3.0 Description of Watershed Analysis

The goal of the TMDL process is attainment of water quality standards, which include the beneficial uses appropriate for each waterbody. A step in this process is an in-depth watershed analysis which forges the links between the identified impairments and the actions needed to address them. Factors that cause impairment are varied; generally, they can be grouped as either pollutant loads to a stream or as unfavorable environmental conditions within the water or stream corridor (e.g., low in-stream dissolved oxygen or poor habitat quality). Although the TMDL process was originally designed to only address pollutant loading, ultimately its purpose is to bring a water resource into attainment of its beneficial use designations. The beneficial uses in Ohio include aquatic life use designations, and these generally require in-stream conditions as well as pollutant loadings be addressed to achieve full attainment. Indeed, without consideration of other impairing factors, even extreme limitations on pollutants may not result in attainment of beneficial uses. The attainment of aquatic life uses is a goal of this TMDL report and both loading and in-stream conditions are included.

The analysis of the load-based factors entails determination of the *existing load*, calculation of the *loading capacity*, and the *allocation* of the allowable load to each source. The *existing load* is the quantity of a pollutant that is received by a waterbody from all significant sources (e.g. runoff and discharges from pipes to the stream) prior to TMDL implementation. The *loading capacity* is the quantity of a pollutant that a waterbody can receive and achieve in-stream water quality criteria and targets. This is known as the allowable load. *Allocation* involves the distribution of the total allowable load among the various load sources within the watershed.

The analysis of the environmental in-stream conditions (e.g. habitat degradation) follows a similar pattern. The existing condition and the characteristics associated with it (e.g. channel form or sediment quality) are evaluated. A desired state of the condition (the allowable or target condition) is determined which, if achieved, will move the resource towards attainment of its use designation. Determination of the optimal levels, types, or interactions of each of the characteristics associated with the condition being evaluated is similar to the allocation of allowable load described above.

Modeling methods based on mathematical equations and qualitative relationships are generally used for these analyses. The load that a waterbody receives can be calculated using empirically based formulas and data specific to the landscape. The reactions these pollutants undergo in a waterbody have been extensively studied by the scientific community and can be calculated using equations based on this research and in-stream data. However, existing conditions for physically based, non-load factors such as habitat, channel form, and location of active flood plain are difficult to simulate; therefore, an evaluation of these rely mainly on observed data.

The Big Darby Creek watershed analyses are described in this chapter. The impairments addressed and their interactions are discussed in Section 3.1. Targets for the impairing causes are presented in Section 3.2. An overview of the methods used in the watershed analyses is given in Section 3.3.

3.1 Linking the Biological Assessment, Watershed Characteristics, and In-stream Criteria: a Roadmap to Navigate How to Get from Impairment to Attainment

A stream becomes impaired when its capacity to handle stressors is exceeded. This occurs when the external inputs to the stream become excessive, or when the stream characteristics are altered so that it can no longer assimilate these stresses without harm to the aquatic life, or a combination of these occur. The way to get from impairment to attainment is to reverse these changes so that both the external inputs and the stream's ability to handle them are in balance. The challenge for watershed planners and stakeholders to determine how this balance can be achieved in concert with other considerations. Increasing the ability of the stream to handle load may be more desirable for local landowners than reducing load, or vice versa, or some combination of both.

The relationships among major stream integrity components are shown in Figure 3.1 (adapted from Ohio NPSMP, 2004). An illustration of the relationships using storm water runoff as an example is as follows: a portion of rain runs off the land and into a stream bringing with it accumulated soil and pollutants (1). Stream flow increases, resulting in higher velocities, water levels, and stream turbulence (2). This increased energy of the water influences channel form by eroding, moving, and depositing sediment material along its length (3). The type and amount of sediment material deposited can positively affect the habitat if it provides high quality substrate (e.g. cobble and gravel) or negatively affect it if it blankets the bed with fine grained material (e.g. silt and clay) (4b). Channel form also affects how pollutants in the runoff are processed by changing the rate or type of reactions that occur (4a). The chemistry of the water can either positively affect the biota (aquatic life) by providing essential nutrients or negatively affect it by having toxic effects. The quality of the available habitat in which these organisms live also has a large effect on the health and population of aquatic life (5). If the organisms have a viable aquatic environment, the

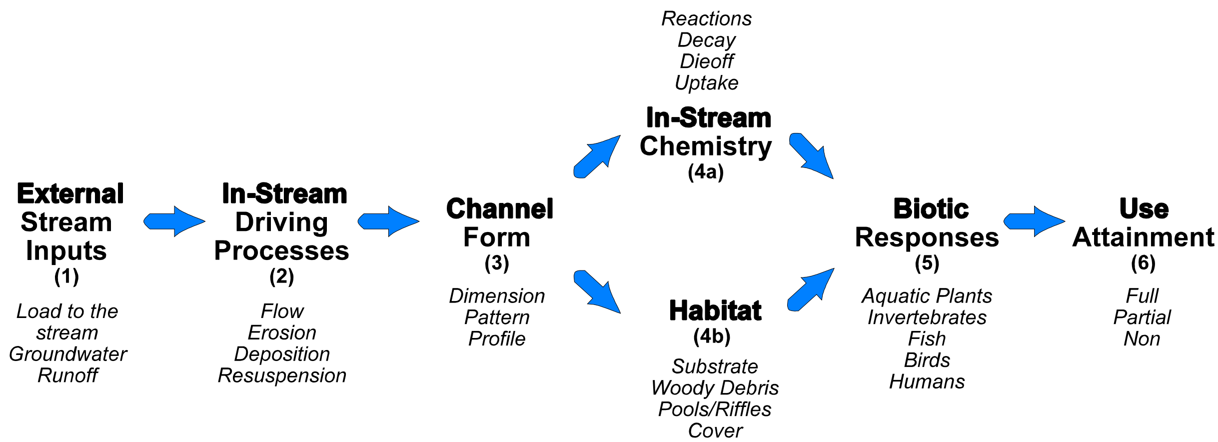

Figure 3.1 Flow diagram of the major stream integrity components

aquatic life use designation metrics (based on population density, species types, and individual specimen health) will be at levels indicative of full attainment status. Otherwise, the use is considered impaired (6).
The specific factors associated with the major stream components addressed in this report include:

1. Load-based pollutants *Figure 3.1 (1)*
   - total phosphorus
   - eroded sediment
   - bacteria
   - ammonia
   - metals
2. Flow quantity *Figure 3.1 (2)*
   - groundwater recharge
   - baseflow and runoff quantity
3. ***Geomorphology*** of the channel *Figure 3.1 (3)*
   - flood plain dimension
4. In-stream conditions *Figure 3.1 (4a)*
   - dissolved oxygen
   - total suspended solids
   - in-stream concentrations of the load-based pollutants
   - temperature (addressed by implementation actions of other factors)
5. Habitat quality *Figure 3.1 (4b)*
   - substrate, in-stream cover, channel, riparian, pool/riffle, and gradient quality
   - bedload
   - attributes that have a strong association with degraded aquatic communities

Each cause of impairment listed in Chapter 2 relates to one or more of the above factors. Each of these factors has a numeric target condition associated with it that serves as a goal that if all are met the water resource would be expected to attain its use designation.

3.2 Target Conditions

3.2.1 Load-based Pollutants and In-stream Conditions

Phosphorus and Total Suspended Solids
Nutrients were identified as a cause of impairment in the Big Darby Creek basin. Nutrients rarely approach concentrations in the ambient environment that are toxic to aquatic life, and nutrients in small amounts are essential to the functioning of healthy aquatic ecosystems. However, nutrient concentrations in excess of the needs of a balanced ecosystem can exert negative effects by increasing algal and aquatic plant life production (Sharpely et al., 1994). This increases turbidity, decreases average dissolved oxygen concentrations, and increases fluctuations in diel dissolved oxygen

River ***geomorphology*** is the study of the channel forming processes that operate in river systems.

and pH levels. Such changes shift species composition away from functional assemblages comprised of intolerant species, benthic insectivores, and top carnivores typical of high quality streams towards less desirable assemblages of tolerant species, niche generalists, omnivores, and detritivores typical of degraded streams (Ohio EPA, 1999). Such a shift in community structure lowers the diversity of the system; the IBI and ICI scores reflect this shift and may a stream may be precluded from achieving its aquatic-life use designation. Phosphorus was selected as the nutrient to focus on because it is frequently the limiting nutrient to algal growth in the fresh water streams of Ohio.

Total suspended solids (TSS) are particles in the water that can be trapped by a filter. High concentrations of TSS can reduce the amount of sunlight available to aquatic organisms and decrease water clarity. This leads to a number of effects including reduction of aquatic plants available for consumption by higher level organisms, lower dissolved oxygen, and the impaired ability of fish to see and catch food. TSS particles can also hold heat resulting in increased stream temperature. Further, TSS can clog fish gills, retard growth rates, decrease resistance to disease, and prevent egg and larval development. When TSS settles, eggs of fish and invertebrates are smothered, larvae can suffocate, and habitat quality is degraded (http://bcn.boulder.co.us/basin/data/FECAL/info/TSS.html).

While the Ohio EPA does not currently have statewide numeric criteria for phosphorus and TSS, 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 the biological communities of Ohio streams. It recommends total phosphorus (TP) and TSS target concentrations based on observed concentrations associated with acceptable ranges of biological community performance within each ***ecoregion***. The targets applicable to the Big Darby Creek watershed are shown in Table 3.1. It is important to note that these targets are not codified in Ohio's water quality standards; therefore, there is a certain degree of flexibility as to how they can be used in a TMDL setting.

Ohio's standards also include narrative criteria that prohibit excessive input of pollutants to water resources of the state. There are five applicable narrative criteria and these are listed under the organic enrichment discussion below. They apply to excessive concentrations of nutrients and sediment as well as to organic enrichment.

Ecoregions denote areas of general similarity in ecosystems and in the type, quality, and quantity of environmental resources such as geology, soils, and natural vegetation.

Table 3.1 TP and TSS targets for the Big Darby Creek watershed[1]

Watershed Size / *Use Designation:*	TP mg/l		TSS mg/l	
	WWH	*EWH*	*WWH*	*EWH*
Headwaters (drainage area < 20 mi^2)	0.07	0.05	10	10
Wadeable (20 mi^2 ≤ drainage area < 200 mi^2)	0.11	0.08	31	26
Small Rivers (200 mi^2 ≤ drainage area < 1000 mi^2)	0.16	0.17	44	41

[1] Based on the Eastern Corn Belt Plains Ecoregion

Sediment

In the context of this TMDL, bedload is the streambed material and the soil particles and solids that have settled out of the water column. The total sediment load carried by the stream is the sum of TSS and bedload. The sediment load to the stream generally implies the runoff of soil particles and the solids loading from septic and point sources. The actual quantity of bedload is difficult to calculate accurately, and this load is not necessarily indicative of impairment as it is not necessarily the quantity of streambed sediment that is a stressor but rather the size and quality of the sediment particles themselves. Therefore, a qualitative approach similar to habitat measurements is used to determine the relative difference in the bedload between stream sites. The bedload and habitat targets will be discussed jointly in Section 3.2.4.

Bacteria and Pathogens

Excessive loading of pathogenic organisms is the cause of recreational use impairment in the Big Darby Creek sub-basin. The number of pathogenic organisms present in polluted waters are generally difficult to determine, and these organisims are highly varied in their characteristics and types. Therefore, scientists and public health officials typically choose to monitor nonpathogenic bacteria that are usually associated with pathogens transmitted by fecal contamination but are more easily sampled and measured. These associated bacteria are called indicator organisms (U.S. EPA, 2001). For the purpose of this report, fecal coliform bacteria were selected as the indicator organism.

Numeric targets for fecal coliform are derived from bacteriological water quality standards. The criterion for fecal coliform specified in OAC 3745-1-07 are applicable during the recreation season defined as May 1st to October 15th, and state that the geometric mean content, based on not less than five samples within a thirty-day period, shall not exceed 1,000 per 100 ml and shall not exceed 2,000 per 100 ml in more than 10 percent of the samples taken during any thirty-day period. As written these criteria establish both chronic and acute permissible in-stream fecal coliform concentration.

Dissolved Oxygen and Organic Enrichment

Organic enrichment is the term used to describe the excess loading of organic oxidizable material which results in depressed dissolved oxygen (dissolved oxygen) concentrations. The potential sources of organic enrichment are numerous, and the degree of the impact upon dissolved oxygen and aquatic life is dependent on a complex array of in-stream and near-stream processes and conditions. Organic enrichment is not explicitly listed in Ohio water quality standards, but falls under the general water quality criteria of Ohio Administrative Code (OAC) 3745-1-04 applicable to all waters of the state, wherein, to every extent practical and possible as determined by the director, these waters shall be:

(a) Free from suspended solids or other substances that enter the waters as a result of human activity and that will settle to form putrescent or otherwise objectionable sludge deposits, or that will adversely affect aquatic life;
(b) Free from materials entering the waters as a result of human activity producing color, odor or other conditions in such a degree as to create a nuisance;
(c) Free from substances entering the waters as a result of human activity in concentrations that are toxic or harmful to human, animal or aquatic life and/or are rapidly lethal in the mixing zone;
(d) Free from nutrients entering the waters as a result of human activity in concentrations that create nuisance growths of aquatic weeds and algae;
(e) Free from public health nuisances associated with raw or poorly treated sewage.

Low dissolved oxygen is the primary deleterious effect on aquatic life resulting from organic enrichment. One measurable endpoint of this TMDL is to attain the dissolved oxygen water quality criterion at all times including summer, low-flow conditions that are critical to aquatic life. The dissolved oxygen criteria varies with aquatic life use designation; these criteria are listed in Table 3.2.

Table 3.2 Dissolved Oxygen (mg/l) criteria[1]

	Aquatic Life Use Designation				
	EWH	WWH	MWH	CWH	LRW
Average over a 24-hour period	6.0	5.0	4.0	7.0	3.0
Minimum	5.0	4.0	3.0	6.0	2.0

[1] From Table 7-1 of OAC 3745-1-07

Ammonia, Metals, Temperature and Other Pollutants

Ohio's water quality criteria for ammonia nitrogen are based on the stream's designated use, pH and temperature. The criteria are tabularized and can be found in OAC 3745-1-07, Tables 7-2 through 7-8. Ohio's water quality criteria for metals are based on the stream's hardness. The criteria are tabularized and can be found in OAC 3745-1-07, Table 7-9. Temperature criteria vary by use and by month, and are listed in Tables 7-1 and 7-14 in OAC 3745-1-07. All of these tables are located at: http://www.epa.state.oh.us/dsw/rules/01-07.pdf.

Ammonia, metals, and other miscellaneous pollutants are not impairing factors for the entire watershed. Only certain sources in some sub-watersheds are associated with these pollutants. The specific criteria and targets used to establish allowable loads for these sources will be specified in the load tables or will be identified in the analyses if loads are not calculated for them.

3.2.2 Flow Quantity and Changes in Hydrology

Hydrology is the distribution and movement of water in the environment; it follows a cyclical pattern as depicted in Figure 3.2 (FISRWG, 1998). Precipitation falls on the land where it can do one of three things: be intercepted by plants or storage structures, run off the land surface, or infiltrate into the ground. The infiltrated water can be stored in the soil layer (called the unsaturated zone) or percolate deeper into the groundwater region (the saturated zone). Migration of precipitation to groundwater is called groundwater recharge. Evaporation, plant uptake of soil water, and plant transpiration returns water to the atmosphere completing the cycle.

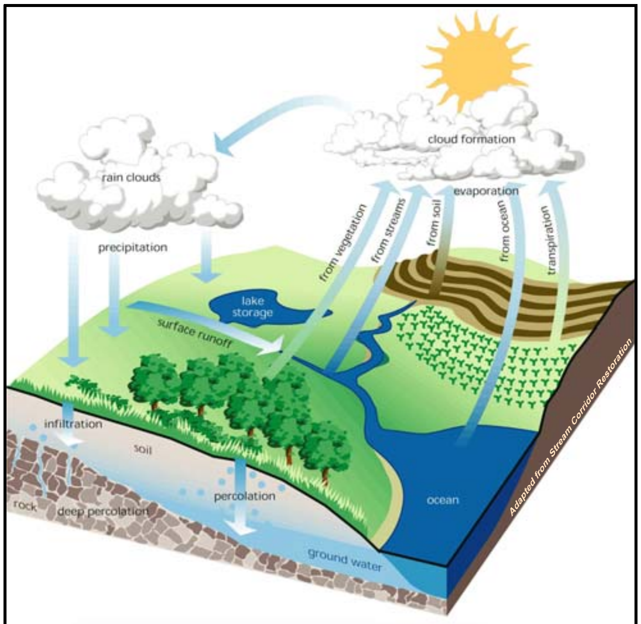

Figure 3.2 The Hydrologic Cycle

Streamflow is the sum of groundwater seepage (baseflow), surface runoff, and direct precipitation. The hydrology of a watershed establishes a streamflow pattern including a range of peak and low streamflow amounts and the frequency at which a particular streamflow occurs. Over time, this pattern develops a dynamic equilibrium with the stream channel and flood plain, and they are formed in balance with the energy of the reoccurring streamflows and the geology of the system. This dynamic equilibrium, in part, depends on the magnitude and frequency of the ***effective discharge*** remaining constant over time and the ability of the flood plain to dissipate the energy of flows exceeding the effective discharge (Ward, 2002).

Changes to hydrology due to human intervention can alter the natural streamflow regime. Changes in the land cover and use from a more natural state to a more managed state results in increased surface runoff and decreased groundwater recharge. As watersheds become increasingly impervious due to roofs, roads, parking lots, and managed fields and lawns, less water is able to infiltrate/percolate to the groundwater leading to reduced baseflows, and more precipitation runs off the land faster during storms leading to higher peak flows. Agriculturally managed lands with poorly drained soils mimic this process to a lesser degree, as infiltrated water is

The ***effective (or bankfull) discharge*** is the flow which has the largest influence on forming the stream channel.

intercepted by drainage tiles and routed to nearby streams. Additional changes to the hydrologic cycle include interception, storage, and discharge of water for municipal and industrial uses. The amount of water may remain the same, but the balance and the pattern of the flow is altered.

Direct alteration of the stream channel and riparian zones by channelization, levees, changes to the bank materials, or other related actions also affect the streamflow regime. Natural channels seek to reduce the energy of the streamflow by slowing the water in meanders and having available areas adjacent to the stream where excess flow can spread and velocity of the flow can decrease (the active flood plain). This reduces flooding outside of the active flood plain, decreases bank and bed erosion, allows suspended material to be deposited on the flood plain instead of the streambed, and results in lower overall peak stream flows and stream stage. As channels are straightened and/or confined, the stream flow energy does not have an outlet with which to decrease its power. This propagates downstream increasing peak flows, channel down-cutting, flooding downstream, bank erosion, and channel de-stabilization. Other stressors are contributed to as well such as increased sedimentation, suspended solids, and degraded habitat.

The numeric targets associated with flow quantity and hydrology are based on the relationship of baseflow and runoff to total streamflow and the amount of groundwater recharge from a stable hydrologic and streamflow regime. This is determined from historic USGS flow data in the watershed and hydrologic model results per sub-watershed based on land use prior to de-stabilization of stream patterns. Most sub-watersheds in the Darby have a stable hydrologic pattern currently and the hydrologic targets for these areas are the existing condition. Developed and developing watersheds have hydrologic targets established from conditions that existed prior to the significant alteration in the streamflow regime.

3.2.3 Geomorphology of the Channel

The hydrology of a watershed is a driving force for both streamflow and stream form. Stream form and the processes associated with it is the geomorphology of the channel. The geomorphology impacts the aquatic environment by affecting the way pollutants are processed in the stream and by setting the foundation for aquatic habitat. Geomorphological processes include the erosion, transport, and deposition of sediment by streamflow which form the channel and the flood plain. The channel and flood plain, in turn, affect how sediment is processed. The relationship is dynamic, and the system works towards a balance between input of material and output of it.

Maintaining the dynamic equilibrium of the Big Darby Creek watershed is part of the suite of actions needed to restore and protect this system. A consistent effective discharge and the ability to dissipate energy associated with higher flows are key factors to this equilibrium. Other contributing factors include achieving a balance between sediment transport, storage and supply and allowing the main channel to adjust its dimension, pattern, and profile to maintain equilibrium (Ward et al., 2002).

Adequate flood plain that is available to the stream during higher flow events is crucial to maintaining such a stable stream system. An adequate width is one which includes the meander pattern of the stream over time and provides an area for flow dissipation during high flow events. The numeric targets for flood plain widths used in this report are from the research of scientists at the Ohio Department of Natural Resources (ODNR). Their research indicates that the wider the stream corridor is, the better it is for the stream environment; however, the area immediately adjacent to the channel is the most critical. The flood plain width targets are in multiples of the bankfull channel width. The ***bankfull width*** for streams in the Big Darby watershed can be estimated from an equation developed by Dan Mecklenburg of the ODNR (personal communication, November 2004). This is the equation of the regression line of bankfull data points, drainage areas, and other stream channel parameters collected in west central Ohio streams. The equation relates bankfull width (W, ft) to drainage area (DA, mi^2):

$$W = 13.3\ DA^{0.43} \qquad \textit{(Equation 3.1)}$$

ODNR established active floodplain performance standards for streams as a function of stream quality (Ohio NPSM, 2004). Ten times the bankfull width is typical of the highest quality streams and is prescribed as the recommended flood plain width for streams designated EWH. Five times the bankfull width is frequently associated with streams of moderate quality; this factor is prescribed for streams designated WWH. Finally, three times the bankfull width is a minimum; this factor is prescribed for streams designated MWH. These multipliers combined with equation 3.1 result in the following minimum flood plain widths (B, ft) per aquatic life use designation:

$$B_{EWH} = 133\ DA^{0.43} \qquad \textit{(Equation 3.2)}$$

$$B_{WWH} = 67\ DA^{0.43} \qquad \textit{(Equation 3.3)}$$

$$B_{MWH} = 40\ DA^{0.43} \qquad \textit{(Equation 3.4)}$$

The flood plain width is the total width including the flood plain on both sides of the stream and the bankfull width. The equations represent the minimum width needed based on scientific data specific to the Big Darby Creek area. It is also essential that the flood plain be accessible to the stream during bankfull storm events.

Watershed groups and other interest groups such as the Hellbranch Environmentally Sensitive Development Area (ESDA) External Advisory Group may choose to increase the minimum recommended widths needed based on additional justifications. The equations proposed by the ESDA are based on data applicable to a wider geographic region and therefore vary slightly from those used here. The ESDA group recommended the appropriate flood plain width to be the largest of the following 3 quantities: the 100-year regulatory flood plain, the result of their equation similar to Equation 3.2, or 200 feet. More information on geomorphology and the flood plain width

Bankfull width is the width of the active channel during the effective discharge.

targets used in this TMDL report is available at:
http://www.epa.state.oh.us/dsw/nps/NPSMP/SI/sicomponentsmorph.html.

3.2.4 Habitat and Bedload Quality

Ohio EPA uses the Qualitative Habitat Evaluation Index (QHEI) to assess the physical habitat quality of streams and rivers (Rankin 1989, 1995). This index measures the important components of stream habitat that are essential to sustaining high value aquatic communities. The components include substrate quality, instream cover (physical structure), stream channel morphology and condition, riparian quality and bank erosion, pool and run-riffle quality, and gradient. Analysis of an extensive dataset of paired QHEI and IBI scores led to the development of target QHEI scores generally shown to be supportive of the biological assemblages typical of WWH and EWH (Ohio EPA, 1999). Comparisons between the QHEI attributes within each component and the IBI resulted in a list of specific habitat attributes that are particularly associated with degraded communities (referred to as modified attributes). These attributes were then grouped as either high influence or moderate influence modified attributes based on the statistical relationship of the presence of an attribute and the IBI score at each site. The recommended targets for habitat per aquatic life use designation are shown in Table 3.3.

The QHEI can also be used to evaluate the degree of bedload and the quality of the substrate at a particular site. The substrate, riparian characteristic, and channel metrics all evaluate stream attributes related to bedload. The substrate metric includes an assessment of streambed sediment quality, quantity, and origin. The riparian metric evaluates riparian width, quality, and bank erosion. The channel metric describes stream physical morphology including sinuosity and extent of development. Each of these factors influences the degree to which siltation affects a stream, and cumulatively serves as its numeric target. Table 3.3 summarizes the bedload TMDL targets.

Table 3.3 Habitat and Bedload TMDL targets

Attribute	Target	
	WWH	EWH
Habitat TMDL targets:		
Number of any Modified Attributes	<5	<3
Number of High Influence Modified Attributes	<2	0
Overall QHEI Score	≥60	≥75
Bedload TMDL targets:		
Substrate Metric Score	≥13	≥15
Channel Metric Score	≥14	≥15
Riparian Metric Score	≥5	≥5

3.2.5 Protecting the Downstream Use

Aquatic life use designations are determined based on a stream or stream segment's ability to support a particular level of aquatic life; it is a stream-specific determination. When a stream with a lower use designation flows into one with a higher use designation, the criteria of the downstream use needs to be maintained. Therefore, there are times when the applicable criteria in a waterbody may need to be more restrictive than those associated with its designated use in order to protect the designated use of the downstream segment or stream.

3.3 Summary of Methods

A different method of analysis was used for each of the stream integrity components in Figure 3.1. The suite of methods selected address the major impairing factors in the Big Darby Creek watershed; each individual method addresses one or more of the following areas listed by section number:

- 3.3.1 Determine the hydrologic response by quantifying the long term average groundwater recharge rate and baseflow and runoff distribution per sub-watershed.
- 3.3.2 Determine the load contributions to the stream from:
  - nonpoint source activities originating on the watershed landscape;
  - municipal and industrial facilities and activities; and,
  - septic system inputs from systems without functioning leach fields.
- 3.3.3 Determine the in-stream response to external loads. Analyze variations in in-stream concentrations to refine cause and source assessment.
- 3.3.4 Establish current flood plain widths in pilot areas. Determine recommended widths in each sub-watershed.
- 3.3.5 Establish current habitat conditions and quantify desired habitat goals per site.

Multiple methods were needed given resource constraints (time and data availability) and applicability. The techniques selected are the most appropriate, applicable, and available methods for the goals and constraints of this project. Tables 3.5 and 3.7 summarize the evaluation methods selected for this TMDL project.

3.3.1 Hydrologic Response

Description of Method
The hydrologic cycle for the Big Darby Creek and its sub-watersheds was simulated using the Generalized Watershed Loading Function or GWLF model (Haith et al, 1992) through the desktop simulation form of this model called BasinSim 1.0 (Dai et al, 2000). The model predicts stream flow based on precipitation, evapotranspiration, land uses, and soil characteristics. Figure 3.3 shows the hydrologic model of GWLF.

GWLF simulates runoff, groundwater recharge, and stream flow by a water-balance method using measurements of daily precipitation and average temperature. Runoff is calculated using a form of the Natural Resources Conservation Service's Curve Number method (SCS, 1986). The Curve Number determines the amount of precipitation that runs off the surface and is adjusted for antecedent soil moisture before the precipitation event, growing or dormant season, detention potential, and for soil characteristics. The Curve Number is an empirical equation based on an extensive database of observed data. The Curve Number varies by land cover, use, and soil type; the higher the curve number the more runoff produced. The surface runoff flow the Curve Number method predicts any ‘quick response’ flow including interflow and drainage from tiles.

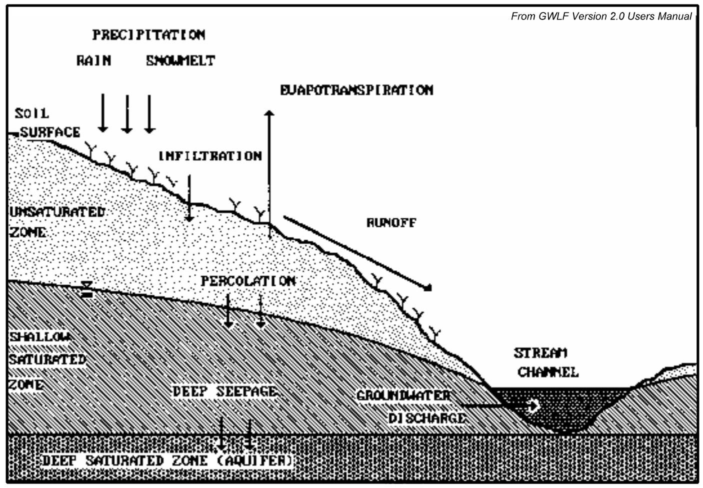

Figure 3.3 The components of the hydrologic cycle calculated by GWLF

Groundwater recharge is determined by tracking daily water balances in the unsaturated and shallow saturated zones; these zones act as reservoirs and have inputs and outputs. The input to the unsaturated zone is the infiltrated water calculated as the amount of the precipitation received less the surface runoff. Outputs of this zone include the moisture lost via plant root uptake (which is lost to the atmosphere in a process called evapotranspiration) and percolation down to the saturated zone. Evapotranspiration is estimated based on the available moisture in the unsaturated zone, the potential evapotranspiration based on day length and temperature, and a cover coefficient based on the type of plant or crop in the area of interest. Percolation occurs when the unsaturated zone volume exceeds the soil water capacity.

The shallow saturated zone receives the percolated water. This zone is treated as a linear reservoir. It can discharge water to the stream as baseflow or lose moisture to deep seepage, at a rate described by the product of the zone's moisture storage and a constant rate coefficient.

Stream flow is computed as the sum of the groundwater discharge from the shallow saturated zone and the surface runoff. The model computes the daily water balance and resulting stream flow allowing comparison of the GWLF-predicted values to a daily record of stream flow such as is collected at USGS flow gages. There are three active USGS gages in the Big Darby Creek watershed:

03230310 Little Darby Creek at West Jefferson, Ohio (162 mi^2 drainage area)
03230450 Hellbranch Run near Harrisburg, Ohio (37 mi^2 drainage area)
03230500 Big Darby Creek at Darbyville, Ohio (534 mi^2 drainage area)

The model was run for each of the areas upstream of these gages using weather data based on several weather stations from around the watershed. A ten year simulation from April 1994 through March 2004 was performed, and the predicted stream flows based on the model results were compared to the observed data from the USGS gages. Two values are used to determine how well the predicted values compare to the observed. The coefficient of determination (the R^2 value) is a statistic that can indicate the relationship between two data sets and is a unitless measure ranging from 0 to 1. Higher values indicate the curve representing the model results are closer to observed data curve with 1 being a perfect fit. The predicted to observed ratio indicates if the model is under or over predicting the stream flow in general and also how well the two data sets compare. The results of this comparison are summarized in Table 3.4.

A joint study by the ODNR and USGS analyzed USGS flow data in Ohio to determine groundwater recharge rates and is summarized in the report *Use of Stream flow Records and Basin Characteristics to Estimate Ground-Water Recharge Rates in Ohio* (ODNR, 2002). The report estimates groundwater recharge rates and the mean baseflow to mean stream flow ratio for USGS gages in Ohio. The three active gages in the Big Darby watershed were included in the report. The findings for these USGS gages based on this study and the GWLF results are also shown in Table 3.4.

Table 3.4 Comparison of GWLF Predicted Streamflow with USGS Streamflow Values

Gage #	Stream	R^2 Value	Predicted to Observed Ratio	ODNR/USGS study % of Mean Stream flow		GWLF Model % of Mean Stream flow	
				Baseflow	Runoff	Baseflow	Runoff
03230310	Little Darby Ck	0.883	1.02	50.8	49.2	51.2	48.8
03230450	Hellbranch Run	0.884	0.99	41.2	58.8	41.4	58.6
03230500	Big Darby Ck	0.895	1.03	46.2	53.8	46.5	53.5

Sources of Data

Landuse, soil, and weather data are critical components of GWLF. A combination of data from a variety of sources supplied the landuse data used in this analysis. No single landuse data set supplied the land cover resolution needed in this analysis. The simulation is for a 10-year period; therefore, land use spanning this period was needed as well. The base layer is the National Land Cover Dataset (NLCD). The NLCD was compiled from Landsat™ satellite imagery circa 1992 and includes 23 classes of land use (USGS, 2000). A more rigorous analysis of forested land cover in the Darby Creek watershed was done by Ohio EPA in 1998. This data was based on 1997 Landsat 5 satellite imagery. The information from this study was merged with the NLCD. The

Ohio EPA funded a project by the University of Cincinnati to update the land use data of Ohio (Ohio EPA, 2001). This dataset is based on 2000 and 2001 Landsat 7 satellite imagery, but has fewer land use classes. The updated and the merged land use sets were compared; where land use changes had occurred based on the newer landuse they were added to the merged dataset (for example, agricultural land changed to urban). Figure 2.1.2 shows the merged land use dataset results and Chapter 2 shows landuse distribution charts by sub-watershed based on this merged dataset. Two other landuse covers were used in the analysis as well. Land use from 1997 based on Landsat Thematic Mapper Data was utilized to refine the row crop land cover into wheat, soybean and corn crops. This data is available online from Ohio State University and Dr. Gordon (http://facweb.arch.ohio-state.edu/sgordon/research/darby/bdlu97.html). The Hellbranch sub-watershed is a rapidly developing area. A third quarter 2003 land use distribution for the Hellbranch was prepared by the Hellbranch Forum and FMSM Engineers. This landuse set was used to evaluate changes in the hydrologic response of the Hellbranch sub-watershed to its changes in landuse.

Soil properties and distribution is collected by the National Resources Conservation Service (NRCS) through county level soil surveys. This data is tabularized and is available in a newer version through the National Soil Information System (NASIS) or the original format the Map Unit Interpretation Record (MUIR). These tables are linked with a digitized mapping system into the Soil Survey Geographic Database (SSURGO). SSURGO is the most detailed soil information available through NRCS and is available on a county basis. However, Logan, Clark, and Champaign counties had only the tabularized data without the associated mapping system available at the time of this study. The Ohio Capability Analysis Program (OCAP) mapping units were linked with the NASIS and MUIR tables to supply the soil information for these counties.

Several weather stations were used from around the Big Darby watershed and its surrounding area. Daily precipitation and temperature data were supplied by NOAA weather stations in the following communities:

- Marysville
- London
- Bellefontaine
- Springfield
- Delaware
- South Charleston
- Urbana
- Columbus

The model stream flow predictions fit the best with observed flow data when the daily averages of all of the weather stations was used as the input weather data set.

3.3.2 Loads to the Stream

3.3.2.1 Total Phosphorus and Sediment

Description of Method

The total phosphorus and sediment loads to the streams of the Big Darby Creek watershed are the sum of the contributions from nonpoint sources, septic systems, and point sources. The load from nonpoint sources was simulated using the GWLF model which uses loading functions specific to each sub-watershed in conjunction with the calculated hydrologic components to predict nutrient and sediment loads from surface runoff and groundwater.

The GWLF model calculates the total nutrient and sediment load per specified watershed area. The Big Darby watershed has 20 sub-watersheds as shown in Figure 2.1; GWLF models were constructed for each of these 20 areas. Within each watershed area GWLF requires that each land use be categorized as either a rural or urban land use which determines how the model calculates the loading from that particular land use area. For the purposes of modeling, “rural” land uses are those with predominantly pervious surfaces, while “urban” land uses are those with predominantly impervious surfaces. Some land uses are appropriate to divide into a pervious (“rural”) and impervious (“urban”) fractions for simulation.

The total phosphorus load is composed of both dissolved and solid-phase forms of phosphorus. Rural loads are transported in runoff water and eroded soil or in a dissolved form from field tiles. The solid-phase rural phosphorus loads are the product of the monthly sediment yield and the average concentration of the phosphorus in the eroded soil. The monthly sediment yield represents the rural sediment load, and is the product of erosion and the sediment delivery ratio. Erosion is calculated using the Universal Soil Loss Equation (USLE) (Wischmeier and Smith, 1978) and watershed-specific input values. The sediment delivery ratio is the ratio of the actual sediment that travels to a watershed outlet versus the total amount of sediment that is detached within the watershed; it is an empirical value relating watershed drainage area to the delivery ratio. The concentration of phosphorus in surface sediment is based on several sources including OSU Extension data and sediment data from the Darby watershed. The dissolved phosphorus load is contributed to by groundwater and rural runoff. Dissolved loads are the product of the volume of water per source and the total phosphorus concentration of that source. Groundwater concentrations were based on groundwater data in the Darby watershed, and dissolved phosphorus concentrations in runoff from each land use was based on empirical nationwide data and tile data collected in the Darby watershed.

For urban land uses, soil erosion is not calculated, and delivery of phosphorus to streams is based on an exponential accumulation and washoff formulation. Nutrients accumulate on urban surfaces over time and approach an asymptotic maximum value. GWLF assumes the accumulation of nutrients reaches 90% of the maximum accumulation in 20 days based in part on research by Sartor and Boyd (1972).
A percentage of this accumulation is washed off during a runoff event. The greater the amount of rain, the greater the washoff percentage is. Data from Amy et al. (1974) indicates that 0.5 inches of rain will wash off 90% of accumulated pollutants. The monthly runoff load from urban land uses is the sum of the daily product of the washoff function and the accumulation function. All nutrients loaded from urban land uses are assumed to move in association with solids.

Data on septic system numbers and performance is not extensively available in the Big Darby watershed. In lieu of this an analysis to determine the potential for failing septic systems was done by Ben Webb, the Darby Creek Watershed Coordinator (Webb, 2004). This analysis used soils and census data in a GIS platform to estimate the number of people served by septic systems and the potential of those systems to not operate optimally based primarily on soil properties. The study found the majority of the soils in the Darby watershed were not conducive to proper home septic system performance.

Ohio EPA discussions with Franklin County Board of Health personnel about this situation determined that where soils are particularly bad, or a proper leach field is not available, alternative systems are installed such as aeration systems. In addition, illegal fixes can occur where existing septic systems are tied into drainage tile. These alternative systems and illegal hook ups can result in direct discharges to waterways. The existing septic loads estimated for this analysis assume most of the septic load to a stream comes from these direct discharges. The known number of alternative systems (Webb, 2004) plus a percentage of the remaining systems to account for other direct septic inputs was estimated. Literature values for flow and septic system quality of total phosphorus and solids and the total number of direct systems determined the septic system load per sub-watershed. Figure 3.4 shows the known number of aerators per township in the Big Darby watershed. The allowable septic load applies only to those systems which meet the legal requirements of OAC 3701-29 and OAC 3701-29-08.

Loads from municipal and industrial facilities which discharge to a waterway were calculated based on actual data from these facilities. Dischargers are generally required to monitor their effluent and report the data to Ohio EPA. In addition, Ohio EPA performs compliance monitoring. Figure 2.1.3 shows the dischargers and their discharge locations in the Big Darby watershed.

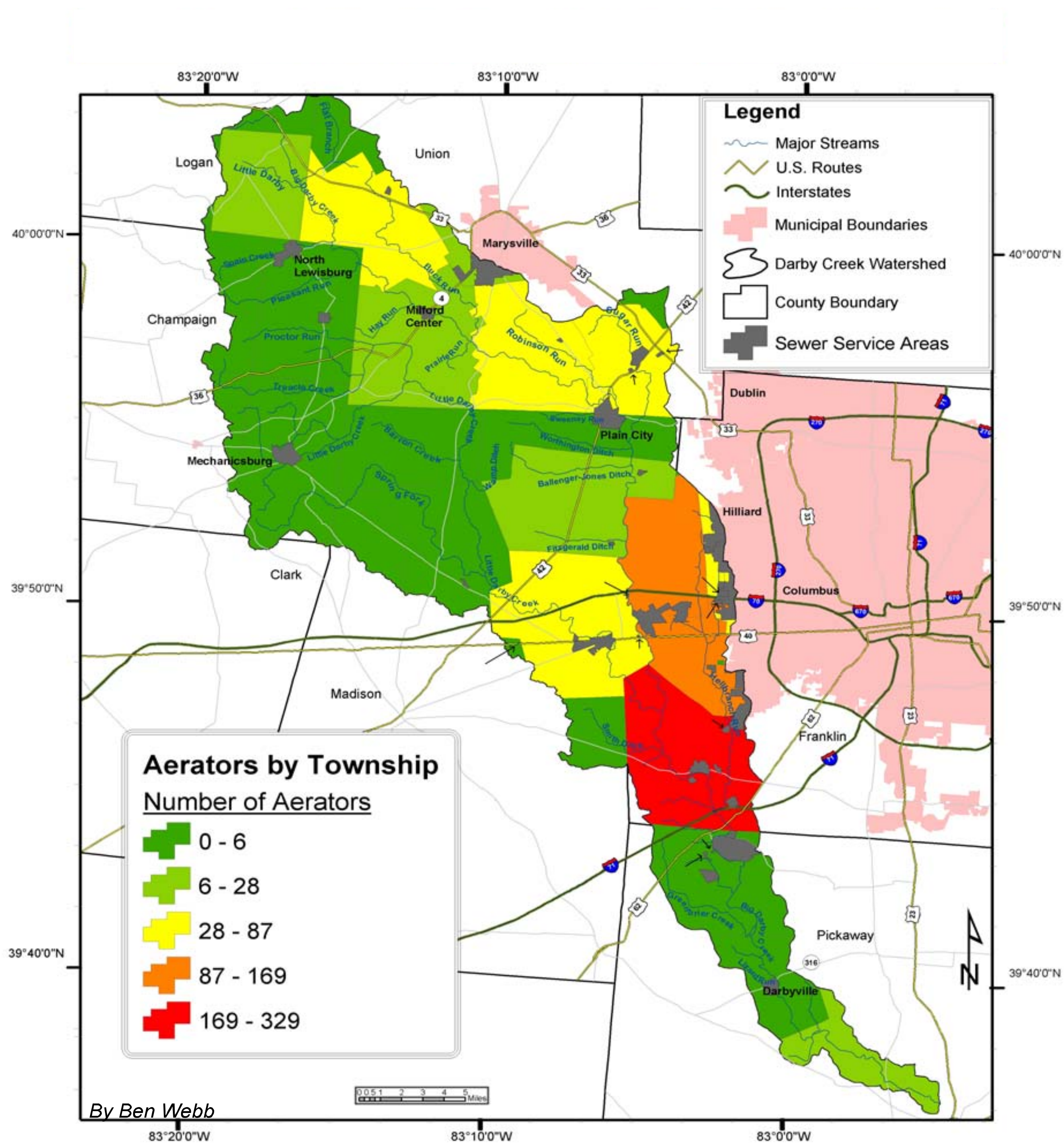

Figure 3.4 Known Aerators by Township in the Big Darby Creek Watershed

TMDL Calculation and Allocation
The allowable total phosphorus and suspended sediment loads were calculated by multiplying the average total annual volume of flow from a sub-watershed by the target in-stream concentrations discussed in Section 3.2.1. This gives an average annual allowable load. The average annual volume is the average of the total annual volumes calculated by GWLF each ***hydrologic year*** from April 1994 through March 2004. The overall percent reduction needed was based on the difference between the existing annual load and the allowable annual load.

The allowable load was allocated among a variety of factors - a margin of safety, a natural load, a point source load, a septic load, a runoff load, and a groundwater load. Five percent of the total load was removed to account for data uncertainties and allocated to the margin of safety factor. A natural load was calculated based on what the runoff and groundwater load would be if the landuse were all unmanaged lands such as forest, prairie, and wetlands. The point source load was the load necessary to meet water quality targets in-stream as calculated by models discussed in Section 3.3.3. The septic load was based on the largest percent reduction needed for the sub-watershed of interest between total phosphorus, suspended sediment, and fecal coliform. The reduction needed by one of these pollutants would result in the same reduction percentage for the other pollutants as the septic systems would need to be returned to functional treatment systems. These allocated loads were removed from the allowable load, and the remaining allowable load was divided by an equal percent reduction between the groundwater and runoff loads.

3.3.2.2 Bacteria and Pathogens

Description of Method
The total fecal coliform load to each sub-watershed is the sum of the washoff load from the land, direct animal inputs, septic system loads, and point source loads. The U.S. EPA's Bacteria Indicator Tool (BIT) was employed to estimate the fecal coliform load accumulated within each sub-watershed in the Big Darby Creek watershed, the direct animal inputs, and the septic system loads. Point source loads were based on actual data as reported by each facility or as monitored by Ohio EPA. Fecal coliform is the indicator bacteria used in this analysis to represent pathogen and other bacteria levels. BIT estimates the monthly accumulation rate of fecal coliform bacteria on four land uses (cropland, forested, built-up, and pastureland), as well as the asymptotic limit for the accumulation should no washoff occur. The tool also estimates the direct input of fecal coliform bacteria to streams from grazing livestock and failing septic systems (U.S. EPA, 2000).

BIT requires three types of values: user-defined, default, and literature. User-defined values are to be specific to the study area. User-defined values required by the tool are land use distribution, numbers of livestock, wildlife densities, number of home sewage treatment systems (HSTS), and the failure rate of HSTS. Default values are supplied by the tool, but it is suggested that they be modified to reflect patterns in the study area.

A ***hydrologic year*** as defined by GWLF is from April 1st to March 31st.

Default values include fraction of each manure type applied each month, fraction of manure type that is incorporated into the soil, and time spent grazing and confined by livestock. Like default values, literature values are supplied by the tool, but they may be replaced with user values if better information is available for the study area. Literature values required by the tool are animal waste production rates and fecal coliform bacteria content, fecal coliform bacteria accumulation rates for built-up land uses, and raw sewage fecal coliform bacteria content and waste production.

Literature and most default values were unchanged because limited watershed-specific information was available. User-defined values were determined via the following methods:

- The land use distribution was derived as discussed in Section 3.3.1. The land use was reclassified to agree with the land use categories of BIT.

- The number of HSTS and the percentage of those which are failing were based on the analysis discussed in Section 3.3.2.1.

- Information regarding livestock counts was obtained from county census data in consultation with Soil and Water Conservation District staff per county.

- Populations of wildlife and dogs were derived from countywide figures. Information regarding dog populations was obtained from county census data. Information regarding wildlife populations was obtained from Ohio Department of Natural Resource census data. In each case, the total number of animals within the county was divided by the total number of acres of relevant land use in the county. The resulting animal densities (animals per acre) were used to estimate the animal populations within each sub-watershed.

- Direct input of bacteria by cattle in streams was limited only to those streams with evidence of cattle access as determined by Ohio EPA and ODNR field staff. Direct input of bacteria by geese in streams was limited to those areas where a concentration of geese are likely to occur or were observed to occur such as golf courses and other mowed areas along waterways.

BIT predicts the maximum surface accumulation rate of fecal coliform, and the asymptotic limit of accumulation should no washoff occur. The actual washoff load was determined by combining the accumulation from BIT, the runoff computed by GWLF, and literature values relating runoff to washoff rates as discussed in Section 3.3.2.1.

TMDL Calculation and Allocation

The allowable bacteria load for the recreational season (May-October) was determined based on the allowable monthly load for each month in the season. The allowable monthly load for each month was calculated by dividing the total existing monthly load by the total monthly stream flow volume to give the average in-stream concentration of bacteria for that month. This existing concentration was compared to the 30-day fecal coliform criterion and the needed percent reduction was determined. The recreational season allowable load was the product of the needed percent reduction and the total seasonal existing load.

Table 3.5 Summary of the Methods Used to Evaluate Loads to the Stream

Evaluation Method	Sources	Parameters	Time Period
GWLF	Overland Runoff Groundwater Air Deposition	Sediment Total Phosphorus Flow	Monthly Loads; Daily Flows
GIS/ Literature Values	Septic	Solids Total Phosphorus Flow	Daily
BIT	Overland Accumulation Direct Animal Access Septic	Fecal Coliform	Monthly Loads
Monitored Effluent Data	Municipal and Industrial Point Sources	Solids and TSS Total Phosphorus Fecal Coliform Flow Ammonia	Daily
GWLF/ In-stream Data	Bank Erosion	Sediment	Annual

Notes:
Existing conditions evaluated based on a 10-year simulation from April 1994- March 2004.
Loads totaled for each of the 20 sub-watersheds in the Big Darby Creek watershed.
Allowable loads are the product of the average yearly total stream flow and applicable targets.

The allowable load was allocated to point sources, septic systems, and nonpoint sources consisting of washoff and direct animal inputs. The margin of safety is implicit and discussed in Section 3.5. Point sources were a very insignificant portion of the total load, and as such, were set at their existing permitted loads. The septic system allocation was based on the largest percent reduction needed between total phosphorus, suspended sediment, and fecal coliform for the sub-watershed of interest. These allocated loads were removed from the allowable load, and the remaining allowable load was divided by an equal percent reduction between the washoff and direct animal input loads.

3.3.3 Response in the Stream

Total Phosphorus, TSS, and Bacteria
Duration curves show the percent of time a value is equaled or exceeded within its data set. Flow duration curves relate any individual flow within a flow record with the percent of time that particular flow value is equaled or exceeded. In this application, flow

duration curves are developed by ordering median daily flows from high to low and calculating the rank of each flow value as a percentage of the entire flow record. A long term continuous record of flow is needed to properly characterize the hydrologic response of a watershed. A load duration curve (LDC) is simply the flow duration curve multiplied by the applicable water quality target concentration, such as a water quality criterion. Flow multiplied by the allowable in-stream concentration gives the allowable load for that flow. The load duration curve is the TMDL for each flow condition observed in the period of record. The utility of the load duration curve (or the TMDL curve) is increased by adding observed loads to the LDC graph. The observed load can then be compared to the allowable load under the range of flow conditions data were collected for. If there are sufficient observed data, patterns may emerge that demonstrate which hydrologic conditions have loads exceeding the target. This assists with allocating the available load and helps to direct implementation actions. Duration curves do not predict or simulate conditions. Instead, they serve as a method to visualize patterns in the observed data and to set allowable loads based on observed flows and known in-stream targets.

Load duration curves for total phosphorus, total suspended solids, and fecal coliform were developed at the three active USGS gages in the watershed where long term continuous flow records were available. Where chemistry data was available, these plots have individual points depicted which show the in-stream response to the existing watershed loading at the sampling location and flow. The curves themselves show the allowable load. An observed load above the TMDL curve does not necessarily indicate a violation; however, the overall trend of the data over time is indicative of the general watershed condition.

Dissolved Oxygen and Ammonia

The GWLF model predicts only loads to the stream; it does not predict the chemical response that occurs within the stream to input loads. The Enhanced Stream Water Quality Model version K (QUAL2K) predicts the in-stream chemical concentration response of several parameters including dissolved oxygen and ammonia to various inputs and stream conditions under steady, non-varying flows. The major constituent interactions are shown in Figure 3.5 (adapted from Brown and Barnwell, 1987). QUAL2K is an updated version of the QUAL2E model, and it has several new elements including bottom algae and sediment-water interaction simulations (Chapra et al., 2003).

QUAL2K represents the stream as a series of computational elements grouped together within a specified stream reach. A reach is defined as a length of stream that has similar physical properties (gradient, cross section, etc.) and rate constants (decay, settling, source). QUAL2K conceptualizes the stream as a sequential series of completely mixed reactors (the computational elements). It calculates the output from each computational element based on the input from the previous element and on reactions that occur within the element itself.

QUAL2K is appropriate for use only with steady, non-variable stream flows and predicts the average daily in-stream concentration of modeled parameters. It is, therefore, not well suited to work directly with GWLF results which are monthly loads under varying conditions. QUAL2K was used in this project to predict the in-stream concentration of dissolved oxygen and nitrogen compounds during low-flow summer conditions and in-stream phosphorus concentration during average summer conditions. These conditions are considered very stressful to stream biota, and therefore, allocations of loads need to be protective of this critical state. QUAL2K simulates in-stream concentrations which can then be compared to water quality criteria to evaluate if violations of these numeric criteria and targets have the potential to occur. Inputs such as point source loads can be adjusted until the predicted in-stream concentrations meet the water quality criteria. This provides a means of developing the wasteload allocation portion of the TMDL equation. In addition, it enables calculation of appropriate effluent limitations for dissolved oxygen demanding substances that in conjunction with the nutrient reductions and stream channel and habitat improvements recommended in this TMDL report, will serve to address the low dissolved oxygen conditions in the watershed.

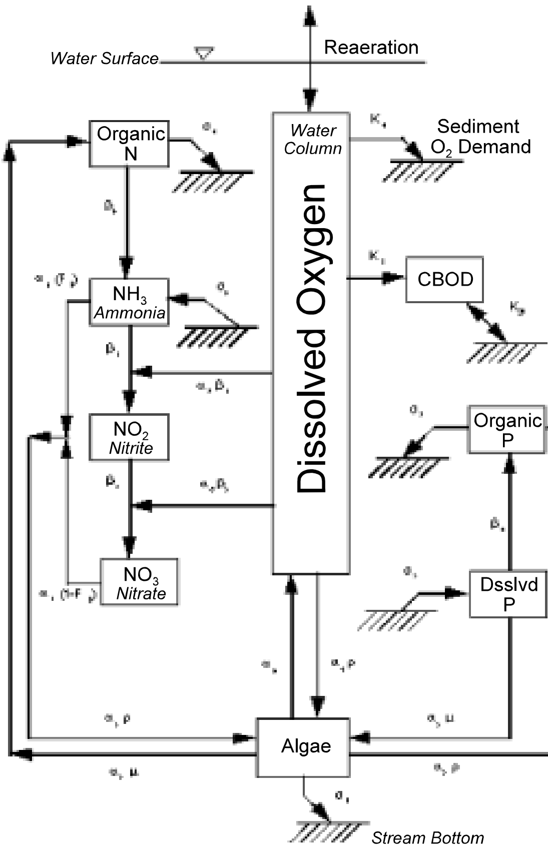

Figure 3.5 QUAL2E Constituent Interactions, and the Basis for the QUAL2K Major Interactions

Six areas in the Big Darby watershed were selected for QUAL2K model development applications. These areas have the potential to be significantly influenced by point source discharges, or are areas that have particularly sensitive mussel populations, or both conditions are present. The six QUAL2K modeled areas include:

- Big Darby Creek from Township Rd 157 (upstream of Flat Branch) to Buck Run Rd (downstream of Pleasant Run).
- Spain Creek from upstream N. Lewisburg WWTP to the mouth.
- Little Darby Creek from S.R. 29 in Mechanicsburg to Irwin Rd.
- Little Darby Creek from upstream Treacle Ck to S.R. 161 in Chuckery.

- Big Darby Creek from upstream Plain City WWTP to Lucas Rd.
- Big Darby Creek from Darbydale to Scioto-Darby Rd.

The models were calibrated with data collected in the summer of 2004. Hydraulic variables were calibrated first, followed by the chemical parameters (biochemical oxygen demand, the nitrogen compounds, and phosphorus), and lastly by dissolved oxygen.

3.3.4 Flood Plain

The overriding goal was to interpolate the actual active floodplain zone using limited field observation. The bankfull height is the incipient stage just prior to full interaction of the stream with the flood plain. When stream stage slightly exceeds the bankfull height, the flood plain becomes inundated. Because capturing evidence of the bankfull height is time-consuming and point-based (e.g., points where there is a change in land slope from flat to steep or a change in vegetation type), a method for interpolating the bankfull height and subsequently depicting the active flood plain (i.e., the inundation zone) was needed.

The ability to generate continuous terrain data (i.e., a digital elevation model) from digital contour data was a critical stage in simulating the active flood plain zone. Digital contour data was produced from 1:24,000-scale USGS topographic quadrangles. Using analytical techniques available in geographical information systems (GIS), field-derived elevations of the active flood plain were anchored to stream centerlines using the hydrologic flow path. This flow path is determined by water flowing from a source to a sink where direction is determined solely by steepest-descent. Once flood plain height was anchored to the stream centerline at selected cross-sections, heights for incremental points within these anchors were interpolated linearly as a function of flow length from the anchor. Stream centerlines were derived from USGS 1:24,000-scale hydrography.

Dunne and Leopold (1978) showed that the maximum bankfull depth (D_{max}, ft) is a strong function of drainage area (DA, mi^2). A drainage area-depth relationship was derived empirically for streams in west central Ohio (including many observations from the Big Darby Creek watershed) and shown in the form:

$$D_{max} = 1.9\ DA^{0.26}$$ *(Equation 3.5)*

Knight and Shiono (1996) suggest that a flood depth of 1.1 to 1.3 (typically 1.2) times the maximum bankfull depth produces maximum interaction of a river with its floodplain. This would suggest a depth capable of maximum pollutant assimilation. Similarly, Rosgen (1996) suggested a water level of two times the maximum bankfull depth yields the width of the flood-prone area. Hence, two flood plain zones resulting from inundation levels of 1.5 and 2 times the maximum bankfull depth are predicted in this simulation. Flood plain set backs are recommended in this TMDL primarily for pollutant assimulation purposes. The appropriate target flood plain to compare the estimated existing flood plain to is the 1.5 times the maximum bankfull depth (e.g. Actual 1.5x) value on Tables 4.1.3 and 4.4.2.

While the active flood plain is predicted from the maximum bankfull depth, the recommended flood plain width is determined from the bankfull width. Bankfull width, like bankfull depth, has a functional relationship with drainage area (Dunne and Leopold, 1978). A drainage area-width relationship was derived empirically for streams in west central Ohio (including many observations from the Big Darby Creek watershed) and shown in Equation 3.1.

3.3.5 Habitat Quality and Bedload

Description of Method
The QHEI is a quantitative expression of a qualitative, visual assessment of habitat in free flowing streams and was developed by the Ohio EPA to assess available habitat for fish communities (Rankin, 1989, 1994). 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 are subdivided into specific attributes that are assigned a point value reflective of the attribute's impact on the aquatic life. Highest scores are assigned to the attributes correlated to streams with high biological diversity and integrity 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 are evaluated on site, recorded on the form, the score totaled, and the data later analyzed in an electronic database. The evaluation form is available on line at http://www.epa.state.oh.us/dsw/bioassess/QHEIFieldSheet062401.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 due to 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.

QHEI scores can range from 12 to 100. The appropriate QHEI target score was 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. 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.

The analysis of the QHEI components as they relate to IBI scores led to the development of a list of attributes that are associated with degraded communities. These attributes are modifications of natural habitat and are listed in Table 3.6. These modified attributes were further divided into high influence or moderate influence attributes based on the statistical strength of the relationships. The presence of these attributes can strongly influence the aquatic biology and the QHEI score itself may not reflect this effect. This explains why habitat can be impaired even with a QHEI score above 60 (because other less influential habitat components are in place).

These three factors appear to have about an equal weight. An accumulation of four modified attributes corresponds to fewer than 50% of sites achieving a WWH target IBI score of 40. High influence modified attributes are particularly detrimental given that the presence of one is likely to result in impairment, and two will likely preclude a site from achieving an IBI of 40 (OEPA, 1999). The QHEI score of 60 or greater is correlated with IBIs of 40 or greater. A complete habitat TMDL needs to reflect both a good QHEI score and the relative presence of these modified attributes.

TMDL Calculation and Allocation

The habitat TMDL equation presented below reflects the relationship between the QHEI score, modified attributes, and aquatic community performance. It is based upon a total score of three (3), and is the sum of three component scores each worth one point.

Habitat TMDL = QHEI Score ≥ Target + Modified Attribute Score + High Influence Attribute Score
= 1 + 1 + 1
= 3

The bedload TMDL equation presented below is a subset of those factors of the QHEI most directly related to sediment type, quality, build up, and source origin. The sediment TMDL is a score of 32 for WWH sites and 35 for EWH sites. The individual components of the bedload TMDL (QHEI scores for substrate, channel, and riparian) are allocated as described below.

Bedload TMDL = Substrate + Channel Morphology + Riparian Zone/Bank Erosion

For WWH ≥ 13 + 14 + 5
≥ 32

For EWH ≥ 15 + 15 + 5
≥ 35

Table 3.6 provides additional detail describing the habitat and sediment TMDLs.

Table 3.6 Details of Habitat and Bedload TMDLs

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

Habitat TMDL Categories			
QHEI Score	≥ 60	≥ 75	+1
High Influence #	< 2	0	+1
Total # Modified	< 5	< 3	+1
		Habitat TMDL	3

Modified Attributes	
High Influence	Moderate Influence
•Silt/Muck Substrate	•Recovering Channel
•No Sinuosity	•Sand Substrate (Boat)
•Sparse/No Cover	•Hardpan Substrate Origin
•Max Depth < 40 cm (Wade)	•Fair/Poor Development
•Channelized or No Recovery	•Only 1-2 Cover Types
	•No Fast Current
	•High/Moderate Embeddedness
	•High/Mod Riffle Embeddedness
	•No Riffle
	•Heavy/Moderate Silt Cover
	•Low SInuosity
	•Intermittent and Poor Pools
	•Max Depth < 40 cm (Headwater)

Notes:

Headwater streams have drainage areas < 20 mi^2

Wadeable streams have drainage areas ≥20 mi^2 and < 200 mi^2

Boat refers to sites requiring a boat to collect the data; generally sites having drainage areas > 100 mi^2

The empirical nature of the QHEI and the data that underlie it provide measurable targets that are parallel concepts to a loading capacity for a pollutant. The components provide a way to evaluate whether habitat is a limiting factor for the fish community and which attributes are the likely stressors. The QHEI can assess both the source of the sediment (riparian corridor, bank stability) and the effects on the stream itself (i.e., the historic sediment deposition) and thus, has aspects of both a loading model and a receiving stream model. When used with biological indices, the numeric measurability of the index provides a means to monitor progress when implementing a TMDL and to validate that a target has been reached.

Table 3.7 Summary of Methods to Evaluate In-stream Responses and Habitat

Parameter	Evaluation Method	Applicable Conditions	Evaluated Locations
Total Phosphorus	LDC	All flow conditions	USGS gages
	QUAL2K	Average flow	Significant point source effected areas
Sediment			
Total Suspended	LDC	All flow conditions	USGS gages
Bedload	QHEI	Cumulative, chronic conditions	Individual sites
Fecal Coliform	LDC	All flow conditions	USGS gages
Dissolved Oxygen	QUAL2K	Low flow	Significant point source affected areas
Ammonia	QUAL2K	Low flow	Significant point source affected areas
Habitat	QHEI	Cumulative, chronic conditions	Individual sites
Flood Plain	GIS	Cumulative, chronic conditions	Upper Darby and Hamilton Ditch (existing conditions) Entire watershed (target conditions)

3.4 Critical Conditions and Seasonality

Aquatic Life

The critical condition for aquatic organisms is the summer when the aquatic life activity and biomass production are at their highest levels and the organisms are most sensitive to environmental conditions. Summer is also when excessive algal growth, high in-stream temperatures, and reduced stream flows occur leading to the lowest dissolved oxygen levels. Ohio EPA biological, habitat, and nutrient targets are protective of the critical period as they are based on data collected only during the summer months. Further, assessing the biology during the summer months evaluates the biological performance during the most critical time of the year.

Seasonality is accounted for in the 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 measurement of these indices during the summer period reflects the biotic performance during critical conditions.

Nutrients and Sediment

The critical condition for nutrient enrichment is the summer warm season, when the potential for primary production is highest. The summer concentration of phosphorus in the water column, however, is dependent upon more than summer phosphorus load contributed to the stream. As phosphorus readily attaches to sediment, detachment of adsorbed phosphorus in bottom sediments can lead to elevated in-stream concentrations regardless of the magnitude of short-term loads. As a result, it is the long-term, or chronic, phosphorus load and sediment load that is more directly related to the degradation of water quality. For this reason phosphorus and sediment TMDLs were developed on an annual basis. The use of a 10-year record of daily weather and stream flow data in GWLF incorporates seasonal and hydrologic variability and protects for all conditions including critical ones.

Seasonality and critical conditions were also considered in the Load Duration Curves used to establish TMDLs for total phosphorus and suspended sediment at USGS gage sites. The LDC approach utilizes all daily recorded flow values in the period of record. Therefore, the critical conditions and seasonal variation are included in the analysis.

Dissolved Oxygen and Ammonia

The conditions that are the most critical to the in-stream dissolved oxygen and ammonia concentrations of the Big Darby Creek occur when water temperatures are high and stream flow is low such as occurs during the summer months. Dissolved oxygen and ammonia in-stream concentrations were simulated under these summer conditions. Point source dischargers were included in this simulation at their maximum permissible loading. These circumstances formed the conditions at which the point sources were evaluated and wasteload allocations were established in this TMDL.

During the winter, water temperatures are lower, dissolved oxygen saturation levels and stream flows are higher, and the aquatic vegetation is reduced. Therefore, the majority of the factors causing low dissolved oxygen concentrations do not exist in the winter months. Simulations protective of summer conditions will be protective of all seasons.

Pathogens

The critical condition for pathogens is a “first flush” situation during the summer when pre-storm flows are the lowest and build-up of bacteria is at its highest. Summer is also the period when the probability of recreational contact is the greatest. For these reasons recreational use designations are only applicable in the period from May 1 to October 15. Pathogen TMDLs were developed for the same May to October time-period in consideration of the critical condition, and for agreement with Ohio WQS.

3.5 Margin of Safety

The statute and regulations require that a TMDL include a margin of safety to account for any lack of knowledge concerning the relationship between load and wasteload allocations and water quality (CWA § 303(d)(1)(C), 40 C.F.R. § 130.7(c)(1)). U.S. EPA guidance explains that the margin of safety may be implicit, i.e., incorporated into the

TMDL through conservative assumptions in the analysis, or explicit, i.e., expressed in the TMDL as a loading set aside. The implicit and explicit margin of safety factors used in the analyses are described below.

The List of Impaired Waters (the 303(d) List)
It is important to keep in mind during the evaluation of the TMDL a major difference in Ohio's program from other state programs. In Ohio, one way a stream segment is listed on the 303(d) list is for failure to attain the appropriate aquatic life use as determined by direct measurement of the aquatic biological community. Other State programs rely solely on chemical samples in comparison to chemical criteria to determine water quality and designated use attainment. However, relying solely on chemical data does not take into account any of the parameters or other factors for which no criteria exist but that affect stream biology nor does it account for multiple stressor situations. Therefore, the chemical specific approach misses many biologically impaired streams and may not detect a problem until it is severe. Ohio's approach incorporates an increased level of assurance that Ohio's water quality problems are being identified. Likewise, de-listing requires attainment of the aquatic life use determined by the direct measurement of the aquatic biological community. This provides a high level of assurance (and an implicit margin of safety) that if the TMDL allocations do not lead to sufficiently improved water quality then the segments remain on the list until true attainment is achieved.

Total Phosphorus and Sediment
A margin of safety was incorporated both implicitly and explicitly into these TMDLs. An implicit margin of safety is incorporated into the target development process. The explicit margin of safety is 5% of the loading capacity specifically reserved to account for any additional uncertainty following the application of the implicit measures. This explicit percentage was selected based on the availability of data, the high level of calibration achieved by the model, and the use of annual loadings which all contribute to decreasing the uncertainty associated with the data and model predictions.

A conservative assumption implicit in target development lies in the selection of the median statistic used to represent the phosphorus and TSS targets for the WWH streams and the 75th percentile for EWH streams that corresponds to an unimpaired biological community. Since Ohio EPA's evaluation of data for generating target values is based on measured performance of aquatic life and since full attainment can be observed at concentrations above these targets (reinforcing the concept that habitat and other factors play an important role in supporting fully functioning biological communities), water quality attainment can occur at levels higher than the targets. The difference between the actual level where attainment can be achieved and the selected target is an implicit margin of safety.

Pathogens
A margin of safety was implicitly incorporated into the pathogen TMDL. The fecal coliform load to the streams in each sub-watershed was quantified, as was the fecal coliform loading capacity at the outlet of each sub-watershed. Loading capacity was calculated as the product of the seasonal flow volume and the fecal coliform target

concentration. No attempt was made to link downstream loading capacity with upstream loading via in-stream processing. Rather, the load reductions recommended by this report are based upon a direct comparison between the two quantities. In reality, considerable die-off occurs between the source of loading and the TMDL endpoint and this loss represents an implicit margin of safety.