
Total Maximum Daily Load for Fecal Coliform Bacteria
to Town Branch, North Carolina

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Cape Fear River Basin

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Total Maximum Daily Load for fecal coliform bacteria to Town Branch

1.0 INTRODUCTION

On the 2000 North Carolina 303(d) list, the North Carolina Division of Water Quality (DWQ) has identified a 3.6-mile segment (16-17) of Town Branch in the Cape Fear Basin as impaired by fecal coliform bacteria. The impaired segment extends from the stream's source to its confluence with the Haw River. This section of the stream is located in subbasin 03-06-02. Town Branch is designated as a class C water. Class C waters are freshwaters that are protected for secondary recreation, fishing, and propagation and survival of aquatic life.

Section 303(d) of the Clean Water Act (CWA) requires states to develop a list of waters not meeting water quality standards or which have impaired uses. This list, referred to as the 303(d) list, is submitted biennially to the U.S. Environmental Protection Agency (EPA) for review. The 303(d) process requires that a Total Maximum Daily Load (TMDL) be developed for each of the waters appearing on Part I of the 303(d) list. A TMDL is the maximum amount of a pollutant (e.g., fecal coliform) that a waterbody can receive and still meet water quality standards, and an allocation of that load among point and nonpoint sources. The objective of a TMDL is to estimate allowable pollutant loads and allocate to known sources so that actions may be taken to restore the water to its intended uses (USEPA, 1991). Generally, the primary components of a TMDL, as identified by EPA (1991, 2000a) and the Federal Advisory Committee are as follows:

Target identification or selection of pollutant(s) and endpoint(s) for consideration. An endpoint is an instream numeric target. The pollutant and endpoint are generally associated with measurable water quality related characteristics that indicate compliance with water quality standards. North Carolina indicates known problem pollutants on the 303(d) list.

Source assessment. Sources that contribute to the impairment should be identified and loads quantified, to the extent that that is possible.

Reduction target. Estimation or level of pollutant reduction needed to achieve water quality goal. The level of pollution should be characterized for the waterbody, highlighting how current conditions deviate from the target endpoint. Generally, this component is identified through water quality modeling.

Margin of safety. The margin of safety addresses uncertainties associated with pollutant loads, modeling techniques, and data collection. Per EPA (2000a), the margin of safety may be expressed explicitly as unallocated assimilative capacity (portion of TMDL) or implicitly through conservative assumptions. The margin of safety should be included in the reduction target.

Allocation of pollutant loads. Allocating available pollutant load (TMDL), and hence pollutant control responsibility, to the sources of impairment. The wasteload allocation portion of the TMDL accounts for the loads associated with existing and future point sources. The load allocation portion of the TMDL accounts for the loads associated with existing and future nonpoint sources. Any future nonpoint source loading should remain within the TMDL that is calculated in this assessment; in other words, this TMDL does not leave allocation for future sources.

Seasonal variation. The TMDL should consider seasonal variation in the pollutant loads and endpoint. Variability can arise due to streamflows, temperatures, and exceptional events (e.g., droughts and hurricanes).

Critical conditions. Critical conditions occur when fecal coliform levels exceed the standard by the largest amount. If the modeled load reduction is able to meet the standard during critical conditions, then it should meet the standard at all, or nearly all, times.

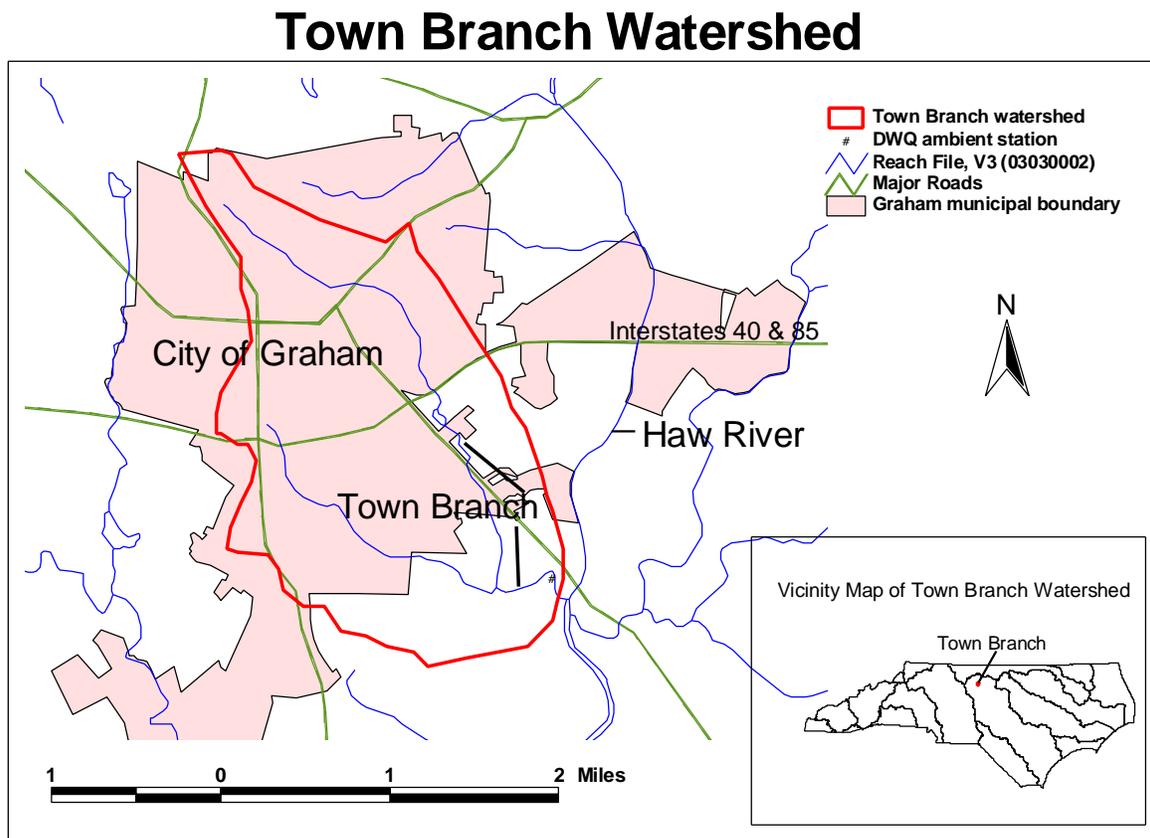
Section 303(d) of the CWA and the Water Quality Planning and Management regulation (USEPA, 2000a) require EPA to review all TMDLs for approval or disapproval. Once EPA approves a TMDL, then the waterbody may be moved to Part III of the 303(d) list. Waterbodies remain on Part III of the list until compliance with water quality standards is achieved. Where conditions are not appropriate for the development of a TMDL, management strategies may still result in the restoration of water quality.

The goal of the TMDL program is to restore designated uses to water bodies. Thus, the implementation of bacteria controls will be necessary to restore designated uses in Town Branch. Although an implementation plan is not included as part of this TMDL, reduction strategies are needed. The involvement of local governments and agencies will be critical in developing an implementation plan and reduction strategies. DWQ will seek to begin development of the implementation plan during public review of the TMDL.

1.1 Watershed Description

Town Branch, located in the upper Cape Fear River basin, drains into the Haw River about three miles northeast of the City of Graham (see Figure 1). The creek's watershed lies entirely within Alamance County and is slightly less than 4 square miles in area. The City of Graham (2000 population of 12,833) covers more than three-quarters of the watershed. DWQ has an ambient water quality monitoring site (Storet number B1260000) near the creek's confluence with the Haw.

Figure 1.



The land use/land cover characteristics of the watershed were determined using 1996 land cover data that were developed from 1993-94 LANDSAT satellite imagery. The North Carolina Center for Geographic Information and Analysis, in cooperation with the NC Department of Transportation and the United States Environmental Protection Agency Region IV Wetlands Division, contracted Earth Satellite Corporation of Rockville, Maryland to generate comprehensive land cover data for the entire state of North Carolina. Tabulated land cover/land use data for the

Town Branch watershed are shown in Table 1. During the formation of this geographic dataset, developed land was identified using the proportion of synthetic cover present; low density developed was 50-80% synthetic cover, and high density developed was 80-100% synthetic cover (Earth Satellite Corporation, 1997). Assuming that synthetic cover is impervious, and that all non-developed land cover classes have 1% impervious cover, the Town Branch watershed is estimated to have 29-42% impervious surface.

Table 1. Land use/land cover in Town Branch watershed.

Land Use/Land Cover	Town Branch Watershed Acres
High Density Developed	275 (10.8%)
Low Density Developed	991 (38.8%)
Cultivated	5 (0.0%)
Managed Herbaceous	395 (15.5%)
Forest	886 (34.7%)
Total	2552

The USGS 14-digit hydrologic unit code (HUC) for Town Branch is 030300020080.

1.2 Water Quality Monitoring Program

There are two sources of fecal coliform data for this project: 1) ambient monitoring data; 2) special study data collected by the City of Graham. More information on each is provided below and a more detailed report is included in Appendix I.

Town Branch was listed as impaired based on data from the ambient monitoring station, which is located at SR 2109 (Cooper Rd.) or about one-quarter mile upstream from the stream's confluence with the Haw River. Fecal coliform samples are collected at this site on a monthly basis.

The second source of Town Branch fecal coliform data is a special study conducted by the City of Graham in July and August of 2001. Ten samples were collected at three different sites, including: Town Branch at Cooper Road (ambient site at SR 2109); Town Branch at the wastewater treatment plant (just upstream of major tributary, County Home Branch); County Home Branch at Gilbreath Street. The purposes of this study were to evaluate whether the creek was complying with the state fecal coliform standard, and to provide information on bacteria source areas in watershed.

The ambient monitoring data were used in model calibration. Both sets of monitoring data may be seen in Appendix I.

1.3 Water Quality Target

The North Carolina fresh water quality standard for fecal coliform in Class C waters (T15A: 02B.0211) states:

Organisms of the coliform group: fecal coliforms shall not exceed a geometric mean of 200/100ml (membrane filter count) based upon at least five consecutive samples examined during any 30 day period, nor exceed 400/100 ml in more than 20 percent of the samples examined during such period; violations of the fecal coliform standard are expected during rainfall events and, in some cases, this violation is expected to be caused by uncontrollable nonpoint source pollution; all coliform concentrations are to be analyzed using the membrane filter technique unless high turbidity or other adverse conditions necessitate the tube dilution method; in case of controversy over results, the MPN 5-tube dilution technique will be used as the reference method.

The instream numeric target, or endpoint, is the restoration objective expected to be reached by implementing the specified load reductions in the TMDL. The target allows for the evaluation of progress towards the goal of reaching water quality standards for the impaired stream by comparing the instream data to the target. For this TMDL the water quality target is the geometric mean concentration of 200cfu/100ml over a 30-day period. A geometric mean is obtained by calculating the average of the log values of the individual samples. Basically, the geometric mean will discount higher values so that it should be lower than the arithmetic mean (average of measurements, no log taken). Cfu stands for colony-forming units; it may also be referred to as simply 'counts' in this assessment. In this TMDL, DWQ will consider the entire model period to address the portion of the standard that limits the percentage of instantaneous excursions over 400cfu/100ml to twenty percent.

In order to evaluate the fecal coliform model, monitor water quality conditions and assess progress of the TMDL, an evaluation location was established for the Town Branch watershed. The evaluation location of this watershed is Town Branch at SR 2109, which is the location of the ambient monitoring station.

2.0 SOURCE ASSESSMENT

A source assessment is used to identify and characterize the known and suspected sources of fecal coliform bacteria in the watershed. DWQ completed a source assessment and used it to develop the water quality model for the TMDL calculation.

2.1 Point Source Assessment

General sources of fecal coliform bacteria are divided between point and nonpoint sources. Currently, there are no facilities in the watershed that discharge waste through the National Pollutant Discharge Elimination System (NPDES), which is considered to be the regulatory approach for all but the smallest of point sources. The City of Graham has a municipal treatment facility (NPDES NC0021211), however that discharges into the Haw River. North Carolina also has general wastewater permits for package plants (small sand filter operations), but there is very limited information about those; DWQ cannot identify any that discharge to Town Branch.

2.2 Nonpoint Source Assessment

Nonpoint sources of fecal coliform bacteria include those sources that can not be identified as entering the waterbody at a specific location (e.g., a pipe). Nonpoint source pollution includes urban, agricultural and background sources. For this TMDL, background loading is considered to be that which originates from wildlife; this is primarily from forestland, but wildlife are considered to exist on cropland as well (see 2.2.5 Wildlife below). Fecal coliform bacteria may originate from human and non-human sources. Table 2 lists the potential human and animal nonpoint sources of fecal coliform bacteria (Center for Watershed Protection, 1999). The nonpoint sources of fecal coliform bacteria in Town Branch include runoff from urban development (stormwater), sewer line systems (leaky sewer lines and sewer system overflows), wildlife, failing septic systems, and probably illicit connections in unknown locations.

2.2.1 Livestock

DWQ conferred with an Alamance County extension agent, Paul Walker, to derive estimates for livestock populations in the Town Branch watershed. From this conversation, DWQ decided that no livestock reside in the watershed, and that none would be accounted for in the TMDL model.

Table 2. Potential sources of fecal coliform bacteria in urban and rural watersheds (Center for Watershed Protection, 1999).

Source Type		Source		
Human Sources	Sewered watershed	Combined sewer overflows		
		Sanitary sewer overflows		
		Illegal sanitary connections to storm drains		
		Illegal disposal to storm drains		
	Non-sewered watershed	Failing septic systems		
		Poorly operated package plant		
		Landfills		
		Marinas		
		Non-human Sources	Domestic animals and urban wildlife	Dogs, cats
				Rats, raccoons
Pigeons, gulls, ducks, geese				
Livestock and rural wildlife	Cattle, horse, poultry			
	Beaver, muskrats, deer, waterfowl			

2.2.2 Miscellaneous Sources

Illicit discharges (e.g., straight pipes) and any loading that occurs during baseflow (no runoff) are called ‘miscellaneous sources’ in the TMDL allocation. In the model, miscellaneous sources are treated as a constant, instream source of bacteria. It is necessary to separate these instream sources from land based ones, because they are defined as one instream source through modeling. That is, it is difficult to determine individual estimates for the fecal coliform that originates from illicit discharges, but it is possible to estimate them cumulatively in the model during periods of low streamflow. During such periods, contributions from nonpoint sources of fecal coliform, which rainfall transport, are assumed to be negligible. What is being fit to the model, through calibration, is a constant instream source of fecal coliform.

2.2.3 Failed Septic Systems

Failing septic systems have been cited as a potential source of fecal coliform bacteria to water bodies (USEPA, 2000). For the most part, household waste from the City of Graham and its surroundings is treated at the municipal treatment plant, which discharges to the Haw River. Based on investigation by the City of Graham, it appears that there are at least 13-16 legacy septic tanks (no longer in active use) and just a few currently used septic tanks in the watershed (Quick, 2002). DWQ estimates that there are 4 failing legacy septic systems in the Town Branch watershed. During the public comment period on the draft Town Branch TMDL, the City of Graham alerted DWQ to

additional failing septic systems in a neighborhood immediately north and south of Cheek Lane (Sullivan, 2002). After consulting the map and other information provided by the City of Graham, DWQ decided to add 20 more failing septic systems to the TMDL model. Negotiations are in progress to annex this neighborhood to the City of Graham; this may lead to connecting the neighborhood to Graham's sewage collection and treatment systems.

Additionally, DWQ assumed that, on average, there are 3 people per system. Assuming the average concentration of septic waste reaching the stream is 1.0×10^4 counts/100 ml and that the septic overcharge flow rate is 70 gallons/day/person (Horsely & Whitten, 1996), the contribution from failing septic systems is 4.77×10^7 counts/hour. DWQ also assumed that 60% of the septic overcharge reached the stream channel; this estimate is not scientifically based and was selected as a seemingly moderate to high number for transport from a failing septic system to the stream network. The loading rate from septic systems using these assumptions was 1.61×10^8 counts/30 days.

2.2.4 Urban Development/Sanitary Sewer Overflows

Fecal coliform bacteria can originate from various urban sources. These sources include pet waste, runoff through stormwater sewers, illicit discharges/connections of sanitary waste, leaky sewer systems and sanitary sewer overflows.

Fecal coliform accumulation rates on urban land cover were derived using the following:

- 1) the proportion of the watershed that is covered by high and low density developed land cover;
- 2) the types of urban land use that occurs in the watershed (e.g., residential, and heavy and light commercial);
- 3) the fecal coliform build-up (accumulation) rates for each land-use in 2), as calculated from instream stormwater samples collected by the United States Geological Survey (USGS) from December 1993 to September 1997 in Mecklenburg County (Bales et al., 1999). In the USGS study, each of the urban land uses was paired with a sample site. The land use descriptions and calculated accumulation rates for fecal coliform may be seen in Table 3.

Table 3. Rate of accumulation and maximum storage of fecal coliform by land use (from Bales et al., 1999).

Land Use	Rate of Accumulation (count per acre per day)	Maximum Storage (count per acre)
Residential	6.86×10^9	1.44×10^{10}
Heavy Commercial	2.68×10^9	5.63×10^9
Light Commercial/Light Industrial	3.20×10^{10}	6.72×10^{10}
Woods/Brush	5.48×10^9	1.15×10^{10}

A step-by-step description of the approach to determine initial urban fecal coliform accumulation rates follows. DWQ first calculated the proportion of low and high-density land cover in the Town Branch watershed. Using local knowledge of the watershed, the NC GIS land cover data were converted into the four land use classes referenced by the USGS study (see Table 4). By combining the proportions of the four land classes with the accumulation rates, DWQ assigned a comprehensive urban accumulation rate of fecal coliform. The accumulation rate is an important model parameter that describes how much fecal coliform is generated on each land use; actual fecal coliform loading (delivery) to the stream network is determined through subsequent modeling. Essentially, the model tracks fecal coliform build-up through the accumulation rate and simulates fecal coliform wash-off as precipitation falls. More description of the model appears later in this document.

Table 4. Estimated conversion from NC GIS land cover to land use in USGS study. Note that this is for urban (developed) land cover only*

Watershed	Urban Land cover classification (from GIS database)	Land use classification (estimated)
Town Branch	21.7% high density developed, 78.3% low density developed	16% light commercial/industrial 4% heavy commercial 51% light residential 29% woods/brush

By combining the information in Tables 3 and 4, DWQ calculated initial estimates of urban accumulation and maximum storage. The results are shown in Table 5.

Table 5. Initial (pre-calibration) estimates of accumulation and storage.

Watershed	Rate of Accumulation (count per acre per day)	Maximum Storage (count per acre)
Town Branch	1.03×10^{10}	1.85×10^{10}

Since these numbers are based on studies in different, somewhat distant watersheds (Mecklenburg Co.), they were subject to calibration in the model.

The city of Graham owns and operates a wastewater treatment plant and sewage collection system. From 1997-2001, Graham reported seventeen sanitary sewer overflows (SSOs) of greater than 1000 gallons, including five SSOs of greater than 50,000 gallons. DWQ did not explicitly account for SSOs in the modeling; rather, DWQ used a relatively high (compared to other land uses), constant value for urban interflow fecal coliform concentration in the calibration model, which, along with a calibrated urban accumulation rate may account for leaky sewers and infrequent SSOs.

2.2.5 Wildlife

Wildlife can be a source of fecal coliform bacteria in forest, wetland, pasture and cropland areas. Wildlife deposit fecal material in these areas, which can be transported to a stream in a rain event. Wildlife in Town Branch watershed is expected to include deer, raccoons, squirrels, and birds (including waterfowl). DWQ derived population density estimates for all but squirrels and non-waterfowl birds; consequently, these animals were not included in the model.

DWQ obtained estimates for deer population of 15-30 per square mile from the North Carolina Wildlife Resources Commission (WRC, 2001). The lower end of the range (15) was applied to cropland and pastureland, and the higher end of the range (30) was applied to forestland. DWQ assumed that no wildlife live in areas with urban land cover.

There was very little basis for estimating populations of raccoon, duck and geese density – this is one of many areas of uncertainty in the model. DWQ considered that there are 5 geese and 10 ducks per square mile of forestland and managed herbaceous land, and that there are 10 raccoons

per square mile on such land. The numbers for geese, duck and raccoon are not scientifically based and are intended as a rough, moderate estimate.

2.3 Source Assessment Conclusion

All of the aforementioned source assessment data were entered into a spreadsheet called Fecal Tool, which calculates accumulation rates on the different land covers, and loading from direct sources such as leaking septic systems and miscellaneous instream sources. TetraTech, Inc. developed Fecal Tool. Output from this spreadsheet was used in the initial estimates for the corresponding parameters in the water quality model. Some of the model parameter estimates calculated in the spreadsheet were later altered through calibration (e.g., urban coliform accumulation rates).

3.0 MODELING APPROACH

An important component of the TMDL is to establish the relationship between instream water quality and sources of fecal coliform. A model that simulates or statistically characterizes hydrology and water quality is a helpful tool for this purpose. Models provide the relative contribution of the sources, as well as the predictions of water quality resulting from changes in these source contributions; these are the basic elements of Total Maximum Daily Load determination.

3.1 Model Framework

The model selected for this TMDL needed to meet several objectives:

- 1) To simulate watershed loading and instream transport of fecal coliform bacteria, and to capture some of the temporal and spatial variation that those processes demonstrate.
- 2) To simulate instream fecal coliform concentrations over several years, so that critical conditions (definition on page 2) may be identified. Critical conditions will be the basis for this TMDL.
- 3) To evaluate seasonal effects on the production and fate of fecal coliform bacteria.

EPA's BASINS software includes a model, Nonpoint Source Model (NPSM), that is suited for TMDL development. NPSM is based on another model, the Hydrologic Simulation Program – FORTRAN (HSPF). Because it meets the objectives stated above, DWQ chose NPSM as the model for this TMDL.

NPSM (HSPF) is a dynamic watershed model capable of simulating nonpoint source runoff and associated pollutant loads. It does this by tracking water and fecal coliform in the watershed. Specifically, modules named PWATER and IWATER are used to calculate the components of the water budget, and to predict the runoff from pervious and impervious areas, respectively (EPA, 1993). The model considers the following hydrologic processes: precipitation, interception, surface runoff, interflow, groundwater, evaporation and evapotranspiration. Fluxes or storages within subroutines of the model simulate these processes. Fecal coliform is simulated in the PQUAL and IQUAL modules (from pervious and impervious land segment) using simple relationships with water. Fecal coliform occurs in both the surface and subsurface outflow, though the former is considered to be more complex in the model. On the surface, fecal coliform can be affected by adhesion to the soil, and by light, wind, temperature and direct human influence. The approach is to simulate fecal coliform using basic accumulation (build-up) and depletion rates, in concert with depletion by wash-off; in other words, fecal coliform outflow from the surface is a function of the water flow and the amount of fecal coliform in storage (EPA, 1993). Constant rates are assumed for subsurface loading from the different land use categories.

NPSM (HSPF) performs flow routing and pollutant decay in stream reaches through the RCHRES module. Flow is assumed to be unidirectional and decay is assumed to be first-order in nature (see section 3.2.1 below). Also, NPSM allows discrete simulation of the required components of the TMDL (e.g., WLA and LA components).

3.2 Model Setup

Town Branch was modeled as a single watershed (no subwatershed delineation) based on Reach File 3 (RF3) stream coverage and a digital elevation model of the area. The farthest downstream point of the delineation was the DWQ ambient water quality sampling station, B1260000, or Town Branch at SR 2109 near Graham. Dewberry and Davis Consultants compiled hourly meteorological data from a weather station near Greensboro (see Figure 3 for specific location and its proximity to Town Branch watershed). The meteorological data begin on 7/1/1996 and end on 8/11/2001. DWQ measured the stream channel cross section near the watershed outlet (Appendix IV), and incorporated this into the model's f-table (table that describes relationship between streamflow depth and streamflow volume).

3.2.1 Instream Decay Rate

Once fecal coliform bacteria reach a waterbody, environmental factors influence the extent of their growth and decay. Physical factors that influence the bacteria populations include photo-oxidation, adsorption, flocculation, coagulation, sedimentation and temperature (USEPA, 1985). Chemical toxicity, pH, nutrient levels, algae and the presence of fecal matter may also influence the fecal coliform population. The water quality model utilizes a first order decay rate to calculate instream decay of fecal coliform bacteria.

$$C_t = C_o e^{-kt}$$

C_t = coliform concentration at time t (cfu/100ml)

C_o = initial coliform concentration (cfu/100ml)

k = decay rate constant (day⁻¹)

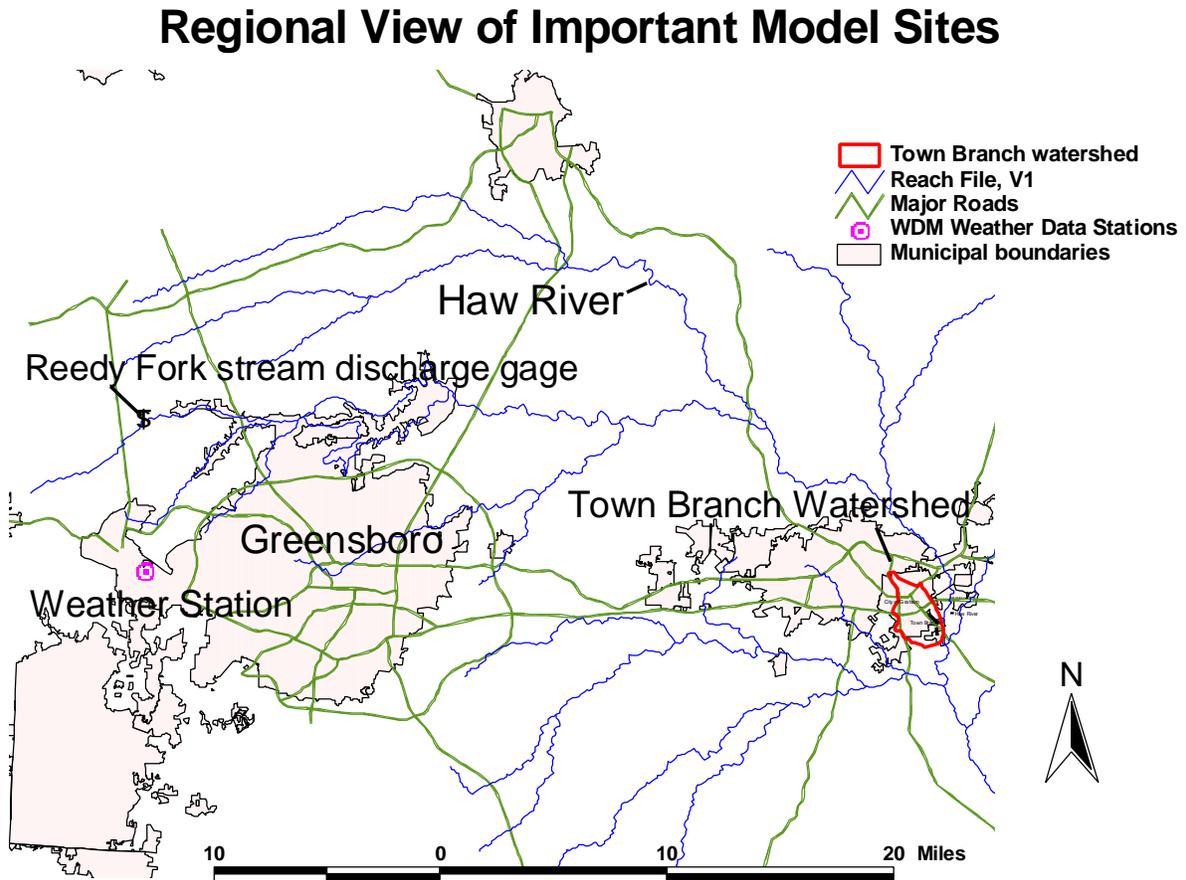
t = exposure time (days)

Bacterial die-off has been modeled as a first-order decay equation, using a decay rate (k) between 0.7/day and 1.5/day (Center for Watershed Protection, 1999). Another study found that the median decay rate for fecal coliform was 1.15/day (Lombardo, 1972); that value was used in the Town Branch model for the existing condition and allocation runs.

3.3 Hydrologic Calibration

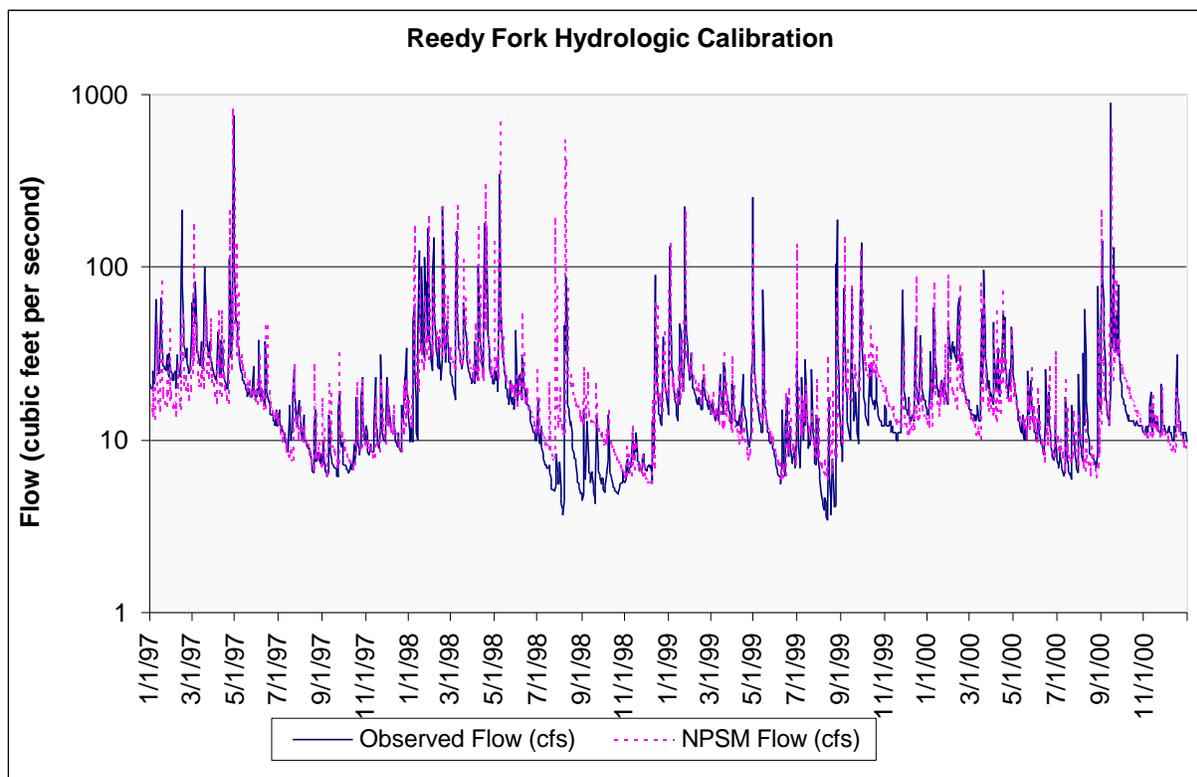
Because NPSM is driven by precipitation and by the subsequent treatment of the water budget, it is important to calibrate the hydrologic parameters prior to calibrating the water quality parameters. In the hydrologic calibration, simulated streamflows were compared to the historic streamflow data recorded at a continuous stream gage. There is not a continuous gage in Town Branch, so instead DWQ used one at Reedy Fork near Oak Ridge (USGS 02093800), which is about 30 miles away (see Figure 2 below). The Reedy Fork watershed is relatively similar to the Town Branch watershed in terms of shape, however it has proportionally less urban land cover and is considerably larger in area (about 20 square miles to 4 square miles). To calibrate the model, hydrologic parameters, including infiltration, upper and lower zone storage, groundwater storage and recession, interflow, and evapotranspiration, were adjusted within a recommended range until the simulated and observed hydrographs were as close as possible. DWQ determined the best match by assessing statistical fit; more description is provided below.

Figure 2.



A four-year period from 1/1/97 to 12/31/00 was used as the calibration period for the hydrologic parameters. Relative fit of the modeled flow compared to the recorded flow is shown in Figure 3 below. The hydrologic parameters used to calibrate the model developed at the Reedy Fork gage were assumed to apply to the Town Branch watershed, and were used to develop the water quality model for Town Branch watershed.

Figure 3. Simulated and observed flows recorded at USGS 02093800 Reedy Fork, 1997-2001.



Four conventional statistics for assessing model fit are correlation coefficient (r), the root mean squared error (RMSE), mean error (ME) and mean absolute error (MAE). DWQ calculated these to calibrate the model. Further description on each of the statistics is provided below, and the formulas for these statistics appear in Appendix II; much of this follows Stow et al. (in review). A log transformation was used because, as with most environmental data, fecal coliform has a log normal distribution. The log transformation more equally weights low and high values when calculating fit statistics (it gives less leverage to the relatively few high values).

Correlation coefficient, r , is a measure of the variability in the observed data that is explained by the model. This was chosen instead of r^2 , because r^2 hides some negative correlation. The closer it is to 1, the better. If the correlation between observed and predicted values is close to 1, the values don't necessarily track each other, they just tend to vary similarly (Stow et al., in review). For the Reedy Fork hydrologic calibration, using log base 10 values, the four-year correlation coefficient is 0.79; this is a typical level of prediction for hydrologic models (Stow, 2002).

The root mean squared error (RMSE) is the standard deviation of the model residuals, which are the difference between the model predictions and observed data. A lower RMSE is better (0 is best), though its value is relative to what the model attempts to predict; the mean of the observed data is a good measure to compare. In this application, the RMSE is 0.19 and the observed mean is 1.20 (log base 10 values), which indicates decent precision.

The average error (AE) and average absolute error (AAE) are measures of aggregate model bias. Again, closer to 0 is better, though for the mean error, values near zero can be misleading since negative and positive differences can offset each other (Stow et al., in review). For the Reedy Fork hydrologic calibration, the AE and AAE were 0.01 and 0.13, respectively. This indicates that the model does not over- or under-predict consistently, and again, that the precision is good.

Table 6. Hydrologic calibration fit statistics

Statistic	Value (using log base 10)
r	0.79
RMSE	0.19
AE	0.01
AAE	0.13
Observations (n)	1,461
Obs. mean	1.20

DWQ tested the Reedy Fork calibration on North Buffalo Cr. and found it to be a reasonable fit there as well. North Buffalo Cr. is in between Reedy Fork and Town Branch, and has a proportion of urban land cover that is more similar to the Town Branch watershed.

3.4 Water Quality Calibration

Once the hydrologic calibration is complete the model is calibrated for water quality by adjusting parameters until simulated and observed fecal coliform concentrations achieve acceptable agreement. To calibrate the model, several parameters were adjusted including the accumulation rates of fecal coliform bacteria, wash-off rates, maximum storage of fecal coliform bacteria and contributions from direct sources. By matching the trends in simulated and observed

concentrations resulting from a variety of streamflows, the model may be a reasonable predictor of instream water quality. Selected values from the water quality calibration may be seen in Appendix III.

Through model calibration, DWQ estimated that the constant instream source (see miscellaneous sources, Section 2.2.2) is 7.2×10^6 counts/30 days. Illicit discharges are assumed to be included in this estimate.

DWQ focused on calibrating urban coliform accumulation and maximum storage rates in the Town Branch watershed, as that was identified as the primary source through the source assessment. Through calibration, these values decreased by approximately 80% from the values shown in Table 5 (estimates from Mecklinburg Co. USGS study). It seems rather evident that the Charlotte values are much too high for the Town Branch watershed. DWQ also calibrated urban interflow concentration, which was considered to be a constant value in the model.

The calibration period for the water quality model spanned October, 1996 into August, 2001. The beginning time was limited by the meteorological file, which began in July, 1996. DWQ allowed three months for the model to stabilize before comparing predicted and observed data. The meteorological file also limited the simulation end time.

3.4.1 Calibration Results

Fecal coliform samples collected at B1260000 (the ambient monitoring station) between October, 1996 and August, 2001 were compared to simulated concentrations and rainfall collected at the meteorological stations. The calibration objective was to obtain the best fit to the observed data, as determined by the same statistics used in the hydrologic calibration (r , RMSE, AAE, AE; see Section 3.3). Graphical fit of the model to observed data is shown in Figures 4 and 5. These figures indicate that the model does a fair job at simulating the response of fecal coliform bacteria over time, with variations in flow. The model calibration statistics for fecal coliform are not nearly as good as those for the hydrologic calibration. Additionally, the model results indicate that instream fecal coliform concentrations following rainfall events frequently exceed the fecal coliform standard, while instream concentrations during dry periods typically do not exceed the standard. Finally, a plot of modeled flow and fecal coliform concentration appears in Appendix V. One important concept that

this figure demonstrates is higher fecal coliform concentrations occur in Town Branch following rain events.

Table 7. Water quality calibration fit statistics

Statistic	Value (using log base 10)
r	0.47
RMSE	0.79
AE	-0.38
AAE	0.72
Observations (n)	50
Obs. mean	2.58

Figure 4. Simulated versus observed fecal coliform concentrations from 9/1996 to 3/1999

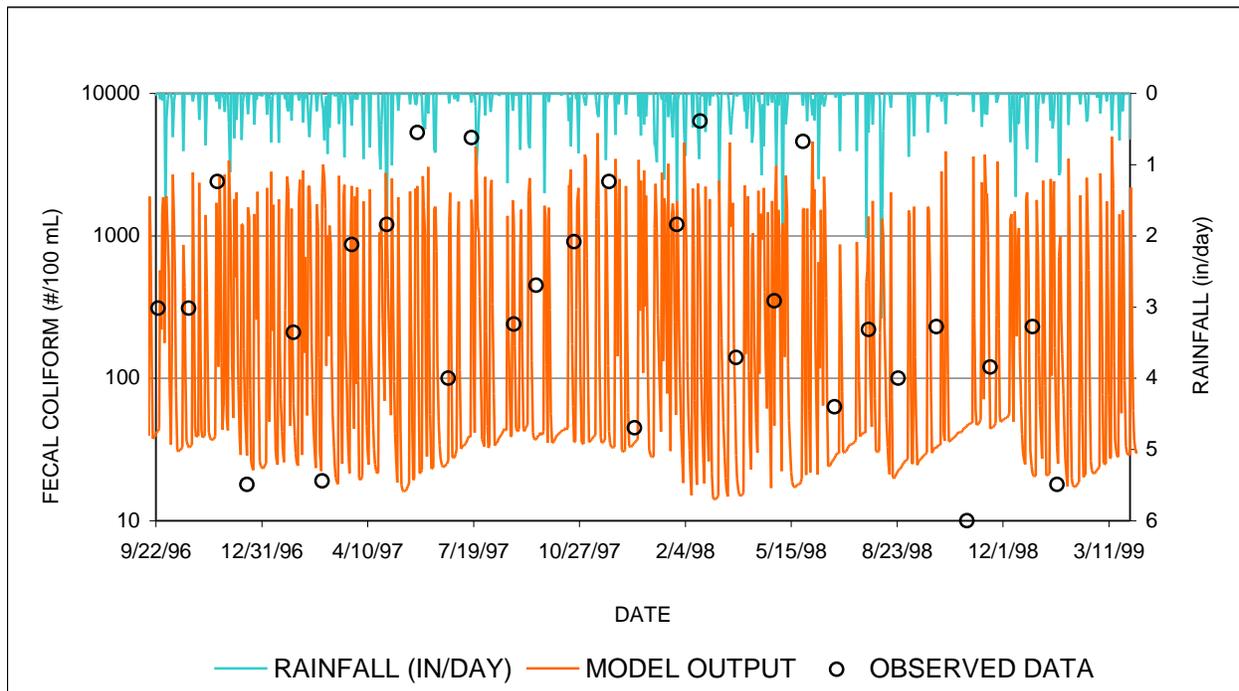
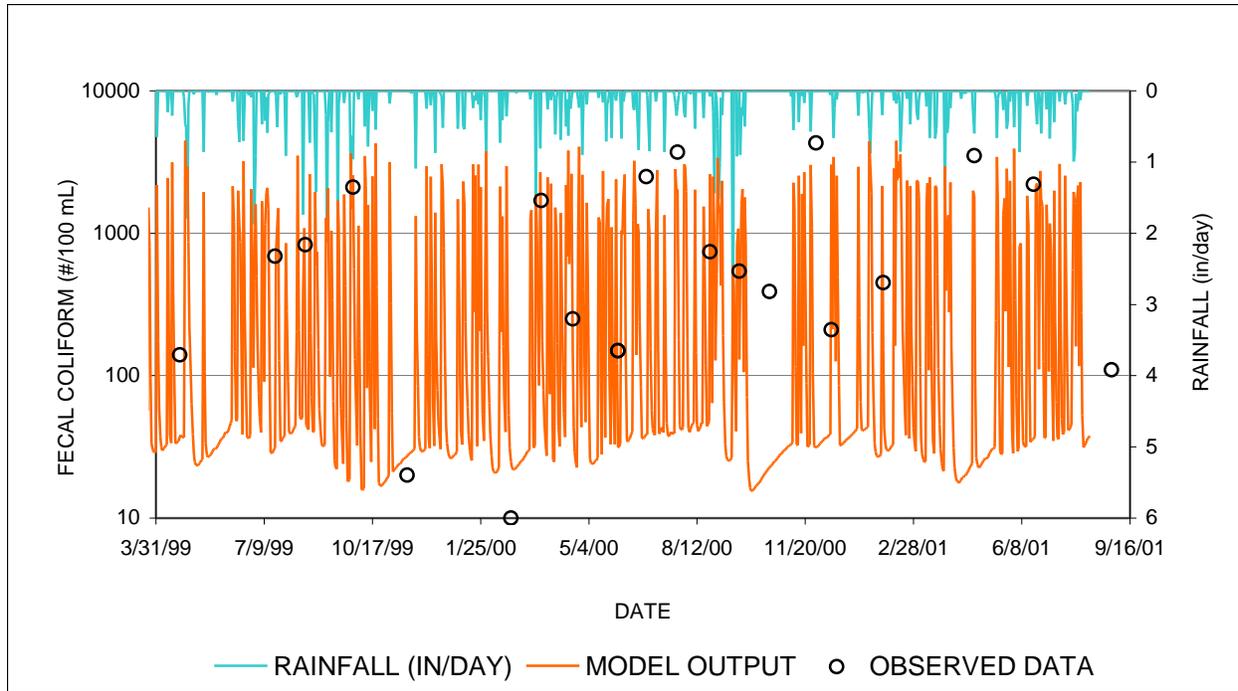


Figure 5. Simulated versus observed fecal coliform concentrations from 3/1999 to 8/2001



The low correlation coefficient indicates a lack of predictive power. On the other hand, the relatively small RMSE, AE and AAE suggest that the model may predict the mean fairly well, but there may be a lot of individual scatter about the mean.

To resolve this discrepancy, DWQ examined modeling efficiency, which is calculated using the following formula:

$$\frac{\left(\sum_{i=1}^n (O_i - \bar{O})^2 - \sum_{i=1}^n (P_i - O_i)^2 \right)}{\sum_{i=1}^n (O_i - \bar{O})^2}$$

where:

\bar{O} = mean of the observations

O_i = i^{th} of n observations

P_i = i^{th} of n predictions

The modeling efficiency measures how well the model predicts relative to the average of the observations. In terms of its value, the following guidelines apply:

- The closer to 1, the better. A value near 1 indicates a close match between model predictions and observations.
- If > 0 , then the model predicts better than the average of the observations.
- If < 0 , then the mean of the observations predict better than the model.
- If $= 0$, then the model predicts individual observations no better than the average of the observations.

The modeling efficiency for the Town Branch coliform model is -0.40 . This confirms that the model predictive precision is low.

3.4.2 Prediction Uncertainty

The inability to accurately simulate specific observed data points can sometimes be attributed to more specific aspects of a model, such as differences in rainfall at the meteorological gage and in the watershed, or illicit point discharges. More often though, the lack of agreement between modeled and observed fecal coliform is due to the general high degree of uncertainty associated with predicting any water quality variable, especially fecal coliform. Prediction uncertainty comes from a number of sources, including (from Reckhow and Chapra, 1983 and Reckhow, 1995):

- Gaps in our scientific knowledge.
- Natural variability – spatial and temporal variability in chemistry, hydrology and ecology is great. Model predictions are on a much coarser scale than what occurs in nature.
- Measurement error – measurement of fecal coliform in the field and laboratory has error.
- Aggregation error – with increased endpoint specificity (space and time), the uncertainty associated with the prediction increases.
- Model error:
 - Mis-specification – model expressions that characterize processes may be wrong.
 - Error in parameters – reaction rates may be inappropriate.
 - Error in model inputs – e.g., loading terms such as accumulation rate of bacteria have error.

Unfortunately, many water quality models employed for TMDL analysis, including NPSM, are not adept at characterizing prediction uncertainty. With these models, all we know is that the uncertainty is certain to be large. Emphasizing an adaptive management approach is one way to address this. Specifically, the model may guide initial decision making, but continued observation of the watershed and creek, as fecal coliform controls are implemented (e.g., exclusion fencing, leaky sanitary sewer repair), is expected to be our best approach for determining the appropriate level of management. This is especially true, considering the results of the water quality model calibration, for the Town Branch TMDL.

4.0 Total Maximum Daily Load

A Total Maximum Daily Load is the maximum amount of a pollutant that a water body can receive and still meet water quality standards, and an allocation of that amount among point and nonpoint sources. A TMDL comprises the sum of wasteload allocations (WLA) for point sources, load allocations (LA) for nonpoint sources, and a margin of safety. This definition is expressed by the equation:

$$\text{TMDL} = \sum \text{WLA} + \sum \text{LA} + \text{MOS}$$

The objectives of the TMDL are to estimate allowable pollutant loads, and to allocate to the known pollutant sources in the watershed, so the appropriate control measures can be implemented and the water quality standard can be achieved.

The TMDL will be expressed in units of counts/30 days, as this is the period over which the water quality target/standard is evaluated.

The two main components of a TMDL, the reduction target, including a margin of safety, and the allocation strategy will be presented in the following sections.

4.1 Reduction Target

To determine the amount of fecal coliform load reduction necessary to comply with the water quality standard, the period of critical conditions must be established. Critical conditions, and loading that represents current conditions and TMDL conditions were determined in the following manner:

- 1) The calibrated model was rerun for the entire, nearly 5-year period.
- 2) Simulated fecal coliform concentrations for the nearly 5-year period were plotted as rolling 30-day geometric mean concentrations. A 30-day geometric mean is determined by calculating the geometric mean of an individual day's fecal coliform prediction and the daily predictions for the 29 days that precede it. The rolling aspect is achieved by moving to the next day and performing the same calculation (the earliest date from the previous 30-day geometric mean calculation would be dropped).
- 3) DWQ applied load reductions in the model until all of the 30-day geometric means were below the standard. The date on which the last 30-day geometric mean peak falls below the criterion determines when critical conditions occur. The 30-days prior to and including this date form the critical conditions period, during which the TMDL is determined.
- 4) For the 30-day critical period, DWQ calculated current loading from the calibrated model, before any load reductions were taken.
- 5) Next, again using the 30-day critical period, DWQ calculated loading during TMDL conditions (after load reductions were taken), when the predicted instream fecal coliform concentrations indicated no exceedances of the water quality standard. With no predicted exceedances of the standard, the model fulfills the TMDL criterion of allowing the maximum load while still achieving water quality standards.
- 6) For both the current condition case and the TMDL condition case, the simulated daily fecal coliform loads from sources such as runoff from all lands, leaking septic systems and miscellaneous sources were summed for the 30-day critical period.

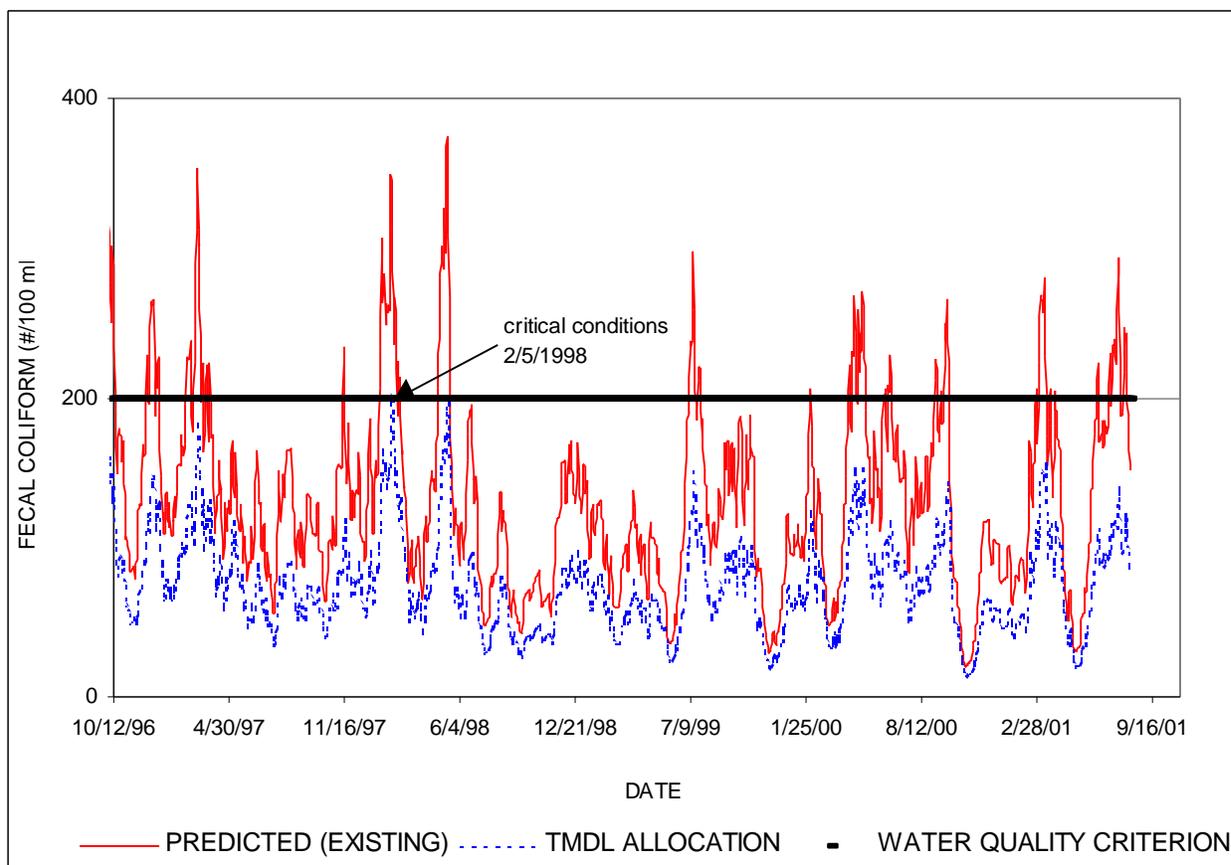
These six steps will be further explained in the following sections.

4.1.1 Critical Conditions

The Town Branch fecal coliform monitoring data indicate that elevated fecal coliform levels occur throughout the year, primarily during wet weather conditions. To determine when critical conditions occur, DWQ applied load reductions in the model until all of the 30-day geometric means were below the standard. The date on which the last 30-day geometric mean peak falls below the criterion determines when critical conditions occur. By definition, the 30-days prior to and

including this date from the critical conditions period. See Figure 6 below. For the Town Branch fecal coliform model, this occurred on February 5, 1998. The critical conditions occur between January 7, 1998 and February 5, 1998.

Figure 6. Reduction of **rolling 30-day geometric mean** of fecal coliform from existing loading to TMDL allocation.



Rain was recorded in Greensboro on 17 days during the 30-day critical period; at least 0.10 inch fell on 11 of those days. To wit, November and December, 1997 had 2.19 and 2.66 inches of precipitation, respectively, while the 30-day critical period had 7.62 inches of precipitation. Include the day before the critical period (January 6) and the total increases to 8.35 inches.

Relatively high fecal coliform accumulation rates resulted from the model calibration (see Section 3.4), and consequently, rainy periods such as the critical conditions period produce high instream

fecal coliform concentrations, as even small (>0.10 inch precipitation) events wash recently accumulated bacteria into the stream network.

4.1.2 Current Conditions

Current loading conditions were calculated by summing the loading from the critical 30-day period **before** any reductions were taken (calibrated model).

DWQ separated the principal coliform source categories, as used in NPSM, in Table 8; these include runoff from all lands, leaking septic systems and miscellaneous sources. **Runoff from all lands** includes estimated fecal coliform load from deposits by wildlife, as well as an estimate of loading from urban areas. **Leaking septic systems** estimates loading related to septic systems. **Miscellaneous sources** is an estimate of loading from unknown, or illicit, instream sources. According to the model, storm-driven runoff from all land provides the largest load of fecal coliform bacteria to the stream. Loads from miscellaneous sources are constant loads that are applied directly to the stream; these sources will have the greatest impact on instream water quality during periods of low flow.

Table 8. Summary of predicted existing coliform loads in the Town Branch watershed.

Runoff from all lands ¹ (counts/30 days)	Leaking septic systems (counts/30 days)	Miscellaneous sources ² (counts/30 days)	Instream conc. ³ (counts/100 ml)
1.03 x 10 ¹²	1.61 x 10 ⁸	7.20 x 10 ⁶	350

¹ Includes urban runoff and wildlife.

² Includes illicit discharges.

³ Maximum simulated concentration during the critical period (geometric mean).

4.1.3 Margin of Safety

TMDL conditions were calculated by summing the loading from the critical 30-day period **after** reductions were taken to bring all of the 30-day geometric means below the criterion. Before this is done, however, a margin of safety must be included.

A TMDL requirement is that a margin of safety must be included to provide further insurance that the impaired waterbody will meet its designated uses once load reductions are realized. The margin of safety may be accounted for implicitly, through conservative (more protective of water quality) model assumptions, or explicitly, by reserving a portion of the allocated load. The Town Branch

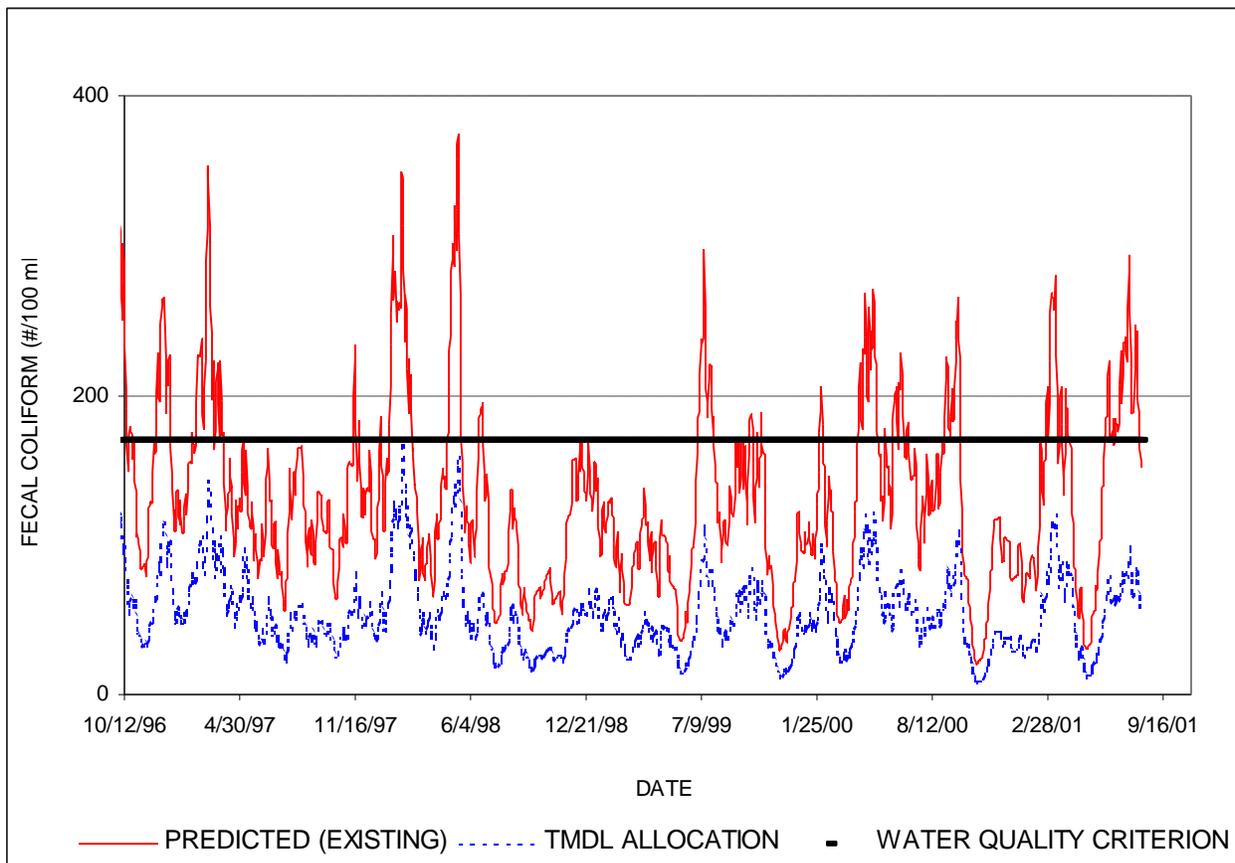
TMDL includes explicit and implicit margins of safety; more explanation on the margin of safety follows below.

In Figure 7 below, observe that the target for the rolling 30-day geometric mean of fecal coliform is 170 counts/100 ml, instead of the standard of 200 counts/100 ml. By using this lower target, DWQ provides an explicit margin of safety for the Town Branch TMDL. This explicit margin of safety may be interpreted to account for 15% greater assurance of achieving the instream water quality target.

$$[(200-170)/200]*100 = 15\%$$

Also, an implicit margin of safety is included because the model assumes that bacteria delivered from the land surface do not decay as it travels from its source to the stream network; in reality, some decay would occur, though it is difficult to estimate or model.

Figure 7. Reduction of rolling 30-day geometric mean of fecal coliform to include explicit margin of safety.



4.1.4 TMDL Allocation

To calculate the TMDL, DWQ summed the loads from the critical 30-day period **after** reductions were taken to bring all of the 30-day geometric means below the criterion, plus the explicit margin of safety (170 counts/100 ml).

The allocation strategy for the Town Branch fecal coliform TMDL is limited to nonpoint sources, as there are no permitted point sources in the watershed. An allocation scenario that predicts compliance with the instream water quality criterion and the required reductions from the individual categories may be seen in Table 9. A nonlinear relationship between fecal coliform inputs and instream fecal coliform concentration produces an inequitable reduction in load and concentration in percent terms (51% reduction in concentration requires 60 or more % reduction in load).

Table 9. Allocation strategy by major nonpoint sources for TMDL conditions

Runoff from all lands (counts/30 days)	Leaking septic systems (counts/30 days)	Miscellaneous Sources ² (counts/30 days)	Instream f.c. concentration ¹ (counts/100 ml)
3.25×10^{11}	6.46×10^7	2.88×10^6	170
68% reduction	60% reduction	60% reduction	51% reduction

¹ Maximum simulated instream concentration during critical period. Percent reduction represents the difference in simulated instream concentration between the existing loads (Table 8., 350 counts/100 ml) and TMDL allocation scenario (this table, 170 counts/100 ml).

² Should not include illicit discharges.

The nonpoint sources are summed to produce a load allocation (LA), which is displayed in Tables 10 and 11 below.

Tables 10 and 11. Allocation strategy by TMDL component for Town Branch.

In terms of load:

Wasteload allocation (WLA) (counts/30 days)	Load allocation (LA) (counts/30 days)	Explicit Margin of safety (MOS) ¹ (counts/30 days)	TMDL (counts/30 days)
0	3.25×10^{11}	0.90×10^{11}	4.15×10^{11}

¹ Explicit margin of safety is equal to 22% since the load allocation is reduced by that much from the TMDL allocation (e.g., $[(4.15 \times 10^{11} - 3.25 \times 10^{11}) / 4.15 \times 10^{11}] * 100 = 22\%$).

In terms of concentration:

Wasteload allocation (WLA) (counts/100 ml)	Load allocation (LA) (counts/100 ml)	Explicit Margin of safety (MOS) ¹ (counts/100 ml)	TMDL (counts/100 ml)
0	170	30	200

¹ Explicit margin of safety is equal to 15.0% since the instream water quality target is reduced to 170 counts/100 ml from 200 counts/100 ml (e.g., $[(200-170)/200] = 15\%$).

The explicit margin of safety differs depending on whether it is viewed in terms of concentration or load (15% vs. 22%, respectively). This is because of a nonlinear relationship between load and concentration.

The implicit margin of safety, from the assumption that fecal coliform bacteria do not decay as they are transported from the land surface to the stream network, is not quantified nor included in the tables above. Basically though, by not including this decay, the listed load allocation is higher than if the decay were included. Consequently, the actual (expected) load allocation will be lower than what is shown in Tables 10 and 11. Because less fecal coliform should actually be delivered to the streams, therein lies the implicit margin of safety.

4.2 Instantaneous portion of standard

To assess the instantaneous portion of the fecal coliform standard, DWQ considered observed data and predictions from the full modeling period. The observed data from 1995 to 2001 show that 44% of the samples were over 400 counts/100 ml. The calibrated model has 28% of the daily predictions over 400 counts/100 ml. The TMDL model that meets the geometric mean part of the fecal coliform standard (overall about a 70% reduction) drops the percent of daily predictions above 400 counts/100 ml to less than 19% over the nearly 5 year model period.

4.3 Seasonal variation

DWQ used a nearly 5-year simulation period to assess the TMDL. This longer period allows for consideration of seasonal variation.

5.0 SUMMARY AND FUTURE CONSIDERATIONS

The sources of fecal coliform in the Town Branch watershed include urban sources in the Graham area, and wildlife in the forested areas of the watershed. The Nonpoint Source Model in EPA's Basins software was used to simulate instream fecal coliform concentrations and to allocate the fecal coliform loads to the various sources. In order for the water quality target to be met, the final allocation of the fecal coliform requires the major sources (not wildlife as that is considered part of background) to reduce loading by approximately 70%. DWQ considers the major source to be runoff from urban areas, possibly including leaking sewer lines. In fact, based on the special study monitoring which is shown in Appendix I, and based on the model results, it appears that if Town Branch is to meet the fecal coliform standard, the City of Graham must considerably reduce loading from runoff of urban areas, as well as address SSOs, possibly through infrastructure repair. As evidenced by Appendix V, the fecal coliform problem in Town Branch occurs following rain events. Additional monitoring is required to identify specific sources of fecal coliform, in terms of both area and animal. Finally, it would be beneficial to the fecal coliform impairment of Town Branch if the City of Graham would annex, and connect to the sewer system, the neighborhood in the southern portion of the watershed where septic system failure rate is high (see Section 2.2.3 Failing Septic Systems).

5.1 Monitoring

Fecal coliform monitoring will continue on a monthly interval at the ambient monitoring site (SR2109). The continued monitoring of fecal coliform concentrations will allow for the evaluation of progress towards the goal of reaching water quality standards. In addition to this data collection, further fecal coliform monitoring may be considered. Additional monitoring could focus on fecal coliform source assessment in the watershed; this would further aid in the evaluation of the progress towards meeting the water quality standard. Also, a synoptic survey of instream fecal coliform during storm events may improve model calibration during those important loading events.

To comply with EPA guidance, North Carolina may adopt new bacteria standards in the near future using *Escherichia coli* (*E. coli*) and enterococci. Thus, future monitoring efforts to measure compliance with this TMDL should include *E. coli* and enterococci. Per EPA recommendations (EPA, 2000b), if future monitoring for *E. coli*/enterococci indicates the standard has not been

exceeded, these monitoring data may be used to support delisting the water body from the 303(d) list. If a continuing problem is identified using E. coli/enterococci, the TMDL may be revised.

5.2 Implementation

An implementation plan is not included in this TMDL. The involvement of local governments and agencies will be needed in order to develop the implementation plan. Graham was very helpful in the development of this TMDL; they conducted a monitoring program in 2001 to assess compliance with the water quality criterion, and to better identify source areas (see Appendix I). Additionally, a local planning agency (Piedmont Triad Council of Governments), with collaboration from DWQ, developed a proposal for Section 319 funds to implement the Town Branch fecal coliform TMDL. In June, that proposal was awarded and work is scheduled to begin in 2003.

6.0 PUBLIC PARTICIPATION

The City of Graham was notified of DWQ's intention to develop the Town Branch fecal coliform TMDL. The county extension service supplied information on wildlife and livestock to aid in the source assessment portion of the TMDL.

To publicly notice the Town Branch fecal coliform TMDL, DWQ submitted a legal advertisement to the daily newspaper for nearby Burlington. The advertisement appeared in this newspaper on June 19, 2002. Additionally, also on June 19, 2002, DWQ electronically distributed a draft of the TMDL and public comment information to the known interested parties. Finally, DWQ held a public meeting in Graham on June 24, 2002 to present the TMDL and offer opportunity for questions and comments by the public. Eleven people, mostly employees of the City of Graham, attended this meeting.

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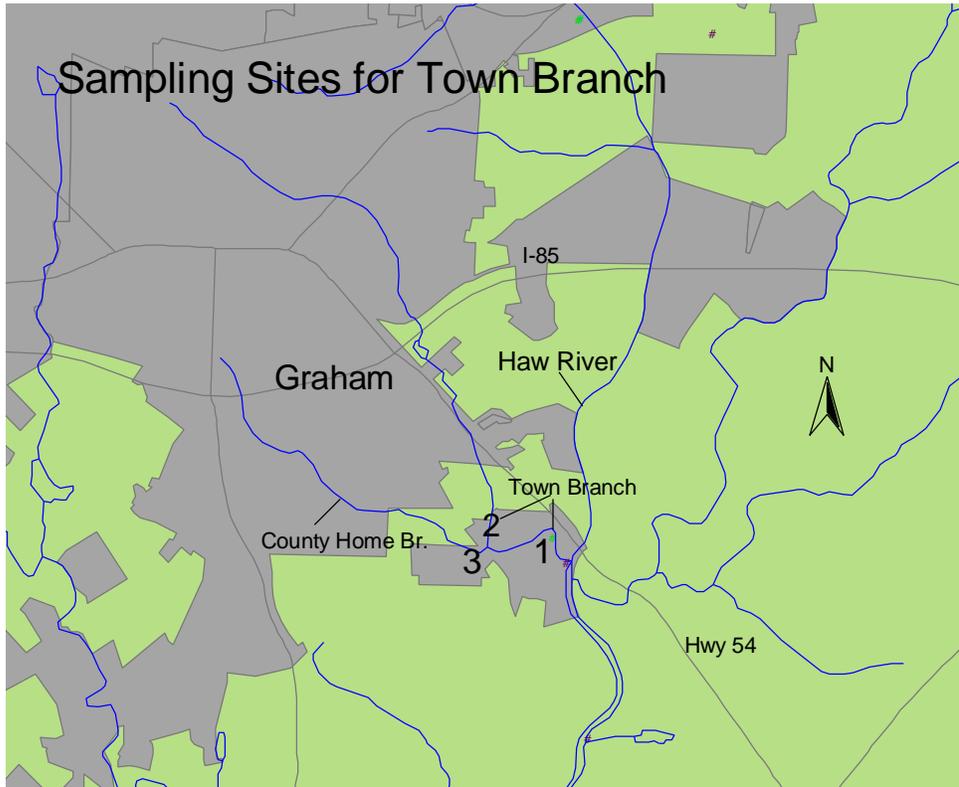
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APPENDIX I. OBSERVED DATA

Table A. Data from DWQ Ambient Station – Town Branch at SR 2109

DATE	Fecal Coliform (#/100 ml)	DATE	Fecal Coliform (#/100 ml)
1/19/95	110	10/28/98	10
2/23/95	260	11/19/98	120
3/22/95	680	1/21/99	18
4/12/95	640	4/22/99	140
5/18/95	620	7/19/99	690
6/21/95	9100	7/12/99	230
7/24/95	4400	8/16/99	830
9/26/95	220	9/29/99	2100
10/23/95	380	11/18/99	20
12/20/95	230	2/22/00	10
1/25/96	270	3/21/00	1700
2/26/96	27	4/19/00	250
3/26/96	320	5/31/00	150
4/17/96	320	6/26/00	2500
5/29/96	4000	7/25/00	3700
6/24/96	1600	8/24/00	740
7/24/96	400	9/20/00	540
8/27/96	200	10/18/00	390
9/24/96	310	11/30/00	4300
10/23/96	310	12/14/00	210
11/19/96	2400	1/31/01	450
12/17/96	18	4/25/01	3500
1/30/97	210	6/19/01	2200
2/26/97	19	8/30/01	110
3/26/97	870	9/26/01	640
4/28/97	1200	10/23/01	120
5/27/97	5300	11/28/01	48
6/25/97	100		
7/17/97	4900		
8/26/97	240		
9/16/97	450		
10/22/97	910		
11/24/97	2400		
12/18/97	45		
1/27/98	1200		
2/18/98	6400		
3/24/98	140		
4/29/98	350		
5/26/98	4600		
6/25/98	63		
7/27/98	220		
8/24/98	100		
9/29/98	230		

Special Study by City of Graham during July and August, 2001. The purposes of this study were to evaluate whether the creek was complying with the state fecal coliform standard, and to provide information on bacteria source areas in watershed.



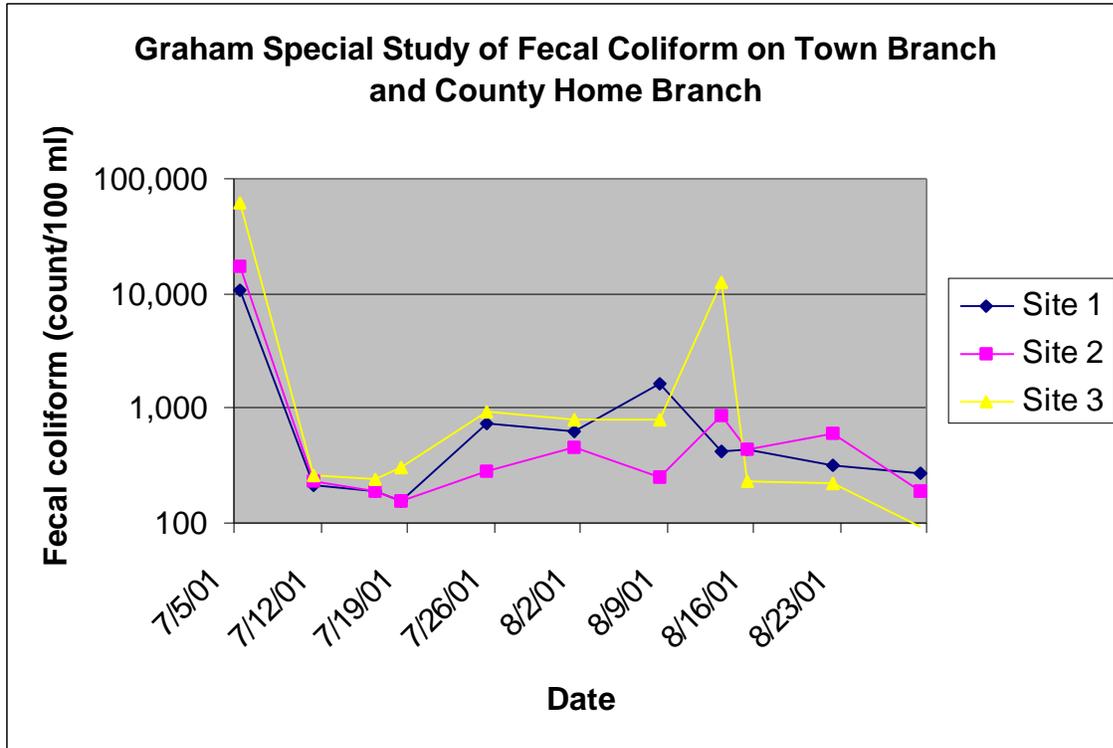
Site 1 - SR2109, Town Branch at Cooper Rd.

Site 2 - Upper Town Branch at Graham WWTP entrance

Site 3 - County Home Branch at Gilbreath St.

Heavy rains occurred on 7/4/2001, which explains the extremely high fecal coliform concentrations on 7/5/2001.

As will be evidenced below, Town Branch had fecal coliform levels that exceed the water quality criterion, and consequently, that pollutant impairs one of the stream's designated uses. County Home Branch, which is characterized by low density residential development, typically had the highest fecal coliform levels.



Individual Sample Results

Site One is at SR2109 - Town Branch at Cooper Rd.

Date	Counts/100 ml
7/5/01	10,571
7/11/01	210
7/16/01	192
7/18/01	156
7/25/01	724
8/1/01	620
8/8/01	1645
8/13/01	417
8/15/01	438
8/22/01	317
8/29/01	276

Site Two - upper Town Branch at Graham WWTP entrance

Date	Counts/100 ml
7/5/01	17,560
7/11/01	230
7/16/01	191
7/18/01	156
7/25/01	279
8/1/01	460
8/8/01	249
8/13/01	852
8/15/01	440
8/22/01	597
8/29/01	192

Site Three - County Home Branch at Gilbreath St.

Date	Counts/100 ml
7/5/01	61,000 >
7/11/01	260
7/16/01	245
7/18/01	303
7/25/01	938
8/1/01	800
8/8/01	800 >
8/13/01	12,300 >
8/15/01	233
8/22/01	218
8/29/01	92

Summary of Town Branch Fecal Coliform Data from City of Graham Special Study
(for station locations see map on next page)

Station Description	Dates	Number of Days	Observations	Geometric Mean
Town Branch at SR 2109	7/5/2001 to 8/3/2001	30	6	557
Town Branch at SR 2109	7/11/2001 to 8/9/2001	30	6	408
Town Branch at SR 2109	7/16/2001 to 8/14/2001	30	5	457
Town Branch at SR 2109	7/18/2001 to 8/16/2001	30	6	525
Town Branch at SR 2109	7/25/2001 to 8/22/2001	30	6	591
Town Branch at SR 2109	8/1/2001 to 8/29/2001	29	6	504

Station Description	Dates	Number of Days	Observations	Geometric Mean
Town Branch above WWTP	7/5/2001 to 8/3/2001	30	6	499
Town Branch above WWTP	7/11/2001 to 8/9/2001	30	6	246
Town Branch above WWTP	7/16/2001 to 8/14/2001	30	5	305
Town Branch above WWTP	7/18/2001 to 8/16/2001	30	6	351
Town Branch above WWTP	7/25/2001 to 8/22/2001	30	6	439
Town Branch above WWTP	8/1/2001 to 8/29/2001	29	6	412

Station Description	Dates	Number of Days	Observations	Geometric Mean
County Home Branch at Gilbreath	7/5/2001 to 8/3/2001	30	6	980
County Home Branch at Gilbreath	7/11/2001 to 8/9/2001	30	6	476
County Home Branch at Gilbreath	7/16/2001 to 8/14/2001	30	5	905
County Home Branch at Gilbreath	7/18/2001 to 8/16/2001	30	6	897
County Home Branch at Gilbreath	7/25/2001 to 8/22/2001	30	6	849
County Home Branch at Gilbreath	8/1/2001 to 8/29/2001	29	6	577

Station Description	Dates	Number of Days	Observations	Geometric Mean
All Stations	7/5/2001 to 8/3/2001	30	18	648
All Stations	7/11/2001 to 8/9/2001	30	18	363
All Stations	7/16/2001 to 8/14/2001	30	15	502
All Stations	7/18/2001 to 8/16/2001	30	18	549
All Stations	7/25/2001 to 8/22/2001	30	18	604
All Stations	8/1/2001 to 8/29/2001	29	18	493

APPENDIX II. FIT STATISTICS FOR MODEL CALIBRATION

1) r – the correlation coefficient of the model predictions and observations:

$$r = \frac{\sum_{i=1}^n (O_i - \bar{O})(P_i - \bar{P})}{\sqrt{\sum_{i=1}^n (O_i - \bar{O})^2 \sum_{i=1}^n (P_i - \bar{P})^2}},$$

2) RMSE - the root mean squared error:

$$\text{RMSE} = \sqrt{\frac{\sum_{i=1}^n (P_i - O_i)^2}{n}},$$

3) RI – the reliability index

$$\text{RI} = \exp \sqrt{\frac{1}{n} \sum_{i=1}^n \left(\log \frac{O_i}{P_i} \right)^2},$$

4) AE – the average error

$$\text{AE} = \frac{\sum_{i=1}^n (P_i - O_i)}{n} = \bar{P} - \bar{O},$$

5) AAE – the average absolute error

$$\text{AAE} = \frac{\sum_{i=1}^n |P_i - O_i|}{n}, \text{ and}$$

6) MEF – the modeling efficiency

$$\text{MEF} = \frac{\left(\sum_{i=1}^n (O_i - \bar{O})^2 - \sum_{i=1}^n (P_i - O_i)^2 \right)}{\sum_{i=1}^n (O_i - \bar{O})^2},$$

where n = the number of observations, O_i = the i th of n observations, P_i = the i th of n predictions, and \bar{O} and \bar{P} are the observation and prediction averages, respectively. All observations and predictions were log-transformed before calculating the fit statistics so that differences between predicted and observed values would not be highly skewed and dominated by a small proportion of high values.

APPENDIX III. MODEL CALIBRATION INFORMATION

Calibrated Hydraulic Parameters for HSPF application to Reedy Fork
(later applied to Town Branch)

Parameter	Description/Units	Calibration value	Typical range*
LZSN	Lower zone nominal storage (inches)	7.0	3 - 8
INFILT	Soil infiltration rate (in./hr.)	0.10	0.01 – 0.25
LSUR	Length of assumed overland plane (ft.)	300	200 - 500
SLSUR	Slope of assumed overland plane	0.035	0.01 – 0.15
AGWRC	Groundwater recession rate (/day)	0.99-forest, 0.96-nonforest	0.92 – 0.99
UZSN	Upper zone nominal storage (inches)	0.56	0.10 – 1.0
INTFW	Interflow inflow (no units)	0.60	Default is 0.75
IRC	Interflow recession coefficient	0.40	0.5 – 0.7
LZETP	Lower zone evapotranspiration	0.20	0.2 – 0.7

* From Basins Technical Note 6 – Estimating Hydrology and Hydraulic Parameters for HSPF

Calibrated Water Quality Parameter for HSPF application to Town Branch

Land use/PARAMETER	ACQOP	SQOLIM	WSQOP	IOQC
Urban	2×10^9	3.6×10^9	0.7	6.7×10^5
Managed Herbaceous	1.95×10^8	3.52×10^8	1.5	11,300
Cropland	1.95×10^6	3.52×10^6	1.5	11,300
Forest	1.95×10^6	3.52×10^6	2.8	5,670

ACQOP is the accumulation rate (in count/acre/day)

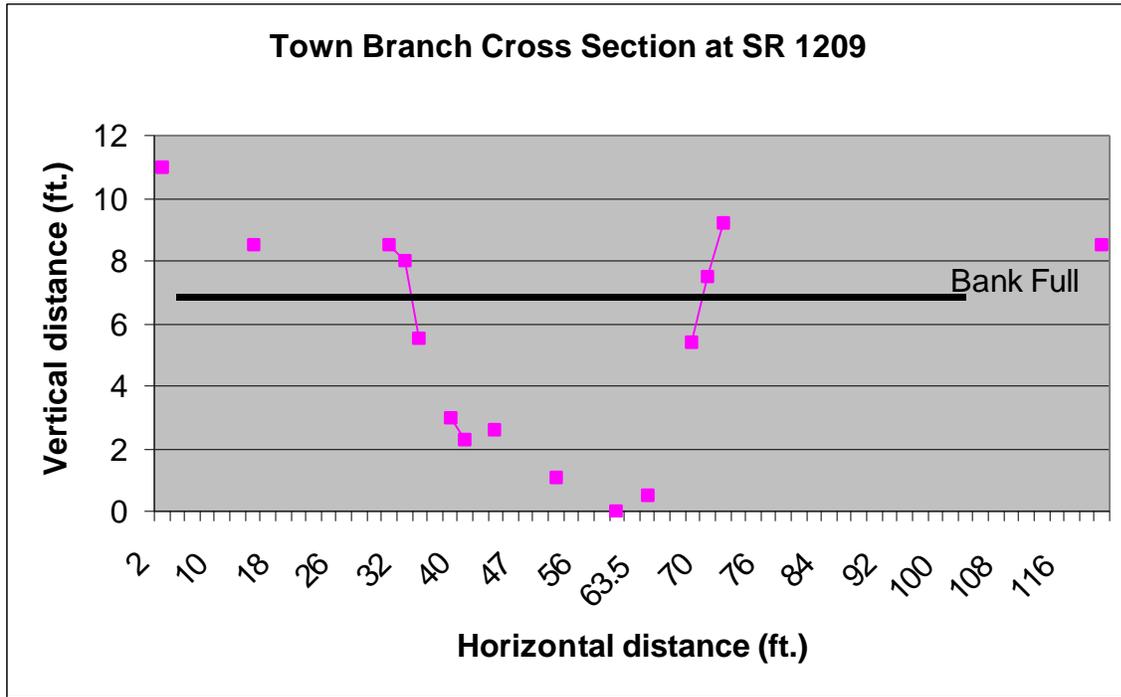
SQOLIM is the maximum storage rate (in count/acre)

WSQOP is the surface runoff rate removing 90% of pollutant (in inches)

IOQC is the interflow concentration (in count/acre/day)

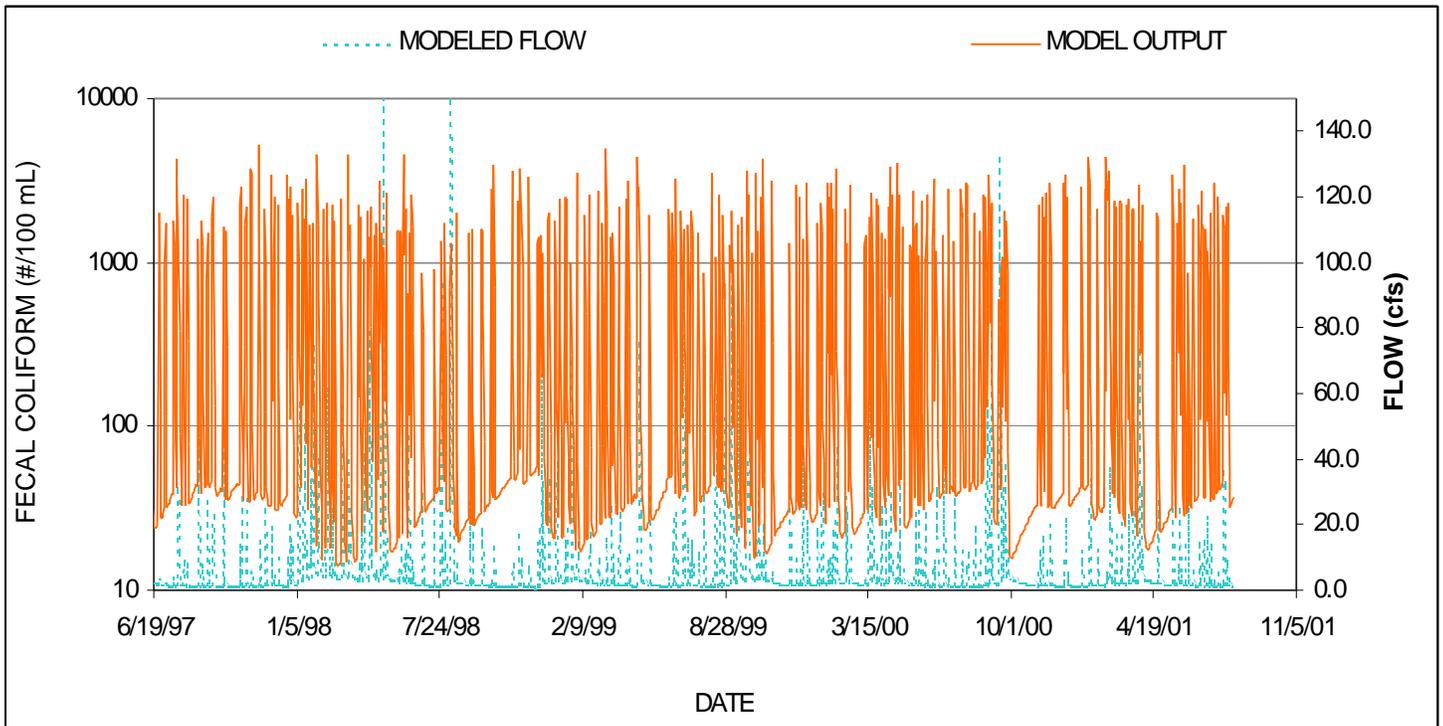
These values were calculated in Fecal Tool, except for managed herbaceous, which was assumed to have an accumulation rate that approaches urban land (it is usually associated with urban land in this watershed).

APPENDIX IV. CHANNEL CROSS SECTION.



This cross section was used to develop the model F-table (table that describes relationship between streamflow depth and streamflow volume).

APPENDIX V. MODELED FLOW and MODEL FECAL COLIFORM PREDICTIONS
(Calibration run, also shown in Figures 4 and 5)



This figure demonstrates that the higher fecal coliform concentrations in Town Branch occur following rainfall events. During dry stretches the concentration is below the criterion.