APPENDIX A

Land Use Distribution in the Barren River Watershed

Table A-1. MRLC Land Use Distribution of Barren River Subwatersheds

Land Use	HUC-12 Subwatershed (05110002__) or Drainage Area			
	Donaho Branch DA		Town Creek DA	
	[acres]	[%]	[acres]	[%]
Deciduous Forest	22.0	4.3	703.4	34.0
Emergent Herbaceous Wetlands	0.0	0.0	0.0	0.0
Evergreen Forest	11.8	2.3	19.3	0.9
High Intensity Commercial/ Industrial/Transp.	37.6	7.4	105.9	5.1
High Intensity Residential	4.9	1.0	8.0	0.4
Low Intensity Residential	14.7	2.9	87.8	4.2
Mixed Forest	17.6	3.4	199.5	9.6
Open Water	0.0	0.0	0.7	0.0
Other Grasses (Urban/recreation; e.g. parks)	26.2	5.1	145.0	7.0
Pasture/Hay	174.8	34.2	584.7	28.3
Quarries/Strip Mines/Gravel Pits	0.0	0.0	0.0	0.0
Row Crops	201.3	39.4	215.1	10.4
Transitional	0.0	0.0	0.0	0.0
Woody Wetlands	0.0	0.0	0.0	0.0
Total	510.8	100.0	2,069.4	100.0

APPENDIX B

Water Quality Monitoring Data

There are several water quality monitoring stations that provide data for waterbodies identified as impaired for pathogens in the Barren River Watershed. The location of these monitoring stations is shown in Figure 5. Monitoring data recorded by TDEC at these stations are tabulated in Table B-1.

Table B-1. TDEC Water Quality Monitoring Data – Barren River Subwatersheds

Monitoring Station	Date	E. Coli [cts./100 mL]
DONOH000.4SR	8/17/04	170
	9/23/04	120
	10/19/04	>2400
	11/18/04	63
	12/21/04	56
	1/20/05	1000
	2/7/05	230
	3/16/05	380
	5/9/05	110
	6/15/05	270
TOWN001.1MA	7/18/00	>2400
	8/10/00	>2400
	9/20/00	120
	10/12/00	38
	11/13/00	1100
	12/14/00	2400
	1/24/01	2000
	5/16/01	110
	6/21/01	1400
	12/14/04	39
	1/11/05	820
	2/15/05	1200
	3/15/05	54
	4/13/05	53
	6/7/05	77
	7/13/05	>2400

Table B-1 (Cont.). TDEC Water Quality Monitoring Data – Barren River Subwatersheds

Monitoring Station	Date	E. Coli
		[cts./100 mL]
TOWN001.3MA	7/18/00	100
	8/10/00	190
	9/20/00	100
	10/12/00	100
	11/13/00	>2400
	12/14/00	330
	1/24/01	67
	5/16/01	180
	6/21/01	240
	12/14/04	59
	1/11/05	>2400
	2/15/05	62
	3/15/05	140
	4/13/05	53
	6/7/05	47
	7/13/05	>2400

APPENDIX C

Load Duration Curve Development
and
Determination of Daily Loading

The TMDL process quantifies the amount of a pollutant that can be assimilated in a waterbody, identifies the sources of the pollutant, and recommends regulatory or other actions to be taken to achieve compliance with applicable water quality standards based on the relationship between pollution sources and in-stream water quality conditions. A TMDL can be expressed as the sum of all point source loads (Waste Load Allocations), nonpoint source loads (Load Allocations), and an appropriate margin of safety (MOS) that takes into account any uncertainty concerning the relationship between effluent limitations and water quality:

$$TMDL = \Sigma \text{ WLAs} + \Sigma \text{ LAs} + MOS$$

The objective of a TMDL is to allocate loads among all of the known pollutant sources throughout a watershed so that appropriate control measures can be implemented and water quality standards achieved. 40 CFR §130.2 (i) (http://www.epa.gov/epacfr40/chapt-I.info/chi-toc.htm) states that TMDLs can be expressed in terms of mass per time, toxicity, or other appropriate measure.

C.1 Development of TMDLs and Load Reductions

E. coli TMDLs, WLAs, and LAs were developed for impaired subwatersheds and drainage areas in the Barren River Watershed using Load Duration Curves (LDCs). Daily Loads for TMDLs, WLAs, and LAs are expressed as a function of daily mean in-stream flow (daily loading function).

C.1.1 Development of Flow Duration Curves

A flow duration curve is a cumulative frequency graph, constructed from historic flow data at a particular location, that represents the percentage of time a particular flow rate is equaled or exceeded. Flow duration curves are developed for a waterbody from daily discharges of flow over a period of record. In general, there is a higher level of confidence that curves derived from data over a long period of record correctly represent the entire range of flow. The preferred method of flow duration curve computation uses daily mean data from U.S. Geological Survey (USGS) continuous-record stations (http://waterdata.usgs.gov/tn/nwis/sw) located on the waterbody of interest. For ungaged streams, alternative methods must be used to estimate daily mean flow. These include: 1) regression equations (using drainage area as the independent variable) developed from continuous record stations in the same ecoregion; 2) drainage area extrapolation of data from a nearby continuous-record station of similar size and topography; and 3) calculation of daily mean flow using a dynamic computer model, such as the Loading Simulation Program C++ (LSPC).

Flow duration curves for impaired waterbodies in the Barren River Watershed were derived from LSPC hydrologic simulations based on parameters derived from calibrations at two USGS monitoring stations (03436100, Red River at Port Royal; 03416000, Wolf River near Byrdstown) (see Appendix D for details of calibration). For example, a flow-duration curve for Donaho Branch at RM 0.4 was constructed using simulated daily mean flow for the period from 10/1/95 through 9/30/05 (RM 0.4 corresponds to the location of monitoring station DONOH00.4SR). This flow duration curve is shown in Figure C-1 and represents the cumulative distribution of daily discharges arranged to show percentage of time specific flows were exceeded during the period of record (the highest daily mean flow during this period is exceeded 0% of the time and the lowest daily mean flow is equaled or exceeded 100% of the time). Flow duration curves for other impaired waterbodies were derived using a similar procedure.

C.1.2 Development of Load Duration Curves and Determination of TMDLs

When a water quality target concentration is applied to the flow duration curve, the resulting load duration curve (LDC) represents the allowable pollutant loading in a waterbody over the entire range of flow. Pollutant monitoring data, plotted on the LDC, provides a visual depiction of stream water quality as well as the frequency and magnitude of any exceedances. Load duration curve intervals can be grouped into several broad categories or zones, in order to provide additional insight about conditions and patterns associated with the impairment. For example, the duration curve could be divided into four zones: high flows (exceeded 0-10% of the time), moist conditions (10-40%), median or mid-range flows (40-70%), and low flows (70-100%). Impairments observed in the low flow zone typically indicate the influence of point sources, while those further left on the LDC (representing zones of higher flow) generally reflect potential nonpoint source contributions (Stiles, 2003).

E. coli load duration curves for impaired waterbodies in the Barren River Watershed were developed from the flow duration curves developed in Section C.1.1, E. coli target concentrations, and available water quality monitoring data. Load duration curves and daily loading functions were developed using the following procedure (Town Creek is shown as an example):

1. A target load-duration curve (LDC) was generated for Town Creek at Mile 1.1 by applying the E. coli target concentration of 941 CFU/100 mL to each of the ranked flows used to generate the flow duration curve (ref.: Section C.1.1) and plotting the results. The E. coli target maximum load corresponding to each ranked daily mean flow is:

   $(\text{Target Load})_{\text{Town Creek}}$ = (941 CFU/100 mL) x (Q) x (UCF)

   where: Target Load = TMDL (CFU/day)
   Q = daily mean instream flow (cfs)
   UCF = the required unit conversion factor

   TMDL = 2.30 x 10^{10} x Q

2. Daily loads were calculated for each of the water quality samples collected at monitoring station TOWN001.1MA (ref.: Table B-1) by multiplying the sample concentration by the daily mean flow for the sampling date and the required unit conversion factor.

   Note: *In order to be consistent for all analyses, the derived daily mean flow was used to compute sampling data loads, even if measured ("instantaneous") flow data was available for some sampling dates.*

   Example – 10/19/04 sampling event:
   Modelled Flow = 1.59 cfs
   Concentration = 2400 CFU/100 mL
   Daily Load = 9.31x10^{10} CFU/day

3. Using the flow duration curves developed in C.1.1, the "percent of days the flow was exceeded" (PDFE) was determined for each sampling event. Each sample load was then plotted on the LDCs developed in Step 1 according to the PDFE. The resulting E. coli LDC for Town Creek is shown in Figure C-2.

LDCs of other impaired waterbodies were derived in a similar manner and are shown in Appendix E.

C.2 Development of WLAs, LAs, and MOS

As previously discussed, a TMDL can be expressed as the sum of all point source loads (WLAs), nonpoint source loads (LAs), and an appropriate margin of safety (MOS) that takes into account any uncertainty concerning the relationship between effluent limitations and water quality:

$$TMDL = \Sigma \text{ WLAs} + \Sigma \text{ LAs} + MOS$$

Expanding the terms:

$$TMDL = [\Sigma WLAs]_{WWTF} + [\Sigma WLAs]_{MS4} + [\Sigma WLAs]_{CAFO} + [\Sigma LAs]_{DS} + [\Sigma LAs]_{SW} + MOS$$

For E. coli TMDLs in each impaired subwatershed or drainage area, WLA terms include:

- $[\Sigma WLAs]_{WWTF}$ is the allowable load associated with discharges of NPDES permitted WWTFs located in impaired subwatersheds or drainage areas. Since NPDES permits for these facilities specify that treated wastewater must meet instream water quality standards at the point of discharge, no additional load reduction is required. WLAs for WWTFs are calculated from the facility design flow and the Monthly Average permit limit.
- $[\Sigma WLAs]_{CAFO}$ is the allowable E. coli load for all CAFOs in an impaired subwatershed or drainage area. All wastewater discharges from a CAFO to waters of the state of Tennessee are prohibited, except when either chronic or catastrophic rainfall events cause an overflow of process wastewater from a facility properly designed, constructed, maintained, and operated to contain:
    - All process wastewater resulting from the operation of the CAFO (such as wash water, parlor water, watering system overflow, etc.); plus,
    - All runoff from a 25-year, 24-hour rainfall event for the existing CAFO or new dairy or cattle CAFOs; or all runoff from a 100-year, 24-hour rainfall event for a new swine or poultry CAFO.

  Therefore, a WLA of zero has been assigned to this class of facilities.
- $[\Sigma WLAs]_{MS4}$ is the required load reduction for discharges from MS4s. E. coli loading from MS4s is the result of buildup/wash-off processes associated with storm events.

LA terms include:

- $[\Sigma LAs]_{DS}$ is the allowable E. coli load from "other direct sources". These sources include leaking septic systems, illicit discharges, and animals access to streams. The LA specified for all sources of this type is zero CFU/day (or to the maximum extent practicable).
- $[\Sigma LAs]_{SW}$ is the allowable E. coli load from nonpoint sources indirectly going to surface waters from all land use areas (except areas covered by a MS4 permit) as a result of the buildup/wash-off processes associated with storm events (i.e. precipitation induced).

Since $[\Sigma WLAs]_{CAFO} = 0$, and $[\Sigma LAs]_{DS} = 0$, the expression relating TMDLs to precipitation-based point and nonpoint sources may be simplified to:

$$TMDL - MOS = [WLAs]_{WWTF} + [\Sigma WLAs]_{MS4} + [\Sigma LAs]_{SW}$$

As stated in Section 8.4, an explicit MOS, equal to 10% of the E. coli water quality targets (ref.: Section 5.0), was utilized for determination of the percent load reductions necessary to achieve the WLAs and LAs:

Instantaneous Maximum (lake, reservoir, State Scenit River, Tier II, and Tier III):

Target – MOS = (487 CFU/100 ml) – 0.1(487 CFU/100 ml)

Target – MOS = 438 CFU/100 ml

Instantaneous Maximum (other):

Target – MOS = (941 CFU/100 ml) – 0.1(941 CFU/100 ml)

Target – MOS = 847 CFU/100 ml

30-Day Geometric Mean: Target – MOS = (126 CFU/100 ml) – 0.1(126 CFU/100 ml)

Target – MOS = 113 CFU/100 ml

C.2.1 Daily Load Calculation

Since WWTFs discharge must comply with instream water quality criteria (TMDL target) at the point of discharge, WLAs for WWTFs are expressed as a constant term. In addition, WLAs for MS4s and LAs for precipitation-based nonpoint sources are equal on a per unit area basis and may be expressed as the daily allowable load per unit area (acre) resulting from a decrease in in-stream E. coli concentrations to TMDL target values minus MOS:

$[WLAs]_{MS4}$ = LA = (TMDL – MOS – $[WLAs]_{WWTF}$) / DA

where: DA = waterbody drainage area (acres)

Using Town Creek as an example:

$TMDL_{Town\ Creek}$ = (941 CFU/100 mL) x (Q) x (UCF)

= $2.3 \times 10^{10} \times Q$

$MOS_{Town\ Creek}$ = TMDL x 0.10

MOS = $2.30 \times 10^{9} \times Q$

$WLA[MS4]_{Town\ Creek} = LA_{Town\ Creek}$

= {TMDL – MOS – WLA[WWTFs]} / DA

= $\{(2.30 \times 10^{10} \times Q) - (2.30 \times 10^{9} \times Q) - (5.343 \times 10^{10})\} / (2069.37)$

WLA[MS4] = LA = $1.000 \times 10^{7} \times Q - 2.582 \times 10^{7}$

TMDLs, WLAs, LAs and MOS for other impaired waterbodies were derived in a similar manner and are summarized in Table C-1.

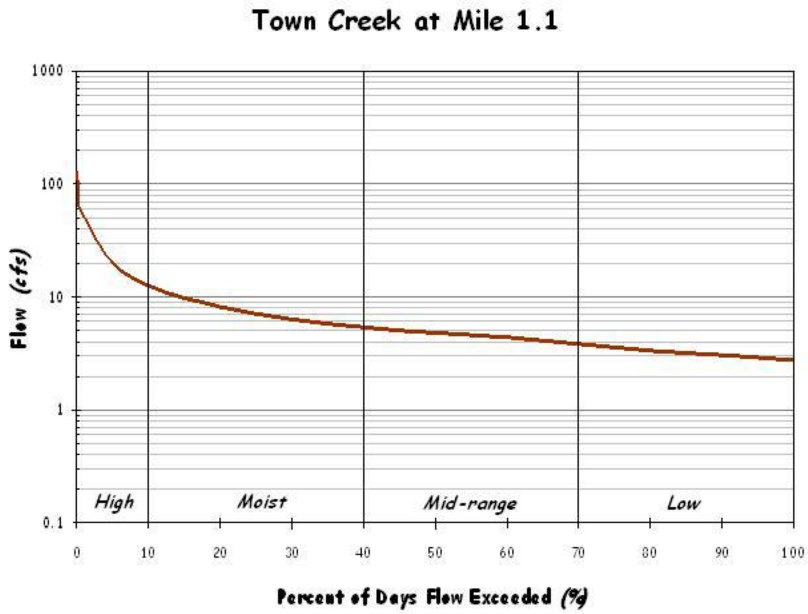

Figure C-1. Flow Duration Curve for Town Creek at Mile 1.1

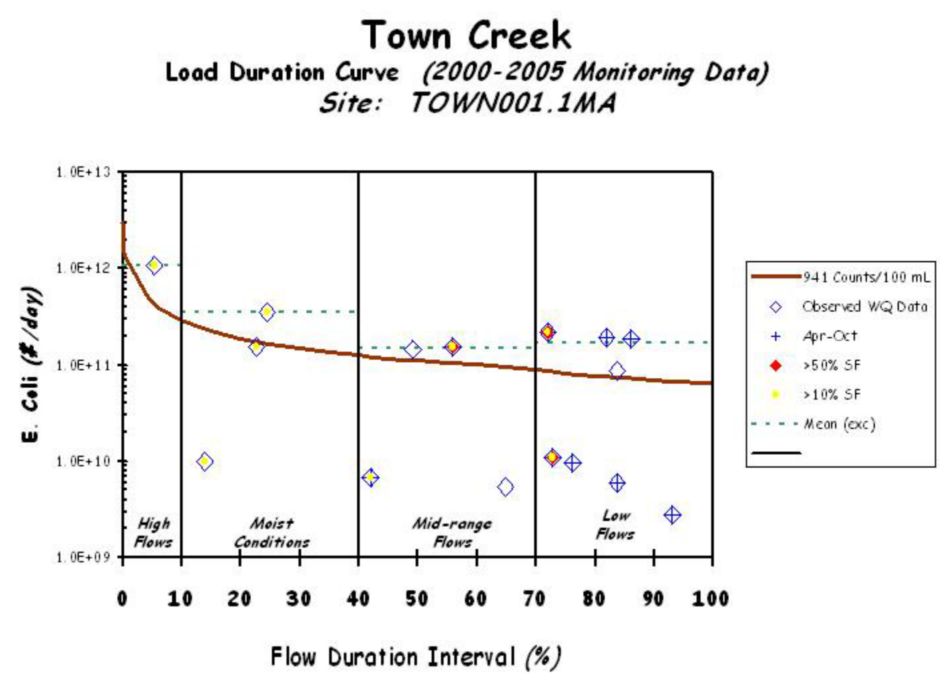

Figure C-2. E. Coli Load Duration Curve for Town Creek at Mile 1.1

Table C-1 TMDLs, WLAs, & LAs for Impaired Subwatersheds and Drainage Areas in the Barren River Watershed

HUC-12 Subwatershed (05110001__) or Drainage Area (DA)	Impaired Waterbody Name	Impaired Waterbody ID	TMDL	MOS	WLAs			LAs
					WWTFs [a]	Leaking Collection Systems	MS4s	
			[CFU/day]	[CFU/day]	[CFU/day]	[CFU/day]	[CFU/day/acre]	[CFU/day/acre]
0501	Donaho Branch	TN05110002008 – 0600	2.30×10^{10} * Q	2.30×10^{9} * Q	NA	0	4.052×10^{7} * Q	4.052×10^{7} * Q
0601	Town Creek	TN05110002027 – 0421	2.30×10^{10} * Q	2.30×10^{9} * Q	5.343×10^{10}	0	NA	1.000×10^{7} * Q – 2.582×10^{7}

Notes: NA = Not Applicable.
Q = Mean Instream Daily Flow (cfs)

a. WLAs for WWTFs are expressed as E. coli loads (CFU/day). All current and future WWTFs must meet instream water quality standards at the point of discharge as specified in their NPDES permit; at no time shall concentration be greater than the appropriate E. coli standard (487 CFU/100 mL or 941 CFU/100 mL).

APPENDIX D

Hydrodynamic Modeling Methodology

HYDRODYNAMIC MODELING METHODOLOGY

D.1 Model Selection

The Loading Simulation Program C++ (LSPC) was selected for flow simulation of pathogen-impaired waters in the subwatersheds of the Barren River Watershed. LSPC is a watershed model capable of performing flow routing through stream reaches. LSPC is a dynamic watershed model based on the Hydrologic Simulation Program - Fortran (HSPF)

D.2 Model Set Up

The Barren River Watershed was delineated into subwatersheds in order to facilitate model hydrologic calibration. Boundaries were constructed so that subwatershed "pour points" coincided with HUC-12 delineations, 303(d)-listed waterbodies, and water quality monitoring stations. Watershed delineation was based on the NHD stream coverage and Digital Elevation Model (DEM) data. This discretization facilitates simulation of daily flows at water quality monitoring stations.

Several computer-based tools were utilized to generate input data for the LSPC model. The Watershed Characterization System (WCS), a geographic information system (GIS) tool, was used to display, analyze, and compile available information to support hydrology model simulations for selected subwatersheds. This information includes land use categories, point source dischargers, soil types and characteristics, population data (human and livestock), and stream characteristics.

An important factor influencing model results is the precipitation data contained in the meteorological data files used in these simulations. Weather data from multiple meteorological stations were available for the time period from January 1970 through December 2005. Meteorological data for a selected 11-year period were used for all simulations. The first year of this period was used for model stabilization with simulation data from the subsequent 10-year period (10/1/95 – 9/30/05) used for TMDL analysis.

D.3 Model Calibration

Hydrologic calibration of the watershed model involves comparison of simulated streamflow to historic streamflow data from U. S. Geological Survey (USGS) stream gaging stations for the same period of time. Two USGS continuous record stations located near the Barren River Watershed with a sufficiently long and recent historical record was selected as the basis of the hydrology calibration. The USGS station was selected based on similarity of drainage area, Level IV ecoregion, land use, and topography. The calibration involved comparison of simulated and observed hydrographs until statistical stream volumes and flows were within acceptable ranges as reported in the literature (Lumb, et al., 1994).

Initial values for hydrologic variables were taken from an EPA developed default data set. During the calibration process, model parameters were adjusted within reasonable constraints until acceptable agreement was achieved between simulated and observed streamflow. Model parameters adjusted include: evapotranspiration, infiltration, upper and lower zone storage, groundwater storage, recession, losses to the deep groundwater system, and interflow discharge.

The results of the hydrologic calibration for Red River at Port Royal, TN, USGS Station 03436100, drainage area 914 square miles, are shown in Table D-1 and Figures D-1 and D-2. The results of the hydrologic calibration for Wolf River near Byrdstown, TN, USGS Station 03416000, drainage area 103 square miles, are shown in Table D-2 and Figures D-3 and D-4.

Table D-1. Hydrologic Calibration Summary: Red River at Port Royal, TN (USGS 03436100)

		914.2661224	
Simulation Name:	USGS03436100	**Simulation Period:**	
		Watershed Area (ac):	585317.62
Period for Flow Analysis			
Begin Date:	**10/01/81**	**Baseflow PERCENTILE:**	2.5
End Date:	**09/30/91**	*Usually 1%-5%*	
Total Simulated In-stream Flow:	**197.11**	Total Observed In-stream Flow:	**206.32**
Total of highest 10% flows:	**96.31**	Total of Observed highest 10% flows:	**96.89**
Total of lowest 50% flows:	**21.34**	Total of Observed Lowest 50% flows:	**21.60**
Simulated Summer Flow Volume (months 7-9):	**14.58**	Observed Summer Flow Volume (7-9):	**16.04**
Simulated Fall Flow Volume (months 10-12):	**45.65**	Observed Fall Flow Volume (10-12):	**40.70**
Simulated Winter Flow Volume (months 1-3):	**84.64**	Observed Winter Flow Volume (1-3):	**87.97**
Simulated Spring Flow Volume (months 4-6):	**52.23**	Observed Spring Flow Volume (4-6):	**61.61**
Total Simulated Storm Volume:	**184.37**	Total Observed Storm Volume:	**191.96**
Simulated Summer Storm Volume (7-9):	**11.40**	Observed Summer Storm Volume (7-9):	**12.43**
Errors (Simulated-Observed)		*Recommended Criteria*	Last run
Error in total volume:	**-4.47**	10	
Error in 50% lowest flows:	**-1.19**	10	
Error in 10% highest flows:	**-0.61**	15	
Seasonal volume error - Summer:	**-9.08**	30	
Seasonal volume error - Fall:	**12.16**	30	
Seasonal volume error - Winter:	**-3.78**	30	
Seasonal volume error - Spring:	**-15.23**	30	
Error in storm volumes:	**-3.95**	20	
Error in summer storm volumes:	**-8.25**	50	

Criteria for Median Monthly Flow Comparisons	
Lower Bound (Percentile):	25
Upper Bound (Percentile):	75

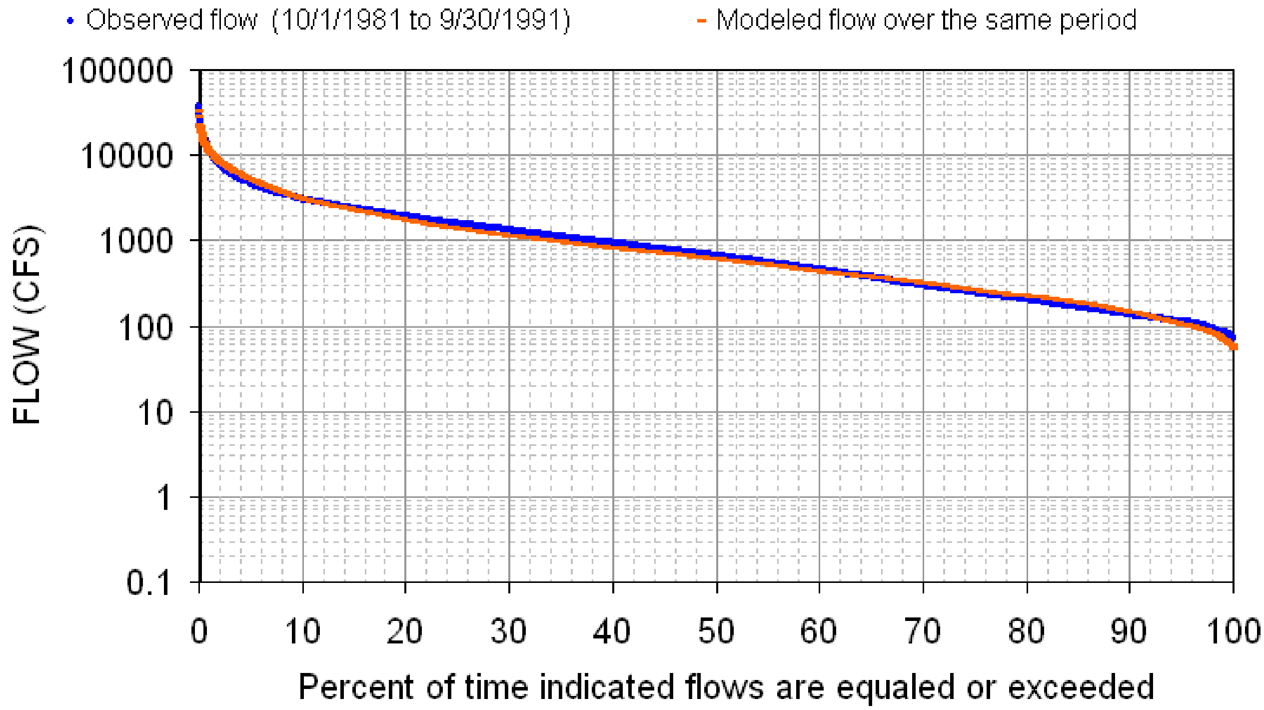

Figure D-1. Hydrologic Calibration: Red River, USGS 03436100 (WYs1982-1991)

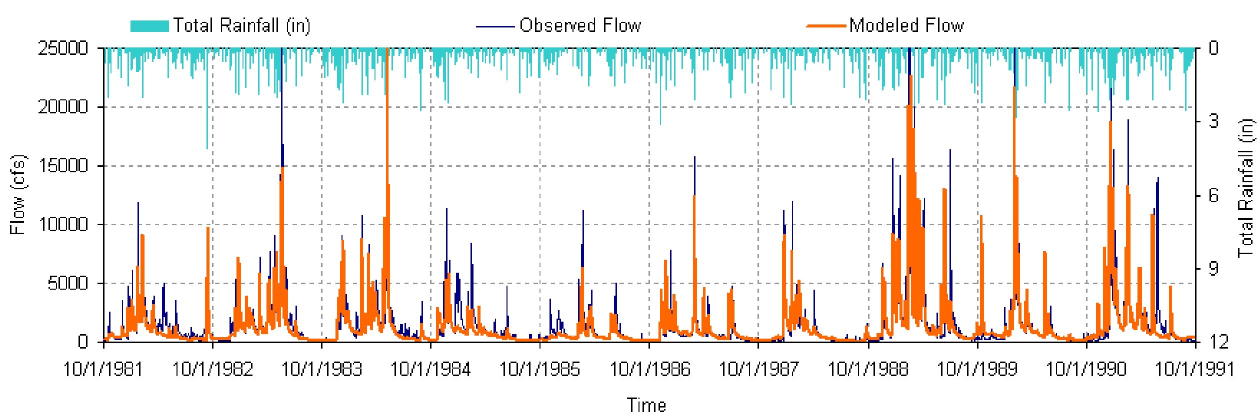

Figure D-2. 10-Year Hydrologic Comparison: Red River, USGS 03436100

Table D-2. Hydrologic Calibration Summary: Wolf River near Byrdstown, TN (USGS 03416000)

		103.1800656	
Simulation Name:	USGS03416000	**Simulation Period:**	
		Watershed Area (ac):	66056.38
Period for Flow Analysis			
Begin Date:	**10/01/83**	**Baseflow PERCENTILE:**	2.5
End Date:	**09/30/91**	*Usually 1%-5%*	
Total Simulated In-stream Flow:	**173.64**	Total Observed In-stream Flow:	**180.87**
Total of highest 10% flows:	**89.46**	Total of Observed highest 10% flows:	**99.83**
Total of lowest 50% flows:	**15.70**	Total of Observed Lowest 50% flows:	**13.14**
Simulated Summer Flow Volume (months 7-9):	**10.72**	Observed Summer Flow Volume (7-9):	**8.54**
Simulated Fall Flow Volume (months 10-12):	**50.59**	Observed Fall Flow Volume (10-12):	**42.02**
Simulated Winter Flow Volume (months 1-3):	**73.95**	Observed Winter Flow Volume (1-3):	**86.04**
Simulated Spring Flow Volume (months 4-6):	**38.37**	Observed Spring Flow Volume (4-6):	**44.28**
Total Simulated Storm Volume:	**165.60**	Total Observed Storm Volume:	**172.89**
Simulated Summer Storm Volume (7-9):	**8.73**	Observed Summer Storm Volume (7-9):	**6.54**
Errors (Simulated-Observed)		*Recommended Criteria*	Last run
Error in total volume:	**-4.00**	10	
Error in 50% lowest flows:	**19.48**	10	
Error in 10% highest flows:	**-10.39**	15	
Seasonal volume error - Summer:	**25.54**	30	
Seasonal volume error - Fall:	**20.40**	30	
Seasonal volume error - Winter:	**-14.05**	30	
Seasonal volume error - Spring:	**-13.33**	30	
Error in storm volumes:	**-4.22**	20	
Error in summer storm volumes:	**33.54**	50	

Criteria for Median Monthly Flow Comparisons	
Lower Bound (Percentile):	25
Upper Bound (Percentile):	75

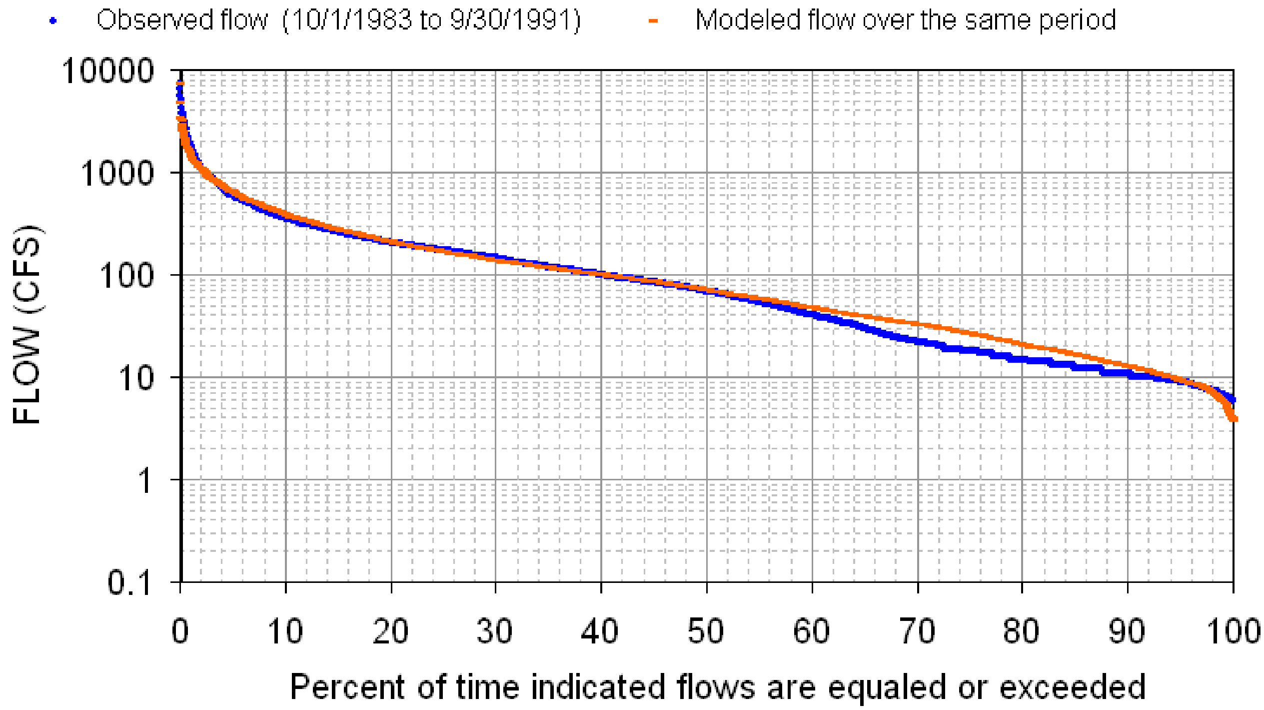

Figure D-3. Hydrologic Calibration: Wolf River, USGS 03416000 (WYs1984-1991)

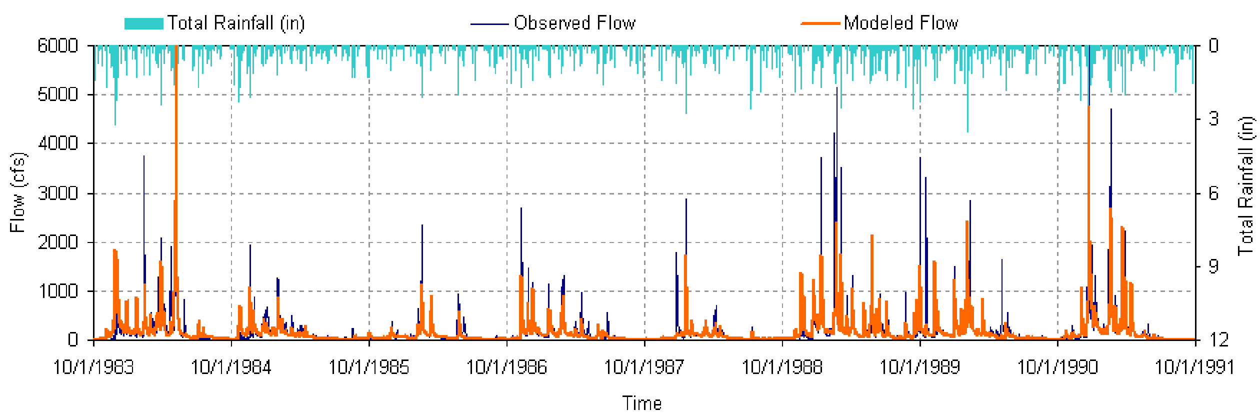

Figure D-4. 8-Year Hydrologic Comparison: Wolf River, USGS 03416000

APPENDIX E

Source Area Implementation Strategy

All impaired waterbodies and corresponding HUC-12 subwatersheds or drainage areas have been classified according to their respective source area types in Section 9.5, Table 9. The implementation for each area will be prioritized according to the guidance provided in Section 9.5.1 and 9.5.2, with examples provided in Section E.1 and E.2, below. For all impaired waterbodies, the determination of source area types serves to identify the predominant sources contributing to impairment (i.e., those that should be targeted initially for implementation). However, it is not intended to imply that sources in other landuse areas are not contributors to impairment and/or to grant an exemption from addressing other source area contributions with implementation strategies and corresponding load reduction. For mixed use areas, implementation will follow the guidance established for both urban and agricultural areas, at a minimum.

E.1 Urban Source Areas

For impaired waterbodies and corresponding HUC-12 subwatersheds or drainage areas identified as predominantly urban source area types, the following example for Town Creek provides guidance for implementation analysis:

The Town Creek watershed, HUC-12 051100020601, lies near Lafayette. The drainage area for Town Creek at mile 1.1 is approximately 2,069 acres (3.23 mi^2); therefore, four flow zones were used for the duration curve analysis (see Sect. 9.1.1).

Note: The Final 2006 303(d) List includes Minor Municipal Point Source and Urbanized High Density Area as Pollutant Source categories for Town Creek; therefore, Town Creek is listed in the Urban source area type in Section 9.5, Table 9.

The flow duration curve for Town Creek at mile 1.1 was constructed using simulated daily mean flow for the period from 10/1/95 through 9/30/05 (mile 1.1 corresponds to the location of monitoring station TOWN001.1MA). This flow duration curve is shown in Figure E-1 and represents the cumulative distribution of daily discharges arranged to show percentage of time specific flows were exceeded during the period of record. Flow duration curves for other impaired waterbodies were developed using a similar procedure (Appendix C).

The E. coli LDC for Town Creek at Mile 1.1 (Figure E-2) was analyzed to determine the frequency with which observed daily water quality loads exceed the E. coli target maximum daily loading (941 CFU/100 mL x flow [cfs] x conversion factor) under four flow conditions (low, mid-range, moist, and high). Observation of the plot illustrates that exceedances occur under multiple flow zones indicating the Town Creek watershed may be impacted by both point and non-point-type sources. LDCs for other impaired waterbodies were developed using a similar procedure (Appendix C) and are shown in Figures E-3 to E-4.

Critical conditions for the Town Creek watershed (HUC-12 051100020601) occur during low flows, typically indicative of point source contributions (see Table E-2, Section E.4). However, the moist and mid-range flow conditions have comparable percent load reduction goals (PLRGs) to meet WQs. In addition, exceedances of the E. coli water quality standard are well distributed across the full range of flows and all flow zones, though the magnitude of exceedances varies widely.

Figure E-1. Flow Duration Curve for Town Creek at Mile 1.1

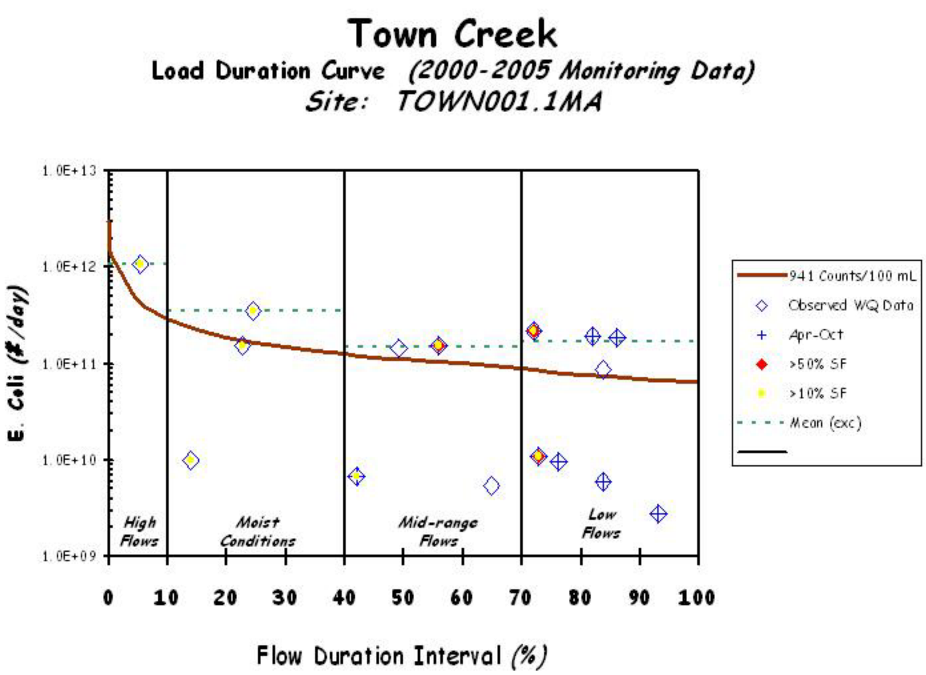

Figure E-2. E. Coli Load Duration Curve for Town Creek at Mile 1.1

Table E-1. Load Duration Curve Summary for Implementation Strategies (Example: Town Creek subwatershed, HUC-12 051100020601) (4 Flow Zones).

Hydrologic Condition		High	Moist	Mid-range	Low*
% Time Flow Exceeded		0-10	10-40	40-70	70-100
Town Creek (051100020601)	Number of Samples	1	3	4	8
	% > 941 CFU/100 mL[1]	100.0	33.3	50.0	50.0
	Load Reduction[2]	60.8	17.7	13.6	24.6
TMDL (CFU/day)		4.508E+11	1.647E+11	1.058E+11	7.314E+10
Margin of Safety (CFU/day)		4.508E+10	1.647E+10	1.058E+10	7.314E+09
WLA (WWTFs) (CFU/day)		5.343E+10	5.343E+10	5.343E+10	5.343E+10
WLAs (MS4s) (CFU/day/acre)[3]		NA	NA	NA	NA
LA (CFU/day/acre)[3]		1.702E+08	4.580E+07	2.019E+07	5.990E+06
Implementation Strategies[4]					
Municipal NPDES			L	M	H
Stormwater Management			H	H	
SSO Mitigation		H	M	L	
Collection System Repair			H	M	L
Septic System Repair			L	M	H
Potential for source area contribution under given flow condition (H: High; M: Medium; L: Low)					

* The Low Flow zone represents the critical conditions for E. coli loading in the Town Creek subwatershed.
1 Tennessee Maximum daily water quality criterion for E. coli.
2 Reductions (percent) based on mean of observed percent load reductions in range.
3 LAs and MS4s are expressed as daily load per unit area in order to provide for future changes in the distribution of LAs and MS4s (WLAs).
4 Watershed-specific Best Management Practices for Urban Source reduction. Actual BMPs applied may vary and should not be limited according to this grouping.

Results indicate the implementation strategy for the Town Creek watershed will require BMPs targeting point sources (dominant under low flow/baseflow conditions). Table E-1 presents an allocation table of LDC analysis statistics for Town Creek E. coli and implementation strategies for each source category covering the entire range of flow (Stiles, 2003). The implementation strategies listed in Table E-1 are a subset of the categories of BMPs and implementation strategies available for application to the Barren River watershed for reduction of E. coli loading and mitigation of water quality impairment from urban sources. Targeted implementation strategies and LDC analysis statistics for other impaired waterbodies and corresponding HUC-12 subwatersheds and drainage areas identified as predominantly urban source area types can be derived from the information and results available in Tables 10 and E-6.

Table E-6 presents LDC analyses (TMDLs, WLAs, LAs, and MOS) and PLRGs for all flow zones for all E. coli impaired waterbodies in the Barren River watershed.

E.2 Agricultural Source Areas

There are no impaired waterbodies with corresponding HUC-12 subwatersheds or drainage areas classified as source area type predominantly agricultural in the Barren River watershed.

E.3 Forestry Source Areas

There are no impaired waterbodies with corresponding HUC-12 subwatersheds or drainage areas classified as source area type predominantly forested, with the predominant source category being wildlife, in the Barren River watershed.

E.4 Calculation of Percent Load Reduction Goals and Determination of Critical Flow Zones

In order to facilitate implementation, corresponding percent reductions in loading required to decrease existing, in-stream E. coli loads to TMDL target levels (percent load reduction goals) were calculated. The following example is from Town Creek at mile 1.1.

1. For each flow zone, the mean of the percent exceedances of individual loads relative to their respective target maximum loads (at their respective PDFEs) was calculated. Each negative percent exceedance was assumed to be equal to zero.

Date	Sample Conc. (CFU/100 mL)	Flow (cfs)	Existing Load (CFU/Day)	Target (TMDL) Load (CFU/Day)	Percent Reduction
12/14/04	39	10.29	9.82E+09	2.37E+11	0 (-2313)
1/11/05	820	7.61	1.53E+11	1.75E+11	0 (-14.8)
1/24/01	2000	7.22	3.53E+11	1.66E+11	53.0
Percent Load Reduction Goal (PLRG) for Moist Zone (Mean)					**17.7**

2. The PLRGs calculated for each of the flow zones, not including the high flow zone, were compared and the PLRG of the greatest magnitude indicates the critical flow zone for prioritizing implementation actions for Town Creek.

Example – *Moist Conditions Flow Zone Percent Load Reduction Goal =17.7*
Mid-Range Flow Zone Percent Load Reduction Goal = 13.6
Low Flow Zone Percent Load Reduction Goal = 24.6

Therefore, the critical flow zone for prioritization of Town Creek implementation activities is the Low Flow Zone and subsequently actions targeting point source controls.

PLRGs and critical flow zones of the other impaired waterbodies were derived in a similar manner and are shown in Table E-6.

Table E-2. Summary of Critical Conditions for Impaired Waterbodies in the Barren River Watershed.

Waterbody ID	Moist	Mid-range	Dry	Low
Donaho Branch	Ò			
Town Creek				Ò

* All Waterbody(ies) have 4 flow zones.

Geometric Mean Data

For cases where five or more samples were collected over a period of not more than 30 consecutive days, the geometric mean E. coli concentration was determined and compared to the target geometric mean E. coli concentration of 126 CFU/100 mL. If the sample geometric mean exceeded the target geometric mean concentration, the reduction required to reduce the sample geometric mean value to the target geometric mean concentration was calculated.

Example: *Insufficient monitoring data were available for all Barren River watershed impaired waterbody monitoring stations. The following example is from the Clear Fork of the Cumberland River watershed:*

Monitoring Location = Little Elk Creek
Sampling Period = 7/1/04 – 7/29/04
Geometric Mean Concentration = 1128.4 CFU/100 mL
Target Concentration = 126 CFU/100 mL
Reduction to Target = 88.8%

For impaired waterbodies where monitoring data are limited to geometric mean data only, results can be utilized for general indication of relative impairment and, when plotted on a load duration curve, may indicate areas for prioritization of implementation efforts. For impaired waterbodies where both types of data are available, geometric mean data may be utilized to supplement the results of the individual flow zone calculations.

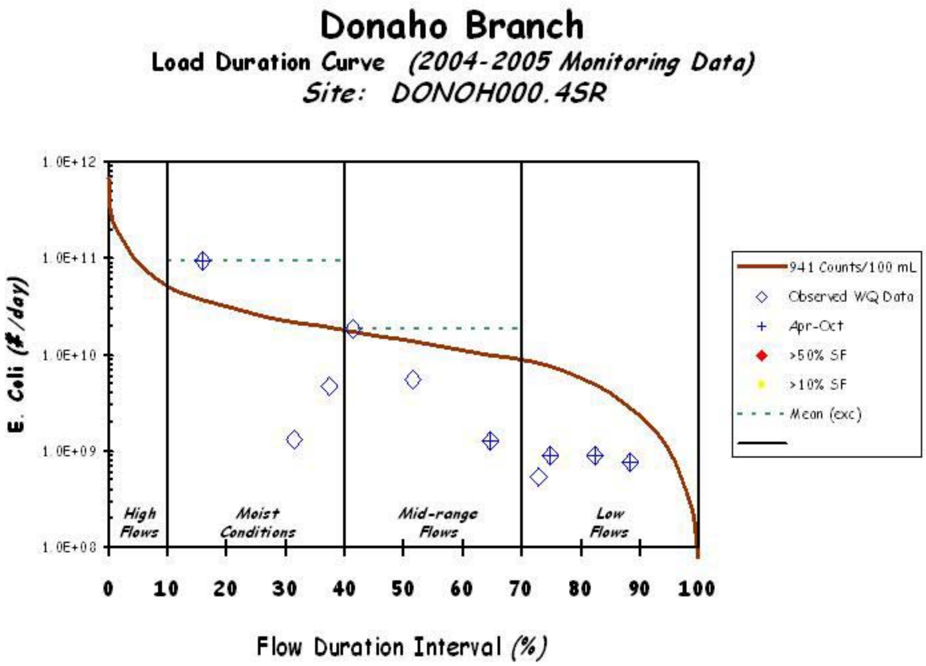

Figure E-3. E. Coli Load Duration Curve for Donaho Branch

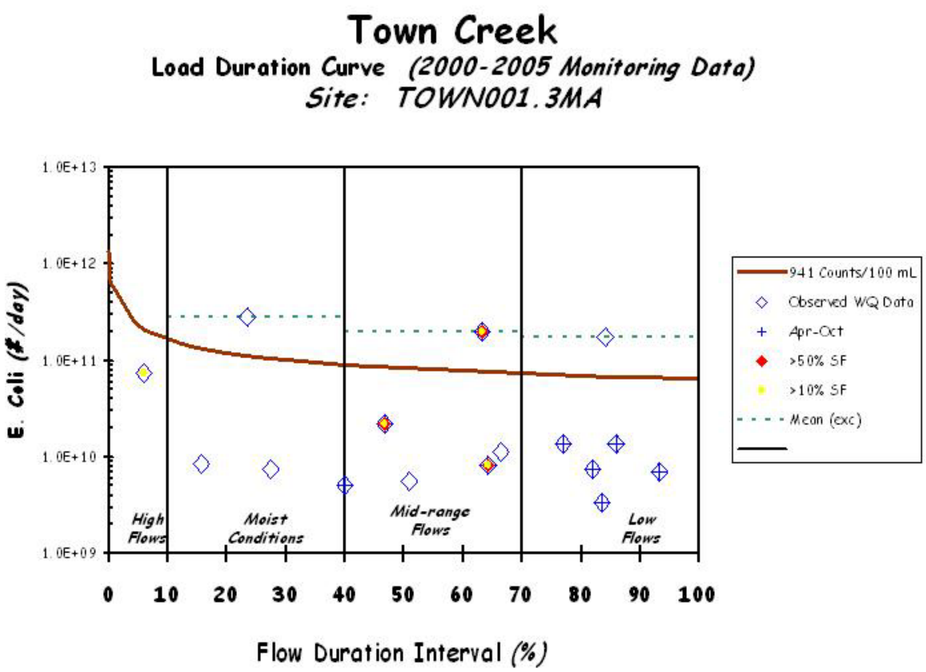

Figure E-4. E. Coli Load Duration Curve for Town Creek at Mile 1.3

Table E-3. Calculated Load Reduction Based on Daily Loading – Donaho Branch

Sample Date	Flow Regime	Flow	PDFE	Concentration	Load	% Reduction to Achieve TMDL	Average of Load Reductions	% Reduction to TMDL – MOS
		[cfs]	[%]	[CFU/100 ml]	[CFU/day]	[%]	[%]	[%]
10/19/04	Moist Conditions	1.59	15.9%	2400	9.31E+10	**60.8**		
12/21/04		0.96	31.4%	56	1.32E+09	0.0		
2/7/05		0.84	37.4%	230	4.75E+09	0.0	**20.3**	**21.6**
1/20/05	Mid-Range Flows	0.76	41.4%	1000	1.87E+10	**5.9**		
3/16/05		0.60	51.5%	380	5.55E+09	0.0		
9/23/04		0.44	64.8%	120	1.28E+09	0.0	**2.0**	**5.1**
11/18/04	Low Flows	0.35	73.0%	63	5.46E+08	0.0		
5/9/05		0.33	74.9%	110	9.00E+08	0.0		
8/17/04		0.22	82.4%	170	9.00E+08	0.0		
6/15/05		0.12	88.4%	270	7.76E+08	0.0	**NR**	**NR**

Note: NR = No reduction required
NA = Not applicable

Table E-4. Calculated Load Reduction Based on Daily Loading – Town Creek – Mile 1.1

Sample Date	Flow Regime	Flow [cfs]	PDFE [%]	Concentration [CFU/100 ml]	Load [CFU/day]	% Reduction to Achieve TMDL [%]	Average of Load Reductions [%]	% Reduction to TMDL – MOS [%]
12/14/00	High Flows	18.49	5.3%	2400	1.09E+12	**60.8**	**60.8**	**64.7**
12/14/04	Moist Conditions	10.29	13.9%	39	9.82E+09	0.0		
1/11/05		7.61	22.7%	820	1.53E+11	0.0		
1/24/01		7.22	24.5%	2000	3.53E+11	**53.0**	**17.7**	**19.2**
4/13/05	Mid-Range Flows	5.30	42.1%	53	6.87E+09	0.0		
2/15/05		4.87	49.2%	1200	1.43E+11	**21.6**		
6/21/01		4.56	55.9%	1400	1.56E+11	**32.8**		
3/15/05		4.14	65.0%	54	5.46E+09	0.0	**13.6**	**17.2**
7/13/05	Low Flows	3.74	72.2%	2400	2.20E+11	**60.8**		
9/20/00		3.70	73.0%	120	1.09E+10	0.0		
5/16/01		3.52	76.2%	110	9.47E+09	0.0		
7/18/00		3.28	82.0%	2400	1.93E+11	**60.8**		
6/7/05		3.21	83.8%	77	6.04E+09	0.0		
11/13/00		3.20	83.9%	1100	8.62E+10	**14.5**		
8/10/00		3.16	86.3%	2400	1.85E+11	**60.8**		
10/12/00		2.96	93.3%	38	2.76E+09	0.0	**24.6**	**27.1**

Note: NR = No reduction required
NA = Not applicable

Table E-5. Calculated Load Reduction Based on Daily Loading – Town Creek – Mile 1.3

Sample Date	Flow Regime	Flow [cfs]	PDFE [%]	Concentration [CFU/100 ml]	Load [CFU/day]	% Reduction to Achieve TMDL [%]	Average of Load Reductions [%]	% Reduction to TMDL – MOS [%]
12/14/00	High Flows	9.09	6.0%	330	7.34E+10	0.0	**NR**	**NR**
12/14/04	Moist Conditions	5.81	15.8%	59	8.39E+09	0.0		
1/11/05		4.85	23.6%	2400	2.85E+11	**60.8**		
1/24/01		4.55	27.4%	67	7.45E+09	0.0		
4/13/05		3.92	40.0%	53	5.08E+09	0.0	**15.2**	**16.2**
6/21/01	Mid-Range Flows	3.73	46.9%	240	2.19E+10	0.0		
2/15/05		3.63	51.0%	62	5.51E+09	0.0		
7/13/05		3.40	63.3%	2400	2.00E+11	**60.8**		
9/20/00		3.38	64.3%	100	8.26E+09	0.0		
3/15/05		3.34	66.5%	140	1.14E+10	0.0	**12.2**	**12.9**
5/16/01	Low Flows	3.09	77.0%	180	1.36E+10	0.0		
7/18/00		2.99	82.1%	100	7.33E+09	0.0		
6/7/05		2.96	83.7%	47	3.41E+09	0.0		
11/13/00		2.96	84.3%	2400	1.74E+11	**60.8**		
8/10/00		2.94	86.0%	190	1.37E+10	0.0		
10/12/00		2.87	93.4%	100	7.01E+09	0.0	**10.1**	**10.8**

Note: NR = No reduction required
NA = Not applicable

Table E-6 Summary of TMDLs, WLAs, & LAs expressed as daily loads for Impaired Waterbodies in the Barren River Watershed (HUC 05110002)

Waterbody Description	Hydrologic Condition			Flow[a]	PLRG	TMDL	MOS	WLAs			LAs
	Flow Regime	PDFE Range	Flow Range					WWTFs [b]	LCS	MS4s	
		[%]	[cfs]	[cfs]	[%]	[CFU/d]	[CFU/d]	[CFU/d]	[CFU/d]	[CFU/d/ac]	[CFU/d/ac]
Donaho Branch Waterbody ID: **TN05110002008 – 0600** HUC-12: 0501	High Flows	0 – 10	2.23 – 9.41	3.93	NA	9.039×10^{10}	9.039×10^{9}	NA	0	1.592×10^{8}	1.592×10^{8}
	Moist	10 – 40	0.79 – 2.23	1.15	20.3	2.645×10^{10}	2.645×10^{9}			4.660×10^{7}	4.660×10^{7}
	Mid-Range	40 – 70	0.39 – 0.79	0.55	2.0	1.265×10^{10}	1.265×10^{9}			2.229×10^{7}	2.229×10^{7}
	Low Flows	70 – 100	0 – 0.39	0.18	NR	4.140×10^{9}	4.140×10^{8}			7.294×10^{6}	7.294×10^{6}
Town Creek Waterbody ID: **TN05110002027 – 0421** HUC-12: 0601	High Flows	0 – 10	12.57 – 50.36	19.60	60.8	4.508×10^{11}	4.508×10^{10}	5.343×10^{10}	0	NA	1.702×10^{8}
	Moist	10 – 40	5.43 – 12.57	7.16	17.7	1.647×10^{11}	1.647×10^{10}				4.580×10^{7}
	Mid-Range	40 – 70	3.86 – 5.43	4.60	13.6	1.058×10^{11}	1.058×10^{10}				2.019×10^{7}
	Low Flows	70 – 100	2.80 – 3.86	3.18	24.6	7.314×10^{10}	7.314×10^{9}				5.990×10^{6}

Notes: NA = Not Applicable.
NR = No Reduction Required.
PLRG = Percent Load Reduction Goal to achieve TMDL.
LCS = Leaking Collection Systems
Shaded Flow Zone for each waterbody represents the critical flow zone.

a. Flow applied to TMDL, MOS, and allocation (WLA[MS4] and LA) calculations. Flows represent the midpoint value in the respective hydrologic flow regime.

b. WLAs for WWTFs are expressed as E. coli loads (CFU/day). All current and future WWTFs must meet water quality standards at the point of discharge as specified in their NPDES permit; at no time shall concentration be greater than the appropriate E. coli standard (487 CFU/100 mL or 941 CFU/100 mL).