Appendix A: Model Development for the Upper Little Miami River

Part 1. The Receiving Water Model

1.0 Introduction

This section describes the methods used in the modeling analysis of dissolved oxygen (D.O.) in the Upper Little Miami TMDL. It is intended to be used as a supplement to the TMDL report and relies on the report to provide a description of the study area, project objectives and results. The purpose of this section is to document the major steps and decisions made in the modeling process.

1.1 Model Structure and Approach

Dissolved oxygen was modeled using the Enhanced Stream Water Quality Model QUAL2E-UNCAS (QUAL2E) (Brown and Barnwell, 1987). It is a one-dimensional (the D.O. gradient is significant only in the main direction of flow), steady-state (the D.O. profile represents an equilibrium situation where inputs are assumed constant) model which was used to simulate D.O., CBOD, phosphorous, and the nitrogen series. QUAL2E uses a mass balance approach as its basic premise; this approach divides each reach in the study area into computational elements which represent a series of linked completely mixed reactors. Each element is a separate system which has an initial external input and internal interactions that either add to or reduce the dissolved oxygen. The final output is the summation of the input and these interactions and it represents the input into the next element. The major constituent interactions used in the Upper Little Miami model are depicted in Figure A1.

The Little Miami study area was divided into 42 reaches; each reach was further divided into computational elements with a length of 0.2 mile. The model representation of the stream network showing the computational elements and reaches is presented in Table A2.

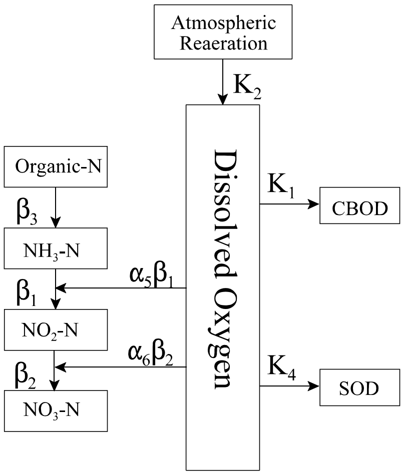

Figure A1. Constituent Interactions for the Upper Little Miami TMDL

1.2 Calibration and Verification

Calibration and verification of the Upper Little Miami River D.O. model was conducted using data from multiple stream surveys conducted by the Ohio EPA during the summers of 1989 through 1999. The study area was divided into three segments based on the area each data collection surveys focused on. The three sections include the upper portion of the study area (Headwaters to Clifton Dam), the middle portion (Clifton Dam to downstream Beaver Ck), and the lower portion (downstream of Beaver Ck to Caesar Ck). A QUAL2E model was constructed for each section and calibrated and verified with the appropriate field data. The sections were then merged resulting in a total of 42 reaches (see Table A2).

The calibration began with an initial data set populated only by measured values from the field survey selected for calibration. A range of values for each unknown input was then estimated using the field survey data and literature values. Initial estimates of the unquantified inputs based on the predefined ranges were then incorporated into the data set. The model results were compared to the observed data and the estimated inputs adjusted accordingly. The inputs to adjust were selected by performing a first-order error analysis on the data set to determine which inputs the model was most sensitive to. Then a sensitivity analysis was performed for these inputs and a final value was selected based on the sensitivity analysis results. The model was calibrated in stages for all values simulated by the model. The hydraulic simulations were calibrated first followed by the nitrogen series (organic, ammonia, nitrite and nitrate nitrogens), CBOD and dissolved oxygen. The final dissolved oxygen calibration graph is shown in Figure A2.

Kinetic coefficients developed in the calibration were applied to another field data set for model verification. Fine tuning of the coefficients was done as necessary and both the calibration and validation data sets were re-run until the comparison of the predicted results compared reasonably well to the observed data for both data sets. After calibration and verification, a simulation representing the current situation under critical conditions was run to estimate the deviation of the current conditions from the desired target (D.O. water quality criteria). Implementation option simulations were then run for selected remediation scenarios under critical conditions to determine TMDLs that would meet the D.O. criteria.

1.3 Sources of Data

The majority of the data used in the modeling was field data collected by Ohio EPA. The types of data that were collected include:

- time of travel dye studies to measure stream velocity
- chemical sampling including grab and 24-hr composites samples
- flow measurements of the mainstem and tributaries
- instream D.O., pH, temperature and conductivity hourly recordings for 48 hour intervals
- cross-sectional measurements
- sediment oxygen demand measurements

All point sources including effluents and tributaries were sampled for water quality and flow to quantify their contributions to the Little Miami for calibration and validation purposes. Other data sources include the effluent data collected by the dischargers as required by their NPDES permits. These data are collected over time and are more representative of the effluent quality than the ‘snapshot picture’ that is measured during a field survey. This data was used in the critical condition simulations for facilities that did not have a permit limit for a particular substance (otherwise, the permit limit was used). Additionally, flow data collected at USGS stream gage stations (USGS, 1981) were used to define the critical ambient flow values for the simulations.

1.4 Description of Inputs

Forcing Functions

Forcing functions are the user-specified inputs that drive the system being modeled (Brown and Barnwell, 1987). The Upper Little Miami River D.O. model has three applicable types of forcing functions. These functions and a description of the source of the input data are as follows:

1. Headwater Inputs - The averages of all the chemical samples taken from the mainstem and modeled tributaries upstream of the point sources (respectively) were used as the headwater qualities in the critical condition simulations.

2. Point Sources and Withdrawals – The point source effluents and tributaries were sampled during each stream survey and the appropriate water quality was input for the calibration or validation data sets. The critical simulations assumed that the entities were discharging at their design flows and monthly average concentration limits if applicable or at their 50th percentile values as calculated from the discharger's self-reported data if no permit limit applied. Unmodeled tributary concentrations for the critical simulations were based on the average of all data collected at the mouth. Critical flow conditions for the tributaries and the mainstem were input as the lowest 7-day average flow that has occurred in any 10-year period (the 7Q10).

3. Incremental Inflows – Nonpoint sources such as drains, tiles and groundwater inflows were included as incremental inflows and were assumed to occur uniformly over the entire length of the reaches. Incremental inflow rates were estimated by calculating an incremental flow rate per mile based on differences in the upstream and downstream flow sites. The length of the reach multiplied by the flow rate/mile gave the total inflow per reach. All field-collected flow data sets had unaccounted flow after subtracting the upstream measured flow and all other known flow sources from the downstream flow site. This supports the assumption that there are nonpoint (anthropogenic or natural) inflows even during lower flow conditions. The critical simulations used the inflow rates from the data survey conducted during the lowest flow conditions. The water quality of the incremental inflows was set to background concentrations.

Hydraulics Data

Hydraulic data includes stream flow, velocity and water depth. Velocity was measured using a Rhodamine dye time of travel survey and the water depths were calculated from cross-sectional data measured at representative sites. This data was used to establish depth and velocity relationships with flow. Flow dependent depth and velocity functions are used to predict the depths and velocities of the stream that would occur under different stream flows than they were measured at. These relationships were established using the following power functions:

$$\text{Depth} = aQ^b$$

$$\text{Velocity} = cQ^d$$

Where: Q = Stream flow
a,c = Stream constants for depth and velocity
b,d = Depth and velocity coefficients

The constants and coefficients were calculated from log-log plots of the stream velocity or depth data where sufficient field data existed to determine such relationships. Where only limited data existed, the coefficients were assumed as follows:

b = 0.6 for free flowing reaches
d = 0.4 for free flowing reaches

QUAL2E uses the following equation to predict width:

$$W = Q / (V * D)$$

Where: W = Width (ft)
Q = Flow (ft^3/s)
V = Velocity (ft/s)
D = Depth (ft)

Dispersion

QUAL2E assumes that complete mixing occurs from side to side and top to bottom in a river. Mixing also occurs as the water travels down the river due mainly to the horizontal and vertical velocity gradients and river channel changes (Thomann and Mueller, 1987). This mixing is referred to as longitudinal dispersion. The time of travel dye studies were used to estimate the longitudinal dispersion using the following equation:

$$E_x = M * (2\,A\,s_p)^{-2} * (\pi\,t_p)^{-1}$$

Where: E_x = Longitudinal dispersion coefficient for reach x
M = Mass of dye introduced to the stream
A = Average cross-sectional area of reach x
s_p = Peak concentration of the dye in reach x
t_p = Time to peak concentration of the dye for reach x

QUAL2E requires that a value for the longitudinal dispersion *constant* be used. The dispersion constant is a dimensionless value which relates the dispersion coefficient to the depth and shear velocity. The relationship is expressed as:

$$K = E_x \,/\, (D * U^*)$$

Where: K = Dispersion constant
U^* = Shear velocity

Model Coefficients and Constants

The constants and coefficients selected during model calibration are shown in Table A1. The coefficients α_5 and α_6 represent the oxygen uptake per unit of oxidized ammonia and nitrite. The values used are recommended by U.S. EPA (1985) and are based on the stoichiometry of the reactions. The Manning's roughness factor used in the model was based on the lowest value recommended in the QUAL2E manual (Brown and Barnwell, 1987) for natural river channels that are winding with pools and shoals.

The measured nitrogen series concentrations did not exhibit decay in the study area; however, a first order error analysis of the model indicated that both the predicted ammonia, nitrate, and nitrite concentrations were sensitive to the rate constant for the biological oxidation of ammonia to nitrite (β_1) and to the rate constant for the biological oxidation of nitrite to nitrate (β_2). A sensitivity analysis was conducted on ammonia, nitrite, and nitrate by varying the value of β_1 and β_2 respectively and seeing how the predicted concentrations compared to the observed ones. The values of β_1 and β_2 that gave the best fit and remained in the range of suggested values in the QUAL2E manual (Brown and Barnwell, 1987) were selected. Field measurements of organic nitrogen did exhibit a decay; however, the predicted organic nitrogen and ammonia concentrations did not calibrate well with the observed data when the field estimated value of β_3 was used. Instead, a sensitivity analysis was performed to determine what value gave the best predicted concentrations of ammonia and organic nitrogen when compared with observed values.

The instream measured concentrations of CBOD did not exhibit any conclusive decay patterns. An empirical relationship between the CBOD decay rate (K_1) and depth (D) has been observed. The equation, $K_1 = 0.2\,(D/8)^{-0.434}$, gave the best predicted fit for CBOD and D.O. and was used to determine K_1 for the entire study area. Minimal settling was observed for the CBOD and the nitrogen series in some tributaries; however, the majority of the system had a settling constants assumed to be zero.

The stream reaeration rate was calculated using predictive equations selected based on stream slope and flow as suggested by Ohio EPA guidance (OEPA, 1984). The recommended predictive equation for the upper and middle portions of the study area were the Parkhurst-Pomeroy and Bansal equations. The Thackston-Krenkel reaeration equation was recommended for the lower section of the study area. The D.O. profiles of other predictive equations were compared to the D.O. profile resulting from the above selections; however, the three equations applied to the specified stream sections gave the best fit to the observed data.

Sediment oxygen demand (SOD) is a measure of the oxygen consumed by biochemical decompositions of organic matter in stream sediments and is represented by the rate coefficient K_4. SOD measurements were recorded in low velocity sections of the Little Miami River by a benthic respirometer (SOD chamber). The SOD rates measured by this chamber ranged from 0.006 to 0.2 g/ft2/day. The value of K_4 used in the model needed to represent an average value over an entire reach. The K_4 values used in this model ranged from 0.01 to 0.07 depending on the reach characteristics. These values were used based on the measured data, the descriptions of the sites where SOD was measured, the reach characteristics and the results of the calibration and validation model runs.

Table A1. Summary of Coefficients for D.O. Modeling in the Upper Little Miami River

Coefficient[1]	Description	Units[2]	Value Used
α_5	O_2 uptake per unit NH_3 oxidized	mg O/ mg N	3.43
α_6	O_2 uptake per unit NO_2 oxidized	mg O/ mg N	1.14
n	Manning's roughness	–	0.030-0.033
β_1	Rate constant for biological oxidation of NH_3 to NO_2	day^{-1}	0.9-1.0
β_2	Rate constant for biological oxidation of NO_2 to NO_3	day^{-1}	0.5-1.1
β_3	Rate constant for biological oxidation of Org-N to NH_3	day^{-1}	0.3-0.1
K_1	CBOD decay rate	day^{-1}	variable[3]
K_2	Reaeration rate	day^{-1}	variable[4]
K_4	Sediment oxygen demand	$g/ft^2/day$	0.01 - 0.07

[1] Refer to Figure A1 for pictorial representation of the rates.
[2] Presented as the value at 20 degrees C for first-order rate constants β_1, β_2, β_3, K_1, K_2, and K_4.
[3] CBOD decay is variable with average reach depth.
[4] Reaeration is variable with average reach depth and velocity.

Temperature Effects on Coefficients

First-order kinetic coefficients are temperature dependent and the QUAL2E standard is to input the reaction rate value at 20 degrees C. The program then corrects to the actual reaction rate based on the ambient temperature of the receiving water during simulations. The temperature corrections are calculated using the following formula:

$$X_T = X_{20}\,\theta^{(T-20)}$$

Where

X_T = the value of the coefficient at the ambient temperature (in degrees C)
X_{20} = the value of the coefficient at the standard temperature of 20 degrees C

θ = an empirical constant derived from literature values
T = the ambient temperature (in degrees C)

The temperature correction values used were:

Kinetic Coefficient	Correction Factor
K_1	1.047
K_2	1.024
K_4	1.065
β_1	1.083
β_2	1.047
β_3	1.047

Dam Effects

Dams affect both the upstream and downstream D.O. concentrations. The upstream D.O. concentrations are negatively impacted due to the change in the hydraulics of the stream (decreasing natural stream reaeration, increasing deoxygenation rates of CBOD decay). This impact is captured in the field measurements of the stream hydrology. Oxygen is input to the stream from reaeration over dams so downstream D.O. concentrations are increased. QUAL2E predicts the dam reaeration using the Gameson equation. The inputs required by this equation include:

H = the height through which water falls;
a = an empirical parameter indicating water quality
b = an empirical parameter indicating dam shape

A summary of the dam data is:

Dam Location	**H [*] (ft)**	**a[1]**	**b[2]**
Clifton Dam	16.3	1	1
Waynesville Mill Dam	5	1.2	1.3

[1] The higher the value, the better the water quality. A value of 1.0 indicates slightly polluted water.

[2] A value of 1 indicates a weir with free fall.

[*] Ohio Department of Natural Resources supplied the Clifton Dam height; visual observation by Ohio EPA and the owner of Rivers Edge Canoe Livery determined the Waynesville Dam height.

Relationship between CBOD5 and Ultimate CBOD

QUAL2E uses ultimate CBOD (CBODU) as its default input and output CBOD measure. Waters dominated by domestic waste effluents and waters that are not strongly influenced by industrial wastes typically have 20-day CBOD values that closely approximate the ultimate values (OEPA, 1998). Therefore, CBOD20 and CBODU will be considered equal for the purposes of this study.

The WLAs based on the model output are expressed as CBODU; however, most municipal treatment works' NPDES permits are expressed as CBOD5. The following equation was used to convert from CBODU to CBOD5:

CBOD5 = 0.50 * CBODU . . . . for municipal plants with secondary treatment

CBOD5 = 0.43 * CBODU . . . . for municipal plants with advanced treatment

1.5 Quantified Comparison of Observed and Modeled Dissolved Oxygen

A statistical measure of how well a constructed model compares to observed data is relative error. This technique gives an indication of model adequacy and is the absolute value of the difference between the observed and the predicted values divided by the observed value. The median percent relative error for the calibrated Upper Little Miami model is 8%. A study of 20 different state-of-the-art models was conducted and the median percent relative error in measured versus simulated D.O. was compared. The results (USEPA, 1997) show that 60 percent of the models studied had relative median errors greater than 8%. The Little Miami TMDL model compares well to those models studied and indicates that the Little Miami model should give credible results.

1.6 Summary

The Upper Little Miami River watershed was modeled using QUAL2E and field collected data. The predicted dissolved oxygen concentrations compared reasonably well with the measured values for all areas and the model can be relied on to give credible results. A set of inputs reflective of critical conditions was used to determine the current critical D.O. profile. The conditions that were considered critical (and not subject to change) are low flow conditions (7Q10) determined from data collected at either the Little Miami River near Oldtown USGS gage station (#03240000) since 1952 or the Massie Creek at Wilberforce, Ohio USGS gage station (#03241500) also since 1952 . The effects of various loading changes were then estimated to determine what changes were necessary in the current study area to result in attainment of the dissolved oxygen criteria.

Table A2. QUAL2E Model Representation of the Upper Little Miami River

The number inside each box is the river mile location one edge of the box represents. Each box is an element of 0.2 mile in length, and each row is a reach.

Upper Section:

Reach	Elmnt	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	107	106.8	106.6	106.4	106.2	106	105.8	105.6	105.4	105.2	105	104.8									
2	104.8	104.6	104.4	104.2	104	103.8	103.6	103.4	103.2	103	102.8	102.6	102.4	102.2	102	101.8	101.6	101.4	101.2		
3	101.2	101	100.8	100.6																	
4	1.4	1.2	1	0.8	0.6	**Gilroy Ditch**															
5	0.6	0.4	0.2	0																	
6	100.6	100.4	100.2	100	99.8	99.6	99.4	99.2	99												
7	99	98.8	98.6	98.4	98.2	98	97.8	97.6	97.4	97.2	97	96.8	96.6	96.4	96.2	96	95.8	95.6	95.4	95.2	95
8	95	94.8	94.6	94.4	94.2	94	93.8	93.6	93.4												
9	93.4	93.2	93	92.8	92.6	92.4	92.2														
10	92.2	92	91.8	91.6	91.4	91.2	91	90.8	90.6	90.4	90.2	90	89.8								
11	89.8	89.6	89.4																		

Middle Section:

Reach	Elmnt	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	89.4	89.2	89	88.8	88.6	88.4	88.2	88	87.8	87.6	87.4	87.2	87	86.8	86.6	86.4	86.2	86	85.8	85.6	
2	85.6	85.4	85.2																		
3	0.6	0.4	0.2	0	**Yellow Springs**																
4	85.2	85	84.8	84.6	84.4	84.2	84	83.8	83.6	83.4	83.2										
5	83.2	83	82.8	82.6	82.4	82.2	82	81.8	81.6	81.4	81.2	81	80.8								
6	80.8	80.6	80.4	80.2	80	79.8	79.6														
7	79.6	79.4	79.2	79	78.8	78.6	78.4	78.2	78	77.8											
8	77.8	77.6	77.4	77.2	77																
9	77	76.8	76.6	76.4	76.2	76	75.8	75.6													
10	75.6	75.4	75.2	75	74.8	74.6	74.4														
11	74.4	74.2	74	73.8	73.6	73.4	73.2	73	72.8												
12	1.4	1.2	1	**Beaver Creek**																	
13	4.8	4.6	4.4	4.2	4	3.8	3.6	3.4	3.2	3	2.8	2.6	2.4	**Little Beaver Creek**							
14	2.4	2.2	2	1.8	1.6	1.4	1.2	1.0	0.8	0.6	0.4	0.2	0								
15	1.0	0.8	0.6	0.4	0.2	0	**Beaver Creek**														
16	72.8	72.6	72.4	72.2	72	71.8	71.6														

Table A2. QUAL2E Model Representation of the Upper Little Miami River *(continued)*

Lower Section:

Rch	Elmn	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	71.6	71.4	71.2	71	70.8	70.6	70.4	70.2	70	69.8	69.6	69.4	69.2	69	68.8	68.6					
2	68.6	68.4	68.2	68	67.8	67.6	67.4	67.2	67	66.8	66.6										
3	66.6	66.4	66.2	66	65.8	65.6	65.4	65.2													
4	65.2	65	64.8	64.6	64.4	64.2	64	63.8													
5	5.2	5	4.8	4.6	4.4	4.2	4	3.8	3.6	3.4	3.2	3	2.8	2.6	2.4	2.2	**Glady Run**				
6	2.2	2	1.8	1.6	1.4	1.2	1	0.8	0.6	0.4	0.2	0									
7	63.8	63.6	63.4	63.2																	
8	63.2	63	62.8	62.6	62.4	62.2	62	61.8	61.6	61.4	61.2	61	60.8								
9	60.8	60.6	60.4	60.2	60	59.8	59.6	59.4	59.2												
10	59.2	59	58.8	58.6	58.4	58.2															
11	58.2	58	57.8	57.6	57.4	57.2	57														
12	57	56.8	56.6	56.4	56.2	56	55.8	55.6	55.4	55.2											
13	55.2	55	54.8	54.6	54.4	54.2	54	53.8													
14	53.8	53.6	53.4	53.2	53																
15	53	52.8	52.6	52.4	52.2	52	51.8	51.6	51.4	51.2	51	50.8									

42 Reaches Total

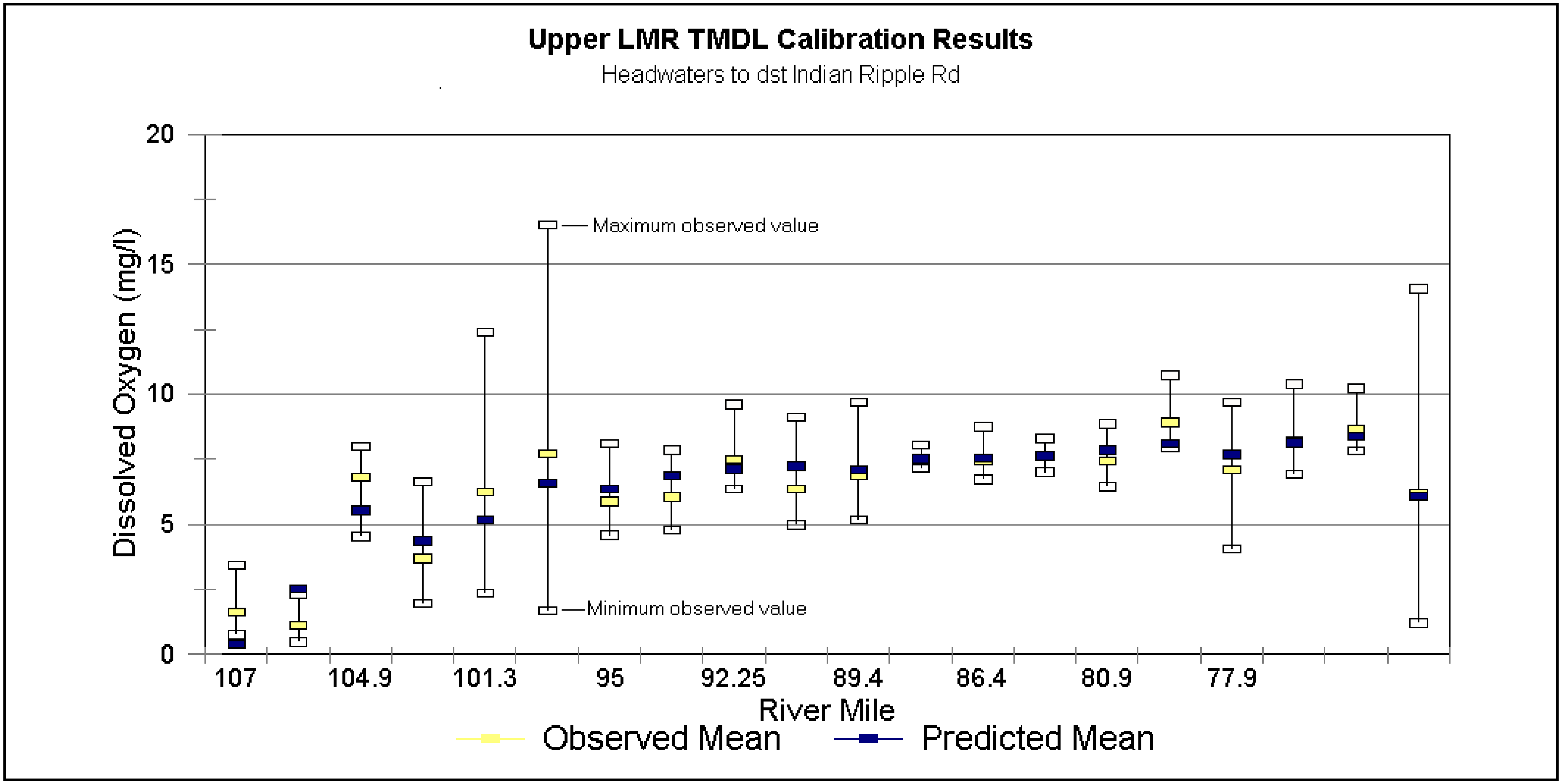

Figure A2. Comparison of dissolved oxygen observed data to QUAL2E predicted values per river mile. The whisker plots represent the range of dissolved oxygen values observed over a 48 hour period; the dark boxes are the predicted mean dissolved oxygen value for that river mile.

Part 2. The Watershed Loading Model[1]

2.0 Introduction

This section describes the methods used in the loading analysis of phosphorus and sediment in the Upper Little Miami TMDL. It is intended to be used as a supplement to the TMDL report and relies on the report to provide a description of the study area, project objectives and results. The purpose of this section is to document the steps and decisions made in the modeling process.

2.1 Model Structure and Approach

Loading of water, sediment, and nutrients in the Upper Little Miami River watershed was simulated using the Generalized Watershed Loading Function or GWLF model (Haith et al., 1992). The complexity of the loading function model falls between that of detailed, process-based simulation models and simple export coefficient models which do not represent temporal variability. GWLF provides a mechanistic, but simplified simulation of precipitation-driven runoff and sediment delivery, yet is intended to be applicable without calibration. Solids load, runoff, and ground water seepage can then be used to estimate particulate and dissolved-phase pollutant delivery to a stream, based on pollutant concentrations in soil, runoff, and ground water.

GWLF simulates runoff and streamflow by a water-balance method, based on measurements of daily precipitation and average temperature. Precipitation is partitioned into direct runoff and infiltration using a form of the Natural Resources Conservation Service's (NRCS) Curve Number method (SCS, 1986). The Curve Number determines the amount of precipitation that runs off directly, adjusted for antecedent soil moisture based on total precipitation in the preceding 5 days. A separate Curve Number is specified for each land use by hydrologic soil grouping. Infiltrated water is first assigned to unsaturated zone storage where it may be lost through evapotranspiration. When storage in the unsaturated zone exceeds soil water capacity, the excess percolates to the shallow saturated zone. This zone is treated as a linear reservoir that discharges to the stream or loses moisture to deep seepage, at a rate described by the product of the zone's moisture storage and a constant rate coefficient.

Flow in streams may derive from surface runoff during precipitation events or from ground water pathways. The amount of water available to the shallow ground water zone is strongly affected by evapotranspiration, which GWLF estimates from available moisture in the unsaturated zone, potential evapotranspiration, and a cover coefficient. Potential evapotranspiration is estimated from a relationship to mean daily temperature and the number of daylight hours.

The user of the GWLF model must divide land uses into “rural” and “urban” categories, which determines how the model calculates loading of sediment and nutrients. For the purposes of modeling, “rural” land uses are those with predominantly pervious surfaces, while “urban” land uses are those with predominantly impervious surfaces. It is often appropriate to divide certain land uses into pervious (“rural”) and impervious (“urban”) fractions for simulation. Monthly sediment delivery from each “rural” land use is computed from erosion and the transport capacity of runoff, whereas total erosion is based on the universal soil loss equation (USLE) (Wischmeier and Smith, 1978), with a modified rainfall erosivity coefficient that accounts for the precipitation energy available to detach soil particles (Haith and Merrill, 1987). Thus, erosion can occur when there is precipitation, but no surface

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[1] Much of the Part 2 verbiage provided by Tetra Tech, Inc. (Tetra Tech, 2000)

runoff to the stream; delivery of sediment, however, depends on surface runoff volume. Sediment available for delivery is accumulated over a year, although excess sediment supply is not assumed to carry over from one year to the next. Nutrient loads from rural land uses may be dissolved (in runoff) or solid-phase (attached to sediment loading as calculated by the USLE).

For "urban" land uses, soil erosion is not calculated, and delivery of nutrients to the water bodies is based on an exponential accumulation and washoff formulation. All nutrients loaded from urban land uses are assumed to move in association with solids.

2.2 GWLF Model Inputs

GWLF application requires information on land use, land cover, soil, and parameters that govern runoff, erosion, and nutrient load generation.

Land Use/Land Cover

Digital land use/land cover (LULC) data for the Upper Little Miami River watershed were obtained from the National Land Cover Dataset (NLCD). The NLCD is a consistent representation of land cover for the conterminous United States generated from classified 30-meter resolution Landsat thematic mapper (TM) satellite imagery data. The NLCD is classified into urban, agricultural, forested, water, and transitional land cover subclasses. The imagery was acquired by the Multi-Resolution Land Characterization (MRLC) Consortium, a partnership of federal agencies that produce or use land cover data. The imagery was taken in 1991. Table A3 summarizes the acreage in each land use category in the Upper Little Miami River watershed.

Table A3. Land uses in Upper Little Miami River watershed, 1991 (MRLC data).

Land Use	Acres	% of Total
Open Water	3784	0.90%
Low Intensity Residential	23508	5.60%
High Intensity Residential	2282	0.54%
Commercial/ Industrial	5066	1.21%
Barren/ Transitional	551	0.13%
Deciduous Forest	45457	10.83%
Evergreen Forest	1209	0.29%
Mixed Forest	159	0.04%
Pasture/Hay	83282	19.84%
Row Crops	247426	58.93%
Urban/ Recreational Grasses	6193	1.48%
Woody Wetlands	689	0.16%
Emergent Herbaceous Wetlands	238	0.06%
Total:	**419844**	**100.00%**

Soil data for the Upper Little Miami River watershed were obtained from the NRCS State Soil and Geographic (STATSGO) database (http://www.ftw.nrcs.usda.gov/stat_data.html). Attribute data associated with soil map units were used to assign soil hydrologic groups and to estimate values for some of the USLE parameters, as described in sections below.

The upper LMR watershed was divided up into five sub-basins to accommodate the recommended basin size for GWLF and to increase the resolution (especially helpful during the implementation phase). These divisions were based on physical and geological characteristics and drainage area size. Subwatershed 1 covers the headwaters of the Little Miami River to Clifton Mill Dam. Subwatershed 2 begins at this dam and ends just upstream of Beaver Creek. Subwatershed 3 contains Beaver Creek and ends at Caesar Creek. Subwatershed 4 is the Caesar Creek basin excluding Anderson Fork. Subwatershed 5 is Anderson Fork (refer to Figure 2 in the main report). The subwatersheds, land uses, census information, and the soils coverages were overlain in a Geographic Information System (GIS) environment. For the purposes of the GWLF modeling of runoff and erosion, the land use categories were assigned to a rural or an urban category as shown in Table A4. Runoff and erosion potential are expected to be affected both by land use and by the soil hydrologic group, so each land use group was divided into sub-categories based on the hydrologic group (A, B, C or D) of the underlying soil type.

Table A4. Land Use Groupings for GWLF Modeling

NLCD Land Use	Pollutant Simulation
Deciduous Forest	Rural
Evergreen Forest	Rural
Mixed Forest	Rural
Urban/Recreational Grasses	Rural
Transitional (Barren)	Rural
Low Intensity Residential	Urban
Pasture/Hay	Rural
Row Crops	Rural
Commercial/Industrial/Transportation	Urban
Woody Wetlands	Rural
Emergent Herbaceous Wetlands	Rural
High Intensity Residential	Urban
Open Water	--

Rainfall and Runoff

Meteorology:

Hydrology in GWLF is simulated by a water-balance calculation, based on daily observations of precipitation and temperature. A search was made of available Midwestern Regional Climate Center reporting stations. The most appropriate available meteorological data is summarized in Table A5.

Table A5. Weather stations used in the ULMR GWLF model

Station #	Station Name	Latitude	Longitude
332067	Dayton_MCD	39°46'	84°10'
339219	Wilmington_3_N	39°29'	83°49'
332928	Franklin_2_W	39°32'	84°19'
337935	Springfield_New_Wtr_Wrks	39°58'	83°49'
339361	Xenia_6_SSE	39°37'	83°54'

Data for these stations for 1989 through 2000 were obtained directly from the Midwestern Regional Climate Center. Average monthly precipitation based on the median of all the daily precipitation values for all five stations for the 1989-2000 time period are summarized in Table A6. Figure A3 shows the variability in monthly precipitation over the 1989 - 2000 period. The weather data is organized by water year which starts April 1 and ends March 31 of each year.

Table A6. Average monthly precipitation based on the median of all 5 weather stations for the period from April 1989 - March 2000

Month	Average Total Precipitation (inches)
January	3.2
February	1.8
March	2.8
April	4.0
May	4.7
June	3.2
July	3.4
August	2.3
September	1.7
October	2.5
November	2.5
December	3.0

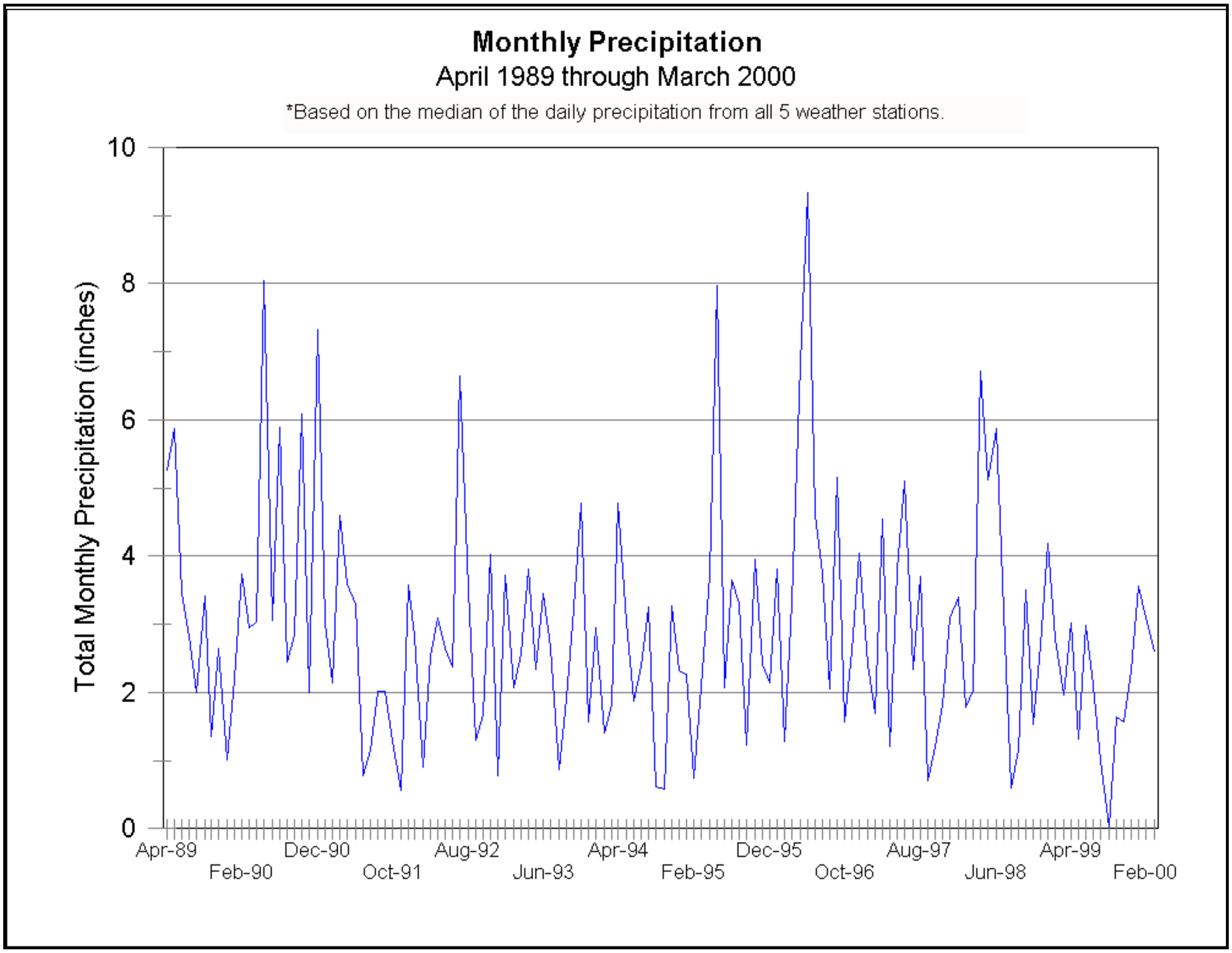


Figure 2. Upper Little Miami River Area Monthly Total Precipitation, 1980-1998.

<u>Evapotranspiration Cover Coefficients:</u>
The portion of rainfall returned to the atmosphere is determined by GWLF based on temperature and the amount of vegetative cover. For urban and barren land uses, the cover coefficient was calculated as (1 - impervious fraction). For all other land uses it was assumed that land had vegetative cover during the growing season (cover coefficient = 1), and limited vegetative cover during the dormant season (cover coefficients ranging from 0.3 to 1 depending on land use). The cover coefficients were area-averaged to result in one coefficient value for the growing season (March-October) and one for the dormant season (November-February).

<u>Soil Water Capacity:</u>
Water stored in soil may evaporate, be transpired by plants, or percolate to ground water below the rooting zone. The amount of water that can be stored in soil (the soil water capacity) varies by soil type and rooting depth. Based on soil water capacities reported in the STATSGO database, soil types

present in the watershed, and GWLF user's manual recommendations, the GWLF default soil water capacity of 10 cm was used.

Recession and Seepage Coefficients:
The GWLF model has three subsurface zones: a shallow unsaturated zone, a shallow saturated zone, and a deep aquifer zone. Behavior of the second two stores is controlled by a ground water recession and a deep seepage coefficient. The recession coefficient was set to 0.04 per day and the deep seepage coefficient to 0.007, based on several calibration runs of the model.

Runoff Curve Numbers:
The direct runoff fraction of precipitation in GWLF is calculated using the curve number method from the SCS TR55 method literature based on land-use and soil hydrologic group (SCS, 1986). Curve numbers vary from 25 for undisturbed woodland with good soils, to, in theory, 100, for impervious surfaces. The hydrologic soil group was determined from available soils data and curve numbers were calculated for each land use category/soil hydrologic group. The KLSCP (see next section) and curve numbers calculated for the Upper Little Miami River watershed are summarized in Table A7. These numbers represent the weighted average per soil type and land use area. For each land use, the table also indicates whether GWLF simulates nutrient loading via the USLE equation ("rural" areas) or a buildup-washoff formulation ("urban" areas).

Table A7. Runoff Curve Numbers for Upper Little Miami River Watershed.

Land Cover	**KLSCP** (weighted average)*	**Curve Number** (weighted average)*	**Methodology**
Barren (Transitional)	0.0016	84	USLE
Commercial/Industrial/Transportation	0.0043	98	Buildup-Washoff
Deciduous Forest	0.0024	79	USLE
Evergreen Forest	0.0054	65	USLE
Urban/Recreational Grasses	0.0050	74	USLE
High Intensity Residential	0.0040	98	Buildup-Washoff
Low Intensity Residential	0.0015	86	Buildup-Washoff
Pasture	0.0021	79	USLE
Row Crops	0.0108	89	USLE
Water	0.0000	100	USLE
Wetlands	0.00095	100	USLE

* Weighted averages based on soil type and area of land use.

Erosion

GWLF simulates rural soil erosion using the Universal Soil Loss Equation (USLE). [Note: For land uses indicated as "Buildup-Washoff" in Table 4, solids loads are generated separately, as described below in the section entitled Parameters Governing Nutrient Load Generation.] This method has been applied extensively, so parameter values are well established. This computes soil loss per unit area (sheet and rill erosion) at the field scale by

$$A = RE * K * LS * C * P$$

where

A = rate of soil loss per unit area,
RE = rainfall erosivity index,
K = soil erodibility factor,
LS = length-slope factor,
C = cover and management factor, and
P = support practice factor.

Soil loss or erosion at the field scale is not equivalent to sediment yield, as substantial trapping may occur, particularly during overland flow or in first-order tributaries or impoundments. GWLF accounts for sediment yield by (1) computing transport capacity of overland flow, and (2) employing a sediment delivery ratio (SDR) which accounts for losses to sediment redeposition.

Rainfall Erosivity (RE):

Rainfall erosivity accounts for the impact of rainfall on the ground surface, which can make soil more susceptible to erosion and subsequent transport. Precipitation-induced erosion varies with rainfall intensity, which shows different average characteristics according to geographic region. The factor is used in the Universal Soil Loss Equation and is determined in the model as follows:

$$RE_t = 64.6 * a_t * R_t 1.81$$

where

RE_t = Rainfall erosivity (in megajoules mm/ha-h),
a_t = Location- and season-specific factor, and
R_t = Rainfall on day t (in cm).

The erosivity coefficient (a_t) was assigned a value of 0.3 for the growing season and 0.12 for the dormant season, based on erosivity coefficients provided in the GWLF User's Manual.

Soil Erodibility (K) Factor:

The soil erodibility factor indicates the propensity of a given soil type to erode, and is a function of soil physical properties and slope. Soil erodibility factors were extracted from the STATSGO soil coverage. For each land use category, the K factors of the soil types underlying all land of this category were area-averaged to result in an overall K factor for the land use category.

Length-Slope (LS) Factor:

Erosion potential varies by slope as well as soil type. The calculation for the LS factor is (Wischmeier, 1978; Moore, 1986):

$$LS = (0.045 * x_k)^b * (65.41 * \sin^2\phi_k + 4.56 * \sin\phi_k + 0.065)$$

where

ϕ_k = arctan(s_k/1000), where s_k is the median slope
x_k = slope length (m)
b = a factor of percent slope, as follows:

Percent Slope	b
0-1	0.2
1 - 3.5	0.3
3.5 - 5	0.4
5 +	0.5

Slope was based on digital elevation data (http://gcmd.gsfc.nasa.gov/cgi-bin/md/getdif.pl?format=sgml&morph_dic=dif_to_dif-display-html.dic&entry_ids=7_MIN_DEM) and was determined using a second-order finite difference method (Skidmore, 1989) which calculates the elevation rise to the elevation run of a particular point of interest based on the 4 neighboring elevation points. The median of these slopes per soil type and land use was then used in the length slope equation discussed above. The slope length varied by subwatershed and was assumed to range from 100 to 150 meters based on a visual analysis and spatial analyst function of the topographic and elevation data in a GIS platform.

Cover and Management (C) and Practice (P) Factors:

The mechanism by which soil is eroded from a land area and the amount of soil eroded depends on soil treatment resulting from a combination of land uses (e.g., forestry versus row-cropped agriculture) and the specific manner in which land uses are carried out (e.g., no-till agriculture versus non-contoured row cropping). Land use and management variations are represented by cover and management factors in the universal soil loss equation and in the erosion model of GWLF. Cover and management factors were drawn from several sources (Wischmeier and Smith, 1978; Haith et al., 1992; Novotny and Olem, 1994) and from communications with USDA, NRCS, and SWCD staff involved with the watershed. The values used in the modeling are summarized in Table 5. The C factor for row crop is the sum of the C factors per cover and management practice multiplied by the estimated percent of the watershed that utilized that particular cover and management practice. Practice (P) factors were generally set to 1, consistent with recommendations for non-agricultural land.

Table 5. Cover and Management Factors for Upper Little Miami River Watershed Land Uses*

Land Use	C	P
Barren (Transitional)	0.013	1
Commercial/Industrial/Transportation	0.04	1
Deciduous Forest	0.01	1
Evergreen Forest	0.01	1
Urban/Recreational Grasses	0.04	1
High Intensity Residential	0.04	1
Low Intensity Residential	0.013	1
Pasture	0.013	1
Row Crops	0.14- 0.154	1
Water	0	1
Wetlands	0.01	1

* C and P factors are not required for the "urban" land uses which are modeled in GWLF via a buildup-washoff formulation rather than USLE.

Sediment Delivery Ratio:

The sediment delivery ratio (SDR) converts erosion to sediment yield, and indicates the portion of eroded soil that is carried to the watershed mouth from land draining to the watershed. The BasinSim program (a Windows version of GWLF) includes a built-in utility which calculates the sediment delivery ratio based an empirical relationship of SDR to watershed area (SCS, 1973). The sediment delivery ratio for the entire Upper Little Miami River watershed was calculated as 0.06.

Nutrient Load Generation

Groundwater Nutrient Concentrations:

The GWLF model requires input of groundwater nutrient concentrations excluding loads due to septic systems, which are accounted for separately. Even in the absence of septic system loads, groundwater concentrations are expected to increase with a shift from forest to either agriculture or development, due to the input of fertilizer on crops, lawns, and gardens. The effect is greatest for nitrate, which is highly soluble, but some elevation of groundwater concentrations of phosphorus is also expected with increased development.

Groundwater nutrient concentrations were estimated as an area-weighted average of concentrations expected for managed land (agriculture, and residential, commercial, and industrial development) and unmanaged land (e.g., forest). Groundwater concentrations for unmanaged land were assigned a value of 0.005 mg/l for phosphorus and 0.22 for nitrogen; managed lands were assigned a groundwater phosphorus concentration of 0.075 mg/l and a groundwater nitrogen concentration of 1.57 mg/l. These values were based on data collected by USGS from seven shallow wells in the watershed area. These numbers are consistent with several other data sources as well including: the National Eutrophication Study for Shawnee Lake; data from 56 STORET stations sampled at baseflow in the upper LMR basin, and Omernik (1977). The resulting overall groundwater concentrations for the watershed were 0.012 mg/L phosphorus and 1.57 mg/L nitrogen.

Dissolved and Solid Phase Nutrient Concentrations for Rural Land Uses:
GWLF requires a dissolved phase concentration for surface runoff from rural land uses. Particulate concentrations are taken as a general characteristic of area soils, determined by bulk soil concentration and an enrichment ratio indicating preferential association of nutrients with the more erodible soil fraction, and not varied by land use. The estimates of dissolved phase concentrations were selected from the GWLF User's Manual and are shown in Table 6. The solid phase total phosphorus concentration in Table 6 represent the average of the data from the Ohio State University Extension Service.

Table 6. Dissolved and Solids Phase Nutrient Concentrations for Rural Land Uses.

GWLF Land Use Group	Nitrogen		Phosphorus	
	Dissolved Phase (mg/L)	Solids Phase (mg/kg)	Dissolved Phase (mg/L)	Solids Phase (mg/kg)
FOREST	0.25	3800	0.01	500
PASTURE	3.00	3800	0.25	500
ROWCR	2.90	3800	0.26	500
GRASS	0.65	3800	0.06	500
WETLAND	0.25	3800	0.01	500

Buildup/Washoff Parameters for Urban Land Uses:
Nutrients and solids generated from urban land uses are described by a buildup/washoff formulation. Pollutant accumulation is summarized by an exponential buildup rate, and GWLF assumes that 95% of the limiting pollutant storage is reached in a 20-day period without washoff. The resulting buildup parameters (from the GWLF User's Manual) are summarized in Table 10.

Table 7. Pollutant Buildup Rates for Urban Land Uses.

Land use	Nitrogen build up (kg/ha-d)	Phosphorus build up (kg/ha-d)
Commercial/Industrial/Transportation	0.101	0.112
High Intensity Residential	0.101	0.112
Low Intensity Residential	0.045	0.0045

Septic Systems:
GWLF contains routines for the simulation of nutrient loading from both normal and failing septic systems. The number of septic systems in each subwatershed was estimated by laying the subwatershed boundaries over the 1990 Census information via a GIS platform. Census information is stored in geographic tracts that did not exactly match the watershed boundaries. Where a boundary intersected more than half of the census tract then all of the information was included as being in the subwatershed. Where more than half of the census tract lay outside of the watershed boundary, it was not included. The census includes a basic inventory of the number of septic, public, and other sewage systems per tract. The number of septic systems in each subwatershed was then assumed to be the sum of the septic and the other sewage categories (anything that was not recorded as a public system). Several assumptions had to be made to categorize the systems according to their performance. These

assumptions were based on the data provided by the public health departments, where available, and best professional judgement otherwise. The basic classification method used is as follows:

- All systems listed as 'other' in the census were assumed to be direct discharges.
- A majority of the systems built before 1970 were assumed to be ponded based on lack of construction guidance/regulations before 1974.
- Assumed five percent of the septic systems were short-circuited.
- All others were assumed normally operating systems.

Table 8 summarizes the results of these assumptions.

Table 8. Estimated number of people (per capita) served by various types[1] of septic systems in the Upper Little Miami River watershed.

Subwatershed		Normal	Ponded	Short circuited	Direct
1	Headwaters to Clifton Mill Dam	2378	6504	468	702
2	Clifton Dam to Beaver Ck	8119	11383	1026	1391
3	Beaver Ck to Caesar Ck	8869	9780	982	1857
4	Caesar Ck except Anderson Frk	6415	7014	707	1333
5	Anderson Fork	2680	3350	317	495
	Entire watershed:	*28461*	*38031*	*3500*	*5778*

[1] Normal: Septic systems conform to EPA standards and operate efficiently.
Ponded: System failure results in surfacing of effluent.
Short-circuited: Systems are close to surface water (< 15 meters); negligible absorption of phosphorus takes place.
Direct Discharge: Illegal systems discharge effluent directly into surface waters.

Parameter values affecting nutrient loading from septic systems were based on the GWLF User's Manual. Effluent phosphorus from failing septic systems was set to 2.0 g/day, while effluent nitrogen was set to 13.0 g/day. Plant uptake rates were assumed to be 1.5 g/day nitrogen and 0.5 g/day phosphorus.

Point Sources:

Nutrient loads from point sources are calculated outside of the GWLF model and are added in directly. The point source information was based on data received from the facilities in their Monthly Operating Reports and stored in an Ohio EPA database. Data from 1990 through 1999 was used. The average daily load in kilograms was calculated per parameter and per season based on 50th percentile values (if less then 10 observations were available, the mean was used instead) for each year.

Total nitrogen (TN) loads were calculated based on the sum of the total Kjeldahl nitrogen(TKN), nitrate nitrogen (NO_3-N), and nitrite nitrogen (NO_2-N) per facility. If a municipal wastewater treatment facility did not monitor for one or more of these components, the following ratios were used to estimate the total nitrogen for the facility:

13% TN = Organic Nitrogen
3% TN = Ammonia Nitrogen
16% TN = TKN (Organic + Ammonia Nitrogen)
84% TN = NO_2-NO_3 Nitrogen
100 % TN

These ratios were based on all the available effluent data in the basin. If a wastewater treatment facility did not monitor for total phosphorus, its average effluent flow was multiplied by the average seasonal concentration from all reported treatment plants in the basin. The average annual total phosphorus concentration was 1.84 mg/l. All other facilities (not municipal treatment plants) which did not monitor for nutrients in their effluent were included by multiplying the facility's average flow by background nutrient values of the basin. The total monthly point source nutrient load per subwatershed was calculated by summing the average daily nutrient loads from all point sources in the subwatershed and multiplying by 30.

2.3 Comparison of Observed and Modeled Data

The GWLF model was calibrated to the Little Miami River watershed by comparing observed flow data from water year 1989 through 2000 to predicted data for the same time period. Several USGS streamflow gages were used to determine the observed flow at the bottom of the study area (e.g., the most downstream point). The USGS gage on the LMR near Oldtown, Ohio (# 03240000) has a full period of record from 1952 to date. However, this gage is located in the middle of the study area where U.S. Highway 68 crosses the LMR. The USGS gage 03242050 (LMR near Spring Valley, Ohio) is 2.8 miles downstream of Glady Run and is closer to the most downstream point in the study area but still would not include flow from Caesar Creek (subwatersheds 4 and 5). Also, flow data at this gage station was recorded only from 1968-1983; however stage has been recorded to date. A regression relationship between the flow at the Oldtown gage to the flow at the Spring Valley gage was developed and the Spring Valley gage flow record was populated through March 2000 using this regression equation. The location of the observed flow values needed to calibrate the model is at a point in the mainstem just downstream of the Caesar Ck confluence. The observed flow at this downstream point was calculated by multiplying the daily Spring Valley flow by the ratio of drainage areas between the Spring Valley gage and the point of interest downstream of Caesar Ck.

The entire watershed was modeled to predict the streamflow at a point just downstream of the Caesar Creek confluence. These predicted values were then statistically compared to the observed flow data discussed above. The model predicts monthly streamflows fairly accurately with a coefficient of determination (r^2) of 0.87. The r^2 value is a measure of the 'fit' of the predicted data to the observed data. The higher the r^2 value (to a maximum of 1) the more accurately the model predicts variations in the data. The average ratio of the predicted values to observed is 1.003.

The model also predicts nutrient loads to the stream. It is difficult to calibrate the predicted modeled loads based on observed data because the actual ('observed') load to the stream is extremely difficult, if not impossible, to measure unless the modeled area is limited to a very small plot of land. However, a rough estimate of the actual load to the stream can be made by monitoring the load in the stream. The load in the stream is effected by instream process which GWLF would not incorporate; therefore, it is a rough estimate only, especially useful in measuring trends in the data as opposed to a strict calibration procedure.

The load in the stream was determined using a U.S. Army Corp of Engineers procedure called FLUX (Walker, 1996). FLUX is an interactive program designed for use in estimating the loadings of nutrients or other water quality components passing a tributary sampling station over a given period of time. Data requirements include:

h. grab-sample nutrient concentrations, typically measured at a weekly to monthly frequency for a period of at least 1 year;

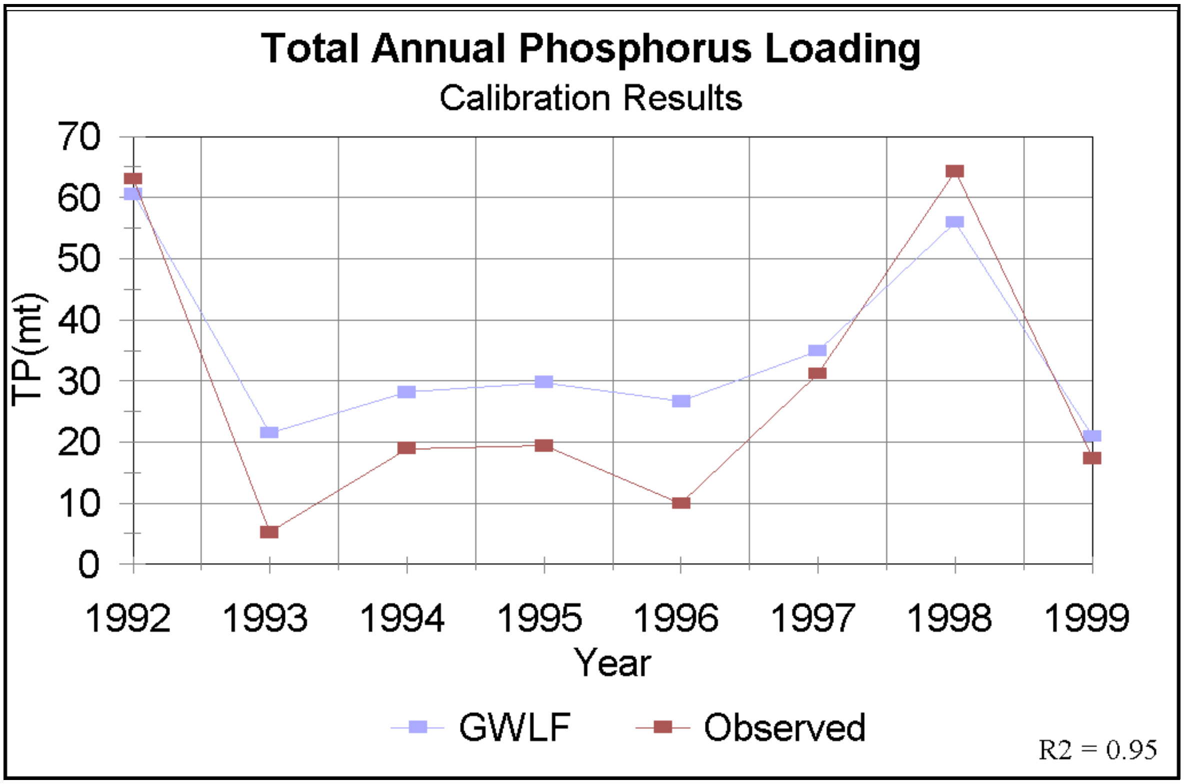
i. corresponding flow measurements (instantaneous or daily mean values); and,
j. a complete flow record (mean daily flows) for the period of interest.

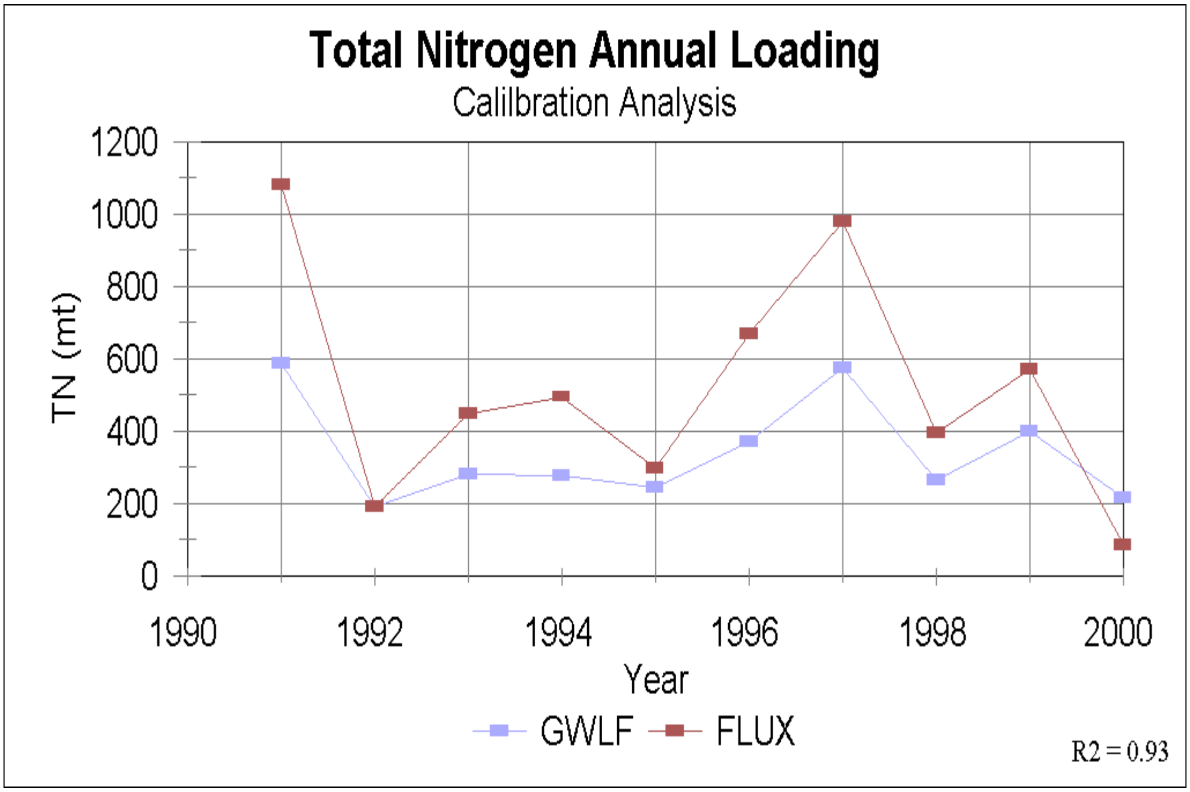
Using six calculation techniques, FLUX maps the flow/concentration relationship developed from the sample record onto the entire flow record to calculate total mass discharge and associated error statistics. Uncertainty is characterized by error variances of the loading estimates. A variety of graphic and tabular output formats are available to assist the user in evaluating data adequacy and in selecting the most appropriate calculation method for each application.

The data from the mainstem site at U.S. 68 was used to provide the grab sample concentrations and corresponding flow values. Approximately 61 chemistry grab samples were collected between 1993 and 1998 during various stream conditions. The FLUX program generated the annual load per year from 1992 through 1999 and this was considered the observed loading data. Since the U.S. 68 site is situated in subwatershed 2, only subwatershed 1 and a portion of subwatershed 2 could be calibrated for loading. The following graphs demonstrate that the predicted trends match the observed trends well. The r^2 values range from 0.93 to 0.95 and reflect that the variations are well described by the model. It is important to note that the 'observed' and predicted annual load values are not expected to match given that the instream processes are included in the observed but not the predicted measurements and that the location of the monitoring station does not line up well with a defined subwatershed boundary.

1.6 Summary

The Upper Little Miami River watershed was modeled using GWLF and data from a wide range of sources. The predicted nutrient loadings and flow compare reasonably well with observed data, and the model can be relied on to give credible results for its intended applications. The model results are based on daily data from 1989 through 2000; this covers seasonal and annual variations in the watershed. The model was used to determine the existing loading for phosphorus, nitrogen, and sediment in the upper Little Miami watershed. An additional application of the model was to predict the effect changes in land management and other factors (such as septic improvements) would have on nutrient loads. This will be discussed further in the implementation plan (a future addendum to the report).


Total Annual Phosphorus Loading
Calibration Results
TP(mt)
70
60
50
40
30
20
10
0
1992
1993
1994
1995
1996
1997
1998
1999
Year
GWLF
Observed
R2 = 0.95


Total Nitrogen Annual Loading
Calilbration Analysis
TN (mt)
1200
1000
800
600
400
200
0
1990
1992
1994
1996
1998
2000
Year
GWLF
FLUX
R2 = 0.93