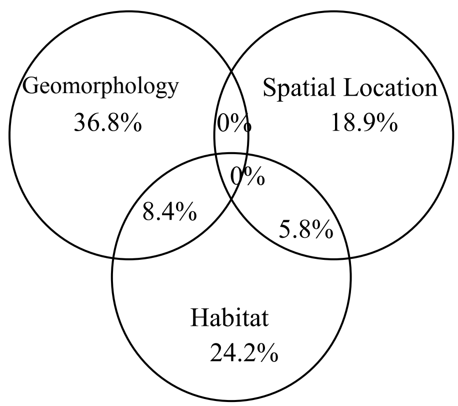
Figure 5.3 Canonical correspondence analysis ordination of the individual metrics of the Index of Biotic Integrity (IBI) (excludes DELT metrics because of limited available data for this metric for most sites analyzed) superimposed on an ordination of environmental variables for the Olentangy River watershed.

5.2.5 CCA Variance partitioning

All of the environmental variables in the data explained seventy-nine percent of the variability in IBI metrics, yet were not statistically significant most likely because the data set included a lot of intercorrelated variables (Figure 5.4a). The pure effects of geomorphology (36.8%) explained more variation than spatial location (18.9%) and habitat as represented by the QHEI (24.2%). Shared variation between geomorphology and habitat represented 8.4% while shared variation between habitat and spatial location represented 5.8%. There was no shared variation between geomorphology and spatial location or among the three categories combined. Total uncertainty, or the environmental variables that influence IBI metrics that can not be accounted for because they were not measured or could not be quantified, is 21%.

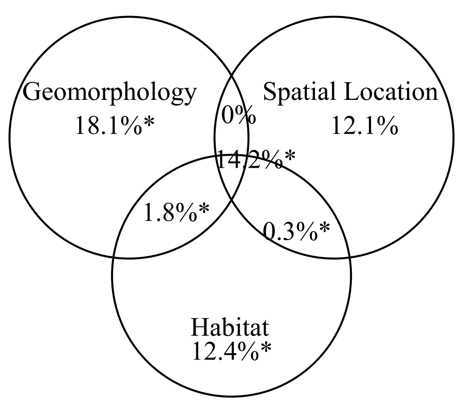
Fifty-nine percent of the variability in IBI metrics was explained by modeling only the most significant variables from each category (Figure 5.4b). The pure effects of geomorphology (18.1%) explained more variation than spatial location (12.1%) and habitat as represented by the QHEI (12.4%). Shared variation between geomorphology and habitat was 1.8%; and between habitat and spatial location was 0.3%. There was no shared variation between geomorphology and spatial location. Shared variation among all three categories was 14.2%. Total uncertainty for the reduced data set is 41%. Although using only significant environmental variables resulted greater uncertainty, we have more confidence in the statistical model. Using this model, we were able to explain 60% to 80% of the variation in fish assemblages as represented by IBI metrics in the Olentangy River watershed. These results are consistent with findings from other authors (Williams et al., 2002).

(a) All Biological and Environmental Variables



Total uncertainty: 21%

(b) Only Significant Biological and Environmental Variables



Total uncertainty: 41%

Figure 5.4 CCA variance partitioning results showing the pure effects and shared variation of each environmental category geomorphology, spatial location, and habitat represented by QHEI for (a) all variables of the data set, and (b) the reduced data set of significant variables. *An * indicates significance ($p<0.05$) with a Monte Carlo test.*

We also explored how the results would change if some of the variables with high leverage were removed from the analysis. First, it appeared that Deep Run and Sugar Run had high leverage and were strongly associated with geomorphology variables width-to-depth ratio and average fall (Figure 5.2). We eliminated these sites from the analysis and re-ran the variance partitioning using significant variables. Results indicated that although variability explained by the pure effects of each of the three categories decreased, geomorphology and spatial location explained equal variability, which was more than QHEI.

In the second leverage analysis, we examined how the results would change if there were more equal sites within a particular watershed represented. For example, the original analysis contained 7 sites on Whetstone Creek and 4 sites on Shaw Creek whereas the other sub-watersheds contained only one to two sites each. In this analysis we only allowed three sites each from Whetstone Creek and Shaw Creek (at the outlet, in the middle, at the top). Again, variability explained by the pure effects of each environmental category was less, but geomorphology and spatial location explained similar amounts of variability in the IBI, which was more than QHEI.

5.3 Predicted Water Quality Analysis

In a similar correlation and regression analysis as the one described above, we evaluated the influence of predicted, or modeled, environmental variables on IBI score in the Olentangy River watershed. Using measured data from the 36 sites mentioned in Chapter 4 (Appendix 4.C), the OSU team generated water chemistry (total phosphorus, nitrate-N and total suspended solids) from SWAT, calculated the 1.6-year floodplain ratios and stage-discharge ratios using the STREAM spreadsheet modules, and developed a qualitative geomorphology index (see Chapter 4). Predicted, or estimated, geomorphology variables associated with the 1.6 year recurrence interval were used in a regression analysis ($p<0.1$) along with predicted water chemistry, IBI score, spatial location, and habitat represented by metrics of the QHEI.

We obtained SWAT-generated water chemistry for 33 of the 36 sites. Nineteen of 36 sites had corresponding data for geomorphology, IBI, QHEI, water chemistry, and spatial location data primarily because: 1) 7 of the 36 sites were on the Olentangy River mainstem, which was used as the reference point for the spatial location of the other streams in the watershed; 2) 5 sites did not have corresponding QHEI or IBI data; and 3) 5 sites were removed from the analysis because of missing geomorphology data leaving a total sample size of 19 sites. Regression analysis of the 19 sites indicated that SWAT generated nitrate-N ($p = 0.072$); distance downstream to the next highest order stream ($p = 0.018$), and pool quality ($p = 0.030$) were most significant in influencing IBI scores for these locations ($R^2 = 0.78$). This is an interesting result because it was the first time in this study that any water chemistry constituent was significantly related to IBI score.

Results of the regression indicated that Whetstone Creek 29.3 had large leverage. This is likely because it had a very high value for distance to next order stream compared to the other sites. We removed this site from the analysis and re-ran the regression (n = 13). Results were similar in that SWAT-generated nitrate-N (p = 0.096) and pool quality (p = 0.025) were most significant in influencing IBI scores at these locations (R^2 = 0.73). Upon analyzing both sets of regression coefficients generated for these variables, they appear to be rational and quite similar. For example, the regression coefficient for nitrate-N is negative indicating that as nitrate-N increases in the watershed, IBI scores will decrease. Therefore, we have some confidence that the statistical relationships between IBI score and significant environmental variables is not a statistical anomaly.

In an effort to add more sites to further increase our confidence in the statistical model, we eliminated the spatial location category and, where 2003-2004 IBI data was not available, we used the next most recent data. This increased the sample size to 25 sites (3 sites had no water chemistry data, and 8 sites were eliminated because of missing data). Results of the regression analysis (*p<0.1)* show that QHEI score (p = 0.007), gradient (p = 0.003), SWAT-generated total phosphorus (p = 0.071), cross-sectional area (p = 0.091), and width to depth ratio (p = 0.007) were most significant in influencing IBI scores at these locations (R^2 = 0.71). When QHEI score is removed, quality of in-stream cover replaces it in the regression analysis.

Upon analyzing the regression coefficients generated for these variables, they appear to be less rational than those generated for the smaller data set. For example, the regression coefficient for total phosphorus is positive indicating that as total phosphorus increases in the watershed, IBI scores will increase. Therefore, we have less confidence that the statistical model is giving correct relationships between IBI score and significant environmental variables.

A more comprehensive analysis was not performed because of the mixed results and because we might have been attempting to use generated data beyond an appropriate level. Delineation and parameterization of SWAT was conducted at a scale where representative water quality data would be obtained at an 11-digit HUC scale and to a lesser extent at a 14-digit HUC scale. Geomorphology relationships to hydrology estimations were developed to help identify if bankfull relationships were consistent and to identify if floodplain widths satisfied a minimum threshold to aid in sustaining dynamic equilibrium and meander migration.

5.4 Discussion

It is not surprising that, statistically, the Olentangy River watershed could be partitioned into three distinct regions: the Lower, the Upper, and Whetstone Creek. Each region has distinct geology and land use that may lend them to more unique habitats and fish assemblages. Fish assemblages represented by IBI score and metrics were most influenced by geomorphology, followed by habitat represented by the QHEI and spatial location within the watershed. This suggests that more focus should be placed on incorporating geomorphology into watershed analyses, such as the TMDL, than is currently done.

Having few sample sites (n = 28) to conduct the CCA analysis that were not randomly chosen (at least, statistically) limits our ability to extrapolate the results beyond those sites to the entire watershed, and further detailed analyses would be necessary for those sites. However, we did find some interesting patterns concerning the mismatch of sampling scales in the data sets we did have. Biology and geomorphology were sampled at the reach-level. Spatial location and predicted water chemistry were sampled at the watershed-level. Measured water chemistry was sampled at a specific location within the reach. Predicted water chemistry was modeled at the HUC-11 or HUC-14 level. This mismatch of data resulted in fewer sites available for analysis. Having more complete data sets allows more effective statistical analyses because the more sophisticated analyses do not allow data sets with missing values.

Only two of the QHEI metrics, pool quality and gradient, were significant in influencing IBI metrics. Compared to spatial location, which explained a similar amount of variation in IBI scores and requires little field work and is less time intensive, the QHEI is difficult to quantify and may be biased by site selection or by the person conducting the QHEI. From a resource-saving standpoint, it appears that spatial location could be a better metric to gauge fish assemblage than QHEI. Geomorphology explains more variability in IBI metrics and provides more statistically defensible data than the more qualitative QHEI. However, the QHEI remains important because it explains unique variation in habitat over time. Perhaps, more focus should be placed on better quantifying the QHEI metrics, especially the two sub-metrics which seemed to explain most of the variation – pool quality and gradient.

Measured water quality parameters were not significantly correlated to the IBI. Predicted total phosphorus and nitrate-N, however, were significant but only for a study of a limited number of sites within the watershed. Also, while the relationship between nitrate-N concentration and IBI score was logical, the relationship between IBI score and total phosphorus concentration was not.

Reasons for water quality not playing a greater role as a stressor are numerous. First, measured constituents may not have exhibited wide enough variation between specific sites to be pulled out in the statistics, whereas modeled constituents reflected wider variation over the entire watershed. Second, IBI scores for this limited number of sites may not have varied enough; therefore, not many environmental or chemical variables would have varied with them. Perhaps it is necessary to conduct intensive water quality sampling at a sub-watershed scale (1 to 2 square miles) to really understand its effect on biology. While we recognize this is not always feasible because of resource limitations, it is really the best way to identify non-point sources at their source. Third, though water quality signatures may be above target values in some instances, they may not be high enough yet to cause an effect on fish assemblages in the watershed, or high enough to be the largest stressor when compared to physical parameters such as geomorphology and habitat. As an alternative to intensive sampling, useful insight might be obtained by conducting the simulation model at a higher resolution.

The combination of physical habitat, geomorphology, water quality and spatial location within the watershed allowed the examination of the effects of multiple stressors within the watershed using fish assemblages as an indicator. Results from this study demonstrate the importance of including environmental parameters and incorporating regional conditions into biological assessments beyond qualitative metrics alone. While the study would have certainly benefited from more complete data sets allowing for a larger sample size, CCA-type analyses are quite good at extracting statistically defensible patterns in variation for small data sets (Williams et al., 2005). However, we stress caution in extrapolating results from a limited number of sites to the entire watershed. Recognizing the limitations of this study, this chapter presents an interesting “case study” on what data are gathered and how they can be analyzed to determine what suites of environmental variables most influence fish assemblages.

Unfortunately, the data for which complete datasets are available do not necessarily represent the range of conditions within the entire watershed. Because of this potential bias, we are unable to extrapolate these results beyond the sample size of our analyses. Future efforts should focus on collecting more complete data sets, at least at a statistically representative subset of reaches within the watershed, so that results of modeling efforts will be more applicable at the watershed scale. This is perhaps the missing piece of the TMDL puzzle that will allow a direct link of non-point sources of pollution with ecological function of specific sites, a necessary step to reduce and/or eliminate non-point source pollution within a watershed.

Chapter 6: Summary, Conclusions and Recommendations

6.0 Introduction

This chapter is a summary of Chapters 1 through 5 of the Olentangy River watershed TMDL report prepared by a team of faculty, staff, and students at The Ohio State University. This chapter has been prepared to facilitate reporting by Ohio Environmental Protection Agency (EPA).

6.1 Scope of Work and Objectives

The primary goal of this study was to conduct, in collaboration with Ohio EPA, a research study on the Olentangy River watershed that would contribute to Total Maximum Daily Load (TMDL) development for the watershed. Ohio is one of the few states with Water Quality Standards that considers not only water quality but also biology and physical habitat. Integrating biology, habitat and water quality together in a quantitative manner is complex and has seen limited study. Furthermore, the role of stream processes and stream geomorphology in influencing stream health is relatively unknown and has generally not been considered in TMDL studies around the nation.

Work presented in this report was primarily performed by faculty, staff, and students in the College of Food Agricultural and Environmental Sciences at The Ohio State University. However, it was conducted in collaboration with personnel at the Ohio EPA. Much of the aquatic life data used in the analyses were obtained by Ohio EPA. Measured discharge data were obtained from the United State Geological Survey (USGS). Measured water quality data were obtained from several sources including Heidelberg College, the USGS, and Ohio EPA. Stakeholders provided valuable input and greatly helped with identifying potential sites and arranging access to those sites. Primary stakeholders included members of the Friends of the Lower Olentangy Watershed (FLOW) and the Olentangy Watershed Alliance (OWA).

6.2 Overview of the Olentangy River Watershed

The Olentangy River watershed originates in Crawford County, Ohio and flows 88.5 miles south to its confluence with the Scioto River near downtown Columbus, Ohio – a drainage area of about 540 mi^2. Portions of the Olentangy River mainstem near Worthington, OH are designated as Exceptional Warmwater Habitat by the Ohio EPA. A biological and water quality study of the lower Olentangy River watershed from the Delaware Dam south to Columbus, OH found that, while most of this portion of the watershed was in attainment status, all of the nine tributaries studied were in non-attainment status (Ohio EPA, 1999). The report concluded that the urban nature of the lower watershed in and near Columbus, OH, continuing development in Delaware County, OH, and degraded conditions of the tributaries threatened the overall good water quality of the lower Olentangy River watershed.

Pollution sources in the watershed are diverse because it spans an array of land uses from rural/agricultural to residential to urban. A large dam is located on the main stem of the river and two stream flow gages with the longest period of record are located downstream of the dam. Calibration for discharge required consideration of release information for the dam together with routing discharge through the dam based on knowledge of stage-storage-discharge rating curves available from the United States Army Corps of Engineers.

6.3 Total Phosphorus (TP), Nitrate-N and Total Suspended Solids (TSS) Targets

In the state of Ohio, the primary objectives for water quality targets used in TMDL studies are to enhance and/or sustain attainment of aquatic life use designations for lotic water systems within a watershed. Ohio EPA target TMDL concentrations for the Olentangy River watershed are reported in Table 6.1.

Table 6.1 TMDL targets to support aquatic life in the Olentangy River watershed (flow-weighted concentrations in mg/l).

Target	TP	Nitrate-N	TSS
Ohio EPA Recommended Target			
Headwaters (DA < 20mi^2)	0.07	1.0	9
Wade-able (20mi^2 < DA < 200mi^2)	0.11	1.0	31
Small Rivers (200mi^2 < DA < 1000mi^2)	0.16	1.5	44
OSU TMDL Recommended Targets			
WWH with DA > 1000 mi^2	0.20	2.5	100
WWH with DA < 1000 mi^2			
Factor of Safety (FS) of 1.5	0.16	2.0	80
EWH with DA > 1000 mi^2	0.16	2.0	80
EWH with 20 mi^2 < DA < 200 mi^2			
(FS of 2.0)	0.12	1.5	60
EWH with DA < 20 mi^2 (FS of 3.0)	0.08	1.0	40

Also presented in Table 6.1 are suggested TMDL targets we feel are scientifically defendable and consistent with constituent chemistry associations within lotic water system in the state of Ohio. These targets are based on a goal to sustain aquatic life communities with an IBI score of at least 40.

6.4 SWAT Parameterization and Calibration

6.4.1 Model Overview and Watershed Delineation

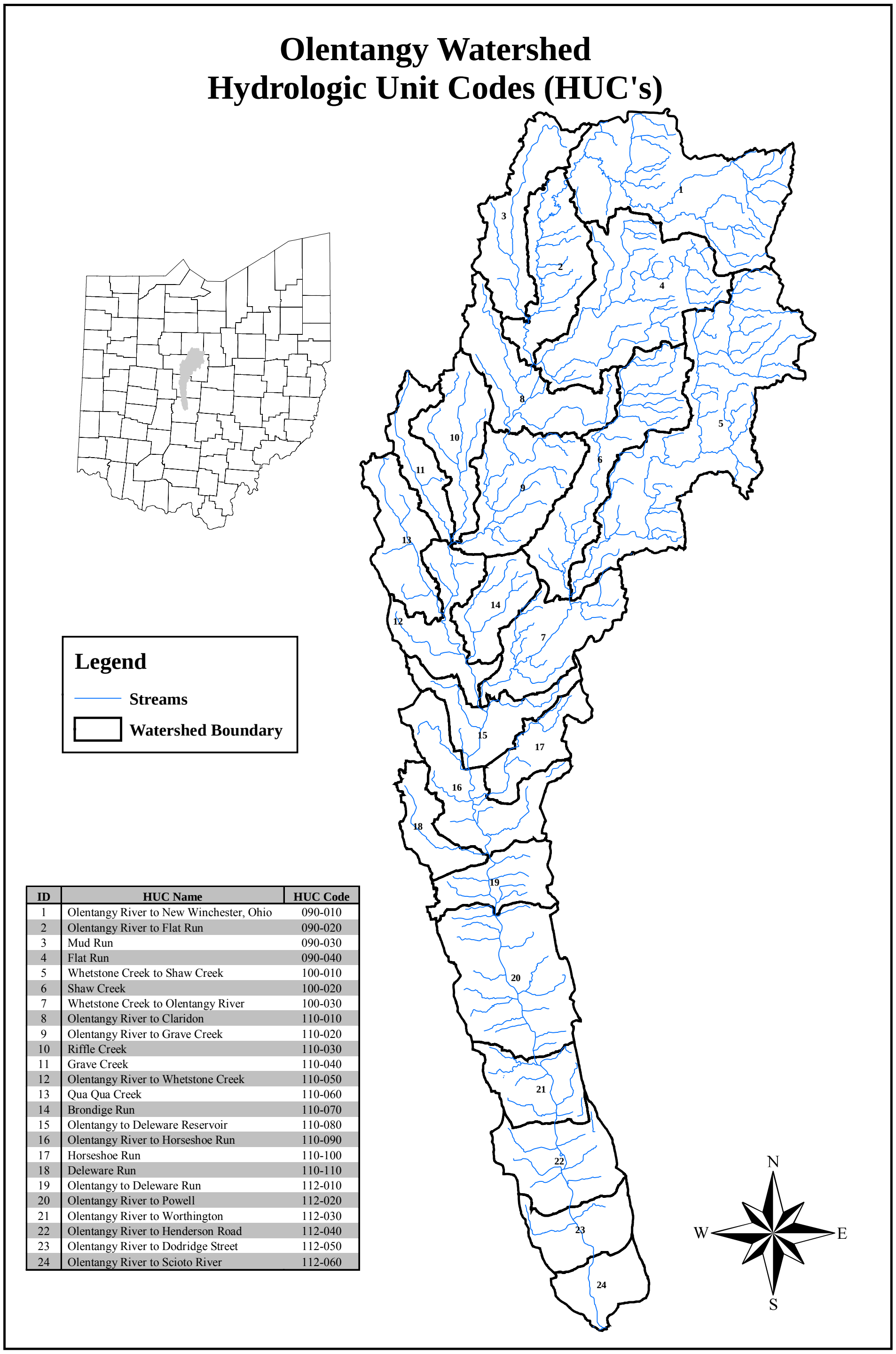
The Soil and Water Assessment Tool (SWAT) was used to model the Olentangy River watershed. SWAT is a daily time step, watershed-scale model developed and supported by the United States Department of Agriculture-Agricultural Research Service (USDA-ARS) at the Blackland Research Center in Temple, Texas. SWAT was developed to predict the impact of land management practices on water, sediment, and nutrient yields in large complex watersheds with varying soils, topography, land use and land management practices. The model used in this study was a customized version of SWAT 2005 capable of simulating a restrictive layer of material in the soil profile and its impact on subsurface drainage, watershed hydrology, and pollutant transport. The SWAT development team in Texas provided extensive assistance in resolving modeling and model code difficulties.

In SWAT, the driving force behind modeling the hydrologic response of a watershed is calculating a daily water balance. SWAT algorithms simulate or account for many physical processes associated with the movement of water and nutrients in a watershed. Simulation of these processes can be separated into two phases: the land phase and the routing phase. The land phase controls the amount of water, sediment, and nutrient loading to the channel in each sub-basin allowing the model to reflect differences in calculations of physical processes associated with heterogeneous hydrologic response units (HRUs). The most important physical processes modeled in the land phase include climate, surface runoff, infiltration, evapotranspiration, lateral flow, percolation, seepage, and return flow. After calculating water, sediment, and nutrient loadings from the landscape SWAT routes the loadings through the stream network. During the routing phase flow and nutrients from point source discharges are added to the channel. The simulation period for the SWAT modeling began on January 1, 1985 and ended on December 31, 2002. Calendar year 1985 was used as a “warm up” year to account for any errors in initializing the model. Subsequently, all model predictions for 1985 were excluded in model evaluation, calibration, and reporting.

SWAT divides a watershed into sub-basins and HRUs. Sub-basins can be delineated to represent HUCs (Figure 6.1) but, generally, it is desirable to use even smaller drainage areas to more accurately represent variations that impact hydrology and nutrient transport in the watershed. Each sub-basin has a specific geographic location in the watershed and outputs from sub-basins are routed through the stream network. We delineated 147 sub-basins for the Olentangy River watershed. Within a sub-basin the landscape is further divided into HRUs. HRUs do not posses a spatial location within the sub-basin and all calculations of hydrology and pollutant transport on the landscape are performed at the HRU level. Land use estimates for the watershed are summarized in Table 6.2.

Table 6.2 Actual and modeled land use (%) for the Olentangy River watershed.

Land Use	Actual (%)	Modeled (%)
Agriculture	57	64
Urban	12	11
Forest	16	13
Pasture	14	12
Water	<1	<1



ID	HUC Name	HUC Code
1	Olentangy River to New Winchester, Ohio	090-010
2	Olentangy River to Flat Run	090-020
3	Mud Run	090-030
4	Flat Run	090-040
5	Whetstone Creek to Shaw Creek	100-010
6	Shaw Creek	100-020
7	Whetstone Creek to Olentangy River	100-030
8	Olentangy River to Claridon	110-010
9	Olentangy River to Grave Creek	110-020
10	Riffle Creek	110-030
11	Grave Creek	110-040
12	Olentangy River to Whetstone Creek	110-050
13	Qua Qua Creek	110-060
14	Brondige Run	110-070
15	Olentangy to Deleware Reservoir	110-080
16	Olentangy River to Horseshoe Run	110-090
17	Horseshoe Run	110-100
18	Deleware Run	110-110
19	Olentangy to Deleware Run	112-010
20	Olentangy River to Powell	112-020
21	Olentangy River to Worthington	112-030
22	Olentangy River to Henderson Road	112-040
23	Olentangy River to Dodridge Street	112-050
24	Olentangy River to Scioto River	112-060

Figure 6.1 14-digit HUCs in the Olentangy River watershed.

The primary goal of modeling the hydrology of the Olentangy River watershed was to determine the impact of anthropogenic activities on water quality. To develop representative management scenarios we used government-collected statistical data on agriculture, sources of literature applicable to Ohio, and the judgment of experts, extension personnel, local agencies, and producers. Statistical agricultural data from Ohio were used extensively to develop management scenarios representative of agricultural practices in the watershed. Twenty agricultural management scenarios were developed to represent variation in crop types, management strategies, and timing of management activities from year to year. Each of the twenty scenarios was then applied to 5% (1/20) of the agricultural land in the watershed.

6.4.2 Point Source Dischargers

SWAT is capable of incorporating point source discharges into stream reaches at the outlet of the sub-basin in which they are located. For the Olentangy River TMDL study, the input used was average daily point source loads for each individual month of the simulation period. Within the Olentangy River watershed six point sources are considered major dischargers by Ohio EPA (Table 6.3). Monthly Operating Reports (MOR) were obtained from Ohio EPA and used to calculate point source loadings to the receiving stream. We developed a strategy to lump all minor dischargers into groups based on their proximity to a major discharger. We determined, in conjunction with Ohio EPA staff, that design flows and permit limits would be used to calculate loads for minor dischargers. This facilitated the comparison of non-point source and major and minor point source loads.

Table 6.3 Discharge-weighted average concentrations for point source pollutant dischargers over the simulation period (developed from Ohio EPA MOR data).

Facility Name	Ohio EPA Permit	Discharge (MGD)	Total P (mg/l)	NO_3-N (mg/l)	Sediment (mg/l)
Galion WWTP	2PD00030	2.57	2.57	11.5	6
Marion WWTP	2PJ00002	0.88	2.02	12.3	12
Mt. Gilead WWTP	4PB00102	0.53	5.03	6.0	12
Cardington WWTP	4PA00100	0.27	2.98	6.2	12
Delaware WWTP	4PD0004	3.51	2.22	8.9	7
Ohio Environmental Control Center (OECC)	4PK00001	1.92	1.02	8.5	3

6.4.3 Non-Point Source Dischargers

The primary inputs used to simulate urban conditions are reported in Table 6.4. Other types of land use, including various types of forest and wetlands, occur in smaller amounts in the Olentangy River watershed. These land uses were modeled with SWAT default scenarios.

Table 6.4 Urban land use parameters for input into the SWAT model.

Urban Land Use	Impervious Area (fraction)	Directly Connected Impervious Area (fraction)	Curb Density (miles/acre)
High Density Residential	0.60	0.44	0.06
Low Density Residential	0.12	0.10	0.06
Commercial	0.67	0.62	0.07
Industrial	0.84	0.79	0.04
Transportation	0.98	0.95	0.03
Institutional	0.51	0.47	0.03

6.4.4 Hydrology Parameters and Model Calibration

To accurately predict the movement of pollutants through the watershed the hydrologic cycle, simulated by the SWAT model, must conform to what is happening in the watershed. The first phase of the cycle, the landscape phase, depends on climatic inputs, physical properties of the land, and management activities on the landscape. The second phase of the cycle includes routing water through the stream system and is impacted by physical properties of the stream channel, anthropogenic manipulation of stream flow through control structures, and addition of point source discharges. Several parameters used to model landscape and channel processes were changed from SWAT default values for calibration purposes because we had better values based on knowledge of the system, and/or because we developed alternative values based on analysis of a dataset.

Surface runoff is simulated in SWAT using the NRCS Curve Number procedure. SWAT initially selects curve numbers from NRCS standard tables based on land cover and soil type. These curve numbers are then adjusted based on the slope of the HRU with a procedure developed by Williams (1995). Soils in the Olentangy River watershed are in hydrologic soil groups B and C. SWAT automatically selects NRCS curve numbers based on hydrologic soil group and land use. Curve number ranges for common land use types are included in Table 6.5.

Table 6.5 Assigned curve numbers from SWAT model.

Land Use	NRCS Curve Number[1]
Agricultural Row Crops	75-85
Forest	66-77
Pasture	69-79
Grasses	59-83
Urban (various densities)	65-94

[1]Ranges assigned to SWAT land uses for hydrologic groups B and C.

Evapotranspiration includes all processes by which water on or in the earth's surface is transformed to water vapor. Potential Evapotranspiration (PET) is the rate that evapotranspiration occurs from growing vegetation when soil-water is not limited. The following PET methods have been incorporated into SWAT: (1) the Penman-Monteith method that requires solar radiation, air temperature, relative humidity and wind speed data (Monteith, 1965; Allen, 1986; Allen et al., 1989); (2) the Hargreaves method that only requires air temperature data (Hargreaves et al., 1985); and (3) the Priestley-Taylor method that requires solar radiation, air temperature and relative humidity data (Priestley and Taylor, 1972).

6.4.5 Subsurface Drainage and Groundwater Recharge

The subsurface drainage component of SWAT is simple compared to other field-scale models capable of simulating subsurface drainage, but other studies where tile drainage was predicted has shown good agreement with measured results in studies at the watershed scale (Du et al., 2005). SWAT has four variables specific to subsurface drainage. Two were altered from default values to more accurately represent conditions in the Olentangy River watershed.

SWAT also models the amount of ground water recharge in the watershed. For the calibrated baseline simulation the ground water recharge was estimated as 4 inches. This amount is in agreement with an Ohio Department of Natural Resources report that estimates recharge rates between 4 inches and 6 inches for the Olentangy River watershed (Dumouchell and Schiefer, 2002).

6.4.6 Routing Flow in Channels

In SWAT, channels are approximated as a two-stage system. The first (lower) stage is the main fluvial channel and the second stage is the floodplain. SWAT uses Manning's equation and Manning's *n* values to calculate flow velocities for water routing. Manning's *n* values of 0.044 and 0.050 were assigned globally to tributaries and main channels, respectively. The main fluvial channel was approximated as a trapezoid that is sized based on bankfull dimensions that are a function of a regional curve. SWAT calculates and assigns channel dimensions using a known relationship between drainage areas and channel widths and depths. Channel dimensions were based on the Upper Scioto River regional curve developed as part of this study. Channel width to depth ratios also were updated based on the new dimensions. Flows were routed through the channel network using a variable storage routing method.

6.4.7 Calibration

We used the standard procedure outlined in the SWAT User's Manual (Neitsch et al., 2002b) to calibrate the Olentangy River TMDL model. SWAT-predicted stream flow was evaluated against measured results for USGS gages at Claridon (03223000), Delaware (03225500), and Worthington (03226800) (Table 6.6).

Table 6.6 Results of regression analysis of observed versus predicted flow (ft^3/s) at USGS gage stations in the Olentangy River watershed.

USGS Gage	Time	Slope	Intercept	R^2
Claridon	Annual	0.92	5.5	0.84
Claridon	Monthly	0.83	17.7	0.80
Claridon	Daily	0.57	60.2	0.51
Delaware	Annual	1.05	4.8	0.97
Delaware	Monthly	1.06	-0.1	0.98
Worthington	Annual	0.86	67.9	0.92
Worthington	Monthly	1.01	30.9	0.95

Examination of regression results for individual months of flow (Table 6.7) suggested that additional calibration or better data inputs, such as temperature, might have improved prediction of flows during winter months. Average annual water balance for the calibrated model is reported in Table 6.8

Table 6.7 Statistics from monthly flow regression analysis.

Month	Slope	Intercept	R^2
January	0.55	126.1	0.46
February	0.57	67.8	0.77
March	0.82	-12.6	0.90
April	0.63	-5.5	0.75
May	0.80	13.2	0.93
June	0.61	45.4	0.50
July	0.99	18.5	0.98
August	0.92	23.7	0.95
September	0.84	9.4	0.63
October	0.93	6.0	0.96
November	0.92	22.7	0.74
December	1.13	32.2	0.95

Table 6.8 Average annual mass water balance.

Component of Hydrologic Cycle	Water Depth[1] (inches)
Precipitation	39.1
Potential Evapotranspiration	42.7
Actual Evapotranspiration	24.6
Surface Runoff	7.6
Tile and Lateral Flow	2.6
Groundwater Flow	2.7
Total Aquifer Recharge	4.1
Water Yield	12.8

[1]Water Depth is depth of water in inches across the watershed area and is the sum of the surface runoff, tile and lateral flow and groundwater flow.

Sediment and Nutrient Parameters

The following sections discuss the parameters used to calibrate nutrient loadings in the Olentangy River TMDL model. Because phosphorus is primarily transported by attachment to sediment particles calibration for sediment impacted phosphorus calibration.

The following datasets were used in model calibration of sediment and nutrients: (1) grab samples from the Ohio EPA chemical and biological assessment of the Olentangy River watershed (2003); (2) results from a City of Delaware 319 Project; (3) a report to the Great Lakes Commission (Whiting, 2003); and (4) data from Heidelberg College's Water Quality Lab long-term monitoring station on the Scioto River at Chillicothe, Ohio (*http://wql-data.heidelberg.edu/*).

Ohio EPA grab samples were taken at 35 locations in the upper Olentangy River watershed from April 2003 to October 2003. Each location was typically sampled 6 times. Samples were analyzed for a suite of pollutants including TP, nitrate-N, and TSS. Results from this study were used to determine general water quality trends and signatures throughout the watershed. Because samples were collected during a limited sampling season they were not used for additional calibration.

As part of a 319 project to develop a management plan for the upper Olentangy River watershed, the City of Delaware (COD) collected water samples monthly or bimonthly depending on time of year at 8 locations. Two of those sites included the Olentangy River at Claridon and the Olentangy River near Worthington. Because of their proximity to USGS stream gages, these two sites were used for calibration because we could combine flow data and pollutant concentrations to determine flow-weighted averages (Table 6.9).

Table 6.9 Comparison of modeled nutrient concentrations and sampling results in the Olentangy River and Scioto River watersheds.

Location	Source	Average TP (mg/l)	Average NO_3-N (mg/l)	Average TSS (mg/l)	FW TP (mg/l)	FW NO_3-N (mg/l)	FW TSS (mg/l)	TSS:TP
Claridon	SWAT	0.50	5.9	56	0.37	3.6	172	464
Outlet[1]	SWAT	0.35	5.4	70	0.32	3.8	114	356
Scioto[2]	Heidelberg	0.30	3.7	69	0.34	4.4	145	426
Claridon	COD	-	-	-	0.49	3.6	126	257
Worthington	COD	-	-	-	0.23	3.7	47	204
Scioto[3]	Heidelberg	-	-	-	0.37	3.3	170	459

[1]Outlet is the confluence of the Olentangy to the Scioto River – downstream of Worthington.
[2]Scioto River at Chillicothe.
[3]Results from this row are taken from the Heidelberg database but include only samples taken on the same days as the City of Delaware (COD) samples.

Crop Yields

An important component of SWAT is the plant growth model. To simulate plant growth SWAT uses a simplified version of EPIC (Erosion-Productivity Impact Calculator; Williams et al., 1984). For SWAT to give reasonable predictions of hydrology and pollutant transport this component must work well because water and nutrient uptake and nutrient transformations into various pools will affect loadings to the stream system. One way to determine if crop growth appears to be simulated properly is to compare predicted crop yields to actual reported crop yields (Table 6.10).

Table 6.10 Comparison of Actual and Predicted Crop Yields

Crop	Actual Yield[1] (bushels/acre)	Predicted Yield[2] (bushels/acre)	% of Actual
Corn	120	87	73
Soybeans	38	28	74
Wheat	58	42	72

[1]Actual Yield Data was calculated with Ohio's National Agricultural Statistics Service data for Crawford, Marion, Morrow, and Delaware counties.
[2]Predicted Yield data was calculated from SWAT results.

6.4.8 Conclusions on SWAT Model Calibration

Statistically, the correlation between observed and predicted flow, water quality, and crop yields in this study are comparable to or better than most published manuscripts or SWAT applications in TMDL studies. For model calibration we used a procedure outlined in the SWAT User's Manual and changed SWAT parameters within suggested ranges (Neitsch et al., 2002b). The SWAT model is an approximation of a complex system and is not able to simulate all processes at the exact spatial and temporal scales that they occur. Many processes are approximated by empirical algorithms that sometimes contain parameters that are difficult to quantify and/or cannot be determined based on actual measurements. The potential exists that other modeling assumptions might have resulted in improved results. The SWAT model literally has hundreds of variables that could be used to calibrate the model. Also, measured data are never exact, and some of the unexplained variability between observed and predicted outputs is because of uncertainties and/or errors in the measured inputs and outputs.

6.5 Modeling Results and Discussion

A TMDL is the maximum amount of a flow constituent, such as a nutrient or TSS, that can be discharged to a stream and still allow the stream to meet its designated use. Designated uses may include agricultural or public water supply, recreational uses, or aquatic life uses. Designated uses are assigned to stream reaches by Ohio EPA. TMDL load reductions are determined by comparing simulated or measured loads, or concentrations (i.e., 11-digit or 14-digit HUC, entire watershed outlet, USGS gage station, etc.), with a target load or concentration at a point in the system. Measured data often are inadequate or unavailable so simulation models like SWAT are used to estimate loads. For the Olentangy River watershed background loads are estimates of the amount of TP, nitrate-N and TSS that would be transported to the stream if land use was natural with no additional human inputs. Prior to European settlement, natural conditions would have been a mixture of forests, grasses, and wetland. For ease of analysis it was assumed in determining background conditions that each of these three land uses occurred throughout the watershed.

Model outputs included landscape-level values and reach-level values. Values reported at the landscape level are specific to a watershed area and flow, nutrients and TSS generated from that area. In this study, landscape level results are reported by 14-digit HUC. Values reported at the reach scale are associated with the entire contributing drainage area to that point in the stream system. For example, nutrient and TSS concentrations at the outlet reach of the 14-digit HUC 090-020 (Olentangy River to Flat Run) would include all flow, nutrients and TSS transported from HUC 090-010 (Olentangy Headwaters to New Winchester, OH), HUC 090-030 (Mud Run) and HUC 090-020. For each HUC and each target water quality constituent, load reductions were determined to satisfy the recommended Ohio EPA headwater and small river warmwater habitat (WWH) target, and an alternative WWH target that was presented in Table 6.1. Selection of the appropriate target for a specific HUC should be made by Ohio EPA.

6.5.1 SWAT Land Management Scenarios

Management scenarios modeled as part of this study fall into the following four groups: (1) baseline conditions, (2) background loads, (3) buffer strips, and (4) crop rotation and fertilizer application. In the Olentangy River watershed, as well as much of the Midwest, row crop agriculture typically follows one of three crop rotations: corn-soybean, corn-soybean-soybean, or corn-soybean-winter wheat. According to agricultural statistics, the corn-soybean-wheat rotation is least common, as wheat accounts for about 5% to 15% of planted cropland in this watershed in a given year. Inclusion of small grains into crop rotations usually has water quality benefits; therefore, a SWAT management scenario was developed to predict potential impacts of including wheat into all crop rotations. Each scenario was developed by taking the baseline scenario without point source discharges and changing land management practices to a default corn-soybean-winter wheat rotation.

Load and load reductions for the 11-digit HUCs are reported in Table 6.11. Within each HUC, load reductions vary from 11% to 97% depending on the constituent, source of the constituent, and target that is applied. In most cases, load reductions of more than 40% for the 14-digit HUCs will be needed to satisfy any of the targets. In many cases, particularly for TSS, reductions of more than 60% will be needed. To aid in interpreting the results we have created a map showing a *Reduction Index* to meet water quality target conditions at the 14-digit HUC scale. To create the *Reduction Index* value TP, nitrate-N, and TSS reductions were weighted by multiplying them by 6, 3, and 1, respectively. The sum of the weighted values for a HUC was then divided by 10 to give a *Reduction Index* from 0 to 100. Values less than 33 were then assigned a “low” qualitative index and values of 33-66 and 66+ were assigned a medium and high qualitative index, respectively. These results were then mapped against each target and are presented in Figure 6.2 to Figure 6.5.

Table 6.11 Load reductions (%) needed to meet various target limits reported in Table 6.1.

11-digit HUC	Constituent (mg/l)	Headwaters Target[1]	Wadeable Target[1]	Small River Target[1]	Alternative Target[2]
TP					
5060001090	0.31	77	65	48	48
5060001100	0.24	71	54	33	33
5060001110	0.37	81	70	57	57
5060001120	0.18	61	39	11	11
Nitrate-N					
5060001090	3.5	71	71	57	43
5060001100	4.1	76	76	63	51
5060001110	4.8	79	79	69	58
5060001120	4.5	78	78	67	56
TSS					
5060001090	318	97	90	86	75
5060001100	268	97	88	84	70
5060001110	233	96	87	81	66
5060001120	141	94	78	69	43

Caution should be taken when interpreting the results presented in Figure 6.2 to Figure 6.5. Low and medium load reduction areas are mainly along the main stem of the Olentangy River and in urban/urbanizing areas from Delaware to Columbus, OH. Because insufficient detailed information was available to adequately simulate urban conditions, impacts associated with development activities have not been considered. Some of these areas are currently forested but will become more urban in the near future.

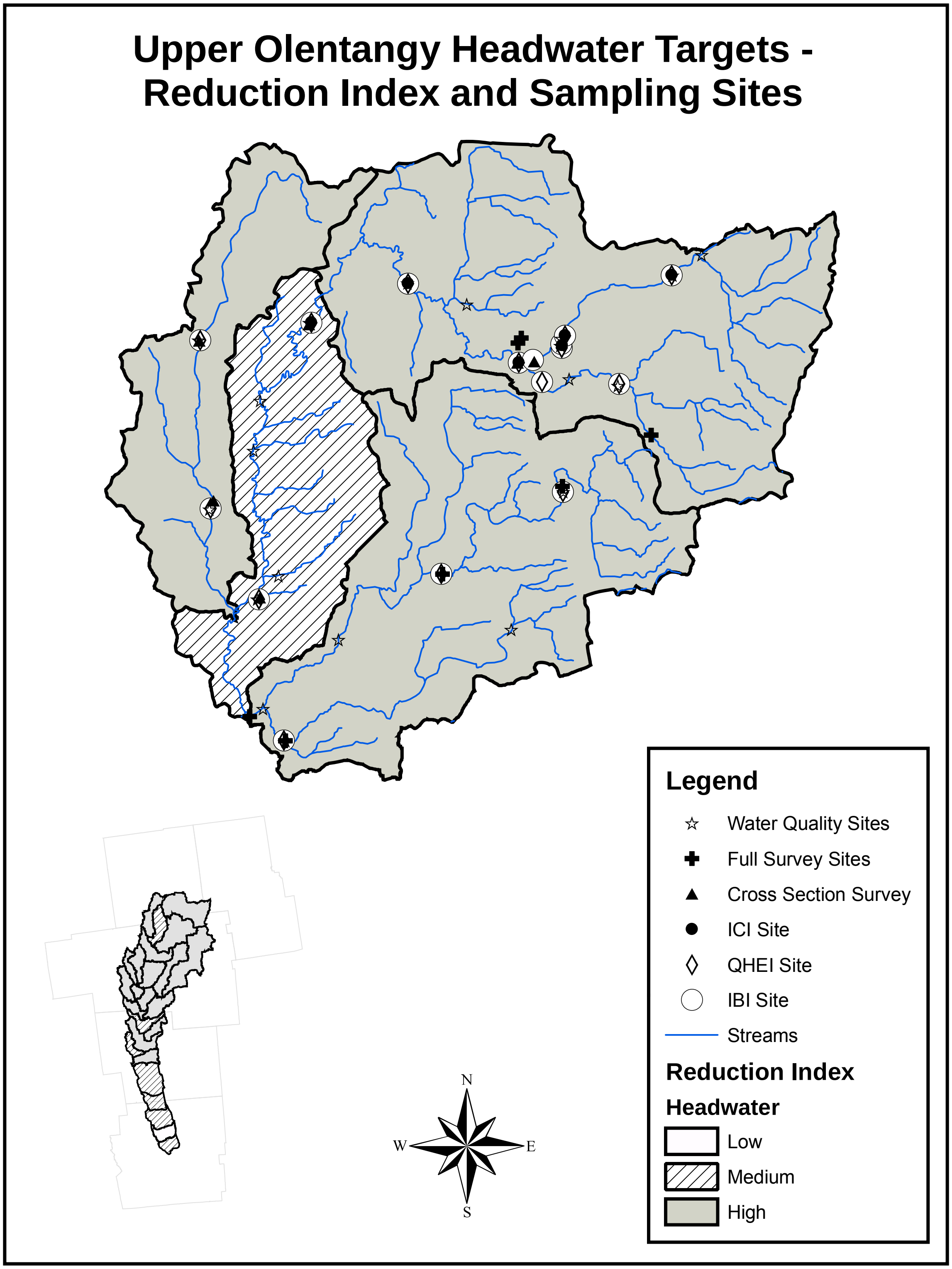


Figure 6.2a Upper Olentangy (HUC 05060001-090) reduction index map (Ohio EPA headwater targets) and locations of sampling sites for the 2003/2004 TMDL biological, habitat, water quality, and geomorphology assessments.

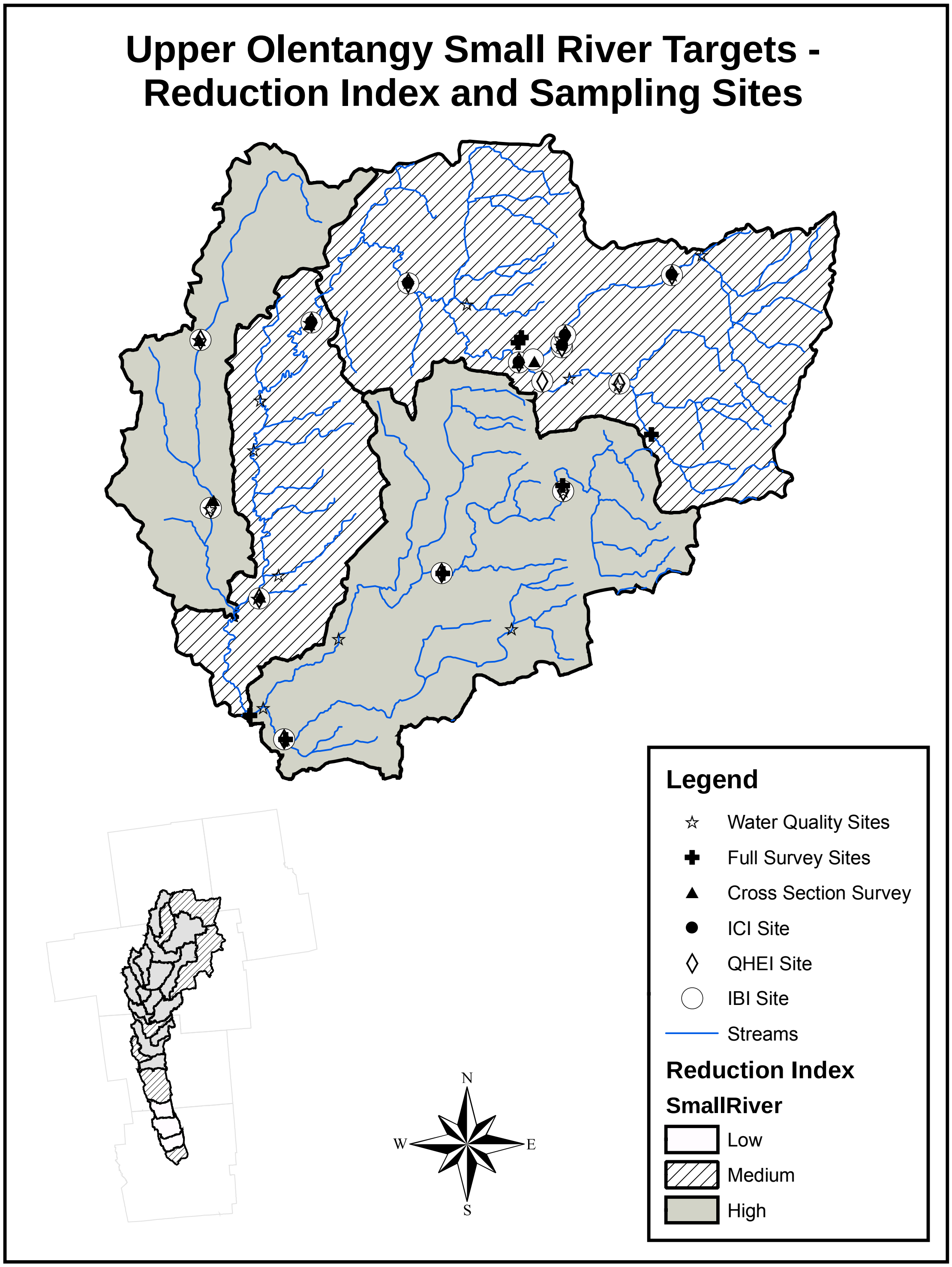


Figure 6.2b Upper Olentangy (HUC 05060001-090) reduction index map (Ohio EPA small river targets) and locations of sampling sites for the 2003/2004 TMDL biological, habitat, water quality, and geomorphology assessments.

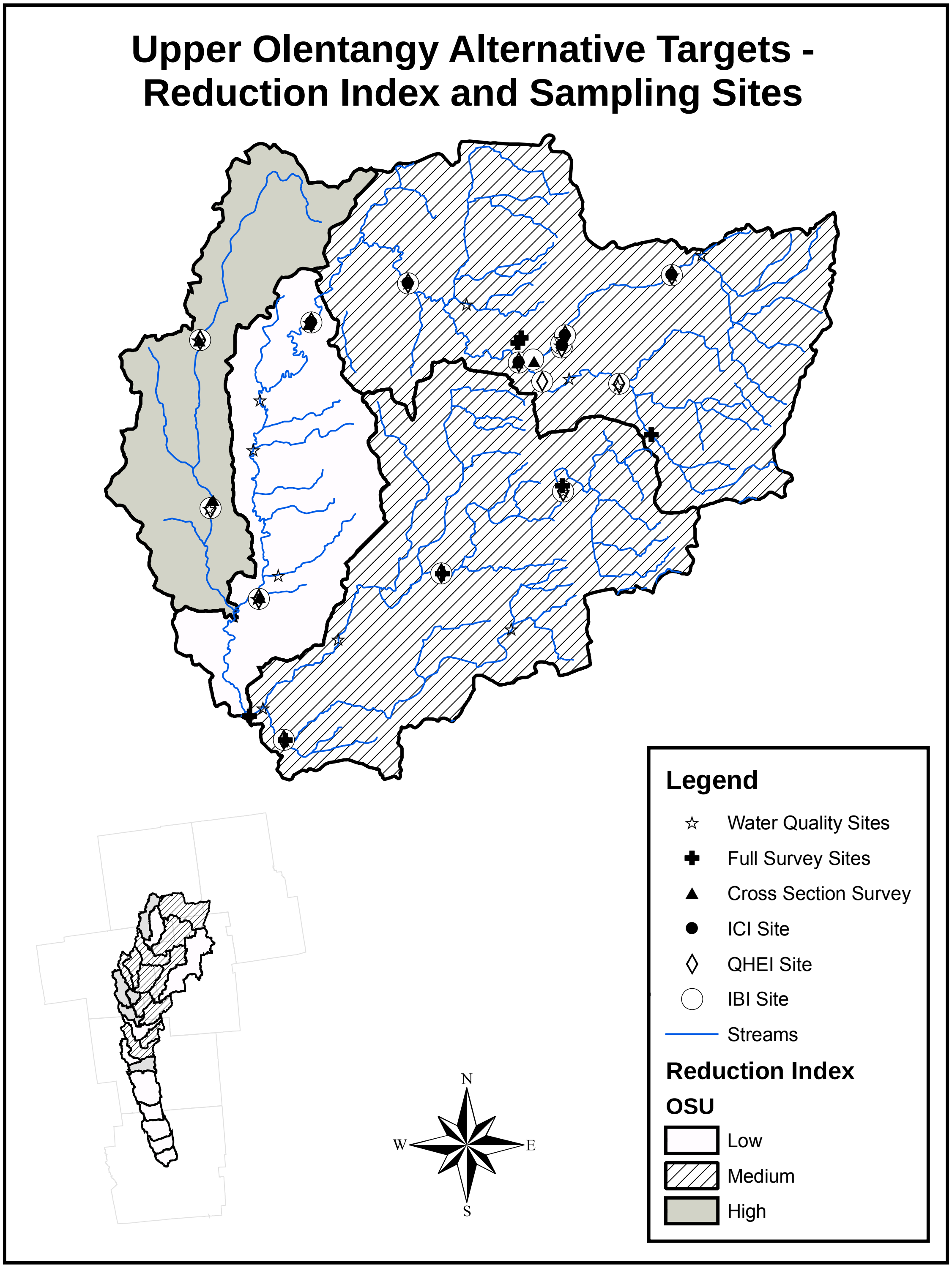


Figure 6.2c Upper Olentangy (HUC 05060001-090) reduction index map (OSU alternative targets) and locations of sampling sites for the 2003/2004 TMDL biological, habitat, water quality, and geomorphology assessments.

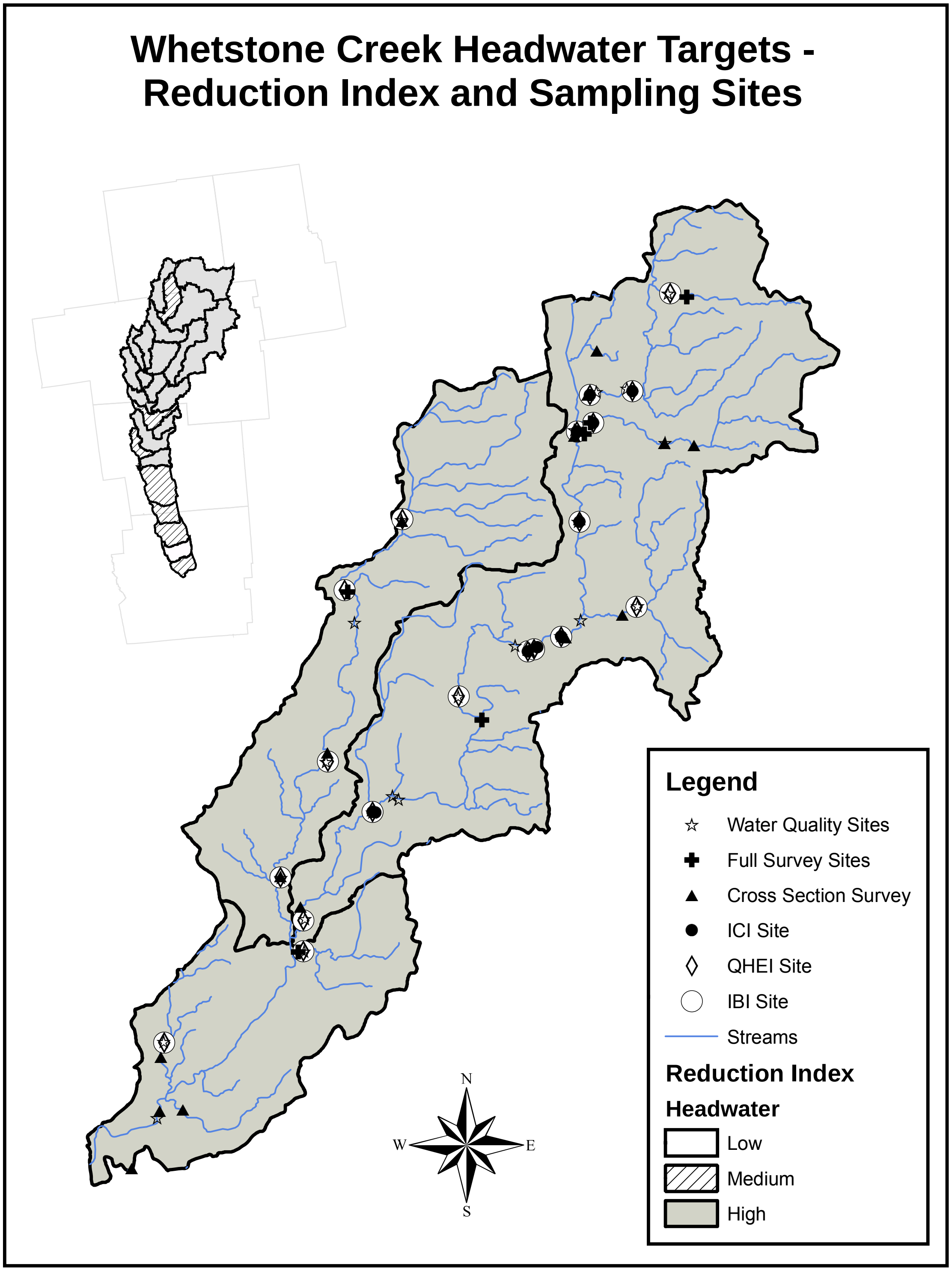


Figure 6.3a Whetstone Creek (HUC 05060001-100) reduction index map (Ohio EPA headwater targets) and locations of sampling sites for the 2003/2004 TMDL biological, habitat, water quality, and geomorphology assessments.

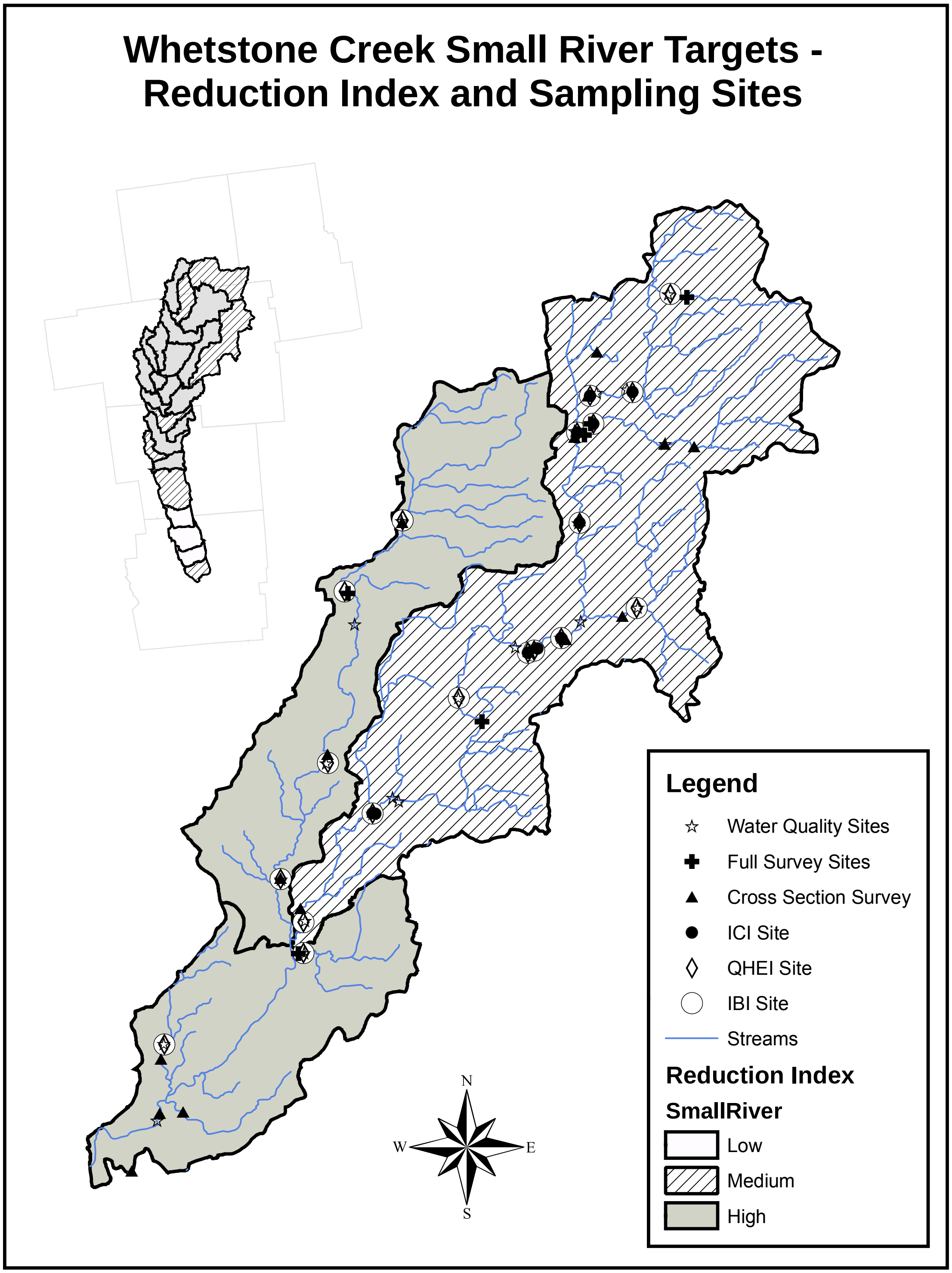


Figure 6.3b Whetstone Creek (HUC 05060001-100) reduction index map (Ohio EPA small river targets) and locations of sampling sites for the 2003/2004 TMDL biological, habitat, water quality, and geomorphology assessments.

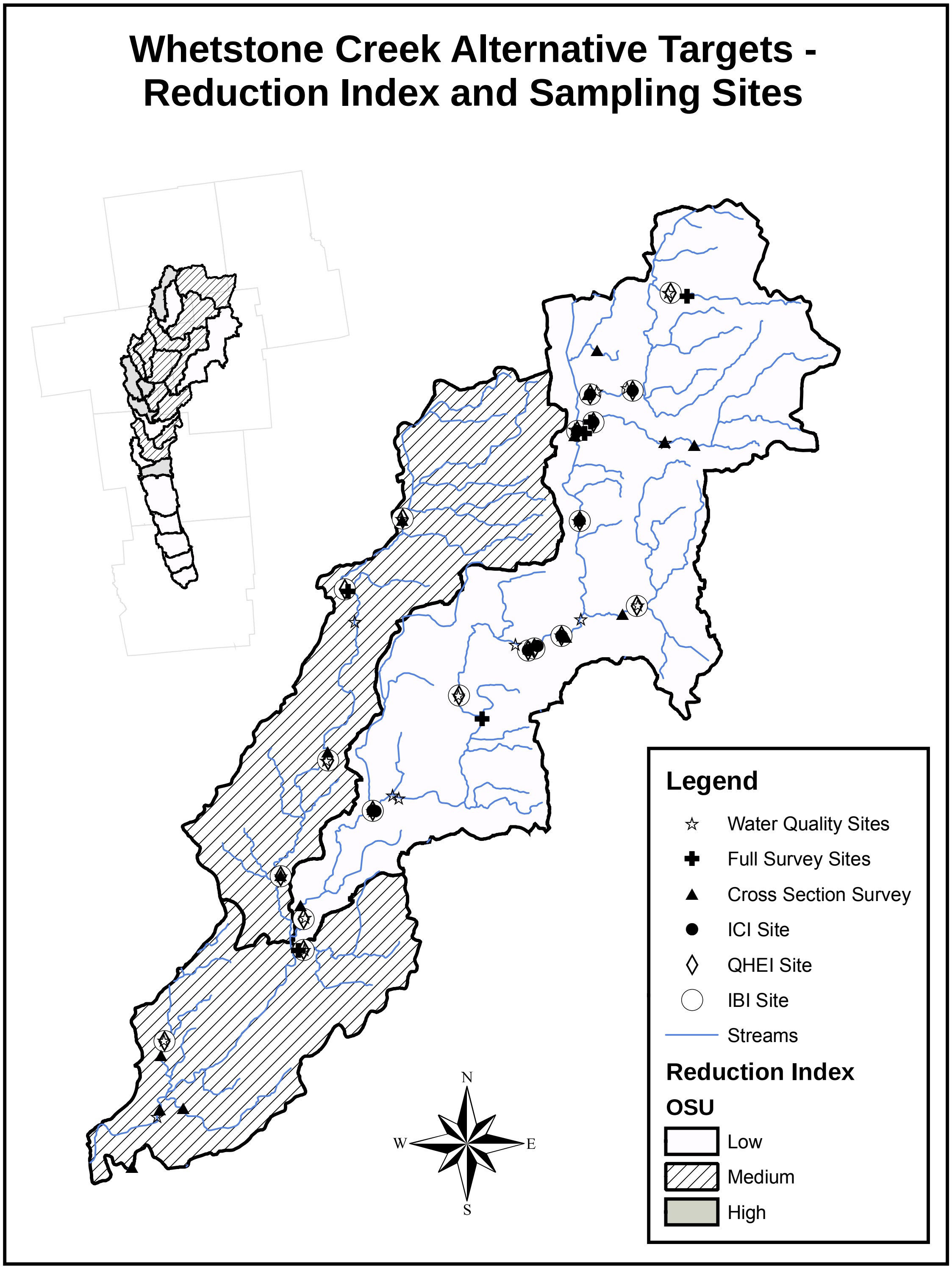


Figure 6.3c Whetstone Creek (HUC 05060001-100) reduction index map (OSU alternative targets) and locations of sampling sites for the 2003/2004 TMDL biological, habitat, water quality, and geomorphology assessments.

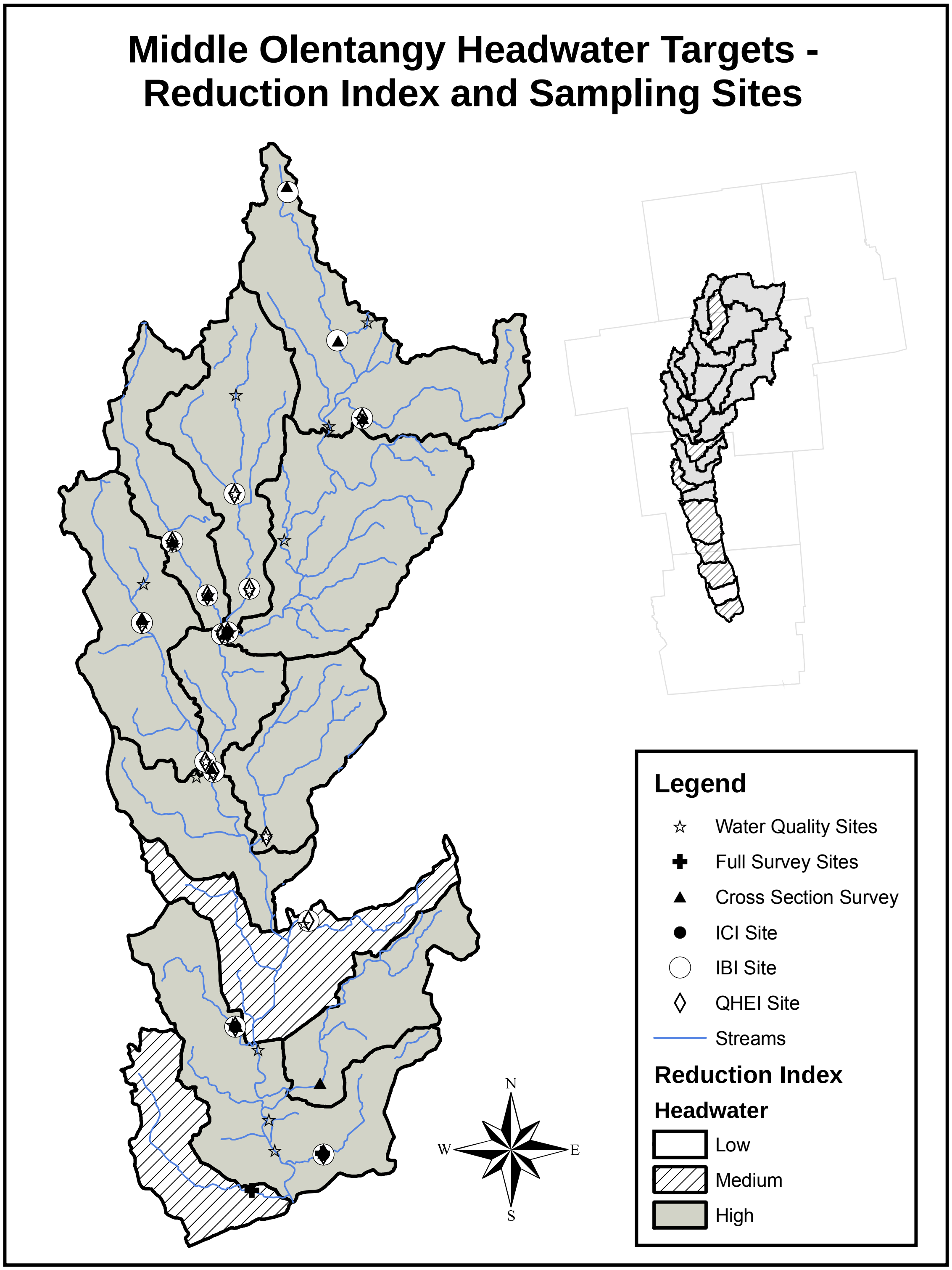


Figure 6.4a Middle Olentangy (HUC 05060001-110) reduction index map (Ohio EPA headwater targets) and locations of sampling sites for the 2003/2004 TMDL biological, habitat, water quality, and geomorphology assessments.

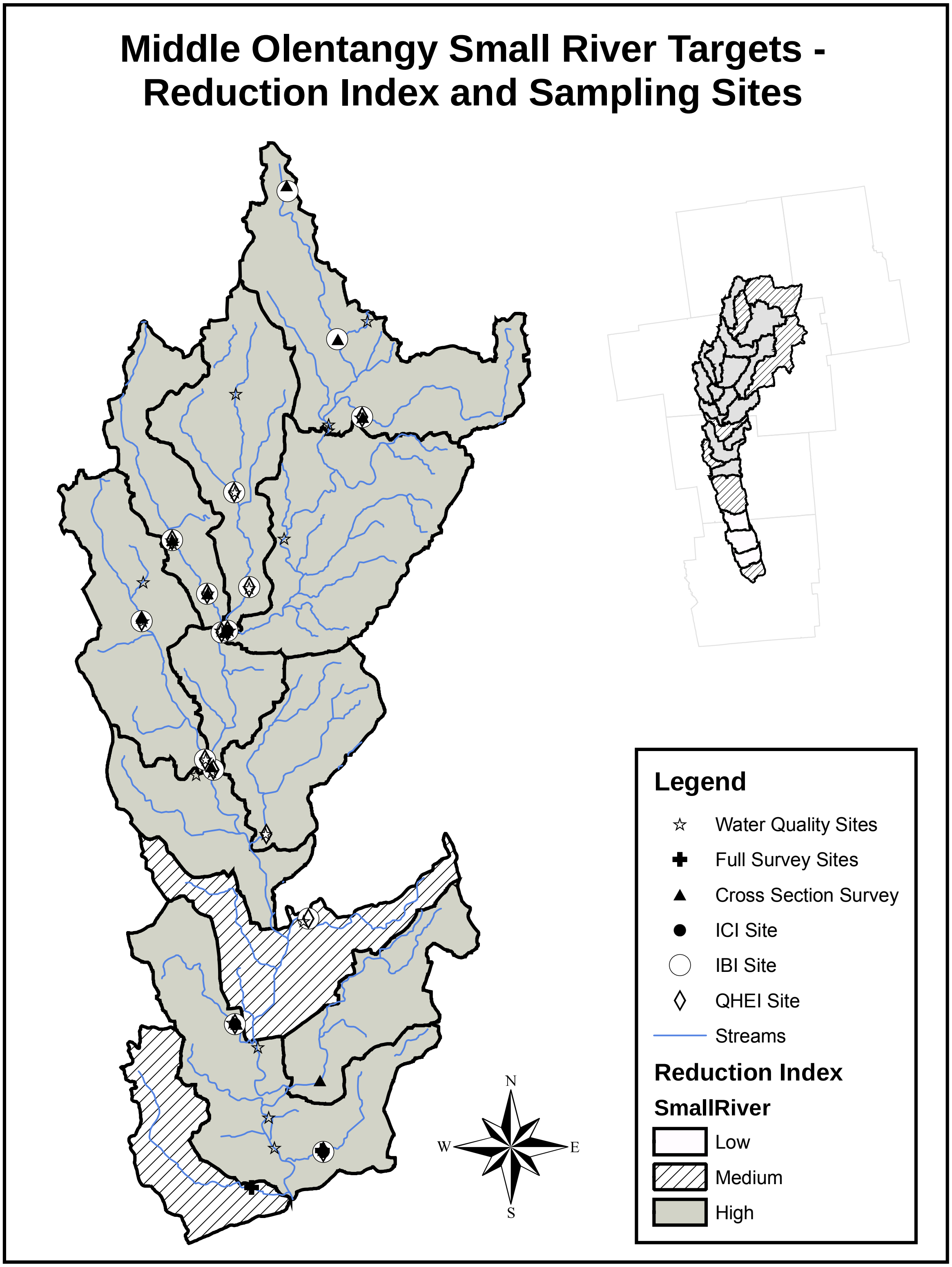


Figure 6.4b Middle Olentangy (HUC 05060001-110) reduction index map (Ohio EPA small river targets) and locations of sampling sites for the 2003/2004 TMDL biological, habitat, water quality, and geomorphology assessments.

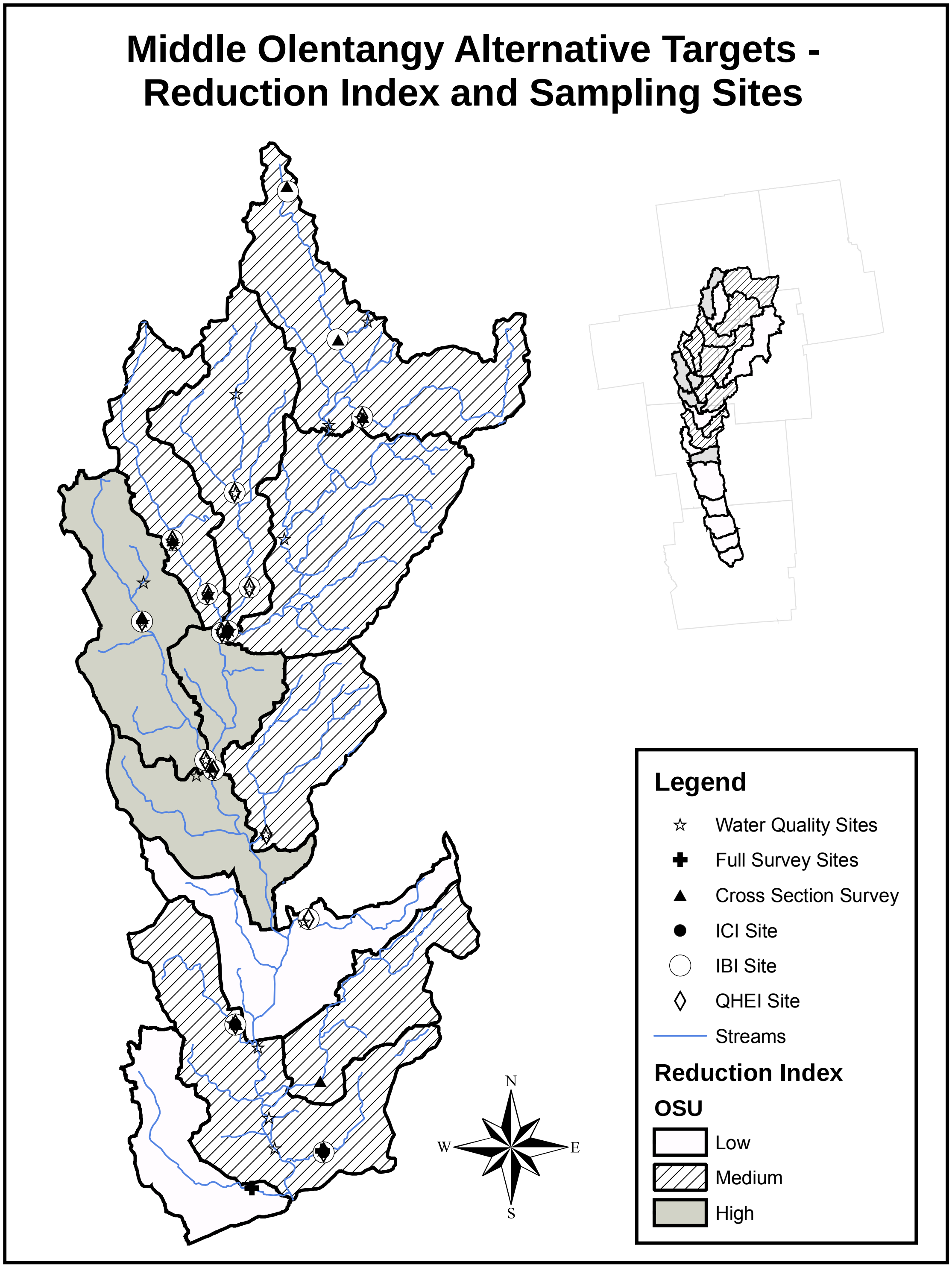


Figure 6.4c Middle Olentangy (HUC 05060001-110) reduction index map (OSU alternative targets) and locations of sampling sites for the 2003/2004 TMDL biological, habitat, water quality, and geomorphology assessments.

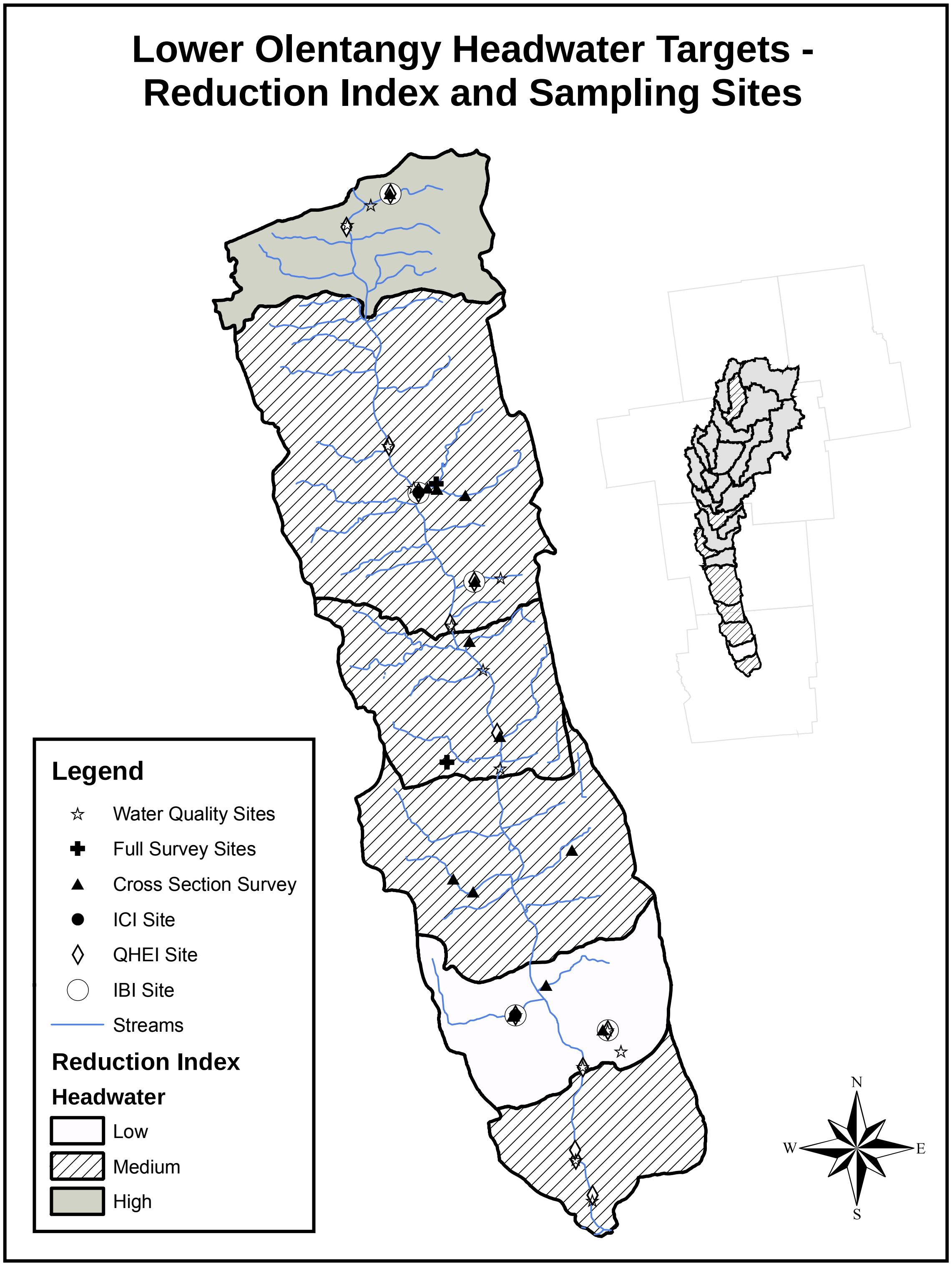


Figure 6.5a Lower Olentangy (HUC 05060001-120) reduction index map (Ohio EPA headwater targets) and locations of sampling sites for the 2003/2004 TMDL biological, habitat, water quality, and geomorphology assessments.

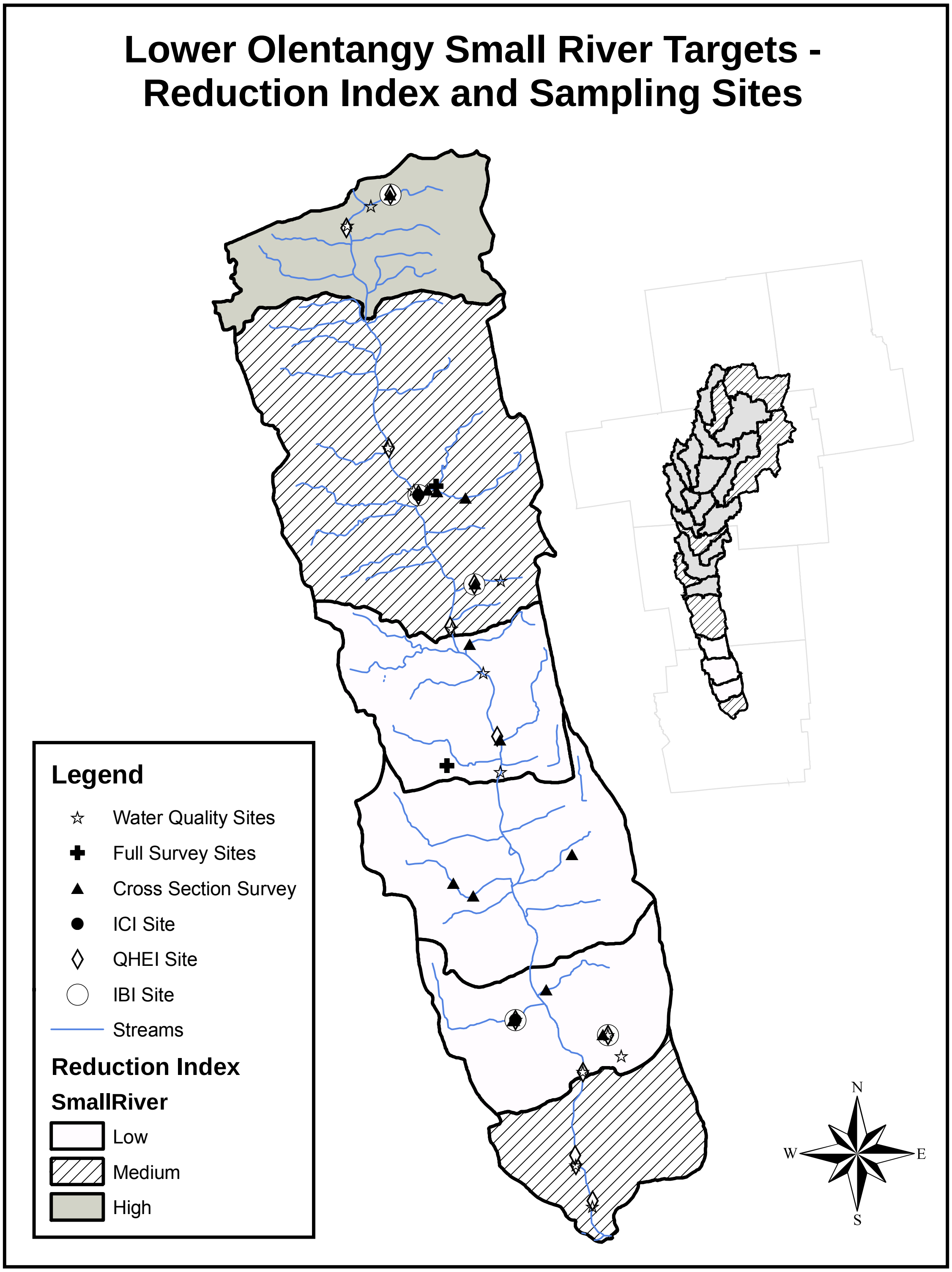


Figure 6.5b Lower Olentangy (HUC 05060001-120) reduction index map (Ohio EPA small river targets) and locations of sampling sites for the 2003/2004 TMDL biological, habitat, water quality, and geomorphology assessments.

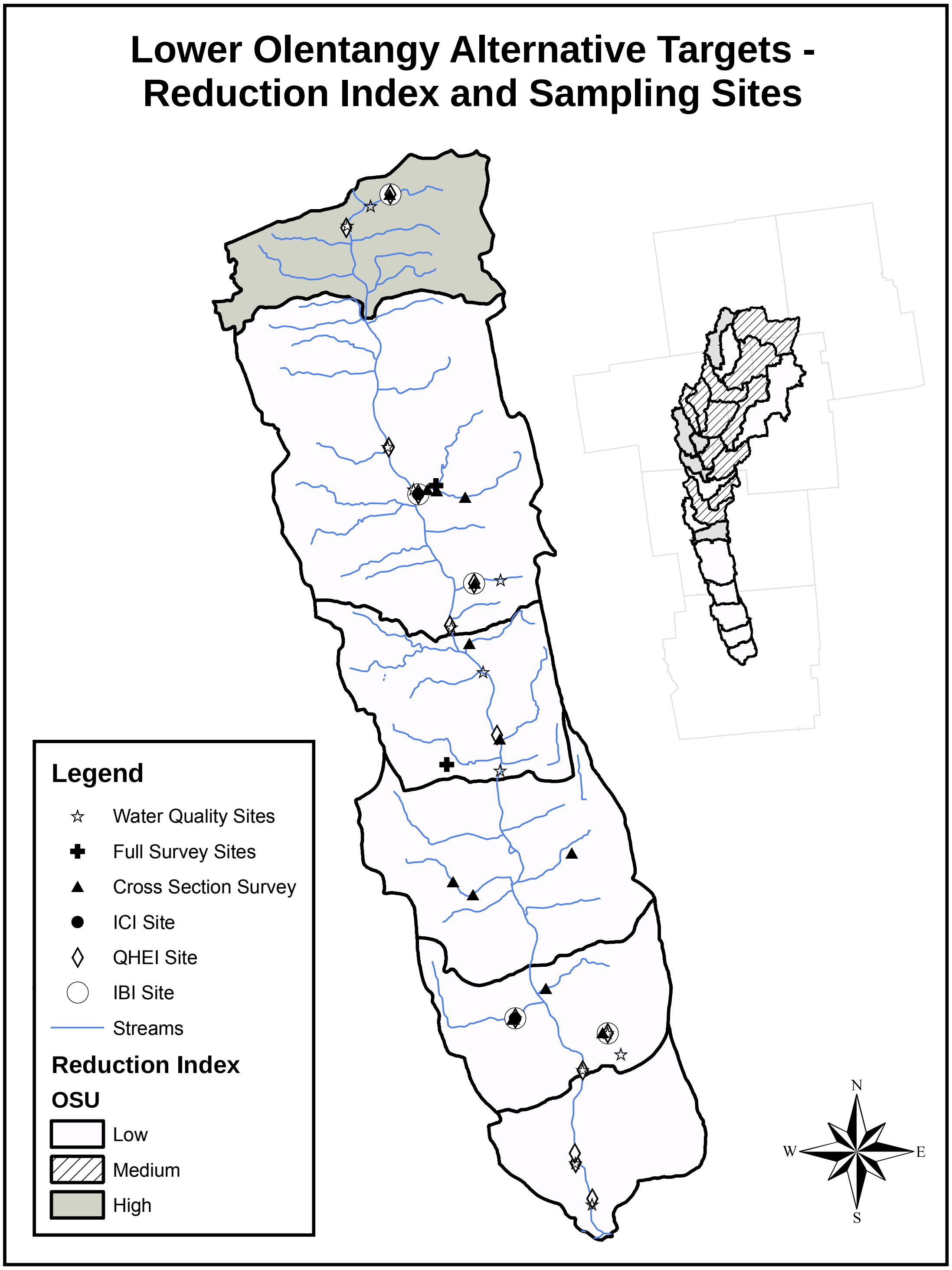


Figure 6.5c Lower Olentangy (HUC 05060001-120) reduction index map (OSU alternative targets) and locations of sampling sites for the 2003/2004 TMDL biological, habitat, water quality, and geomorphology assessments.

6.5.2 Landscape Management Scenarios

Two types of SWAT modeling results have been provided in this report. First, landscape-level result to the stream system, which are specific to a 14-digit HUC. In other words, this is the amount of nutrients and sediment that enter the stream system for a particular land area. Second, is a reach-level result, which is the amount of nutrients and sediment that passes through a point in the stream system. This is the combined load from all upstream areas that may include many 14 digit HUCs.

Reach-level concentrations and loadings for HUCs with the highest landscape-level loadings of TP, nitrate-N, and TSS concentrations are presented in Figure 6.6 to Figure 6.8. We present the reach-level results to facilitate understanding of potential load reductions for various alternative management scenarios at one point in the system. Results for all reach-level and landscape-level loads are available in Appendix 3A and 3B. The best management strategies to reduce TP loadings appear to be the use of grass buffers adjacent to agricultural fields. It is probable that SWAT overestimates the efficiency of these systems as surface runoff often collects in rills and then bypasses much of the buffer.

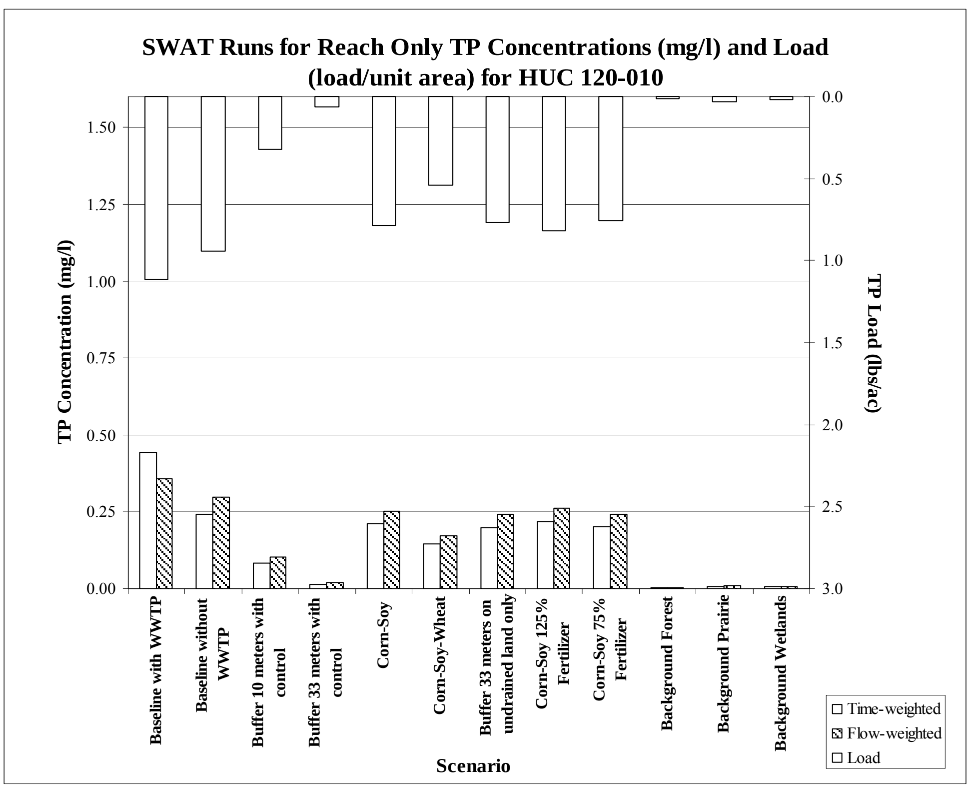


Figure 6.6 HUC with highest Total Phosphorus loads in a reach.

Predicted average annual nitrate-N concentrations from the landscape varied from 1.1 mg/l to 8.7 mg/l. HUC 110-050 (Olentangy to Whetstone Creek; Figure 6.7) exhibited the highest nitrate-N concentrations. This watershed is predominately agricultural with significant amounts of subsurface drainage. HUC 120-020 had the lowest predicted nitrate-N loading rate to the channel because of the high percentage of forest and pasture land use in the watershed at the time the land use data was developed. This area along the Olentangy River in Delaware and Franklin counties is developing quickly, and infrastructure is being constructed to support additional growth.

Evaluations of alternative management scenarios suggest that a combination of buffer strips and head control structures (for agricultural drainage water management) on subsurface drained agricultural land would be needed to satisfy any of the targets. Other strategies to reduce nitrate-N from agricultural land would be similar to those for TP. Nitrate-N discharges from urban areas are often high, and educational programs that promote proper use of less fertilizer on lawns and other grassed areas might be the best strategy to reduce these loads.

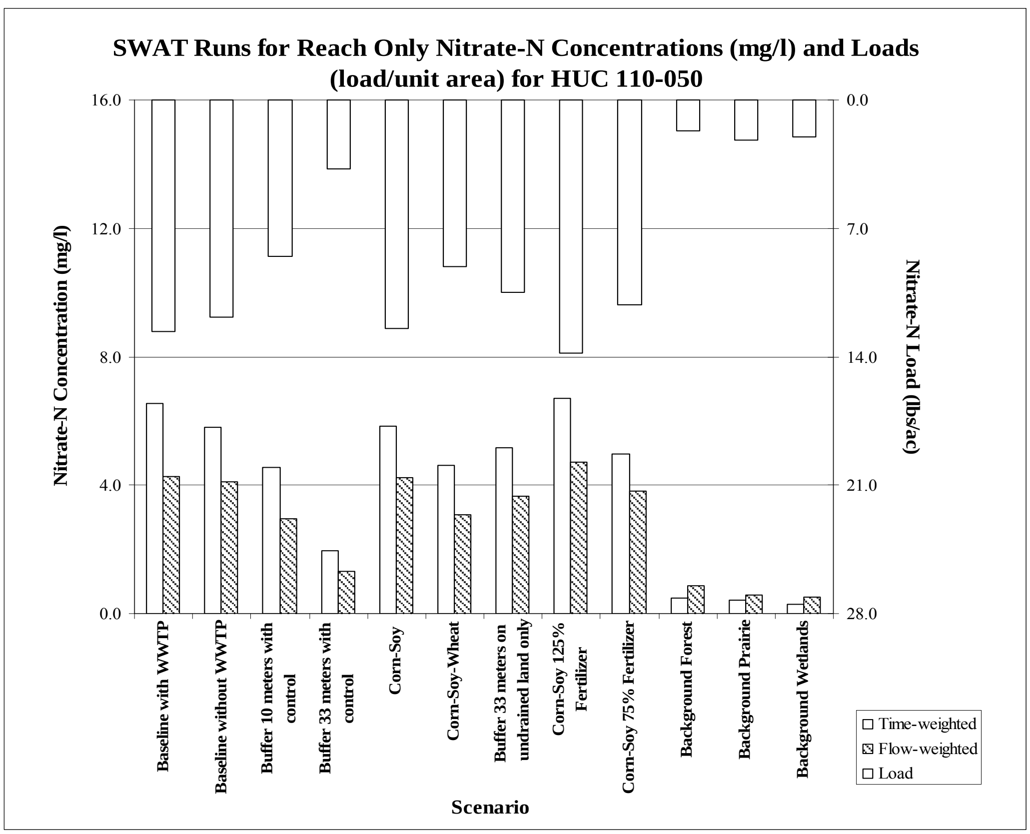


Figure 6.7 HUC with highest nitrate-N loads in a reach.

Predicted TSS concentrations generated from the landscape ranged from 19 mg/l to 636 mg/l. The highest TSS concentration was predicted in HUC 120-010 (Olentangy River to Delaware Run; Figure 6.8), which is the same HUC that had the highest TP loads. In this HUC, buffer/filter strips seem to have the most potential to reduce sediment delivery to the stream system. The corn-soybean-wheat rotation also showed reductions in TSS when compared to the baseline condition. Winter wheat serves as a cover crop and can potentially reduced erosion during winter months.

As stated earlier, caution must be exercised if trying to make direct comparison between groups of scenarios. Assumptions made in the development of management scenarios could produce results that do not seem consistent with expected results if compared to a scenario that does not make the same assumptions. As an example, we evaluated sediment loadings to the stream channel for Horseshoe Run (HUC 110-100). Under the baseline condition, the landscape load to the channel was predicted to be 0.47 tons per acre per year. In the corn-soybean rotation scenario, which would typically be the most intensive and highest input agricultural system, predicted sediment yields were much less at 0.26 tons per acre per year. Taken at face value, this result seemed erroneous, but a closer look at assumptions related to the timing of tillage operations provides useful insight on the problem.

In the baseline scenario for Horseshoe Run, much of the cropland received fall tillage. Fall tillage operations leave soils bare and unprotected during winter months. Furthermore, combinations of large precipitation events and frozen soils with little capability for infiltration can create conditions conducive to excessive erosion. In the corn-soybean rotation scenario all tillage operations were completed in the spring prior to planting. In this scenario, crop residue remained on the land during the winter months, thus reducing overland flow and erosion. To illustrate the impact of timing of tillage operations on sediment yields we altered the corn-soybean rotation (with spring tillage) scenario so that all tillage operations occurred during the fall. Results showed that TSS loads were much higher with fall tillage.

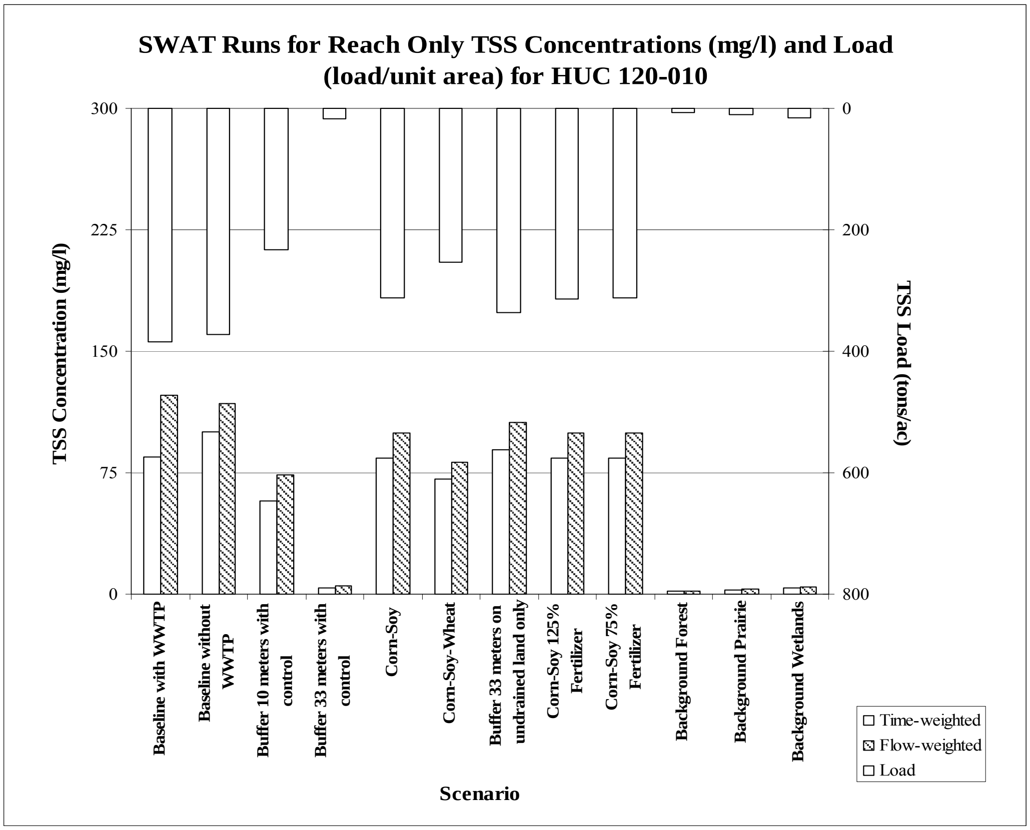


Figure 6.8 HUC with highest TSS loads in a reach.

6.5.3 Channel Degradation

SWAT can simulate deposition and degradation in stream channels. Degradation and down-cutting of the stream bed can be modeled in SWAT with knowledge of the erodibility of channel materials and a channel cover factor. Channel erodibility is similar to the USLE K-value, but K-values for the landscape are not appropriate to use for the stream bed and banks. This is because the environment of channel and floodplain soils is very different than the same soils that occur on the landscape. To date, the best method to determine erodibility of channel materials is with a jet device used in situ (Hanson, 1990). Because of time and resource constraints we were unable to collect data to support parameterization of this component of SWAT.

A channel cover factor is also used to model degradation, down-cutting and widening in SWAT. Channel cover factor is defined as the ratio of degradation from a channel with a specified vegetative cover to the degradation of a channel with no vegetative cover. Because we were unable to collect field data for these parameters, we conducted a sensitivity analysis to determine to what degree SWAT predictions were impacted by simulating channel degradation. The SWAT User Manual notes that channel erodibility values are typically an order of magnitude less than USLE K-factors for the same soil (Neitsch et al., 2002b). Upon evaluation of SWAT output at Claridon, it was evident that, under the worst case scenario, time-weighted and flow-weighted predicted concentrations of TSS increased by a factor of 2 to 3. This could suggest that a portion of the TSS predicted at Claridon is generated from the stream system itself and current modeling results of landscape erosion are over-predicted. Careful consideration must be given to this as it is possible that water quality targets may not be met by addressing landscape erosion only.

Evaluating the same SWAT simulations at the confluence of the Scioto River shows the immense potential for TSS derived from channel erosion below Claridon and, in particular, below the Delaware Dam. Using the same channel erodibility and cover factors, SWAT predicted increases in TSS concentrations that are 8 to 10 times higher than baseline conditions. SWAT predictions of changes in channel size suggest that cross-sectional area of the channel could increase by a multiple of two or more in many of the tributary systems below Delaware, OH.

6.6 Stream Geomorphology and Watershed Hydrology

Knowledge of stream geomorphology was obtained for the following purposes: (1) to determine if aquatic life use attainment and biological indicators were related to stream geomorphology; (2) to aid in evaluating if the stream is in dynamic equilibrium; (3) to help identify and diagnose stream bed and bank scour or instability problems; (4) to help identify and diagnose sediment deposition (aggradation) problems; (5) to aid in evaluating potential land use change impacts and to help identify measures to minimize potential adverse impacts; and (6) to provide representative channel dimension geometry information for use with the SWAT simulation model.

6.6.1 Stream Geomorphology Measurements

Stream geomorphology measurements ranged from: (1) making bankfull stage measurements at USGS gages; (2) obtaining cross-section dimensions at a representative riffle or run; (3) conducting pebble counts at some sites where cross-section data were obtained; and (4) conducting a comprehensive reach survey. Sites were selected to obtain stream geomorphology information at or near locations where Ohio EPA made IBI, ICI, and QHEI determinations.

For each reach survey information was obtained on channel materials, dimension, pattern and profile. Procedures used generally were consistent with guidelines presented by Harrelson et al. (1994). The survey was conducted with a laser level, 100-foot measuring tape, and a telescoping rod with a laser receiver. For each reach, a longitudinal survey was conducted over a stream length equal to at least 20 channel widths so that the survey encompassed at least two bends. Occasionally, it was only possible to survey one bend. Features typically measured included: channel cross-sections at 2-3 points along the reach; bed profile along the thalweg; water surface profile; azimuths of the banks from each feature to the next reach; the bankfull discharge elevation at points along the reach where it was easily identified; the top of the bank; and bed material particle size distribution. Each survey included at least one representative cross-section in a riffle feature that also had distinct bankfull features.

At each gage location, bankfull discharge was determined by identifying and measuring the stage of a bankfull fluvial feature, computing the channel cross-sectional area associated with the measured stage, and then calculating the discharge conveyed by the cross-sectional area. Many of the streams were entrenched, so the dominant bankfull feature was typically a narrow floodplain or bench located below the top of the bank. These features exhibited a combination of changes in the bank material, slope, particle size distribution, and vegetation. Using the gage as a point of reference, bankfull stage was measured at the most prominent observed bankfull feature using a laser level, a telescoping rod, and a laser receiver. Time was recorded and used to obtain the water stage elevation (at the time of measurement) from the real-time USGS gage. Determination of the cross-sectional area and bankfull discharge was based on published USGS measurements at the gage, a USGS gage rating curve, and our measurement of the bankfull stage.

6.6.2 Determining Geomorphology Relationships

Stream geomorphology measurements were entered into one or more of a suite of spreadsheets called STREAM (Spreadsheet Tools for River Evaluation, Assessment and Monitoring). The STREAM modules were developed by Dan Mecklenburg, at the Ohio Department of Natural Resources (ODNR), with input from Andy Ward at The Ohio State University (Mecklenburg and Ward, 2005).

The hydrology features in the *Contrasting Channel* spreadsheet were used to estimate the 0.8-year, 1.6-year, and 50-year recurrence interval (RI). In the spreadsheet, the stage associated with these discharges was then plotted on an estimate of the channel cross-section based on regional curves for the Upper Scioto River. These stages were then transferred to a version of the *Two-Stage Channel* spreadsheet customized to provide some of the output presented in Appendix 4.B. Hydrology models developed by USGS (Koltun and Roberts, 1990; Koltun, 2003; Sherwood, 1986) are built into the spreadsheet and calibration of these models is discussed in Section 4.2.

Two factors that provide useful indicators of equilibrium conditions are the *flooded width ratio* and the *bank height ratio*. The *flooded width ratio* is the width of flow when the bankfull discharge is just exceeded divided by the bankfull width. The *bank height ratio* is the height to the top of the bank divided by the bankfull discharge stage height. Ward and Mecklenburg (2002) suggest that for natural streams the *flooded width ratio* should be at least 8 times the bankfull width and the *bank height ratio* needs to be much less than 1.5 to sustain dynamic equilibrium. Estimating these ratios requires considerable judgment. In order to provide a constant point of reference we determined width and depth ratios associated with the 0.8-year, 1.6-year, and 50-year RI discharge. For the Olentangy River watershed most bankfull dimensions are associated with a discharge less than the predicted 1.6-year RI discharge and, in some cases, a discharge less than the 0.8-year RI discharge.

6.6.3 Discharge Relationships

Annual peak discharge data for the USGS gages in the Upper Scioto River watershed were sorted, ranked, and plotted using the Weibull Method (Ward and Trimble, 2003). Log regression equations were fitted to the data to best represent discharge versus recurrence interval relationships. Regression equations were used to estimate discharge recurrence intervals for bankfull flows at each gage. Effective discharge at the Higby, Ohio gage was determined based on USGS daily measurements of sediment and discharge. A spreadsheet tool was used to develop a Wolman-Miller model of the geomorphic work (Mecklenburg and Ward, 2004; Ward and Mecklenburg, 2005).

6.6.4 Results

Geomorphology cross-section or reach measurements were made at a total of 84 sites, which included 28 sites on Thorn Run and Flat Run watersheds. The remaining 56 sites were distributed across the entire watershed. To avoid biasing the results, only 5 of the sites for Flat Run and 2 of the sites for Thorn Run were used in the analysis. Bankfull measurements were made at 8 USGS gages in the Upper Scioto River Basin (the total watershed draining to the gage at Higby, Ohio).

A regional curve for the Upper Scioto River Basin is shown in Figure 6.9. The regional curve is based on 48 of the geomorphology sites and all 8 USGS gages. Results of the annual peaks series analysis to determine a relationship between bankfull discharge and recurrence interval are presented in Table 6.12. Also reported in Table 6.12 is the effective discharge at the Higby, Ohio gage on the Scioto River (Powell et al., 2005). Results show that, based on the method used, the recurrence interval of bankfull discharge is 0.8 years to 1.3 years.

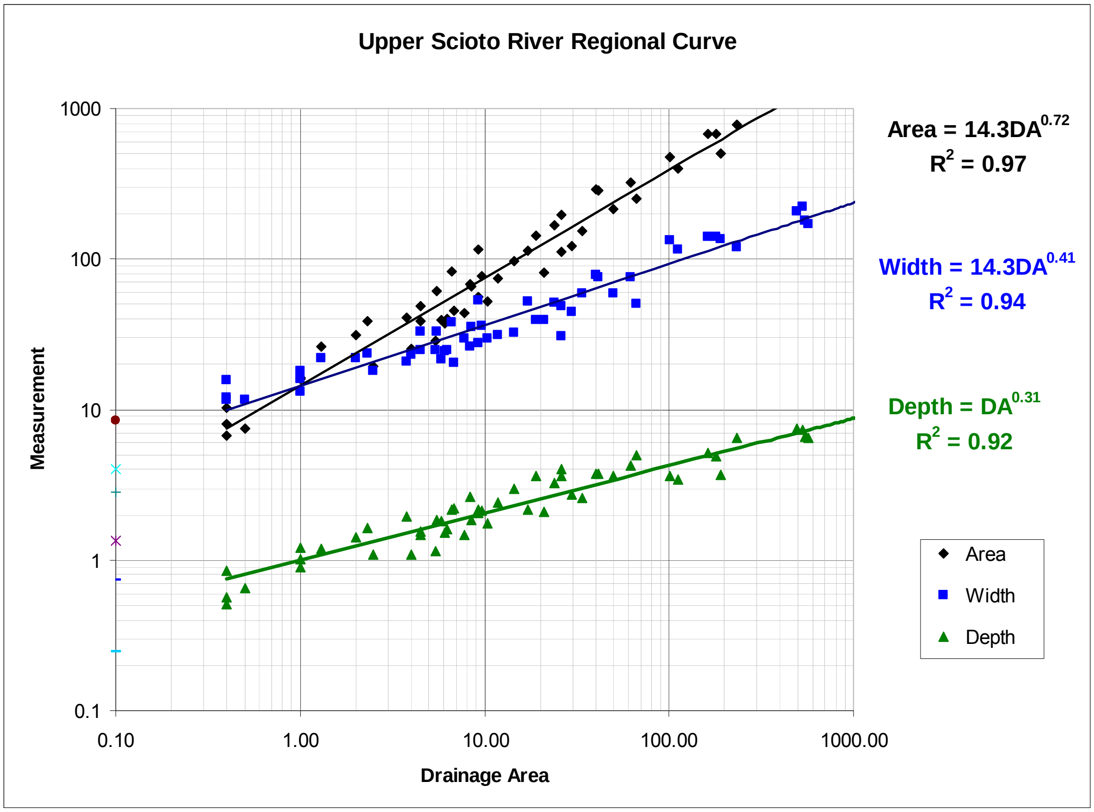


Figure 6.9 Regional curve for the Upper Scioto River basin.

The main purpose in obtaining information on hydrology and stream geomorphology of ditches and streams in the Olentangy River watershed was to identify problem areas and to ascertain if aquatic life and habitat were associated with geomorphology. In order to conduct that analysis, sites were selected in HUCs located on the main tributaries and at several locations along the main stem of the Olentangy River. At each of these sites, we identified the stage of the 0.8-year, 1.6-year, and 50-year RI discharges, and calculated flooded width and depth ratios and a qualitative geomorphology index.

Table 6.12 Recurrence interval of bankfull discharges at gages in the Upper Scioto River basin.

Site	Gage	Drainage Area (mi^2)	Bankfull Discharge (cfs)	Recurrence Interval (years)
Little Darby @ West Jefferson	03230310	162	1500	0.9
Big Walnut @ Central College	03228500	190	1000	0.8
Big Walnut @ Sunbury	03228300	501	2220	0.8
Big Walnut @ Reese	03229500	544	4000	0.9
Big Darby @ Darbyville	03230500	534	4180	1.1
Scioto @ Prospect	03219500	567	3300	0.9
Scioto @ Chillicothe	03231500	3849	14700	1.1
Scioto @ Higby	03234500	5131	27000	1.3
Scioto @ Higby	03234500	5131	18000[1]	1.0

[1]Effective discharge at the USGS gage on the Scioto River at Higby, OH.

A summary of the 36 sites considered in this analysis is presented in Table 6.13. In general, the geomorphology of the watershed is fairly good as many streams have some connection with wooded active floodplains. For all but a few of the sites there were bankfull features associated with predicted discharge having a recurrence interval less than 1.6 years and often less than or similar to 0.8 years. This result is consistent with the recurrence interval of bankfull and effective discharge at the USGS gages. At most locations the particle size at incipient motion, calculated based on bankfull depth and bed slopes estimated from the GIS data from the SWAT model, was similar to the measured D_{50} or D_{84}. However, there is evidence of incision at many locations. The frequency of out of bank flows associated with the bankfull discharge is probably declining and, in most locations, the flooded width is much less than desirable for natural stream systems and often less than three times the bankfull width.

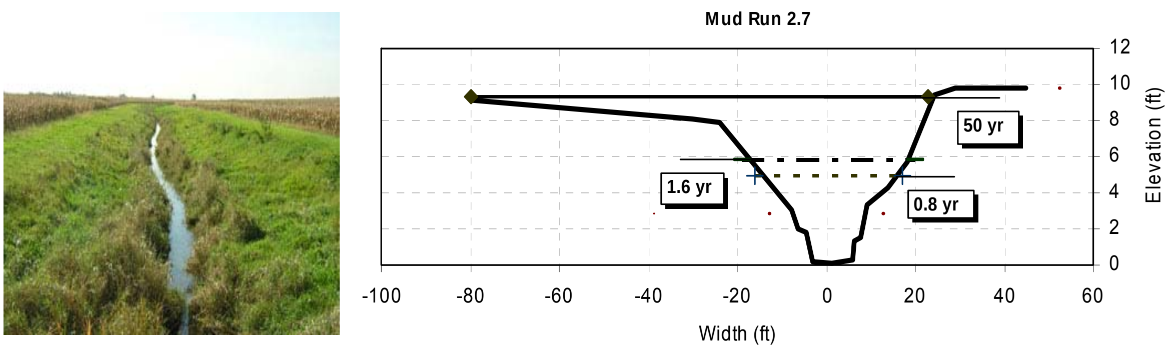
Table 6.13 Qualitative assessment of geomorphology of primary sites in the Olentangy River watershed.

Site	River Mile	Shear Stresses	Regional Curve Ratio	Stage Discharge Ratio	Flooded Ratio	Visual Obs.	Index Score
Adena Brook	0.3	between	2.3	1.2	0.9	good	1
Big Run N Trib	0.5	between	1.8	1.1	1.0	good	2
Big Run S. Trib	1.3	same	1.5	1.4	1.0	good	2
Walhalla Ravine	0.9	larger	1.4	1.2	5.8	good	5
Bee Run	0.1	between	0.8	1.1	9.6	poor	7
Deep Run	0.9	smaller	1.15	1.3	1.8	good	3
Delaware Run	1.2	same	0.9	1.1	2.5	poor	7
E.Br. WC	2.4	same	1.3	1.3	1.0	good	4
Grave Creek	1.4	same	0.7	1.1	1.9	poor	3
Flat Run	0.1	larger	1.5	1.2	1.3	excellent	2
Horseshoe Run	0.9	smaller	0.7	1.1	4.4	good	6
Indian Run	0.9	same	0.7	1.1	4.3	poor	6
Kempton Run	1.1	same	1.7	1.3	1.0	good	2
Fisher Run	1.5	larger	0.7	1.5	1.7	poor	-1
Mill Run	0.9	between	0.5	1.4	1.5	poor	0
Mud Run	2.7	larger	0.6	1.2	1.5	good	2
Norris Run	1.3	between	1.2	1.2	5.2	good	7
Otter Creek	1.1	larger	1.1	1.2	6.8	poor	5
Olentangy River	12.1	larger	1.4	1.3	1.4	good	2
Olentangy River	40.8	same	1.2	1.3	3.9	excellent	9
Olentangy River	45.5	same	1.2	1.3	2.3	good	6
Olentangy River	63.4	larger	0.9	1.2	4.2	good	6
Olentangy River	74.0	--	0.8	1.3	1.2	poor	1*
Olentangy River	84.5	same	1.2	1.3	1.3	excellent	6
Olentangy River	85.2	same	1.5	1.1	4.6	excellent	8
QuaQua Creek	0.1	same	1.1	1.2	2.0	excellent	7
Rocky Fork	4.4	same	1.0	1.2	3.4	excellent	9
Rush Run	1.5	--	0.9	1.2	2.2	poor	3*
Shaw Creek	1.6	larger	0.8	1.6	5.3	good	4
Sugar Run	1.3	smaller	0.9	1.4	2.9	excellent	5
Thorn Run	1.3	same	1.6	1.3	2.7	good	5
Turkey Run	0.7	between	1.5	1.4	1.0	poor	0
Trib to OR 13.3	0.1	between	1.2	1.3	1.0	good	4
Whetstone Creek	2.0	same	0.9	1.4	1.2	good	4
Whetstone Creek	9.2	between	1.2	1.2	1.1	good	4
Whetstone Creek	29.3	between	1.1	1.2	1.2	poor	3

*Bed material not measured; Actual Index Score may be higher or lower than what is indicated in the table.

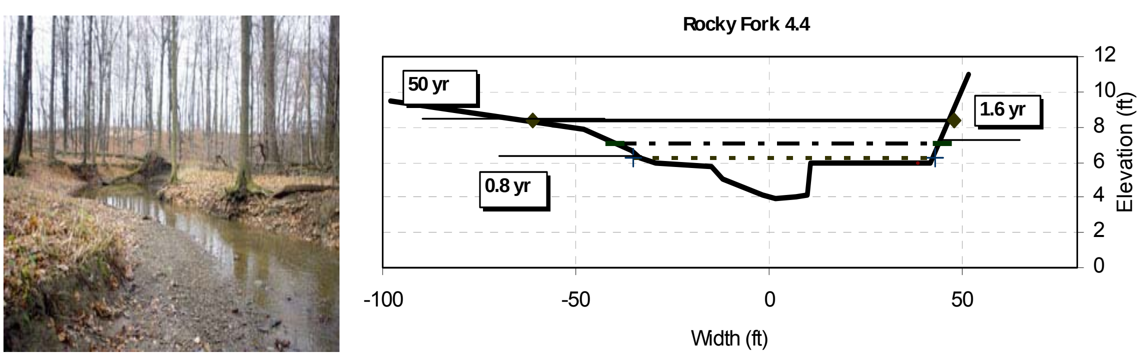
An example of how the data were used is shown in Figure 6.10. Figure 6.10a shows a fairly stable agricultural ditch that is building benches and has a grass buffer. However, the system is very incised, straight, and needs a narrower channel and slightly higher benches to prevent aggradation. Figure 6.10b shows a stream that is well-attached to a broad, wooded active floodplain. Bed material size is very consistent with shear stresses associated with the bankfull discharge. Incision is small and bankfull dimensions are similar to those predicted by the regional curve.

a) Mud Run at river mile 2.7, with poor geomorphology



Site	Shear Stresses	Regional Curve (Fraction)	Stage Discharge Ratio	Floodplain Ratio	Visual Observation	Index Score
Mud Run	larger	0.6	1.2	1.5	good	1

b) Rocky Fork at river mile 4.4, with excellent geomorphology



Site	Shear Stresses	Regional Curve (Fraction)	Stage Discharge Ratio	Floodplain Ratio	Visual Observation	Index Score
Rocky Fork	same	1	1.2	3.4	excellent	9

Figure 6.10 Example of: a) an agricultural ditch with relatively poor geomorphology (Geomorphology Index = 1); and b) a stream with excellent geomorphology (Geomorphology Index = 9).

Aggradation occurs in many locations in the watershed primarily because of structures in the channel such as low rise weirs, bridges and log jams. Most of the small headwater systems are modified channels or agricultural ditches. These systems are a mosaic of: small wooded areas with attachment to the floodplain; straight and deep ditches that are flanked by grass buffer strips or row crops and are building benches in the lower half of the ditches; un-maintained ditches, or ditch reaches that are attempting to recover; and maintained sections with various levels of aggradation depending on the frequency of maintenance. At a few locations, cattle grazing caused localized bank instability problems. Periodically within this mosaic, there is evidence of urbanization and commercial activities adversely impacting dynamic equilibrium. At several locations and, in particular, from a few miles north of Delaware, Ohio to the confluence with the Scioto River in the center of Columbus, Ohio, urbanization is the main threat to sustaining equilibrium.

6.7 Statistical Analysis of Biological and Environmental Variables

The structure and function of aquatic communities is influenced by a number of spatial and temporal factors. At the watershed scale, factors like climate, geomorphology, and zoogeography influence regional species pools (Williams et al., 2002). Regional pools, in turn, are influenced by biotic interactions and abiotic factors producing local species assemblages (Tonn et al., 1990). The structure of local fish assemblages has been linked to factors including geography, geology and climate, richness of regional species pool (Angermeier and Winston, 1998), stream order and network position (Pusey et al., 1995; Williams et al., 2005), local stream habitat, water quality, and flow characteristics (Matthews et al., 1994).

Because streams are intimately linked to terrestrial, landscape-level and local processes, aquatic biota such as fishes and macroinvertebrates are useful environmental indicators for explaining impacts of disturbances on streams. Ohio is one of the few states that incorporates biology and the physical habitat into Water Quality Standards (Yoder and Rankin, 1998). The Ohio Environmental Protection Agency (EPA) uses a variety of multi-metric indices to assess stream structure and function, including the Index of Biotic Integrity (IBI; Karr, 1981; 1986; Fausch et al., 1984), the Invertebrate Community Index (ICI; DeShon, 1995), and the Qualitative Habitat Evaluation Index (QHEI; Rankin, 1989; 1995) among others. While these indices are useful for revealing water quality problems and potential correlative sources, the ecological relationships among biota and habitat are not easily elucidated. Integrating biology, habitat, and water quality in a quantitative manner is complex and has seen limited study. Furthermore, the role of stream processes and stream geomorphology in influencing stream function is relatively unknown and generally has not been considered in Total Maximum Daily Load (TMDL) studies around the nation.

Our first objective was to identify key environmental variables within the watershed and reach scales that structure stream fish assemblages. Our second objective was to evaluate the relative influence of environmental variables from different spatial scales in determining fish assemblages. Our third objective, which is discussed in section 6.8, was to compare geomorphology and water chemistry variables measured in the field with estimates from computer models. Physical habitat, geomorphology, spatial location, and water quality variables were assessed by site with multiple regression techniques to detect spatial and temporal differences in IBI score.

To conduct this study, we had the benefit of access to Ohio EPA's extensive database of IBI, ICI, QHEI, and water chemistry for the Olentangy River watershed. The Ohio State University (OSU) team collected geomorphology, spatial location, and computer model-generated water chemistry at many locations throughout the watershed based on places that had existing Ohio EPA biological data.

6.7.1 IBI and Environmental Variables

IBI relies on 12 community metrics within three broad categories (species richness and composition, trophic composition, and fish abundance and condition) to assess fish community attributes that are presumed to correlate with biotic integrity. Although no one metric alone can indicate this consistently, all of the IBI metrics combined include the redundancy needed to obtain a consistent measure of biotic integrity (Angermeier and Karr, 1986). Therefore, we analyzed the influence of environmental variables on the aggregate IBI score for each site. Ohio EPA collected IBI data for a total 170 sites in the Olentangy River watershed from 1979 to 2004. Seventy-nine of those sites were surveyed in 2003 and 2004. Where more than one IBI score was calculated for one site in the same sampling year, the IBI scores were averaged. Where IBI score was calculated for both 2003 and 2004, the most recent data were used.

The IBI-type assessments often use ecoregions (Omernik and Gallant, 1988) as the basic classification unit. In this case, all streams within an ecoregion are assumed to be similar, and test sites are compared with reference sites within the ecoregion. Frequently, however, streams are not homogeneous at the ecoregion scale (Wang et al., 2003), and finer-scale classifications have been developed based on physical attributes that are important in structuring biological assemblages. In these cases, test sites are compared with reference sites having similar characteristics such as stream size or use designation (Ohio EPA, 1987).

6.7.2 Physical Habitat

The QHEI was developed based on knowledge of fish habitat and is intended to be both positively and negatively correlated with IBI scores. While we test the correlation of the QHEI and its metrics to IBI scores in this study, of greater importance is how the QHEI compares to other environmental variables such as geomorphology, water quality, and spatial location within the watershed in affecting IBI scores. In our study, stream habitat is represented by QHEI metrics: substrate quality, channel morphology, pool/glide quality, riffle/run quality, in stream cover, riparian zone quality and gradient (ft/mile). Ohio EPA has QHEI data for a total of 155 sites in the Olentangy River watershed from 1979 to 2004. Data on QHEI were collected by Ohio EPA during 2003 and 2004 at 77 of those locations. Where data were available for both 2003 and 2004, the most recent data was used.

6.7.3 Geomorphology

Linking stream geomorphology to physical habitat characteristics may partially explain differing channel responses to effects of land use change on stream communities. Measured geomorphology variables were: slope (feet/feet, reach surveys; slope from cross-section surveys was estimated using the SWAT model), bankfull width (feet), mean depth (feet), cross sectional area (square feet), sinuosity, entrenchment ratio, width of the flood prone area (feet), hydraulic radius (feet), width to depth ratio, and bed material size (D_{50} and D_{84}; millimeters). Measured data, including both entire reach surveys and cross-sectional surveys, were collected at 54 sites throughout the Olentangy River watershed by the OSU team in 2004. Fifty of those sites contained corresponding IBI data to analyze geomorphologic influence on 2003 and 2004 IBI scores.

6.7.4 Spatial Location

Because the location of stream channels within a drainage network appears to influence IBI scores causing resource manager to underestimate biotic integrity in headwater tributary streams or over estimate the quality of main channel tributary streams (Osborne et al., 1992), we described the relationship of a given stream reach to upstream and downstream influences within the Olentangy River watershed. Spatial location in reference to the Olentangy River mainstem was represented by stream order (as described by Strahler, 1952), drainage area (mi^2), river mile, distance downstream to next order stream (feet), distance upstream to a wooded riparian zone (feet), and percent wooed riparian zone within one square mile of the survey site. Spatial location variables were created by the OSU team as a way to express connectivity of the Olentangy watershed for a total of 76 sites using visual observation and ArcGIS 1:24,000 scale topographic maps, Digital Elevation Models and aerial photographs. Sixty-six of those sites had corresponding IBI information and were used to determine spatial location influence on IBI scores.

6.7.5 Water Quality

Measured water chemistry, represented by the mean and median values of the following constituents analyzed from Ohio EPA grab samples collected in 2004, include: nitrate-N, ammonia-N, nitrite-N, total phosphorus, total suspended solids, fecal coliform, total Kjeldahl nitrogen, and biological oxygen demand (BOD). Eighty-three sites were sampled in the Olentangy River watershed during 2003-2004. Forty-nine of those sites contained corresponding 2003-2004 IBI data and were used to analyze measured water chemistry influence on IBI score. However, the grab samples only provide a snapshot in time of the water quality signature of the watershed.

6.7.6 Species–Environment Statistical Methods

In assessing the response of biology (IBI score and metrics) to physical, chemical and spatial factors, we sought a statistically succinct way of handling large amounts of information available to us through our own investigations and data provided by Ohio EPA. For complex, large-scale questions in community ecology, standard parametric multivariate tools (i.e., MANOVA) often are inappropriate for testing hypotheses and data rarely meet the assumptions of these tests (Williams et al., 2005). Typical univariate analyses usually are inappropriate because intercorrelated response variables do not adequately express the complexity of the relationship between independent and dependent variables (McCune and Grace, 2002; Williams et al., 2005).

In order to employ multivariate statistical techniques to shorten a long list of variables containing somewhat redundant information about the watershed, the information must be uncorrelated linear combinations of variables derived from the original data set. To reduce the data set from seven to nine variables per category to three to five variables per category, for example, we first assessed the correlation of the variables to each other and to IBI score. First, we created a correlation matrix for each of the four categories of variables: habitat represented by QHEI, geomorphology, spatial location, and water quality. We began by setting our minimum correlation threshold to 0.3, and eliminated any variables below this threshold. Then, we assessed the variables against each other to determine which variables grouped together. Finally, we assessed the grouped variables for correlation to IBI score. For example, river mile, stream order and drainage area are highly correlated with each other and with IBI score within the spatial location category. Stream order showed the strongest correlation to IBI score, followed by drainage area, therefore, river mile was eliminated from the list of variables describing spatial location.

We then conducted linear and stepwise multiple regression analyses to determine which of the remaining variables were significant ($p < 0.05$, except water quality variables where $p < 0.1$) to further reduce the data set. To ensure that significant variables were not inadvertently eliminated during the correlation analysis, we also conducted linear and stepwise multiple regression analyses using all the variables of the original data set. In our study, correlation and simple linear regression analyses were done using the Systat v.11 statistical software package (SSI, 2004).

We used canonical correspondence analysis (CCA; ter Braak, 1986) to determine the relationship of fish (IBI metrics; dependent variables) to the environmental factors which are most important in contributing to spatial segregation in the Olentangy River watershed: stream habitat, geomorphology, water quality and spatial location (independent variables). CCA is a direct gradient analysis widely utilized in ecology for ordinating species and environmental data simultaneously where an ordination of one multivariate matrix is constrained by multiple linear regressions on variables in a second matrix (McCune and Grace, 2002). The underlying assumption of CCA is that species exhibit Gaussian-type (unimodal) responses to environmental gradients; or, that within their range species will be most abundant around their environmental optima for survival (ter Braak and Verdonschot, 1995). Recent authors have used similar multivariate techniques to test hypotheses about species-environment relationships at different spatial and temporal scales or the effects on aquatic assemblages (ter Braak and Verdonschot, 1995; Jongman et al., 1995; Wang et al., 2003; Williams et al., 2003; Williams et al., 2005). We applied CCA using the computer program Canoco (ter Braak and Smilauer, 2002). Variables with a p-value less than 0.05, using Monte Carlo tests (1,000 permutations), were retained in the analysis. We then inferred the nature of the species – environment relationship from intraset canonical correlation coefficients of environmental variables with CCA axes.

We used a variance partitioning technique to relate variation in IBI metrics to the explanatory variables for each category (as described in Williams et al., 2005). Variance partitioning is accomplished by a series of partial CCAs. For each of the three categories of environmental variables (geomorphology, QHEI, and spatial location), we used the other two categories as covariates in the analysis to assess the pure effects of each. We computed the percent variance in IBI metrics that was explained by each independent variable set (i.e., geomorphology, habitat, spatial location). For each partial CCA, we used Monte Carlo tests (1,000 permutations) to estimate the significance of each variable ($p < 0.05$).

6.7.7 Results

Nine environmental variables out of 32 from the four categories habitat, geomorphology, spatial location, and water quality were retained following correlation (Table 6.14). None of the water quality constituents were significant, and thus were not retained for regression analysis. An example of regression analysis results is presented in Table 6.15. The most significant environmental variables influencing IBI score in the Olentangy River watershed were pool quality (p = 0.005), gradient (p = 0.041), stream order (p < 0.000), and elevation at the mouth (p = 0.023).

Table 6.14 Correlation analysis results from SYSTAT showing environmental variables retained for regression analysis (bold variables have $r^2 = 0.3$ or greater).

Environmental Categories			
Habitat		**Geomorphology**	
Original Variables	*Reduced Data Set*	*Original Variables*	*Reduced Data Set*
• QHEI Score • In-stream Cover • Channel Quality • Riparian Quality • Pool/Glide Quality • Riffle/Run Quality • Gradient (ft/mi)	• **Pool Quality** • **Gradient (ft/mi)**	• Stream Length (mi) • Elevation (source, ft) • Elevation (mouth, ft) • Average Fall (ft/ft) • D_{50} (mm) • D_{84} (mm) • Width of the flood prone area • Cross sectional area (ft^2) • W:D ratio • Entrenchment Ratio • Hydraulic Radius (ft)	• **Elevation (mouth, ft)** • **Average Fall (ft/ft)** • **Cross sectional area (ft^2)** • **W:D ratio**
Spatial Location		**Water Quality**	
Original Variables	*Reduced Data Set*	*Original Variables*	*Reduced Data Set*
• Stream Order • Distance upstream to wooded riparian zone (ft) • Riparian zone percentage • Distance downstream to next higher order stream (ft) • River Mile • Drainage Area (mi^2)	• **Drainage Area (mi^2)** • **Stream Order** • **Riparian zone percentage**	• Nitrate (median, mean) • Ammonia (median, mean) • Nitrite (median, mean) • Total phosphorus (median, mean) • Total Suspended Solids (median, mean) • Fecal coliform (median, mean) • Total Kjeldahl Nitrogen (median, mean) • Biological Oxygen Demand (BOD; median, mean)	• **None significant**

Table 6.15 Systat linear regression results for (a) all variables of the spatial location category (independent variables) and IBI score (dependent variable), and (b) reduced set of significant variables from the correlation analysis (*p < 0.05*).

(a) All Spatial Location Variables

Dep Var: IBI N: 66 Multiple R: 0.796 Squared multiple R: 0.634
Adjusted squared multiple R: 0.597 Standard error of estimate: 6.264

Effect	Coefficient	Std Error	Std Coef	Tolerance	t	P(2 Tail)
CONSTANT	17.019	2.600	0.000	.	6.545	0.000
RM	0.811	0.880	0.726	0.010	0.921	0.361
DRNAREA	-0.159	0.066	-0.330	0.328	-2.398	0.020
STREAMORDER	7.803	1.311	0.912	0.264	5.952	0.000
DISTTORIP	0.001	0.000	0.122	0.802	1.391	0.169
RIPZONEPCT	0.170	0.062	0.251	0.748	2.753	0.008
DISTNXTORDR	-0.000	0.001	-0.663	0.010	-0.842	0.403

(b) Reduced Spatial Location Data Set

Dep Var: IBI N: 66 Multiple R: 0.793 Squared multiple R: 0.629
Adjusted squared multiple R: 0.598 Standard error of estimate: 6.257

Effect	Coefficient	Std Error	Std Coef	Tolerance	t	P(2 Tail)
CONSTANT	17.309	2.578	0.000	.	6.715	0.000
DRNAREA	-0.149	0.065	-0.308	0.338	-2.276	0.026
STREAMORDER	7.777	1.309	0.909	0.265	5.941	0.000
DISTTORIP	0.001	0.000	0.111	0.818	1.277	0.207
RIPZONEPCT	0.164	0.061	0.242	0.757	2.671	0.010
DISTNXTORDR	0.000	0.000	0.057	0.618	0.568	0.572

The environmental variables most important in explaining fish assemblages were determined by examining correlation with CCA ordination axes. The correlation of an environmental variable with each axis indicates the strength of its relationship with a particular stream and/or fish assemblage attributes. Arrows indicating relative importance and direction of environmental variables were placed on the axes by Canoco. Each arrow points in the direction of maximum variation in value of the corresponding variable. The most important environmental variables (in terms of explaining IBI metrics) have longer arrows than less important variables. Only significant variables from the regression analysis were used for the CCA.

Canonical correspondence analysis reflected spatial differences (Figure 6.11) within the Olentangy River watershed and between fish assemblage attributes represented by metrics of the IBI score. The first and second axes explained 90% of variance. The lower portion of the Olentangy River watershed is distinctly different from the Whetstone Creek watershed streams and only similar to the upper portion of the watershed near the Delaware Reservoir. The upper portion of the watershed is distinctly different from the Whetstone Creek watershed except for streams closest to the boundary between the two watersheds including Flat Run, Claypool Run, and Mitchell Run. Stream reaches within the lower Olentangy watershed tend to be higher gradient and wider than they are deep most likely because they are predominantly bedrock controlled and located in ravine-like settings. Streams located in the upper Olentangy watershed tend to be low gradient agricultural streams with relatively poor riparian zones and in-stream habitat. Streams within the Whetstone Creek watershed tend to be higher gradient with relatively good in-stream habitat and riparian zones.

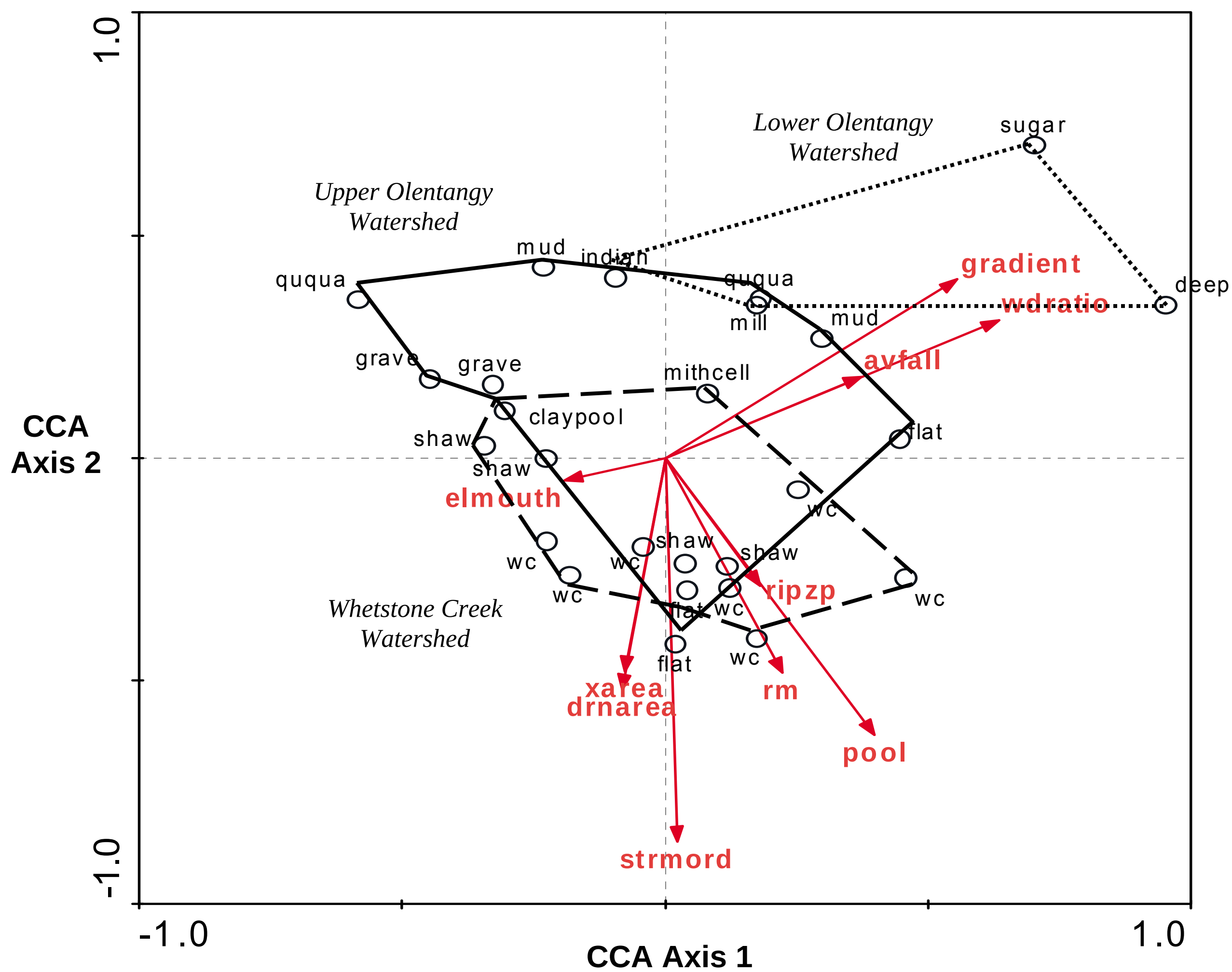


Figure 6.11 CCA ordination diagram showing stream reaches superimposed on significant environmental variables (arrows; *p<0.05*) most closely associated with axes CCA1 and CCA2 using Canoco. *Variables include: Stream order (strmord), pool quality (pool), river mile (rm), drainage area (drnarea), cross sectional area (xarea), riparian zone percentage (ripzp), elevation at the mouth (elmouth), gradient, average fall (avfall), and width to depth ratio (wdratio). Regions of the watershed are identified and partitioned by dashed line boundary (Whetstone Creek Watershed), dotted line boundary (Lower Olentangy Watershed below Delaware Reservoir), and solid line boundary (Upper Olentangy Watershed above Delaware Reservoir). Overlap of boundaries indicates similarity between sites and regions of the watershed.*

CCA Variance partitioning

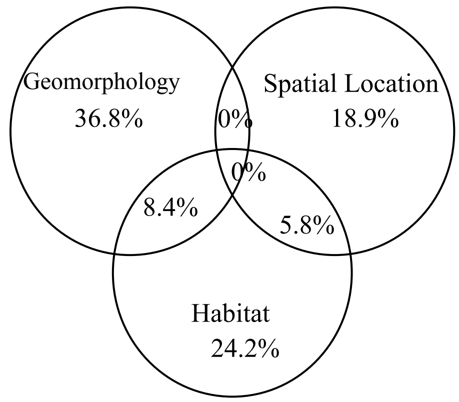
All of the environmental variables in the data explained seventy-nine percent of the variability in IBI metrics, yet were not statistically significant most likely because the data set included a lot of intercorrelated variables (Figure 6.12a). The pure effects of geomorphology (36.8%) explained more variation than spatial location (18.9%) and habitat as represented by the QHEI (24.2%). Shared variation between geomorphology and habitat represented 8.4% while shared variation between habitat and spatial location represented 5.8%. There was no shared variation between geomorphology and spatial location or among the three categories combined. Total uncertainty, or the environmental variables that influence fish assemblages that can not be accounted for because they were not measured or could not be quantified, is 21%.

Fifty-nine percent of the variability in IBI metrics was explained by modeling only the most significant variables from each category (Figure 6.12b). The pure effects of geomorphology (18.1%) explained more variation than spatial location (12.1%) and habitat as represented by the QHEI (12.4%). Shared variation between geomorphology and habitat was 1.8%; and between habitat and spatial location was 0.3%. There was no shared variation between geomorphology and spatial location. Shared variation among all three categories was 14.2%. Total uncertainty for the reduced data set is 41%. Although using only significant environmental variables resulted greater uncertainty, we have more confidence in the statistical model. Using this model, we were able to explain 60% to 80% of the variation in fish assemblages as represented by the IBI in the Olentangy River watershed. These results are consistent with findings from other authors (Williams et al., 2002).

We also explored how the results would change if some of the variables with high leverage were removed from the analysis. First, it appeared that Deep Run and Sugar Run had high leverage and strongly associated with geomorphology variables width to depth ratio and average fall. We eliminated these sites from the analysis and re-ran the variance partitioning using significant variables. Results indicated that although variability explained by the pure effects of each of the three categories decreased, geomorphology and spatial location explained equal variability, which was more than QHEI.

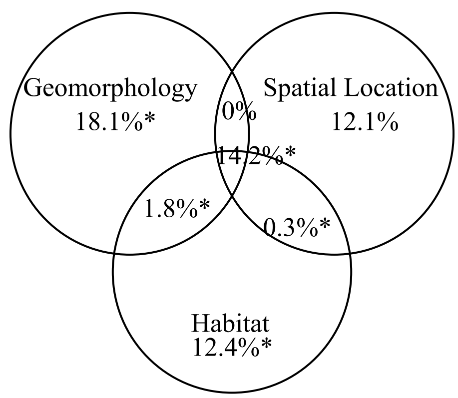
In the second leverage analysis, we examined how the results would change if there were more equal sites within a particular watershed represented. For example, the original analysis contained 7 sites on Whetstone Creek and 4 sites on Shaw Creek whereas the other sub-watersheds contained only one to two sites each. In this analysis we only allowed three sites each from Whetstone Creek and Shaw Creek (at the outlet, in the middle, at the top). Again, variability explained by the pure effects of each environmental category was less, but geomorphology and spatial location explained similar amounts of variability in IBI score, which was more than QHEI.

(a) All Biological and Environmental Variables



Total uncertainty: 21%

(b) Only Significant Biological and Environmental Variables



Total uncertainty: 41%

Figure 6.12 CCA variance partitioning results showing the pure effects and shared variation of each environmental category geomorphology, spatial location, and habitat represented by QHEI for (a) all variables of the data set, and (b) the reduced data set of significant variables. *An * indicates significance (p<0.05) with a Monte Carlo test.*

6.8 Predicted Water Quality Analysis

In a similar correlation and regression analysis as the one described previously, we evaluated the influence of predicted, or modeled, environmental variables on IBI score in the Olentangy River watershed. Using measured data from the 36 sites mentioned in Section 6.6.5, the OSU team generated water chemistry (total phosphorus, nitrate-N and total suspended solids) from SWAT, calculated the 1.6-year floodplain ratios and stage-discharge ratios using the STREAM spreadsheet modules, and developed a qualitative geomorphology index. Predicted, or estimated, geomorphology variables associated with the 1.6 year recurrence interval were used in a regression analysis ($p<0.1$) along with predicted water chemistry, IBI score, spatial location, and habitat represented by metrics of the QHEI.

We obtained SWAT-generated water chemistry for 33 of the 36 sites. Nineteen of 36 sites had corresponding data for geomorphology, IBI, QHEI, water chemistry, and spatial location data primarily because: (1) 7 of the 36 sites were on the Olentangy River mainstem, which was used as the reference point for the spatial location of the other streams in the watershed; (2) 5 sites did not have corresponding QHEI or IBI data; and (3) 5 sites were removed from the analysis because of missing geomorphology data leaving a total sample size of 14 sites. Regression analysis of the 14 sites indicated that SWAT generated nitrate-N ($p = 0.072$); distance downstream to the next highest order stream ($p = 0.018$), and pool quality ($p = 0.030$) were most significant in influencing IBI scores for these locations ($R^2 = 0.78$). This is an interesting result because it was the first time in this study that any water chemistry constituent was significantly related to IBI score.

Results of the regression indicated that Whetstone Creek 29.3 had large leverage. This is likely because it had a very high value for distance to next order stream compared to the other sites. We removed this site from the analysis and re-ran the regression ($n = 13$). Results were similar in that SWAT-generated nitrate-N ($p = 0.096$) and pool quality ($p = 0.025$) were most significant in influencing IBI scores at these locations ($R^2 = 0.73$). Upon analyzing both sets of regression coefficients generated for these variables, they appear to be rational and quite similar. For example, the regression coefficient for nitrate-N is negative indicating that as nitrate-N increases in the watershed, IBI scores will decrease. Therefore, we have some confidence that the statistical relationships between IBI score and significant environmental variables is not a statistical anomaly.

In an effort to add more sites to further increase our confidence in the statistical model, we eliminated the spatial location category and, where 2003-2004 IBI data was not available, we used the next most recent data. This increased the sample size to 25 sites (3 sites had no water chemistry data, and 8 sites were eliminated because of missing data). Results of the regression analysis ($p<0.1$) show that QHEI score ($p = 0.007$), gradient ($p = 0.003$), SWAT-generated total phosphorus ($p = 0.071$), cross-sectional area ($p = 0.091$), and width to depth ratio ($p = 0.007$) were most significant in influencing IBI scores at these locations ($R^2 = 0.71$). When QHEI score is removed, quality of in-stream cover replaces it in the regression analysis.

Upon analyzing the regression coefficients generated for these variables, they appear to be less rational than those generated for the smaller data set. For example, the regression coefficient for total phosphorus is positive indicating that as total phosphorus increases in the watershed, IBI scores will increase. Therefore, we have less confidence that the model is giving correct relationships between IBI score and significant environmental variables. A more comprehensive analysis was not performed because of the mixed results and because we might have been attempting to use generated data beyond an appropriate level.

6.9 Discussion and Conclusions

It is not surprising that, statistically, the Olentangy River watershed could be partitioned into three distinct regions: the Lower, the Upper, and Whetstone Creek. Each region has distinct geology and land use that may lend them to more unique habitats and fish assemblages. Fish assemblages represented by IBI score were most influenced by geomorphology, followed by habitat represented by the QHEI and spatial location within the watershed. This suggests that more focus should be placed on incorporating geomorphology into watershed analyses, such as the TMDL, than is currently done.

Having few sample sites (n = 28) to conduct the CCA analysis that were not randomly chosen (at least, statistically) limits our ability to extrapolate the results beyond those sites to the entire watershed, and further detailed analyses would be necessary for those sites. However, we did find some interesting patterns concerning the mismatch of sampling scales in the data sets we did have. Biology and geomorphology were sampled at the reach-level. Spatial location and predicted water chemistry were sampled at the watershed-level. Measured water chemistry was sampled at a specific location within the reach. Predicted water chemistry was modeled at the HUC-11 or HUC-14 level. This mismatch of data resulted in fewer sites available for analysis. Having more complete data sets allows more effective statistical analyses because the more sophisticated analyses do not allow data sets with missing values.

Only two of the QHEI metrics, pool quality and gradient, were significant in influencing IBI metrics. Compared to spatial location, which explained a similar amount of variation in IBI metrics and requires little field work and is less time intensive, the QHEI is difficult to quantify and may be biased by site selection or by the person conducting the QHEI. From a resource-saving standpoint, it appears that spatial location could be a better metric to gauge fish assemblage than QHEI. Geomorphology explains more variability in IBI metrics and provides more statistically defensible data than the more qualitative QHEI. However, the QHEI remains important because it explains unique variation in habitat over time. Perhaps, more focus should be placed on better quantifying the QHEI metrics, especially the two sub-metrics which seemed to explain most of the variation – pool quality and gradient.

Measured water quality parameters were not significantly correlated to the IBI. Predicted total phosphorus and nitrate-N, however, were significant but only for a study of a limited number of sites within the watershed. Also, while the relationship between nitrate-N concentration and IBI score was logical, the relationship between IBI score and total phosphorus concentration was not.

The combination of physical habitat, geomorphology, water quality and spatial location within the watershed allowed the examination of the effects of multiple stressors within the watershed using fish assemblages as an indicator. Results from this study demonstrate the importance of including environmental parameters and incorporating regional conditions into biological assessments beyond qualitative metrics alone. While the study would have certainly benefited from more complete data sets allowing for a larger sample size, CCA-type analyses are quite good at extracting statistically defensible patterns in variation for small data sets (Lance Williams, personal communication). However, we stress caution in extrapolating results from a limited number of sites to the entire watershed.

Unfortunately, the data for which complete datasets are available do not necessarily represent the range of conditions within the entire watershed. Because of this potential bias, we are unable to extrapolate these results beyond the sample size of our analyses. Future efforts should focus on collecting more complete data sets, at least at a statistically representative subset of reaches within the watershed, so that results of modeling efforts will be more applicable at the watershed scale. This is perhaps the missing piece of the TMDL puzzle that will allow a direct link of non-point sources of pollution with ecological function of specific sites, a necessary step to reduce and/or eliminate non-point source pollution within a watershed.

Chapter 7: Recommendations for Implementation

7.0 Introduction

A key objective for preserving or restoring aquatic communities in the Olentangy River watershed is to determine ways for human activities to proceed without disrupting the existing natural system. This chapter of the TMDL report outlines ways to implement the guidelines and loading reductions provided in Chapter 6. The current condition of the watershed, main problems affecting water quality in the watershed, and a variety of ways to reduce pollutant loading to the system will be discussed in this chapter.

7.1 Condition of the Watershed

Ohio EPA conducted a comprehensive physical, chemical and biological survey of the Whetstone Creek watershed in 1995 and the Lower Olentangy watershed in 1999. Field work to measure physical and chemical conditions in key stream segments was done in 2003 and 2004.

The Ohio EPA study showed that the river generally has good water quality on the main stem, but that status is threatened due to urbanization and on-going development. None of the tributaries from Flat Run to the mouth at Columbus, OH were in full attainment. Data from 2003-2004 show that Whetstone Creek and its tributaries were not in attainment of its Exceptional Warmwater Habitat designation but met the Warmwater Habitat designation standards.

Before presenting some of the main problems affecting stream health and water quality, it may be useful to discuss a few terms: *nutrients*, *pollutants*, *point source pollution* and *non-point source pollution*. *Nutrients*, such as nitrate and phosphorus, are essential for crop growth. Some nutrients are also required in stream systems to support plant growth and other biological processes. Nutrients can become *pollutants w*hen there is too much and the quality, safety, and productivity of public waters is negatively affected.

Pollutants affecting water quality may come from *point sources* or *non point sources*, or a combination of both. Water pollution from *point sources* can be identified easily, and comes from a distinct location such a pipe or a wastewater treatment plant. Point sources of pollution easier to measure, are typically controlled by permits issued from the Ohio EPA, and are often monitored to ensure compliance with permit discharge limits. *Non Point Source* (NPS) water pollution comes from non-direct or unidentified places in the watershed. NPS pollution happens when rain or melted snow runs over land or through the ground, picks up pollutants, and carries them into rivers, lakes, and oceans. Non-point sources of pollution are often difficult to identify, isolate and control. The most common NPS pollutants in the Olentangy River Watershed are sediment and nutrients such nitrate and phosphorus from fertilizers and pesticides. The main sources of NPS pollution in the Olentangy River watershed include agricultural, grazing and forestry practices; septic systems; construction and urban development; and the straightening and dredging of stream channels.

Ohio residents should be concerned about NPS pollution because it affects drinking water and the environment. NPS pollution is now the biggest reason we have water quality problems in Ohio, and sediment is the most common pollutant. NPS pollution causes contamination of rivers and streams that lead to unsafe drinking water, destroyed habitat, severe flooding, fish kills, property loss, and many other environmental and human health problems.

Failure to obtain full attainment in the main stem was primarily due to urban runoff, the impoundment of the river by low head dams, and contamination of sediments by metals and organic compounds, such as pesticides. The tributaries are in non-attainment due to multiple impacts including: sewage releases from combined sewer and sanitary sewer overflows, urban runoff, loss of river bank vegetation and channelization. The following sections will outline the main causes of impairment and water quality degradation identified in the watershed assessment and modeling study of the Olentangy watershed conducted from 2003 through 2005. Point Source and Non-Point Source (NPS) pollution impairments will be addressed individually.

7.2 Point Sources

7.2.1 City of Galion WWTP (Upper Olentangy Watershed)

Discharge of treated waste water from the City of Galion WWTP has a significant impact on water quality in the Olentangy River downstream of the treatment plant. High levels of nitrate and total phosphorus are common for low flow conditions during summer months. The impact of this treatment plant can be quite large simply because there are not large flows from the upstream drainage area to dilute the WWTP discharge. This portion of the watershed is currently meeting its QHEI WWH standards but scores fall below attainment from about river mile 56.6 to river mile 74.0. This could be a result of channelization and impoundments from log jams or small check dams. IBI scores are generally meeting WWH standards with scores falling slightly from river mile 68.1 to river mile 84.5, and increase in the headwaters.

7.2.2 City of Marion WWTP on Grave Creek (Middle Olentangy Watershed)

This point source has a large impact to water quality simply because of its location in the watershed. Treated wastewater is discharged into Grave Creek, a headwater stream, with relatively little flow from a small upstream drainage area. QHEI scores for Grave Creek from about river mile 0.9 to the confluence with the Olentangy River are excellent and are good enough to meet EWH biological standards. Grave Creek is designated as MWH from the headwaters to river mile 2.6. QHEI MWH standards are met from above river mile 0.9 to the headwaters. This is because of lack of riparian area and poor riffle/pool quality from channelization and agricultural practices. IBI scores are fairly low throughout Grave Creek with WWH attainment occurring only at river mile 0.3. MWH attainment occurs throughout with lowest possible scores for MWH attainment occurring in the headwaters. Any high IBI scores in this section are likely a result of movement of fish between Grave Creek and the Olentangy mainstem. Grave Creek, especially the further it is from the Olentangy River mainstem is unlikely to meet water quality standards.

7.2.3 Mt. Gilead and Village of Cardington WWTP (Whetstone Creek Watershed)

Point source loads and concentrations for these facilities are typical of other treatment plants in the watershed and throughout the state. Their impact on water quality is buffered by flows from upstream areas dilute the discharge. The Ohio EPA is currently working with the Mt. Gilead WWTP to improve their treatment capacity and efficiency. The Whetstone Creek mainstem from the headwaters to river mile 2.6 is listed as EWH. The mainstem is generally meeting its QHEI and IBI standards, but scores decrease moving from the headwaters toward the confluence with the Olentangy River and Delaware Reservoir.

7.2.4 City of Delaware and Ohio Environmental Control Center WWTP (Lower Olentangy Watershed)

These facilities have continued to increase discharge volumes over the years and will play an important role in water quality and stream health of the lower portion of the Olentangy River. The City of Delaware is expanding their treatment capacity with a $25 million dollar improvement project with state of the art treatment technologies. Rapid development outside of the City limits also ensures that discharges from the Ohio Environmental Control Center will continue to increase over time. A portion of the Olentangy River mainstem is listed as State Resource Water (SRW), having exceptional recreational or ecological significance. QHEI and IBI scores are currently meeting EWH and WWH standards in the Lower Olentangy River mainstem. The highest QHEI scores occur from about river mile 7.8 to river mile 19.8. The lowest QHEI scores occur near river mile 2.0, which is reported to have the poorest quality in the entire watershed. Although, this portion of the river is meeting biological standards, there has been a general trend toward decreasing QHEI and IBI scores over time because of increased urbanization, low head dams, and hydrologic influences from the Delaware Dam releases. Currently, none of the tributaries in the Lower Olentangy River are meeting biological or water quality standards.

7.3 Non-Point Sources

NPS pollution is diffuse and can be more difficult to identify. The types of NPS pollution that impact water quality and stream health in the Olentangy River watershed are discussed below. Watersheds that are significantly impacted by a particular NPS problem are identified.

7.3.1 Agriculture

Excess nutrients from production of livestock and row crops are a significant source of NPS pollution. Areas susceptible to erosion are also a source of total phosphorus. Sites with intense subsurface drainage and high application rates of fertilizer typically have higher nitrate levels. Conservation practices such as filter strips, agricultural drainage water management, cover cropping, conservation tillage, and livestock fencing can be good strategies to reduce NPS pollution on agricultural land. Cost sharing programs to implement conservation practices is currently available through voluntary incentive programs such as the Scioto CREP.

Water quality and stream health are impaired by maintenance of agricultural headwater streams or ditches. Traditional maintenance techniques that create a trapezoidal geometry often promote sedimentation of ditches by reducing stability of the ditch banks. The ability to process nutrients within the ditch system is also likely impacted. Furthermore, little is known about the actual benefits (i.e., increased crop yield) that should be expected from regular maintenance activities. Channel maintenance can be quite costly to landowners and could exceed the benefits. To date, this problem has not been thoroughly studied by researchers or conservation professionals. A recently funded research study to be conducted by the Ohio State University should provide further insight into this question and provide tools and procedures to evaluate these issues. For further information on the importance of stream or channel geomorphology please consult Chapter 4 of Ohio State University's Olentangy River Watershed TMDL Study.

Excess nutrients and sediment runoff from agricultural land to streams is the major source of NPS pollution in the Upper and Middle Olentangy River watersheds and the Whetstone Creek watershed. Erosion and loss of nutrients also impacts soil quality and crop yields. Recommended conservation practices to reduce nutrient and soil loss from agricultural fields are outlined in the Comprehensive Management Plan for the Upper Olentangy Watershed (UOWAPT, 2004).

7.3.2 Septic systems

Throughout the Olentangy River watershed many areas are impacted by discharges from failing septic systems as well as septic systems that bypass treatment and are directly discharged into streams and ditches. High nutrient and bacteria loads can make water unsafe for consumption by humans or livestock. High bacteria levels also impact recreational areas such as lakes and public beaches.

Reports from local health departments suggest that failing septic systems are a widespread problem throughout the watershed. Areas with higher concentrations of homes with failing septic systems pose a significant threat and could potentially secure state and federal funding to develop package treatment facilities or extend sewage treatment services from nearby municipalities. This type of funding is discussed later in this chapter.

7.3.4 Urbanization

Runoff from urban areas contributes nutrient and other pollutant loadings to the Olentangy River watershed. Perhaps the biggest impact from urban areas is the change in hydrology or the way in which water moves over and through the landscape. As urbanization occurs and the amount of impervious surface increases, the amount of surface runoff to the stream system increases. Changes in flows and sediment supply to a stream typically result in a change in geomorphology, or channel shape and pattern.

A typical response to increased flows from urbanization is for the channel to downcut through the streambed. As stream banks become steep they will often fail and the material will be redistributed by flowing water to create new floodplains for the downcut channel. Floodplains that a stream system creates are important for dissipating energy from flood flows and processing of pollutants during high flows. Channels without attached floodplains can have poor water quality and may not provide good habitat for aquatic organisms.

Geomorphology and water quality impacts as a result of urbanization are evident in many areas of the watershed. Fore example, the Olentangy River mainstem downstream of the City of Galion was deeply incised. Further urbanization without adequate stormwater control could cause additional degradation. The upper reaches of Riffle Creek recently were channelized to improve drainage for development east of Marion, OH. Channelization, bank hardening, and small weirs are evident in Mt. Gilead and Cardington, OH. Most headwater streams in the Lower Olentangy River watershed have already been impacted significantly by urban development. Many of the headwater streams along the Olentangy River between the City of Delaware and Franklin County have a likelihood of becoming significantly degraded from urban development.

7.4 Pollutant Reductions

The Ohio EPA has collected information on water quality, stream ecology, and stream habitat for decades. Based on their analysis of the data they have developed water quality targets for various uses of streams. Further information on water quality targets is available in Chapter 1 of the Olentangy River Watershed TMDL Study by the Ohio State University modeling team. Table 1 presents the reductions in pollutant loadings to streams needed to meet those targets.

Table 1. Percentage reductions by nutrient needed to meet state Water Quality Standards.

Assessment Unit	Pollutant		
	Total Phosphorus[1]	Nitrate-Nitrogen[1]	Total Suspended Solids[1]
Upper Olentangy	48%	57%	86%
Whetstone Creek	33%	63%	84%
Middle Olentangy	57%	69%	81%
Lower Olentangy	11%	67%	69%

[1]Based on Ohio EPA small river water quality targets.

7.5 Management Activities to Improve Water Quality

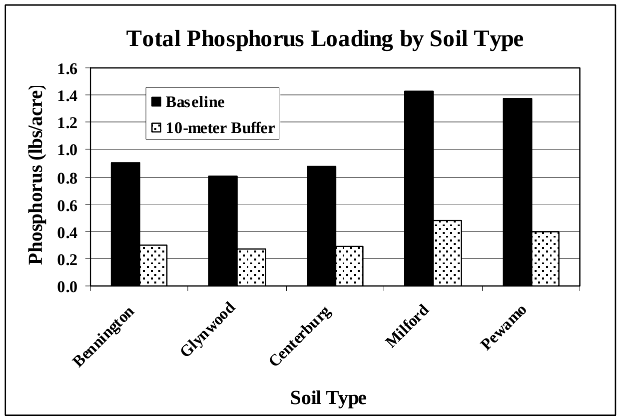
As part of the modeling activities for the Olentangy River watershed TMDL, the SWAT (Soil and Water Assessment Tool) computer model developed by the USDA-Agricultural Research Service was used to predict the potential impact of agricultural Best Management Practices (BMPs). Some results from that analysis are presented below. Results were grouped by soil type to be more site-specific.

The first alternative management practice that was evaluated was to include a 10-meter (33 feet) buffer strip on all stream miles within the watershed. Figure 2a through 2c show the impact of a 10-meter (33 feet) buffer on total phosphorus, nitrate-nitrogen, and sediment compared to the existing or ‘baseline’ condition. Loading rates are reported as a rate per unit area per year.

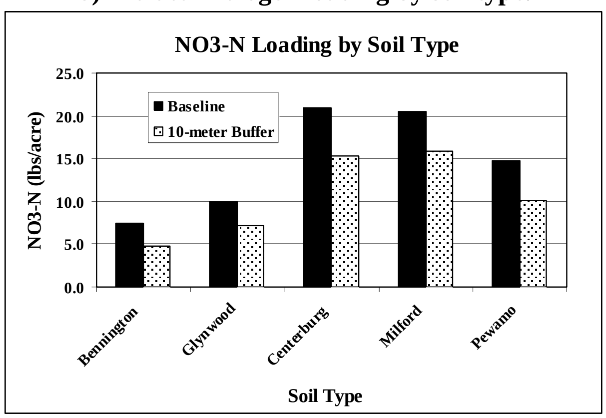
For all soil types, nutrient loading is lower when a 10-meter (33-foot) buffer is applied to the system than when no buffer is there, which is reflected by the existing or ‘baseline’ condition. Total suspended sediment and total phosphorus experienced a greater reduction in loading than nitrate-nitrogen compared to the baseline condition.

Figure 2a-c. Comparison of no buffer (baseline) to a 10-meter (33 feet) buffer on nutrient loading by soil type in the Olentangy River watershed.

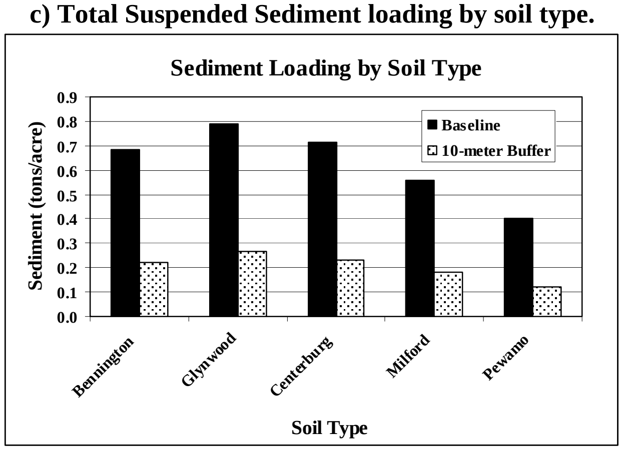
a) Total Phosphorus loading by soil type.



b) Nitrate-Nitrogen loading by soil type.



c) Total Suspended Sediment loading by soil type.

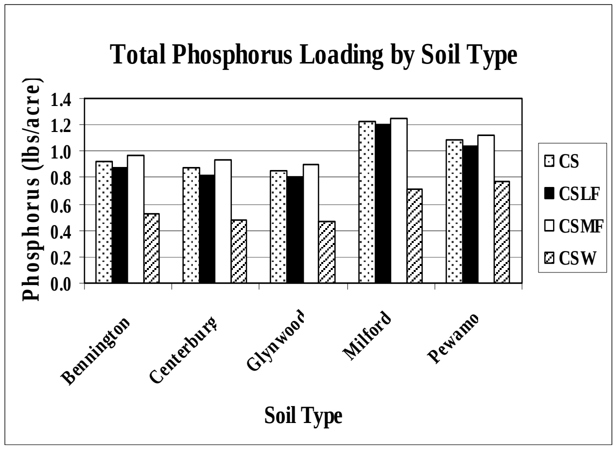


The second group of alternative management scenarios that was analyzed was fertilizer application rates and alternative crop rotations (Figures 3A-3C). The baseline condition for this study was a standard corn-soybean rotation (CS). To determine the water quality impacts of increased and decreased fertilizer application rates two scenarios were developed: corn-soybean rotation with 25% more fertilizer (CSMF) and corn-soybean rotation with 25% less fertilizer (CSLF). To determine the impact of including a small grain crop into the rotation we developed a model scenario with a corn-soybean-wheat (CSW) crop rotation.

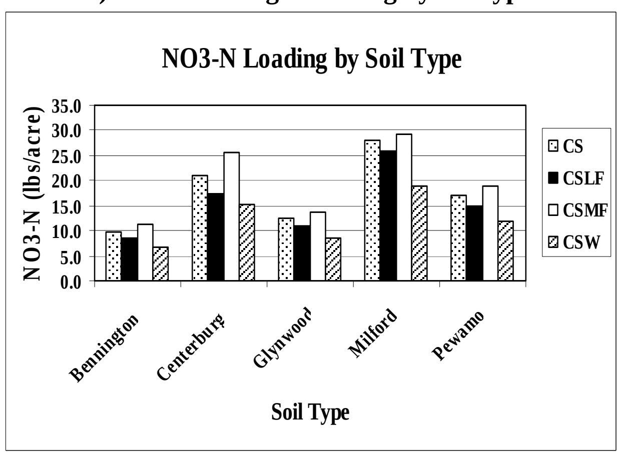
Total phosphorus and nitrate nitrogen loadings were higher when 25% more fertilizer (CSMF) was applied and were lower when 25% less fertilizer was applied across all soil types. Sediment loadings were essentially unchanged. Alternative crop rotation of corn-soybean-wheat (CSW) resulted in lower loadings for all nutrients. The results suggest that a combination of alternative management practices such as applying less fertilizer, installing a 10-meter (33-foot) buffer strip, and incorporating wheat into the standard corn-soybean rotation would be useful to reduce loading of total phosphorus, nitrate-nitrogen, and sediment across a range of soil types in the Olentangy River watershed.

Figure 3a-3c. Comparison of fertilizer application rates and alternative crop rotations on nutrient loadings by soil type in the Olentangy River watershed.

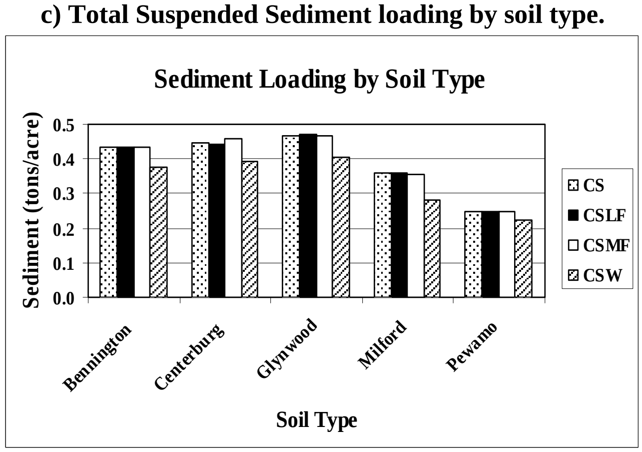
a) Total Phosphorus loading by soil type.



b) Nitrate-Nitrogen loading by soil type.



c) Total Suspended Sediment loading by soil type.



7.6 Implementation

7.6.1 Point Source Discharge Control

Point sources of pollutants are issued individual NPDES permits for the discharge of pollutants to the Olentangy River watershed. These permits are issued for construction activities and industrial activities, and are issued to control animal feeding operations as well as stormwater discharged from a discrete conveyance, such as pipes or confined conduits. NPDES individual and general permits are issued to individuals, private entities, and local government entities by Ohio EPA. Chapter 2 and 3 of the Olentangy River Watershed TMDL Study establish appropriate effluent limitations for point source discharges to the watershed.

7.6.2 Non-point Source Control

Managing Agricultural Drainage, Channel Erosion and Flooding

Agricultural productivity has been enhanced by maintaining a system of subsurface tile drains and adequate outlets that are mainly concentrated in the lower gradient Middle and Upper Olentangy watersheds. Agricultural drainage, erosion control and flood reduction strategies, if left un-managed, can threatened the overall ecological health of the Olentangy River watershed. Ecological health is intimately related to stream hydrology and geomorphology and is dependent upon the preservation and improvement of those features. The adverse impacts of nutrient and sediment loadings that occur at high stream flows can be attenuated by improving the management of sediment bedload, habitat and floodplain width. Chapters 1 to 4 of the Olentangy River Watershed TMDL Study provide targets and recommendations regarding sediment (as total suspended solids), habitat and floodplain widths. Water quality benefits realized by attaining these targets can include increasing the natural filtering of pollutants, providing in-stream habitat, increasing the assimilative capacity of the system, and providing adequate floodplain to dissipate the energy of sediment and stream flow.

Agricultural BMPs and Programs

The challenge of implementing the TMDL recommendations, specifically those necessary to meet geomorphology and floodplain width targets established in Chapter 4, will be to find acceptable methods that simultaneously manage and that meet the needs for agricultural production and the ecological needs of the Olentangy River watershed. These methods include several programs that stress voluntary adoption of best management practices (BMPs) by landowners and operators to promote improved drainage through environmentally sound means. Common to all of these programs are the goals of achieving a reduction in erosion and overland runoff, improving nutrient management practices, and offering education and cost incentives.

Scioto River Watershed Conservation Reserve Enhancement Program (CREP)

The Scioto River Watershed Conservation Reserve Enhancement Program (CREP) is a federally and locally funded initiative that is aimed at creating 70,000 acres in a combination of buffers and wetlands on cropland and marginal pastureland throughout the entire Scioto basin. The Olentangy River watershed makes up the headwaters of the Scioto basin.

The Scioto CREP is a voluntary, incentive-based conservation program that has emerged out of the 1996 Farm Bill as a part of the older Conservation Reserve Program (CRP). The Scioto CREP officially began in February of 2005 and the enrollment period is expected to continue for two years, or as long as acres remain available (i.e., the 70,000 acre total is not yet reached). There are no county limits to the number of acres that can be enrolled therefore it is hard to predict the extent at which the program's conservation practices will be installed in any given area. Practices that are eligible through this program include both native and non-native grass filter strips, hardwood and coniferous tree plantings, wildlife habitat buffers, and the installation and use of water table management infrastructure. CREP contracts are for 14 to 15 years in duration and enrollees are under no obligation to maintain those conservation practices after that time. This program is being advertised and administered through county Soil and Water Conservation Districts, Natural Resource Conservation Service (NRCS) and Farm Service Agency (FSA) staff. Information regarding this program is available *http://www.dnr.state.oh.us/soilandwater/sciotocrep/default.htm.*

Environmental Quality Incentives Program (EQIP)

The Environmental Quality Incentives Program (EQIP) is a United States Department of Agriculture (USDA) program that began following the 1996 Farm Bill and is administered by the Natural Resource Conservation Service (NRCS). The objective of this incentive-based, voluntary program is to increase the use of agriculturally related best management and conservation practices. EQIP is available to operators throughout the entire Olentangy River watershed irrespective of whether they own or rent the land that they farm. Through this program operators receive cost share and/or incentive payments for employing conservation management practices. Contracts are 5 years in length.

There are numerous conservation practices that are eligible for payments. These practices cover broad categories such as nutrient and pesticide management, conservation tillage, conservation crop rotation, cover cropping, manure management and storage, pesticide and fertilizer handling facilities, livestock fencing, pastureland management, and drainage water management among others. However, funding for these practices is competitive and limited to the allocations made to any respective county in Ohio. Each county in receives a baseline of $100,000 per year (this baseline allocation is subject to change due to budgetary constraints). Interested farm operators are to submit an application for EQIP funding for a specific conservation practice to their county's District Conservationist (NRCS). The District Conservationist ranks each of these applications according to a scoring system that takes into account the type of practice and the size of the area affected by the practice. The priorities reflected by this scoring system are determined both at the state level (through the State Technical Committee) and the local level (Local Workgroup). The state's priorities account for 66% of the total points possible, leaving 33% to be determined by local priorities. Currently, state priorities focus on livestock related conservation practices. Operators are ultimately funded based upon their ranking and the availability of EQIP dollars in the county. More information regarding this program is available on the NRCS website at *www.nrcs.usda.gov.*

Section 319 Non-Point Source Grants

Section 319 of the 1987 Clean Water Act created a national program to control and prevent non-point source pollution of the Nation's surface and ground water resources. The Ohio EPA, Ohio's designated water quality agency, is responsible for administering the program in Ohio. A goal of 80% aquatic life use attainment for Ohio waters by 2010 is a state priority. In concert with this goal, the Section 319 Implementation Grant program is designed to provide financial assistance to projects that eliminate or reduce water quality impairments caused by non-point source pollution (NPS) and prevent future NPS related impairments.

A clear, strong rationale for project work is required for each award along with a match of local resources. This rationale directs Ohio 319 awards to watersheds with state-endorsed watershed action plans, Acid Mine Drainage Abatement - Treatment Plans, and late-stage TMDLs. In each case, demonstrable aquatic life use impairments due to NPS pollution must be addressed by the project. Project categories that will be funded include: 1) Stream Restoration and or Renaturalization Projects; 2) Acid Mine Drainage Abatement and AML Reclamation Projects; 3) Agricultural Best Management Practices and Projects; 4) Riparian Restoration Projects; 5). Riparian Protection and Conservation Easement Projects; 6) Source Water (public water supplies) Protection Implementation Grants. Other projects may be funded particularly if they are highly effective and innovative means to eliminate NPS pollutants and restore impaired waters.

Applicants may apply for a maximum of $500,000 for a three-year period. Each project funded must provide an additional 40% matching share. The total federally funded share of project costs may not exceed 60%. Ohio's 319 Program has funded over 225 local and state level NPS projects. Work done for the Olentangy River watershed TMDL was accomplished through 319 grant funding. The latest Ohio EPA 319 Grant program Request for Proposals and Application Package can be found at *http:/www.epa.state.oh.us/dsw.*

The Ohio Water Pollution Control Loan Fund (WPCLF)

The Ohio EPA's Division of Environmental and Financial Assistance (DEFA) administers the Water Pollution Control Loan Fund. The WPCLF provides financial and technical assistance for numerous types of non-point source pollution control actions, and for treatment works improvements, such as wastewater treatment plant expansions and upgrades, new and replacement sewers, correction of clean water inflow and infiltration into sewers, combined sewer overflows (CSOs), and sewer separation projects. Ohio EPA, through the WPCLF, has awarded over $3 billion in loans state-wide since 1989.

The WPCLF awards low interest loans for a wide variety of projects to protect or improve the quality of ground water, rivers, streams, lakes, and other water resources. For example, while conventional long-term financing may be 4.75%, the standard WPCLF rate is 3.25%. WPCLF pre-award interest rates are adjusted quarterly to maintain this discount. The WPCLF offers even lower interest rates to small or hardship communities. A small community is defined as any incorporated area with a population of 5,000 or less, or any unincorporated area that has a current project service population of 5,000 or less and that charges the entire debt for the project solely to the project service population. Currently, small communities receive an interest rate of 2.75%. Hardship communities, defined as a service population equal to or less than 2,500 and a median household income of $45,500 or less, will receive an interest rate of 0.0%. Communities with a service population between 2,500 and 10,000 and with a median household income of $38,000 or less will receive an interest rate of 1.0%. Interest rates may be further reduced if a community utilizes any of the several discount programs offered by the WPCLF, including construction of septage receiving and treatment facilities, conversion of Class B to Class A sludge, and participation in the Water Resource Restoration Sponsor Program (WRRSP).

Water Resource Restoration Sponsorships

The WRRSP funds the reasonable cost of non point source projects that fully protect and/or restore critical surface water and wetland habitats. This may include several kinds of actions that may be specified within a TMDL. By advancing a portion of the estimated amount of interest due from the loan of a sponsoring WPCLF recipient, Ohio EPA can provide assistance to the WRRSP project which, unlike a loan, is not required to be repaid. The amount of funds available and projects to be funded by the WRRSP are identified in DEFA's annual Program Management Plan. In the past, approximately $15 million per year has been made available through the WRRSP.

Table 2 provides a list of priority BMP practices recommended for the Middle and Upper Olentangy River sub-watersheds and potential funding sources for each practice. The number in parentheses corresponds to a description of the practice provided in the Ohio Farm Bureau Federation document entitled *Ohio Agricultural Environmental Assurance Alliance: Producer Self-Assessment Program*. Where a number is not provided, a brief description is given below.

Table 2. List of priority BMP practices recommended for the Middle and Upper Olentangy River watershed and their funding source.

Hydrologic Unit Code (HUC)	Sub-watershed Areas	Priority BMP Practices	Funding Source
05060001-090	Olentangy River Headwaters to Flat Run; Mud Run; Flat Run	Livestock Use Exclusion (472)	EQIP
		Watering Facility (614)	EQIP
		Waste Storage Facility (313)	EQIP
		Cover Crop and Green Manure (340)	319
		Conservation Crop Rotation (328)	CRP/319
		Filter Strips (393A)	CREP
		Residue Management (329A)	CREP
		Riparian Forest Buffer (391)	CREP
		Nutrient Management (590)	319
		Agricultural Drainage Water Management	CREP/319
		Two-stage Ditch Maintenance	319
		Modified Relay Intercropping	319
		Septic System Upgrades	EPA Loan
05060001-100	Whetstone Creek Headwaters to Delaware Lake; Shaw Creek	Livestock Use Exclusion (472)	EQIP
		Watering Facility (614)	EQIP
		Cover Crop and Green Manure (340)	319
		Conservation Crop Rotation (328)	CRP/319
		Filter Strips (393A)	CREP
		Residue Management (329A)	CREP
		Riparian Forest Buffer (391)	CREP
		Nutrient Management (590)	319
		Critical Area Planting (342)	
		Grassed Waterway (412)	CREP
		Heavy Use Protection Area (561)	
		Prescribed Grazing (528A)	EQIP
		Waste Storage Facility (313)	EQIP
		Septic System Upgrades	EPA Loan
05060001-110	Olentangy River from Flat Run to Delaware Run; Riffle Creek; Grave Creek; Qua Qua Creek; Brondige Run; Horseshoe Run; Delaware Run	Livestock Use Exclusion (472)	EQIP
		Cover Crop and Green Manure (340)	319
		Conservation Crop Rotation (328)	CRP/319
		Filter Strips (393A)	CREP
		Residue Management (329A)	CREP
		Riparian Forest Buffer (391)	CREP
		Nutrient Management (590)	319
		Agricultural Drainage Water Management	CREP/319
		Two-stage Ditch Maintenance	319
		Modified Relay Intercropping	319

Septic System Upgrades

Nearly 1 million households in Ohio are located beyond the city sewer and must treat and dispose of wastewater on site (Mancl and Slater, 2001). Septic systems are simple to operate and, when properly designed, constructed and maintained, they do an excellent job of removing pollutants from wastewater to protect Ohio's water resources. Septic systems consist of two basic parts -a septic tank and a soil absorption system. The septic tank provides a small portion of the treatment by creating a large, quiet compartment to allow solid material to settle out of the wastewater and collect in the tank. Once the large solid material is settled out, the sewage flows into a deep layer of unsaturated soil, where the soil and microorganisms remove the pollutants before the wastewater enters groundwater or surface water. Septic tanks are installed to allow solids to settle out of sewage and hold these solids in the tank. Over the years of operating, accumulated solids begin taking up too much room in the tank, reducing the volume available for settling. When this happens, solids start escaping the tank and can clog the soil in the soil absorption field. Property owners must pump their systems often and upgrade a septic system every 20 to 30 years to ensure their system is not discharging effluent. More information on septic system upgrades and funding sources is available at *http://www.epa.state.oh.us/dsw/nps/HSTS_Guidance.html.*

Two-stage Ditch Maintenance

Petition ditch maintenance and privately maintained drainage projects occur through out the Middle and Upper Olentangy sub-watersheds. Often within conventional ditches, small benches begin to form but these unintentional benches are removed with periodic ditch maintenance. Flows contained within the small channel are narrower and thus deeper. Deeper flow has a greater ability to scour and reduce the accumulation of fine sediment building up on the bed. As a result, the steep ditch banks are prone to erosion and failure is common. Also, rather than settling out, sediment is left in the water column creating a water quality problem. As an alternative to traditional ditch maintenance, conversion to a two-stage design can help improve water quality while maintaining the water conveyance capacity of the ditch. The two-stage concept abandons traditional practices of excavating ditches to maintain the characteristic trapezoidal shape and leaves the benches, or small floodplains, that form inside the ditch. The two-stage configuration moderates the bed shear stresses. The shear stress becomes higher for frequent flows when accumulation of fine sediment is a concern but becomes less at high flows when erosion is more of a concern. This suggests that two-stage channels should be significantly less prone to filling in with sediment and thus require less maintenance. Two-stage ditch construction has demonstrated benefits both for drainage and ecology. Research by Ohio State University and Ohio Department of Natural Resources suggests two-stage ditches result in reduced maintenance, greater assimilative capacity, better habitat and increased pollutant assimilation (Mecklenburg, 2004).

Modified Relay Intercropping (MRI)

This practice involves the production of two different crops in one growing season (i.e., planting regular soybeans into standing wheat 20 to 30 days before wheat harvest). The benefits of MRI include harvesting two crops per year, the potential to increase farm income while hedging production risk, and protecting the environment. In the MRI system, a crop is growing in the field for 12 consecutive months preventing soil erosion. Long-term research by Ohio State University's Ohio Agricultural Research and Development Center (OARDC) in Crawford County, OH has shown MRI wheat yield to be nearly 90% of conventional wheat (Prochaska, 2003). More information on this practice can be found in the Ohio State University Fact Sheet AGF-504-04 (*http://ohioline/osu.edu/agf-fact/0504.html*).

Agricultural Drainage Water Management

Water management simply means the control or regulation of soil-water conditions in the profile of agricultural soils through the use of water control structures and site-specific strategies. Water management strategies in order of least to most system management required include: (1) conventional subsurface drainage, which lowers the water table the depth of an installed drain pipe; (2) controlled drainage, which allows the drainage outlet to be set to any level between the ground surface and the drain depth; and (3) sub-irrigation, which provides both drainage and irrigation in one system. More information on agricultural drainage water management can be found at *http://www.ag.ohio-state.edu/~agwatmgt/*.

7.7 Implementation Strategy and Reasonable Assurances

As part of an implementation strategy, reasonable assurances provide a level of confidence that the load allocations in this TMDL will be implemented by federal, state, or local authorities. Implementation of the Olentangy River Watershed TMDL will be accomplished by both state and local action. State implementation of the TMDL will be accomplished through Ohio EPA permitting requirements, certification programs, and procedures.

Locally, a watershed action plan was developed by Friends of the Lower Olentangy Watershed and local stakeholders and accepted for the Lower Olentangy River sub-watersheds in 2004. In 2005, a watershed action plan also was developed by the Olentangy Watershed Alliance, The Ohio State University, and local stakeholders and has been conditionally accepted for the Upper Olentangy River. These two watershed action plans, funded by local match money and 319 funding, are well poised to evaluate and implement TMDL recommendations through a locally driven process. In the Upper Olentangy sub-watersheds, a project has been approved and funded to study and monitor agricultural drainage ditches and their impacts on water quality and aquatic ecology. Special emphasis will be given to the two-stage ditch concepts and construction. This project also provides much needed programming money to implement the Scioto CREP Program. In the Middle Olentangy, plans are underway to remove five low head dams from the scenic river section of the Olentangy River mainstem. In the Lower Olentangy, discussions are underway about removal of the 5th Avenue dam. Extensive public involvement for several years has occurred through these processes.

At the federal level, the $207 million Scioto River Watershed CREP was recently established with the goal to create 70,000 acres of filter strips, riparian buffers, wildlife habitat, wetlands, and tree plantings to reduce sediment and nutrient runoff into the river and its tributaries. The program area includes all or part of 31 Ohio counties, an area of approximately 6,300 square miles and home to nearly 2 million Ohioans. A goal is to improve biodiversity in the entire watershed. Also, funding provided through EQIP, and Section 319 continue provide cost share dollars to implement voluntary activities in the watershed.

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