West Fork White River, Muncie to Hamilton-Marion County Line TMDL for *E. coli* Bacteria

TMDL Report

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1.0 INTRODUCTION

1.1 Background

The West Fork White River (WFWR) from Muncie to the Hamilton-Marion county line drains approximately 1,100 square miles in central Indiana (Figure 1). Several segments of this stretch of the WFWR appear on Indiana's section 303(d) list of impaired waters for failing to fully support the state's recreation use (Table 1 and Figure 2). These impairments were identified based on data collected by the Indiana Department of Environmental Management (IDEM) during the 1996 and 2001 water quality surveys. Data from those surveys resulted in violations of the *Escherichia Coli (E. coli)* standard. *E. coli* is a bacterium that indicates the presence of human sewage and/or animal manure. It can enter rivers through direct permitted discharges, combined sewer overflows (CSOs), illicit and failing septic systems, and storm runoff carrying wastes from wildlife, domestic, and agricultural animals. *E. coli* is also an indication of the possible presence of other disease causing organisms or pathogens.

Table 1. Impaired waterbodies listed for *E. coli* from the 2002 section 303(d) list in the WFWR watershed above the Hamilton-Marion county line.

Stream Segment	Waterbody ID	Designated Use	Support Status
West Fork White River (Muncie to Madison County)	IN05120201030	Recreation	Impaired
West Fork White River (Madison County)	IN05120201050	Recreation	Impaired
West Fork White River (Hamilton County)	IN05120201050	Recreation	Impaired
Killbuck Creek	IN05120201040	Recreation	Impaired
Pipe Creek	IN05120201060	Recreation	Impaired
Stony Creek	NA	Recreation	Impaired
Duck Creek	IN05120201070	Recreation	Impaired

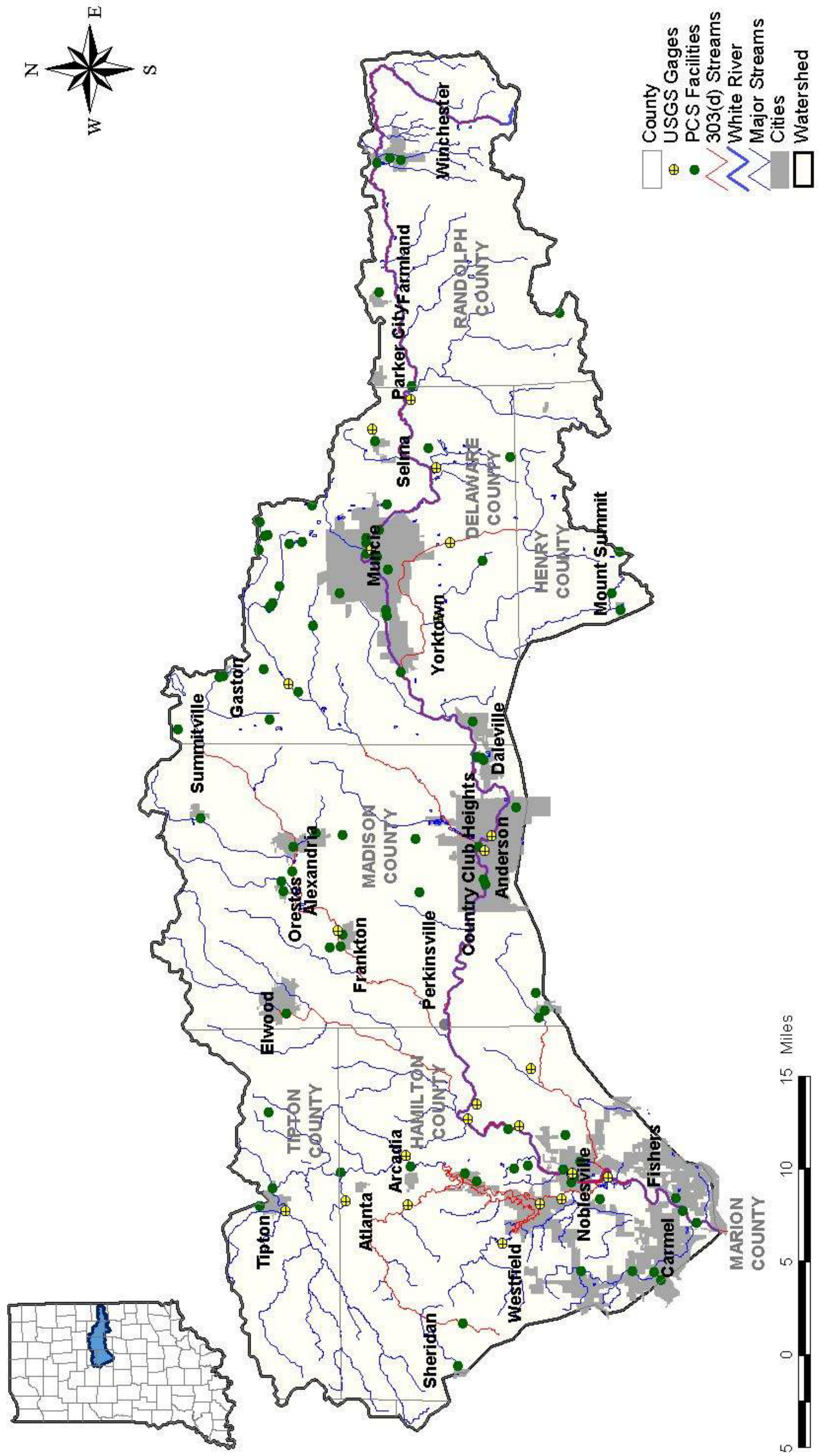

Figure 1. Political map of the WFWR watershed above the Hamilton-Marion county line.

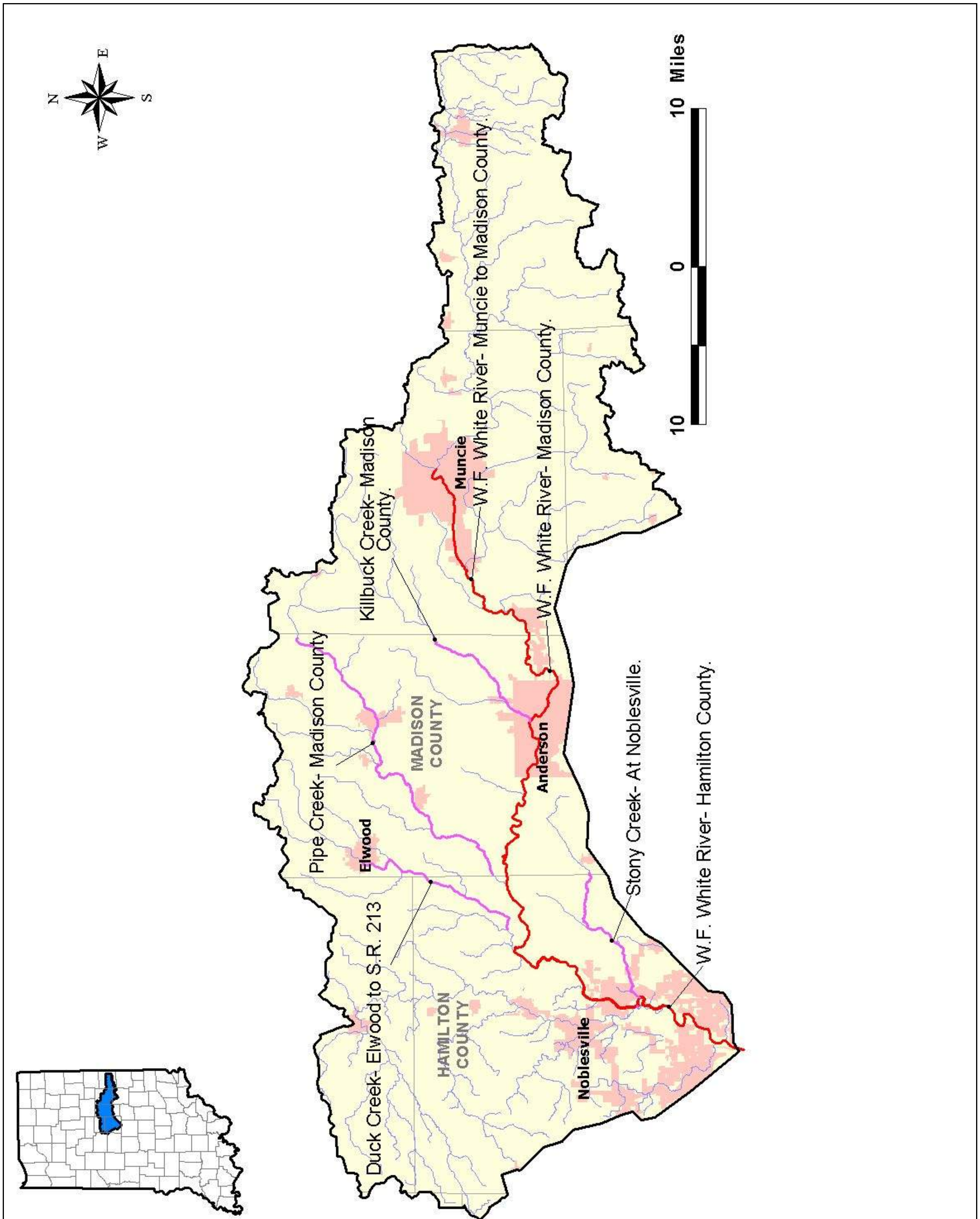

Figure 2. Waters in the WFWR watershed above the Hamilton-Marion county line that are listed for *E. coli*.

1.2 Document Purpose and Content

The Clean Water Act and U.S. Environmental Protection Agency (USEPA) regulations require that states develop Total Maximum Daily Loads (TMDLs) for all waters on the section 303(d) lists. A TMDL is the sum of the allowable amount of a single pollutant that a waterbody can receive from all contributing point and nonpoint sources and still support its designated uses. IDEM is in the final stages of developing *E. coli* TMDLs for the WFWR above the Hamilton-Marion county line. The overall goals and objectives of the project are to

- Further assess the water quality of the WFWR and identify key issues associated with the impairments and potential pollutant sources.
- Use the best available science to determine the maximum load of *E. coli* that the river can receive and still fully support all of its designated uses.
- Use the best available science to determine current loads and sources of *E. coli.*
- If current loads exceed the maximum allowable load, determine the load reduction that is needed.
- Identify feasible and cost-effective actions that can be taken to reduce loads.
- Inform and involve the public throughout the project to ensure that key concerns are addressed and the best available information is used.
- Submit a final TMDL report to USEPA for review and approval.

Previous reports described the physical setting of the WFWR watershed; discussed the spatial and temporal extent of *E. coli* concentrations; identified the nature, location, and magnitude of potential sources of *E. coli*; and proposed a modeling framework for completing the TMDL (Tetra Tech, 2002; Tetra Tech, 2003a; Tetra Tech, 2003b). This TMDL report combines the results of all previous reports, allocates the allowable loads among the existing sources, and addresses the regulatory requirements of the TMDL process.

Section 2 of this document describes the WFWR watershed and discusses several characteristics of the watershed that are significant to *E. coli* conditions. Section 3 presents the relevant water quality standards and summarizes the available sampling data. Section 4 discusses all of the significant sources of *E. coli* and the information that was used to estimate the magnitude of loading and Section 5 discusses the technical approach that was used to evaluate the impact of the loadings on instream conditions. Section 6 allocates the existing loads to the various source categories and addresses several TMDL regulatory requirements, such as margin of safety and seasonality. Sections 7 and 8 discuss public participation and implementation, respectively.

2.0 DESCRIPTION OF THE WATERSHED

The WFWR is located in central Indiana and the segment of interest for this TMDL extends from the confluence of Muncie Creek and the West Fork White River in the City of Muncie to the Hamilton-Marion county line. The watershed associated with this segment is 1160 square miles and encompasses portions of Tipton, Hamilton, Madison, Delaware, Henry and Randolph Counties (Figure 1). The watershed is the upstream portion of the larger Upper White River basin which the U.S. Geological Survey (USGS) has designated as Hydrologic Unit Code 05120201.

The sections below provide information on the population, land uses, topography, and climate associated with the watershed. Obtaining an understanding of these topics is a critical first step in developing a TMDL because they provide information on the potential sources of *E. coli*, as well as characteristics of the watershed that might affect water quality.

2.1 Population

The population of the WFWR watershed above the Hamilton-Marion county line is approximately 200,000 with the majority concentrated in the cities of Anderson, Muncie, Noblesville, Fishers and Carmel (Table 2). The major population center in the watershed is Muncie, with a year 2000 population of approximately 67,000 people (US Census Bureau, 2000). Hamilton County is one of the fastest growing counties in the country, with a 68 percent increase in population from 1990 to 2000. This population growth has resulted in considerable land use change in the watershed, as well as an increase in the need for centralized and de-centralized wastewater treatment.

Table 2. Population data for cities within the WFWR watershed above the Hamilton-Marion county line[1].

City	County	1990 Population	2000 Population	Percent Change
Anderson	Madison	59,949	59,734	-0.36
Carmel	Hamilton	25,380	37,733	48.67
Elwood	Madison/Tipton	9,490	9,737	2.60
Fishers Town	Hamilton	7,508	37,835	403.93
Muncie	Delaware	71,035	67,430	-5.07
Noblesville	Hamilton	17,655	28,590	61.94
	Totals	191,017	241,059	26.20

[1]Note that portions of some cities are outside the watershed.

2.2 Topography

The WFWR watershed above the Hamilton-Marion county line lies in the Tipton Till Plain, a physiographic region characterized by flat to gently rolling terrain. Topography in the watershed is a result of continental glaciation during the most recent ice age. Figure 3 presents the general topography within the watershed. Elevation ranges from 734 feet at the Hamilton-Marion county line to more than 1200 feet in the headwaters (USGS, 1993). The average slope in the watershed is 1.0 percent (calculated by measuring the average slope of each 100 foot by 100 foot parcel of land in the watershed with a geographic information system (GIS)).

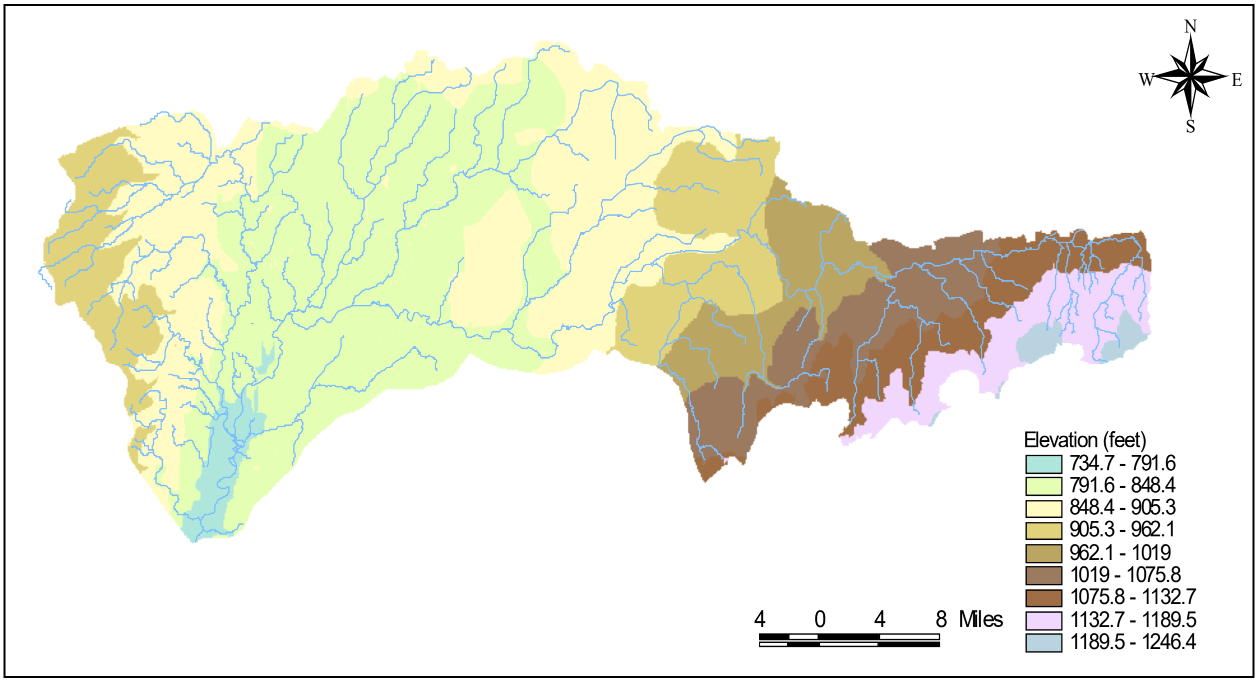

Figure 3. Topography in the WFWR watershed above the Hamilton-Marion county line.

2.3 Land Use

Land use information for the WFWR watershed above the Hamilton-Marion county line is available from the Multi-Resolution Land Characteristics Consortium (MRLC). The land use data are derived from images acquired by Landsat's Thematic Mapper satellite during the early 1990s. These data categorize the land use for each 100 foot by 100 foot parcel of land in the watershed.

Figure 4 displays the spatial distribution of the land uses and Table 3 provides a breakdown of the land uses in the watershed. The watershed is mostly row crop agriculture with areas of low-density residential lands concentrated around the cities of Muncie, Anderson, and Indianapolis. It should be pointed out that since the MRLC data are based on satellite imagery from the early 1990s, land uses in some parts of the watershed have changed. This is especially true of the area near Carmel and Fishers. Estimates of the extent of such change were made using the population data presented above and these updated estimates were used for development of the TMDL.

Row crop agriculture and buffer strip adjacent to WFWR between Muncie and Anderson.

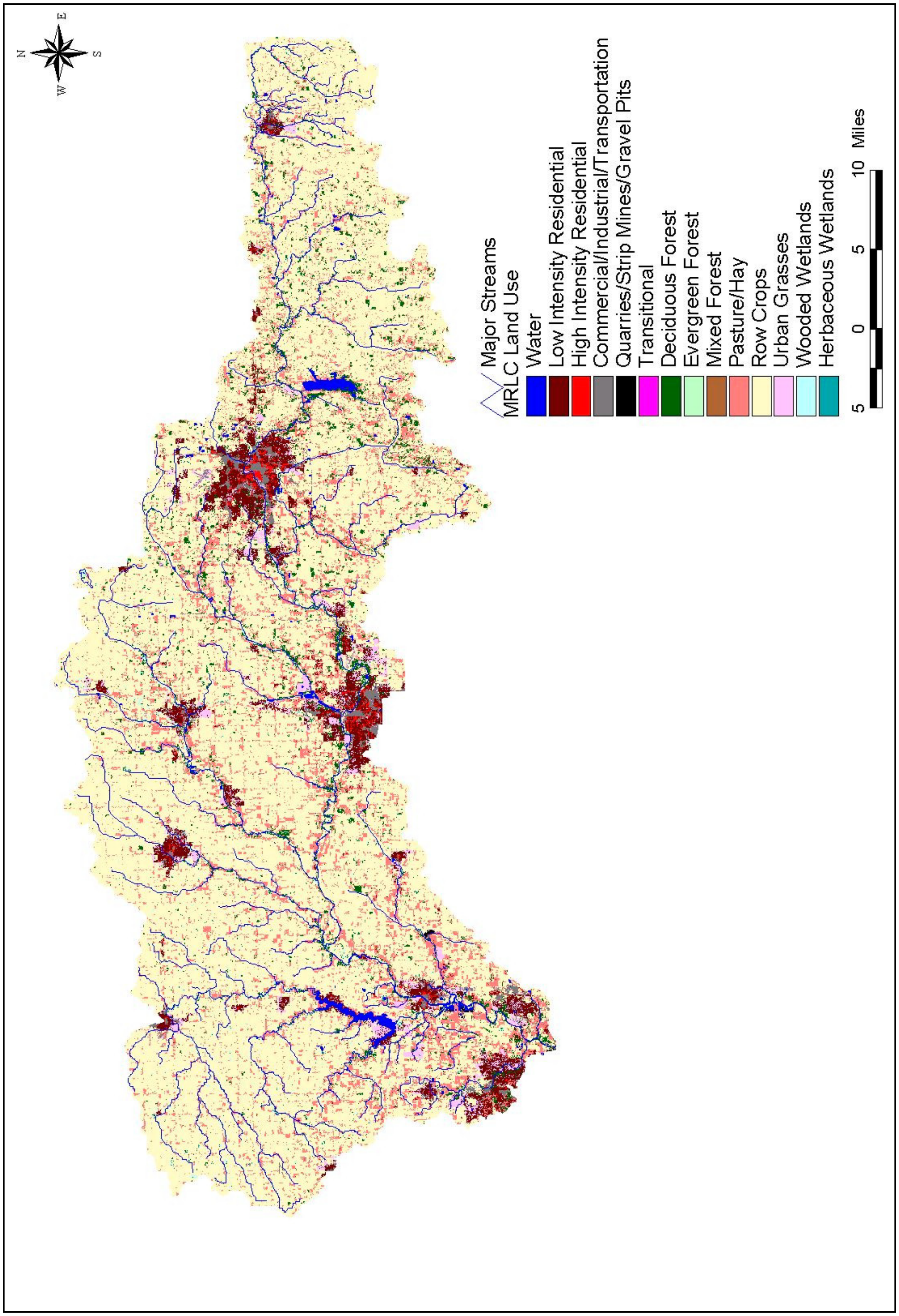

Figure 4. Land use in the WFWR watershed above the Hamilton-Marion county line.

Table 3. Land use distribution in the WFWR watershed above the Hamilton-Marion county line.

Land Use	Area (acres)	Percent (%)
Row Crops	540,650	72.80
Pasture/Hay	99,487	13.40
Low Intensity Residential	30,685	4.13
Deciduous Forest	30,079	4.05
Urban Grasses	14,606	1.97
Commercial/Industrial/Transportation	9,138	1.23
Wooded Wetlands	8,387	1.13
Water	5,184	0.70
High Intensity Residential	3,475	0.47
Herbaceous Wetlands	474	0.06
Quarries/Strip Mines/Gravel Pits	310	0.04
Evergreen Forest	155	0.02
Mixed Forest	25	0.00
Total	**742,655**	**100**

Source: MRLC, 2000.

2.4 Soils

Soils data from the Natural Resources Conservation Service (NRCS) were used to characterize soils in the watershed. General soils data and map unit delineations are available through the State Soil Geographic (STATSGO) database. GIS coverages provide accurate locations for the soil map units at a scale of 1:250000 (USDA, 2002). A map unit is composed of several soil series having similar properties. Identification fields in the GIS coverages can be linked to a database that provides information on chemical and physical soil characteristics, which can in turn be used in setting up and calibrating a watershed model.

The hydrologic soil group classification is a means for grouping soils by similar infiltration and runoff characteristics during periods of prolonged wetting. Typically, clay soils that are poorly drained have lower infiltration rates, while sandy soils that are well drained have the greatest infiltration rates. NRCS has defined four hydrologic groups for soils (Table 4). The corresponding spatial distribution of hydrologic soil groups in the WFWR watershed is illustrated in Figure 5. The upstream portion of the watershed consists of moderately drained soils with low organic content. The downstream portion of the watershed consists of well-drained sandy and silty soils. Note that the A/D and B/D classifications in Figure 5 indicate soils that are well drained when dry but poorly drained when wet.

Table 4. Characteristics of hydrologic soil groups.

Soil Group	Characteristics	Minimum Infiltration Capacity (inches/hour)
A	Sandy, deep, well drained soils; deep loess; aggregated silty soils	0.30-0.45
B	Sandy loams, shallow loess, moderately deep and moderately well drained soils	0.15-0.30
C	Clay loam soils, shallow sandy loams with a low permeability horizon impeding drainage (soils with a high clay content), soils low in organic content	0.05-0.15
D	Heavy clay soils with swelling potential (heavy plastic clays), water-logged soils, certain saline soils, or shallow soils over an impermeable layer	0.00-0.05

Source: NRCS, 1972

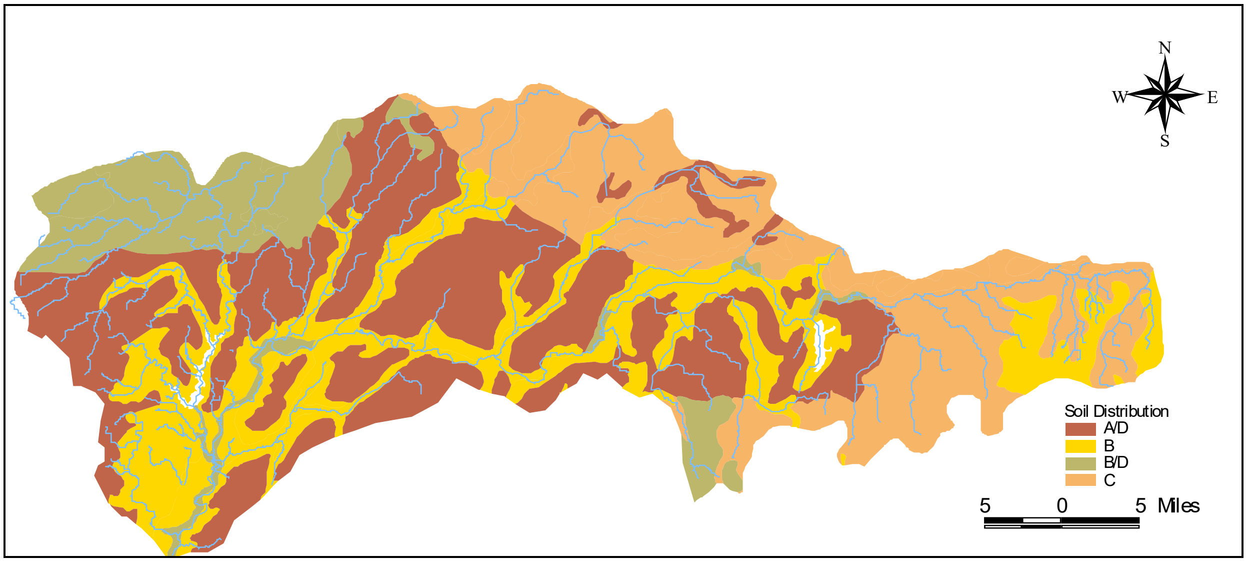

Figure 5. Hydrologic soil groups in the WFWR watershed.

2.5 Climate

The WFWR watershed has a climate characterized by warm summers and cool winters. Temperatures range from around 26 degrees Fahrenheit in January to 74 degrees Fahrenheit in July (MRCC, 2002). Several National Climatic Data Center (NCDC) gages are located in or near the watershed (Figure 6). These stations record climatic variables such as temperature, precipitation, wind speed and potential evapotranspiration. The closest stations are at the Richmond Water Works (station 93815) and the Indianapolis Airport (station 93819). Several additional stations within the watershed have data for only precipitation and temperature. These include Farmland 5 (station IN2825), the Anderson Sewage Treatment Plant (station IN0177) and Tipton 5 SW (station IN8784). Figure 6 shows the locations of these climate and precipitation stations.

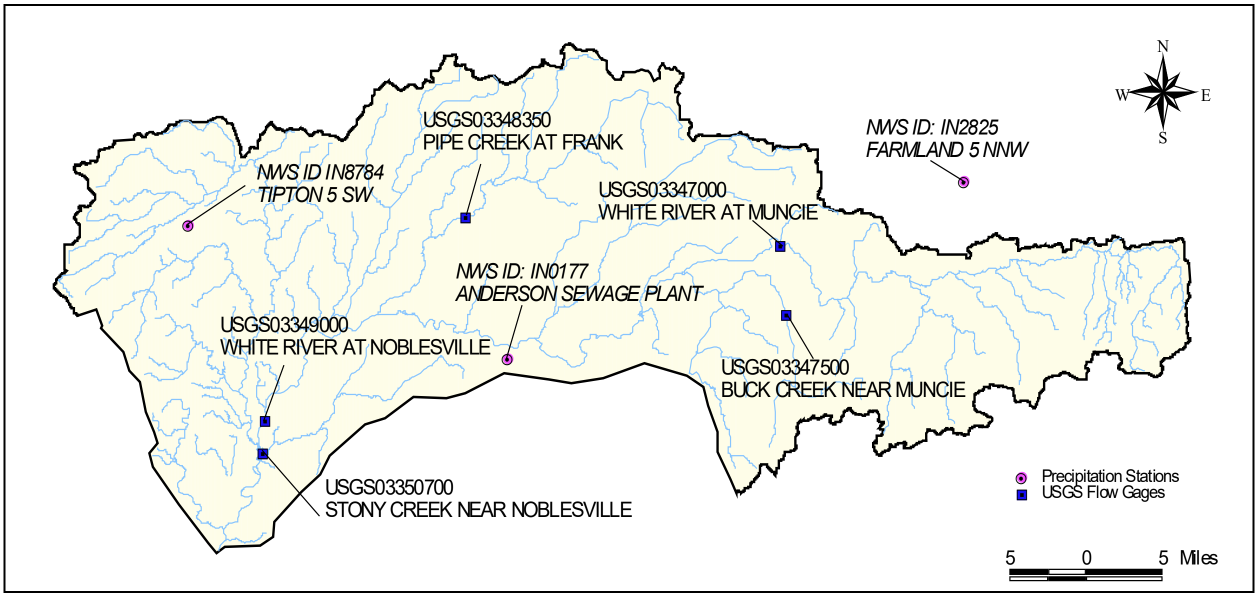

Figure 6. Location of precipitation and stream flow stations in the WFWR watershed.

During a ten-year period between 1990 and 2000, the average annual precipitation in the watershed was approximately 40.6 inches with a maximum in 1990 of 58.6 inches and a minimum of 28.5 inches in 1999. The mean annual number of days when precipitation exceeds 0.10 inch is about 75 days. Figure 7 presents a comparison of annual precipitation data for several stations in the WFWR watershed. Precipitation events are important to this TMDL because many of the sources of *E. coli* (e.g., combined sewer overflows, stormwater) are associated with runoff.

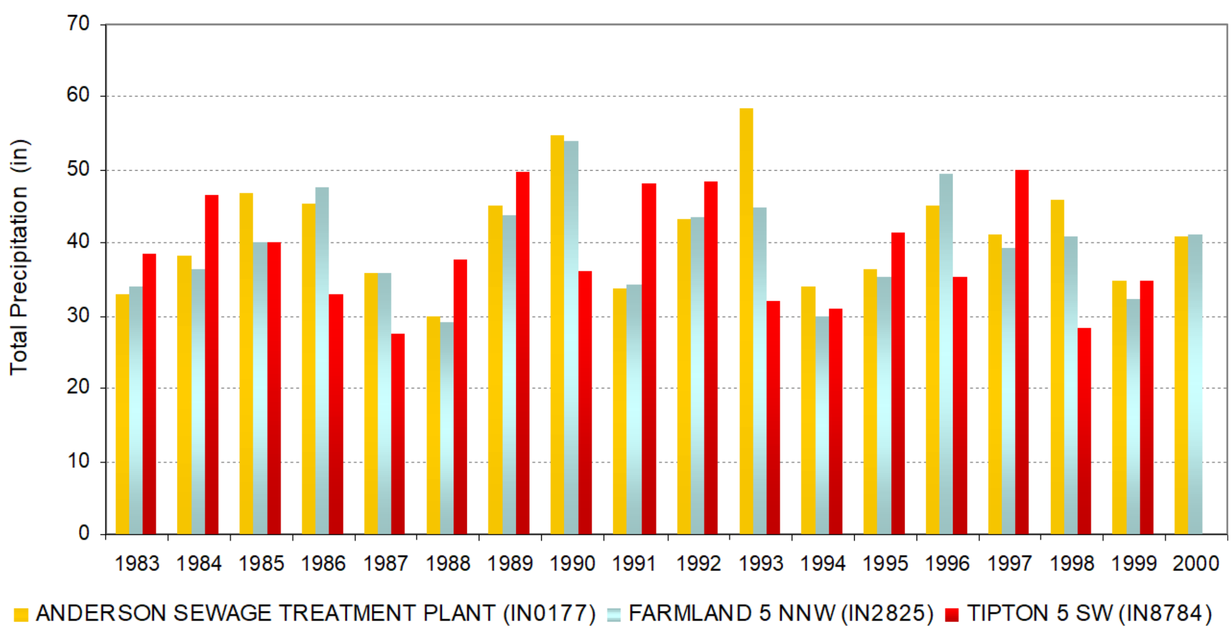

Figure 7. Annual precipitation at WFWR watershed climate stations.

2.6 Hydrology

The U. S. Geological Survey (USGS) has five active stream flow stations in the WFWR watershed above the Hamilton-Marion county line. Several other stations in the watershed stopped recording flow during the 1990s (White River at Anderson, Killbuck Creek near Gaston, Cicero Creek at Noblesville). The locations of the active stations are presented in Figure 8 and the period of record information for these stations is presented in Table 5.

The flow data spans several years that overlap with the available climate information. This provides a good hydrologic picture of the watershed. Furthermore, the USGS gages monitor flow for a range of drainage areas—from small subwatersheds (36 square miles) up to nearly the entire watershed (858 square miles). Having information for various sized drainage areas was useful in the modeling effort. A hydrograph for the most downstream USGS gage is shown in Figure 8. The hydrographs for the other gages are similar and indicate that flows are typically the greatest in March and April during spring rains and snowmelt and lowest in the late summer and early fall.

Table 5. Active USGS stations in the WFWR watershed.

Station ID	Station Name	First Date Available	Last Date Available	Drainage Area (sq. miles)
03347000	White River at Muncie	4/1/1931	9/30/2002	241
03347500	Buck Creek near Muncie	10/1/1954	9/30/2002	36
03348350	Pipe Creek at Frankton	5/1/1968	9/30/2002	113
03350700	Stony Creek Near Noblesville	6/27/1967	9/30/2002	51
03349000	White River at Noblesville	10/1/1946	9/30/2002	858

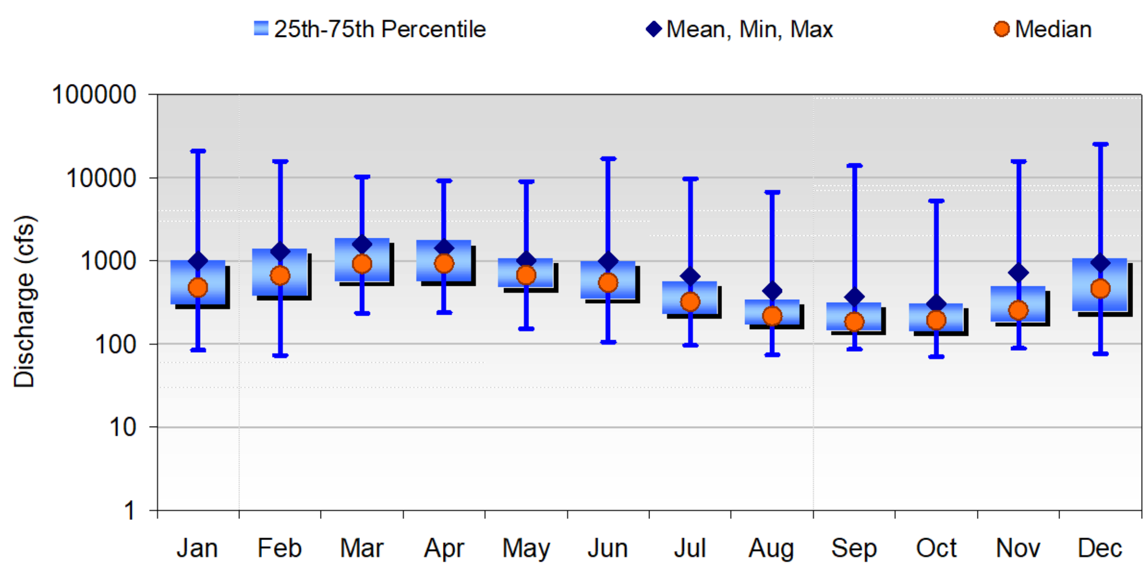

Figure 8. Average monthly flows in the WFWR at Noblesville. Data cover the period January 1, 1970 to September 30, 2001.

3.0 INVENTORY AND ASSESSMENTOF WATER QUALITY INFORMATION

IDEM monitors the presence of *E. coli* under the Surface Water Quality Assessment program. The state has adopted a rotating basin approach to water quality planning, monitoring, assessment, reporting, protection and restoration. This rotating basin approach to watershed management began in 1996. The Upper West Fork of the White River watershed was one of the first monitored under the current program. Therefore the WFWR watershed above the Hamilton-Marion county line was monitored and assessed in 1996 and then again in 2001. The monitoring strategy is designed to describe the overall environmental quality of each major river basin and to identify which water bodies do not meet water quality standards.

IDEM sampling station at Jackson Street bridge in Muncie.

IDEM has sampled water quality data for 146 monitoring stations in the WFWR watershed above the Hamilton-Marion county line. The database contains more than 14,834 records for approximately 50 different parameters (e.g., dissolved oxygen, pH, phosphorus, nitrogen, total suspended solids). The data cover a period from 1991 to 2001 and therefore include the 1996 and 2001 assessments that were done in support of IDEM's 303(d) listing. Figure 9 presents the locations of surface water quality stations in the watershed, including the four stations with the most data.

IDEM has identified three segments of the WFWR and four tributaries as impaired and listed on Indiana's 2002 section 303(d) list for violations of the *E. coli* water quality standards. Several parameters were sampled to address the pathogen impairment. These include *E. coli*, fecal coliform, temperature, pH and turbidity. Appendix A presents a summary of the *E. coli* data for all the stations in the watershed and the sections below present the results of a spatial and temporal analysis of the data.

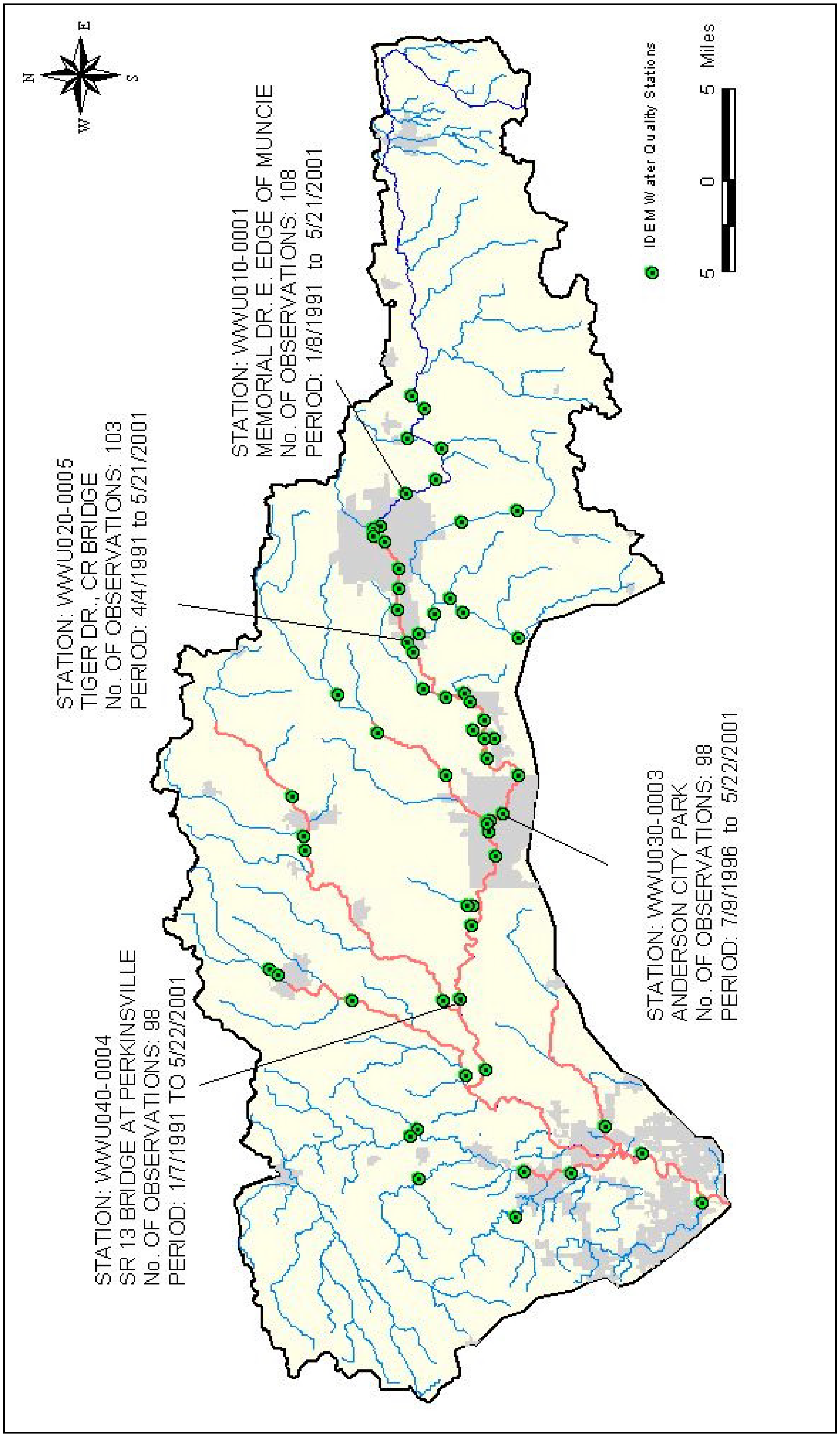

Figure 9. Location of IDEM surface water quality monitoring stations and identification of sites with the most data.

3.1 Confirmation of Impairment and its Extent

Under the Clean Water Act, every state must adopt water quality standards to protect, maintain, and improve the quality of the nation's surface waters. These standards represent a level of water quality that will support the Clean Water Act's goal of "swimmable/fishable" waters. Water quality standards consist of three different components:

- **Designated uses** reflect how the water can potentially be used by humans and how well it supports a biological community. Examples of designated uses include aquatic life support, drinking water supply, and recreation. Every water in Indiana has a designated use or uses; however, not all uses apply to all waters.
- Criteria express the condition of the water that is necessary to support the designated uses. **Numeric criteria** represent the concentration of a pollutant that can be in the water and still protect the designated use of the waterbody. **Narrative criteria** are the general water quality criteria that apply to all surface waters. These criteria state that all waters must be free from sludge; floating debris; oil and scum; color- and odor-producing materials; substances that are harmful to human, animal or aquatic life; and nutrients in concentrations that may cause algal blooms
- The **antidegradation policy** establishes situations under which the state may allow new or increased discharges of pollutants, and requires those seeking to discharge additional pollutants to demonstrate an important social or economic need. This policy only applies to surface water within the Great Lakes system.

All water bodies in Indiana are designated for recreational use. The numeric criteria associated with protecting the recreational use are described below.

> "This subsection establishes bacteriological quality for recreational uses. In addition to subsection (a), the criteria in this subsection are to be used to evaluate waters for full body contact recreational uses, to establish wastewater treatment requirements, and to establish effluent limits during the recreational season, which is defined as the months of April through October, inclusive. *E. coli* bacteria, using membrane filter (MF) count, shall not exceed one hundred twenty-five (125) per one hundred (100) milliliters as a geometric mean based on not less than five (5) samples equally spaced over a thirty (30) day period nor exceed two hundred thirty-five (235) per one hundred (100) milliliters in any one (1) sample in a thirty (30) day period." [Source: Indiana Administrative Code Title 327 Water Pollution Control Board. Article 2. Section 1-6(a). Last updated November 1, 2003.]

The Muncie to Hamilton-Marion county line segment of the WFWR has been listed as impaired for violations of the *E. coli* criteria. The sections below discuss the nature of this impairment.

3.1.1 Comparison with Geometric Mean Standard

The geometric mean portion of the standard requires that five samples be collected during a 30-day period. Historically, not all sampling has been conducted at this frequency. However, sampling during the 2001 assessment was done at the necessary frequency and the spatial distribution of violations to the standard is presented in Figure 10. The violations of the geometric mean standard confirm the impairment of the WFWR from Muncie through Madison County and into Hamilton County. Of the 29 stations with suitable data to compare to the standard, all but four exhibited at least one violation of the standard.

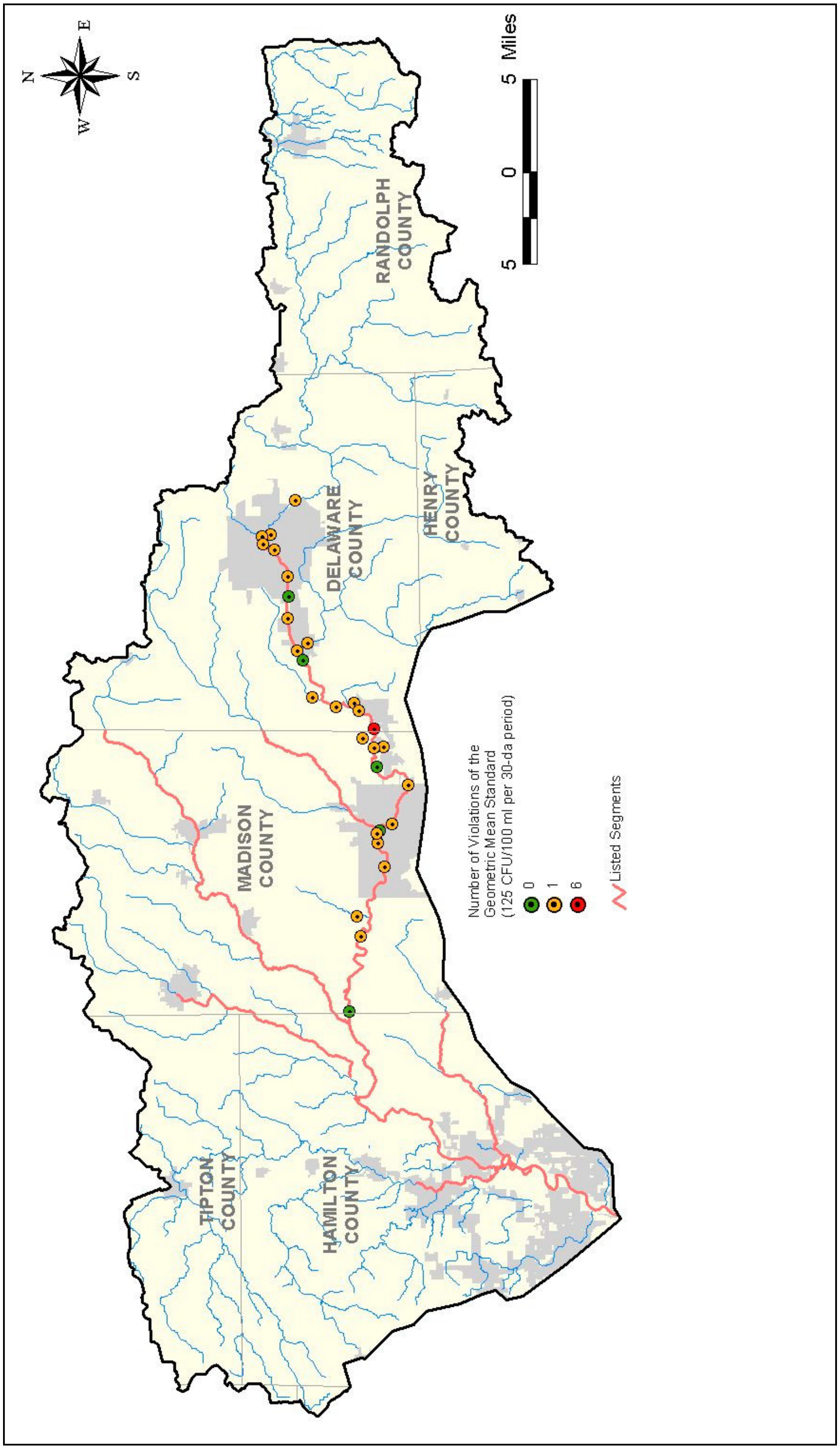

Figure 10. Violations of the geometric mean standard at IDEM stations with sufficient data to make a comparison.

3.1.2 Comparison with the Never Exceed Standard

The never exceed standard applies to all grab samples collected during the recreational season. Figure 11 presents the spatial distribution of violations to the standard within the watershed. All but seven stations exhibited at least one violation of the standard, with percentages ranging from 0 to 100 percent of samples collected. Conditions appear to be similar throughout the watershed, with both mainstem and tributary stations showing violations. All stations in the segment between Muncie and Anderson had at least one violation of the standard.

The frequency of violations at stations with a significant amount of data (more than 10 samples) was evaluated to provide a more comprehensive view of the extent of impairments. Table 6 identifies the four stations with the most observations. For these stations the frequency of violations ranges from 43 percent at the most upstream site to 69 percent of samples at the Tiger Drive station, just west of Muncie.

Table 6. Violations of the never exceed standard at selected stations.

Station	Location	Total Observations	Number of Violations	Frequency of Violations (percent)
WWU040-0004	State Route 13 Bridge in Perkinsville	98	50	51.0
WWU020-0005	Tiger Drive County Road bridge north of Yorktown High School	103	71	69.0
WWU030-0003	Anderson City Park near old water works dam site	104	56	53.8
WWU010-0001	Memorial Drive on the east edge of Muncie	108	47	43.5

The seasonal variation of *E. coli* concentrations can also be explored. Data from station WWU020-0005 (west of Muncie) were used to calculate monthly means for the data period 1991 through 2001. These means and respective error statistics are plotted in Figure 12 and indicate that all means for this station violate the "never-exceed" standard, with the highest concentrations occurring in May and the lowest in June. Figure 12 through Figure 15 show similar data for other stations in the watershed.

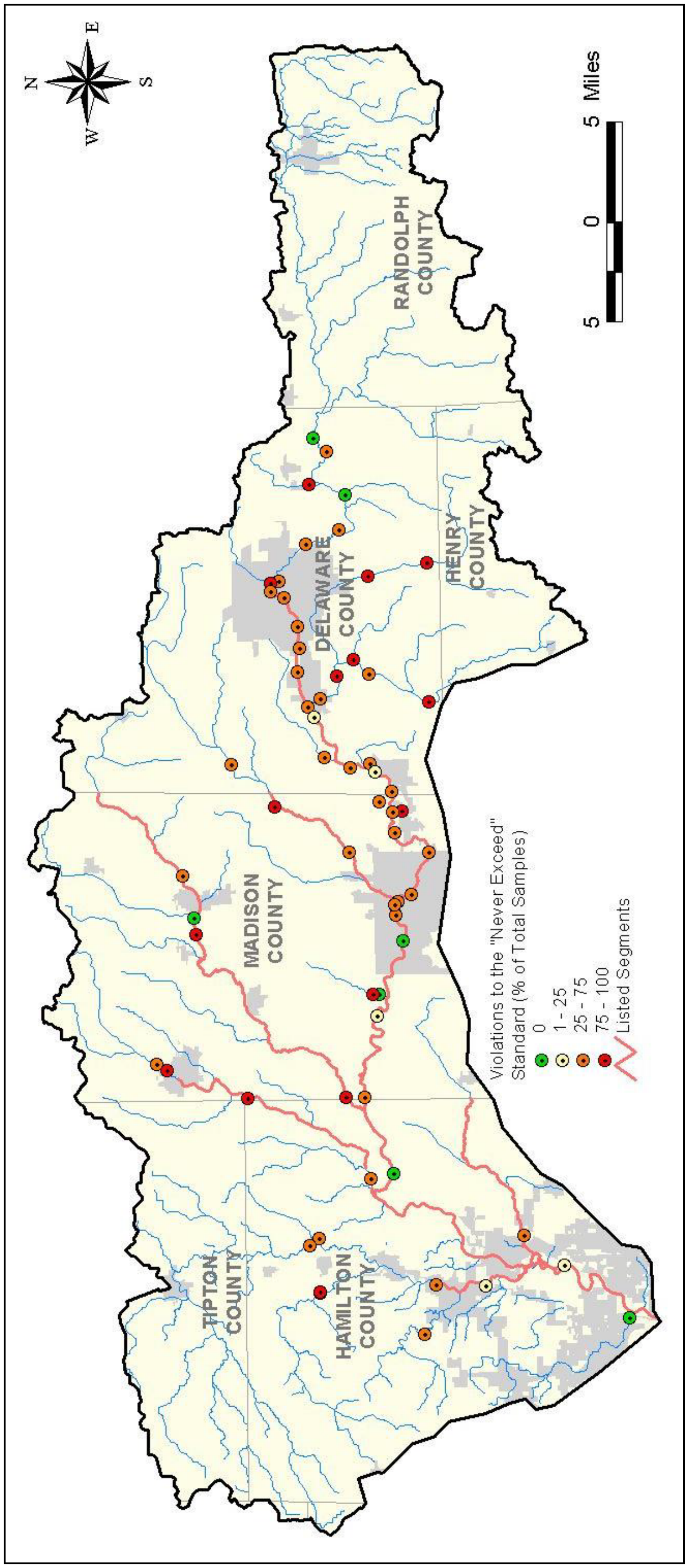

Figure 11. Violations of the never exceed standard.

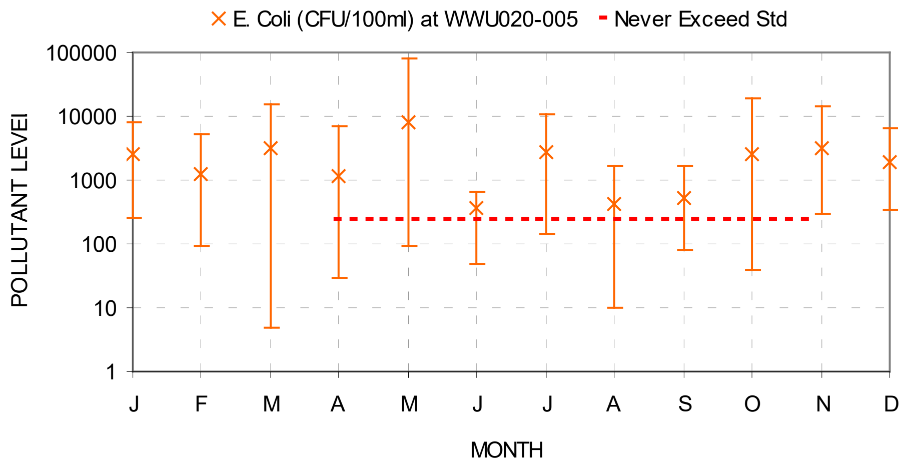

Figure 12. Minimum, maximum, and average *E. coli* concentrations for station WWU020-0005 (on the WFWR at the Tiger Drive bridge north of Yorktown High School). Data cover the period April 4, 1991, to May 21, 2001.

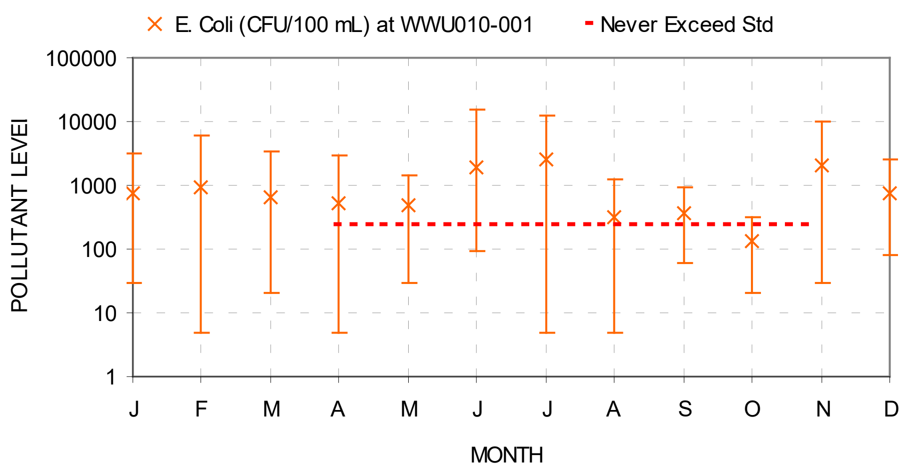

Figure 13. Minimum, maximum, and average *E. coli* concentrations for station WWU010-0001 (at the east edge of Muncie). Data cover the period January 8, 1991, to May 21, 2001.

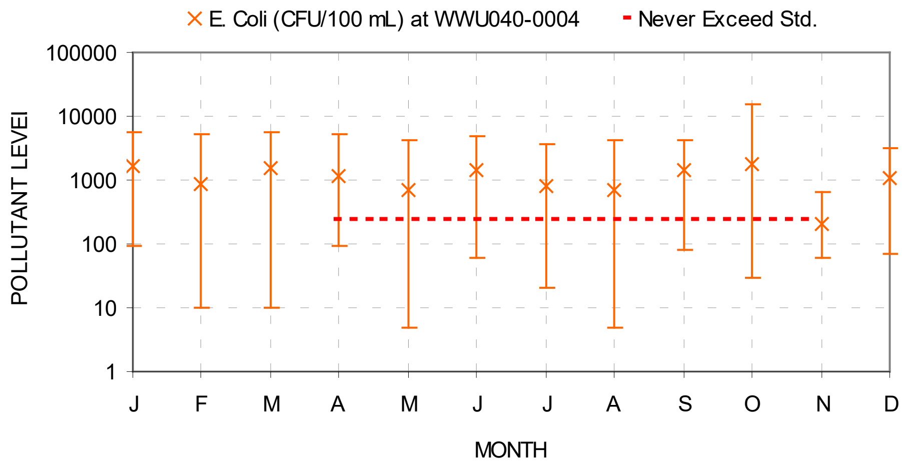

Figure 14. Minimum, maximum, and average *E. coli* concentrations for station WWU040-0004 (in Perkinsville). Data cover the period January 7, 1991, to May 22, 2001.

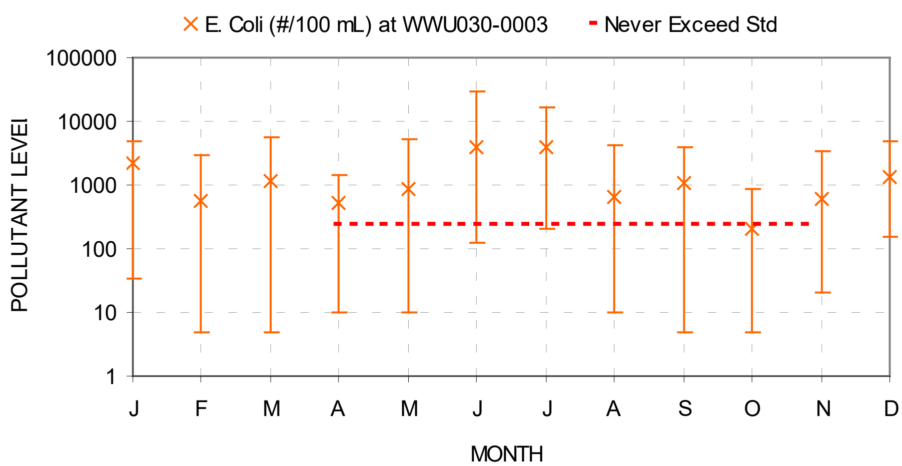

Figure 15. Minimum, maximum, and average *E. coli* concentrations for station WWU030-0003 (at the Anderson City Park). Data cover the period July 9, 1996, to May 22, 2001.

The comparisons of water quality data against the “never exceed” standard show widespread (both in terms of geography and season) violations. Therefore the analysis verifies impairment of the WFWR through Madison and Hamilton Counties.

4.0 SOURCE ASSESSMENT

This section summarizes the available information on significant sources of *E. coli* in the WFWR watershed. Estimating the magnitude of loadings from the various source categories is critical to the TMDL development process because it allows for focused implementation efforts.

4.1 Point Sources

The term point source refers to any discernible, confined and discrete conveyance, such as a pipe, ditch, channel, tunnel or conduit, by which pollutants are transported to a water body. It also includes vessels or other floating craft from which pollutants are or may be discharged. By law, the term "point source" also includes concentrated animal feeding operations, which are places where animals are confined and fed. By law, storm water runoff from certain areas is also considered a point source because the water is transported through a pipe or ditch.

Estimating the transport of *E. coli* into a surface water body from some point sources is a fairly straightforward matter. Both wastewater treatment plants (WWTP) and combined sewer overflows (CSOs) discharge though a constructed conveyance to a waterbody. Many of the organisms transported in this way are removed through treatment process, and permit limits are established to ensure that WWTPs meet water quality standards. However, in some instances failures or leaks may occur, or a wet weather event may create flows that exceed the capacity of the WWTP and therefore raw wastes bypass treatment and are discharged directly to streams. This can lead to a discharge of *E. coli* contaminated water exceeding the permitted limits into the river system.

4.1.1 Wastewater Treatment Plants

Treated municipal sewage is a point source of bacterial contamination. Not all human pathogens are removed or rendered harmless by treatment processes. Raw sewage entering the WWTP typically has a total coliform count of 10,000,000 to 1,000,000,000 (1E+7 to 1E+9)[A] counts per 100 mL) (Novotny et al., 1989). Associated with raw sewage are proportionally high concentrations of pathogenic bacteria, viruses and protozoans. A typical wastewater treatment plant reduces the total coliform count by about three orders of magnitude. The magnitude of reduction, however, varies with the treatment process employed.

Treatment of municipal waste is generally identified as primary, secondary, or advanced (previously called tertiary treatment), although the distinctions are somewhat arbitrary. Primary treatment involves removing suspended solids with screens and the use of gravity settling ponds followed by disinfection. Most protozoan cysts settle out in ponds after 11 days due to their size (Environmental Microbiology, 1997). Secondary treatment uses biological treatment to decompose organic matter to cell material and by-products, and the subsequent removal of cell matter, usually by gravity settling. Activated sludge processes involve the production of a mass of microorganisms capable of stabilizing waste aerobically. Secondary treatment by activated sludge typically reduces coliform bacteria concentrations by 90 to 99 percent.

Advanced treatment is any practice beyond secondary treatment and is very effective in destroying most pathogens. Advanced treatment can include filtration, coagulants, and disinfection. Disinfection is the most common treatment technique to combat waterborne diseases, and the most frequently used disinfectant is chlorine (USEPA, 2001). Chlorine kills many microbes, including most pathogens, except

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[A] Because the counts of *E. coli* can be so large, scientific notation is typically used to express them. Scientific notation is a method scientists have developed to express very large numbers. Scientific notation is based on powers of the base number 10. The number 10,000,000 is written as 1×10^7 or 1E+7.

protozoan cysts, which are resistant to chlorine. Other disinfectants used are ozone, ultraviolet light, and iodine.

As authorized by the Clean Water Act, the National Pollutant Discharge Elimination System (NPDES) permit program controls water pollution by regulating point sources that discharge pollutants into waters of the United States. WWTPs with active NPDES permits in the WFWR watershed are listed in Table 7 and shown in Figure 16. There are currently 21 facilities that discharge *E. coli* to the WFWR or one of its tributaries (IDEM, 2002). Relevant statistics for conduit flow and *E. coli* reported by the facilities in their discharge monitoring reports (DMR) were used during the development of the model and are summarized in Section 6. A lack of flow and/or *E. coli* data for some of the smallest facilities required the use of best professional judgment and literature values to obtain inputs to the model.

Table 7. Permitted facilities in the WFWR that discharge *E. coli*.

NPDES Permit Number	Description	County
IN0020044	Alexandria Municipal Sewage Treatment Plant	Alexandria
IN0032476	Anderson Municipal Sewage Treatment Plant	Anderson
IN0032719	Elwood Municipal Sewage Treatment Plant	Elwood
IN0059943	Gasamerica, Hinkle Creek Wastewater Treatment Plant	Bakers Corner
IN0051951	Hamilton Western Utilities Inc	Carmel
IN0038857	I-69 Auto Truck Plaza Inc.	Muncie
IN0037133	Interventions, Inc.	Gaston
IN0038407	Jackson Mobile Home Park	Muncie
IN0061301	Mount Pleasant Utilities	Yorktown
IN0025631	Muncie Sanitary District	Muncie
IN0031640	Perry Elementary School	Selma
IN0039471	Quiet Acres Mobile Home Park	Selma
IN0053627	Resting Wheels Mobile Home Park	Anderson
IN0025364	Royerton Elementary School	Muncie
IN0038598	Suburban Estates Mobile Home Park	Noblesville
IN0025526	Tall Timber Mobile Home Park	Noblesville
IN0021474	Tipton Municipal Sewage Treatment Plant	Tipton
IN0031135	Union Elementary and High School	Modoc
IN0025151	Wesdel Jr-Sr High School	Gaston
IN0021024	Winchester Municipal Sewage Treatment Plant	Winchester
IN0020150	Yorktown Municipal Sewage Treatment Plant	Yorktown

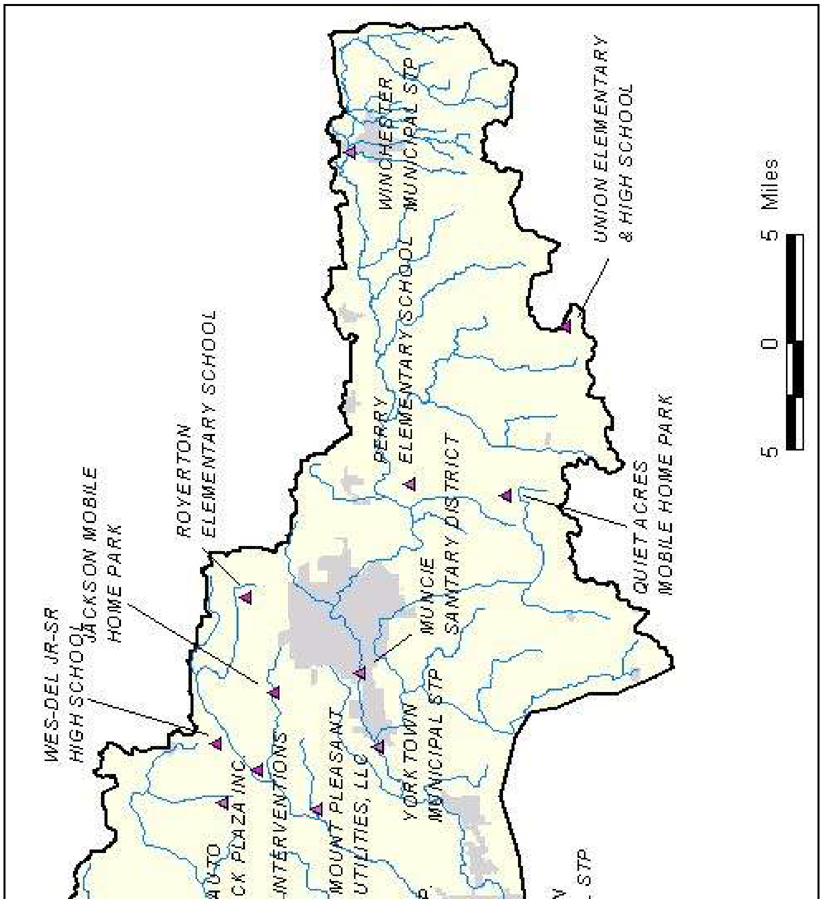

Figure 16. Location of permitted facilities in the WFWR watershed.

4.1.2 Combined Sewer Overflows

Combined sewer systems are sewers that are designed to collect rainwater runoff, domestic sewage, and industrial wastewater in the same pipe. Most of the time, combined sewer systems transport all of their wastewater to a sewage treatment plant, where it is treated and then discharged to a water body. During periods of heavy rainfall or snowmelt, however, the wastewater volume in a combined sewer system can exceed the capacity of the sewer system or treatment plant (Figure 17). For this reason, combined sewer systems are designed to overflow occasionally and discharge excess wastewater directly to nearby streams, rivers, or other water bodies. These overflows, called combined sewer overflows (CSOs), can contain not only storm water but also untreated human and industrial waste, toxic materials, and debris. Because they are associated with wet weather events, CSOs typically discharge for short periods of time at random intervals.

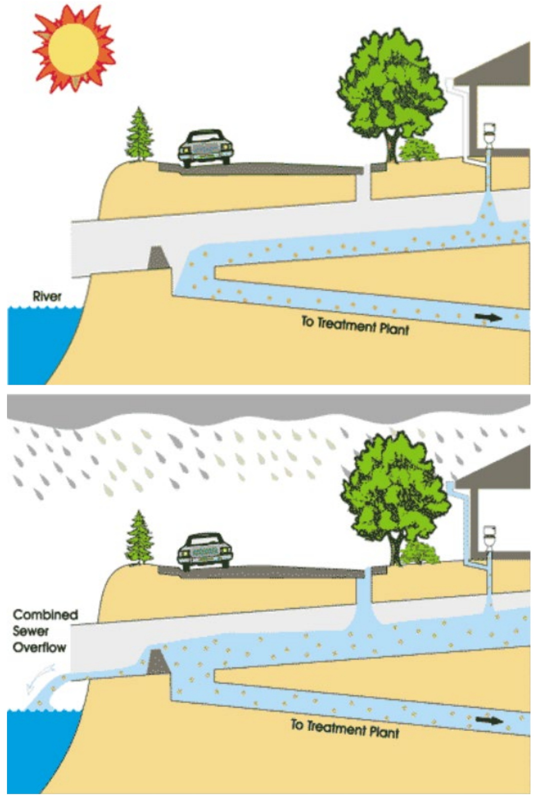

Figure 17. Schematic illustrating CSO discharges to a stream. During dry weather, sewage flows to the treatment plant. During wet weather, stormwater and sewage overflow into the stream.

Several communities in the WFWR watershed have combined sewer systems that are potential sources of *E. coli*. The cities of Muncie and Anderson provided useful information on the location of their CSOs, typical discharge volumes, and *E. coli* characteristics which were subsequently used in the modeling effort. Similar information for the CSOs in the other communities had to estimated based on the bypass data in their discharge monitoring reports (DMRs) and best professional judgment. The following equation was used to calculate loadings used as input to the model:

Daily Load (count/day) = Volume of Overflow on that Day (L/day) x 350,000 *E. coli* counts/100 mL x 1000 mL/1 L

Table 8. Communities with combined sewer systems in the WFWR watershed.

Community	Number of CSO Outfalls
Alexandria	4
Anderson	19
Elwood	14
Muncie	22
Noblesville	7
Tipton	7

4.1.3 Storm Water Phase II Communities

Storm water runoff can contribute *E. coli* bacteria and other pollutants to a waterbody. Material can collect on streets, rooftops, parking lots, sidewalks, yards and parks and then during a precipitation event this material can be flushed into gutters, drains, and culverts and be discharged into a waterbody.

The U.S. EPA developed rules in 1990 that established Phase I of the NPDES storm water program. The purpose of this program is to prevent harmful pollutants from being washed by storm water runoff into Municipal Separate Storm Sewer Systems (MS4s) (or from being dumped directly into the MS4) and then discharged into local waterbodies. Phase I of the program required operators of medium and large MS4s (those generally serving populations of 100,000 or greater) to implement a storm water management program as a means to control polluted discharges from MS4s. Only the City of Indianapolis met Phase I criteria within the State of Indiana.

Under Phase II, rules have been developed to regulate most MS4 entities (cities, towns, universities, colleges, correctional facilities, hospitals, conservancy districts, homeowner's associations and military bases) located within mapped urbanized areas, as delineated by the U.S. Census Bureau, or, for those MS4 areas outside of urbanized areas, serving an urban population greater than 7,000 people. The following entities within the WFWR watershed fall under the Phase II guidelines:

- Anderson
- Arcadia
- Muncie
- Carmel
- Fisher
- Noblesville
- Parker City
- Selma
- Yorktown
- Westfield
- Hamilton County
- Madison County
- Delaware County
- Randolph County

Operators of Phase II-designated small MS4s are required to apply for NPDES permit coverage and to implement storm water discharge management controls (known as “best management practices” (BMPs)).

Loads of *E. coli* from urban storm water sources in the WFWR watershed were quantified during the modeling phase of the TMDL and are summarized in Section 6.

4.1.4 Confined Feeding Operations

Indiana law defines a confined feeding operation as any livestock operation engaged in the confined feeding of at least 300 cattle, or 600 swine or sheep, or 30,000 fowl, such as chickens, ducks and other poultry. IDEM regulates these confined feeding operations under IC 13-18-10, the Confined Feeding Control Law. Draft rules regulating confined feeding operations were re-adopted by the Water Management Board on November 14, 2001 and became effective on March 10, 2002.

The animals raised in confined feeding operations produce manure that is stored in pits, lagoons, tanks and other storage devices. The manure is then applied to area fields as fertilizer. When stored and applied properly, this beneficial re-use of manure provides a natural source for crop nutrition. It also lessens the need for fuel and other natural resources that are used in the production of fertilizer. Confined feeding operations, however, can also pose environmental concerns, including the following:

- Manure can leak or spill from storage pits, lagoons, tanks, etc.
- Improper application of manure can contaminate surface or ground water
- Manure overapplication can adversely impact soil productivity.

Although confined feeding operations themselves are point sources, the runoff of applied manure is a nonpoint source. Therefore the discussion of confined feeding operations in the WFWR watershed is presented in Section 4.2.2.

4.2 Nonpoint Sources

Nonpoint sources of pathogens are much more difficult to identify and quantify than are point sources. In urban areas, nonpoint sources can include leaking or faulty septic systems, pet waste, storm water runoff (outside of Phase II communities), and other sources. In more rural areas, major contributors can be pasture land runoff, manure storage and spreading, and wildlife.

4.2.1 Septic Systems

Septic systems that are properly designed and maintained should not serve as a source of contamination to surface waters. However, septic systems do fail for a variety of reasons. Common soil-type limitations in central Indiana which contribute to failure are: seasonal water tables, compact glacial till, bedrock, coarse sand and gravel outwash and fragipan. When these septic systems fail hydraulically (surface breakouts) or hydrogeologically (inadequate soil filtration) there can be adverse effects to surface waters down gradient (Horsely and Witten, 1996). Another issue regarding certain septic systems in Indiana is that some are illegally connected to tile-drainage pipes in agricultural watersheds, providing a direct source of fecal matter to streams.

A survey of county health officials (Taylor et al., 1997) found that up to 80 percent of countywide septic systems were either failing or illegally connected to ditches or tile lines. In addition, most homes built prior to 1980 in rural areas do not have absorption fields.

Site-specific information on the location of areas with high septic vulnerability were only available for Hamilton County. Similar information for other parts of the watershed were based on the Census and soils data. The following assumptions were used to calculate loads from septic systems:

- Total number of septic systems (derived from US Census 1990 and 2000)
- Assume 2.5 percent of all systems are within 100 feet of a perennial stream (derived from a GIS analysis)
- Estimated population served by the septic systems (an average of 2.5 people per household, US Census 2000)
- An average daily discharge of 265 liters/person/day (Horsley and Witten, 1996)
- Septic effluent *E. coli* concentration of 1,000,000 (1E+6) counts/100 mL (Powelson and Mills, 2001)
- Average septic failure rate (including systems illegally connected to tile drains) of 40 percent (Taylor et al., 1997)

The calculations used to estimate *E. coli* loads from these systems is:

Daily Load (count/day) = Number of Systems within 100 Feet of a Stream x Percent Systems Failing x 2.5 Persons Served per System x 265 L/Person/Day x 1E+6 counts/100 mL x 1000 mL/L

The loading from septic systems is summarized in Section 6.

4.2.2 Agriculture

Lands used for agricultural purposes can be a source of *E. coli* bacteria. Runoff from pastures, livestock operations, improper land application of animal wastes, and livestock with access to waterbodies are all potential agricultural sources of *E. coli*.

Animals grazing in pasturelands deposit manure directly upon the land surface. Even though a pasture may be relatively large, and animal densities low, manure will often be concentrated near the feeding and watering areas in the field. These areas can quickly become barren of plant cover, increasing the possibility of contaminated runoff during a storm event. The occurrence and degree of *E. coli* loads from livestock are linked to temporally and spatially variable hydrologic factors, such as precipitation and runoff–except when manure is directly deposited into a waterbody (USEPA, 2001).

The application of manure that has been improperly composted can contribute bacteria that are conveyed into surface water during runoff events. Animal wastes must be handled, stored, utilized and/or disposed of in an efficient way to avoid this problem because bacterial content of animal waste varies with collection, storage and application methods. Manure in the WFWR watershed is applied to both cropland and pasture land.

Grazing animals, confined animal feeding operations and manure application are all potential sources of *E. coli* in the WFWR watershed. The number of livestock estimated to be in the watershed is derived from data available from the latest agricultural census (1997), which is shown in Table 9. The number of livestock in the watershed is based on either (1) site-specific estimates made by local U.S. Department of Agriculture officials or (2) the proportion of the county that overlaps the watershed.

The number of livestock associated with confined feeding operations in the WFWR watershed is shown in Table 10. Indiana law defines a confined feeding operation as any livestock operation engaged in the confined feeding of at least 300 cattle, or 600 swine or sheep, or 30,000 fowl, such as chickens, ducks and other poultry.

Table 9. Agricultural census information for the counties within the WFWR watershed (USDA, 1997).

County	Number of Beef Cows	Number of Milk Cows	Number of Other Cattle	Number of Total Cattle	Number of Hogs and Pigs	Number of Sheep and lambs
Delaware	1,591	569	2,697	4,857	24,502	506
Hamilton	1,480	294	2,493	4,267	24,010	900
Madison	2,299	104	4,082	6,485	26,111	785
Randolph	1,850	845	5,167	7,862	50,936	1,039
Tipton	NA	NA	--	2,004	56,821	445
Total	7,220	1,812	14,439	25,475	182,380	3,675

Table 10. Confined feeding operations in the WFWR watershed.

County	Number of Beef Cows	Number of Dairy Cows	Number of Veal	Number of Swine	Number of Chickens	Number of Turkeys	Number of Ducks	Number of Sheep
Delaware	0	0	0	30,958	0	0	0	0
Hamilton	50	50	0	19,657	0	0	0	0
Madison	905	1,200	0	28,549	0	0	0	0
Randolph	40	50	0	61,244	100,000	0	0	0
Tipton	1,150	0	0	41,504	288,000	0	0	0
Total	2,145	1,300	0	181,912	388,000	0	0	0

EPA's Fecal Load Estimation Spreadsheet Tool was modified for *E. coli* and used to estimate the amount of *E. coli* bacteria introduced directly to streams in the WFWR watershed, as well as estimate accumulation rates of *E. coli* bacteria on the land surface. The tool quantifies the *E. coli* bacteria component of waste generated by warm-blooded animals and distributes these quantities to streams and to the land surface based on land use type.

The following assumptions were made to calculate existing *E. coli* loads and accumulation rates. The assumptions are based on default values in EPA's Estimation Spreadsheet Tool complemented by discussions with local U.S. Department of Agriculture officials.

- Cattle manure is applied to both cropland and pasture. A maximum of 75 percent of the manure that is applied is available for runoff to account for infiltration, incorporation into soil, and *E. coli* die-off.
- When grazing, fifty percent of the cattle can be assumed to have direct access to streams. Therefore cattle waste is transported to surface waters through surface runoff or is contributed directly to streams.
- Cattle are either kept in feedlots or allowed to graze during specified months (depending on the season). We assumed that cattle graze 25 percent of the time in the winter and 75 percent of the time during other seasons. During grazing, cattle spend 0.15 percent of their time directly in the stream, which is equivalent to 9.8 hours over the course of one year.
- No manure is imported into the watershed.

Loads used in the model were calculated using the following equation:

Daily Load (count/day) = Animals with Access to Stream x Waste Production Rate (grams/animal/day) x *E. coli* Count in Waste (count/gram)

4.2.3 Wildlife

Wildlife living in the watershed can contribute *E. coli* into the waterbody. Many animals spend time in, or near, waterbodies. Raccoons, deer, waterfowl, beaver, muskrat, rabbits, squirrels, and other animals all create potential sources for fecal bacteria contamination. One method to differentiate between all of the potential sources is to use DNA fingerprinting of the *E. coli* bacteria present in the waterbody, and match the results with a library of *E. coli* strands. This allows an estimation of the amount of pollution coming from which species. However, this methodology is not an available resource to this TMDL because it is costly and requires the development of a location-specific DNA library. Another method, used in this TMDL, is to estimate the wildlife population and the amount of *E. coli* that each organism may contribute and model the results. For modeling purposes the geese, raccoons, and deer populations are assumed to represent the wildlife contribution since population data for other wildlife species in the watershed were not readily available.

Population estimates for geese, raccoons, and deer were made based on information available from the Indiana Department of Natural Resources. IDNR estimates that the Canada geese population has increased dramatically in the past two decades and is approaching estimates of 100,000 birds statewide (IDNR, 2003a). Canada geese readily use urban habitats around apartments, office complexes and golf courses and often spend significant time near water and wetlands. IDNR estimates that raccoon populations can approach one per acre under ideal conditions. Even in less favorable habitat, they still may occur at the rate of about one raccoon per 40 acres. They are most numerous where a good mixture of woodlands, cropland, and shallow water are found. The fertile farmland of central Indiana is therefore home for many raccoons. White-tailed deer occupy both forest and non-forest habitat types throughout Indiana. Population estimates are available from the Indiana Department of Natural Resources (IDNR, 2003b) and are approximately 10 per square mile.

Wildlife contributes to the potential impact of contaminated runoff from animal habitats, such as urban park areas, forest and cropland. Actual loads are dependent on hydrologic factors: the wildlife contribute bacteria to the land surface, where they accumulate and are available for runoff during storm events. Estimates of the impact potential associated with land use and wildlife can be made in terms of bacterial cell count per acre per year (count/ac/yr). Some assumptions are necessary to compute these estimates, including the following:

- Animal count, density and distribution
- *E. coli* content of animal waste (available from the literature)
- Daily waste production of each animal

The results of the estimates for the WFWR watershed are shown in Table 11 and these accumulation rates were used as inputs to the watershed model.

Table 11. Estimated loadings from wildlife in the WFWR watershed.

Animal	EC (count/animal/ day)	Animal Count (number/ac)	Accumulation Rate (count/ac/yr)	Impacted Land Use
Geese	5.38E+08[a]	0.0043[c]	2.31E+06	Wetlands, Urban Grasses
Deer	4.32E+09[b]	0.0167[c]	7.21E+07	Forest, Grassland, Pasture and Cropland
Raccoon	1.60E+08[b]	0.0300[c]	4.80E+06	Forest and Cropland

[a] Roll and Fujioka (1997)
[b] Estimate based on *E. coli* literature
[c] IDNR estimate

4.2.4 Domestic Pets

Domestic pets can be potential sources of *E. coli* much in the same way that wildlife can. Cats and dogs can contribute fecal material within the watershed that may accumulate and then be washed off during storm events. This source is more significant in heavily populated areas where large numbers of pets are to be found.

A 1999 national study reported that 39 percent of households own at least one dog and 32 percent own at least one cat. Applying these values to the number of households in the WFWR watershed (approximately 135,000) results in an estimate of 52,650 households with dogs and 43,200 households with cats. The national average number of dogs per dog-owning household is 1.41 and the national average number of cats per cat-owning household is 2.4. Using these values results in an estimate of 74,240 dogs and 103,700 cats in the WFWR watershed. The *E. coli* loads from these animals were captured in the modeling of loads from urban and residential areas.

5.0 TECHNICAL APPROACH

Establishing the relationship between the in-stream water quality targets and source loadings is a critical component of TMDL development. It allows for the evaluation of management options that will achieve the desired source load reductions. The link can be established through a number of techniques, ranging from qualitative assumptions based on sound scientific principles to sophisticated modeling techniques. In selecting an appropriate modeling platform to support management initiatives and development of TMDLs for the WFWR, the following criteria were considered and addressed (expanding on classification of Mao, 1992):

- Technical Criteria
- Regulatory Criteria
- User Criteria

Technical criteria refer to the model's simulation of the physical system in question, including watershed and/or stream characteristics/processes and constituents of interest. Regulatory criteria make up the constraints imposed by regulations, such as water quality standards or procedural protocol. User criteria comprise the operational or economical constraints imposed by the end-user and include factors such as hardware/software compatibility and financial resources.

To meet the objectives defined for the WFWR TMDL, it was determined that development of a comprehensive watershed model was necessary to represent the watershed. A watershed model is essentially a series of algorithms applied to watershed characteristics and meteorological data to simulate naturally occurring land-based processes over an extended period of time, including hydrology and pollutant transport. Many watershed models are also capable of simulating in-stream processes using the land-based calculations as input. The reasons that a comprehensive watershed model were determined to be necessary for this project including the following:

- Land use in the WFWR watershed includes row crop agriculture, older urban areas, and rapidly developing suburban areas. Different potential sources of pathogens are associated with each of these land use types (e.g., cattle, manure application, failing septic systems, combined sewer overflows, wastewater treatment plants, domestic pets) and each land use also has affected the natural hydrology of the watershed. The model must therefore be able to address a mixed land use watershed.
- Rainfall intensity and volume play an important role in pathogen loadings. The model must provide adequate time-step estimation of flow and not over-simplify storm events by only predicting monthly or seasonal output. It should provide accurate representation of rainfall events and resulting peak runoff.
- Different sources influence receiving waters in different ways and at different times (through different transport mechanisms). For example, surface runoff impacts waterbodies differently than direct stream contributions. The model must therefore be capable of simulating these transport mechanisms.
- Representation of the potential impacts from combined sewer overflows during significant rainfall events, and associated loads to the WFWR, had to be addressed.
- The selected model had to be capable of simulating daily *E. coli* counts so that applicable averaging periods and peak levels can be determined and compared to numeric targets. The selected model had to also be able to address seasonal variations in hydrology and water quality and critical conditions (i.e., periods when *E. coli* concentrations are at their highest) as required by TMDL regulations. Critical conditions in the WFWR watershed vary temporally and spatially and occur both when storm runoff contributes high loads of *E. coli* from wet weather sources, and when low flows concentrate loads from constant sources.

IDEM and its consultant selected the Hydrologic Simulation Program - FORTRAN (HSPF) to be used to support TMDL development in the WFWR watershed. HSPF is a comprehensive watershed and receiving water quality modeling framework that was originally developed in the mid-1970's. During the past several years it has been used to develop hundreds of USEPA-approved TMDLs and it is generally considered the most advanced hydrologic and watershed loading model available. USEPA has recently upgraded the coding of the HSPF model to increase its speed and flexibility. The new version of the model is called the Loading Simulation Program in C++ (LSPC). LSPC integrates a geographical information system (GIS), comprehensive data storage and management capabilities, the original HSPF algorithms, and a data analysis/post-processing system into a convenient PC-based windows interface that dictates no software requirements. LSPC was used for this project because it best matches the required technical, regulatory, and user criteria described above.

Development and application of the LSPC model to address the project objectives involved a number of important steps:

1. Watershed Segmentation
2. Configuration of Key Model Components
3. Model Calibration and Validation
4. Model Simulation for Existing Conditions and Scenarios

5.1 Watershed Segmentation

Watershed segmentation refers to the subdivision of the entire WFWR watershed into smaller, discrete subwatersheds for modeling and analysis. This subdivision was based on the stream networks and topographic variability, and secondarily on the locations of flow and water quality monitoring stations, consistency of hydrologic factors, land use consistency, and existing watershed boundaries (from previous studies or for management considerations). Figure 18 shows the resulting watershed segmentation.

5.2 Configuration of Key Model Components

Configuration of the model itself involved consideration of four major components: meteorological data, land use representation, hydrologic and pollutant representation, and waterbody representation. These components provide the basis for the model's ability to estimate flow and pollutant loadings. Meteorological data essentially drive the watershed model. Rainfall and other parameters are key inputs to LSPC's hydrologic algorithms. The land use representation provides the basis for distributing soils and pollutant loading characteristics throughout the basin. Hydrologic and pollutant representation refers to the LSPC modules or algorithms used to simulate hydrologic processes (e.g., surface runoff, evapotranspiration, and infiltration), and pollutant loading processes (primarily accumulation and washoff). Waterbody representation refers to LSPC modules or algorithms used to simulate flow and pollutant transport through streams and rivers.

Meteorological data are a critical component of the watershed model. Appropriate representation of precipitation, wind speed, potential evapotranspiration, cloud cover, temperature, and dew point are required to develop a valid model. These data provide necessary input to LSPC algorithms for hydrologic and water quality representation. Meteorological data were accessed from a number of sources in an effort to develop the most representative dataset for the WFWR watershed.

In general, hourly precipitation data are recommended for nonpoint source modeling. Therefore, only weather stations with hourly-recorded data were used in the modeling process. Long-term hourly precipitation data from three National Climatic Data Center (NCDC) weather stations located within or near the WFWR watershed were available and are shown in Figure 18. A review of the NCDC rainfall

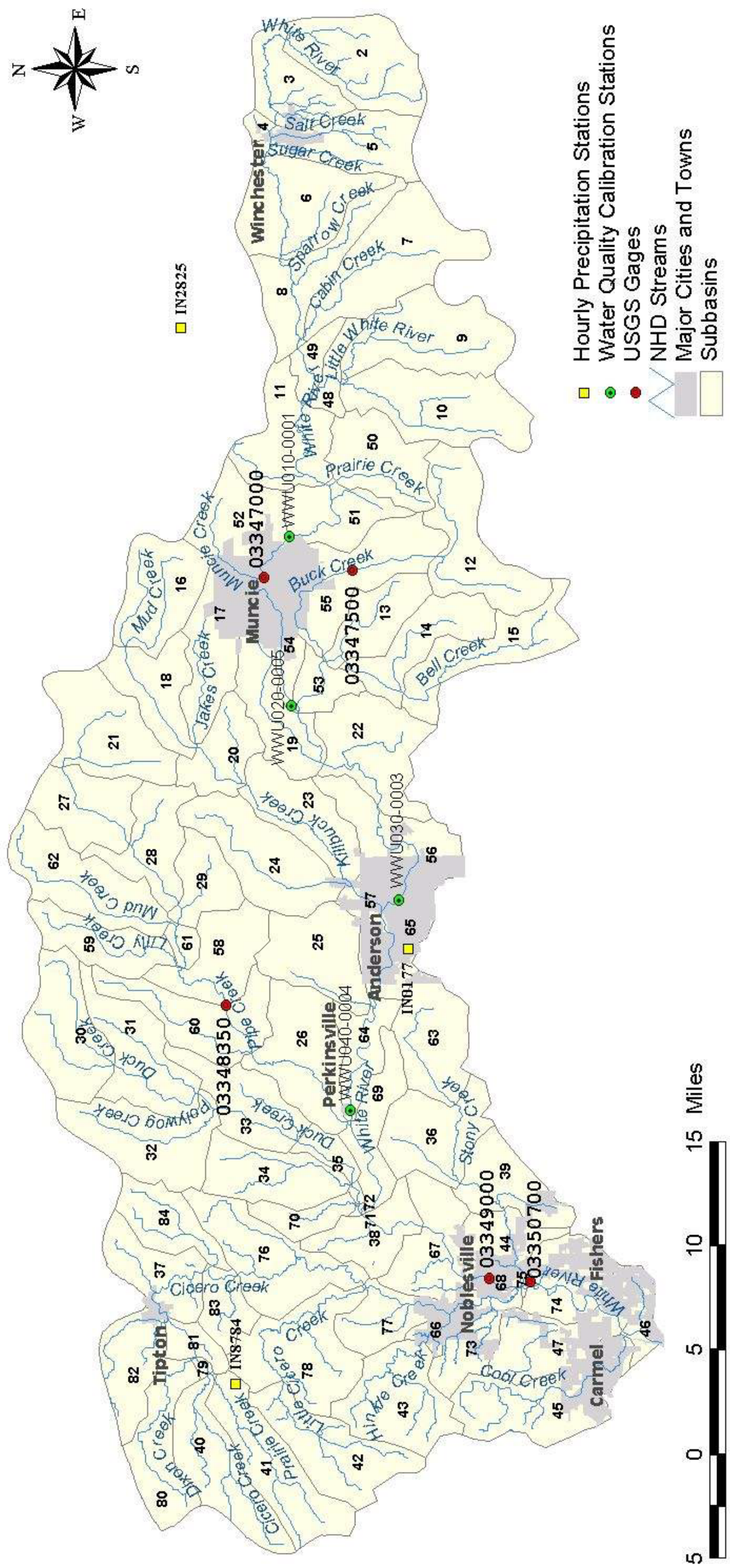

Figure 18. Watershed segmentation of the WFWR.

data showed that they sufficiently represented rainfall variability throughout the basin. Rainfall-runoff processes for each of the subwatersheds in the model were driven by rainfall data from the selected stations (e.g., subwatersheds in the closest proximity to the Anderson station were driven by this station's data).

The watershed model requires a basis for distributing hydrologic and pollutant loading parameters. This is necessary to appropriately represent hydrologic variability throughout the basin, which is influenced by land surface and subsurface characteristics. It is also necessary to represent variability in pollutant loading, which is highly correlated to land practices. The basis for this distribution was provided by a land use coverage of the entire watershed.

As discussed in the Data Report (Tetra Tech, 2002) land use GIS data has been collected from two sources: (1) USEPA/USGS MultiResolution Land Characteristics (MRLC) Consortium data and (2) estimates of updated land use data for growing areas of the watershed from local officials and census data. data. Eight separate land use categories were represented in the model (Table 12). Selection of these land use categories was based on the availability of monitoring data that can be used to characterize individual land use contributions and critical pathogen-contributing practices associated with different land uses.

Table 12. Modeling land use categories.

MRLC Land Use	Modeled Land Use Category
Row Crops	Cropland
Deciduous Forest	Forest
Evergreen Forest	Forest
Mixed Forest	Forest
Pasture/Hay	Pasture
Other Grasses	Pasture
Quarries/Strip Mines/Gravel Pits	Strip Mines
Low-Intensity Residential	Urban Pervious/Impervious
High-Intensity Commercial	Urban Pervious/Impervious
High-Intensity Residential	Urban Pervious/Impervious
Open Water	Water
Woody Wetlands	Wetlands
Emergent Herbaceous Wetlands	Wetlands

LSPC algorithms require that land use categories be divided into separate pervious and impervious land units for modeling. This division was made for the appropriate land uses (primarily urban and agricultural), to represent impervious and pervious areas separately. The division was based on typical impervious percentages associated with different land use types from the Soil Conservation Service's TR-55 Manual. LSPC model algorithms simulating major hydrologic and pollutant loading processes were then applied to each pervious and impervious land unit.

The LSPC PWATER (water budget simulation for pervious land segments) and IWATER (water budget simulation for impervious land segments) modules, which are identical to those in HSPF, were used to represent hydrology for all pervious and impervious land units (Bicknell et al., 1996). Designation of key hydrologic parameters in the PWATER and IWATER modules of LSPC were required. These parameters are associated with infiltration, groundwater flow, and overland flow. The STATSGO Soils Database served as a starting point for designation of infiltration and groundwater flow parameters. For parameter values not easily derived from STATSGO, documentation on past HSPF applications were accessed. Starting values were refined through the hydrologic calibration process (described later in this section).

Pollutant loading processes for *E. coli* were represented for each land unit using the LSPC PQUAL (simulation of quality constituents for pervious land segments) and IQUAL (simulation of quality constituents for impervious land segments) modules, which are identical to those in HSPF. These modules simulate the accumulation of pollutants during dry periods and the washoff of pollutants during storm events. Starting values for parameters relating to land-use-specific accumulation rates and buildup limits were derived from the literature. These starting values were refined through the water quality calibration process.

Modeling the entire WFWR watershed required routing flow and pollutants through numerous stream networks. These stream networks connect all of the subwatersheds represented in the watershed model. Routing required development of rating curves for major streams in the networks, in order for the model to simulate hydraulic processes. Hydraulic formulations typically estimate in-stream flow, water depth, and velocity using continuity and momentum equations. Streams were assumed to be completely-mixed, one-dimensional segments with a trapezoidal cross-section. The rating curves consisted of a representative depth-outflow-volume-surface area relationship. In-stream flow calculations were made using the HYDR (hydraulic behavior simulation) module in LSPC, which is identical to the HYDR module in HSPF. In-stream pollutant transport was performed using the ADCALC (advective calculations for constituents) and GQUAL (generalized quality constituent simulation) modules.

5.3 Model Calibration and Validation

After initially configuring the WFWR watershed model, model calibration and validation were performed. Model calibration and validation covered the period 1990 to 1999. This length of time is considered adequate to very good for establishing the model baseline because it covers a period of both wet and dry years. Calibration refers to the adjustment or fine-tuning of modeling parameters to reproduce observations. The calibration was performed for different LSPC modules at multiple locations throughout the watershed. This approach ensured that heterogeneities were accurately represented. The model validation was performed to test the calibrated parameters at different locations or for different time periods, without further adjustment.

Calibration and validation were completed by comparing time-series model results to monitoring data. Output from the watershed model were in the form of hourly/daily average flow and hourly/daily average *E. coli* counts for each of the subwatersheds. Flow monitoring data are available at USGS flow gauging stations located throughout the watershed, while water quality monitoring data are available at fewer locations.

Hydrology was the first model component calibrated, and it involved a comparison of observed data from in-stream USGS flow gauging stations to modeled in-stream flow and an adjustment of key hydrologic parameters. Examples of the results of the calibration are shown in Figure 19 . Error statistics are shown in Table 13. More detailed results of the calibration are shown in Appendix B.

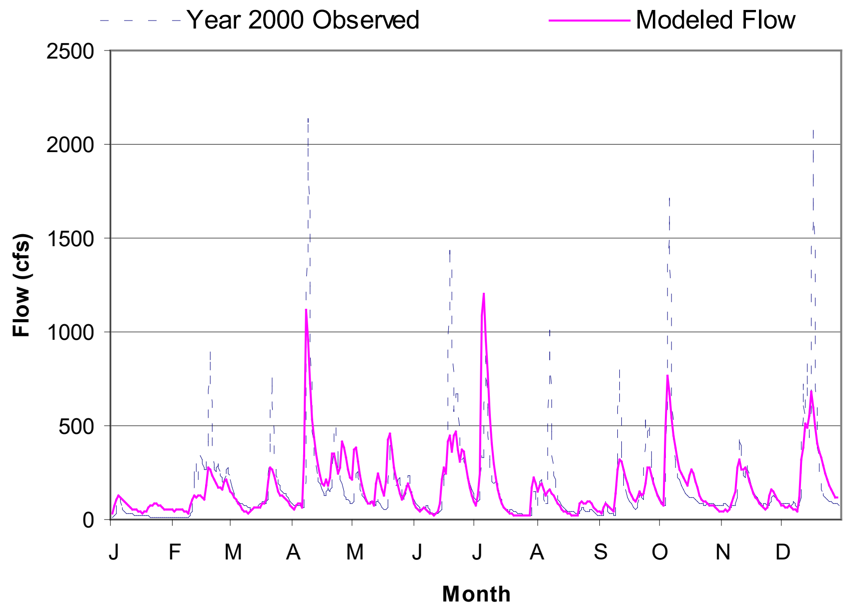

Figure 19. Example of hydrologic calibration plot for the USGS gage in Muncie.

Table 13. Results of WFWR hydrologic modeling for the period 1990 to 2000 at the USGS gage in Muncie.

Total Simulated In-stream Flow:	**134.69**	Total Observed In-stream Flow:	**138.59**
Total of Highest 10% flows:	**66.60**	Total of Observed Highest 10% Flows:	**74.72**
Total of Lowest 50% flows:	**12.62**	Total of Observed Lowest 50% Flows:	**13.13**
Simulated Summer Flow Volume (months 7-9):	**20.28**	Observed Summer Flow Volume (7-9):	**17.57**
Simulated Fall Flow Volume (months 10-12):	**29.70**	Observed Fall Flow Volume (10-12):	**25.85**
Simulated Winter Flow Volume (months 1-3):	**41.82**	Observed Winter Flow Volume (1-3):	**48.85**
Simulated Spring Flow Volume (months 4-6):	**42.88**	Observed Spring Flow Volume (4-6):	**46.32**
Total Simulated Storm Volume:	**128.77**	Total Observed Storm Volume:	**131.52**
Simulated Summer Storm Volume (7-9):	**18.79**	Observed Summer Storm Volume (7-9):	**15.81**
Errors (Simulated-Observed)		*Recommended Criteria*	
Error in total volume:	**-2.90**	10	
Error in 50% lowest flows:	**-4.00**	10	
Error in 10% highest flows:	**-12.19**	15	
Seasonal volume error - Summer:	**13.39**	30	
Seasonal volume error - Fall:	**12.98**	30	
Seasonal volume error - Winter:	**-16.80**	30	
Seasonal volume error - Spring:	**-8.04**	30	
Error in storm volumes:	**-2.14**	20	
Error in summer storm volumes:	**15.88**	50	

Key considerations in the hydrology calibration included the overall water balance, the high-flow-low-flow distribution, storm flows, and seasonal variation. Two criteria for goodness of fit were used for calibration: graphical comparison and the relative error method. Graphical comparisons are extremely useful for judging the results of model calibration; time-variable plots of observed versus modeled flow provided insight into the model's representation of storm hydrographs, baseflow recession, time distributions, and other pertinent factors often overlooked by statistical comparisons. The model's accuracy was primarily assessed through interpretation of the time-variable plots. The relative error method was used to support the goodness of fit evaluation through a quantitative comparison. A small relative error indicates a better goodness of fit for calibration.

After hydrology was sufficiently calibrated, water quality calibration was performed. Modeled versus observed in-stream concentrations were directly compared during model calibration. The water quality calibration consisted of executing the watershed model, comparing water quality time series output to available water quality observation data, and adjusting pollutant loading and in-stream water quality parameters within a reasonable range. The objective was to best simulate low flow, mean flow, and storm peaks at water quality monitoring stations representative of different regions of the basin (and different land uses, in particular).

Adjusted water quality parameters included pollutant buildup, washoff, and subsurface concentrations. Estimated loads from some of the source categories also had to be adjusted. For example, initial loads from septic systems were determined to be too high in some subwatersheds and were adjusted based on the modeling results.

Water quality calibration adequacy was primarily assessed through review of time-series plots. Looking at a time series plot of modeled versus observed data provides more insight into the nature of the system and is more useful in water quality calibration than a statistical comparison. Flow (or rainfall) and water quality were compared simultaneously, and thus provided insight into conditions during the monitoring period (dry period versus storm event). The response of the model to storm events was studied and compared to observations. Ensuring that the storm events were represented within the range of the data over time is the most practical and meaningful means of assessing the quality of a calibration. An example water quality calibration plot is shown in Figure 20 and additional plots are shown in Appendix B.

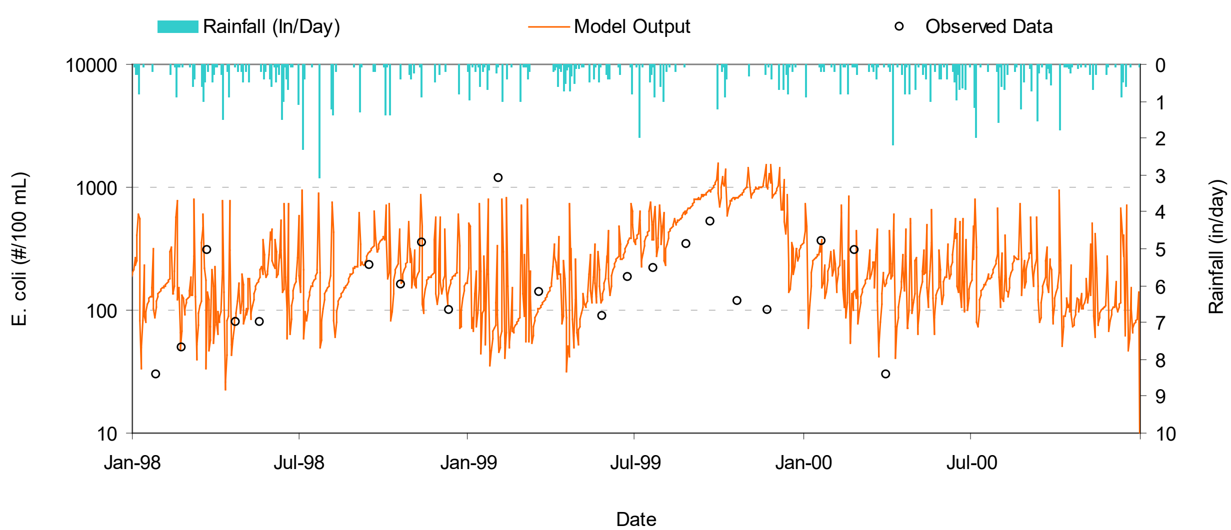

Figure 20. Comparison of modeled to observed predicted *E. coli* at station WWU010-0001 (east edge of Muncie) for the period January 1, 1998, to December 31, 2000.

6.0 ALLOCATIONS

A TMDL is the total amount of a pollutant that can be assimilated by the receiving water while still achieving water quality standards. TMDLs can be expressed in terms of mass per time or by other appropriate measures. TMDLs are composed of the sum of individual wasteload allocations (WLAs) for point sources and load allocations (LAs) for nonpoint sources and natural background levels. In addition, the TMDL must include a margin of safety (MOS), either implicitly or explicitly, that accounts for the uncertainty in the relationship between pollutant loads and the quality of the receiving waterbody. Conceptually, this is defined by the equation:

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

To develop *E. coli* TMDLs for each of the listed waterbodies in the WFWR watershed, the following approach was taken:

- Simulate baseline conditions
- Assess source loading alternatives
- Determine the TMDL and source allocations

Components of the TMDLs for *E. coli* are presented in terms of organism counts per time in this report. The counts can be divided by the corresponding flows to obtain counts/100 mL.

6.1 Baseline Conditions

The calibrated model provided the basis for performing the allocation analysis and was first used to project baseline conditions. Baseline conditions represent existing nonpoint source loading conditions and permitted point source discharge conditions. The baseline conditions allow for an evaluation of in-stream water quality under the "worst currently allowable" scenario.

Permitted conditions for the various NPDES facilities in the watershed were simulated at permitted levels (water quality standards) of daily 125 *E. coli* counts/100 mL (constant) and at design flows for wastewater treatment plants. Loads from combined sewer overflows were set to zero.

Average recreation season counts associated with baseline conditions were calculated using the predicted in-stream counts of *E. coli* for the impaired waterbodies. The total counts over the recreation season (April to October) were calculated by summing the predicted flow multiplied by the counts. This is described by the following expression:

Counts (organisms/recreation season) = Σ(Daily Count (count/100 mL) x Daily Flow (cfs) x 28.3 liter/1cfs x 3600 seconds/day x 213 days between April 1 and October 31

These counts, averaged over the simulation years and classified into the appropriate source categories, are reported under the baseline columns of Table 14. The same information is presented graphically in Figure 21.

Table 14. Baseline loads at each of the various TMDL assessment points for the period April 1 to October 31.

TMDL Assessment Point	Loading from In-stream Cattle (counts/rec season)	Loading from WWTPs (counts/rec season)	Loading from Septic Systems (counts/rec season)	Loading from Other Nonpoint Sources[1] (counts/rec season)	Loading from Combined Sewer Overflows (counts/rec season)
WWU010-0001 Memorial Drive, E. Edge, Muncie	3.52E+12	1.34E+12	1.30E+13	3.36E+14	0
WWU030-0003 Anderson City Park	2.55E+13	2.65E+13	1.44E+14	4.74E+14	0
WWU040-0004 Perkinsville	2.91E+13	4.80E+13	1.64E+14	4.95E+14	0
Hamilton-Marion County Line	1.89E+14	5.95E+13	1.58E+15	5.74E+15	0

[1]Includes loading from all remaining land uses (barren, urban, cropland, pasture, forest, and wetlands).

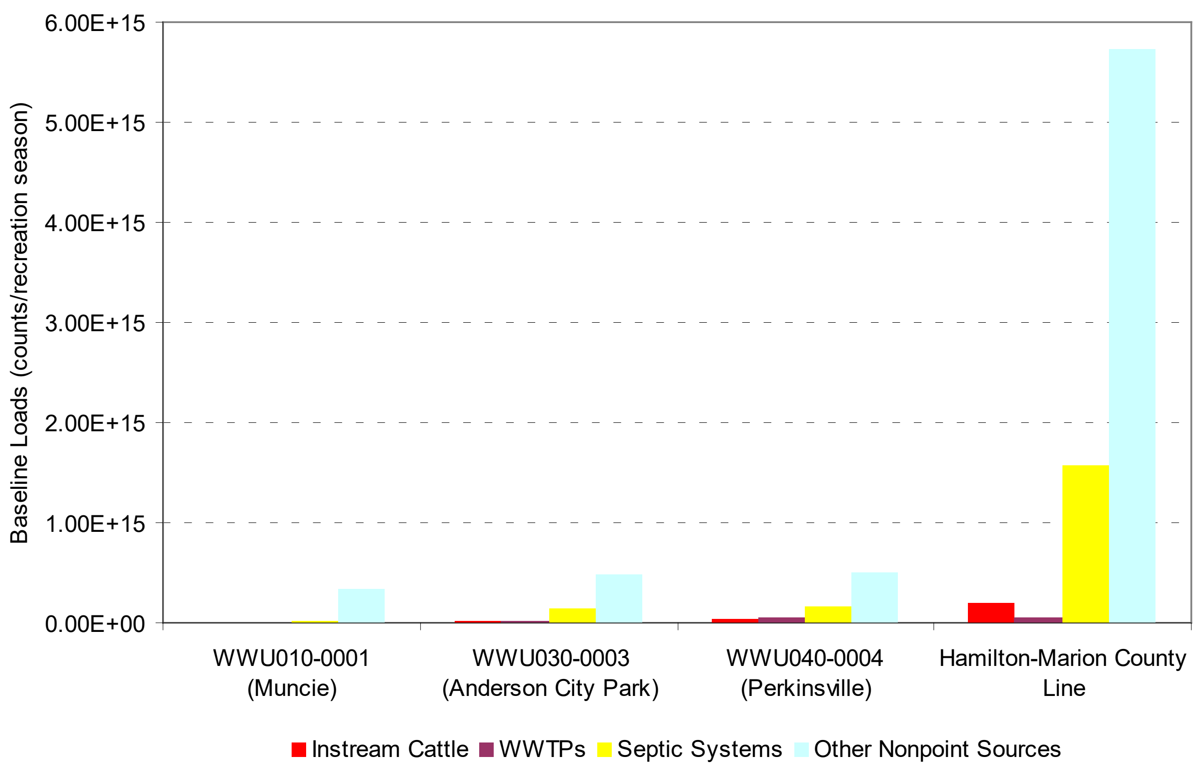

Figure 21. Baseline loads at each of the various TMDL assessment points.

6.2 TMDLs and Source Allocations

Simulation of baseline conditions provided the basis for evaluating stream response to variations in source contributions. The simulations revealed that, once loads from CSOs were removed, stormwater runoff form other nonpoint sources and septic systems are the dominant sources of *E. coli*. These results facilitated developing an effective allocation strategy.

A top-down methodology was followed to develop the TMDLs and allocate loads to sources. Impaired headwaters were analyzed first, because their impact had an effect on downstream water quality. Loads were reduced from applicable sources for these waterbodies, and TMDLs were developed. Model results from the selected successful scenarios were then routed through downstream waterbodies. Therefore, when TMDLs were developed for downstream impaired waterbodies, upstream loads were representing conditions meeting water quality criteria. Using this method, contributions from all sources were weighted equitably.

Table 15. Cumulative allocated loadings from each source at the impaired water quality stations for the period April 1 to October 31.

TMDL Assessment Point	Loading from In-stream Cattle (counts/rec season)	Loading from WWTPs (counts/rec season)	Loading from Septic Systems (counts/rec season)	Loading from Other Nonpoint Sources[1] (counts/rec season)
WWU010-0001 Memorial Drive, E. Edge, Muncie (Sub 51)	1.28E+12	1.34E+12	4.74E+12	2.45E+13
WWU030-0003 Anderson City Park	1.86E+12	2.65E+13	1.05E+13	2.11E+13
WWU040-0004 Perkinsville	2.22E+12	4.80E+13	1.25E+13	2.63E+13
Hamilton-Marion County Line (46)	1.17E+13	5.95E+13	9.79E+13	2.58E+12

[1]Includes loading from all remaining land uses (barren, urban, cropland, pasture, forest, and wetlands).

6.3 Wasteload Allocations (WLAs)

WLAs were calculated for all permitted facilities and are presented in Table 16. The WLAs are presented on a recreation-season basis and were developed to meet TMDL targets under a range of conditions observed throughout the recreation season. The WLAs developed for this TMDL do not result in a decrease in the current permitted load.

6.4 Load Allocations (LAs)

LAs were made for the following dominant nonpoint source categories:

- Stormwater Runoff
- Septic Systems
- Livestock

The LAs are summarized in Table 16. The LAs are presented on a recreation-season basis and were developed to meet TMDL targets under a range of conditions observed throughout the recreation season. The necessary reductions are very large because of the need to meet the "never exceed" portion of the water quality standards (i.e., the model was run with reduced loads until the predicted *E. coli* counts were never greater than 235/100 mL).

Table 16. Allocations for the WFWR *E. coli* TMDL for the period April 1 to October 31.

TMDL Assessment Point	Baseline Point Source Loads (counts/ rec season)	WLAs (counts/ rec season)	Baseline Nonpoint Source Loads (counts /rec season)	LAs (counts/ rec season)	TMDL = WLA + LA + MOS (counts/ rec season)	Percent Reduction
WWU010-0001 Memorial Drive, E. Edge, Muncie	1.34E+12	1.34E+12	3.53E+14	3.05E+13	3.19E+13	91%
WWU030-0003 Anderson City Park	2.65E+13	2.65E+13	6.43E+14	3.35E+13	6.00E+13	91%
WWU040-0004 Perkinsville	4.80E+13	4.80E+13	6.88E+14	4.10E+13	8.90E+13	88%
Hamilton-Marion County Line	5.95E+13	5.95E+13	7.51E+15	1.12E+14	1.72E+14	98%

7.0 MARGIN OF SAFETY

Section 303(d) of the Clean Water Act and EPA's regulations at 40 CFR 130.7 require that "TMDLs shall be established at levels necessary to attain and maintain the applicable narrative and numeric water quality standards with seasonal variations and a margin of safety which takes into account any lack of knowledge concerning the relationship between limitations and water quality." The margin of safety can either be implicitly incorporated into conservative assumptions used to develop the TMDL or added as a separate explicit component of the TMDL (USEPA, 1991).

A 5 percent explicit MOS was incorporated for the TMDLs by basing the allocation decisions on achieving the numeric criteria minus 5 percent (e.g., the allocation decisions were based on not exceeding 223 counts/100 mL rather than 235 counts/100 mL). A relatively low MOS was chosen because of the low error associated with the modeling. The model is reducing the uncertainty associated with the relationship between load limitations and water quality

8.0 SEASONAL VARIATION

A TMDL must consider seasonal variation in the derivation of the allocation. By using continuous simulation (modeling over a period of several years), seasonal variations in hydrologic conditions and source loadings were inherently taken into account. The *E. coli* counts simulated on a daily time step by the model were compared to TMDL targets and an allocation that would meet these targets throughout the recreation season was developed.

9.0 PUBLIC PARTICIPATION

Public participation is an important and required component of the TMDL development process. The following public meetings have been held in the watershed to discuss this project:

- A **Kickoff Meeting** was held at the Anderson Public Library on October 1, 2002 during which IDEM described the TMDL Program and Tetra Tech provided a summary of the data that had been gathered to that point.
- A **Source Assessment and Modeling Framework Meeting** was held at the Anderson Public Library on May 20, 2003 during which Tetra Tech described the results of the effort to quantify potential sources of *E. coli* in the watershed and described the modeling framework that was to be used to develop the TMDL.

A final meeting will be held on December 4, 2003 to present the draft TMDL report. IDEM will also be accepting written comments on the draft report for a period of 30 days.

10.0 IMPLEMENTATION

The analysis conducted for this TMDL indicates the need for significant reductions in *E. coli* loading to meet water quality standards. The most significant sources of *E. coli* include CSOs, nonpoint source runoff, livestock, and failing septic systems. Indiana already has a strategy for bringing CSOs into compliance by 2005. The strategy is being incorporated into the individual municipal wastewater treatment plant NPDES permits of the affected communities, including those in the WFWR watershed.

Reduction of loads from the other nonpoint sources will require a voluntary approach and the implementation of a variety of best management practices (BMPs). Many efforts in the watershed are already underway and future activities should build on this foundation. Among the BMPs that should be considered are the following:

Septic System Outreach Program. Many homeowners do not realize they have a failing septic system, whereas others may know, but choose not to remedy the problem because of cost. One recommendation is to initiate an outreach program to educate residents about septic systems, and in some cases provide funding to help fix or replace failing systems. The components of an example outreach program are illustrated below:

- Make homeowners aware of the age, location, type, capacity, and condition of their septic system
- Teach homeowners to recognize a failing septic system.
- Teach homeowners about proper septic system maintenance.
- Provide information about different types of septic systems, and their costs, advantages, and disadvantages.
- Provide consultation and inspection services to homeowners.
- Teach homeowners about water quality concerns in their watershed.

Septic System Maintenance. In addition to conducting a public outreach campaign, an effort should be made to identify and repair failing systems. In some cases extremely old systems might need to be replaced. Systems located in close proximity to the WFWR or tributaries should be targeted first. This effort should be coordinated by the local health departments. Homeowners should also be required to pump out or inspect their septic tanks on a regular schedule. Septic tanks should be pumped when the solids in the tank accumulate to a point where the effluent no longer has enough time to settle and clarify.

Livestock Exclusion. An effort should be made to exclude livestock from riparian areas. This will reduce the quantity of pathogens that are directly deposited into surface waters. It will also allow the stream buffer to become more vegetated and stable, which can reduce the risk of streambank erosion, provide shade and habitat for aquatic species, and filter nutrients and sediments from runoff. The largest operations located in closest proximity to the WFWR or major tributaries should be targeted first. Livestock are usually excluded by fencing. Several alternatives are available for providing water to animals that can no longer obtain it directly from the stream. These include pipelines, ponds, wells, troughs, and tanks. Options are also available for providing livestock stream crossings and alternative shade areas.

Structural Urban BMPs. The main goal of structural urban BMPs is to increase the amount of water infiltration and reduce the amount of runoff. By doing this, stormwater and pollutants carried by stormwater are prevented from directly entering a stream. Some common structural urban BMPs are listed below:

- Infiltration (or detention) basin
- Infiltration trench
- Dry or wet ponds
- Porous pavement
- Constructed wetlands

The premise of each of these BMPs is to route stormwater to a holding basin so that more water can infiltrate and suspended solids can settle out of the water. The effectiveness of each of these BMPs depends on the retention time, the size (volume of the basin), flow, and type of soils. Pollutant removal effectiveness also depends on these factors.

These and other appropriate BMPs should be identified and discussed by the key stakeholders in the watershed to develop an appropriate implementation strategy. A locally led group should provide guidance and direction for implementation activities needed to achieve the necessary load reductions and should develop a schedule and funding opportunities.

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