State of Ohio
Environmental Protection Agency

Division of Surface Water

Total Maximum Daily Loads for the Twin Creek Watershed

Twin Creek upstream of Halderman Road

Final Report
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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

1.0 INTRODUCTION

The Twin Creek watershed is located in southwestern Ohio near the Indiana border, where its waters originate in Darke County, meander south into Preble County, and pass through the towns of Lewisburg, West Alexandria, and Gratis. Southeast of Gratis, the watershed continues into Montgomery County, with the mainstem finally joining the Great Miami River in Warren County in the town of Carlisle.

Ohio EPA conducted a comprehensive physical, chemical and biological survey of the Twin Creek watershed in 2005, and several problems/threats were identified. The survey results were published in October 2007; major findings are summarized in this report. Having identified the problems/threats, the next step is an analysis called the Total Maximum Daily Load (TMDL). This report documents the TMDL process for the Twin Creek watershed.

The Twin Creek watershed TMDL is required because portions of the Twin Creek and its tributaries do not attain their water quality goals for aquatic life and recreation. When a waterbody fails to attain its designated uses, it is said to be impaired. Impairment in the Twin Creek watershed was determined based upon the 2005 assessment. The assessment included biological, water chemistry and sediment sampling. Detailed results of the assessment can be found in the report titled *Biological and Water Quality Study of Twin Creek and Select Tributaries* (Ohio EPA, 2007).

1.1 The Clean Water Act Requirement to Address Impaired Waters

The Clean Water Act (CWA) Section 303(d) requires States, Territories, and authorized Tribes to list and prioritize waters for which technology-based limits alone do not ensure attainment of water quality standards. Lists of these impaired waters (the Section 303(d) lists) are made available to the public for comment, then submitted to the U.S. Environmental Protection Agency (U.S. EPA) for approval in even-numbered years. Further, the CWA and U.S. EPA regulations require that Total Maximum Daily Loads (TMDLs) be developed for all waters on the Section 303(d) lists. The Ohio EPA identified the Twin Creek watershed (assessment units 05080002 030 and 040) as impaired on the 2006 303(d) list (available at http://www.epa.ohio.gov/dsw/tmdl/2006IntReport/2006OhioIntegratedReport.aspx).

In the simplest terms, a TMDL can be thought of as a cleanup plan for a watershed that is not meeting water quality standards. A TMDL is defined as a calculation of the maximum amount of a pollutant that a waterbody can receive and still meet water quality standards and an allocation of that quantity among the sources of the pollutant. Ultimately, the goal of Ohio's TMDL process is full attainment of Water Quality Standards (WQS), which would subsequently lead to the removal of the waterbodies from the 303(d) list. Table 1 summarizes how the impairments identified in the Twin Creek watershed are addressed in this TMDL report. Impairments and actions are subdivided into "assessment units" (11-digit hydrologic units) and subwatersheds (14-digit hydrologic units). Figure 1 shows a map of the hydrologic units referred to in Table 1.

Table 1. Summary of causes of impairment to aquatic life use and primary contact recreation use with actions taken to address impairments for the Twin Creek watershed.

Assessment Unit	Narrative Description	Causes of Impairment	Action Taken
05080002 030 *Priority points: 6*	Twin Creek (headwaters to upstream Bantas Fork)	Phosphorus (total)	Addressed via habitat and sediment TMDLs / 4B alternative
		Excess algal growth	Addressed via habitat TMDL
		Sedimentation/ siltation	Sediment TMDL
		Ammonia (total)	Addressed via habitat and sediment TMDLs / not addressed
		Low DO	Addressed via habitat TMDL
		Organic enrichment[1]	4B alternative
		Natural conditions (flow or habitat)	Natural limitations – no action
		Bacteria (recreation use)	Fecal coliform TMDL
030 010	Twin Creek above Millers Fk.	Sedimentation/siltation	Sediment TMDL
		Excess algal growth	Addressed via habitat TMDL
030 020	Millers Fork	Sedimentation/siltation	Sediment TMDL
		Low DO	Addressed via habitat TMDL
		Ammonia	Addressed via habitat TMDL
		Low flow (interstitial)	Natural limitations – no action
		Natural habitat (shallow bedrock)	Natural limitations – no action
030 030	Twin Cr. below Millers Fk. to above Price Cr. (except Swamp Cr.)	Phosphorus	4B alternative
		Organic enrichment	4B alternative
		Bacteria (recreation use)	Fecal coliform TMDL
030 040	Swamp Creek	Ammonia	Not addressed
		Phosphorus	Addressed via habitat and sediment TMDLs
		Sedimentation/siltation	Sediment TMDL
		Bacteria (recreation use)	Fecal coliform TMDL
		Low flow	Natural limitations – no action
030 050	Price Creek	Low DO	Addressed via habitat TMDL
		Ammonia	Addressed via habitat and fecal coliform TMDLs
		Phosphorus	Addressed via habitat TMDL

Assessment Unit	Narrative Description	Causes of Impairment	Action Taken
		Bacteria (recreation use)	Fecal coliform TMDL
		Low flow	Natural limitations – no action
030 060	Twin Creek below Price Cr. to above Bantas Fk.	Sedimentation/siltation	Sediment TMDL
		Low DO	Addressed via habitat TMDL
		Bacteria (recreation use)	Fecal coliform TMDL
		Low flow (interstitial)	Natural limitations – no action
05080002 040 *Priority points: 5*	Twin Creek (upstream Bantas Fork to mouth)	Low DO	Addressed via habitat TMDL / not addressed until further data are collected
		Sedimentation/siltation	Sediment TMDL
		Ammonia (total)	Not addressed until further data are collected
		Phosphorus (total)	Not addressed until further data are collected
		Chemical oxygen demand	Not addressed until further data are collected
		Natural conditions (flow)	Natural limitations – no action
		Bacteria (recreation use)	Fecal coliform TMDL
040 010	Bantas Fork above Goose Cr.	Low flow	Natural limitations – no action
040 020	Goose Creek	Phosphorus	Will not be addressed until further data are collected
		Ammonia	Will not be addressed until further data are collected
		Chemical oxygen demand (COD)	Will not be addressed until further data are collected
		Low DO	Will not be addressed until further data are collected
		Bacteria (recreation use)	Fecal coliform TMDL
		Low flow	Natural limitations – no action
040 030	Bantas Fork below Goose Cr. to Twin Cr.	Low flow	Natural limitations – no action
040 040	Twin Creek below Bantas Fk. to above Aukerman Cr.	No impairment	No action needed
040 050	Aukerman Creek	No impairment	No action needed

Assessment Unit	Narrative Description	Causes of Impairment	Action Taken
040 060	Twin Creek below Aukerman Cr. to above Tom's Run	No impairment	No action needed
040 070	Tom's Run	Low DO	Addressed via habitat TMDL
		Sedimentation/ siltation	Sediment TMDL
		Low flow (interstitial)	Natural limitations – no action
040 080	Twin Creek below Tom's Run to G. Miami R. (except L. Twin Cr.)	No impairment	No action needed
040 090	Little Twin Creek	Low flow	Natural limitations – no action

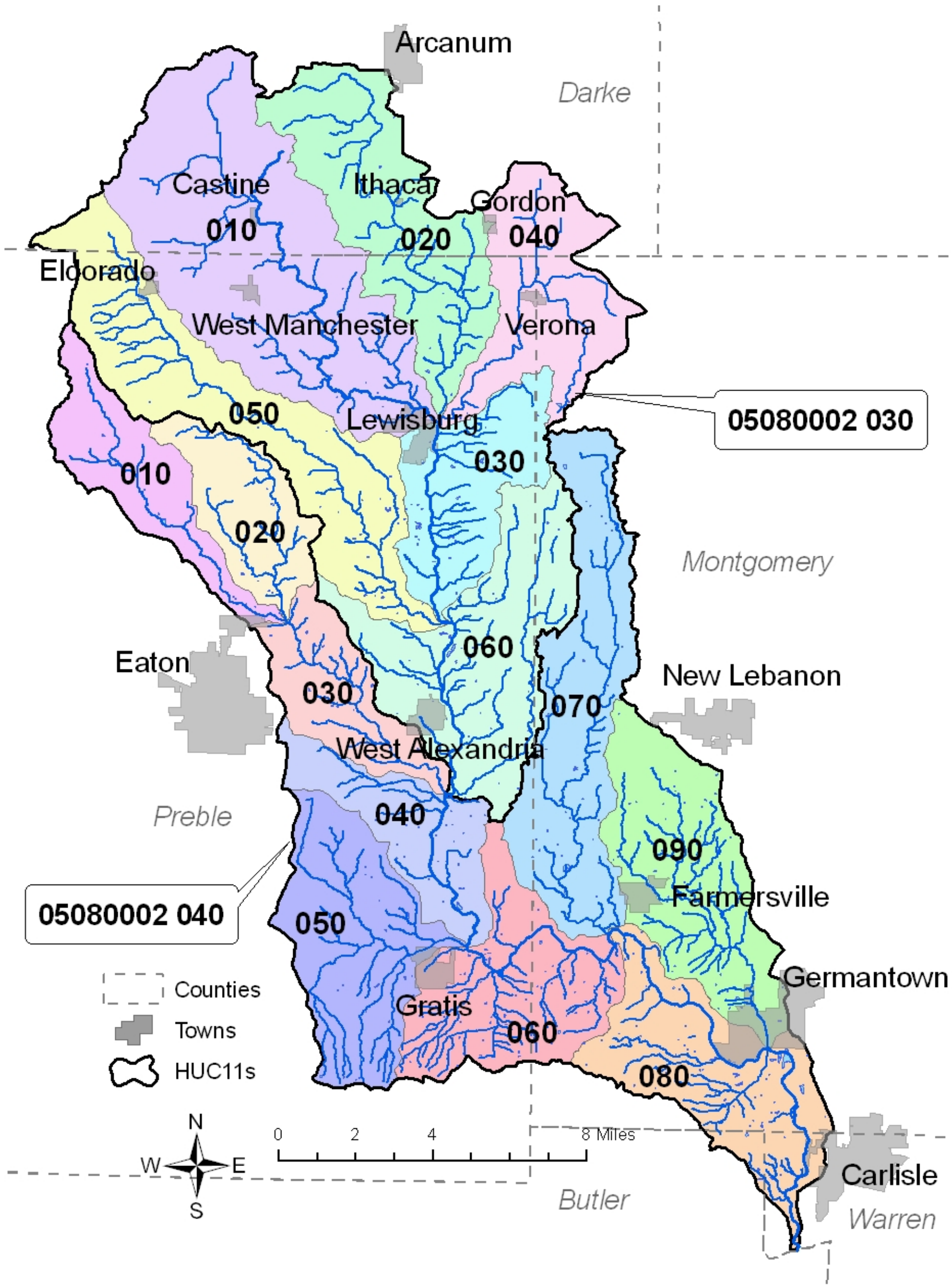

Figure 1. Map showing 11-digit and 14-digit hydrologic units.
Note: The last three digits of 14-digit numbers are shown within each 14-digit subwatershed in bold text.

1.2 Public Involvement

Public involvement is fundamental to the success of water restoration projects, including TMDL efforts. From the beginning, Ohio EPA has invited participation in all aspects of the TMDL program. The Ohio EPA convened an external advisory group in 1998 to assist the Agency with the development of the TMDL program in Ohio. The advisory group issued a report in July 2000 to the Director of Ohio EPA on their findings and recommendations. The Twin Creek watershed TMDL project has been completed using the process endorsed by the advisory group.

Three Valley Conservation Trust (3VCT), a local non-profit group, was awarded an Ohio Department of Natural Resources Watershed Coordinator grant in 2004. This grant, which is partially funded with Clean Water Act Section 319 money, allowed the organization to hire a watershed coordinator. A major requirement of the grant is development of a Watershed Action Plan (WAP) for Twin Creek. Several meetings were held within the watershed to solicit input from the public and to inform them of the project and this survey. The watershed coordinator position was vacated, but 3VCT is committed to the completion of the WAP for Twin Creek. The 3VCT will no longer participate in the watershed coordinator grant; however, Miami University has assumed the grant for implementation and integration with any TMDL project that may be developed. The 3VCT has also been approved to receive a 319 project grant to purchase easements and repair stream bank erosion along the stream.

During the TMDL process, Ohio EPA has met several times with the Watershed Advisory Group (WAG) to discuss sampling results, the TMDL process, and implementation ideas. The WAG has assisted with local perspective on problems and with discussing possible implementation actions for improving impairments. In addition, the watershed coordinator has provided valuable consultation for Ohio EPA throughout the implementation chapter writing process. Ohio EPA also participated in the Fall Gathering at Aukerman Creek in September 2008. A fish electroshocking demonstration was completed during the festival at which time Ohio EPA also discussed some of the high quality biology in Twin Creek.

Consistent with Ohio's current Continuous Planning Process (CPP), the draft TMDL report was available for public comment from June 18 through July 18, 2009. A copy of the draft report was posted on Ohio EPA's web page (http://www.epa.ohio.gov/dsw/tmdl/index.aspx). A summary of the comments received and the associated responses was completed after the public comment period and is included in Appendix F of the final report.

Continued public involvement is critical to the success of any TMDL project. Ohio EPA will continue to support the implementation process and will facilitate, to the fullest extent possible, restoration actions that are acceptable to the communities and stakeholders in the study area and to Ohio EPA. Ohio EPA is reluctant to rely solely on regulatory actions and strongly upholds the need for voluntary actions facilitated by the local stakeholders, watershed organization, and agency partners to restore the Twin Creek watershed.

2.0 WATERBODY OVERVIEW

The Twin Creek watershed drains an area of 316 square miles (mi^2) in southwestern Ohio. Twin Creek, 47.03 miles long, originates in Darke County, Butler Township, flows southeast into Preble County and generally south through the eastern portion of the county, then southeast through the southwest corner of Montgomery County, and then into Warren County, Franklin Township where it meets the Great Miami River (Figure 2). The average gradient is 9.1 feet per mile (from an elevation of 1067 to 645 feet above mean sea level; Ohio DNR 1960). Principal tributaries to Twin Creek include Maple Swamp Ditch (essentially the mainstem above RM 47.0), Millers Fork, Swamp Creek, Price Creek, Lesley Run, Bantas Fork, Aukerman Creek, Tom's Run and Little Twin Creek.

2.1 Watershed Boundaries

To facilitate analysis in this TMDL, the land drained by the Twin Creek is divided into two watersheds. The two watersheds are upper Twin Creek and lower Twin Creek. The upper watershed, corresponding to Hydrologic Unit Code (HUC) 05080002 030, includes Twin Creek from its headwaters to upstream of Bantas Fork. Associated tributaries studied in this sub-basin included Maple Swamp Ditch, Dry Fork, Miller's Fork, Swamp Creek, Unnamed Tributary to Swamp Creek at River Mile (RM) 6.45, Price Creek, and Lesley Run. The lower watershed, corresponding to HUC 05080002 040, includes Twin Creek from Bantas Fork to the confluence with the Great Miami River. Associated tributaries studied in this sub-basin included Bantas Fork, Goose Run, Aukerman Creek, Unnamed Tributary to Aukerman Creek at RM 2.88, Unnamed Tributary to Twin Creek at RM 18.29, Tom's Run, and Little Twin Creek.

2.2 Ecoregion

The Twin Creek watershed is located within the Eastern Corn Belt Plains (ECBP) ecoregion. An ecoregion is an area having broad similarity with respect to climate, soil, topography and dominant natural vegetation. Less variation of aquatic biological communities, chemical water quality and physical stream attributes is expected within an individual ecoregion compared to the variation of these characteristics throughout all of Ohio. For this reason some of Ohio's WQS are ecoregion-specific.

The Twin Creek watershed is typified by gently rolling glacial till plains including moraines, kames and outwash features (Omernik and Gallant, 1988). Original vegetation was mostly beech forest with areas of elm-ash swamp forests. Near the Great Miami River confluence, an area of oak-sugar maple and bottomland hardwood forest existed in pre-settlement times. Remnants of these forest types still exist in isolated locations (Gordon, 1966). Silurian and Ordovician era bedrock is exposed principally as limestone with some shale outcrops. Soils are considered nearly level to gently sloping and tend to be neutral to slightly alkaline. Drainage varies from well to very poorly drained.

2.3 Land Use

Land use is predominantly row crop agriculture for corn, soybeans, and winter wheat with some livestock production. There is some variation between the upper and lower assessment units of Twin Creek. The upper watershed (Hydrologic Assessment Unit (HUC) 05080002 030 – Twin Creek headwaters to upstream Bantas Fork) is 75% row crop while the lower catchment (HUC 05080002 040 – Twin Creek and tributaries downstream and including Bantas Fork) is 62.3% row crop. This difference is accounted for with the upper basin having only 9.7% of its area in forest while the lower has 21.6% forest. The Five Rivers MetroParks owns or holds conservation easements on 4332 acres within lower Twin Creek. Much of this land was purchased with the intent of protecting the water quality of Twin Creek. Another 1200 acres are pending protection at this time (Dave Nolin, personal communication). Another difference between the upper and lower watersheds is the level of urban/recreational grasses. Upper Twin Creek has 0.6% in this category while lower Twin Creek has 8.2%, which reflects the presence of the village of Germantown, the largest community in the watershed.

Upland soils in the watershed vary from the well-drained Miamian-Celina association to the very poorly-drained Brookston-Crosby association. Even the well-drained soils have significant inclusions of poorly-drained soils, so drainage is needed to support agricultural crop production. An extensive tile drainage system has been installed and the extreme headwaters of many small streams have been straightened and deepened to accelerate water movement away from fields. Each county has programs that maintain the artificial structure of these streams. Maintained streams are located in the upper parts of the watershed where landforms are level to gently sloping. Along larger streams, soils tend to be either Ross-Medway or Fox Ockley-Thackery associations, which are very well-drained, having formed in the floodplains over sand and gravel aquifers with deposited materials from the upland.

Much of the Twin Creek watershed overlies the Great Miami River Buried Valley Aquifer System. This ancient river valley filled with glacially deposited sand, gravel and clay till to depths of 200 feet is the principal water source for the area. Designated as a Sole Source Aquifer by the U.S. EPA in 1988, all federally funded projects within the aquifer must be reviewed for their potential water quality impact. Additionally, many communities have enacted or are considering wellhead protection legislation.

Figure 2. Location of the Twin Creek watershed.

2.4 Sources of Pollution

Sources of pollution to the Twin Creek watershed include nonpoint, regulated point, home sewage treatment systems, livestock with stream access and channel maintenance. These sources are defined in following sections. Each section provides information concerning pollutant delivery pathways of and the primary environmental condition affected by the source.

2.4.1 Point Sources

Industrial and municipal point sources include wastewater treatment plants and factories. Wastewater treatment plants can contribute to bacteria, nutrient enrichment, siltation, and flow alteration problems. Industrial point sources, such as factories, sometimes discharge water that is excessively warm or cold, changing the temperature of the stream. Point sources may contain other pollutants such as chemicals, metals and silt.

NPDES dischargers are entities that possess a permit through the National Pollutant Discharge Elimination System (NPDES). NPDES permits limit the quantity of pollutants discharged and impose monitoring requirements. NPDES permits are designed to protect public health and the aquatic environment by helping to ensure compliance with state and federal regulations. NPDES entities generally discharge wastewater continuously. They primarily affect water quality under average- to low-flow conditions because the potential for dilution is lower. NPDES dischargers located near the origin of a stream or on a small tributary are more likely to cause severe water quality problems because their effluent can dominate the natural stream flow.

Small package plants are the source of some impairment in Goose Run. Package plants are typically small wastewater treatment plants that use extended aeration for treatment. Insufficient data were collected to address this source of impairment in this TMDL report. The Lewisburg Wastewater Treatment Plant (WWTP) is the source of some impairment in the Twin Creek mainstem. There are several other NPDES permittees in the watershed, but they did not appear to be sources of impairment to the biology of the streams as the streams into which they discharged met the applicable biocriteria. All facilities carrying individual NPDES permits are listed in Table 2.

Table 2. Individual NPDES permits in the Twin Creek watershed.

Ohio EPA Permit No.	Facility	Design Flow (MGD)	Average Flow (MGD)	Receiving Stream	Permit Expiration Date
HUC 0508002 030 010 Twin Creek above Millers Fork					
1PA00025	West Manchester WWTP	0.065	0.034	Twin Creek	1/31/2013
HUC 05080002 030 030 Twin Creek below Millers Fork to above Price Creek (Except Swamp Creek)					
1PB00019	Lewisburg WWTP	0.261	0.230	Twin Creek	3/31/2010
1PG00092	Preble Co. SD #2 WWTP	0.015	0.0278	Unnamed trib to Twin Creek	2/28/2010
1IH00012	P& G Pet Care	0.075	0.03832	Twin Creek	9/30/2013
1IN00184	North American Nutrition	0.006	0.00322	Twin Creek	2/28/2009
HUC 05080002 030 040 Swamp Creek					
1PA00027	Verona WWTP	0.085	0.01847	Swamp Creek	12/31/2010
HUC 05080002 030 050 Price Creek					
1PA00014	El Dorado WWTP	0.10	0.0434	Price Creek	7/31/2010
HUC 05080002 030 060 Twin Creek below Price Creek to above Bantas Fork					
1PB00035	West Alexandria	0.300	0.191	Twin Creek	4/30/2012

Ohio EPA Permit No.	Facility	Design Flow (MGD)	Average Flow (MGD)	Receiving Stream	Permit Expiration Date
	WWTP				
1PV00125	Creekside MHP	0.0045	0.0005	Twin Creek	3/31/2010
HUC 05080002 040 020 Goose Creek					
1IN00212	Dayton Travel Center	0.02	0.01218	Unnamed trib to Goose Creek	3/31/2009
1PZ00020	Pilot Travel Center	0.02	0.0062	Unnamed trib to Goose Creek	4/30/2011
HUC 05080002 040 060 Twin Creek below Aukerman Creek to above Tom's Run					
1PB00041	Gratis WWTP	0.119	0.117	Twin Creek	8/31/2013
HUC 05080002 040 090 Little Twin Creek					
1PB00010	Farmersville WWTP	0.22	0.221	Riegle Ditch	3/31/2012

2.4.2 Nonpoint Sources

Nonpoint source (NPS) pollution consists of contaminants contributed by diffuse sources. In the context of this TMDL, NPS pollution refers to sediment and phosphorus delivered to the stream system via surface runoff, ground water, and sub-surface tile drainage. NPS pollution is intermittent by nature because it is primarily driven by rainfall or snowmelt. It is most apparent during high stream-flow as increased pollutant concentrations, but its effects extend to average and low-flow conditions. Settling sediment contributes to siltation, while phosphorus adsorbed to the sediments influences water chemistry even as the flow recedes.

Row crop cultivation is a common land use in Ohio. Frequently, cultivated cropland involves surface (ditch construction and stream modification) and subsurface (tile) drainage, and a challenge is to carry out actions that improve water quality while maintaining adequate drainage for profitable agriculture. The land application of manure, especially during winter months, can be a large source of both bacteria and nutrients entering streams and subsurface drainage tiles. Many cropland practices involve the channelization of streams, which creates deeply incised and straight ditches or streams. This disconnects waterways from floodplains, which has damaging impacts on the quality of the system. The resulting channel is less able to assimilate nutrients and other pollution. The regularity of the stream channel, lack of in-stream cover and increased water temperatures reduce biological diversity.

Home Sewage Treatment Systems

Home Sewage Treatment Systems (HSTS) are small wastewater treatment units serving individual homes or businesses. HSTS are typically located on the property of the home or business from which they treat waste. HSTS are often referred to as onsite wastewater treatment systems or on-lot systems. These terms are approximately synonymous. Unsewered communities are typically comprised of a collection of homes and businesses each served by HSTS. There are many types of HSTS. The efficacy with which each system treats waste is dependent upon its age, the manner in which it is maintained, and characteristics of the site where it is located. Important site characteristics include soil drainage, water-table depth, bedrock depth, land slope, and parcel-lot size.

HSTS affect water quality under multiple conditions. HSTS discharging directly to a stream or river, such as many aeration or illicit systems, behave similarly to a point source. These types of systems primarily affect water quality under dry, low-flow conditions. HSTS discharging indirectly to a stream via a tile drain or intermittent ditch may exhibit effects akin to a nonpoint source. Wastewater discharged to a dry tile or ditch may be of insufficient volume to sustain flow to the stream, but pollutants can accumulate and eventually be flushed by rainfall. These types of systems primarily affect water quality under wet-weather, high-flow conditions.

Additional pollutant delivery pathways associated with HSTS exist, but those discussed above are believed the most significant in the Twin Creek watershed. HSTS are regulated by general permits issued by local health authorities.

Animal Feeding Operations

Agricultural livestock operations can vary widely in how they are managed. Pasture land and animal feeding operations can be sources of nutrients and pathogens. Frequently livestock are permitted direct access to streams. Direct access not only allows direct input of nutrients and pathogens, but also erodes the stream bank, causing excess sediments to enter the stream and habitat degradation. The most critical aspect of minimizing water quality impacts from any size animal feeding operation is the proper management of manure.

Grazing livestock with stream access is a source of impairment to the Twin Creek watershed. Livestock is granted stream access to provide a source of water or to allow movement to pasture. Either of these situations can result in the contribution of large pollutant loads to the stream system. Of particular concern is bacterial contamination, because unrestricted livestock can deposit waste directly into the stream. This results in very high local bacteria concentrations, and can potentially affect downstream use as well. Fortunately, these locally high concentrations have not yet caused overall impairment to the lower reaches of the Twin Creek mainstem.

Of greater import in the Twin Creek basin is that grazing livestock with stream access can also contribute to habitat and channel degradation. Livestock often graze to the stream edge, eliminating essential riparian vegetation. Further, livestock trample, collapse, and de-stabilize stream banks. This can result in elevated in-stream sediment concentrations and downstream siltation.

2.4.3 Habitat

The Qualitative Habitat Evaluation Index (QHEI) is a tool developed and used by the Ohio EPA to assess stream habitat quality. It is designed to provide an empirical evaluation of general habitat characteristics that are essential to fish communities and generally important to other aquatic life. The QHEI is composed of six principal habitat categories. Total QHEI score equals the sum of the habitat category scores, with a maximum possible QHEI score is one-hundred (100). The QHEI score of a stream segment is established in the field by a trained evaluator.

Specific subscores of the QHEI were identified as pertaining directly to the attainment of aquatic life in the Twin Creek watershed. Specific targets for these scores are included and discussed in further detail in Appendix B.

Stream Geomorphology and Floodplains

Stream geomorphology pertains to the shape of stream channels and their associated floodplains. In particular, it deals with aspects of the stream system that include riffle and pool features, sinuosity (meander patterns), slope, cross-sectional dimensions, floodplain connectivity as well as the processes that form and maintain them. The capacity of a stream system to assimilate pollutants such as nutrients, sediment, and organic matter depends on features related to its geomorphology. This is especially the case for floodplains which, if connected to the channel, can store large quantities of sediment as well as process nutrients and organics that are flowing through its sub-surface (i.e., parafluvial flow). Nutrient loads entering streams from upland sources are also reduced by biological uptake occurring in floodplains (Forshay and Stanley, 2005).

Aquatic community structure, which is integral to Ohio's water quality standards, responds to habitat and water quality conditions intimately related to stream geomorphology (Danehy et al., 1999; Clarke et al., 2003). Hence it is expected that aquatic life in the Twin Creek watershed will reflect habitat modifications that affect geomorphology.

Streams are stable when there is a balance between sediment inputs to the system (i.e., supplied by the landscape) and sediment transport. In other words, erosion and deposition processes that normally occur in streams equal one another and neither occurs excessively. Habitat such as bed substrate, riffles, and pools maintain sufficient quality to support biological communities when streams are stable. However, stream instability leads to extremes in erosion that removes or damages these habitats or leads to excessive sediment deposition that degrades stream quality.

Stream stability is manifest in channels where stream bed elevation remains consistent over several decades or longer (Ward et al., 2004). Additionally, the average width and depth of the channel is consistent even though moderate erosion and depositional processes create changes in the stream. For example, even in stable stream systems channel meanders will migrate down their valley by eroding bank material on outside bends while sediment is deposited along inside bends. However, there is no net change in the average width and depth of the channel.

Importance of Floodplains

A well-connected floodplain is critical for stream stability (Ward et al., 2004). Floodplains reduce the intensity of stream erosion once the bankfull depth (i.e., the channel is filled) is exceeded because flow depths increase slowly relative to increasing discharge. For most stable streams, floodplains begin to flood for flows that roughly correspond to a 1- to 2-year return interval (RI). Flow depth is directly related to shear stress acting on the stream's bed and banks, which is a fundamental cause of erosion. The power to erode bed and bank material increases at a much slower rate for streams with well connected floodplains compared to those that are entrenched and as a consequence, stream stability is closely tied to floodplain connectivity.

Floodplains are sinks for suspended sediment during high flows, which is when the landscape sediment load is large. Flow velocity, which is directly related to the flow's capacity to keep sediment suspended, is relatively slow in the floodplain allowing more material to fall out of suspension. This is due to the shallower depths, increased surface contact, and a greater amount of flow impedances in the floodplain compared to the channel. By storing a significant proportion of the landscape sediment load in the floodplain, the substrate within the channel has less fine material maintaining high quality for this habitat.

From a purely biological perspective, separation of a channel from its floodplain (e.g., from channelization), has deleterious effects on fish and other aquatic life. Important refugia associated with relatively slow flow velocities and cover becomes inaccessible during high flow events. The stress of high flows on aquatic organisms is substantial; therefore, refugia have an important role in stream ecosystems (Schwartz and Herricks, 2005). Reice et al. (1990) contends that disturbance associated with high flows is the primary factor determining aquatic community composition. In addition, floodplain disconnection limits the export of organic matter to the stream, which serves as food subsidies and structural habitats (Wallace et al., 1997; Baer et al., 2001).

2.5 Population

Agriculture, the predominating land use in the Twin Creek watershed, has contributed to overall water quality impairment basin-wide where impairment exists. However, impairment is not widespread. With proper management, it is conceivable that both agriculture and water quality can continue to coexist in years to come. However, given Twin Creek's proximity to the greater Dayton metropolitan area, possible future impacts resulting from urbanization should be considered. Population stability in the past 10 years has resulted in little change to the urbanized areas of Twin Creek, and thus is considered to be a contributing factor to the watershed's overall stability. However, the effects of urbanization have been documented as impacting water quality in some of Ohio's higher quality streams, some of which were once dominated by agriculture as well. Increased development in the outlying suburbs of Columbus, Ohio has had negative impacts on EWH portions of the Olentangy River (Ohio EPA, 2005). West of Columbus, the status of Big Darby Creek, a State and National Scenic River, is considered vulnerable to similar development patterns (Ohio EPA, 2004). In order to avoid a similar scenario in Twin Creek, development should be carefully monitored. The continued purchase of conservation easements, when feasible, should be sought as a proactive and protective measure, should the notion of increased urbanization become realized.

Development typically impacts streams in two ways: first, an intense period of land disturbance during construction of roads, sewers, and buildings, then the resulting altered landscape that handles water differently than the pre-construction landscape. Near-term impacts include stream channelization and pollution from construction site runoff as housing and infrastructure expand to accommodate the growth. Long-term impacts include an increase in the watershed's total impervious surface, which results in faster runoff and higher-volume storm flows. More impervious surface can also result in reduced stream flows caused by lessened infiltration and ground water recharge. These changes in the hydrologic regime of a stream system can increase streambank erosion and destabilize channels, resulting in greater siltation downstream and increasingly ephemeral tributary stream flow.

3.0 STATUS OF WATER QUALITY

TMDLs are required when a waterbody fails to meet water quality standards (WQS). Every state must adopt WQS to protect, maintain, and improve the quality of the nation's surface waters. WQS represent a level of water quality that will support the Clean Water Act goal of swimmable and fishable waters. Ohio's WQS, set forth in Chapter 3745-1 of the Ohio Administrative Code (OAC), include four major components: beneficial use designations, narrative criteria, numeric criteria, and anti-degradation provisions.

Beneficial use designations describe the existing or potential uses of a waterbody. They consider the use and value of a waterbody for public water supply; protection and propagation of aquatic life; recreation in and on the water; and agricultural, industrial or other purposes. Ohio EPA assigns beneficial use designations to each waterbody in the state. Use designations are defined in paragraph (B) of rule 3745-1-07 of the OAC and are assigned in rules 3745-1-08 to 3745-1-32. Attainment of uses is based on specific numeric and narrative criteria.

Numeric criteria are estimations of chemical concentrations, degree of aquatic life toxicity, and physical conditions allowable in a waterbody without adversely impacting its beneficial uses. Narrative criteria, located in rule 3745-1-04 of the OAC, describe general water quality goals that apply to all surface waters. These criteria state that all waters shall be free from sludge, floating debris, oil, scum, color and odor-producing materials; substances that are harmful to human or animal health; and nutrients in concentrations that may cause excessive algal growth.

Antidegradation provisions describe the conditions under which water quality may be lowered in surface waters. Under such conditions water quality may not be lowered below criteria protective of existing beneficial uses unless lower quality is deemed necessary to allow important economic or social development. Antidegradation provisions are in Sections 3745-1-05 and 3745-1-54 of the OAC.

3.1 Aquatic Life Beneficial Use Designations

Warmwater Habitat (WWH) is characterized by the typical assemblage of aquatic organisms in Ohio rivers and streams. WWH represents the principal restoration target for the majority of water resource management efforts in Ohio, and is in line with the Clean Water Act goal of fishable waters.

Exceptional Warmwater Habitat (EWH) is applied to waters that support unusual and exceptional assemblages of aquatic organisms. These assemblages are characterized by a high diversity of species, particularly those that are highly intolerant, threatened, endangered, or of special status (i.e., declining species). EWH represents a protection goal for the management of Ohio’s best water resources.

Modified Warmwater Habitat (MWH) is applied to waters that have been subject to maintained and essentially permanent modification. The MWH designation is appropriate if the modification is such that WWH criteria are unattainable. Additionally, the modification must be sanctioned by state or federal law. MWH aquatic communities are generally composed of species that are tolerant to low dissolved oxygen, silt, nutrient enrichment and poor quality habitat. Where this use designation is applied, the allowable conditions in the MWH-designated stream may be driven by the need to protect a higher downstream aquatic life use designation (e.g., WWH, EWH).

Aquatic life use attainment is dependent upon numeric biological criteria (biocriteria). Biocriteria are based on aquatic community characteristics that are measured both structurally and functionally. The rationale for using biocriteria has been extensively discussed elsewhere (Karr, 1991; Ohio EPA, 1987a,b; Yoder, 1989; Miner and Borton, 1991; Yoder, 1991; Yoder and Rankin, 1995).

Ohio's biocriteria are based upon three evaluation tools: the Index of Biotic Integrity (IBI), the Modified Index of Well-Being (MIwb) and the Invertebrate Community Index (ICI). These three indices are based on species richness, trophic composition, diversity, presence of pollution-tolerant individuals or species, abundance of biomass and the presence of diseased or abnormal organisms. The IBI and the MIwb apply to fish; the ICI applies to macroinvertebrates. Details regarding IBI, MIwb and ICI sampling procedures are described in the *Manual of Ohio EPA Surveillance Methods and Quality Assurance Practices* (Ohio EPA, 1987c). Provisions addressing biocriteria are in paragraph (A)(6) of Section 3745-1-07 of the OAC.

Ohio EPA uses IBI, MIwb, and ICI assessment results of reference-site sampling to establish biocriteria. Least-impacted reference sites are periodically evaluated to determine minimum-expected index scores associated with various stream sizes, designations, and ecoregions. Attainment of aquatic life use designation is determined by comparison of biological assessment results to biocriteria. If an assessment site meets all applicable biocriteria for the IBI, MIwb and ICI, then it is in full attainment. If it achieves none of the applicable biocriteria, then it is in non-attainment. If it achieves some, but not all, then it is in partial attainment. Table 3 presents biocriteria applicable in the Twin Creek watershed.

Table 3. ECBP ecoregion criteria.

Biological Index	Assessment Method	WWH	EWH	MWH
IBI	Headwater	40	50	24
IBI	Wading	40	50	24
IBI	Boat	42	48	24
MIwb	Headwater	NA[1]	NA[1]	NA[1]
MIwb	Wading	8.3	9.4	4.0
MIwb	Boat	8.5	9.6	4.0
ICI	All[2]	36	46	22

1. Not applicable to drainage areas less than 20 mi^2.
2. Limited to sites with appropriate conditions for artificial-substrate placement.

3.1.1 Aquatic Life Use Attainment in Study Area

The results of the 2005 Twin Creek study in the mainstem confirmed the exceptional warmwater habitat (EWH) status. While Twin Creek does not stand out in terms of species diversity when compared to other similarly-sized, high quality Ohio streams, when biological performance is considered in terms of mean index scores, Twin Creek is among the best. The mean Index of Biotic Integrity (IBI, a fish index) of Twin Creek in 2005 (53.3) is the highest in Ohio when compared to similar-sized streams sampled in the last 10 years. The 2005 Invertebrate Community Index (ICI) mean (48.9), which included one score below the EWH criterion, still was high enough to rank third-highest in the state among comparable streams in the last 10 years. This kind of performance is attributed not only to Twin Creek's assimilative nature, but also to the good stewardship demonstrated by the landowners along this water body. Natural riparian corridors, important for bank stabilization, contaminant filtering, and stream shading were left intact throughout most of Twin Creek's length. Given the abundance of agricultural land use throughout the watershed, such protection of this important habitat feature is commendable.

The Twin Creek watershed is comprised of two Watershed Assessment Units (WAUs). The upper watershed, corresponding to HUC 05080002 030, includes Twin Creek from its headwaters to upstream of Bantas Fork. Associated tributaries studied in this sub-basin included Maple Swamp Ditch, Dry Fork, Miller's Fork, Swamp Creek, Unnamed Tributary to Swamp Creek at River Mile (RM) 6.45, Price Creek, and Lesley Run. The lower watershed, corresponding to HUC 05080002 040, includes Twin Creek from Bantas Fork to the confluence with the Great Miami River. Associated tributaries studied in this sub-basin included Bantas Fork, Goose Run, Aukerman Creek, Unnamed Tributary to Aukerman Creek at RM 2.88, Unnamed Tributary to Twin Creek at RM 18.29, Tom's Run, and Little Twin Creek. In all, 48 stations with drainage areas ranging from 3.3 to 316 mi^2 were sampled to determine attainment of aquatic life uses. Of these, 15 (31%) were in partial attainment of their existing or recommended use. No stations were in non-attainment, and 1 station was left unassessed because it lacked a fish sample. In all cases where aquatic life use goals were not fully met, macroinvertebrate performance was the limiting factor. The most prominent causes of impairment in the Twin Creek watershed are described below.

Biological performance is often a byproduct of surrounding land use, a concept that is illustrated in Twin Creek, particularly in the headwaters. There, agriculture dominates a landscape that is comprised of hydric soils that, left unaltered, drain poorly and can lead to saturated conditions not conducive to crop production. Therefore, an extensive network of field tiling exists in order to render the soils suitable for planting. To facilitate drainage via this network, many of the streams in the upper portion of the watershed have been ditched, straightened, stripped of riparian buffer, or otherwise altered in order to act as receiving waters that quickly and effectively move excess water away from planting fields. The 'artificial' stream segments that result from these alterations are left with substandard habitat features that more readily allow for impairments attributable to siltation and nutrient enrichment from unfiltered runoff. That said, the upper portion of Maple Swamp Ditch, upper Miller's Fork, upper Swamp Creek, upper Lesley Run, and upper Tom's Run were found to have been adversely influenced by such modifications. None of the macroinvertebrate communities found in these stream segments were in attainment of their current or recommended aquatic life use.

Most of the streams cited above were additionally impaired by naturally-occurring low flows. August 2005 in particular was extraordinarily dry, with significant precipitation not occurring until August 30, when remnants of Hurricane Katrina saturated the area. However, base flows in the beginning of September, when macroinvertebrate sampling began, still remained low. In addition to hydromodification, upper Miller's Fork, upper Swamp Creek, upper Lesley Run, and upper Tom's Run were affected by low flow conditions. Upper Price Creek, lower Lesley Run, the upper and lower reaches of Bantas Fork, upper Goose Run, and upper Little Twin Creek experienced flow-related impairments as well. Where the fish communities sampled were found to be intact and apparently adapted to the changes in flow regime, the benthic communities were exhibiting distress. In these cases, most sensitive taxa that would normally be present in a flowing stream with riffle/run complexes were not found.

Only two stations were acknowledged as being potentially influenced by point source wastewater discharge, in spite of numerous system bypasses reported at many of the facilities. Goose Run at RM 4.4, while experiencing notably low flows at the time of sampling, also had large growths of filamentous algae, indicative of nutrient enrichment several upstream package wastewater facilities. The fair benthic community collected here subsequently fell short of the applicable WWH biocriterion. On Twin Creek itself, downstream from the Lewisburg WWTP, while a good narrative ICI score was garnered, the EWH criterion for that reach was not achieved. Nutrient enrichment from either the Lewisburg WWTP, runoff from an upstream municipal park, or contaminated storm water via a culvert at the Salem Road bridge could be responsible for the impairment.

Table 4. Aquatic life use attainment status for stations sampled in the Twin Creek basin based on data collected July-October 2005. The Index of Biotic Integrity (IBI), Modified Index of well being (MIwb), and Invertebrate Community Index (ICI) are scores based on the performance of the biotic community. The Qualitative Habitat Evaluation Index (QHEI) is a measure of the ability of the physical habitat to support a biotic community. In cases where a new aquatic life use is recommended, attainment status is based on that recommendation.

River Mile Fish/Invertebrate	IBI	MIwb[a]	ICI[b]	QHEI	Attainment Status[c]	Causes	Sources
Twin Creek (14-500)	*ECBP Ecoregion – EWH Existing*						
Upper Twin Creek Assessment Unit – HUC 05080002-030							
46.5[H] /46.6	48 [ns]	N/A	VG[ns]	43.0	FULL		
42.1[W]/42.0	48[ns]	9.1[ns]	46	75.5	FULL		
38.0[W]/38.1	46[ns]	9.0[ns]	50	61.0	FULL		
35.5[W] /35.4	58	10.2	50	67.0	FULL		
34.9[W] /34.9	58	10.2	38*	71.0	PARTIAL	Organic enrichment[1] Nutrient enrichment: phosphorus	Municipal point source discharges-Lewisburg WWTP
33.6[W] /33.5	58	10.3	52	77.0	FULL		
31.7[W] /31.7	55	9.6	54	72.5	FULL		
27.5[W] /27.6	55	10.4	52	80.0	FULL		
26.7[W] /26.6	56	11.1	44[ns]	88.5	FULL		
Lower Twin Creek Assessment Unit – HUC 05080002-040							
23.9[W] /23.7	54	10.0	50	79.0	FULL		
19.2[W] /19.2	51	9.8	52	76.5	FULL		
19.0[W]/19.0	48[ns]	10.0	E	72.0	FULL		
13.4[W] /13.4	53	10.3	50	88.0	FULL		
9.8[W] /9.7	56	10.4	52	74.0	FULL		
3.4[W] /3.4	51	10.2	E	86.5	FULL		

[1] This cause of impairment will be listed in the revised Biological and Water Quality Study and the 2010 Integrated Report, both to be published in 2010.

River Mile Fish/Invertebrate	IBI	MIwb[a]	ICI[b]	QHEI	Attainment Status[c]	Causes	Sources
0.9[W] /0.9	54	9.8	48	82.0	FULL		
0.1[W] /0.1	54	10.6	46	71.5	FULL		
Upper Twin Creek Assessment Unit (Tributaries) – HUC 05080002-030							
Maple Swamp Ditch -Trib to Twin Creek @ RM 47.03 (14-519) *ECBP Ecoregion – Undesignated – MWH Recommended*							
2.4[H] /2.4	38	N/A	P*	21.0	PARTIAL	Sedimentation/Siltation Excess Algal Growth	Channelization; Loss of Riparian Habitat; Crop Production with Subsurface Drainage. (Darke County ditch maintenance)
ECBP Ecoregion – Undesignated – WWH Recommended							
1.4[H] /1.4	44	N/A	G	38.5	FULL		(Darke County ditch maintenance)
Dry Fork -Trib to Twin Creek @ RM 39.35 (14-515)					*ECBP Ecoregion – WWH Existing*		
0.8[H] /0.8	40	N/A	G	50.0	FULL		
Millers Fork -Trib to Twin Creek @ RM 35.71 (14-513)					*ECBP Ecoregion – EWH Existing – WWH Recommended*		
10.8[H] /10.8	40	N/A	Low F*	33.0	PARTIAL	Low Flow (Interstitial) Sedimentation/Siltation; Low Dissolved Oxygen (DO) Nutrients: ammonia	Natural Channelization; Loss of Riparian Habitat; Crop Production with Subsurface Drainage; Sewage Discharge from Unsewered Area
ECBP Ecoregion – EWH Existing							
8.0[H] /8.0	48[ns]	N/A	G*	66.5	PARTIAL	Natural Habitat (Shallow Bedrock)	Natural
3.9[H] /3.9	48[ns]	N/A	MG[*]	58.0	PARTIAL	Sedimentation/Siltation; Low DO; Nutrients: ammonia	Loss of Riparian Habitat Animal Feeding Operations

River Mile Fish/Invertebrate	IBI	MIwb[a]	ICI[b]	QHEI	Attainment Status[c]	Causes	Sources
Swamp Creek -Trib to Twin Creek @ RM 35.59 (14-512) *ECBP Ecoregion – WWH Existing*							
6.3[H] /6.4	44	N/A	F*	34.0	PARTIAL	Low Flow Nutrients: ammonia, phosphorus; Sedimentation/Siltation	Natural Channelization; Loss of Riparian Habitat; Crop Production w/ Subsurface Drainage
ECBP Ecoregion – EWH Existing							
--- /0.2	---	---	MG*	---	Unknown		
Trib to Swamp Creek @ RM 6.45 (14-521)					*ECBP Ecoregion - Undesignated – WWH Recommended*		
0.3[H] / ---	38[ns]	N/A	---	37.5	(FULL)		
Price Creek -Trib to Twin Creek @ RM 29.74 (14-510)					*ECBP Ecoregion – WWH Existing*		
13.7[H] /13.6	38[ns]	N/A	Low F*	47.0	PARTIAL	Low Flow Low DO; Nutrients: ammonia, phosphorus	Natural Agriculture; Failing On-Site Septic Systems
10.9[H]/10.9	42	N/A	G	62.5	FULL		
ECBP Ecoregion – EWH Existing – WWH Recommended							
3.8[W] /3.9	36[ns]	8.4	50	65.5	FULL		
Lesley Run -Trib to Twin Creek @ RM 24.60 (14-508)					*ECBP Ecoregion - WWH Existing*		
6.0[H] / 4.9	48	N/A	Low F*	35.0	PARTIAL	Low Flow (Interstitial) Sedimentation/Siltation; Low DO	Natural Channelization; Loss of Riparian Habitat; Crop Production w/ Subsurface Drainage
1.2[H] /1.3	38[ns]	N/A	Low F*	60.0	PARTIAL	Low Flow (Interstitial)	Natural

River Mile Fish/Invertebrate	IBI	MIwb[a]	ICI[b]	QHEI	Attainment Status[c]	Causes	Sources
Lower Twin Creek Assessment Unit (Tributaries) – HUC 05080002-040							
Bantas Fork -Trib to Twin Creek at RM 24.32 (14-505) *ECBP Ecoregion - EWH Existing*							
13.7[H] /13.7	46[ns]	N/A	G*	69.0	PARTIAL	Low Flow	Natural
9.4[H] /9.5	56	N/A	54	67.0	FULL		
7.1[W]/7.0	56	8.7 [na*]	50	72.5	FULL		
1.3[W] /1.2	53	9.8	G*	80.5	PARTIAL	Low Flow	Natural
Goose Run -Trib to Bantas Fork @ RM 7.55 (14-506)					*ECBP Ecoregion - WWH Existing*		
4.4[H] /4.2	44	N/A	F*	55.0	PARTIAL	Low Flow Nutrient Enrichment: phosphorus, ammonia, COD, low DO	Natural Upstream Package Plants
ECBP Ecoregion – EWH Existing							
0.3[H] /0.3	56	N/A	VG[ns]	73.0	FULL		
Aukerman Creek -Trib to Twin Creek @ RM 19.29 (14-504) *ECBP Ecoregion - WWH Existing*							
3.3[H]/3.3	50	N/A	VG	82.0	FULL		
1.8[H] /1.8	54	N/A	G	75.5	FULL		
0.5[W] /0.4	46	8.0[ns]	52	70.5	FULL		
Trib to Aukerman Creek @ RM 2.88 (14-520)					*ECBP Ecoregion - Undesignated / WWH Recommended*		
0.5[H]/0.5	48	N/A	VG	73.0	FULL		
Trib to Twin Creek @ RM 18.29 (14-518)					*ECBP Ecoregion – Undesignated – WWH Recommended*		
0.6[H] / 0.7	48	N/A	E	70.5	FULL		
Tom's Run -Trib to Twin Creek @ RM 13.52 (14-502)					*ECBP Ecoregion - WWH Existing*		

River Mile Fish/Invertebrate	IBI	MIwb[a]	ICI[b]	QHEI	Attainment Status[c]	Causes	Sources
12.0[H]/12.0	52	N/A	Low F*	40.5	PARTIAL	Low Flow (Interstitial) Low DO; Sedimentation/Siltation	Natural Channelization; Crop Production w/ Subsurface Drainage
8.5[H] /8.5	40	N/A	Low F*	58.5	PARTIAL	Low Flow (Interstitial)	Natural
0.4[W]/0.4	48	8.7	34[ns]	82.0	FULL		
Little Twin Creek -Trib to Twin Creek @ RM 6.69 (14-501) *ECBP Ecoregion - EWH Existing*							
6.2[H]/6.3	46[ns]	N/A	36*	65.5	PARTIAL	Low Flow	Natural
4.7[H] /4.6	52	N/A	50	59.5	FULL		
2.0[H]/2.0	54	N/A	VG [ns]	77.0	FULL		

H Headwater site.
W Wading site.
B Boat site.
a MIwb is not applicable to headwater streams with drainage areas < 20 mi^2.
b A narrative evaluation of the qualitative sample based on attributes such as EPT taxa richness, number of sensitive taxa, and community composition was used when quantitative data was not available or considered unreliable due to current velocities less than 0.3 fps flowing over the artificial substrates. VP=Very Poor, P=Poor, LF=Low Fair, F=Fair, MG=Marginally Good, G=Good, VG=Very Good, E=Exceptional
c Attainment is given for the proposed status when a change is recommended.
ns Non-significant departure from biocriteria (<4 IBI or ICI units, or <0.5 MIwb units).
* Indicates significant departure from applicable biocriteria (>4 IBI or ICI units, or >0.5 MIwb units). Underlined scores are in the Poor or Very Poor range.
d Limited Warmwater Habitat is an archaic use designation.
e Low flow precluded use of boat method on the second pass.
f Modified Warmwater Habitat criteria for channel modified habitats.
na* The MIwb for RM 7.1, Bantas Fork, was invalidated to due to a sampling error associated with significant bridge effect.

Ecoregion Biocriteria

	IBI			MIwb			ICI		
Site Type	WWH	EWH	MWH	WWH	EWH	MWH	WWH	EWH	MWH
Headwaters	40	50	24				36	46	22
Wading	40	50	24	8.3	9.4	4.0	36	46	22
Boat	42	48	24	8.5	9.6	4.0	36	46	22

3.2 Recreation Beneficial Use Designations

One recreation use designation is applicable to stream and river segments in the Twin Creek watershed: Primary Contact Recreation (PCR). PCR is applied to waters suitable for full-body contact such as swimming and canoeing. Recreational use designations are in effect for only the recreation season. The recreation season is defined as May 1st through October 15th. Recreational use designations are further described in Section 3745-1-7 of the OAC.

Attainment of recreation use designation is evaluated by comparison to bacteriological numeric and narrative criteria. Ohio currently has bacteriological criteria for two parameters: fecal coliform and *Escherichia coli* (*E. coli*). Narrative criteria state that only one of the two criteria must be met to result in attainment. Bacteriological criteria apply outside the mixing zone of permitted discharges.

The numeric criteria for PCR state the geometric mean (at least five samples within 30 days) fecal coliform content shall not exceed 1,000 colony-forming units (cfu) per 100 ml, and fecal coliform content shall not exceed 2,000 cfu per 100 ml in more than ten percent of samples taken in any 30-day period. The numeric criteria for PCR also state that the geometric mean *E. coli* content shall not exceed 126 cfu per 100 ml, and *E. coli* content shall not exceed 298 cfu per 100 ml in more than ten percent of samples taken in any 30-day period.

3.2.1 Recreation Use Attainment in Study Area

Five sampling events for bacteria were collected within thirty days during the month of September 2005. A total of twenty sites designated PCR were sampled on five separate occasions, with 12 sites in the upper Twin Creek assessment unit and 8 sites in the lower Twin Creek assessment unit. In all, 99 of the 100 samples were included in the calculations (one was invalidated because of a lab transport accident). Each site was evaluated for bacteria compliance using WQS in OAC 3745-1-07, Table 7-13.

Tables 5 and 6 display the recreation use impairment for both watershed assessment units. In each case, a site-by-site analysis was performed. Where one site did not attain, the entire 14-digit hydrologic unit was classified as impaired. Where one 14-digit hydrologic unit was impaired, the entire watershed assessment unit was impaired (*i.e.*, both watershed assessment units were impaired). Shaded cells indicate that either the geometric mean criterion was exceeded or that more than 10% of the samples exceeded the higher criterion (2000 cfu/100 ml for fecal coliform and 298 cfu/100 ml for *E. coli*). Figure 3 shows the hydrologic units that were impaired.

Table 5. Recreation use impairment for WAU 05080002 030.

05080002	Description	Data	Geo Mean	90th Percentile	Impaired
030 010	Twin Ck. @ E. Lock Rd.	*E. coli*	189	380	
		Fecal coliform	410	1000	
030 020	Millers Fk. @ Georgetown-Verona Rd.	*E. coli*	125	320	
		Fecal coliform	500	770	
030 030	Twin Ck. dst. Swamp Ck.	*E. coli*	364	2100	X
		Fecal coliform	696	4200	
	Twin Ck. dst. Lewisburg WWTP	*E. coli*	602	6500	
		Fecal coliform	1360	30000	
	Twin Ck. @ RM 33.60 dst. Iams	*E. coli*	451	13000	
		Fecal coliform	702	14000	
	Twin Ck. ust. Pyrmont Rd.	*E. coli*	185	440	
		Fecal coliform	260	700	
030 040	Swamp Ck. @ US 40	*E. coli*	416	1800	X
		Fecal coliform	863	3800	
030 050	Price Ck. @ Pence - Shewman Rd.	*E. coli*	912	23000	X
		Fecal coliform	502.1963	20000	
	Price Ck. ust. SR 503	*E. coli*	336	800	
		Fecal coliform	124	2500	
030 060	Twin Ck. adj. Stotler Rd.	*E. coli*	125	320	X
		Fecal coliform	203	520	
	Twin Ck. dst. W Alexandria WWTP (OMZ)	*E. coli*		560	
		Fecal coliform		1600	
	Lesley Run (Trib to Twin Ck. @ RM 24.60)	*E. coli*	527	1800	
		Fecal coliform	1082	5900	

Table 6. Recreation use impairment for WAU 05080002 040.

05080002	Description	Data	Geo Mean	90th Percentile	Impaired
040 010*	Bantas Fk. above Goose Ck.	*E. coli*	No sample taken in this HUC14		
		Fecal coliform			
040 020	Goose Ck. @ Scheyring Rd.	*E. coli*	214	2400	X
		Fecal coliform	484	7400	
040 030	Bantas Fk. btwn. Goose Cr. to Twin Cr.	*E. coli*	112	520	
		Fecal coliform	244	1000	
040 040	Twin Ck. ust. Halderman Rd.	*E. coli*	160	450	
		Fecal coliform	313	720	
040 050*	Aukerman Creek	*E. coli*	No sample taken in this HUC 14		
		Fecal coliform			
040 060	Twin Ck. @ Enterprise Rd.	*E. coli*	177	930	
		Fecal coliform	414	1800	
040 070	Toms Run adj. Anthony Rd.	*E. coli*	154	870	
		Fecal coliform	266	1000	
040 080	Twin Ck. @ Germantown	*E. coli*	80	860	
		Fecal coliform	167	1500	
040 090	Little Twin Ck. @ Little Twin Rd.	*E. coli*	187	350	
		Fecal coliform	362	830	

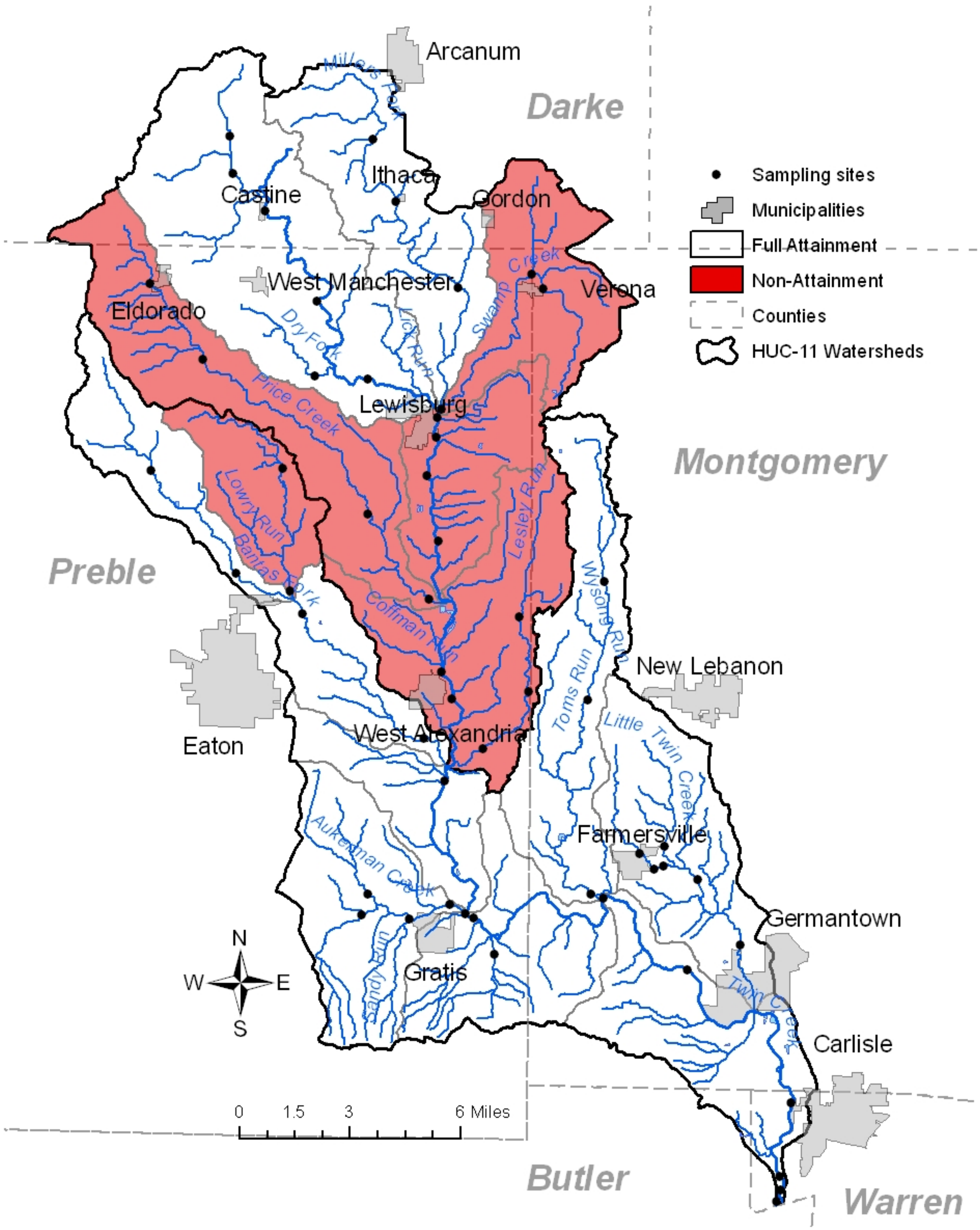

Figure 3. Map showing the 14-digit hydrologic units that did not support the recreation use.

3.3 Fish Tissue Use Designation

Throughout the state of Ohio there is a fish consumption advisory of no more than one meal per week of any sport fish due to mercury contamination.

3.3.1 Fish Tissue Use Attainment in Study Area

For the Twin Creek basin, there is an additional advisory of one meal per month for smallmouth bass ≥13 inches. This advisory is specific for Twin Creek from US 40 in Lewisburg to its confluence with the Great Miami River. This advisory covers Twin Creek through Montgomery, Preble, and Warren Counties. For additional information related to the Fish Consumption Advisory, please see the 2007 Ohio Sport Fish Consumption Advisory homepage at http://www.epa.ohio.gov/dsw/fishadvisory/waters/Twin.aspx.

3.4 Addressing Impaired Uses through TMDL Development

The Twin Creek TMDL is required because portions of the watershed fail to achieve their beneficial use designations for aquatic life. The primary causes of impairment are siltation, nutrient enrichment and habitat alteration. Agricultural land use in the watershed has resulted in habitat alterations and increases in sedimentation and nutrients. Channelization and loss of riparian vegetation were identified as the predominant sources of habitat impairment. Crops with subsurface drainage, overland runoff, and failing home sewage treatment systems were additional sources of sediment, nutrients and bacteria (Table 4). A short summary about the nature of each impairment cause follows.

Siltation/sedimentation describes the deposition of fine soil particles on the bottom of stream and river channels. Deposition typically follows high-flow events that erode and pick up soil particles from the land. Soil particles also transport other pollutants. As the flow decreases, the soil particles fall to the stream bottom. This reduces the diversity of stream habitat available to aquatic organisms.

Nutrient enrichment describes the excess contribution of materials such as nitrogen and phosphorus used by plants during photosynthesis. Excess nutrients are not toxic to aquatic life, but can have an indirect effect because algae flourish where excess nutrients exist. The algae die and their decay uses up the dissolved oxygen that other organisms need to live.

Habitat modification describes the straightening, widening, or deepening of a stream's natural channel. Habitat modification can also include the degradation or complete removal of vegetation from stream banks, which is essential to a healthy stream. These activities can effectively transform a stream from a functioning ecosystem to a simple drainage conveyance.

Many of these sources can be addressed through improvements in habitat as well as strategic use of agricultural best management practices. Because of the connections between habitat modification and nutrient entry into streams, necessary nutrient reductions were addressed through a habitat analysis. Sedimentation impairments were also addressed through the habitat analysis, which takes into account a measurement of embeddedness that provides guidance as to where sediment reductions are necessary.

Two important terms concerning sources of impairment are load and wasteload. When describing the pollutant contribution of a source, *load* is applied to sources that are not regulated by permit. Pollutant runoff from agricultural fields is an example of a load. *Wasteload* is applied to the pollutant contribution of sources regulated by permit. A municipal wastewater treatment plant is an example of a source that contributes to the total wasteload. Loads from all pollutant sources are assigned to either the load or wasteload categories; distinctions are discussed in the following sections.

A loading analysis was also completed to address bacteria impairments. The Lewisburg WWTP was identified as a source of total phosphorus and organic enrichment causing some aquatic life use impairment downstream of the WWTP. Therefore, a 4B alternative was completed (Appendix B).

Loading analyses are discussed in Chapter 5 and details are included in the appendices. Potential implementation actions to address these concerns are discussed in Chapter 6.

4.0 LINKAGE ANALYSIS AND NUMERIC TARGETS

The section evaluates the most likely connection between the observed water quality (Chapter 3) and the sources of concern (Chapter 2)—a step in the TMDL process that is often referred to as the *linkage analysis*.

4.1 General Mechanisms for Water Quality Impairment

The following paragraphs describe the various causes of impairment that were encountered during the Twin Creek study. While these perturbations are presented under separate headings, it is important to remember that they are often interrelated and cumulative in terms of the detrimental impact that can result.

Siltation and Sedimentation

Chemical quality of sediment is a concern because many pollutants bind strongly to soil particles and are persistent in the environment.

The physical and chemical nature of sediment is determined by local geology, land use, and contribution from manmade sources. As some materials enter the water column they are attracted to the surface electrical charges associated with suspended silt and clay particles. Others simply sink to the bottom due to their high specific gravity. Sediment layers form as suspended particles settle, accumulate, and combine with other organic and inorganic materials. Sediment is the most physically, chemically, and biologically reactive at the water interface because this is where it is affected by sunlight, current, wave action, and benthic organisms. Assessment of the chemical nature of this layer can be used to predict ecological impact.

Whenever the natural flow regime is altered to facilitate drainage, increased amounts of sediment are likely to enter streams either by overland transport or increased bank erosion. The removal of wooded riparian areas furthers the erosional process. Channelization keeps all but the highest flow events confined within the artificially high banks. As a result, areas that were formerly flood plains and facilitated the removal of sediment from the primary stream channel no longer serve this function. As water levels fall following a rain event, interstitial spaces between larger rocks fill with sand and silt and the diversity of available habitat to support fish and macroinvertebrates is reduced.

In the study area, soil erosion is the primary nonpoint source pollution. It causes sedimentation in streams. Siltation/sedimentation adversely affects ICI through clogging the spaces that would normally be used by macroinvertebrates. Siltation also reduces IBI score through following mechanism. It can clog the gills of both fish and macroinvertebrates, reduce visibility thereby excluding obligate sight-feeding fish species, and smother the nests of lithophilic fishes. Lithophilic spawning fish require clean substrates with interstitial voids in which to deposit eggs. Conversely, pioneering species benefit. They are generalists and best suited for exploiting disturbed and less heterogeneous habitats. The net result is a lower diversity of aquatic species compared with a typical warmwater stream with natural habitats.

Sediment also impacts water quality, recreation, and drinking water. Nutrients absorbed to soil particles remain trapped in the watercourse. Likewise, bacteria, pathogens, and pesticides which also attach to suspended or bedload sediments become concentrated in waterways where the channel is functionally isolated from the landscape.

Nutrient Enrichment

The element of greatest concern is phosphorus because it is critical for plant growth and is often the limiting nutrient. The form that can be readily used by plants and therefore can stimulate nuisance algae blooms is orthophosphate (PO_4^{3-}). The amount of phosphorus tied up in the nucleic acids of food and waste is actually quite low. This organic material is eventually converted to orthophosphate by bacteria.

Plant photosynthesis produces oxygen, but at night, respiration reverses the process and consumes oxygen. Conversely, oxygen concentrations can become supersaturated during the day, due to abnormally high amounts of photosynthesis, causing gas bubble stress to both fish and invertebrate communities. Oxygen is also used by bacteria that consume dead organic matter. Nutrient enrichment promotes the growth of nuisance algae that subsequently dies and serves as food for bacteria. Under these conditions, oxygen can be depleted unless it is replenished from the air.

Inputs of phosphorus originate from both point and nonpoint sources. Most of the phosphorus discharged by point sources is soluble. Another characteristic of point sources is they have a continuous impact and are human in origin, for instance, effluents from municipal sewage treatment plants. The contribution from failed on-site wastewater treatment systems can also be significant, especially if they are concentrated in a small area. The phosphorus concentration in raw waste water is generally 8-10 mg/l and after secondary treatment is generally 4-6 mg/l.

A characteristic of phosphorus discharged by nonpoint sources is that the impact is intermittent and is most often associated with storm water runoff. Most of this phosphorus is bound tightly to soil particles and enters streams from erosion, although some comes from tile drainage. Phosphorus load from rural storm water varies depending on land use and management practices and includes contributions from livestock feedlots and pastures and row crop agriculture. Crop fertilizer includes granular inorganic types and organic types such as manure or sewage sludge. Pasture land is especially a concern if the livestock have access to the stream. Large feedlots with manure storage lagoons create the potential for overflows and accidental spills. As discussed earlier, having riparian buffers not only reduces soil erosion, but also it can reduce the sediment and associated phosphorus load within runoff with entrapment. Erosion is worse on streams without any riparian buffer zone and streams that are channelized because they no longer have a functioning flood plain and cannot expel sediment during flooding.

Oxygen levels must also be considered, because phosphorus is released from sediment at higher rates under anoxic conditions; therefore as mentioned earlier, lack of tree and shade not only increase water temperature and photosynthesis but also decrease oxygen levels and create anoxic conditions.

Ammonia

Ammonia enters streams through different routes such as surface runoff, tiles, wastewater effluent, direct cattle access, etc. Ammonia gas (NH_3) readily dissolves in water to form the compound ammonium hydroxide (NH_4OH). In aquatic ecosystems an equilibrium is established as ammonia shifts from a gas to undissociated ammonium hydroxide to the dissociated ammonium ion ($NH4^{+1}$). Under normal conditions (neutral pH 7 and 25°C) almost none of the total ammonia is present as gas, only 0.55% is present as ammonium hydroxide, and the rest is ammonium ion. Ammonia criteria are established in the Ohio Water Quality Standards to protect aquatic life.

Ammonia in the free form (NH_3) is toxic to fish. Ammonia in the ionized form (NH_4^+) is innocuous. Ammonia tends to be driven to ionize at higher temperatures (> 20°C) and at higher pH levels (> 8.0). The water quality standard for ammonia accounts for the toxicity of (NH_3). The two variables of temperature and pH are used to establish the ammonia as nitrogen criteria (OAC 3745-1-07 Table 7-7).

Both free and ionized ammonia are rapidly oxidized to nitrite and nitrite by bacteria in the water column. The process of oxidation will deplete the water column of oxygen. In addition, ammonia is also a nutrient for algae and other forms of plant life, which can cause severe diurnal oxygen swings during overloading of natural systems. The *Associations* document (Ohio EPA, 1999) addresses this problem.

Nitrification is the natural biological process during which nitrifying bacteria convert toxic ammonia to less harmful as well as nitrates, most of the ammonia in the soil is converted to nitrites (NO_2^-) and then to nitrates by certain aerobic bacteria through the oxidative process of nitrification. Nitrifying bacteria are widespread in soil and water and are found in highest numbers where considerable amounts of ammonia are present. Once nitrogen has been assimilated by plants, it can be converted to organic forms, such as amino acids and proteins.

The concentration of ammonia in fertilizer and manure is high. Delivery of water, sediments, nutrients including ammonia, and organic matter to stream ecosystems is strongly influenced by the catchment of the stream and can be altered greatly by upland soil and vegetation disturbance. Improving habitat and riparian conditions not only reduces the nutrient loading but also results in greater stream assimilative capacity.

Ammonia in surface water is usually indicative of sanitary pollution. In Twin Creek, the major sources of ammonia are from animal manure or failed septic systems, contributing to nutrient-based impairment. Cattle and swine feedlot runoff contribute ammonia during rain events. Larger swine operations in the watershed land apply liquid manure during non-growing months and in the summer after wheat is harvested. Heavy rainfall after manure is land-applied can travel to surface water via the subsurface drains. Ammonia found during dry periods is an indication of failed septic systems.

Habitat and Flow Alterations

Habitat alterations impact biological communities both directly and indirectly. Indirect impacts include agricultural activities such as the removal of trees and shrubs adjacent to streams (described throughout this report as riparian vegetation/buffer) and field tiling to facilitate drainage. Tree shade is important because it limits the energy input from the sun, moderates water temperature, and limits evaporation. Lack of tree shade increases water temperature, and amount of oxygen soluble in the water column decreases as temperature increases. Removal of the tree canopy further degrades conditions because it eliminates an important source of coarse organic matter essential for a balanced ecosystem.

Riparian vegetation also aids in contaminant filtering through nutrient uptake, and helps bank stabilization through keeping soil in place. Riparian vegetation may decrease runoff rate into streams. In another words, due to the lack of a riparian buffer to slow runoff, trap sediment, and stabilize banks erosion impacts the stream more severely.

Urbanization has direct and indirect impacts on aquatic life. It includes removal of riparian trees, influx of storm water runoff, straightening and piping of stream channels, and riparian vegetation removal. Following a rain event, most of the water is quickly removed from tiled fields or urban settings rather than filtering through the soil, recharging ground water, and reaching the stream at a lower volume and more sustained rate. As a result, small streams more frequently go dry or become intermittent.

The two main sources of oxygen in water are diffusion from the atmosphere (reaeration) and plant photosynthesis. Turbulence at the water surface is critical because it increases surface area and promotes diffusion (or reaeration). The lack of water movement under low flow conditions has much more limited reaeration. As mentioned earlier, the amount of oxygen soluble in water decreases as temperature increases. Lack of oxygen due to reaeration and increased temperature exacerbates degradation from organic loading and nutrient enrichment.

Channelization is considered a habitat alteration that directly and negatively impacts biological communities by limiting the complexity of living spaces available to aquatic organisms. Consequently, fish and macroinvertebrate communities are not as diverse. Additionally, the confinement of flow within an artificially deep channel accelerates the movement of water downstream, exacerbating flooding of neighboring properties.

A natural stream has a functioning flood plain that allows fine grain sediment (which is usually very rich in TP) to settle down on flood plain during periods of high flow. This not only takes care of the bedload, it also help the vegetation and trees to grow up on the flood plain. Consequently, vegetation and tress helps to trap more sedimentation/siltation during runoff. This scenario changes if the stream is impounded by a dam or channelized.

Channelization also eliminates turbulence produced by riffles, meanders, and debris snags. In other words it reduces reaeration, which is a significant source of D.O. (as discussed earlier).

Organic Enrichment and Low Dissolved Oxygen

Dissolved oxygen criteria are established in the Ohio water quality standards to protect aquatic life. The minimum and average limits are tiered values and linked to use designations (Administrative Code 3745-1-07, Table 7-1). Water quality standards dissolved oxygen minimum and/or average criteria were exceeded numerous times in several of the tributaries and occasionally in the mainstem of Twin Creek. Low stream flows, habitat modification, riparian removal, and algal growth resulted in lower dissolved oxygen concentrations. Elevated nutrient levels stimulated algal growth in several locations which resulted in wide diel swings in the dissolved oxygen concentrations.

The amount of oxygen soluble in water decreases as temperature increases. This is one reason why tree shade is so important. The two main sources of oxygen in water are diffusion from the atmosphere and plant photosynthesis.

Turbulence at the water surface is critical because it increases surface area and promotes diffusion. Drainage practices such as channelization eliminate turbulence produced by riffles, meanders, and debris snags. Although plant photosynthesis produces oxygen by day, it is consumed by the reverse process of respiration at night. Oxygen is also consumed by bacteria that decay organic matter, so it can be easily depleted unless it is replenished from the air. Sources of organic matter include poorly treated waste water, livestock waste, sewage bypasses, and dead plants and algae.

4.2 TMDL Linkages

It is very difficult to adequately characterize impairment in the Twin Creek watershed by addressing each cause independently. All the listed causes of impairment are related and should be discussed within an integrated framework. This TMDL attempts to construct such a framework by utilizing multiple predictive and empirical tools to describe the problem and prescribe a solution.

The intent of an integrated TMDL framework is to approach the problem of impairment from two directions. Impairment can result when pollutant loads to a stream become excessive, the capacity of the stream to assimilate pollutants is diminished, or some combination of both. This TMDL establishes goals and recommends corrective actions intended to reverse these changes and restore balance by addressing both pollutant loading and assimilation.

This TMDL uses total phosphorus in-stream concentrations along with measures of habitat quality as indicators of relative stream health and function. Each parameter serves as a primary or secondary indicator of one or more of the listed causes of impairment.

Table 7 and the following sections describe the numeric targets used to develop TMDLs for each cause of impairment. Numeric targets represent a “goal” condition at which the designated uses of the waterbody should be restored.

Table 7. Aquatic life use causes of impairment and TMDLs developed to address them.

HUC 14	Description	RM	Causes	QHEI: habitat	QHEI: sediment	4B	Natural[1]	Not add-ressed	Bac-teria
05080002 030									
010	Maple Swamp Ditch	2.4	Sedimentation/siltation		X				
			Excess algal growth	X					
020	Millers Fork	10.8	Low flow (interstitial)				X		
			Sedimentation/siltation		X				
			Low DO	X					
			Ammonia	X					
		8.0	Shallow bedrock				X		
		3.9	Sedimentation/siltation		X				
			Low DO	X					
			Ammonia	X					
030	Twin Creek	34.9	Nutrient enrichment			X			
			Organic enrichment			X			
040	Swamp Creek	34.0	Low flow				X		
			Sedimentation/siltation		X				
			Phosphorus	X	X				
			Ammonia					X	
050	Price Creek	13.7	Low flow				X		
			Low DO	X					
			Ammonia	X					X
			Phosphorus	X					
060	Lesley Run	6.0	Low flow (interstitial)				X		
			Sedimentation/siltation		X				
			Low DO	X					
		1.2	Low flow (interstitial)				X		
05080002 040[2]									
010	Bantas Fork	13.7	Low flow				X		
020	Goose Run	4.4	Low flow				X		
			Phosphorus					X	
			Ammonia					X	
			COD					X	
			Low DO					X	
030	Bantas Fork	1.3	Low flow				X		
070	Tom's Run	12.0	Low flow (interstitial)				X		
			Sedimentation/siltation		X				
			Low DO	X					
		8.5	Low flow (interstitial)				X		
090	Little Twin Creek	6.2	Low flow				X		

1 Impairments from natural causes do not need TMDLs.
2 HUCs 05080002 040 050, 060 and 080 do not have any impairment present; they are not included in this table.

4.3 Selection of Water Quality Target Values

TMDL development entails identifying the minimum threshold conditions under which the water quality standards can be met. These conditions, or targets, are often presented as a pollutant concentration. For Twin Creek TMDL concentration based targets are established for total phosphorus and fecal coliform bacteria. Conditions not associated with a specific pollutant concentration can also have targets provided that those conditions are measureable through a suitable means. Both habitat quality and sediment loading have targets that are not based on concentrations but rather on scores from a qualitative index.

The targets used for fecal coliform bacteria come directly from the water quality standards. In contrast, aquatic life use (ALU) requires that surrogate targets not included in the water quality standards be used. The attainment status of ALU is based on measures of the aquatic community captured in three biological indices. These indices do not reflect any specific water quality stressors in need of abatement and do not lend themselves for TMDL development. However, the stressors causing ALU impairment are identified during the water quality assessment and placed on the 303(d) list (see Section 3.1.1).

To make the connection between the water quality standards and the water quality stressors responsible for preventing ALU attainment, the Ohio EPA analyzed a large database to establish suitable targets. The *Association between Nutrients, Habitat, and the Aquatic Biota of Ohio's Rivers and Streams* (Ohio EPA, 1999) documents the results of statistical analyses comparing the biological indices used in the water quality standards and several water quality variables such as nutrients and habitat index scores. All of the targets used to address the TMDLs for ALU, total phosphorus, habitat and sediment, are based on the findings documented in the *Association between Nutrients, Habitat, and the Aquatic Biota of Ohio's Rivers and Streams* (Ohio EPA, 1999).

4.3.1 Nutrient Targets: Total Phosphorus

For the purpose of this TMDL, total phosphorus is used as an indicator for the degree of nutrient enrichment because it is frequently the limiting nutrient to primary production in streams and rivers of Ohio. While the Ohio EPA does not currently have statewide numeric criteria for nutrients, potential targets have been identified in a technical report titled *Association Between Nutrients, Habitat, and the Aquatic Biota in Ohio Rivers and Streams* (Ohio EPA, 1999). This document provides the results of a study analyzing the effects of nutrients and other parameters on aquatic biological communities in Ohio streams and rivers. TP target concentrations are identified based on observed concentrations associated with acceptable ranges of biological community performance within each ecoregion. It is important to note that these targets are not codified in Ohio's WQS, so there is some flexibility as to how they can be used in a TMDL.

The total phosphorus targets used in this report are shown in Table 8.

Table 8. EWH total phosphorus targets for the Eastern Corn Belt Plains (ECBP) ecoregion.

Watershed Size	TP (mg/l)
Headwaters (drainage area < 20 mi^2	0.05
Wadeable (20 mi^2 <drainage area< 200 mi^2	0.08

4.3.2 Fecal Coliform

The water quality standards for fecal coliform bacteria are meant to protect recreational water uses by limiting the risk for human illness caused by exposure to pathogenic microorganisms. Pathogenic organisms include bacteria, viruses, and protozoan. Humans can be exposed to water-borne pathogens through skin contact or accidental ingestion, which can lead to skin irritation, gastroenteritis, or other more serious illnesses.

Since a large number of pathogens enter waterbodies in association with human or animal wastes, fecal coliform are appropriate surrogates for pathogenic organisms.

The criterion for fecal coliform specified in OAC 3745-1-07 are applicable outside the mixing zone and vary for waters determined primary contact recreation (PCR) and secondary contact recreation (SCR). For PCR the standard states the geometric mean content, based on not less than five samples within a thirty-day period, shall not exceed 1000 counts per 100 ml and shall not exceed 2000 counts per 100 ml in more than 10 percent of the samples taken during any thirty-day period. The SCR standard varies in that it requires fecal coliform not to exceed the geometric mean value of 5000 per 100 ml in more than ten percent of the samples taken during any thirty-day period. There is no geometric mean component of the standard for SCR designated waters. All of the stream segments in the Twin Creek watershed are designated as PCR.

4.3.3 Habitat Alteration and Sedimentation

Habitat TMDL Targets and the Qualitative Habitat Evaluation Index (QHEI)

Poor habitat quality is an environmental condition, rather than a pollutant load, so development of a load-based TMDL for habitat is not possible. Nonetheless, habitat is an integral part of stream ecosystems and has a significant impact on aquatic community assemblage and consequently on the potential for a stream to meet the biocriteria within Ohio's water quality standards (see Section 3.1). In addition, U.S. EPA acknowledges that pollutants, conditions or other environmental stressors can be subject to the development of a TMDL to abate those stressors in order to meet water quality standards. Thus, sufficient justification for developing habitat TMDLs is established.

The QHEI evaluates six general aspects of physical habitat that include channel substrate, in-stream cover, riparian characteristics, channel condition, pool/riffle quality, and gradient. Within each of these categories or sub-metrics, points are assigned based on the ecological utility of specific stream features as well as their relative abundance in the system. These points are summed within each of the six sub-metrics to give a score for that particular aspect of stream habitat. The overall QHEI score is the sum of all of the sub-metric scores. Through statistical analyses of data for the QHEI and the biological indices, target values have been established for QHEI scores with respect to the various aquatic life use designations (Ohio EPA, 1999). For the aquatic life use designation of warm water habitat (WWH) an overall QHEI score of 60 is targeted to provide reasonable certainty that habitat is not deficient to the point of precluding attainment of the biocriteria. An overall score of 75 is targeted for streams designated as exceptional warm water habitat (EWH) and a minimum score of 45 is targeted for modified warm water habitat (MWH) streams. However, when analyzed on a watershed scale, it has been determined that basin specific goals of QHEI and its subcategories are essential for proper TMDL development.

If analyzed on a basin-wide basis, the empirical nature of the QHEI and the data that underlie it provide measurable targets that parallel concepts to a loading capacity for a pollutant. Data analysis of the QHEI components for each watershed provides a mechanism to evaluate whether habitat is a limiting factor for the fish and macroinvertebrate community as well as which factors are the likely stressors. The QHEI can also allow assessment of both the source of the sediment (riparian corridor, bank stability) and the effects on the stream itself (i.e., the historic sediment deposition).

Sediment TMDL Targets and the Qualitative Habitat Evaluation Index (QHEI)

The QHEI is also used in developing the sediment TMDL for this project. Numeric targets for sediment are based upon sub-metrics of the QHEI. Although the QHEI evaluates the overall quality of stream habitat, some of its component sub-metrics consider particular aspects of stream habitat that are closely related to and/or impacted by the sediment delivery and transport processes occurring in the system. The QHEI sub-metrics used in the sediment TMDL are the substrate, channel morphology, and bank erosion and riparian zone. Table 9 lists targets for each of these metrics.

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

Statistical analysis of the QHEI and QHEI subcategories have led to TMDL target development for habitat and bedload characteristics for the Twin Creek basin. Table 9 indicates the final TMDL values for each of these components. Given this information, each of the biological sampling sites within the watershed can be assessed for habitat and bedload.

Table 9. TMDL targets for habitat and sedimentation/siltation submetrics of the QHEI for Twin Creek watershed streams.
Note: shaded values indicate sub-metrics used for the sedimentation/siltation (bedload) TMDL.

	WWH	EWH
QHEI	49	71.8
Substrate	12.7	15.8
Channelization	10.8	12.7
Riparian	4.4	5.8
Cover	8.8	11.7
Pool	3.8	8.0
Riffle	0.0	4.5
Gradient	7.8	8.0

4.4 Deviation from Targets

Specific locations where nutrients were identified as causes of aquatic life use impairment are listed in Table 4. Targets were exceeded for total phosphorus, ammonia and nitrate.

Habitat targets were not met in several areas of the watershed. In both watershed assessment units, the QHEI subcategories of riffle, pool, gradient and cover had the four greatest deficiencies.

Bacteria exceeded criteria in multiple locations in both watershed assessment units. The most common source for bacteria appeared to be failing home sewage treatment systems, unsewered areas, and impacts from solids from the Lewisburg WWTP.

It should be noted that because of a lack of data, Goose Run impairments will not be addressed in this report.

4.4.1 Sedimentation/siltation

The QHEI sub-metric used in developing sedimentation/Siltation TMDL are substrate, channel morphology and riparian zone. The substrate sub-metric evaluates the most dominant substrate materials and the functionality of coarser substrate in light of silt cover and degree of embeddedness. There are seven sites that have siltation/sedimentation as one of the causes of impairment. Four of these sites also list low DO and low flow as other causes of impairment.

In general Impaired sites within upper portions of Twin Creek such as Miller's Fork, Swamp Creek and Maple Swamp Ditch have more significant deviations from the sedimentation target on the substrate metric. Tom's Run is the only site in the lower WAU listed with a cause of sedimentation/siltation. It has low scores on substrate and channelization.

4.4.2 Nutrients

Miller's Fork (RM 10.8 and 3.9) and Price Creek (RM 13.7) are the headwater sites impaired by ammonia. Most headwater sites in Upper Twin Creek watershed exhibited impairment from hydromodification and destruction of riparian vegetation. Habitat improvement, especially riparian improvement, and also removing septic systems in the Price Creek headwaters (see Table 12) can reduce ammonia loading into stream and consequently eliminate ammonia as one of the causes of impairment(see Section 4.3.1).

The source of ammonia and mechanism of entering stream is not clear for Swamp Creek (RM 34.0); therefore, ammonia at this site cannot be addressed in this TMDL.

In Swamp Creek (RM 34.0) and Price Creek (RM 13.7), phosphorus has been identified as the cause of impairment. Habitat improvement at these sites will address the nutrient issues (see Section 4.3.3). Improving habitat and riparian conditions not only reduces the nutrient loading, but also results in greater stream assimilative capacity. Failing home sewage treatment systems are another source of phosphorus in Price Creek so, as mentioned in Table 12, repairing or removing failing septic systems in Price Creek can reduce phosphorus loading.

Phosphorus is one cause of partial attainment in Twin Creek (RM 34.9). Lewisburg WWTP is considered the main source of phosphorus. This impairment will be addressed via a 4B alternative (Appendix B).

4.4.3 Habitat

There are seven sites impaired by low DO, nutrients (ammonia and/or total phosphorus), and excessive algal growth. Six out of these seven sites have sedimentation/siltation problems. It is believed that addressing the sedimentation/siltation submetrics will eliminate other causes of impairment.

All sites impaired with low DO, nutrients and sedimentation/ siltation have a high deficiency in the riffle metric (Ohio EPA 2007). There are a few sites that have a better riffle score: Little Twin Creek and Bantas Creek, which are impaired by low flow (natural sources), and the Twin Creek mainstem, which is impaired by a point source. Price Creek is the only site with no sedimentation/siltation impairment, which needs habitat improvements to address low DO and nutrient issues. Habitat improvements in this area should focus on components other than sediment (riparian, pool and riffle components).

4.4.4 Low Dissolved Oxygen (DO)

There are four headwater sites with low DO listed as a one of the causes of impairment. All these sites have low flow listed as another cause. As discussed earlier, low stream flows, habitat alteration, riparian removal, and algal growth result in low DO concentrations in four headwater sites. These sites have a low habitat score on riffle. All of these sites are missing diffusion, which is the main source of DO in water (see Section 4.1). In addition, low flow conditions and a lack of tree shade are significant sources of low DO problems.

5.0 TMDLs and Allocations

In 2005, the Ohio EPA staff surveyed the Twin Creek watershed for aquatic life use attainment and recreation use attainment status. Causes of impairment and pollution sources are determined for stream segments that do not meet use attainment. Priority causes of impairment are those believed to be the greatest detriment to the basin. The priority cause of aquatic life use impairment throughout the watershed is habitat, and the priority cause of recreation use impairment is pathogens.

High-magnitude causes of impairment are addressed in Chapters 3 and 4. Impairment causes are also included in this chapter, organized by sites for analysis of habitat and 14-digit hydrologic unit for analysis of pathogens. There are some secondary causes of aquatic life use impairment, mainly on headwater sites, such as low dissolved oxygen and nutrients, which have an overlap with habitat or bacteria impairments. Overlap between the causes and sources of impairment provides additional justification for targeting a subset of high-magnitude causes. A single source may be contributing to multiple causes of impairment, so control strategies aimed at that source could help to remedy multiple problems.

5.1 Analysis Methods

5.1.1 Recreational Beneficial Use Designations (Pathogens)

During the recreation season of 2005, various locations throughout the Twin Creek watershed were sampled multiple times for recreation attainment. The locations of bacteriological sampling within Twin Creek watershed are shown in Appendix C. Results of these samples were analyzed within 14-digit hydrologic units. As a part of the analysis, geometric means and maxima (used as a not-to-exceed value for 10 percent of samples) were calculated for fecal coliform and *E. coli*. The analysis was utilized to evaluate Twin Creek's water quality in light of Ohio's recreation use standards as provided in OAC 3745-1-07(B)(4). The subwatersheds that exceeded the primary contact recreation use standards were chosen for TMDL development; these included 05080002 030 030, 030 040, 030 050, 030 060, and 040 020. TMDL development was conducted to reflect the mean standards for primary contact recreation throughout the season.

5.1.2 Habitat

Habitat alteration is a cause of impairment throughout the Twin Creek watershed. Physical habitat quality is an environmental condition, rather than a contributed load, so development of a traditional, load-based TMDL is impractical. In place of this, Qualitative Habitat Evaluation Index (QHEI) scores are used as a surrogate target. The QHEI is a quantitative composite of six physical habitat variables used to evaluate stream habitat. The variables are: substrate, in-stream cover, riparian characteristics, channel condition, pool/riffle quality, and gradient.

5.1.3 Sedimentation/siltation

Sedimentation/siltation is a major cause of impairment throughout the watershed. Although sedimentation is a contributed load, it is addressed through the following QHEI submetrics: channelization, riparian and substrate (Table 9).

5.1.4 Low dissolved oxygen and nutrients

There are several partial attainment headwater sites with small drainage areas. These sites, in addition to habitat and/or bacteria, have a few different secondary causes of impairments such as dissolved oxygen (DO) and nutrients. All these sites have poor habitat and "natural" listed as sources of impairment (Ohio EPA, 2007). Miller Fork and Swamp Creek have the lowest substrate scores within the whole watershed. Maple Swamp Ditch, with the recommended MWH use designation, is impaired by excessive algal growth. This headwater site has the lowest habitat score in the watershed; however, downstream it is in full attainment. The low DO in the small drainage area of Tom's Run headwaters is associated with poor habitat components and some low flow from natural causes.

For all these partial attainment headwater sites, secondary causes of impairment such as DO and nutrients have an overlap with habitat or bacteria impairment. Overlap between the causes and sources of impairment provides additional justification for targeting a subset of high-magnitude causes. A single source may be contributing to multiple causes of impairment, so control strategies aimed at that source could help to remedy multiple problems.

Ohio EPA has relied extensively on ambient biological assessments since the late 1970s. These assessments combine collection of chemistry (including temperature, pH, dissolved oxygen), biological (fish and macroinvertebrates), and habitat data at hundreds of sites throughout the state each year. These data, as well as research from others, indicate that the health of aquatic life organisms at a particular site depends on the integrated result of chemical, physical, and biological processes occurring in the aquatic environment and adjacent lands (Rankin and Yoder, 1995; Karr et al., 1986; Frey, 1977). Multiple stressors need to be examined, rather than relying on a single factor (e.g., chemical criterion) as a surrogate.

According to data collected and analyzed by Ohio EPA, the lowest TP concentrations tend to be associated with the highest quality stream habitats (sites with QHEI scores >60-70). The correlation of low TP with high quality stream habitat is thought to be the result of TP being sequestered by the diverse aquatic communities that are usually found at sites that have high quality habitat. High quality habitat also results in lower downstream sediment delivery due to the expulsion and filtering effects of better channel morphology and intact riparian buffers, respectively (Ohio EPA, 1999). The reduction in sediment load being transported downstream leads to a concomitant reduction in the fraction of TP that tends to be attached to sediment particles. More recent research reviews indicate that the river channel (especially in headwater streams) has a considerable capacity to retain or process phosphorus within the channel, thereby regulating the downstream delivery of phosphorus without stressing the aquatic communities present (Withers and Jarvie, 2008). Studies have shown that forest buffers prevent nonpoint source pollutants from entering small streams and enhance the in-stream processing of both nonpoint and point source pollutants, thereby reducing their impact on downstream water quality (Sweeney et al., 2004).

In conclusion, habitat condition (both in-stream and riparian) must be taken into account as one of the factors that affects nutrient concentrations in a stream. The results of some of the studies suggest that habitat improvements could increase a stream's capacity to assimilate nutrients.

Habitat alterations, such as channel modification and the denuding of riparian zones, can also have detrimental effects upon in-stream DO concentrations. Denuding riparian zones eliminates or reduces the stream's shade, and the increased intensity of sunlight reaching the stream helps stimulate algal production and increases the water temperature, which lowers oxygen solubility. Also, channelized streams affect DO concentrations by limiting the potential for atmospheric reaeration. Atmospheric reaeration occurs more readily in faster-moving, highly agitated stream segments. Streams with high-quality pool/riffle complexes are more agitated than channelized streams lacking such natural characteristics. Water flowing through a quality riffle consisting of variable substrate effectively stirs oxygen into the stream.

Channelization is the removal of trees from stream banks coupled with deepening and often straightening the stream channel. Channelization and riparian removal are direct causes of sedimentation. These practices can not only impair habitat and cause siltation problems, but they also can cause nutrient enrichment. Because phosphorus is delivered to streams mostly through attachment to fine particles (sediment/silt), any habitat modification to reduce sedimentation will reduce nutrient enrichment too.

5.1.4.1 Twin Creek Mainstem

The only aquatic life use impairment on the mainstem of Twin Creek was downstream of the Lewisburg WWTP. Data showed elevated levels of total phosphorus based on impaired macroinvertebrates. The suggested target value for wadeable streams (drainage area between 20 mi^2 and 200 mi^2) that are exceptional warmwater habitat and in the eastern cornbelt plains ecoregion is 0.08 mg/l (Ohio EPA, 1999). Appendix B contains a 4B alternative to address this impairment.

5.1.4.2 Goose Run

Analysis of the 2005 data revealed impairment in the Goose Run subwatershed (HUC 05080002 040 020) to both aquatic life and recreation uses. A bacteria TMDL was completed for this 14-digit hydrologic unit (see Section 5.2.2). However, habitat was not identified as a cause of impairment, so this subwatershed was not included in the QHEI analysis (see Section 6.3). Causes of biological impairment include low flow (natural source) and phosphorus, chemical oxygen demand (COD), ammonia and low DO from small upstream wastewater treatment systems (package plants[2]).

When Ohio EPA staff returned in 2006 to collect additional data to support a loading analysis, however, the stream was interstitial and no further data could be collected. Therefore, a loading analysis to address the nutrients, COD and DO from the package plants could not be completed. This hydrologic unit will remain as a Category 5 impaired water until further data are collected and a TMDL can be completed. Ohio EPA will include monitoring requirements in the permits for the point sources (see Chapter 6).

5.2 Pathogen TMDL

This section outlines the bacteria TMDL to address the impairment to recreation use.

[2] Package plants are treatment units assembled in a factory and transported to the site. The typical package plant is a smaller version of the extended aeration principle for wastewater treatment that includes an aeration tank and a settling tank.

5.2.1 Method of Pathogen TMDL Development

In the Twin Creek watershed, pathogen TMDLs have been developed for impaired 14-digit HUCs. The U.S. EPA Bacteria Indicator Tool (BIT) build-up model and washoff model were utilized to calculate gross fecal coliform load discharges to the hydrologic units (U.S. EPA, 2000).

The Preble County Health Department has provided data of the distribution of HSTS. The number of HSTS in each 14-digit hydrologic unit is estimated based upon 2000 census demographic information for Preble County. The percentage of failing HSTS is based on information from health departments, field observations and GIS analysis of the age of houses in each watershed. HSTS pollutant loads are estimated as the product of the number of persons served by failing systems in each subwatershed and a per capita wastewater flow rate (Metcalf and Eddy, Inc. 2003).

Bacteria loadings are difficult to accurately quantify because there are rarely adequate data to characterize individual sources. In addition, many factors affect bacteria that are difficult to model. Examples include meteorological conditions, sorption characteristic of pathogens, die-off rates, and waste placement method as well as location to stream network. In such situations, BIT provides a means to make estimations of bacteria loads based upon empirical studies in other watersheds. While the use of such literature and default values results in considerable uncertainty, it is the best option available considering time and resource limitations.

The required loading reductions for the Twin Creek TMDL were estimated by comparing the in-stream 2005 summer pathogen counts to the desired standard (see Section 5.2.2). For example, if the observed average fecal coliform concentration is 4000 cfu per 100 ml and the geometric mean target for fecal coliform is 1000 cfu per 100 ml, loadings must be reduced by 75%. Table 10 summarizes the development of the pathogen TMDLs.

Table 10. Summary of pathogen TMDL development.

Development step	Source	Explanation
Existing load	Surface runoff	BIT tool with spreadsheet runoff model.
	Point source	All point source discharges within the impaired 14-digit hydrologic units were allocated an effluent fecal coliform concentration of 1000 cfu/100ml at their design flow.
	HSTS	Population served by failing HSTS estimated via GIS and county health departments. Fecal coliform load based upon population census and growth/decline estimates and BIT model per capita loading rate.
Reduction factor	In-stream data	The maximum percent of bacteria reduction required to reduce the 2005 summer sampling results to the water quality standard.
Calculation of loading capacity TMDL	-	Product of reduction factor and existing load.
Allocation	Surface runoff	Total allowable load allocation is equal to the sum of all WLAs subtracted from the assimilative capacity (secondary reduction applies to livestock if needed).

Development step	Source	Explanation
	Point sources	All point source discharges within the impaired 14-digit hydrologic units were allocated an effluent fecal coliform concentration of 1000 cfu/100ml at their design flow.
	HSTS	Septic systems are allocated to zero.

5.2.2 Results of Pathogen TMDL

Table 12 shows the maximum and geometric mean for fecal coliform and *E. coli* for all 14-digit hydrologic units within the Twin Creek watershed that are impaired for recreation use. As can be seen, the necessary loading reductions for the Twin Creek TMDL were estimated by comparing the in-stream 2005 summer concentrations to the desired standard (geometric mean and 90^{th} percentile). For all primary recreation use streams the geometric mean target for fecal coliform is 1000 cfu per 100 ml and for *E. coli* is 126 cfu per 100 ml. The 10% of samples maximum target for fecal coliform is 2000 cfu per 100 ml and for *E. coli* is 298 cfu per 100 ml.

The BIT model deals with just fecal coliform. In order to achieve recreation use attainment, and to be conservative, Ohio EPA applied the highest reduction factor to calculate TMDL. As can be seen in Table 12, higher reduction factors are associated with *E. coli*.

Table 13 shows allocated loads for the fecal coliform TMDL. The table is organized by 14-digit hydrologic unit. More detailed tables showing existing and reduced loads are located in Appendix C. In addition, Table 14 shows wasteload allocations for permitted dischargers located in 14-digit hydrologic units that are impaired by fecal coliform bacteria.

The predominant pathogen load is coming from failing home sewage treatment systems (HSTS). In fact, if the HSTS bacteria load is significantly reduced, as shown in Table 11, for three out of five impaired subwatersheds—030 040 (Swamp Creek), 030 060 (Twin Creek below Price Creek to above Bantas Fork), and 040 020 (Goose Creek)—the pathogen target will be achieved. Those three watersheds would no longer require additional fecal coliform reduction. For subwatersheds 030 030 (Twin creek below Millers Fork to above Price Creek except Swamp Creek) and 030 050 (Price Creek), complete removal of HSTS loads should accompany 50% livestock pathogen load reduction in HUC 030 030 and 41% livestock pathogen reduction in HUC 030 050.

<u>Allocations</u>

Existing fecal coliform loads are allocated for each impaired watershed to meet the seasonal TMDL. The TMDL applies only during the recreation season (May 1 through October 15). All point source dischargers within the impaired subwatersheds are given a fecal coliform effluent bacteria limit of 1000 cfu/100 ml at their design flow (see Table 13). HSTS are predominant sources from which no wasteload is expected; therefore, first they are reduced to zero discharge. Fecal coliform from livestock in streams are also allocated as needed. Loads modeled as coming from unmanaged lands do not need any reduction unless the bacteria WQS hasn't been met after the elimination of all livestock and HSTS bacteria loads.

Table 11. Reduction factors for bacteria in the Twin Creek watershed.

HUC 14 (05080002)	Basin Description	Type of Data	2005 Results		Criteria		Reduction		Highest Reduction
			Geometric Mean	Max	Geometric Mean	Max	Geometric Mean	Max	
030 030	Twin Cr. below Millers Fk. to above Price Cr. [except Swamp Cr.]	*E. coli*	367	2540	126	298	66.00%	88.00%	88%
		Fecal coliform	657	5180	1000	2000	-52.00%	61.00%	
030 040	Swamp Cr.	*E. coli*	416	1800	126	298	70.00%	83.00%	83%
		Fecal coliform	863	3800	1000	2000	-16.00%	47.00%	
030 050	Price Cr.	*E. coli*	249	3020	126	298	49.00%	90.00%	90%
		Fecal coliform	554	4250	1000	2000	-81.00%	53.00%	
030 060	Twin Cr. below Price Cr. to above Bantas Fk.	*E. coli*	281	977	126	298	55.00%	69.00%	69%
		Fecal coliform	525	3210	1000	2000	-90.00%	38.00%	
040 020	Goose Cr.	*E. coli*	214	2400	126	298	41.00%	88.00%	88%
		Fecal coliform	484	7400	1000	2000	-107.00%	73.00%	

Table 12. Allocations for bacteria sources (units: number of colonies per day).

HUC 14 (05080002)	Narrative	Total NPS	PS* (WWTP)	Septics Reduction (%)	Livestock Reduction (%)	Septics	Livestock	TMDL
030 030	Twin Cr. below Millers Fk. to above Price Cr. (except Swamp Cr.)	1.46E+12	1.49E+10	100	50	0	1.01E+13	1.16E+13
030 040	Swamp Cr.	1.78E+12	3.22E+09	97.5 **	0	3.70E+12	2.4E+13	2.94E+13
030 050	Price Cr @ Pence-Sherman Rd	2.91E+12	3.79E+09	100	41	0	2.32E+13	2.61E+13
030 060	Twin Cr. below Price Cr. to above Bantas Fk.	3.11E+12	1.15E+10	87.9	0	1.68E+13	3.49E+13	5.49E+13
040 020	Goose Cr.	1.36E+12	1.51E+09	92.9	0	2.13E+13	1.52E+13	3.80E+13

* For a list of wasteload allocations for individual facilities, see Table 13.
** The Verona WWTP has accounted for a 48.2% reduction; therefore, an additional reduction of 49.3% (97.5-48.2) is needed. See Appendix D for details.

Table 13. Wasteload allocations for permitted dischargers in impaired 14-digit watersheds.

Facility	Permit #	Design flow (MGD)	Geometric mean standard (cfu/100 ml)	Wasteload Allocation (cfu/100 ml/day)
05080002 030 030				
Lewisburg WWTP	1PB00019	0.261	1000	9.88E+09
Preble Co. SD#2 WWTP	1PG00092	0.051	1000	1.93E+09
P & G Pet Care	1IH00012	0.075	1000	2.84E+09
N. American Nutrition	1IN00184	0.006	1000	2.27E+08
			Total	**1.49E+10**
05080002 030 040				
Verona WWTP	1PA00027	0.085	1000	3.22E+09
			Total	**3.22E+09**
05080002 030 050				
El Dorado WWTP	1PA00014	0.1	1000	3.79E+09
			Total	**3.79E+09**
05080002 030 060				
West Alexandria WWTP	1PB00035	0.3	1000	1.14E+10
Creekside MHP	1PV00125	0.0045	1000	1.70E+08
			Total	**1.15E+10**
05080002 040 020				
Dayton travel Center	1IN00212	0.02	1000	7.57E+08
Pilot Travel Center	1PZ00020	0.02	1000	7.57E+08
			Total	**1.51E+09**

5.3 Habitat Analysis

The QHEI is a quantitative expression of habitat quality, determined by visual assessment. This scoring method was developed by the Ohio EPA to assess available habitat for fish communities in free flowing streams (Rankin 1989, 1995, 2006). The QHEI is a composite score of six physical habitat categories: 1) substrate, 2) in-stream cover, 3) channel morphology, 4) riparian zone and bank erosion, 5) pool/glide and riffle/run quality, and 6) gradient. Each of these categories is subdivided into specific attributes that are assigned a point value respective of the attribute's impact on the aquatic life. Highest scores are assigned to the attributes correlated to streams with high biological diversity and lower scores are progressively assigned to less desirable habitat features.

A QHEI evaluation form is used by a trained evaluator while in the stream itself. Each of the components is evaluated on-site, recorded on the form, the score totaled, and the data later analyzed in an electronic database. The evaluation form is available online at http://www.epa.ohio.gov/portals/35/documents/QHEIFieldSheet061606.pdf.

The QHEI is a macro-scale approach that measures the emergent properties of habitat (sinuosity, pool/riffle development) rather than the individual factors that shape these properties (current velocity, depth, substrate size). The QHEI is used to evaluate the characteristics of a short stream segment, as opposed to the characteristics of a single sampling site. As such, individual sites may have poorer physical habitat because of a localized disturbance yet still support aquatic communities closely resembling those sampled at adjacent sites with better habitat, provided water quality conditions are similar. However, QHEI evaluations are segment specific and do not give a strong indication of the quality of the habitat in other stream segments.

The maximum possible QHEI score is 100. Statewide QHEI target scores were determined by statistical analysis of Ohio's statewide database of paired QHEI and IBI scores. Simple linear and exponential regressions and frequency analyses of combined and individual components of QHEI metrics in relation to the IBI were examined. The regressions indicated that the QHEI is significantly correlated with the IBI. QHEI scores greater than 75 indicate excellent stream habitat, scores between 60 and 75 indicate good habitat quality, and scores less than 45 demonstrate habitat not conducive to WWH. Scores between 45 and 60 need separate evaluation by trained field staff to determine the potential aquatic life use for the stream.

Two use designations are found within the Twin Creek basin. The Twin Creek basin contains 27 exceptional warmwater habitat (EWH) sites and 18 warmwater habitat (WWH) sites. Also, there is a modified warmwater habitat (MWH) site upstream of Maple Swamp Ditch that is a partially impaired site with the lowest habitat score within the watershed. There is no QHEI target for MWH.

The data analysis was completed on both WWH and EWH streams. The minimum statewide QHEI target is 60 for WWH sites and 70 for EWH (Ohio EPA, 1999). However, in some cases it is possible to calculate basin-specific goals for QHEI and its subcategories.

If analyzed on a basin-wide basis, the empirical nature of the QHEI and the data that underlie it provide measurable targets that parallel concepts to a loading capacity for a pollutant. Data analysis of the QHEI components for each watershed provides a mechanism to evaluate whether habitat is a limiting factor for the fish and macroinvertebrate community as well as which factors are the likely stressors. The QHEI can also allow assessment of both the source of the sediment (riparian corridor, bank stability) and the effects on the stream itself (i.e., the historic sediment deposition).

When separated into biological attainment groups, the numeric measurability of the index components provides a means to establish goals and monitor progress toward these goals when implementing a TMDL and to validate when a target has been reached. Current attainment levels of the Twin Creek basin, along with QHEI scores and causes and sources of impairment, are presented in *Biological and Water Quality Study of Twin Creek and Select Tributaries 2005* (Ohio EPA, 2007).

5.3.1 Results of Habitat Analysis

Statistical analysis of the WWH and EWH QHEI subcategory scores has led to TMDL targets development for habitat and sediment characteristics for WWH and EWH partially-impaired sites in the Twin Creek basin. Tables 14 and 15 indicate the final TMDL values for each of these components. Given this information, each of the biological sampling sites within the watershed can be compared for habitat and sediment attainment.

Tables 14 and 15 summarize the target chosen for the QHEI overall score and each subcategory score. Subcategories that apply to the sediment TMDL are shaded. With these watershed-specific targets, site-specific goals for the partial attainment sites can be created to meet the TMDL.

Table 14. TMDL targets for QHEI scores and subcategory scores for warmwater habitat streams in the Twin Creek watershed.

Category Score	TMDL
QHEI	49
Substrate	12.7
Cover	8.8
Channel	10.8
Riparian	4.4
Pool	3.8
Riffle	0.0
Gradient	7.8

Table 15. TMDL targets for QHEI scores and subcategory scores for exceptional warmwater habitat streams in the Twin Creek Basin.

Category Score	TMDL
QHEI	71.8
Substrate	15.8
Cover	11.7
Channel	12.7
Riparian	5.8
Pool	8.0
Riffle	4.5
Gradient	8.0

The results of comparing QHEI subcategory scores to targets are summarized in Tables 16 and 18. Tables 17 and 19 show the subcategories related to the sediment TMDLs. The sites are organized by HUC14 and aquatic life use designation. The allocations are category specific; therefore, the values are listed at the top of each column. The TMDL values developed are valid for warmwater habitat and exceptional warmwater habitat streams. Partially attaining sites as based on biological criteria are presented in bold. The percent deviation of the actual QHEI and QHEI subcategory scores from the allowable TMDL is provided in the Tables 16 and 18. Tables 16 and 18 clearly indicate which components of the habitat need improvement and to what degree for each stream. These tables provide both overall habitat TMDLs. Tables 17 and 19 are organized similarly and present sediment TMDLs. Both sets of tables can be used to guide management decisions and implementation activities. Further details are included in Appendix E.

Table 16. Habitat TMDLs for WWH sites in the Twin Creek watershed.

14-digit HUC	Stream/River Name	River Mile	Attainment	QHEI Score		QHEI Category: Substrate Score		QHEI Category: Cover Score		QHEI Category: Channel Score	
				TMDL ≥ 49		***TMDL ≥ 12.7***		***TMDL ≥ 8.8***		***TMDL ≥ 10.8***	
				Actual	% Deficit	Actual	% Deficit	Actual	% Deficit	Actual	% Deficit
05080002030 Twin Creek (headwaters to above Bantas Fork	Maple Swamp Ditch	1.4	Full	38.5	---	8	---	6	---	6	---
	Dry Fork	0.8	Full	50	---	13	---	9	---	11	---
	Millers Fork	**10.8**	**Partial**	**33**	**33%**	7.5	**41%**	10	**-14%**	8.5	**21%**
	Swamp Creek	**6.3**	**Partial**	**34**	**31%**	9	**29%**	7	**20%**	8	**26%**
	Trib. to Swamp Creek (RM 6.45)	0.3	Full	37.5	---	9.5	---	9	---	8.5	---
	Price Creek	**13.7**	**Partial**	**47**	**4%**	14	**-10%**	11	**-25%**	11	**-2%**
	Price Creek	10.9	Full	62.5	---	15.5	---	14	---	11.5	---
	Price Creek	3.8	Full	65.5	---	17	---	7	---	14	---
	Lesley Run	6	**Partial**	35	**29%**	14	**-10%**	5	**43%**	6	**44%**
	Lesley Run	1.2	**Partial**	60	**-22%**	16.5	**-30%**	11	**-25%**	14.5	**-34%**
05080002040 Twin Creek (above Bantas Fork to GMR)	Goose Run	***4.4***	**Partial**	***55***	**-12%**	18	**-42%**	6	**32%**	14.5	**-34%**
	Aukerman Creek	3.3	Full	82	---	17	---	17	---	17	---
	Aukerman Creek	**1.8**	Full	**75.5**	---	17.5	---	15	---	14.5	---
	Aukerman Creek	0.5	Full	70.5	---	16.5	---	12	---	12	---
	Trib. to Aukerman Creek (RM 2.88)	**0.5**	Full	**73**	---	16	---	15	---	15.5	---
	Trib. to Twin Creek (RM 18.29)	0.6	Full	70.5	---	16.5	---	10	---	16.5	---
	Toms Run	12	***Partial***	40.5	**17%**	10	**21%**	6	**32%**	9	**17%**
	Toms Run	8.5	***Partial***	57	**-16%**	14.5	**-14%**	14	**-59%**	12	**-11%**
	Toms Run	0.4	Full	82	---	16.5	---	17	---	18	---

Table 16 (cont.). Habitat TMDLs for WWH sites in the Twin Creek watershed.

14-digit HUC	Stream/River Name	River Mile	Attainment	Riparian Score (TMDL ≥ 4.4) Actual	Riparian Score % Deficit	Pool Score (TMDL ≥ 3.8) Actual	Pool Score % Deficit	Riffle Score (TMDL ≥ 0.0) Actual	Riffle Score % Deficit	Gradient Score (TMDL ≥ 7.8) Actual	Gradient Score % Deficit
05080002030 Twin Creek (headwaters to above Bantas Fork	Maple Swamp Ditch	1.4	Full	3	---	5	---	4.5	---	6	---
	Dry Fork	0.8	Full	6	---	1	---	0	---	10	---
	Millers Fork	**10.8**	**Partial**	4	**9%**	-1	**126%**	0	**100%**	4	**49%**
	Swamp Creek	**6.3**	**Partial**	5	**-14%**	-1	**126%**	0	**100%**	6	**23%**
	Trib. to Swamp Creek (RM 6.45)	0.3	Full	4.5	---	0	---	0	---	6	---
	Price Creek	**13.7**	**Partial**	4	**9%**	-1	**126%**	0	**100%**	8	**-3%**
	Price Creek	10.9	Full	3.5	---	8	---	0	---	10	---
	Price Creek	3.8	Full	8	---	4	---	5.5	---	10	---
	Lesley Run	6	**Partial**	3	**32%**	-1	**126%**	0	**100%**	8	**-3%**
	Lesley Run	1.2	**Partial**	7	**-59%**	1	**74%**	0	**100%**	10	**-28%**
05080002040 Twin Creek (above Bantas Fork to GMR)	Goose Run	***4.4***	**Partial**	4.5	**-2%**	2	**47%**	0	**100%**	10	**-28%**
	Aukerman Creek	3.3	Full	9	---	8	---	4	---	10	---
	Aukerman Creek	**1.8**	Full	7.5	---	8	---	5	---	8	---
	Aukerman Creek	0.5	Full	7.5	---	9	---	3.5	---	10	---
	Trib. to Aukerman Creek (RM 2.88)	**0.5**	Full	7	---	6	---	3.5	---	10	---
	Trib. to Twin Creek (RM 18.29)	0.6	Full	6	---	6	---	5.5	---	10	---
	Toms Run	12	***Partial***	5.5	**-25%**	4	**-5%**	0	**100%**	6	**23%**
	Toms Run	8.5	***Partial***	5	**-14%**	1.5	**61%**	0	**100%**	10	**-28%**
	Toms Run	0.4	Full	5.5	---	10	---	5	---	10	---

Table 17. Sediment TMDLs for WWH sites in the Twin Creek watershed.

Stream/River 14-digit HUC Name		**River Mile**	**Attainment**	**Sediment Categories**					
				Substrate Score		**Riparian Score**		**Channel Score**	
				TMDL ≥ 12.7		***TMDL ≥ 4.4***		***TMDL ≥ 10.8***	
				Actual	% Deficit	Actual	% Deficit	Actual	% Deficit
05080002030 Twin Creek (headwaters to above Bantas Fork	Maple Swamp Ditch	1.4	Full	8	---	3	---	6	---
	Dry Fork	0.8	Full	13	---	6	---	11	---
	Millers Fork	**10.8**	**Partial**	7.5	**41%**	4	**9%**	8.5	**21%**
	Swamp Creek	**6.3**	**Partial**	9	**29%**	5	**-14%**	8	**26%**
	Trib. to Swamp Creek (RM 6.45)	0.3	Full	9.5	---	4.5	---	8.5	---
	Price Creek	**13.7**	**Partial**	14	**-10%**	4	**9%**	11	**-2%**
	Price Creek	10.9	Full	15.5	---	3.5	---	11.5	---
	Price Creek	3.8	Full	17	---	8	---	14	---
	Lesley Run	6	**Partial**	14	**-10%**	3	**32%**	6	**44%**
	Lesley Run	1.2	**Partial**	16.5	**-30%**	7	**-59%**	14.5	**-34%**
05080002040 Twin Creek (above Bantas Fork to GMR)	Goose Run	***4.4***	**Partial**	18	**-42%**	4.5	**-2%**	14.5	**-34%**
	Aukerman Creek	3.3	Full	17	---	9	---	17	---
	Aukerman Creek	**1.8**	Full	17.5	---	7.5	---	14.5	---
	Aukerman Creek	0.5	Full	16.5	---	7.5	---	12	---
	Trib. to Aukerman Creek (RM 2.88)	**0.5**	Full	16	---	7	---	15.5	---
	Trib. to Twin Creek (RM 18.29)	0.6	Full	16.5	---	6	---	16.5	---
	Toms Run	12	***Partial***	10	**21%**	5.5	**-25%**	9	**17%**
	Toms Run	8.5	***Partial***	14.5	**-14%**	5	**-14%**	12	**-11%**
	Toms Run	0.4	Full	16.5	---	5.5	---	18	---

Table 18. Habitat TMDLs for EWH sites in Twin Creek watershed.

Stream/River Name		River Mile	Attainment	QHEI Score		QHEI Category: Substrate Score		QHEI Category: Cover Score		QHEI Category: Channel Score	
				TMDL ≥ 71.8		*TMDL ≥ 15.8*		*TMDL ≥ 11.7*		*TMDL ≥ 12.7*	
				Actual	% Deficit	Actual	% Deficit	Actual	% Deficit	Actual	% Deficit
05080002030 Twin Creek (headwaters to above Bantas Fork)	Twin Creek	46.5	Full	43	---	13	---	8	---	4.5	---
	Twin Creek	42.1	Full	75.5	---	17.5	---	16	---	15	---
	Twin Creek	38	Full	61	---	13	---	9	---	14	---
	Miller's Fork	**8**	**Partial**	**66.5**	**7%**	**15**	**5%**	**16**	**-37%**	**16**	**-26%**
	Miller's Fork	**3.9**	**Partial**	**58**	**19%**	**9.5**	**40%**	**16**	**-37%**	**12.5**	**2%**
	Twin Creek	35.3	Full	67	---	16	---	13	---	10	---
	Twin Creek	**34.9**	**Partial**	**71**	**1%**	**14.5**	**8%**	**17**	**-45%**	**11**	**13%**
	Twin Creek	33.6	Full	77	---	17	---	17	---	16	---
	Twin Creek	31.7	Full	72.5	---	16	---	16	---	14	---
	Twin Creek	27.5	Full	80	---	17	---	16	---	13	---
	Twin Creek	26.7	Full	88.5	---	18	---	17	---	20	---
05080002040 Twin Creek (above Bantas Fork to GMR)	Bantas Fork	***13.7***	***Partial***	***69***	**4%**	***13.5***	**15%**	***18***	**-54%**	***12***	**6%**
	Bantas Fork	9.4	Full	67	---	15.5	---	13	---	16	---
	Goose Creek	**0.3**	***Partial***	**73**	**-2%**	**18.5**	**-17%**	**15**	**-28%**	**16**	**-26%**
	Bantas Fork	7.1	Full	72.5	---	17	---	13	---	11	---
	Bantas Fork	**1.3**	***Partial***	**80.5**	**-12%**	**18**	**-14%**	**17**	**-45%**	**17**	**-34%**
	Twin Creek	23.9	Full	79	---	18.5	---	12	---	15.5	---
	Twin Creek	19.2	Full	76.5	---	15.5	---	13	---	15.5	---
	Twin Creek	19	Full	72	---	15.5	---	8	---	14.5	---
	Twin Creek	13.4	Full	88	---	19	---	17	---	17.5	---
	Twin Creek	9.8	Full	74	---	17.5	---	11	---	11.5	---
	Twin Creek	3.4	Full	86.5	---	16	---	17	---	17.5	---
	Twin Creek	0.9	Full	82	---	17.5	---	15	---	17.5	---
	Twin Creek	0.1	Full	71.5	---	18	---	11	---	10	---
	Little Twin Creek	6.2	***Partial***	65.5	**9%**	13.5	**15%**	15	**-28%**	11	**13%**
	Little Twin Creek	4.7	Full	59.5	---	14	---	11	---	12	---
	Little Twin Creek	0.1	Full	77	---	17	---	15	---	14	---

Table 18 (cont.). Habitat TMDLs for EWH sites in Twin Creek watershed.

	Stream/River Name	River Mile	Attainment	QHEI Category							
				Riparian Score		Pool Score		Riffle Score		Gradient Score	
				TMDL ≥ 5.8		*TMDL ≥ 8.0*		*TMDL ≥ 4.5*		*TMDL ≥ 8.0*	
				Actual	% Deficit	Actual	% Deficit	Actual	% Deficit	Actual	% Deficit
05080002030 Twin Creek (headwaters to above Bantas Fork)	Twin Creek	46.5	Full	4	---	5	---	2.5	---	6	---
	Twin Creek	42.1	Full	7	---	9	---	5	---	6	---
	Twin Creek	38	Full	5.5	---	5.5	---	6	---	8	---
	Miller's Fork	**8**	**Partial**	**4.5**	**22%**	**5**	**38%**	**0**	**100%**	**10**	**-25%**
	Miller's Fork	**3.9**	**Partial**	**6**	**-3%**	**4**	**50%**	**0**	**100%**	**10**	**-25%**
	Twin Creek	35.3	Full	6	---	8	---	4	---	10	---
	Twin Creek	**34.9**	**Partial**	**4.5**	**22%**	**10**	**-25%**	**4**	**11%**	**10**	**-25%**
	Twin Creek	33.6	Full	7.5	---	6	---	5.5	---	8	---
	Twin Creek	31.7	Full	4	---	10	---	4.5	---	8	---
	Twin Creek	27.5	Full	5.5	---	12	---	6.5	---	10	---
	Twin Creek	26.7	Full	6	---	11	---	6.5	---	10	---
05080002040 Twin Creek (above Bantas Fork to GMR)	Bantas Fork	***13.7***	***Partial***	***6.5***	**-12%**	***10***	**-25%**	***3***	**33%**	***6***	**25%**
	Bantas Fork	9.4	Full	6.5	---	5	---	3	---	8	---
	Goose Creek	**0.3**	***Partial***	**5.5**	**5%**	**8**	**0%**	**4**	**11%**	**8**	**0%**
	Bantas Fork	7.1	Full	7.5	---	10	---	6	---	8	---
	Bantas Fork	**1.3**	***Partial***	**6**	**-3%**	**8**	**0%**	**4.5**	**0%**	**10**	**-25%**
	Twin Creek	23.9	Full	9	---	9.5	---	6.5	---	8	---
	Twin Creek	19.2	Full	6	---	10	---	6.5	---	10	---
	Twin Creek	19	Full	7.5	---	10	---	6.5	---	10	---
	Twin Creek	13.4	Full	6.5	---	11.5	---	6.5	---	10	---
	Twin Creek	9.8	Full	9	---	8	---	7	---	10	---
	Twin Creek	3.4	Full	7.5	---	12	---	6.5	---	10	---
	Twin Creek	0.9	Full	6	---	11	---	7	---	8	---
	Twin Creek	0.1	Full	8	---	10.5	---	6	---	8	---
	Little Twin Creek	6.2	***Partial***	6.5	**-12%**	5	**38%**	4.5	**0%**	10	**-25%**
	Little Twin Creek	4.7	Full	3	---	5	---	4.5	---	10	---
	Little Twin Creek	0.1	Full	6.5	---	10	---	4.5	---	10	---

Table 19. Sediment TMDLs for EWH sites in the Twin Creek watershed.

	Stream/River Name	River Mile	Attainment	Sediment Categories: Substrate Score		Riparian Score		Channel Score	
				TMDL ≥ 15.8		***TMDL ≥ 5.8***		***TMDL ≥ 12.7***	
				Actual	% Deficit	Actual	% Deficit	Actual	% Deficit
05080002030 Twin Creek (headwaters to above Bantas Fork)	Twin Creek	46.5	Full	13	---	4	---	4.5	---
	Twin Creek	42.1	Full	17.5	---	7	---	15	---
	Twin Creek	38	Full	13	---	5.5	---	14	---
	Miller's Fork	**8**	**Partial**	**15**	**5%**	**4.5**	**22%**	**16**	**-26%**
	Miller's Fork	**3.9**	**Partial**	**9.5**	**40%**	**6**	**-3%**	**12.5**	**2%**
	Twin Creek	35.3	Full	16	---	6	---	10	---
	Twin Creek	**34.9**	**Partial**	**14.5**	**8%**	**4.5**	**22%**	**11**	**13%**
	Twin Creek	33.6	Full	17	---	7.5	---	16	---
	Twin Creek	31.7	Full	16	---	4	---	14	---
	Twin Creek	27.5	Full	17	---	5.5	---	13	---
	Twin Creek	26.7	Full	18	---	6	---	20	---
05080002040 Twin Creek (above Bantas Fork to GMR)	Bantas Fork	***13.7***	***Partial***	***13.5***	**15%**	***6.5***	**-12%**	***12***	**6%**
	Bantas Fork	9.4	Full	15.5	---	6.5	---	16	---
	Goose Creek	**0.3**	***Partial***	**18.5**	**-17%**	**5.5**	**5%**	**16**	**-26%**
	Bantas Fork	7.1	Full	17	---	7.5	---	11	---
	Bantas Fork	**1.3**	***Partial***	**18**	**-14%**	**6**	**-3%**	**17**	**-34%**
	Twin Creek	23.9	Full	18.5	---	9	---	15.5	---
	Twin Creek	19.2	Full	15.5	---	6	---	15.5	---
	Twin Creek	19	Full	15.5	---	7.5	---	14.5	---
	Twin Creek	13.4	Full	19	---	6.5	---	17.5	---
	Twin Creek	9.8	Full	17.5	---	9	---	11.5	---
	Twin Creek	3.4	Full	16	---	7.5	---	17.5	---
	Twin Creek	0.9	Full	17.5	---	6	---	17.5	---
	Twin Creek	0.1	Full	18	---	8	---	10	---
	Little Twin Creek	6.2	***Partial***	13.5	**15%**	6.5	**-12%**	11	**13%**
	Little Twin Creek	4.7	Full	14	---	3	---	12	---
	Little Twin Creek	0.1	Full	17	---	6.5	---	14	---

Table 20 shows that, overall, there are more habitat problems in the upstream WAU (05080002 030) than downstream WAU (05000802 040) based on overall QHEI score deficiencies. The table also indicates that in both WAUs, riffle, pool, gradient and cover have the four greatest deficiencies. Pool, riffle, and gradient are difficult to enhance through direct modifications. However, pool and riffle can be improved indirectly through improvements to substrate and channel habitat. Cover can be enhanced through riparian improvements.

Table 20. Percentage of sites falling below QHEI subcategory target values within each 11-digit hydrologic unit.

	05080002 030 (n=22)		05080002 040 (n=25)	
	n	Average deficiency (%)	n	Average deficiency (%)
QHEI	7	17.7	3	10
Substrate	5	24.6	2	18
Cover	2	31.5	2	32
Channel	5	21.2	3	12
Riparian	5	18.8	1	5
Pool	7	95	3	49
Riffle	8	87	5	68.8
Gradient	2	36	2	24

5.4 Critical Condition and Seasonality

Seasonality is accounted for by use of aquatic life indices. Biological and habitat indices are measures of aggregate annual conditions reflecting compounding factors over time. The use of these indices reflects the collective seasonal effects on the biota.

The critical temporal condition for aquatic organisms is the summer season when excessive algal growth, high in-stream temperatures, low dissolved oxygen, and reduced stream flows exert significant stress on the aquatic communities, particularly fish. Nutrient enrichment during the summer season couples with long daylight hours and warm temperature increase algae productivity. Excess algal productivity can ultimately lead to low dissolved oxygen conditions during the daytime hours and large diurnal variation created by night time respiration. Shifts in the food base also alter the aquatic community by allowing otherwise less competitive species to prosper under eutrophic conditions. Measurement of biological indices during the summer period reflects the biotic performance during critical conditions.

Habitat and Sediment

Because water quality goals are based on aquatic life use, the critical condition for the habitat and sediment TMDLs is the summer dry period. During the summer, an environmental stress upon aquatic organisms is the greatest. The presence of high-quality habitat features, such as deep pools and unembedded substrate, is an essential niche to provide refuge for aquatic life. The QHEI quantifies the vital habitat features. Because of the QHEI relevance to aquatic life needs, the scores are utilized as the basis of habitat and sediment TMDLs. QHEI values are assessed during the summer field season. The habitat and sediment TMDLs are therefore reflective of the critical condition.

Fecal Coliform

The critical condition for pathogens is the summer dry period when flows are lowest, and thus the potential for dilution is the lowest. Summer is also the period when the probability of recreational contact is the highest. For these reasons recreation use designations are only applicable in the period May 1 to October 15. Pathogen TMDLs are developed for the same time period in consideration of the critical condition, and for agreement with Ohio WQS.

5.5 Margin of Safety

Margin of safety (MOS) is a required component of TMDLs in order to account for the uncertainty pollutant loading from various sources and the assimilative capacity of receiving waterbodies. The MOS can be incorporated implicitly by the conservative assumptions in the development of TMDLs. Alternatively, the MOS can also be incorporated explicitly by quantitatively allocating a portion of the loading capacity specifically for this purpose.

Habitat and Sediment

For both WWH and EWH, a target value for habitat and sediment and for each one of their subcategories was chosen to be the lowest value of the 95^{th} percent confidence interval (5% significance) of the full attainment group median. This value was chosen to reduce the effects of skewed data sets and to ensure that the full data set values achieve the TMDL goal with statistical significance. In addition, this value statistically assures with 95 percent confidence that the population median of the QHEI or subcategory is at least greater than this value. This goal provides assurance that an acceptable intrinsic safety factor for the TMDL is provided. The 5% statistical significance goal created by 95% confidence interval provides an explicit 5% MOS for targets.

A margin of safety was also implicitly incorporated into the sediment and habitat TMDLs through biological indices. As required by OAC 3745-01-07, WWH full attainment IBI and ICI scores must be 40 and 36, respectively. EWH full attainment IBI and ICI scores must be 50 and 46, respectively. Therefore, using IBI and ICI scores greater than 40 and 36 as representative of the attaining WWH sites, and using IBI and ICI scores greater than 50 and 46 as representative of the attaining EWH sites, provide a direct implicit MOS. In addition, components of the QHEI were analyzed to determine the magnitude at which WWH and EWH attainment are probabable. However, attainment does occur at levels lower than the established targets. The difference between the targets of habitat and sediment components and the levels at which attainment occurs provide an implicit margin of safety.

Fecal Coliform

A significant margin of safety is implicitly incorporated into the pathogen TMDL. Existing load calculations and TMDLs represent the load at the outlet to each 14-digit hydrologic unit. No in-stream decay, sorption, desorption, or flow routing is attempted in the model for pathogens. Therefore, the model utilized is inherently conservative in its development. The reduction factors for each impaired HUC14 were determined by comparing in-stream 2005 bacteria data with bacteria targets (both 30-day geometric mean and 10% of samples maximum aspects for both fecal coliform and *E. coli*). Another implicit factor in the margin of safety was used by utilizing the highest reduction factor to calculate the TMDLs.

5.6 Future Growth

The U.S. Census Bureau (http://quickfacts.census.gov/qfd/states/39/39135.html) shows the population growth in Preble County from April 1st, 2000 to July 1st, 2006 was just 0.4%. A population growth of < 0.1% per year is not significant enough to be incorporated into the TMDL calculations.

6.0 WATER QUALITY IMPROVEMENT STRATEGY

The Twin Creek watershed had little impairment to aquatic life use. The sites that were partially attaining water quality standards were spread out among eight 14-digit HUCs. Because of the sampling approach used at Ohio EPA, causes and sources of impairment at individual sites were assumed to be somewhat representative of sites with similar land uses at a broader scale. It is possible that some stream segments not surveyed are impaired by sources that have been identified in surveyed segments. A broad application across the watershed of some of the recommendations is likely to abate those sources as well. To include such situations, rather than recommending specific actions at stream segments that were found to be impaired, actions are recommended at the 14-digit HUC level based on sources of impairment. Some sources produced multiple causes of impairment, so multiple actions might be necessary to reduce impairment.

Table 21 shows an overview of all of the 14-digit HUCs that contained sites with partial attainment of aquatic life and recreation uses. Causes (e.g., nutrients or sediment) are shown within parentheses following each source that might contribute to that cause of impairment. Tables 22 and 23 each represent a separate 11-digit HUC (see Figure 1 for a map). For each 14-digit HUC, specific actions are recommended. Recommendations were developed after consultation with local technical stakeholders and agency staff. In each case, these actions are intended to be inclusive of possible methods to improve water quality in the watershed based on identified causes and sources of impairment. Because Ohio EPA recognizes that actions taken in any individual subwatershed may depend on a number of factors (including socioeconomic, political and ecological factors), these recommendations are not intended to be prescriptive of actions to be taken, and any number or combination might contribute to improvement, whether applied at sites where actual impairment was noted or other locations where sources contribute indirectly to water quality impairment. Further details about individual practices can be found in Appendix E.

Table 21. Recommended restoration strategies for the Twin Creek watershed.

11-Digit HUC (Location Description) 14-Digit HUC (Location Description) Sources (Causes)	Restoration Categories: Bank & Riparian Restoration	Stream Restoration	Wetland Restoration	Conservation Easements	Dam Modification or Removal	Levee or Dike Modification or Removal	Abandoned Mine Land Reclamation	Home Sewage Planning and Improvement	Education and Outreach	Agricultural Best Management Practices	Storm Water Best Management Practices	Regulatory Point Source Controls
05080002 030: Twin Creek headwaters to upstream Bantas Fork												
030 010: Twin Creek above Millers Fork												
Channelization (sedimentation/siltation, algae)	x	x	x	x					x	x		
Loss of riparian (sedimentation/siltation, algae)	x	x	x	x					x	x		
Crops with subsurface drainage (sedimentation/siltation, algae)			x	x					x	x		
030 020: Millers Fork												
Loss of riparian (sedimentation/siltation, low DO, ammonia)	x	x	x	x					x	x		
Channelization (sedimentation/siltation, low DO, ammonia)	x	x	x	x					x	x		
Crops with subsurface drainage (sedimentation/siltation, low DO, ammonia)			x	x					x	x		
Animal feeding operations (sedimentation/siltation, low DO, ammonia)	x			x					x	x		
Unsewered area (low DO, ammonia)								x	x			x
030 030: Twin Creek below Millers Fk. to above Price Cr. (except Swamp Cr.)												
Lewisburg WWTP (phosphorus, bacteria)												x
030 040: Swamp Creek												
Channelization (ammonia, phosphorus, sedimentation/siltation)	x	x	x	x					x	x		
Loss of riparian (ammonia, phosphorus, sedimentation/siltation)	x	x	x	x					x	x		
Crops - subsurface drainage (ammonia, phosphorus, sedimentation/siltation)			x	x					x	x		
Failing HSTS (bacteria)								x	x			

Table 21 (cont.) Recommended restoration strategies for the Twin Creek watershed.

11-Digit HUC (Location Description) **14-Digit HUC (Location Description)** **Sources (Causes)**	**Restoration Categories** Bank & Riparian Restoration	Stream Restoration	Wetland Restoration	Conservation Easements	Dam Modification or Removal	Levee or Dike Modification or Removal	Abandoned Mine Land Reclamation	Home Sewage Planning and Improvement	Education and Outreach	Agricultural Best Management Practices	Storm Water Best Management Practices	Regulatory Point Source Controls
05080002 030: Twin Creek headwaters to upstream Bantas Fork (cont.)												
030 050: Price Creek												
Agriculture (low DO, ammonia, phosphorus)	x	x	x	x					x	x		
Failing HSTS (low DO, ammonia, phosphorus, bacteria)								x	x			
030 060: Twin Creek below Price Cr. to above Bantas Fork												
Channelization (sedimentation/siltation, low DO)	x	x	x	x					x	x		
Loss of riparian (sedimentation/siltation, low DO)	x	x	x	x					x	x		
Crops with subsurface drainage (sedimentation/siltation, low DO)			x	x					x	x		
Failing HSTS (bacteria)								x	x			
05080002 040: Twin Creek upstream Bantas Fork to mouth												
040 020: Goose Creek *[further sampling recommended]*												
Upstream package plants (phosphorus, ammonia, COD, low DO, bacteria)	x								x	x		x
Failing HSTS (bacteria)								x	x			
040 070: Tom's Run												
Channelization (sedimentation/siltation, low DO)	x	x	x	x					x	x		
Crops with subsurface drainage (sedimentation/siltation, low DO)	x		x	x					x	x		

Table 22. Specific restoration suggestions for the upper Twin Creek watershed.

Restoration Categories		Specific Restoration Actions	05080002 030					
			010: Twin Cr. above Millers Fk.	020: Millers Fork	030: Twin Cr. below Millers Fk. to above Price Cr.	040: Swamp Creek	050: Price Creek	060: Twin Cr. below Price Cr. to above Bantas Fk.
Bank & Riparian Restoration	constructed	Restore streambank using bio-engineering	x					
		Restore streambank by recontouring or regrading	x			x		x
	planted	Plant grasses in riparian areas	x	x		x	x	x
		Plant prairie grasses in riparian areas	x	x		x	x	x
		Remove/treat invasive species						
		Plant trees or shrubs in riparian areas	x	x		x	x	x
Stream Restoration		Restore flood plain		x		x		x
		Restore stream channel	x					x
		Install in-stream habitat structures	x	x		x	x	x
		Install grade structures						
		Construct 2-stage channel	x					
		Restore natural flow						
Wetland Restoration		Reconnect wetland to stream	x	x		x	x	
		Reconstruct & restore wetlands	x	x		x	x	
		Plant wetland species	x	x		x	x	
Conservation Easements		Acquire conservation easements	x	x		x		x
Dam Modification or Removal		Remove dams						
		Modify dams						
		Remove associated dam support structures						
		Install fish passage and/or habitat structures						
		Restore natural flow						
Levee or Dike Modification or Removal		Remove levees						
		Breach or modify levees						
		Remove dikes						
		Modify dikes						
		Restore natural flood plain function						

Table 22 (cont.) Specific restoration suggestions for the upper Twin Creek watershed.

Restoration Categories		Specific Restoration Actions	05080002 030					
			010: Twin Cr. above Millers Fk.	020: Millers Fork	030: Twin Cr. below Millers Fk. to above Price Cr.	040: Swamp Creek	050: Price Creek	060: Twin Cr. below Price Cr. to above Bantas Fk.
Abandoned Mine Land Reclamation	treatment	Construct lime dosers						
		Install slag leach beds						
		Install limestone leach beds						
		Install limestone channels						
		Install successive alkalinity producing systems						
		Install settling ponds						
		Construct acid mine drainage wetland						
	flow diversion	Repair subsidence sites						
		Reclaim pit impoundments						
		Reclaim abandoned mine land						
		Eliminate stream captures						
		Restore positive drainage						
		Cover toxic mine spoils						
Home Sewage Planning and Improvement		Develop HSTS plan		x		x	x	x
		Inspect HSTS		x		x	x	x
		Repair or replace traditional HSTS		x		x	x	x
		Repair or replace alternative HSTS		x		x	x	x
Education and Outreach		Host meetings, workshops, and/or other events	x	x		x	x	x
		Distribute educational materials	x	x		x	x	x
Agricultural Best Management Practices	farmland	Plant cover/manure crops	x	x		x	x	x
		Implement conservation tillage practices		x		x		x
		Implement grass/legume rotations		x		x		x
		Convert to permanent hayland						
		Install grassed waterways	x	x		x		x
		Install vegetated buffer areas/strips	x	x		x	x	x
		Install location-specific conservation buffers	x	x		x	x	x
		Install / restore wetlands	x	x		x	x	
	nutrients / agro-chemicals	Conduct soil testing	x	x		x	x	x
		Install nitrogen reduction practices	x	x		x	x	x
		Develop nutrient management plans	x	x		x	x	x

Table 22 (cont.). Specific restoration suggestions for the upper Twin Creek watershed.

Restoration Categories		Specific Restoration Actions	05080002 030					
			010: Twin Cr. above Millers Fk.	020: Millers Fork	030: Twin Cr. below Millers Fk. to above Price Cr.	040: Swamp Creek	050: Price Creek	060: Twin Cr. below Price Cr. to above Bantas Fk.
Agricultural Best Management Practices (cont.)	drainage	Install sinkhole stabilization structures						
		Install controlled drainage system	x	x				
		Implement drainage water management	x	x				
		Construct overwide ditch						
		Construct 2-stage channel	x					
	livestock	Implement prescribed & conservation grazing practices	x	x		x	x	x
		Install livestock exclusion fencing	x	x		x	x	x
		Install livestock crossings						
		Install alternative water supplies	x	x		x	x	x
		Install livestock access lanes						
	manure	Implement manure management practices	x	x			x	x
		Construct animal waste storage structures	x	x			x	x
		Implement manure transfer practices	x	x			x	x
	misc. infra-structure and mgt	Install chemical mixing pads						
		Install heavy use feeding pads						
		Install erosion & sediment control structures		x		x		x
		Install roof water management practices						
		Install milkhouse waste treatment practices						
		Develop whole farm management plans	x	x		x	x	x
Storm Water Best Management Practices	planning	Develop/implement local ordinances/resolutions						
		Develop local comprehensive land use plans						
	construction practices	Implement erosion controls						
		Implement sediment controls						
		Implement non-sediment controls						
	post construction practices	Reduce pollutant(s) through treatment						
		Reduce pollutant(s) through flow/volume management						

Table 22 (cont.). Specific restoration suggestions for the upper Twin Creek watershed.

Restoration Categories		Specific Restoration Actions	05080002 030					
			010: Twin Cr. above Millers Fk.	020: Millers Fork	030: Twin Cr. below Millers Fk. to above Price Cr.	040: Swamp Creek	050: Price Creek	060: Twin Cr. below Price Cr. to above Bantas Fk.
Storm Water Best Management Practices (cont.)	post development/ storm water retrofit	Implement erosion controls						
		Implement sediment controls						
		Implement non-sediment controls						
		Reduce pollutant(s) through treatment						
		Reduce pollutant(s) through flow/volume mgmt.						
Regulatory Point Source Controls (includes Storm Water, Sanitary, and Industrial)	planning	Develop long-term control plan (CSOs)						
		Develop/implement local ordinances/resolutions						
		Develop water quality management/208 plans						
	collection and new treatment	Install sewer systems in communities		x				
		Implement long-term control plan (CSOs)						
		Eliminate SSOs/CSOs/by-passes						
	enhanced treatment	Issue permit(s) and/or modify permit limit(s)			x			
		Improve quality of effluent			x			
	monitoring	Establish ambient monitoring program						
		Increase effluent monitoring	x		x	x	x	x
	alternatives	Establish water quality trading						
	construction practices	Issue permit(s) and/or modify permit limit(s)						
		Implement erosion controls						
		Implement sediment controls						
		Implement non-sediment controls						
	post construction practices	Issue permit(s) and/or modify permit limit(s)						
		Reduce pollutant(s) through treatment						
		Reduce pollutant(s) through flow/volume management						
	post development/ storm water retrofit	Issue permit(s) and/or modify permit limit(s)						
		Implement erosion controls						
		Implement sediment controls						
		Implement non-sediment controls						
		Reduce pollutant(s) through treatment						
		Reduce pollutant(s) through flow/volume management						
		Reduce volume to CSOs						

Table 23. Specific restoration suggestions for the lower Twin Creek watershed.

Restoration Categories		Specific Restoration Actions	05080002 040	
			020: Goose Creek	070: Tom's Run
Bank & Riparian Restoration	constructed	Restore streambank using bio-engineering		x
		Restore streambank by recontouring or regrading		x
	planted	Plant grasses in riparian areas	x	x
		Plant prairie grasses in riparian areas	x	x
		Remove/treat invasive species		
		Plant trees or shrubs in riparian areas	x	x
Stream Restoration		Restore flood plain		
		Restore stream channel	x	
		Install in-stream habitat structures	x	
		Install grade structures		
		Construct 2-stage channel		
		Restore natural flow		
Wetland Restoration		Reconnect wetland to stream	x	
		Reconstruct & restore wetlands	x	
		Plant wetland species	x	
Conservation Easements		Acquire conservation easements		x
Dam Modification or Removal		Remove dams		
		Modify dams		
		Remove associated dam support structures		
		Install fish passage and/or habitat structures		
		Restore natural flow		
Levee or Dike Modification or Removal		Remove levees		
		Breach or modify levees		
		Remove dikes		
		Modify dikes		
		Restore natural flood plain function		
Abandoned Mine Land Reclamation	treatment	Construct lime dosers		
		Install slag leach beds		
		Install limestone leach beds		
		Install limestone channels		
		Install successive alkalinity producing systems		
		Install settling ponds		
		Construct acid mine drainage wetland		

Table 23 (cont.). Specific restoration suggestions for the lower Twin Creek watershed.

Restoration Categories		Specific Restoration Actions	05080002 040	
			020: Goose Creek	070: Tom's Run
Abandoned Mine Land Reclamation (cont.)	flow diversion	Repair subsidence sites		
		Reclaim pit impoundments		
		Reclaim abandoned mine land		
		Eliminate stream captures		
		Restore positive drainage		
		Cover toxic mine spoils		
Home Sewage Planning and Improvement		Develop HSTS plan	x	
		Inspect HSTS	x	
		Repair or replace traditional HSTS	x	
		Repair or replace alternative HSTS	x	
Education and Outreach		Host meetings, workshops, and/or other events	x	x
		Distribute educational materials	x	x
Agricultural Best Management Practices	farmland	Plant cover/manure crops	x	x
		Implement conservation tillage practices		x
		Implement grass/legume rotations		
		Convert to permanent hayland		
		Install grassed waterways	x	x
		Install vegetated buffer areas/strips	x	X
		Install location-specific conservation buffers	x	X
		Install / restore wetlands	x	
	nutrients / agro-chemicals	Conduct soil testing	x	
		Install nitrogen reduction practices	x	
		Develop nutrient management plans	x	
	drainage	Install sinkhole stabilization structures		
		Install controlled drainage system		
		Implement drainage water management		
		Construct overwide ditch		
		Construct 2-stage channel		
	livestock	Implement prescribed & conservation grazing practices		x
		Install livestock exclusion fencing		x
		Install livestock crossings		
		Install alternative water supplies		x
		Install livestock access lanes		

Table 23 (cont.). Specific restoration suggestions for the lower Twin Creek watershed.

Restoration Categories		Specific Restoration Actions	05080002 040	
			020: Goose Creek	070: Tom's Run
Agricultural Best Management Practices (cont.)	manure	Implement manure management practices		x
		Construct animal waste storage structures		
		Implement manure transfer practices		
	misc. infrastructure and mgt	Install chemical mixing pads		
		Install heavy use feeding pads		
		Install erosion & sediment control structures		x
		Install roof water management practices		
		Install milkhouse waste treatment practices		x
		Develop whole farm management plans		x
Storm Water Best Management Practices	planning	Develop/implement local ordinances/resolutions		
		Develop local comprehensive land use plans		
	construction practices	Implement erosion controls		
		Implement sediment controls		
		Implement non-sediment controls		
	post construction practices	Reduce pollutant(s) through treatment		
		Reduce pollutant(s) through flow/volume management		
	post development/ storm water retrofit	Implement erosion controls		
		Implement sediment controls		
		Implement non-sediment controls		
		Reduce pollutant(s) through treatment		
		Reduce pollutant(s) through flow/volume management		
Regulatory Point Source Controls (includes Storm Water, Sanitary, and Industrial)	planning	Develop long-term control plan (CSOs)		
		Develop/implement local ordinances/resolutions		
		Develop water quality management/208 plans		
	collection and new treatment	Install sewer systems in communities		
		Implement long-term control plan (CSOs)		
		Eliminate SSOs/CSOs/by-passes		
	enhanced treatment	Issue permit(s) and/or modify permit limit(s)		
		Improve quality of effluent	x	

Table 23 (cont.). Specific restoration suggestions for the lower Twin Creek watershed.

Restoration Categories		Specific Restoration Actions	05080002 040	
			020: Goose Creek	070: Tom's Run
Regulatory Point Source Controls (includes Storm Water, Sanitary, and Industrial) (cont.)	monitoring	Establish ambient monitoring program		
		Increase effluent monitoring	x	
	alternatives	Establish water quality trading		
	construction practices	Issue permit(s) and/or modify permit limit(s)		
		Implement erosion controls		
		Implement sediment controls		
		Implement non-sediment controls		
	post construction practices	Issue permit(s) and/or modify permit limit(s)		
		Reduce pollutant(s) through treatment		
		Reduce pollutant(s) through flow/volume management		
	post development/ storm water retrofit	Issue permit(s) and/or modify permit limit(s)		
		Implement erosion controls		
		Implement sediment controls		
		Implement non-sediment controls		
		Reduce pollutant(s) through treatment		
		Reduce pollutant(s) through flow/volume management		
		Reduce volume to CSOs		

In addition to the recommendations included above, Ohio EPA is making several recommendations involving individual NPDES permit holders. Those recommendations are summarized in Table 24. Design flows for facilities are expressed in million gallons per day (MGD).

Table 24. Recommended actions for each individual NPDES permit holder.

Ohio EPA Permit No.	Facility	Design Flow	Recommended Action
HUC 0508002 030 010 Twin Creek above Millers Fork			
1PA00025	West Manchester WWTP	0.065	Next permit cycle: monitor for TP, TKN[a], and NO_3-NO_2[b]
HUC 05080002 030 030 Twin Creek below Millers Fork to above Price Creek (Except Swamp Creek)			
1PB00019	Lewisburg WWTP	0.261	Next permit cycle: issue a new permit with compliance schedule and a new limit of 1.0 mg/l for TP; monitor for TKN and NO_3-NO_2
1PG00092	Preble Co. SD #2 WWTP	0.015	Next permit cycle: monitor for TP, TKN, and NO_3-NO_2
1IH00012	P& G Pet Care	0.075	Next permit cycle: continue to monitor for TP; monitor for TKN and NO_3-NO_2
1IN00184	North American Nutrition	0.006	Next permit cycle: monitor for TP, TKN and NO_3-NO_2 in draft permit
HUC 05080002 030 040 Swamp Creek			
1PA00027	Verona WWTP	0.085	Next permit cycle: monitor for TP, TKN, and NO_3-NO_2
HUC 05080002 030 050 Price Creek			
1PA00014	El Dorado WWTP	0.10	Next permit cycle: monitor for TP, TKN, and NO_3-NO_2
HUC 05080002 030 060 Twin Creek below Price Creek to above Bantas Fork			
1PB00035	West Alexandria WWTP	0.300	Next permit cycle: continue to monitor for TP; monitor for TKN and NO_3-NO_2
1PV00125	Creekside MHP	0.0045	Next permit cycle: monitor for TP, TKN, and NO_3-NO_2
HUC 05080002 040 020 Goose Creek			
1IN00212	Dayton Travel Center	0.02	Next permit cycle: monitor for TP, TKN, and NO_3-NO_2 (2 outfalls)
1PZ00020	Pilot Travel Center	0.02	Next permit cycle: monitor for TP, TKN, and NO_3-NO_2 (2 outfalls)
HUC 05080002 040 060 Twin Creek below Aukerman Creek to above Tom's Run			
1PB00041	Gratis WWTP	0.119	Next permit cycle: continue to monitor for TP; monitor for TKN and NO_3-NO_2
HUC 05080002 040 090 Little Twin Creek			
1PB00010	Farmersville WWTP	0.22	Next permit cycle: continue to monitor for TP; monitor for TKN and NO_3-NO_2

[a] TKN = total Kjeldahl nitrogen
[b] NO_3-NO_2 = nitrate-nitrite

6.1 Reasonable Assurances

The recommendations made in this TMDL report will be carried out if the appropriate entities work to implement them. In particular, activities that do not fall under regulatory authority require that there be a committed effort by state and local agencies, governments, and private groups to carry out and/or facilitate such actions. The availability of adequate resources is also imperative for successful implementation.

When a TMDL is developed for waters impaired by point sources only, the issuance of a NPDES permit(s) provides the reasonable assurance that the wasteload allocations contained in the TMDL will be achieved. This is because 40 C.F.R. 122.44(d)(1)(vii)(B) requires that effluent limits in permits be consistent with the assumptions and requirements of any available wasteload allocation in an approved TMDL.

When a TMDL is developed for waters impaired by both point and nonpoint sources, and the WLA is based on an assumption that nonpoint source load reductions will occur, U.S. EPA's 1991 TMDL Guidance states that the TMDL should provide reasonable assurances that nonpoint source control measures will achieve expected load reductions. To this end, Appendix E discusses organizations and programs that have an important role or can provide assistance for meeting the goals and recommendations of this TMDL. The appendix establishes in greater detail why it is reasonable to be assured of successful implementation.

6.1.1 Local Zoning and Regional Planning

Similar to a regional planning approach, the Three Valley Conservation Trust has broadly applied and encouraged the use of conservation easements to preserve high quality undeveloped land and protect areas under pressure for future development. The following table is from the Conditionally Endorsed Twin Creek Watershed Action Plan, dated November 2007.

Conservation Easements Current, Anticipated and Planned (Pre-2005, 2005-2007, 2008-9, 2010 and beyond)

Subwatershed	#of easement Pre-2005	Acres Pre-2005	#of easement 2005-07	Acres 2005-07	#of easement 2008-09	Acres 2008-09	#of easement 2010	Acres 2010	#of easement >2010	Acres >2010
Upper Twin Creek	0	0	1	3	8	500	30	3900	28302	15.5
Millers Fork	0	0	0	0	4	450	18	2200	15513	17
Upper Twin below Millers Fork	0	0	2	205	2	162	12	1320	9654	17.4
Swamp Creek	2	417	4	527	2	200	20	2500	11486	31.7
Price's Creek	1	91	6	1131	2	366	19	2900	18825	21.1
Twin Creek below Price C.	2	161	6	912	5	470	22	2577	16727	24.6
Upper Bantas	0	0	0	0	2	70	12	1500	7978	19.6
Goose Creek	0	0	0	0	3	300	14	1800	7231	29
Lower Bantas	1	395	5	219	3	520	14	1800	7279	40.3
Twin Creek Below Banta	0	0	1	117	3	240	20	2000	7974	29.5
Aukerman C.	0	0	1	12	2	100	18	2600	13327	20.3
Tom's Run	8	1354	6	653	3	400	25	2900	13033	40.7
Twin C between Aukerman and Tom's Run	2	290	3	1088	3	330	26	3000	16481	28.5
Lower Twin	7	785	5	275	4	430	20	2100	13810	26
Little Twin	0	0	0	0	1	150	10	1400	14531	10.6
Total	23	3493	40	5142	47	4688	280	34497	202151	371.8

6.1.2 Local Watershed Groups

The watershed group is the Twin Creek watershed partnership. The partnership meets about once a month, and produces bi-monthly newsletters. They are part of the Great Miami River network and have been promoting volunteer monitoring through schools and non-profit groups. They participate in local festivals and also education and outreach events. The Preble and Montgomery counties soil and water conservation offices have their web sites and the Twin Creek Watershed partnership's web site is www.twincreekwatershed.org. The partners are planning to update the Twin Creek Watershed Action Plan in 2010.

6.1.3 Past and Ongoing Water Resource Evaluation

Ohio EPA completed an in-depth basin survey for the Twin Creek watershed in 1986, 1995 and in 2005. As part of the five-year rotating basin survey approach, Ohio EPA expects to return to Twin Creek for another in-depth survey by 2019.

In April and July 2008, Miami University conducted a surface and drinking water sampling within the Twin Creek watershed. The project is part of a graduate practicum project for Maria Tomashot, a graduate student at the Institute of Environmental Sciences at Miami University. A total of 43 private wells and 26 surface water samples were collected. The samples were analyzed for 23 different parameters and some of the samples were also analyzed for nitrogen and oxygen isotopes for tracing the source of nitrate. The project is supported by the Miami Conservancy District and Miami University. Results of this project will be available in the spring of 2009. Several macroinvertebrate sampling events were conducted in 2008 with various groups as part of the volunteer monitoring outreach effort. These events were aimed at introducing macroinvertebrates to the residences and highlighting the good water quality of Twin Creek and its tributaries and not for monitoring of water quality.

6.1.4 Potential and Future Evaluation

In December 2007, a proposal was submitted to the source water protection program at Miami Conservancy District to prepare the Source Water Protection Plan for the Village of Gratis and to conduct the nitrate assessment within the Twin Creek watershed. In November 2008, a proposal was submitted to the Education Grant program at Ohio Department of Natural Resources. The grant will support the installation of watershed signs throughout the watershed. The Preble County Historical Society in partnering with the Twin Creek Watershed partners submitted an application to the Clean Ohio Grant to support the wetland enhancement and outreach effort at the Historical Society property. The wetland will be the first restored wetland within the Twin Creek watershed and is currently under construction. An erosion assessment at the Upper Twin Conservation Area is planned. This project will determine the causes of bank erosion and potential solutions. The project is funded by Five Rivers MetroParks.

Poggemeyer Design Group (PDG) is working on a general plan for sewering the Villages of Gordon and Ithaca. PDG recently contacted Verona to determine the feasibility of connection to their newly constructed system. It appears they have capacity, but there has not been a response from the Village of Verona.

At the present time, Castine does not have any planning in place. Ohio EPA staff could discuss their wastewater issues, perhaps with DEFA. The West Manchester system is about a mile to the south of Castine, and if there is capacity available, there could be a possibility of connection.

6.1.5 Revision to the Implementation Approach

An adaptive management approach will be taken in the watershed. Adaptive management is recognized as a viable strategy for managing natural resources (Baydack et al., 1999) and this approach is applied on federally-owned lands. An adaptive management approach allows for changes in the management strategy if environmental indicators suggest that the current strategy is inadequate or ineffective. The recommendations put forth for the watershed are discussed in the last chapter of the main report. If chemical water quality does not show improvement and/or water bodies are still not attaining water quality standards after the implementation plan has been carried out, then a TMDL revision would be initiated. The Ohio EPA would initiate the revision if no other parties wish to do so.

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