Bacteria TMDLs for the Goose Creek Watershed

Submitted by

Virginia Department of Environmental Quality

Virginia Department of Conservation and Recreation

Prepared by

Interstate Commission on the Potomac River Basin

January 28, 2003

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EXECUTIVE SUMMARY

Background

Goose Creek and its tributaries are part of the Potomac River Basin (USGS Hydrologic Unit Code 02070008). The Goose Creek watershed covers 386 square miles in Loudoun and Fauquier Counties on the edge of the Washington D. C. metropolitan area. Most of the watershed remains rural although areas around Leesburg are rapidly being developed. Goose Creek lies in the heart of Virginia's horse country, and many of the state's wineries make their home there, but beef cattle production remains the dominant agricultural activity. The City of Fairfax operates a water supply reservoir and intake on Goose Creek and maintains a second water supply reservoir on a small tributary. Goose Creek has also been designated as a scenic river under Virginia's Scenic River Act.

Bacteria Impairments

Water quality samples collected in the Goose Creek watershed by the Virginia Department of Environmental Quality (VADEQ) from 1992 through 2001 had fecal coliform bacteria concentrations which violated Virginia's instantaneous water quality standard of 1,000 cfu/ 100 mL more than 10% of the time at seven monitoring stations. Based on these violations, VADEQ has assessed the lower mainstem of Goose Creek and portions of the following six tributaries as impaired by fecal coliform bacteria: Cromwells Run, Beaverdam Creek, the North Fork of Goose Creek, Little River, Sycolin Creek, and the South Fork of Sycolin Creek. These waterbodies were placed on Virginia's 303(d) Total Maximum Daily Load Priority List and Report (VADEQ, 1996, 1998 and 2002).

Total Maximum Daily Loads (TMDLs) were developed for the seven waterbodies impaired by fecal coliform bacteria in the Goose Creek watershed. The TMDLs were designed to meet the new Virginia water quality standard for fecal coliform bacteria and the new standard for *E. coli* bacteria. Under the new standard for fecal coliform bacteria, concentrations cannot exceed a geometric mean of 200 fecal coliform bacteria per 100 mL of water for two or more samples over a calendar month nor can more than 10% of the total samples taken during any calendar month exceed 400 fecal coliform bacteria per 100 mL of water. Under the new *E. coli* standards, the geometric mean of two or more samples taken during any calendar month cannot exceed 126 cfu/100mL, and no sample can exceed the instantaneous single sample maximum of 235 cfu/100mL.

Sources of Bacteria

Bacteria, including fecal coliform and *E. coli*, originate from both point and nonpoint sources in the watershed. There are ten point sources in the watershed, primarily wastewater treatment plants, and 21 general permits covering residences and small businesses; their contribution to the total bacteria load is minor in all of the impaired stream segments. Nonpoint sources include failing septic systems, biosolids applications, pets, livestock, and wildlife. Fecal coliform bacteria in wildlife waste from deer, geese, ducks, turkey, beaver, raccoon, and muskrat were quantified. The dominant nonpoint source of fecal coliform bacteria in the Goose Creek watershed is livestock waste deposited on pasture. Fecal waste deposited by cattle directly into streams is also a significant source of bacteria. Management practices were taken into account in determining the fate of livestock waste from beef and dairy cattle.

Modeling

The Hydrological Simulation Program—Fortran (HSPF) was used to simulate the fate and transport of fecal coliform bacteria in the Goose Creek watershed. The watershed was divided into 25 subwatersheds. Six land uses were represented in the model: forest, cropland, pasture, pervious developed land, barren impervious land, and impervious developed land.

The hydrological component of the model was calibrated against average daily streamflow observed at the USGS flow gages on Goose Creek near Middleburg (01643700) and near Leesburg (01644000). The model was calibrated for the simulation period 1988-1995 and verified for the simulation period 1996-2001.

The bacteriological component of the HSPF model was calibrated for the simulation period 1992-1997. The simulation period for verification was 1998-2001. The model was calibrated against observations from 11 VADEQ monitoring stations in the watershed and additional data provided by the Loudoun County Soil and Water Conservation District. The model is able to match the observed violation rates of the instantaneous fecal coliform bacteria standard of 1,000 cfu/ 100 ml to capture the observed correlation between bacteria concentrations and storm flow events, and it reproduces the seasonal trend observed in the monitoring data.

Existing Conditions

Daily fecal coliform bacteria loading rates for forest were determined from wildlife population estimates and wildlife habitat. Daily loading rates for pasture and cropland were calculated on a monthly basis, based on livestock management practices and wildlife habitat. Daily loading rates for developed land were calculated on the basis of pet population, wildlife habitat, and the failure rate of septic systems. The HSPF model was used to determine the bacteria load delivered in runoff from each land use type.

Direct deposition of bacteria by wildlife in streams was calculated on the basis of estimates of wildlife population, habitat, and time spent in streams. Direct deposition of bacteria by cattle was determined on a monthly basis from animal populations and monthly estimates of the time cattle spent in streams. Point sources and septic systems within 50 feet of surface water were also modeled as direct sources.

Table 1 presents the average daily load delivered to surface water from major sources as determined by the model. Loads from pasture runoff and direct deposition of bacteria in stream by cattle are the dominant sources. In most impaired segments pasture loads are larger than the loads from direct deposition by cattle.

Table 1. Average daily fecal coliform bacteria load delivered to surface water by source (cfu/day)

Subwatershed	Direct Sources				Runoff Loads				Total
	Point Sources	Septic	Wildlife	Cattle	Forest	Crop	Pasture	Developed	
N. Fork Goose Creek	3.3E+08	9.8E+03	5.1E+09	1.3E+12	6.5E+08	1.4E+09	1.7E+12	1.4E+10	3.0E+12
Little River	3.0E+05	6.6E+03	8.7E+09	1.2E+12	2.2E+10	1.4E+09	3.2E+12	1.8E+10	4.5E+12
Beaverdam Creek	4.6E+07	1.8E+04	9.7E+09	2.1E+12	1.4E+10	1.8E+09	3.8E+12	2.2E+10	5.9E+12
Cromwells Run		3.5E+03	4.1E+09	3.4E+11	1.2E+10	1.8E+08	9.8E+11	8.6E+09	1.3E+12
Sycolin Creek	6.8E+05		1.7E+09	4.1E+11	3.7E+09	7.9E+08	5.4E+11	5.0E+09	9.7E+11
S. Fork Sycolin Creek			4.5E+08	2.5E+10	1.4E+09	2.6E+06	1.0E+11	1.2E+09	1.3E+11
Lower Goose Creek	5.1E+08	6.3E+04	7.9E+10	2.1E+13	1.7E+11	1.0E+11	3.1E+13	1.7E+11	5.2E+13
Watershed Total	5.2E+08	6.3E+07	8.0E+10	2.1E+13	1.9E+11	1.5E+11	3.1E+13	2.1E+11	5.2E+13

Load Allocation Scenarios

The calibrated HSPF model was used to determine the load reductions necessary to meet both the revised fecal coliform standard and the *E. coli* standard. An implicit Margin of Safety was used in the allocations, based on conservative assumptions incorporated into the development of the model. Since *E. coli* bacteria were not explicitly modeled, the following statistical relationship between fecal coliform concentrations and *E. coli* concentrations, based on water quality monitoring performed across Virginia, was used to estimate simulated *E. coli* concentrations:

$$\text{Log}_2(\text{EC}) = -0.0172 + 0.91905 * \text{Log}_2(\text{FC})$$

Where: EC = *E. coli* concentration (cfu/ 100 ml)
FC = fecal coliform concentration (cfu/ 100 ml)

Ten allocation scenarios were run. Table 2 presents the scenario descriptions and Table 3 presents the results. Only Scenario 8 met all aspects of the fecal coliform standard and the *E. coli* standard. That scenario calls for 100% reduction in the bacteria directly deposited in stream by cattle, a 100% reduction in loads from failing septic systems, a 99% reduction in the bacteria load in runoff from pasture in Little River and Cromwells Run, and a 98% reduction in runoff from pasture everywhere in the watershed. The deep reduction in loads from pasture runoff is necessary to meet the instantaneous *E. coli* standard and to keep the percentage of fecal coliform concentrations above 400 cfu/ 100 ml in any calendar month below 10%.

An analysis of the ten allocation scenarios establishes two key conclusions: (1) in order to meet water quality standards in the impaired segment of the mainstem of Goose Creek, bacteria loads from cattle in streams and pasture runoff must be reduced everywhere in the watershed, and (2) reductions in bacteria loads from cattle in streams and pasture runoff are necessary and sufficient to meet the fecal coliform and *E. coli* water quality standards everywhere in the Goose Creek watershed. In particular, no reductions in loads from direct deposition by wildlife in streams are necessary to meet water quality standards.

Table 2: Allocation scenario descriptions

Scenario	Description
1	No reductions upstream of 1AGOO22.44 except in Cromwells Run Elsewhere (including Cromwells Run): 100% reduction in direct deposition of bacteria by cattle in stream 100% reduction in loads from failing septic systems 100% reduction in loads in runoff from pasture, cropland, and developed land
2	100% reduction in direct deposition of bacteria by cattle in stream everywhere No other reductions upstream of 1AGOO22.44 except in Cromwells Run Elsewhere (including Cromwells Run): 100% reduction in loads from failing septic systems 100% reduction in loads in runoff from pasture, cropland, and developed land
3	100% reduction in direct deposition of bacteria by cattle in stream 100% reduction in loads from failing septic systems
4	100% reduction in loads in runoff from pasture
5	95% reduction in direct deposition of bacteria by cattle in stream 95% reduction in loads from failing septic systems 25% reduction in loads in runoff from pasture
6	100% reduction in direct deposition of bacteria by cattle in stream 100% reduction in loads from failing septic systems 50% reduction in loads in runoff from pasture
7	100% reduction in direct deposition of bacteria by cattle in stream 100% reduction in loads from failing septic systems 95% reduction in loads in runoff from pasture
8	100% reduction in direct deposition of bacteria by cattle in stream 100% reduction in loads from failing septic systems 99% reduction in loads in runoff from pasture in Cromwells Run and Little River 98% reduction in loads in runoff from pasture elsewhere
9	100% reduction in direct deposition of bacteria by cattle in stream 10% reduction in direct deposition of bacteria by wildlife in stream 100% reduction in loads from failing septic systems 75% reduction in loads in runoff from pasture, cropland, and developed land
10	100% reduction in direct deposition of bacteria by cattle in stream 50% reduction in direct deposition of bacteria by wildlife in stream 100% reduction in loads from failing septic systems 75% reduction in loads in runoff from pasture, cropland, and developed land

Table 3. Violation rates for fecal coliform standard and E. coli standard

Scenario	Segment	Watershed	Fecal Coliform Standard		*E. Coli* Standard	
			Geometric Mean[1]	Monthly[1]	Geometric Mean[1]	Instantaneous[2]
1	20	Lower Goose Creek	15.8%	15.0%	17.5%	5.6%
	140	N. Fork Goose Creek	0%	0%	0%	0%
	160	Little River	0%	0%	0%	0%
	180	Beaverdam Creek	0%	0%	0%	0%
	200	Cromwells Run	0%	0%	0%	0%
	230	Sycolin Creek	0%	0%	0%	0%
	240	S. Fork Sycolin Creek	0%	0%	0%	0%
	250	Sycolin Creek	0%	0%	0%	0%
2	20	Lower Goose Creek	0%	14.2%	0%	5.2%
	140	N. Fork Goose Creek	0%	0%	0%	0%
	160	Little River	0%	0%	0%	0%
	180	Beaverdam Creek	0%	0%	0%	0%
	200	Cromwells Run	0%	0%	0%	0%
	230	Sycolin Creek	0%	0%	0%	0%
	240	S. Fork Sycolin Creek	0%	0%	0%	0%
	250	Sycolin Creek	0%	0%	0%	0%
3	20	Lower Goose Creek	0%	44.2%	0%	11.6%
	140	N. Fork Goose Creek	0%	33.3%	0%	9.0%
	160	Little River	0.8%	49.2%	0.8%	13.1%
	180	Beaverdam Creek	0%	37.5%	0%	10.5%
	200	Cromwells Run	0%	29.2%	0%	7.9%
	230	Sycolin Creek	0%	30.0%	0%	9.0%
	240	S. Fork Sycolin Creek	0%	37.5%	0%	10.9%
	250	Sycolin Creek	0%	30.0%	0%	9.0%
4	20	Lower Goose Creek	50.8%	40.0%	50.8%	27.2%
	140	N. Fork Goose Creek	64.2%	61.7%	65.8%	50.2%
	160	Little River	55.0%	56.7%	55.0%	43.5%
	180	Beaverdam Creek	59.2%	55.0%	59.2%	40.7%
	200	Cromwells Run	49.2%	45.8%	49.2%	31.7%
	230	Sycolin Creek	60.8%	58.3%	60.8%	47.2%
	240	S. Fork Sycolin Creek	49.2%	46.7%	49.2%	35.7%
	250	Sycolin Creek	60.8%	58.3%	60.8%	47.2%
5	20	Lower Goose Creek	0%	37.5%	1.7%	10.0%
	140	N. Fork Goose Creek	1.7%	29.2%	2.5%	8.0%
	160	Little River	14.2%	43.3%	15.0%	11.5%
	180	Beaverdam Creek	0%	32.5%	0.8%	9.1%
	200	Cromwells Run	10.8%	35.0%	11.7%	12.9%
	230	Sycolin Creek	0.8%	27.5%	0.8%	8.2%
	240	S. Fork Sycolin Creek	5.0%	33.3%	5.0%	9.6%
	250	Sycolin Creek	0.8%	27.5%	0.8%	8.2%

Scenario	Segment	Watershed	Fecal Coliform Standard		*E. Coli* Standard	
			Geometric Mean[1]	Monthly[1]	Geometric Mean[1]	Instantaneous[2]
6	20	Lower Goose Creek	0%	27.5%	0%	8.1%
	140	N. Fork Goose Creek	0%	21.7%	0%	6.4%
	160	Little River	0%	31.7%	0%	8.7%
	180	Beaverdam Creek	0%	25.0%	0%	7.3%
	200	Cromwells Run	0%	17.5%	0%	5.9%
	230	Sycolin Creek	0%	23.3%	0%	6.4%
	240	S. Fork Sycolin Creek	0%	25.8%	0%	7.6%
	250	Sycolin Creek	0%	23.3%	0%	6.4%
7	20	Lower Goose Creek	0%	0%	0%	1.0%
	140	N. Fork Goose Creek	0%	0%	0%	0.4%
	160	Little River	0%	0.8%	0%	1.4%
	180	Beaverdam Creek	0%	0%	0%	0.7%
	200	Cromwells Run	0%	0%	0%	1.1%
	230	Sycolin Creek	0%	0%	0%	0.1%
	240	S. Fork Sycolin Creek	0%	0%	0%	0.2%
	250	Sycolin Creek	0%	0%	0%	0.1%
8	20	Lower Goose Creek	0%	0%	0%	0%
	140	N. Fork Goose Creek	0%	0%	0%	0%
	160	Little River	0%	0%	0%	0%
	180	Beaverdam Creek	0%	0%	0%	0%
	200	Cromwells Run	0%	0%	0%	0%
	230	Sycolin Creek	0%	0%	0%	0%
	240	S. Fork Sycolin Creek	0%	0%	0%	0%
	250	Sycolin Creek	0%	0%	0%	0%
9	20	Lower Goose Creek	0%	16.7%	0%	5.5%
	140	N. Fork Goose Creek	0%	15.0%	0%	4.7%
	160	Little River	0%	20.0%	0%	6.1%
	180	Beaverdam Creek	0%	19.2%	0%	5.4%
	200	Cromwells Run	0%	4.2%	0%	4.1%
	230	Sycolin Creek	0%	11.7%	0%	4.6%
	240	S. Fork Sycolin Creek	0%	12.5%	0%	4.9%
	250	Sycolin Creek	0%	11.7%	0%	4.6%
10	20	Lower Goose Creek	0%	16.7%	0%	5.5%
	140	N. Fork Goose Creek	0%	15.0%	0%	4.7%
	160	Little River	0%	20.0%	0%	6.1%
	180	Beaverdam Creek	0%	19.2%	0%	5.4%
	200	Cromwells Run	0%	4.2%	0%	4.1%
	230	Sycolin Creek	0%	11.7%	0%	4.5%
	240	S. Fork Sycolin Creek	0%	12.5%	0%	4.9%
	250	Sycolin Creek	0%	11.7%	0%	4.5%

1 Calculated on monthly basis; 2 Calculated on a daily basis.

Summary of TMDL Allocations For Goose Creek

The load allocation that meets both fecal coliform standards and *E. coli* standards in the impaired tributaries and the lower mainstem of Goose Creek calls for the following reductions:

- 99% reduction in loads from pasture runoff in Little River and Cromwells Run
- 98% reduction in loads from pasture runoff elsewhere in the watershed,
- 100% reduction in direct deposition from cattle in streams, and
- 100% reduction in loads from failing septic systems.

The deep reductions in these loads are necessary to meet the instantaneous single sample *E. coli* standard and the limitation on violations in a single month of the instantaneous fecal coliform standard. Explicit reductions in wildlife loads are not necessary to meet water quality standards.

The proposed TMDL allocations were tested by simulating fecal coliform and *E. coli* concentrations under the load allocation over a ten-year period. The ten-year simulation period spans a variety of seasonal variation and flow conditions, and no violations of water quality standards were simulated.

Tables 4.1.1 through 4.7.4 show, for each impaired segment (1) the Total Maximum Daily Load, Wasteload Allocation, and Load Allocation; (2) the Wasteload Allocation assigned to individual permitted sources; (3) the existing loads from nonpoint source categories, their Load Allocations, and the percent reduction in load from each category under the TMDL; and (4) the Wasteload allocation, in terms of *E. coli* bacteria, assigned to individual permitted sources. Nonpoint source loads, both under existing conditions and under the TMDL load allocation, represent loads delivered to surface water (edge-of-stream loads).

Table 4.1.1 Elements of the TMDL for Cromwells Run (Segment 200)

Waterbody (Waterbody ID)	Parameter	TMDL (cfu/yr)	WLA (cfu/yr)	LA[1] (cfu/yr)	MOS (cfu/yr)
Cromwells Run (CRM01A00)	Fecal Coliform	9.80E+12	0	9.80E+12	Implicit

[1] Edge-of-stream load.

Table 4.1.2 Load Allocation[1] for Cromwells Run (Segment 200)

Land Use	Existing Load (cfu/yr)	Allocated Load (cfu/yr)	Percent Reduction
Forest	4.45E+12	4.45E+12	0%
Cropland	6.61E+10	6.61E+10	0%
Pasture	3.57E+14	3.57E+12	99%
Developed Land (without failing septic systems)	2.02E+11	2.02E+11	0%
Failing Septic Systems	2.93E+12	0	100%
Straight Pipes/Septic Systems Within 50 Ft of Surface Water	1.26E+06	0	100%
Direct Deposition from Cattle	1.22E+14	0	100%
Direct Deposition from Wildlife	1.51E+12	1.51E+12	0%
Total Load Allocation	4.88E+14	9.80E+12	98%

[1] Edge-of-stream load.

Table 4.2.1 Elements of the TMDL for North Fork of Goose Creek (Segment 140)

Waterbody (Waterbody ID)	Parameter	TMDL (cfu/yr)	WLA (cfu/yr)	LA[1] (cfu/yr)	MOS (cfu/yr)
North Fork of Goose Creek (NOG01A00)	Fecal Coliform	1.73E+13	1.94E+12	1.54E+13	Implicit

[1] Edge-of-stream load.

Table 4.2.2 Fecal Coliform Wasteload Allocation for North Fork of Goose Creek (Segment 140)

Permit Number	Facility	Existing Load (cfu/ yr)	Allocated Load (cfu/yr)
VA0022802	Purcellville STP	1.38E+12	1.38E+12
VA0026212	Round Hill WWTP	5.51E+11	5.51E+11
VAG406146	Residence	2.76E+09	2.76E+09
VAG406176	Residence	2.76E+09	2.76E+09
Total Wasteload Allocation		1.94E+12	1.94E+12

Table 4.2.3 Load Allocation[1] for North Fork of Goose Creek (Segment 140)

Land Use	Existing Load (cfu/yr)	Allocated Load (cfu/yr)	Percent Reduction
Forest	2.36E+11	2.36E+11	0%
Cropland	5.18E+11	5.18E+11	0%
Pasture	6.17E+14	1.23E+13	98%
Developed Land (without failing septic systems)	3.93E+11	3.93E+11	0%
Failing Septic Systems	4.75E+12	0	100%
Straight Pipes/Septic Systems Within 50 Ft of Surface Water	3.56E+06	0	100%
Direct Deposition from Cattle	3.63E+14	0	100%
Direct Deposition from Wildlife	1.87E+12	1.87E+12	0%
Total Load Allocation	9.89E+14	1.54E+13	98%

[1] Edge-of-stream load.

Table 4.2.4 *E. coli* Wasteload Allocation for North Fork of Goose Creek (Segment 140)

Permit Number	Facility	Existing Load (cfu/ yr)	Allocated Load (cfu/yr)
VA0022802	Purcellville STP	8.70E+11	8.70E+11
VA0026212	Round Hill WWTP	3.48E+11	3.48E+11
VAG406146	Residence	1.74E+09	1.74E+09
VAG406176	Residence	1.74E+09	1.74E+09
Total Wasteload Allocation		1.22E+12	1.22E+12

Table 4.3.1 Elements of the TMDL for Beaverdam Creek (Segment 180)

Waterbody (Waterbody ID)	Parameter	TMDL (cfu/yr)	WLA (cfu/yr)	LA[1] (cfu/yr)	MOS (cfu/yr)
Beaverdam Creek (BEC01A00)	Fecal Coliform	3.73E+13	2.54E+11	3.70E+13	Implicit

[1] Edge-of-stream load.

Table 4.3.2 Fecal Coliform Wasteload Allocation for Beaverdam Creek (Segment 180)

Permit Number	Facility	Existing Load (cfu/ yr)	Allocated Load (cfu/yr)
VA0062189	St. Louis	2.38E+11	2.38E+11
VAG406016	Business	2.76E+09	2.76E+09
VAG406115	Residence	2.76E+09	2.76E+09
VAG406116	Residence	2.76E+09	2.76E+09
VAG406135	Residence	2.76E+09	2.76E+09
VAG406143	Residence	2.76E+09	2.76E+09
VAG406149	Residence	2.76E+09	2.76E+09
Total Wasteload Allocation		2.54E+11	2.54E+11

Table 4.3.3 Load Allocation[1] for Beaverdam Creek (Segment 180)

Land Use	Existing Load (cfu/yr)	Allocated Load (cfu/yr)	Percent Reduction
Forest	5.15E+12	5.15E+12	0%
Cropland	6.53E+11	6.53E+11	0%
Pasture	1.38E+15	2.77E+13	98%
Developed Land (without failing septic systems)	1.96E+10	1.96E+10	0%
Failing Septic Systems	7.94E+12	0	100%
Straight Pipes/Septic Systems Within 50 Ft of Surface Water	6.42E+06	0	100%
Direct Deposition from Cattle	5.44E+14	0	100%
Direct Deposition from Wildlife	3.54E+12	3.54E+12	0%
Total Load Allocation	1.94E+15	3.70E+13	98%

[1] Edge-of-stream load.

Table 4.3.4 *E. coli* Wasteload Allocation for Beaverdam Creek (Segment 180)

Permit Number	Facility	Existing Load (cfu/ yr)	Allocated Load (cfu/yr)
VA0062189	St. Louis	1.50E+11	1.50E+11
VAG406016	Business	1.74E+09	1.74E+09
VAG406115	Residence	1.74E+09	1.74E+09
VAG406116	Residence	1.74E+09	1.74E+09
VAG406135	Residence	1.74E+09	1.74E+09
VAG406143	Residence	1.74E+09	1.74E+09
VAG406149	Residence	1.74E+09	1.74E+09
Total Wasteload Allocation		1.60E+11	1.60E+11

Table 4.4.1 Elements of the TMDL for Little River (Segment 160)

Waterbody (Waterbody ID)	Parameter	TMDL (cfu/yr)	WLA (cfu/yr)	LA[1] (cfu/yr)	MOS (cfu/yr)
Little River (LIV01A00)	Fecal Coliform	2.36E+13	2.76E+09	2.36E+13	Implicit

[1] Edge-of-stream load.

Table 4.4.2 Fecal Coliform Wasteload Allocation for Little River (Segment 160)

Permit Number	Facility	Existing Load (cfu/ yr)	Allocated Load (cfu/yr)
VAG406019	Residence	2.76E+09	2.76E+09
Total Wasteload Allocation		2.76E+09	2.76E+09

Table 4.4.3 Load Allocation[1] for Little River (Segment 160)

Land Use	Existing Load (cfu/yr)	Allocated Load (cfu/yr)	Percent Reduction
Forest	8.03E+12	8.03E+12	0%
Cropland	4.96E+11	4.96E+11	0%
Pasture	1.16E+15	1.16E+13	99%
Developed Land (without failing septic systems)	3.21E+11	3.21E+11	0%
Failing Septic Systems	6.39E+12	0	100%
Straight Pipes/Septic Systems Within 50 Ft of Surface Water	2.40E+06	0	100%
Direct Deposition from Cattle	5.04E+14	0	100%
Direct Deposition from Wildlife	3.19E+12	3.19E+12	0%
Total Load Allocation	1.68E+15	2.36E+13	99%

[1] Edge-of-stream load.

Table 4.4.4 *E. coli* Wasteload Allocation for Little River (Segment 160)

Permit Number	Facility	Existing Load (cfu/ yr)	Allocated Load (cfu/yr)
VAG406019	Residence	1.74E+09	1.74E+09
Total Wasteload Allocation		1.74E+09	1.74E+09

Table 4.5.1 Elements of the TMDL for Sycolin Creek (Segments 230,240,250)

Waterbody (Waterbody ID)	Parameter	TMDL (cfu/yr)	WLA (cfu/yr)	LA[1] (cfu/yr)	MOS (cfu/yr)
Sycolin Creek (SYC02A02)	Fecal Coliform	6.23E+12	2.76E+09	6.22E+12	Implicit

[1] Edge-of-stream load.

Table 4.5.2 Fecal Coliform Wasteload Allocation for Sycolin Creek (Segments 230,240,250)

Permit Number	Facility	Existing Load (cfu/ yr)	Allocated Load (cfu/yr)
VAG406172	Business	2.76E+09	2.76E+09
Total Wasteload Allocation		2.76E+09	2.76E+09

Table 4.5.3 Load Allocation[1] for Sycolin Creek (Segments 230,240,250)

Land Use	Existing Load (cfu/yr)	Allocated Load (cfu/yr)	Percent Reduction
Forest	1.34E+12	1.34E+12	0%
Cropland	2.89E+11	2.89E+11	0%
Pasture	1.98E+14	3.96E+12	98%
Developed Land (without failing septic systems)	1.75E+10	1.75E+10	0%
Failing Septic Systems	1.83E+12	0	100%
Straight Pipes/Septic Systems Within 50 Ft of Surface Water	0	0	100%
Direct Deposition from Cattle	5.44E+13	0	100%
Direct Deposition from Wildlife	6.14E+11	6.14E+11	0%
Total Load Allocation	2.56E+14	6.22E+12	98%

[1] Edge-of-stream load.

Table 4.5.4 *E. coli* Wasteload Allocation for Sycolin Creek (Segments 230,240,250)

Permit Number	Facility	Existing Load (cfu/ yr)	Allocated Load (cfu/yr)
VAG406172	Business	1.74E+09	1.74E+09
Total Wasteload Allocation		1.74E+09	1.74E+09

Table 4.6.1 Elements of the TMDL for South Fork Sycolin Creek (Segment 240)

Waterbody (Waterbody ID)	Parameter	TMDL (cfu/yr)	WLA (cfu/yr)	LA[1] (cfu/yr)	MOS (cfu/yr)
South Fork Sycolin Creek (SFS01A02)	Fecal Coliform	1.41E+12	0	1.41E+12	Implicit

[1] Edge-of-stream load.

Table 4.6.2 Load Allocation[1] for South Fork Sycolin Creek (Segment 240)

Land Use	Existing Load (cfu/yr)	Allocated Load (cfu/yr)	Percent Reduction
Forest	4.93E+11	4.93E+11	0%
Cropland	9.38E+08	9.38E+08	0%
Pasture	3.76E+13	7.52E+11	98%
Developed Land (without failing septic systems)	0	0	0%
Failing Septic Systems	4.34E+11	0	100%
Straight Pipes/Septic Systems Within 50 Ft of Surface Water	0	0	100%
Direct Deposition from Cattle	9.05E+12	0	100%
Direct Deposition from Wildlife	1.63E+11	1.63E+11	0%
Total Load Allocation	4.77E+13	1.41E+12	97%

[1] Edge-of-stream load.

Table 4.7.1 Elements of the TMDL for Goose Creek (Segments 20-250)

Waterbody (Waterbody ID)	Parameter	TMDL (cfu/yr)	WLA (cfu/yr)	LA[1] (cfu/yr)	MOS (cfu/yr)
Goose Creek (GOO01A00)	Fecal Coliform	3.67E+14	3.17E+12	3.63E+14	Implicit

[1] Edge-of-stream load.

Table 4.7.2 Fecal Coliform Wasteload Allocation[1] for Goose Creek (Segments 20-250)

Permit Number	Facility	Existing Load (cfu/ yr)	Allocated Load (cfu/yr)
VA0022802	Purcellville	1.38E+12	1.38E+12
VA0024112	Foxcroft	2.07E+11	2.07E+11
VA0024759	US FEMA	2.49E+11	2.49E+11
VA0024775	Middleburg	3.72E+11	3.72E+11
VA0026212	Round Hill	5.51E+11	5.51E+11
VA0027197	Notre Dame	4.16E+10	4.16E+10
VA0062189	St. Louis	2.38E+11	2.38E+11
VA0080993	Goose Creek	2.76E+10	2.76E+10
VA0089133	Aldie WWTP	4.16E+10	4.16E+10
VAG406015	Residence	2.76E+09	2.76E+09
VAG406016	Business	2.76E+09	2.76E+09
VAG406018	Residence	2.76E+09	2.76E+09
VAG406019	Residence	2.76E+09	2.76E+09
VAG406020	Residence	2.76E+09	2.76E+09
VAG406047	Residence	2.76E+09	2.76E+09
VAG406069	Residence	2.76E+09	2.76E+09
VAG406101	Residence	2.76E+09	2.76E+09
VAG406113	Residence	2.76E+09	2.76E+09
VAG406115	Residence	2.76E+09	2.76E+09
VAG406116	Residence	2.76E+09	2.76E+09
VAG406121	Residence	2.76E+09	2.76E+09
VAG406135	Residence	2.76E+09	2.76E+09
VAG406143	Residence	2.76E+09	2.76E+09
VAG406146	Residence	2.76E+09	2.76E+09
VAG406149	Residence	2.76E+09	2.76E+09
VAG406170	Residence	2.76E+09	2.76E+09
VAG406172	Business	2.76E+09	2.76E+09
VAG406176	Residence	2.76E+09	2.76E+09
VAG406193	Residence	2.76E+09	2.76E+09
VAG406244	Residence	2.76E+09	2.76E+09
Total Wasteload Allocation		3.17E+12	3.17E+12

Table 4.7.3 Load Allocation[1] for Goose Creek (Segments 20-250)

Land Use	Existing Load (cfu/yr)	Allocated Load (cfu/yr)	Percent Reduction
Forest	6.37E+13	6.37E+13	0%
Cropland	3.81E+13	3.81E+13	0%
Pasture	1.12E+16	2.24E+14	98%
Developed Land (without failing septic systems)	9.25E+12	9.25E+12	0%
Failing Septic Systems	5.44E+13	0	100%
Straight Pipes/Septic Systems Within 50 Ft of Surface Water	2.29E+07	0	100%
Direct Deposition from Cattle	7.10E+15	0	100%
Direct Deposition from Wildlife	2.87E+13	2.87E+13	0%
Total Load Allocation	1.85E+16	3.63E+14	98%

[1] Edge-of-stream load.

Table 4.7.4 *E. coli* Wasteload Allocation for Goose Creek (Segments 20-250)

Permit Number	Facility	Existing Load (cfu/ yr)	Allocated Load (cfu/yr)
VA0022802	Purcellville	8.70E+11	8.70E+11
VA0024112	Foxcroft	1.31E+11	1.31E+11
VA0024759	US FEMA	1.57E+11	1.57E+11
VA0024775	Middleburg	2.35E+11	2.35E+11
VA0026212	Round Hill	3.48E+11	3.48E+11
VA0027197	Notre Dame	2.61E+10	2.61E+10
VA0062189	St. Louis	1.50E+11	1.50E+11
VA0080993	Goose Creek	1.74E+10	1.74E+10
VA0089133	Aldie WWTP	2.61E+10	2.61E+10
VAG406015	Residence	1.74E+09	1.74E+09
VAG406016	Business	1.74E+09	1.74E+09
VAG406018	Residence	1.74E+09	1.74E+09
VAG406019	Residence	1.74E+09	1.74E+09
VAG406020	Residence	1.74E+09	1.74E+09
VAG406047	Residence	1.74E+09	1.74E+09
VAG406069	Residence	1.74E+09	1.74E+09
VAG406101	Residence	1.74E+09	1.74E+09
VAG406113	Residence	1.74E+09	1.74E+09
VAG406115	Residence	1.74E+09	1.74E+09
VAG406116	Residence	1.74E+09	1.74E+09
VAG406121	Residence	1.74E+09	1.74E+09
VAG406135	Residence	1.74E+09	1.74E+09
VAG406143	Residence	1.74E+09	1.74E+09
VAG406146	Residence	1.74E+09	1.74E+09
VAG406149	Residence	1.74E+09	1.74E+09
VAG406170	Residence	1.74E+09	1.74E+09
VAG406172	Business	1.74E+09	1.74E+09
VAG406176	Residence	1.74E+09	1.74E+09
VAG406193	Residence	1.74E+09	1.74E+09
VAG406244	Residence	1.74E+09	1.74E+09
Total Wasteload Allocation		2.00E+12	2.00E+12

Reasonable Assurance of Implementation

Virginia's 1997 Water Quality Monitoring, Information, and Restoration Act (WQMIRA) requires the development of implementation plans for TMDLs, even though they are not mandated by current Federal regulations. TMDLs for *E. coli* and fecal coliform bacteria in the Goose Creek watershed will be implemented in stages. Phased implementation will allow the accuracy of the TMDL to be evaluated and insure that the most cost-effective measures are implemented first. The Phase I implementation goal calls for meeting the geometric mean standards for both fecal coliform and *E. coli* bacteria and for no more than 10% of water quality samples to be above 400 cfu/ 100 ml for fecal coliform bacteria and 235 cfu/ 100 ml for *E. coli*. The HSPF model predicts that this can be achieved in all impaired segments by the elimination of the direct deposition of bacteria in streams by cattle and a 50% reduction in bacteria loads in pasture runoff throughout the Goose Creek watershed.

Public Participation

Public participation was solicited throughout the development of the TMDLs. Stakeholders were asked to provide relevant information, and, in turn, were kept informed about the status of the TMDLs, and encouraged to comment on the assumptions, methods, and results.

Three formal public meetings were held on the TMDLs in the Goose Creek watershed. The first took place in Leesburg October 17, 2001. The purpose of the meeting was to explain the reasons for developing the TMDLs and the process by which they would be developed. Two other formal meetings were held to present the results of the TMDLs to the public, one in Leesburg on November 14, 2002, and a second meeting at Marshall on November 20, 2002.

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The TMDL report for the Goose Creek watershed was prepared with the assistance of many private citizens and personnel from state agencies. Special acknowledgment is made to the following individuals and groups who made significant contributions toward the completion of this project:

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Virginia Department of Conservation and Recreation

Virginia Department of Game and Inland Fisheries

Virginia Department of Health

Members of the Goose Creek Technical Advisory Committee

Loudoun County Soil and Water Conservation District

John Marshall Soil and Water Conservation District

Loudoun County Department of Building and Development

Loudoun County Environmental and Historic Resources Program

Loudoun County Office of Mapping and Geographic Information

Fauquier County Department of Community Development

Fauquier County Geographic Information Systems Office

City of Fairfax Department of Utilities

James Madison University

Engineering Concepts, Inc.

Loudoun Watershed Watch

Piedmont Environmental Council

Town of Leesburg Water Pollution Control Division

Synagro, Inc.

Center for Watershed Protection

Swan Research Program of Environmental Studies at Airlie

George Washington University Loudoun County Environmental Indicators Project

CHAPTER 1: INTRODUCTION

1.1 Background

The Clean Water Act (CWA) was established in 1972 to address widespread water pollution issues throughout the nation. Since its inception, one of the primary goals of the CWA has been to assure that waters are of sufficient quality to support designated uses such as fishing and swimming. Unfortunately, approximately 40 percent of all waters across the United States do not currently meet this goal, despite the fact that many pollution sources have implemented nationally required levels of pollution control.

Section 303(d) of the CWA requires states to identify waters that do not meet or are not expected to meet water quality standards after technology-based or other required controls are in place. States must establish a priority ranking for these waters, taking into account the pollution severity and designated uses of the waters. The 303(d) list of impaired waters is updated every two years, and plans must be developed to address identified impairments (US EPA, 1999).

The plans, required under section 303(d) of the CWA and EPA's Water Quality Planning and Management Regulations (40 CFR Part 130), are called Total Maximum Daily Loads (TMDLs) and must be developed for all impaired waters. TMDLs represent the total pollutant loading that a waterbody can receive without violating water quality standards. The TMDL process establishes the allowable loadings of pollutants for a waterbody based on the relationship between pollution sources and in-stream water quality conditions. By following the TMDL process, states can establish water quality based controls to reduce pollution from both point and nonpoint sources to restore and maintain the quality of their water resources (EPA, 1991).

1.2 Water Quality Problem

Goose Creek and its tributaries are part of the Potomac River Basin (USGS Hydrologic Unit Code 02070008). The Goose Creek watershed covers 386 square miles and is located in Northern Virginia. The headwaters of Goose Creek begin near the Blue Ridge Mountains in northwestern Fauquier County and flow east and slightly north for approximately 53 miles toward its confluence with the Potomac River in Loudoun County. Figure 1.1 shows the location of the Goose Creek watershed.

The mainstem of Goose Creek and six of its tributaries were listed as impaired on Virginia's 1998 and draft 2002 303(d) Total Maximum Daily Load Priority List and Report (VADEQ, 1998 and 2002) due to exceedances of the State's water quality standard for fecal coliform bacteria at ambient monitoring stations operated by VADEQ. The impaired stream segments are currently in violation of VADEQ fecal coliform bacteria standards and do not meet designated uses for primary contact recreation (e.g. swimming). The details of the bacteria impairments are presented in Table 1.1.

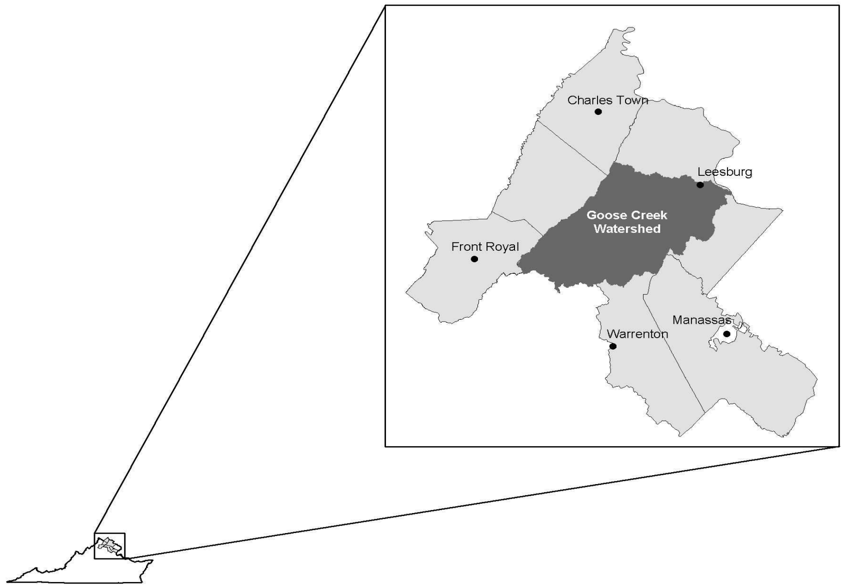


Figure 1.1: Location of the Goose Creek watershed

Table 1.1: Goose Creek watershed bacteria impairments

Stream (Segment ID)	County	Station ID	Year Initially Listed	Impairment		
				Cause	Source	Length (mi)
Cromwells Run (VAN-A05R_CRM01A00)	Loudoun/ Fauquier	1ACRM001.20	1998	FCB	Unknown	3.61
North Fork Goose Creek (VAN-A06R_NOG01A00)	Loudoun	1ANOG005.69	1998	FCB	Unknown	4.29
Beaverdam Creek (VAN-A07R_BEC01A00)	Loudoun	1ABEC004.76	1998	FCB	Unknown	6.32
Little River (VAN-A08R_LIV01A00)	Loudoun	1ALIV004.78	1998	FCB	Unknown	6.13
Sycolin Creek (VAN-A08R_SYC02A02)	Loudoun	1ASYC004.93	1996	FCB	Unknown	7.10
South Fork Sycolin Creek (VAN-A08R_SFS01A02)	Loudoun	1ASFS000.28	2002	FCB	Unknown	3.31
Goose Creek (VAN-A08R_GOO01A00)	Loudoun	1AGOO002.38	2002	FCB	Unknown	4.77

FCB = Fecal Coliform Bacteria
Streams listed in 1996 were assessed for the period April 1, 1993 through March 31, 1995
Streams listed in 1998 were assessed for the period July 1, 1992 through June 30, 1997
Streams listed in 2002 were assessed for the period January 1, 1996 through December 31, 2000

Little River and the main stem of Goose Creek were also listed on the 1998 and draft 2002 303(d) lists for violations of the general standard (aquatic life). The TMDLs addressing the benthic impairments will be developed separately and are expected to be completed within the next nine months. This report addresses only the bacteria impairments in the Goose Creek watershed.

TMDLs are required to assure that the impaired stream segments in Table 1.1 meet water quality standards and support their designated uses. In 1998, the American Canoe Association and the American Littoral Society filed a complaint against EPA for failure to comply with the provisions of Section 303(d) of the CWA in Virginia. As a result, EPA signed a Consent Decree with the plaintiffs in 1999 that contains Virginia's TMDL development schedule through 2010. Of the bacteria impairments shown in Table 1.1, all but one , the South Fork Sycolin Creek ,are included in the Consent Decree. The South Fork Sycolin Creek was targeted for TMDL development by 2004 to allow all currently demonstrated bacteria impairments in the watershed to be addressed at the same time. Figure 1.2 shows the location of the bacteria impairments in the Goose Creek watershed as well as the location of VADEQ's water quality monitoring stations.

1.3 Applicable Water Quality Standards

According to Virginia Water Quality Standards (9 VAC 25-260-5), the term *"water quality standards means provisions of state or federal law which consist of a designated use or uses for the waters of the Commonwealth and water quality criteria for such waters based upon such uses. Water quality standards are to protect the public health or welfare, enhance the quality of water and serve the purposes of the State Water Control Law (§62.1-44.2 et seq. of the Code of Virginia) and the federal Clean Water Act (33 USC §1251 et seq.)."*

Also according to Virginia Water Quality Standards (9 VAC 25-260-10A), *"all state waters are designated for the following uses: recreational uses (e.g., swimming and boating); the propagation and growth of a balanced indigenous population of aquatic life, including game fish, which might be reasonably expected to inhabit them; wildlife; and the production of edible and marketable natural resources (e.g., fish and shellfish)."* This TMDL report addresses the impairment of the swimming use in the Goose Creek watershed.

The applicable water quality criteria for bacteria in the Goose Creek watershed are currently in a state of transition. Following EPA guidance, VADEQ has proposed more stringent fecal coliform bacteria standards as well as new standards for *Escherichia coli* (*E. coli*) bacteria. These new standards were adopted by the State Water Control Board in May 2002, given public notice in June 2002, and approved by EPA on November 8, 2002. They became effective January 15, 2003. While violation of the current standards is what led to the impairments in Goose Creek and its tributaries, the new standards for fecal coliform and *E. coli* will be applicable to the TMDL calculations and must be met in the model scenarios.

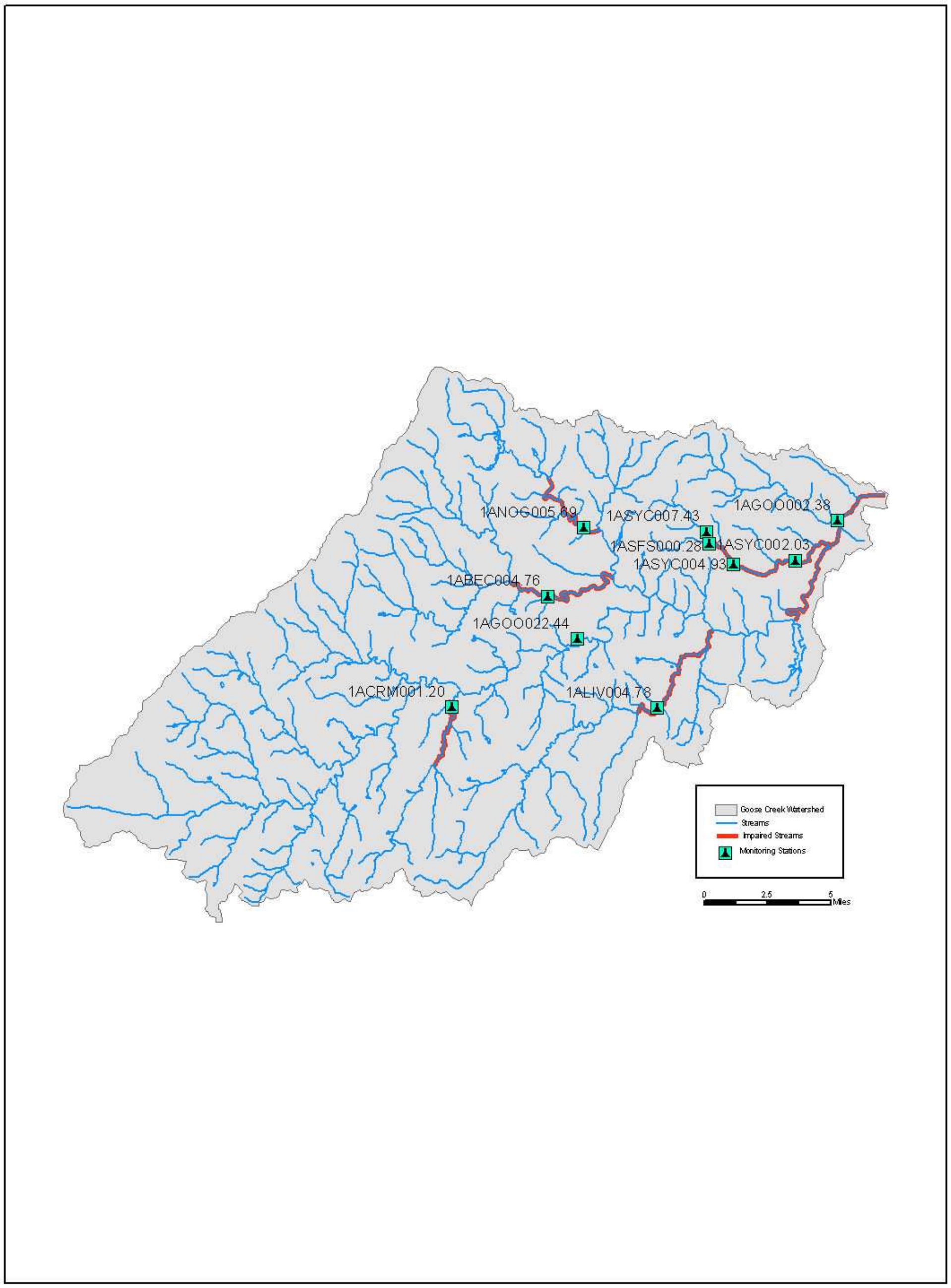


Figure 1.2: Location of impaired stream segments and monitoring stations in Goose Creek

Current criteria (fecal coliform bacteria)

For a non-shellfish supporting waterbody to be in compliance with Virginia bacteria standards for primary contact recreational use, VADEQ specifies the following criteria (9 VAC 25-260-170):

> *"…the fecal coliform bacteria shall not exceed a geometric mean of 200 fecal coliform bacteria per 100 mL of water for two or more samples over a 30-day period, or a fecal coliform bacteria level of 1,000 per 100 mL at any time."*

If the waterbody exceeds either criterion more than 10% of the time, the waterbody is classified as impaired and a TMDL must be developed and implemented to bring the waterbody into compliance with the water quality criterion. Based on the sampling frequency, only one criterion is applied to a particular datum or data set (9 VAC 25-260-170). If the sampling frequency is one sample or less per 30 days, the instantaneous criterion is applied; for a higher sampling frequency, the geometric mean criterion is applied.

New criteria (fecal coliform bacteria and E. coli)

EPA has recommended that all States adopt *E. coli* or enterococci criteria for fresh water and enterococci criteria for marine waters by 2003. EPA is pursuing the States' adoption of these standards because there is a stronger correlation between the concentration of these organisms (*E. coli* and enterococci) and the incidence of gastrointestinal illness than with fecal coliform bacteria. *E. coli* and enterococci are both bacteriological organisms that can be found in the intestinal tract of warm-blooded animals and are both subsets of fecal coliform bacteria. Like fecal coliform bacteria, these organisms indicate the presence of fecal contamination.

The *E. coli* criteria for freshwater are a geometric mean of two or more samples taken during any calendar month of no more than 126 cfu/100mL, and an instantaneous single sample maximum of 235 cfu/100mL. These criteria will apply to a freshwater sampling station as soon as the new standard becomes effective. Fecal coliform criteria will remain in effect only until a minimum of 12 *E. coli* data points have been collected or June 30, 2008, whichever comes first. While the fecal coliform bacteria water quality standard is still in effect, it will be changed to read:

> *"Fecal coliform bacteria shall not exceed a geometric mean of 200 fecal coliform bacteria per 100 mL of water for two or more samples over a calendar month nor shall more than 10% of the total samples taken during any calendar month exceed 400 fecal coliform bacteria per 100 mL of water."*

It is important to note that in the current bacteria standards, either the geometric mean or the instantaneous criterion is applied, depending on the sampling frequency. In the new standards, both the geometric and the instantaneous criteria apply to data sets with two or more samples collected per month. Only the instantaneous criterion applies when one or fewer samples are collected per month.

1.4 Goals and Tasks

The goal of this project was to develop TMDLs for the mainstem of Goose Creek and six of its tributaries. The following tasks were performed to achieve the project goal:

1. Identify potential sources of fecal coliform bacteria in conjunction with a Technical Advisory Committee and other stakeholders.
2. Use literature based estimates to quantify fecal coliform production from each source.
3. Calibrate and verify a hydrological simulation model of the Goose Creek watershed to simulate the deposition and transport of fecal coliform in streams.
4. Account for variations in precipitation, hydrology, and land-use.
5. Use calibrated model to evaluate the impacts of multiple scenarios to reduce bacteria concentrations and meet the applicable criteria for fecal coliform and *E. coli*.
6. Select a TMDL scenario.

CHAPTER 2: WATERSHED CHARACTERIZATION

2.1 General Description of the Goose Creek Watershed

Goose Creek is the largest tributary to the Potomac River in Virginia downstream of the Shenandoah River. The Goose Creek watershed lies in Loudoun and Fauquier Counties on the edge of the Washington D. C. metropolitan area. Most of the watershed remains rural although areas around Leesburg are rapidly being developed. Goose Creek lies in the heart of Virginia's horse country, and many of the state's wineries make their home there, but beef cattle production remains the dominant agricultural activity.

The City of Fairfax operates a water supply intake on Goose Creek just upstream of Leesburg. A 500 ft dam on Goose Creek creates a 200 million gallon reservoir on the mainstem of Goose Creek. A secondary reservoir with a capacity of 1.3 billion gallons is maintained just upstream from the Goose Creek Reservoir on Beaverdam Creek (not to be confused with the impaired waterbody, which is a tributary to the North Fork of Goose Creek) to supply additional water during low flows. The City of Fairfax withdraws approximately 11 million gallons a day, a portion of which is delivered to customers of the Loudoun County Sanitation Authority (Mohsenin, 2002; Boryscuk, 2002).

The entire portion of the mainstem of Goose Creek in Loudoun County has been designated a scenic river under the state's Scenic River Act (Commonwealth of Virginia, 1984).

2.2 Watershed Segmentation

To adequately represent the water resources of Goose Creek in a modeling environment, the watershed was segmented into 25 subwatersheds. The primary level of segmentation occurred at the mouths of major tributary streams. Secondary levels of segmentation occurred at streamflow gages operated by the USGS and at water quality monitoring stations operated by VADEQ. Figure 2.1 shows the segmentation of the Goose Creek watershed. Table 2.1 lists the segments and provides descriptive information for each. When a segment was delineated at a USGS flow gage or a VADEQ water quality monitoring station, the gage or station name is included in parentheses.

2.3 Geology, Climate, and Land Use

2.3.1 Soils and Geology

Goose Creek is located within the Blue Ridge and Piedmont Physiographic Provinces. The dividing line between these two provinces is the Catoctin Ridge of the Bull Run Mountains that runs just west of Route 15. The watershed is characterized by diverse soil series and bedrock geology. The majority of the watershed is characterized by silt and clay loam soils derived from metamorphic and igneous bedrock. Portions of the lower watershed, however, are underlain by sedimentary geology. Slopes in the Blue Ridge are characterized by large areas of boulders and rock outcrops (Blackburn and Truong, 1988).

Soil survey layers in GIS format for Loudoun and Fauquier Counties were analyzed to determine the distribution of soils by Hydrologic Group. Group A soils have the fastest infiltration rates; Group D soils are poorly-drained. Table 2.2 shows the percent distribution of each Hydrologic Group by subwatershed. A large percentage of the soils in the lower portion of the watershed east of Leesburg are poorly-drained Group D soils. Otherwise, moderately well-drained Group B and C soils dominate the rest of the watershed.

Table 2.1: Goose Creek watershed segmentation

Segment Number	Segment Name	Area (mi^2)
10	Goose Creek Mouth	5.16
20	Goose Creek Above Tuscarora Creek (1AGOO002.38)	1.74
30	Tuscarora Creek (1ATUS000.37)	14.35
40	Lower Sycolin Creek	2.38
50	Goose Creek Above Sycolin Creek	0.68
60	Goose Creek Reservoir	2.53
70	Beaverdam Reservoir	5.75
80	Goose Creek Above Beaverdam Reservoir	6.12
90	USGS Gage at Leesburg (01644000)	1.76
100	Middle Sycolin Creek (1ASYC002.03)	6.65
110	Goose Creek Above Little River	8.43
120	Goose Creek Above North Fork Goose Creek	7.99
130	North Fork Goose Creek	20.53
140	Upper North Fork Goose Creek (1ANOG005.69)	23.62
150	Little River	14.62
160	Upper Little River (1ALIV004.78)	40.38
170	Beaverdam Creek	6.24
180	Upper Beaverdam Creek (1ABEC004.76)	47.26
190	Goose Creek at WQS 22.44 (1AGOO022.44)	19.69
200	Cromwells Run (1ACRM001.20)	18.89
210	USGS Gage at Middleburg (01643700)	42.57
220	Goose Creek HUC A04	79.25
230	Upper Sycolin Creek (1ASYC004.93)	1.51
240	South Fork Sycolin Creek (1ASFS000.28)	2.13
250	North Fork Sycolin Creek (1ASYC007.43)	4.37

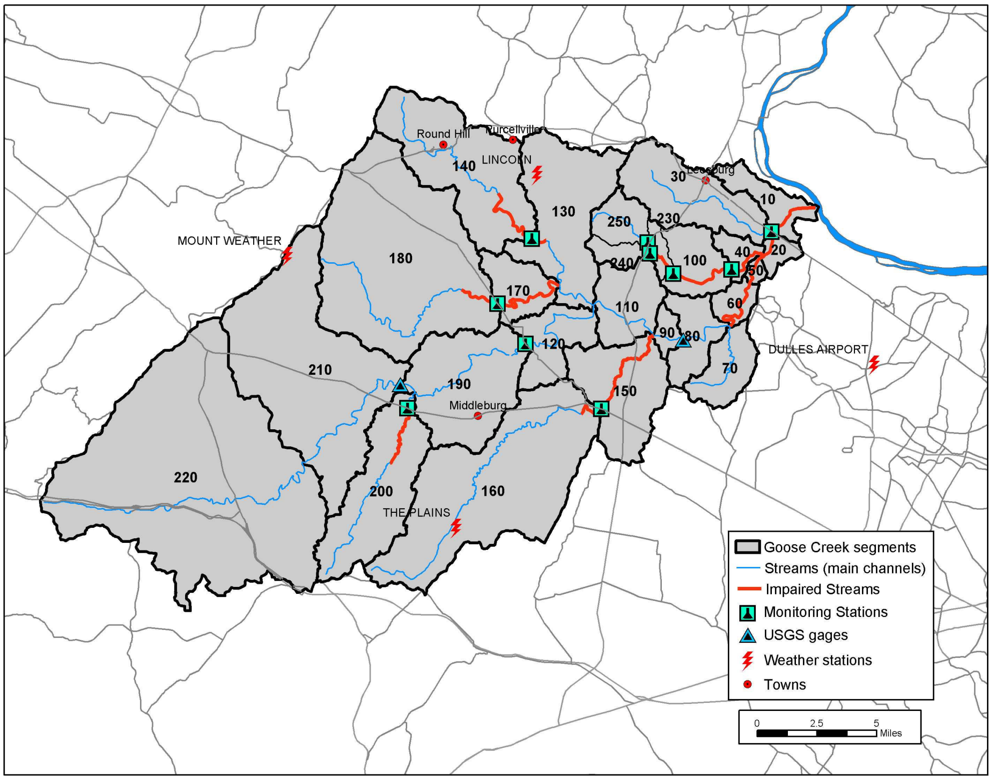


Figure 2.1: Goose Creek model segmentation, monitoring station locations, USGS stream gage locations, and weather station locations.

Table 2.2: Percent distribution of soils by hydrologic group within subwatersheds

Segment	Percent Soils in Hydrologic Group				
	A	B	C	D	Other
10	1%	22%	50%	24%	3%
20	0%	6%	16%	72%	5%
30	0%	32%	43%	23%	2%
40	0%	8%	19%	72%	1%
50	0%	4%	23%	54%	19%
60	0%	23%	22%	50%	5%
70	0%	14%	15%	63%	8%
80	0%	48%	21%	30%	1%
90	0%	75%	17%	6%	2%
100	0%	62%	26%	12%	1%
110	0%	42%	48%	8%	1%
120	0%	45%	50%	3%	2%
130	1%	54%	39%	5%	1%
140	0%	58%	32%	8%	1%
150	0%	49%	38%	12%	1%
160	1%	62%	34%	3%	1%
170	1%	64%	28%	7%	1%
180	0%	60%	29%	10%	1%
190	0%	69%	24%	6%	7%
200	0%	85%	12%	2%	1%
210	0%	64%	27%	8%	1%
220	0%	68%	26%	8%	1%
230	0%	57%	27%	15%	0%
240	0%	30%	68%	2%	1%
250	0%	27%	70%	3%	0%

2.3.2 Climate

The Goose Creek watershed has the typical humid climate that characterizes the Piedmont region of the Middle Atlantic States. There are three meteorological stations in the watershed, at The Plains (448396), Lincoln (444909), and Mt. Weather (445851), and a fourth station at the Dulles International Airport (448903) lies just to the east of the watershed. Figure 2.1 shows the location of these stations with respect to the watershed. Average annual precipitation for these stations is 42.4, 41.6, 41.2, and 41.8 inches, respectively, indicating that precipitation is spread fairly evenly over the watershed. Table 2.3 contrasts average monthly precipitation, maximum and minimum temperatures at Lincoln and Mt. Weather, which is located near the top of the Blue Ridge in the southwest corner of Loudoun County. Mt. Weather has cooler maximum temperatures in the winter, but otherwise there are not great differences in average temperature and precipitation between the stations. Annual snowfall at Mt. Weather is 23.4 inches compared to 22.6 inches at Lincoln (Southeast Regional Climate Center, 2002).

Table 2.3 also shows the Virginia State Climatology Office (2002) estimate of average monthly potential evapotranspiration at Dulles Airport. The estimate is based on the Thornthwaite Method. As Table 2.3 shows, precipitation is fairly even throughout the year but evapotranspiration is significantly higher in the summer months.

Table 2.3 Average Monthly Temperature, Precipitation, and Potential Evapotranspiration in the Goose Creek Watershed

Month	Lincoln (444909) 1930-2000			Mt. Weather (445851) 1948-2000			Dulles Airport (448903)
	Precipitation	Temperature		Precipitation	Temperature		PET (in)
	(in)	Max (°F)	Min (°F)	(in)	Max (°F)	Min (°F)	
Jan	3.02	43.9	24.7	2.76	36.8	21.2	0.00
Feb	2.63	47.1	25.8	2.34	39.4	23.1	0.04
Mar	3.63	56.1	32.8	3.33	47.5	30.0	0.68
Apr	3.40	67.5	42.0	3.38	59.7	40.3	1.96
May	4.09	77.2	51.8	4.27	69.1	50.5	3.53
Jun	3.84	85.0	60.6	4.22	77.1	59.4	4.95
Jul	3.87	88.9	64.9	3.81	81.2	63.7	5.91
Aug	4.11	87.5	63.1	3.56	79.5	62.4	5.33
Sep	3.56	81.0	56.5	3.78	72.8	55.6	3.68
Oct	3.16	70.2	45.0	3.40	62.0	44.9	1.92
Nov	3.17	57.9	36.1	3.39	50.6	35.2	0.74
Dec	3.12	46.3	27.4	2.91	40.1	25.2	0.10
Total	41.59	--	--	41.15	--	--	28.84

2.3.3. Land Use

Land-use patterns in the Goose Creek watershed were identified using results from the 1997 version of the Multi-Resolution Land Characteristics (MRLC) Consortium study (EPA, 2002). The MRLC data were developed using 30-meter resolution satellite imagery collected as part of the Landsat Thematic Mapper program. Cooperating agencies included the U.S. Environmental Protection Agency (EPA), the U.S. Geological Survey (USGS), the U.S. Forest Service (USFS), and the National Oceanic and Atmospheric Administration (NOAA). The MRLC classification scheme includes 21 different land-use classifications. Of those 21 different classifications, 13 were represented in the Goose Creek watershed. Table 2.4 lists the 13 MRLC land-uses found within Goose Creek watershed.

To simplify the modeling process, the MRLC categories represented in the Goose Creek watershed were aggregated into 6 land-use classes. The classes and methods used to aggregate the MRLC data are presented in Table 2.5.

Table 2.4: MRLC land-use categories found in the Goose Creek watershed

Class Number	Land-use Type	Abbreviation
21	Low Intensity Residential	LIR
22	High Intensity Residential	HIR
23	Commercial/Industrial/Transportation	CIT
32	Quarries/Strip Mines/Gravel Pits	QSG
33	Transitional	TR
41	Deciduous Forest	DF
42	Evergreen Forest	EF
43	Mixed Forest	MF
81	Pasture/Hay	PH
82	Row Crops	RC
85	Urban/Recreational Grasses	URG
91	Woody Wetlands	WW
92	Emergent Herbaceous Wetlands	EHW

Table 2.5: Model land-use classes used in the Goose Creek watershed

Land Type	Model Land-use Class	Aggregated MRLC Land-use Classes
Pervious Land	Forest	= DF + EF + MF +WW + EHW
	Cropland	= RC
	Pasture	= PH
	Developed	= 0.15*(HIR+CIT) + 0.6*(LIR) + URG
Impervious Land	Developed Impervious	= 0.85*(HIR+CIT) + 0.4*(LIR)
	Barren	= QSG + TR

Table 2.6 shows the land-use distribution in each modeling segment. Overall, pasture and forest are the two dominant land-use classes in the Goose Creek watershed. Pasture represents about 55% of the total watershed area while forest accounts for about 41%. The remaining 4% of the Goose Creek watershed is comprised of cropland (1.5%), urban pervious (1%), urban impervious (1%), and barren land (0.5%). This general distribution holds true for many of the large subwatersheds in Goose Creek, with pasture making up more than 50% of the watershed area, and pasture and forest together usually comprising at least 92% of the total watershed area.

Loudoun County is one of the fastest growing counties in the nation. During the 1990's the population doubled to about 170,000. Most of this growth occurred east of the watershed, but the area south of Leesburg and west along the Route 7 corridor saw significant growth. The population of Loudoun County is expected to increase by 75% over the next decade and by 44% between 2010 and 2020, and more of the Goose Creek watershed around Leesburg is expected to be developed (Department of Economic Development, 2002). Loudoun County is currently trying to preserve the rural character of the western portion of the county, including much of the Goose Creek watershed. The portion of the watershed in Fauquier County is not expected to experience significant growth (Center for Watershed Protection, 2002).

Table 2.6: Land-use distribution in acres by modeling segment

Segment	Pervious Land (Acres)				Impervious Land (Acres)		Total
	Forest	Cropland	Pasture	Developed	Developed	Barren	
10	1,885	225	651	214	305	23	3,303
20	573	6	407	6	31	91	1,114
30	3,273	596	3,642	739	790	142	9,182
40	521	178	542	23	47	209	1,520
50	220	6	47	12	63	86	434
60	988	56	556	3	15	0	1,618
70	1,903	98	1,660	8	9	0	3,678
80	1,735	109	2,064	7	5	0	3,920
90	571	4	550	2	0	0	1,127
100	1,718	149	2,315	25	20	25	4,252
110	2,652	60	2,664	11	7	4	5,398
120	2,801	47	2,258	3	1	1	5,111
130	4,951	216	7,825	79	64	2	13,137
140	4,780	286	9,598	309	141	2	15,116
150	3,663	247	5,288	93	68	0	9,359
160	11,266	226	13,922	264	158	9	25,845
170	1,677	13	2,299	1	1	4	3,995
180	9,716	345	20,127	35	16	6	30,245
190	4,221	89	7,871	249	171	1	12,602
200	3,217	23	8,653	115	72	8	12,088
210	8,634	297	17,860	244	182	28	27,245
220	27,153	382	22,285	350	458	89	50,717
230	266	63	638	1	1	0	969
240	443	0	921	0	0	0	1,364
250	983	18	1,776	14	8	0	2,799
Total	99,810	3,739	136,419	2,807	2,633	730	246,138

2.4 Streamflow and Water Quality Monitoring Data

Streamflow and water quality monitoring data were reviewed to help characterize the conditions that led to the listing of Goose Creek and its tributaries as impaired. In addition, the data were very crucial to calibrating and verifying a model that simulated the hydrology and the fate and transport of fecal coliform bacteria in the Goose Creek watershed. The sections below describe the location and the extent of data available for streamflow and water quality in Goose Creek.

2.4.1 Streamflow Monitoring Data

Daily streamflow records are currently available from two USGS gaging stations on the mainstem of Goose Creek. Two additional gaging stations were initiated in October 2001, one on Beaverdam Creek and one on the North Fork of Goose Creek, but they are currently only providing provisional data that have not been reviewed by the USGS and were therefore not used in the development of these TMDLs. Table 2.7 presents all four

USGS stations and provides information on the location and period of record of each. Figure 2.1 shows the location of the gages.

Table 2.7: Active USGS streamflow gages in the Goose Creek watershed

Stream	Station ID	Location	Area (mi^2)	Period of Record	Data Gaps
Goose Creek	01643700	Near Middleburg	123	10/01/65 to present	01/29/97 to 06/27/01
Goose Creek	01644000	Near Leesburg	332	07/12/09 to present	None
NF Goose Creek	01643805	Route 729 Bridge	39	10/01/01 to present	None
Beaverdam Creek	01643880	Route 734 Bridge	19	10/01/01 to present	None

Streamflow data during the study period (1988 to 2000) were used to characterize the hydrological conditions in the Goose Creek watershed. Table 2.8 shows mean monthly streamflow in cubic feet per second (cfs) for Goose Creek from 1988 through 2001.

Table 2.8: Mean monthly streamflow (cfs) at USGS gages in Goose Creek watershed (1988 to 2001)

Month	Middleburg Gage (01643700)	Leesburg Gage (01644000)
January	232	580
February	159	488
March	323	826
April	223	531
May	126	305
June	105	217
July	53	114
August	59	140
September	72	167
October	88	186
November	107	267
December	207	444

From the table it is evident that the highest mean monthly flows in Goose Creek occur during the months of December through April, which is typical for watersheds in the Eastern United States. The lower flows typically occur during the months of May through November.

Table 2.9 shows the mean annual streamflow at the Goose Creek gages from 1988 through 2001. For the period of record at each gage, mean streamflow at Middleburg is approximately 136 cfs and at Leesburg the mean streamflow is approximately 318 cfs. These represent “average” conditions at the respective gaging stations.

The period of 1988 through 2001 recorded near-average streamflow conditions for the years of 1990 and 1992. Streamflow conditions during 1988, 1989, 1991, 1995, 1997, 1999, 2000, and 2001 were all slightly below or well below average conditions. Streamflow conditions during 1993, 1994, 1996, and 1998 were all slightly above or well above average conditions.

Table 2.9: Mean annual streamflows (cfs) at the USGS gages in the Goose Creek watershed (1988 to 2001)

Year	Middleburg Gage (01643700)	Leesburg Gage (01644000)	Flow Status
1988	88	252	Low
1989	108	281	Low
1990	132	343	Average
1991	89	227	Low
1992	133	362	Average
1993	174	472	High
1994	140	393	High
1995	101	264	Low
1996	270	751	High
1997	Missing Data	259	Low
1998	Missing Data	518	High
1999	Missing Data	183	Low
2000	Missing Data	211	Low
2001	Missing Data	272	Low

To better understand the impact of hydrological conditions on observed fecal coliform concentrations, the daily mean discharge record at the USGS gage near Leesburg was separated into its baseflow and stormflow components using HYSEP, a USGS software package which automates hydrograph separation of gage records (USGS, 1996). HYSEP can use a number of methods to perform baseflow separation. The local-minimum method was used in this case. The local minimum method calculates baseflow using a straight-line interpolation between local minima in flow. Figure 2.2 gives an example of the resulting hydrograph separation. After the gage record at Leesburg was separated into its baseflow and stormflow components, the stormflow fraction of daily discharge was calculated. This time series was used as an index of hydrological conditions for the whole Goose Creek watershed. In other words, it was assumed that the fraction discharge that was stormflow at the USGS gage was a good indicator of the fraction of discharge that was stormflow at ungaged locations in the watershed.

2.4.2 Water Quality Monitoring Data

VADEQ has sampled water quality at 11 monitoring stations on Goose Creek and its tributaries. Table 2.10 gives the station ID number, the stream name, and the corresponding model segment for each station. The total number of bacteria observations collected and the number of observations after 1992 are also given. Data collected from in-stream fecal coliform sampling conducted at VADEQ monitoring stations were analyzed and impairments were noted beginning in the early 1990s. The 1996 assessment period was from April 1, 1993 to March 31, 1995. The 1998 assessment period was from July 1, 1992 to June 30, 1997. The 2002 assessment period was from January 1, 1996 to December 31, 2000. Samples were taken by VADEQ for the purpose of determining whether or not the instantaneous standard of 1,000 cfu/100 mL was being met. The figures in Appendix A show (1) the time series of fecal coliform bacteria observations collected by VADEQ; (2) seasonal geometric means at the VADEQ monitoring stations; and (3) the relationship between discharge at the USGS gage on Goose Creek near Leesburg and observed fecal coliform concentrations at the VADEQ monitoring stations.

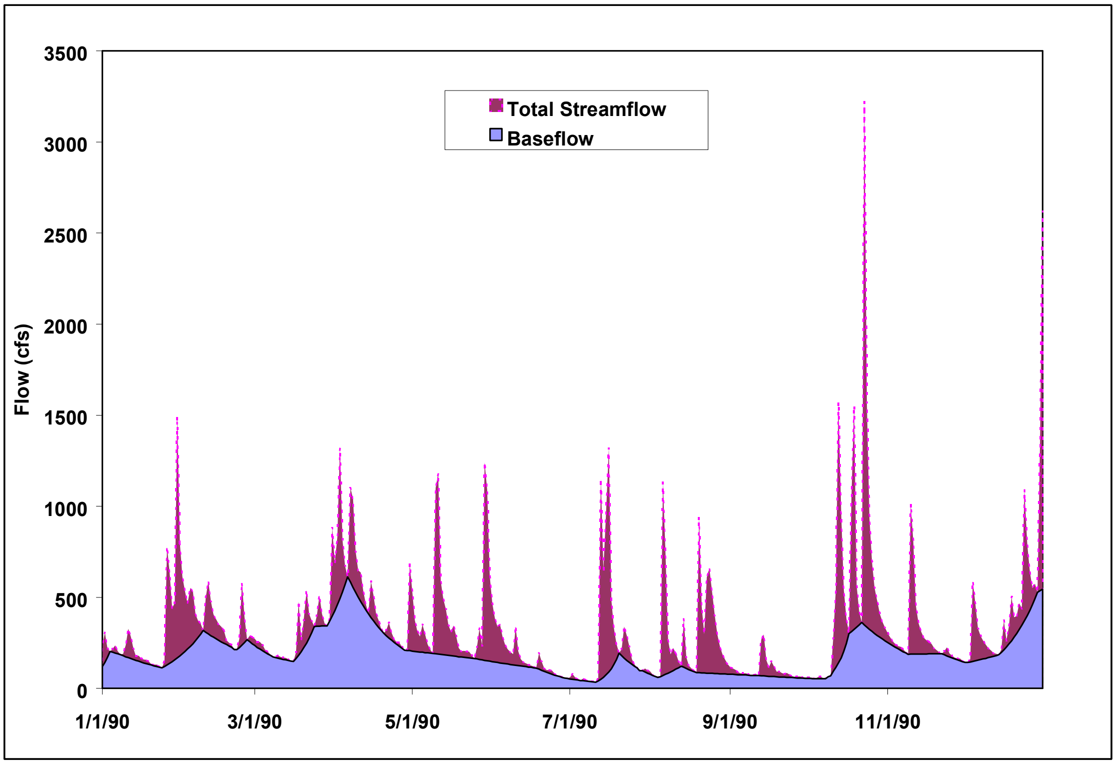


Figure 2.2: Hydrograph separation for Leesburg gage (1990)

Table 2.10: Water quality monitoring station information in Goose Creek watershed

Station ID	Stream Name	Segment	Number of Bacteria Observations after 1992	Total Observations through 2000
1ACRM001.20	Cromwells Run	200	22	22
1AGOO022.44	Goose Creek	190	50	50
1ANOG005.69	N. Fork Goose Creek	140	36	194
1ABEC004.76	Beaverdam Creek	180	37	63
1ALIV004.78	Little River	160	40	40
1ASYC007.43	N. Fork Sycolin Creek	250	12	13
1ASYC004.93	Upper Sycolin Creek	230	10	10
1ASFS000.28	S. Fork Sycolin Creek	240	11	11
1ASYC002.03	Middle Sycolin Creek	100	40	40
1ATUS000.37	Tuscarora Creek	30	41	216
1AGOO002.38	Goose Creek near mouth	20	106	243

During the study period, the method of analysis for fecal coliform bacteria used by VADEQ changed. Prior to February 1995, the Most Probable Number (MPN) method was used for analyzing water samples for fecal coliform bacteria. The MPN uses a series of dilutions to statistically determine the most probable number of fecal coliform bacteria in the original water sample. The MPN method has a maximum detection limit of 8,000 cfu/100 mL. After February 1995, VADEQ switched to a more accurate fecal coliform analysis technique called the Membrane Filtration Technique (MFT). The MFT uses a 0.45 µm filter to capture colony forming units from a water sample. The colony forming units are allowed to form individual colonies in a growth medium and are later counted to determine the number of units per volume of water. The MFT has a maximum detection limit of 16,000 cfu/100 mL.

Additional fecal coliform monitoring has been performed by the Loudoun County Soil and Water Conservation District since 1999. These data were not included in VADEQ's assessment of Goose Creek, but were used here to analyze trends in fecal coliform concentrations and to verify the calibrated fecal coliform simulation model. Table 2.11 shows the location of the LCSWCD stations used in this analysis and the number of observations collected at each location. LCSWCD and other citizen monitoring groups have collected data at additional locations. This data will be incorporated into the implementation plans for the TMDLs.

Table 2.11 Loudoun County Soil and Water Conservation District Stream Monitoring Stations

Site Number	Segment	Location	Number of Observations
1	150	Stoke	11
2	150	Aldie Dam	11
4	180	Route 731	11
6	140	Route 611	11

ICPRB analyzed the observed fecal coliform monitoring data to determine if any temporal and seasonal trends existed or if a relationship existed between observed concentrations and storm events or streamflow conditions. To evaluate the water quality data for annual and seasonal trends as well as relationships to streamflow, ICPRB employed the regression component of the Adjusted Maximum Likelihood Estimator (AMLE) model developed by Cohn (1988). AMLE is used by the USGS and others to estimate the loads of constituents at gaged locations given a time series of observed concentrations. The AMLE is represented by the following equation:

$$\mathrm{Ln}(C) = \beta_0 + \beta_1 \mathrm{Ln}[Q] + \beta_2 \mathrm{Ln}[Q]^2 + \beta_3 T + \beta_4 T^2 + \beta_5 \mathrm{Sin}[2\pi T] + \beta_6 \mathrm{Cos}[2\pi T] + \beta_7 F_r + \varepsilon$$

Where:
- β_0 = regression constant
- $\beta_{1\text{-}7}$ = regression coefficients
- C = fecal coliform concentration (cfu/100 mL)
- Q = streamflow (cfs)

T	=	time (days)
F_r	=	HYSEP estimate of runoff fraction of streamflow
ε	=	regression error term

The β_1 and β_2 terms correspond to variability related to flow dependence, the β_3 and β_4 terms correspond to time trends, and the β_5 and β_6 terms are used to fit a first order Fourier series to the seasonal component of variability. The β_7 term, which is shown in italics, was added to the original model by ICPRB to isolate any relationships that may exist between fecal coliform concentrations in water and the fraction of streamflow that is runoff from storm events.

The AMLE model was run using S-PLUS software as a backward regression model. Table 2.12 shows the results of the application of the AMLE model to VADEQ fecal coliform bacteria data. The results of the AMLE model show that two significant relationships exist for fecal coliform concentrations in streamwater in Goose Creek and its tributaries. The first significant relationship is between the $\beta_6\text{Cos}[2\pi T]$ term and fecal coliform, which is statistically significant for all stations except Tuscarora Creek (1ATUS000.37). In general, the negative coefficient attached to the cosine term indicates a seasonal trend. Specifically, observed fecal coliform concentrations in the Goose Creek watershed are typically highest during the summer months of June, July, and August. The second significant relationship indicates that the β_7F_r term is positively correlated with fecal coliform concentrations for all stations. The positive relationship indicates that higher observed fecal coliform concentrations occur when runoff becomes a higher fraction of total streamflow. These important relationships were built into the model development and calibration procedures.

Table 2.12: Regression results of the AMLE model

Station ID	β_0	β_1	β_2	β_3	β_4	β_5	β_6	β_7	R^2
1ABEC004.76	1.98						-0.33	1.50	0.47
1ANOG005.69	2.39						-0.62	0.52	0.37
1ASYC002.03	2.17						-0.31	0.98	0.24
1ATUS000.37	2.12							0.70	0.11
1AGOO022.44	1.76		0.07				-0.21	0.65	0.27
1AGOO002.38	1.58			0.13	-0.01	-0.13	-0.17	1.21	0.33
1ALIV004.78	2.35						-0.39	1.24	0.52
1ACRM001.20	1.43	0.31					-0.27	1.32	0.62

2.4.3 Bacteria Source Tracking Analysis

Bacteria source tracking (BST) is a recent methodology developed to determine the origin of fecal coliform bacteria from streamwater samples. BST has been successfully used in previous Virginia TMDLs to identify general source categories of fecal coliform bacteria such as human, livestock, and wildlife. Depending on the methods chosen, BST can be used to statistically relate unknown fecal coliform samples to individual sources (e.g. human, cattle, horse, deer, etc.). There are three major groups under which BST methods can fall: molecular, biochemical, and chemical. These methods are described by Hagedorn (2002) as follows:

> Molecular methods are referred to as 'DNA fingerprinting' and are based on the unique genetic makeup of different strains, or subspecies, of fecal bacteria. Biochemical (phenotype) methods are based on an effect of an organism's genes that actively produce a biochemical substance. The type and quantity of these substances produced is what is actually measured. Chemical methods are based on finding chemical compounds that are associated with human wastewaters, and would be restricted to determining is sources of pollution were human or not. (Hagedorn, 2002)

ICPRB worked with Dr. Bruce Wiggins of James Madison University and Engineering Concepts, Inc. to conduct BST analyses in the Goose Creek watershed. The method chosen by Dr. Wiggins was a biochemical analysis called antibiotic resistance analysis (ARA). ARA assumes that the sources of fecal coliform bacteria can be correlated with the resistance of bacteria to antibiotics. Generally, fecal coliform bacteria from human sources are most resistant to antibiotics, those from livestock and domestic animals less resistant, and those from wildlife the least resistant. A statistical technique called discriminant analysis is used to classify the response of bacteria to antibiotics. Bacteria from known sources are first used to determine a classification scheme. That scheme is then applied to unknown samples taken from the water column.

Engineering Concepts, Inc. collected known fecal samples from the following potential sources in the Goose Creek watershed: beef cattle, deer, dogs, horses, humans, and geese. The number of samples collected from the Goose Creek watershed proved too small to obtain a statistically significant classification scheme. The Goose Creek samples were added to a regional "library" of known samples collected from sources in Virginia. The regional library proved adequate to classify water column samples taken for the BST analysis.

VADEQ sampled 11 sites throughout the Goose Creek watershed on a monthly basis from September 2001 through July 2002. Table 2.13 describes the stations that were sampled and their location.

Table 2.13: Stations used in BST analysis

Station ID	Stream Name
1AGOO044.36	Upper Goose Creek
1ACRM001.20	Cromwells Run
1AGOO022.44	Middle Goose Creek
1ANOG005.69	North Fork Goose Creek
1ABEC004.76	Beaverdam Creek
1ALIV004.78	Middle Little River
1ALIV001.70	Lower Little River
1AGOO011.23	Goose Creek at Leesburg gage
1ASYC002.03	Middle Sycolin Creek
1ATUS000.37	Tuscarora Creek
1AGOO002.38	Goose Creek near mouth

The period over which sampling occurred was characterized by very low flows. Sampling caught two storm events at half the stations; at the other half only low flow events were captured. Only the samples collected during storm events had fecal coliform concentrations above 1,000 cfu/100 ml. Because the majority of samples were collected under low flow conditions, the BST analysis may not be fully representative of all the hydrological conditions that occur in the Goose Creek watershed.

The results of the BST analysis can be summarized as follows:

- Beef cattle and deer were the most frequently detected sources of fecal coliform bacteria. They were detected at all stations and were frequently the dominant source in a sample. Beef cattle were the dominant source in the samples collected during a March storm event.
- Bacteria from human sources were detected at all stations, but were not the dominant source at any station. Bacteria from human sources dominated the sampling in September at nearly all stations. For half these stations, the September sample was collected during a storm event.
- Bacteria from geese were detected at all sites but barely above the level of statistical significance.
- Bacteria from horses were detected at all sites but in less than a third of the samples.
- Bacteria from dogs were infrequently detected above a statistically significant level.

Appendix B contains the full report on the BST analysis performed for the Goose Creek TMDLs.

CHAPTER 3: BACTERIA SOURCE ASSESSMENT

3.1 Overview of Potential Sources of Fecal Coliform Bacteria

Potential sources of fecal coliform bacteria in the Goose Creek watershed were assessed using a variety of methods. The first step was to estimate the population of all warm-blooded animals in the Goose Creek watershed that were considered to be important sources of fecal coliform bacteria. Table 3.1 shows the animal populations and human sources considered to be potential sources of fecal coliforms.

Table 3.1: Sources of fecal coliform bacteria in the Goose Creek watershed

Category	Source / Animal Type
Human Sources	Failing Septic Systems
	Straight Pipes
	Point Sources (Sewage Treatment Plants)
	Biosolids Applications
Agricultural and Domestic Sources	Beef Cattle
	Dairy Cattle
	Sheep
	Dogs
	Horses
Wildlife Sources	Deer
	Raccoons
	Muskrats
	Beavers
	Turkeys
	Geese
	Ducks

Information was gathered from state agencies, county soil and water conservation districts, county health departments, citizen monitoring groups, and peer reviewed reports. The second step was to use the population information to estimate the fecal coliform produced by each potential source. The following sections discuss the sources and methods used to estimate fecal coliform loads for each of the 25 modeling segments in the Goose Creek watershed.

3.2 Human Sources

Fecal coliform bacteria from humans can be transported to streams from several different sources including failing septic systems, sewage treatment plants, and from biosolids applications to cropland and pasture.

3.2.1 Septic Systems

Properly functioning septic systems are designed to prevent exposure to pathogens in wastewater by filtering septic tank effluent through the soil. Bacteria from septic systems can enter surface water in two ways: (1) Failing septic systems allow the effluent to reach the surface, where it can drain directly into streams or be transported in runoff; (2) Bacteria from septic effluent can also enter streams through groundwater discharge if the drainfield for a system is located too close to surface water. To estimate the fecal coliform load from septic systems, it is necessary to determine (1) the number of failing systems and (2) the number of systems sufficiently close to surface water to short-circuit treatment. Systems within 50 feet of surface water are usually assumed to provide inadequate treatment of effluent. According to the Loudon County Health Department, there are no known straight pipes draining directly to surface waters in the Goose Creek watershed, although there may be systems which drain directly to ditches where the effluent is vulnerable to transport in surface runoff (Yates, 2002).

3.2.1.1 Calculation of the Number of Septic Systems

Results of a well pollution survey conducted by the Loudoun County Sanitation Authority (LCSA) were used (LCSA, 2002) to estimate the number of septic systems in the Loudoun County portion of the Goose Creek watershed. The survey digitized all potential sources of pollution to groundwater wells into a Geographic Information System (GIS). Septic systems were one of the groundwater pollutant sources included in the study and the age and location of systems built before 2001 were documented. The well pollution survey data were used to estimate the number of existing septic systems in all of the Goose Creek subwatersheds located in Loudoun County.

Population data from the 2000 U. S. Census were used to estimate the number of septic systems in Fauquier County, where a GIS layer similar to the Loudoun County was not available. The 2000 U.S. Census Bureau (USCB) census block data provided estimates of the population in each subwatershed and of the number of people per household (USCB, 2000). This information was used to estimate the number of households in the Fauquier County portion of the Goose Creek watershed and the proportion of those households using septic systems. Only two communities in the Fauquier County portion of the watershed are sewered: The Plains and Marshall; their populations were not included in the analysis.

3.2.1.2 Septic System Surveys in Loudoun County

The Loudoun County Health Department (Keeve, 1992) has conducted septic system surveys in several communities in the watershed where septic system problems were suspected to exist. Table 3.2 lists these communities, their location, the number of systems surveyed, and the number of reported failures.

According to the Loudoun County Health Department (Yates, 2002), all of the failures have been addressed or are being addressed. Most notably, a $1.2 million 0.02 million gallon per day (MGD) wastewater treatment plant was constructed for Aldie. The plant started operation in 1998. Loads from failing systems in surveyed areas were used in model calibration and verification, but were not used in the allocation scenarios because all of the identified failures will be addressed before the implementation phase of the TMDLs.

Table 3.2: Documented septic systems failures in Loudoun County

Community	Segment	Systems Surveyed	Failing Systems	Failure Rate
Hamilton	130	233[1]	24[1]	10.3%
Lincoln	130	60	16	26.7%
Bluemont	180	52	22	42.3%
Unison	180	24	1	4.2%
Willisville	190	22	12	54.6%
Aldie	160	55	11	20.0%

[1] Includes systems surveyed outside of the Goose Creek watershed; An examination of maps of surveyed area indicate 40% of the area is in the Goose Creek Watershed, so 10 failures were judged to be in Segment 130.

3.2.1.3 Estimation of Septic System Failure Rates Outside of Surveyed Areas

Outside of the surveyed areas, the soils in the Loudoun County portion of the watershed are considered good for septic systems. From their records of permits for repairing systems, the Health Department estimates a septic system failure rate of 0.5% outside of the surveyed areas (Yates, 2002).

Similar information on failure rates is not readily available for the Fauquier County portion of the watershed, but the Fauquier County Health Department confirmed that soils in the watershed are more than adequate for septic systems and endorsed the 0.5% failure rate estimated for Loudoun County (Largent, 2002).

The BST study conducted for the Goose Creek TMDLs indicates, however, that fecal coliforms from human sources are widespread in the watershed and that human sources could even be the dominant source for some storm events. Previous TMDLs developed in Virginia have used a formula to estimate septic system failures based on the age of the systems (BSE, 2000a,b, c). Based on extensive fieldwork, the formula assumes 40% of the systems built before 1964, 20% of the systems built between 1964 and 1984, and 5% of the systems built after 1984 to be failing. The age of septic systems in Loudoun County was available in the LCSA well pollution GIS layer, so the formula was used to estimate failure rates in the Loudoun County portion of the watershed. The estimated failure rates were as high as 17% for some subwatersheds, thirty-five times the estimate provided by the Health Department. To take into account both the results of the BST study and the professional judgment of the local health departments, a 5% failure rate was used anywhere in the watershed where septic system surveys had not been performed.

3.2.1.4 Estimation of Septic Systems With 50 Feet of Surface Water

In Loudoun County, the well pollution GIS layer was used to estimate the number of septic systems located within 50 feet of the stream. Because similar information was not available in Fauquier County, the proportion of septic systems located within 50 ft of a stream was calculated for the Loudoun County portion of the Goose Creek watershed.

This proportion was then applied to the total number of septic systems in the Fauquier County portion of the watershed to estimate the total number of septic systems within 50 feet of a stream.

Table 3.3 shows the total number of septic systems and estimated septic system failures by modeling segment. It also shows the estimated number of septic systems located within 50 feet of the stream. Failing septic systems were considered loads applied to land surfaces and delivered to the stream in runoff. Septic systems within 50 feet of a stream were considered continuous loads delivered directly to the stream. Only 0.001% of the load from these systems is assumed to reach surface water in ground water discharge (MapTech, 2002).

Table 3.3: Failing septic systems in Goose Creek watershed

Segment	No. Septic Systems	No. Failing Systems	No. Systems < 50 feet from stream
10	42	2	0
20	24	1	0
30	290	15	0
40	7	0	0
50	2	0	0
60	16	1	0
70	68	3	0
80	118	6	0
90	41	2	0
100	182	9	1
110	139	7	1
120	126	6	0
130	818	59	3
140	957	48	5
150	271	14	0
160	637	40	3
170	141	7	0
180	1,188	79	9
190	317	27	1
200	335	17	2
210	427	21	2
220	947	47	5
230	23	1	0
240	38	2	0
250	189	10	0
Totals	7,343	424	32

3.2.2 Point Sources

Point sources of fecal coliform bacteria in the Goose Creek watershed include all municipal and industrial plants that treat human waste, as well as private residences that fall under general permits. Virginia issues National Pollutant Discharge Elimination

System (NPDES) permits for point sources of pollution. In Virginia, point sources that treat human waste are required to maintain a geometric mean of 200 counts of fecal coliform bacteria per 100 milliliters of water or less in their effluent. Tables 3.4 (VPDES permits) and 3.5 (General permits) show the point sources of pollution in the Goose Creek watershed that are permitted by VADEQ to discharge fecal coliform into surface water. To represent existing conditions, point sources were assumed to discharge fecal coliforms at a concentration of 20 cfu/ 100 ml. This assumption was based upon average fecal coliform concentrations reported in monthly VADEQ Discharge Monitoring Reports (DMRs). In allocation scenarios, the entire allowable point source discharge concentration of 200 cfu/100 mL was used.

Table 3.4: VPDES permitted point sources of fecal coliform bacteria in the Goose Creek watershed

Facility	City	Permit No.	Receiving Stream	Segment
Purcellville STP	Purcellville	VA0022802	NF Goose Creek UNT	140
Foxcroft School	Middleburg	VA0024112	Goose Creek	190
US FEMA – Bluemont	Bluemont	VA0024759	Jeffries Branch UNT	210
Middleburg WWTP	Middleburg	VA0024775	Wancopin Creek	190
Round Hill WWTP	Round Hill	VA0026212	NF Goose Creek	140
Notre Dame Academy	Middleburg	VA0027197	Goose Creek UNT	190
St. Louis Community	St. Louis	VA0062189	Beaverdam Creek UNT	180
Rehau Plastics, Inc.	Leesburg	VA0065200	Cattail Branch UNT	10
Goose Creek Industrial Park WWTP	Leesburg	VA0080993	Sycolin Creek	40
Aldie WWTP	Aldie	VA0089133	Little River	150

Table 3.5: VA General permits for fecal coliform discharge in the Goose Creek watershed

Facility	City	Permit No.	Receiving Stream	Segment
Residence	Leesburg	VAG406015	Sycolin Creek	100
Business	Bluemont	VAG406016	Butcher's Branch	180
Residence	Middleburg	VAG406018	Goose Creek, UNT	190
Residence	Aldie	VAG406019	Hungry Run	160
Residence	Leesburg	VAG406020	Sycolin Creek, UNT	100
Residence	Leesburg	VAG406047	Sycolin Creek	100
Residence	Middleburg	VAG406069	Goose Creek, UNT	190
Residence	Leesburg	VAG406101	Sycolin Creek, UNT	100
Residence	Leesburg	VAG406113	Sycolin Creek	100
Residence	Middleburg	VAG406115	Dog Branch Creek	180
Residence	Bluemont	VAG406116	Butcher's Branch	180
Residence	Leesburg	VAG406121	Sycolin Creek	100
Residence	Bluemont	VAG406135	Butcher's Branch	180
Residence	Bluemont	VAG406143	Butcher's Brunch	180
Residence	Purcellville	VAG406146	Jack's Run	140
Residence	Bluemont	VAG406149	Butcher's Branch, UNT	180
Residence	Linden	VAG406170	Goose Creek, UNT	220
Business	Leesburg	VAG406172	Sycolin Creek	250
Residence	Round Hill	VAG406176	Simpson Creek, UNT	140
Residence	Marshall	VAG406193	Woolfs Mill Run	210
Residence	Leesburg	VAG406244	Dry Mill Branch, UNT	30

UNT = Unnamed Tributary

3.2.3 Biosolids

Class B biosolids in the Goose Creek watershed are applied to both cropland and pasture (McMahon, 2002). Most of the biosolids are generated outside of the watershed, primarily in the metropolitan Washington region, although the Town of Leesburg applied between 250 and 400 dry tons from its wastewater treatment plant to approximately 150 acres during the simulation period. Table 3.6 shows the estimated annual average application rate by segment. The rate varies considerably by year and even more so by month. The table is based on information supplied by Synagro, the primary biosolid distributor in the watershed during the study period, and by the Town of Leesburg.

Table 3.6: Estimated Annual Biosolid Application Rates (dry tons/year)

Segment	1996	1997	1998	1999	2000	Annual Average
30				273		55
70			972	123		219
80			985	848		367
100	309	1,272	1,579	296	299	751
120			302		744	209
130		51	105			31
140				1,383		277
180				620		124
250		921		660		316
Total	309	921	3,943	2,663	1,043	2,349

Note: Segments not listed in table did not have biosolids applications during the simulation period.

Although Class B biosolids are permitted to contain fecal coliform concentrations of 2,000,000 cfu/g, The concentration of fecal coliform bacteria in biosolids from Blue Plains, the largest wastewater treatment plant in the Washington metropolitan area, is estimated to be less than 2,000 cfu/g (MapTech, 2002). The Town of Leesburg estimates that their Class B biosolids contain 10,000 cfu/g (Rockholt, 2002). To isolate their impacts, biosolids were assumed to be applied only to cropland, although in practice they are also applied to pasture.

In 1999, Loudoun County adopted a new biosolids ordinance. The application of Class B biosolids to agricultural land now requires a county permit. The county requires the implementation of strict controls to prevent the transport of pollutants in runoff from fields where biosolids have been applied.

3.2.4 Pets

While pets are a separate source of fecal coliform from human sources, they were included in the human sources section because their population is strongly correlated to the human population. Pet populations, which include dogs and cats, were quantified using estimates of pets per household reported by the American Veterinary Medical Association (AVMA). According to national AVMA estimates, there are 0.534 dogs per household and 0.598 cats per household (AVMA, 2002). Table 3.7 shows pet population estimates for the Goose Creek watershed.

The BST study found little evidence that bacteria from dogs were entering surface water. Cats are even less likely to be a source than dogs, since many cats remain indoors and those who spend all or part of their time outdoors tend to bury, or at least cover, their waste. For these reasons, cats were not modeled as a source of fecal coliform bacteria. Dog waste was assumed to be found in pasture, cropland, and developed land.

Table 3.7: Estimated pet population in the Goose Creek watershed

Segment	Human Population	Households	Dog Population	Cat Population
10	9,862	3,255	1,738	1,946
20	188	73	39	44
30	16,969	6,262	3,344	3,744
40	706	229	122	137
50	0	2	0	0
60	20	7	4	4
70	216	77	41	46
80	287	102	55	61
90	0	41	0	0
100	612	216	115	129
110	286	107	57	64
120	190	78	42	47
130	3,974	1,409	753	843
140	3,824	1,342	716	802
150	717	271	144	162
160	1,536	637	340	381
170	386	145	77	86
180	2,955	1,154	616	690
190	1,959	844	451	505
200	805	335	179	201
210	1,008	427	228	255
220	2,349	947	506	566
230	236	83	45	50
240	26	9	5	5
250	539	190	102	14
Totals	49,650	18,243	9,719	10,782

3.3 Agricultural Sources

Agriculture in Loudoun County has changed significantly over the past decade, according to staff of the Loudoun County Soil and Water Conservation District (LCSWCD). Confined cattle operations have disappeared. Beef cattle are generally kept in improved pasture. The number of dairy farms has greatly diminished. The population of horses has dramatically increased; many households own a small number of horses for recreational use. Beef cattle and horses are by far the predominant livestock in the watershed. While the changes have not been as dramatic in the Fauquier County portion of Goose Creek watershed, the horse population is increasing in the Little River subwatershed and in other areas of the watershed east of Route 15.

Livestock population estimates for the Fauquier County portion of the Goose Creek watershed took, as their starting point, the estimate of livestock populations prepared for DCR's 1995 Hydrologic Unit Planning Questionnaire by the John Marshall Soil and Water Conservation District (JMSWCD). Since the Goose Creek watershed segments are smaller than DCR's hydrologic units, JMSWCD provided a further breakdown of animals where necessary.

For the portion of the Goose Creek watershed in Loudoun County, LCSWCD estimated horse, beef cattle, dairy cattle, and sheep populations for current conditions. DCR's 1995 Hydrological Unit survey formed the basis of estimating livestock populations in the mid-1990s, when the monitoring which formed the basis for listing many of the Goose Creek tributaries took place. LCSWCD staff identified dairy operations that existed at that time, the size of their herds, and their waste management practices. They also provided a breakdown by watershed of beef cattle populations and confined animal feeding operations where necessary.

3.3.1 Dairy Cattle

There were ten dairy operations in the Goose Creek watershed in the early 1990s. Currently, there are only two, one in the Crooked Run watershed in Segment 130, and one in Segment 160, in northern Fauquier County. Table 3.8 gives the number of milking cows, dry cows, and heifers in their herds (LCSWCD, 2002). Table 3.9 gives a breakdown of the number of hours per day that dairy cattle spend in confinement, pasture, or in stream. Neither existing dairy stores the waste from confined animals; both haul the waste daily from confined areas and spread it on fields. Dairy waste in Segment 160 is applied to pasture. Dairy waste in Segment 130 is applied to cropland September through April, and to pasture the remainder of the year. The crop grown is no-till corn.

Table 3.8: Estimated current population of milk cows, dry cows, and heifers in the Goose Creek watershed

Segment	Watershed	Milk Cows	Dry Cows	Heifers	Totals
130	NF Goose Creek	80	8	112	200
160	Little River	85	9	150	244

Table 3.9: Estimated time spent in confinement and in stream for dairy cattle[1]

Month	Hours Per Day in Confinement (Milk cows only)	Hours Per Day in Stream (All cattle)	Hours Per Day in Pasture (All Cattle)	Total Hours
January	18	0.5	5.5	24
February	18	0.5	5.5	24
March	9.6	0.5	13.9	24
April	7.2	0.77	16.03	24
May	7.2	0.6	16.2	24
June	7.2	1	15.8	24
July	7.2	1	15.8	24
August	7.2	1	15.8	24
September	7.2	0.77	16.03	24
October	7.2	0.6	16.2	24
November	9.6	0.5	13.9	24
December	18	0.5	5.5	24

[1] **LCSWCD, 20002 and JMSWCD, 2002**.

Table 3.10 gives an estimated breakdown of the distribution of waste from dairy herds in the mid-1990s. Table 3.11 gives the number of confined animals under each type of waste management practice. It was assumed that dairy waste hauled daily was applied to cropland and pasture according to the schedule for the existing dairy in Segment 130. Stored dairy waste was spread twice a year on cropland, in November and February. A bacterial die-off rate in storage of 0.375/day was assumed for waste stored as a slurry and 0.066/day for dry storage (BSE, 2000). It was assumed that dry cows and heifers deposited their waste onto pastureland and directly into the stream according to the amount of hours spent in both places (Table 3.9).

Table 3.10: Estimated 1995 population of dairy cattle

Segment	Confined Animals	Unconfined Animals in Pasture		Total Cows
	Milk Cows	Dry Cows	Heifers	
130	80	8	112	200
140	390	40	585	1015
150	150	15	225	390
160	175	17	260	452
180	250	25	375	650
250	100	10	150	260

Table 3.11: Waste treatment methods applied to confined milk cow population

Segment	Population of Milk Cows			
	Daily Haul With Pasture Application	Daily Haul With Crop Application	Slurry	Dry Storage
130	0	80	0	0
140	0	20	280	90
150	0	0	150	0
160	150	25	0	0
180	0	250	0	0
250	0	100	0	0

3.3.2 Beef Cattle

Table 3.13 presents estimates of the current annual average beef cattle population and the population circa 1995. The population is seasonal, with many beef cattle shipped out for finishing outside of the watershed. The JMSWCD estimates that only 25% of the cattle remain in Fauquier County from October 15 to April 15, while the LCSWCD estimates that the cattle population in the Loudoun County portion of the watershed drops to 70% of the summer maximum during that same period. Some operations increase their herds over the winter, but overall the beef cattle population in the Goose Creek watershed is highest during the summer.

Currently, there are no permanent confined animal operations in the watershed. Cattle are kept in pasture. In Fauquier County, pasture is better maintained west of Route 17, which may be responsible for the lower rate of water quality violations in Goose Creek upstream of Middleburg. There were confined beef cattle operations in Segment 140, the

North Fork of Goose Creek, and Segment 180, Beaverdam Creek, until the drought of 1999. Detailed information on their operations is not available.

Beef cattle generally have ready access to streams. The implementation of stream bank fencing has increased in the last few years but not significantly over the simulation period (LCSWCD, 2002). According to JMSWCD personnel and seconded by LCSWCD staff, cattle make two trips to the stream per day during the summer and stay for about a half an hour each time. During the winter, the time cattle spend in stream drops to a matter of minutes per day. Table 3.12 gives the average number of hours per day cattle spend in pasture and streams by month. Thirty percent of the cattle are presumed to deposit waste while they are in the stream (BSE, 2000).

Table 3.12: Estimated time spent in confinement and in stream for beef cattle

Month	Hours Per Day in Stream (All cattle)	Hours Per Day in Pasture (All Cattle)	Total Hours
January	0.05	23.95	24
February	0.05	23.95	24
March	0.5	23.5	24
April	0.77	23.23	24
May	0.6	23.4	24
June	1	23	24
July	1	23	24
August	1	23	24
September	0.77	23.23	24
October	0.6	23.4	24
November	0.5	23.5	24
December	0.05	23.95	24

3.3.3 Horses

Table 3.13 also gives estimates of the current horse population in the watershed and the population circa 1995. In contrast to the beef and dairy cattle populations, the horse population in the Goose Creek watershed is growing. Horses are the dominant livestock population in portions of Fauquier County according to representatives from JMSWCD. These areas include the Little River watershed and most of Cromwells Run, although cattle are dominant in the headwaters of Cromwells Run. Loudoun County has the largest population of horses in Virginia (St. Clair, 2002). In Loudoun County, the number of pasture acres per horse decreases moving westward. East of Route 15, there is about 1 acre of pasture per horse, in the North Fork of Goose Creek the ratio is about 1.5 acres per horse, and in Beaverdam Creek the ratio is 2 acres per horse. It was assumed that horses typically deposit their waste onto pastureland and have little if any access to streams.

3.3.4 Other Livestock

Beef cattle and horses are by far the dominant livestock populations in the watershed. The population of sheep is also significant and has stayed relatively constant over the simulation period. Table 3.13 gives the sheep population by model segment. The populations of poultry, swine, and other livestock are insignificant compared to cattle, horses, and sheep.

Table 3.13: Beef cattle, horse, and sheep population estimates for the Goose Creek watershed

Segment	Beef Cattle		Horses		Sheep	
	1995	2002	1995	2002	1995	2002
10	112	20	27	20	4	10
20	70	0	17	0	2	0
30	629	250	152	200	22	100
40	94	0	23	10	3	0
50	8	0	2	0	0	0
60	96	10	23	10	3	0
70	287	50	69	20	10	0
80	357	300	86	50	13	50
90	95	0	23	20	3	0
100	200	200	108	150	50	50
110	460	300	111	250	16	0
120	823	500	245	400	31	150
130	1,453	1,000	689	500	51	0
140	1,782	2,000	845	1,500	63	0
150	914	1,200	221	500	32	0
160	1,800	2,500	1,157	3,500	85	85
170	499	500	198	400	12	0
180	4,370	3,000	1,735	2,500	103	0
190	3,428	3,993	725	2,000	110	0
200	675	675	2,122	2,122	120	120
210	10,914	10,914	923	923	249	249
220	11,000	11,000	400	400	50	50
230	50	50	25	50	0	0
240	50	50	34	150	0	0
250	800	200	71	200	150	150
Totals	40,966	38,712	10,031	15,875	1,182	1,064

3.4 Wildlife Sources

Fecal coliform bacteria from wildlife can be delivered to streams through direct deposition of waste into streams and also through deposit of waste to the land surface where it is susceptible to runoff transport. The wildlife sources analyzed in the Goose Creek watershed include deer, raccoons, muskrats, beavers, turkey, geese, and ducks.

Because no intensive wildlife population surveys were available for the Goose Creek watershed, all wildlife populations were estimated using empirical relationships to typical habitat types provided by VADGIF. Table 3.14 shows the estimates of wildlife density by wildlife type and the source of the information from VADGIF.

Table 3.14: Wildlife density and habitat estimates with VADGIF sources

Animal	Density	Habitat	VADGIF Source
Deer	0.084 / acre	Forest, pasture, cropland, urban pervious	Matt Knox, 2002
Raccoon	0.070 / acre	Within 0 to 600 feet from continuous streams	Randy Farrar, 2002
Muskrat	2.750 / acre	Within 0 to 66 feet from continuous streams	Randy Farrar, 2002
Beaver	4.800 / mile	Continuous streams	Randy Farrar, 2002
Turkey	0.010 / acre	Forest	Norman and Lafon, 1998
Goose	0.020 / acre	Within 0 to 66 feet from continuous streams	Gary Costanzo, 2002
Duck	0.008 / acre	Within 0 to 66 feet from continuous streams	Gary Costanzo, 2002

Using the habitat information provided in the table, potential habitat maps were developed using GIS to estimate wildlife populations for each subwatershed. Table 3.15 shows the estimated wildlife populations by segment in the Goose Creek watershed.

Table 3.15: Estimated wildlife population in Goose Creek watershed

Segment	Deer	Raccoon	Muskrat	Beaver	Turkey	Goose	Duck
10	239	120	304	29	13	66	26
20	84	46	154	12	5	22	9
30	678	365	1,057	102	32	184	73
40	116	63	239	18	6	30	12
50	22	23	154	6	1	9	3
60	132	76	430	22	8	32	13
70	308	62	2	47	17	74	29
80	325	148	324	46	17	78	31
90	92	47	176	13	5	23	9
100	355	161	438	41	17	85	34
110	451	208	444	69	24	108	43
120	431	207	708	58	24	102	41
130	1,102	473	1,204	143	54	263	105
140	1,254	568	1,585	172	58	302	121
150	777	375	1,147	98	38	187	75
160	1,403	1,011	3,487	243	110	517	207
170	337	161	562	37	17	80	32
180	2,550	1,125	2,770	322	120	605	242
190	1,045	507	1,664	147	49	252	101
200	1,012	467	1,368	121	45	242	97
210	2,280	851	1,981	278	106	545	218
220	2,743	1,812	4,677	487	231	1,014	406
230	81	37	100	9	4	19	8
240	114	52	141	13	5	27	11
250	233	106	288	27	11	56	22
Totals	18,164	9,071	25,404	2,560	1,017	4,922	1,968

Wildlife access to the stream was an important consideration in estimating the amount of fecal coliform from wildlife that is delivered directly to streams. Table 3.16 shows the percent of time that wildlife has stream access on a daily basis (Map Tech, 2002).

Table 3.16: Percent of time that wildlife have access to the stream

Animal	Percent of Time with Stream Access
Deer	5%
Raccoon	5%
Muskrat	90%
Beaver	100%
Turkey	5%
Geese	50%
Duck	75%

It was estimated that fecal matter produced within stream access areas was directly deposited into streams about 5% of the time. One exception to this assumption is beavers, which were assumed to deposit 100% of their fecal waste into streams.

3.5 Load Estimates

The total load of fecal coliform produced per day in the Goose Creek watershed can be calculated by multiplying the population of each species by the per capita fecal coliform production rate. Table 3.17 shows average animal weight and the daily per capita bacteria production rate used to estimate loads.

Per capita fecal coliform production rates for beef cattle and horses were taken from the Mountain Run TMDL (Yagow, 2002). These are empirically-based estimates were taken from livestock in a watershed in the Piedmont region of Virginia. Another fecal coliform TMDL in Fauquier County, Thumb Run (GKY, 2002), used these same rates. Because of the large reduction in the dairy cattle population over the course of the simulation, the same production rate was used for both dairy cattle and beef cattle. Production rates for sheep were taken from ASAE (ASAE, 2001) estimates used in previous Virginia fecal coliform TMDLs (BSE 2001a, b, c, 2002).

Per capita fecal coliform production rates for wildlife for the most part were also taken from the Mountain Run TMDL. These were also used in Thumb Run and previous Virginia TMDLs. The one exception was the duck fecal coliform production rate. Previous TMDLs used the ASAE production rate, 2.5×10^{9} cfu/ animal/day. This rate is among the highest reported for any animal despite the relatively small body weight of ducks. The ASAE estimate, however, is based on only six samples with a standard deviation as large as the mean value. The geometric mean of the ASAE value and the value of 5.3×10^{5} cfu/ animal/day determined in the Catoctin Creek TMDLs (Map Tech, 2002) was used to estimate the contribution by ducks to fecal coliform loads.

Table 3.17: Average weight and fecal coliform production by source type

Animal	Average Weight (lbs)	Average Fecal Coliform Production (bacteria/capita/day)
Cattle	1,000	2.07E+10
Horse	1,000	2.34E+08
Sheep	60	1.47E+10
Deer	120	3.47E+08
Beaver	45	5.06E+06
Raccoon	15	1.18E+08
Muskrat	2.5	2.50E+07
Turkey	11	3.80E+06
Goose	10	1.30E+08
Duck	2.5	5.05E+07
Human	150	1.95E+09
Dog	10	4.50E+08

Table 3.18 shows the total number of fecal coliform bacteria produced by each species per segment. On a daily basis, cattle produce the highest amount of fecal coliform bacteria, followed by human beings. Of the wildlife species, deer produce the most bacteria per day.

Fecal coliform bacteria can enter Goose Creek and its tributaries through two major pathways: direct delivery to the stream and delivery in stormwater runoff. First, fecal wastes and their associated bacteria can be deposited directly into the water by animals defecating in the stream, through discharges from wastewater treatment plants, from septic systems whose drainfields are within 50 feet of the stream, and through limited groundwater discharge. Table 3.19 shows the average daily load associated with these direct sources. Of the direct sources, beef cattle are the primary contributor of bacteria to the stream.

Fecal waste deposited on the land can be transported to streams when runoff occurs. Tables 3.20 through 3.23 quantify the average daily bacteria load to the land surface of pasture, cropland, developed land, and forest, respectively. Beef cattle are the dominant source of fecal coliform deposited on pasture. Deer are the dominant source on forest, and failing septic systems are the dominant source on developed land in most segments. Applied dairy cattle waste tends to be the dominant source of bacteria on cropland when and where they are present, but currently dairy waste is only applied to cropland in Segment 130. Biosolids are the dominant source only in Segment 250; otherwise, their contribution on average is less than wildlife.

Most of these bacteria die off on the land surface and are not transported to the stream in runoff. One of the primary purposes of modeling the fate and transport of fecal coliform bacteria is to quantify the bacteria load delivered to the stream in runoff from forest, fields, and other land-based sources.

Table 3.18: Number of fecal coliform bacteria produced by each species per modeling segment

	1995			Current			Current										Totals	
Segment	Beef	Dairy	Horse	Beef	Dairy	Horse	Sheep	Deer	Beaver	Raccoon	Muskrat	Turkey	Goose	Duck	Human	Dog	1995	Current
10	2.32E12		6.32E09	4.14E11		4.68E09	5.88E10	8.29E10	1.47E08	1.42E10	7.60E09	4.94E07	8.58E09	1.31E09	1.92E13	7.82E11	2.34E13	2.15E13
20	1.45E12		3.98E09	0.00E00			2.94E10	2.91E10	6.07E07	5.43E09	3.85E09	1.90E07	2.86E09	4.55E08	3.67E11	1.76E10	1.93E12	4.75E11
30	1.30E13		3.56E10	5.18E12		4.68E10	3.23E11	2.35E11	5.16E08	4.31E10	2.64E10	1.22E08	2.39E10	3.69E09	3.31E13	1.50E12	5.00E13	4.22E13
40	1.95E12		5.38E09	0.00E00		2.34E09	4.41E10	4.03E10	9.11E07	7.43E09	5.98E09	2.28E07	3.90E09	6.06E08	1.38E12	5.49E10	3.55E12	1.60E12
50	1.66E11		4.68E08	0.00E00				7.63E09	3.04E07	2.71E09	3.85E09	3.80E06	1.17E09	1.52E08	0.00E00	0.00E00	1.82E11	1.56E10
60	1.99E12		5.38E09	2.07E11		2.34E09	4.41E10	4.58E10	1.11E08	8.97E09	1.08E10	3.04E07	4.16E09	6.57E08	3.90E10	1.80E09	2.15E12	3.67E11
70	5.94E12		1.61E10	1.04E12		4.68E09	1.47E11	1.07E11	2.38E08	7.32E09	5.00E07	6.46E07	9.62E09	1.46E09	4.21E11	1.85E10	6.69E12	1.77E12
80	7.39E12		2.01E10	6.21E12		1.17E10	1.91E11	1.13E11	2.33E08	1.75E10	8.10E09	6.46E07	1.01E10	1.57E09	5.60E11	2.48E10	8.36E12	7.17E12
90	1.97E12		5.38E09	0.00E00		4.68E09	4.41E10	3.19E10	6.58E07	5.55E09	4.40E09	1.90E07	2.99E09	4.55E08	0.00E00	0.00E00	2.06E12	9.42E10
100	4.14E12		2.53E10	4.14E12		3.51E10	2.35E11	1.23E11	2.07E08	1.90E10	1.10E10	6.46E07	1.11E10	1.72E09	1.19E12	5.18E10	5.87E12	6.38E12
110	9.52E12		2.60E10	6.21E12		5.85E10	2.35E11	1.56E11	3.49E08	2.45E10	1.11E10	9.12E07	1.40E10	2.17E09	5.58E11	2.57E10	1.06E13	7.32E12
120	1.70E13		5.73E10	1.04E13		9.36E10	4.56E11	1.50E11	2.93E08	2.44E10	1.77E10	9.12E07	1.33E10	2.07E09	3.71E11	1.89E10	1.82E13	1.15E13
130	3.01E13	4.14E12	1.61E11	2.07E13	4.14E12	1.17E11	7.50E11	3.82E11	7.24E08	5.58E10	3.01E10	2.05E08	3.42E10	5.30E09	7.75E12	3.39E11	4.41E13	3.05E13
140	3.69E13	2.10E13	1.98E11	4.14E13	2.10E13	3.51E11	9.26E11	4.35E11	8.70E08	6.70E10	3.96E10	2.20E08	3.93E10	6.11E09	7.46E12	3.22E11	6.77E13	5.37E13
150	1.89E13	8.07E12	5.17E10	2.48E13	8.07E12	1.17E11	4.70E11	2.70E11	4.96E08	4.43E10	2.87E10	1.44E08	2.43E10	3.79E09	1.40E12	6.48E10	2.94E13	2.90E13
160	3.73E13	9.36E12	2.71E11	5.18E13	9.36E12	8.19E11	1.25E12	4.87E11	1.23E09	1.19E11	8.72E10	4.18E08	6.72E10	1.05E10	3.00E12	1.53E11	5.22E13	6.73E13
170	1.03E13		4.63E10	1.04E13		9.36E10	1.76E11	1.17E11	1.87E08	1.90E10	1.41E10	6.46E07	1.04E10	1.62E09	7.53E11	3.47E10	1.15E13	1.16E13
180	9.05E13	1.35E13	4.06E11	6.21E13	1.35E13	5.85E11	1.51E12	8.85E11	1.63E09	1.33E11	6.93E10	4.56E08	7.87E10	1.22E10	5.76E12	2.77E11	1.13E14	7.17E13
190	7.10E13		1.70E11	8.27E13		4.68E11	1.62E12	3.63E11	7.44E08	5.98E10	4.16E10	1.86E08	3.28E10	5.10E09	3.82E12	2.03E11	7.75E13	8.95E13
200	1.40E13		4.97E11	1.40E13		4.97E11	1.76E12	3.51E11	6.12E08	5.51E10	3.42E10	1.71E08	3.15E10	4.90E09	1.57E12	8.06E10	1.85E13	1.85E13
210	2.26E14		2.16E11	2.26E14		2.16E11	3.66E12	7.91E11	1.41E09	1.00E11	4.95E10	4.03E08	7.09E10	1.10E10	1.97E12	1.03E11	2.33E14	2.33E14
220	2.28E14		9.36E10	2.28E14		9.36E10	7.35E11	9.52E11	2.46E09	2.14E11	1.17E11	8.78E08	1.32E11	2.05E10	4.58E12	2.28E11	2.35E14	2.35E14
230	1.04E12		5.85E09	1.04E12		1.17E10	5.88E10	2.81E10	4.55E07	4.37E09	2.50E09	1.52E07	2.47E09	4.04E08	4.60E11	2.03E10	1.64E12	1.59E12
240	1.04E12		7.96E09	1.04E12		3.51E10	7.35E10	3.96E10	6.58E07	6.14E09	3.53E09	1.90E07	3.51E09	5.56E08	5.07E10	2.25E09	1.23E12	1.18E12
250	1.66E13	5.38E12	1.66E10	4.14E12	5.38E12	4.68E10	1.47E11	8.09E10	1.37E08	1.25E10	7.20E09	4.18E07	7.28E09	1.11E09	1.05E12	4.59E10	2.33E13	7.60E12
Totals	8.48E14	6.14E13	2.35E12	8.01E14	6.14E13	3.71E12	1.49E13	6.30E12	1.30E10	1.07E12	6.35E11	3.86E09	6.40E11	9.94E10	9.68E13	4.37E12	1.04E15	9.51E14

Table 3.19: Number of fecal coliform bacteria directly deposited into streams per day

Segment	Current		1995		Current		Current						Totals	
	Point Sources	Septic	Beef	Dairy	Beef	Dairy	Deer	Beaver	Raccoon	Muskrat	Goose	Duck	1995	Current
10	3.70E6		5.56E10		9.94E09		2.07E08	1.47E08	3.54E07	3.42E08	2.15E08	4.92E07	5.66E10	1.09E10
20			3.48E10		0.00E00		7.29E07	6.07E07	1.36E07	1.73E08	7.15E07	1.70E07	3.52E10	4.09E08
30	7.57E05		3.12E11		1.24E11		5.88E08	5.16E08	1.08E08	1.19E09	5.98E08	1.38E08	3.16E11	1.27E11
40	5.71E06		4.67E10		0.00E00		1.01E08	9.11E07	1.86E07	2.69E08	9.75E07	2.27E07	4.75E10	6.06E08
50			3.97E09		0.00E00		1.91E07	3.04E07	6.79E06	1.73E08	2.93E07	5.68E06	4.24E09	2.64E08
60			4.77E10		4.97E09		1.15E08	1.11E08	2.24E07	4.84E08	1.04E08	2.46E07	4.89E10	5.83E09
70			1.43E11		2.48E10		2.67E08	2.38E08	1.83E07	2.25E06	2.41E08	5.49E07	1.43E11	2.56E10
80			1.77E11		1.49E11		2.82E08	2.33E08	4.37E07	3.65E08	2.54E08	5.87E07	1.79E11	1.50E11
90			4.72E10		0.00E00		7.98E07	6.58E07	1.39E07	1.98E08	7.48E07	1.70E07	4.76E10	4.49E08
100	1.97E06	1.95E03	9.94E10		9.94E10		3.08E08	2.07E08	4.75E07	4.93E08	2.76E08	6.44E07	1.01E11	1.01E11
110		1.95E03	2.29E11		1.49E11		3.91E08	3.49E08	6.14E07	5.00E08	3.51E08	8.14E07	2.30E11	1.51E11
120			4.09E11		2.48E11		3.74E08	2.93E08	6.11E07	7.97E08	3.32E08	7.76E07	4.11E11	2.50E11
130		5.83E03	7.22E11	1.08E11	4.97E11	1.08E11	9.56E08	7.24E08	1.40E08	1.35E09	8.55E08	1.99E08	8.34E11	6.09E11
140	3.25E08	9.75E03	8.85E11	5.46E11	9.94E11		1.09E09	8.70E08	1.68E08	1.78E09	9.82E08	2.29E08	1.44E12	1.00E12
150	2.46E06		4.54E11	2.10E11	5.96E11		6.74E08	4.96E08	1.11E08	1.29E09	6.08E08	1.42E08	6.67E11	5.99E11
160	3.03E05	6.57E03	8.94E11	2.43E11	1.24E12	1.35E11	1.22E09	1.23E09	2.98E08	3.92E09	1.68E09	3.92E08	1.15E12	1.38E12
170			2.48E11		2.48E11		2.92E08	1.87E08	4.75E07	6.32E08	2.60E08	6.06E07	2.49E11	2.49E11
180	4.62E07	1.76E04	2.17E12	3.50E11	1.49E12		2.21E09	1.63E09	3.32E08	3.12E09	1.97E09	4.58E08	2.53E12	1.50E12
190	1.04E08	1.95E03	1.70E12		1.98E12		9.07E08	7.44E08	1.50E08	1.87E09	8.19E08	1.91E08	1.71E12	1.98E12
200		3.46E03	3.35E11		3.35E11		8.78E08	6.12E08	1.38E08	1.54E09	7.87E08	1.84E08	3.39E11	3.39E11
210	2.37E07	3.90E03	5.42E12		5.42E12		1.98E09	1.41E09	2.51E08	2.23E09	1.77E09	4.13E08	5.43E12	5.43E12
220	5.30E05	9.76E03	5.46E12		5.46E12		2.38E09	2.46E09	5.35E08	5.26E09	3.30E09	7.69E08	5.48E12	5.47E12
230			2.48E10		2.48E10		7.03E07	4.55E07	1.09E07	1.13E08	6.18E07	1.52E07	2.52E10	2.51E10
240			2.48E10		2.48E10		9.89E07	6.58E07	1.53E07	1.59E08	8.78E07	2.08E07	2.53E10	2.52E10
250	6.81E05		3.97E11	1.40E11	9.94E10		2.02E08	1.37E08	3.13E07	3.24E08	1.82E08	4.17E07	5.38E11	1.00E11
Totals	5.15E08	6.27E04	2.04E13	1.60E12	1.92E13	2.43E11	1.58E10	1.30E10	2.68E09	2.86E10	1.60E10	3.73E09	2.20E13	1.95E13

Table 3.20: Number of fecal coliform bacteria deposited on pasture per day

Segment	1995			Current			Current						Totals	
	Beef	Dairy	Horse	Beef	Dairy	Horse	Sheep	Deer	Duck	Goose	Raccoon	Turkey	1995	Current
10	2.26E12		6.32E09	4.04E11		4.68E09	5.88E10	1.81E10	2.76E08	1.83E09	3.09E09	1.08E07	2.35E12	4.91E11
20	1.41E12		3.98E09				2.94E10	1.19E10	1.80E08	1.14E09	2.22E09	7.80E06	1.46E12	4.49E10
30	1.27E13		3.56E10	5.05E12		4.68E10	3.23E11	1.04E11	1.57E09	1.03E10	1.90E10	5.37E07	1.32E13	5.56E12
40	1.90E12		5.38E09			2.34E09	4.41E10	1.72E10	2.50E08	1.63E09	3.18E09	9.77E06	1.97E12	6.87E10
50	1.62E11		4.68E08				0.00E00	1.26E09	2.41E07	1.89E08	4.48E08	6.29E05	1.64E11	1.92E09
60	1.94E12		5.38E09	2.02E11		2.34E09	4.41E10	1.58E10	2.19E08	1.41E09	3.10E09	1.05E07	2.01E12	2.69E11
70	5.80E12		1.61E10	1.01E12		4.68E09	1.47E11	4.82E10	6.38E08	4.24E09	3.30E09	2.92E07	6.02E12	1.22E12
80	7.21E12		2.01E10	6.06E12		1.17E10	1.91E11	5.93E10	7.94E08	5.21E09	9.18E09	3.41E07	7.50E12	6.34E12
90	1.92E12		5.38E09			4.68E09	4.41E10	1.55E10	2.13E08	1.42E09	2.70E09	9.27E06	1.99E12	6.87E10
100	4.04E12		2.53E10	4.04E12		3.51E10	2.35E11	6.76E10	9.09E08	5.93E09	1.04E10	3.55E07	4.39E12	4.40E12
110	9.29E12		2.60E10	6.06E12		5.85E10	2.35E11	7.72E10	1.03E09	6.77E09	1.21E10	4.51E07	9.65E12	6.45E12
120	1.66E13		5.73E10	1.01E13		9.36E10	4.56E11	6.59E10	8.81E08	5.71E09	1.08E10	4.03E07	1.72E13	1.07E13
130	2.94E13	3.40E12	1.61E11	2.02E13	3.40E12	1.17E11	7.50E11	2.28E11	3.06E09	2.00E10	3.33E10	1.23E08	3.40E13	2.48E13
140	3.60E13	1.65E13	1.98E11	4.04E13		3.51E11	9.26E11	2.78E11	3.77E09	2.45E10	4.29E10	1.41E08	5.39E13	4.20E13
150	1.85E13	6.30E12	5.17E10	2.42E13		1.17E11	4.70E11	1.53E11	2.07E09	1.35E10	2.51E10	8.22E07	2.55E13	2.50E13
160	3.64E13	8.69E12	2.71E11	5.05E13	4.80E12	8.19E11	1.25E12	2.63E11	5.46E09	3.55E10	6.45E10	2.27E08	4.69E13	5.77E13
170	1.01E13		4.63E10	1.01E13		9.36E10	1.76E11	6.72E10	8.96E08	5.84E09	1.09E10	3.72E07	1.04E13	1.05E13
180	8.83E13	1.1E13	4.06E11	6.06E13		5.85E11	1.51E12	5.88E11	7.83E09	5.11E10	8.82E10	3.04E08	1.02E14	6.34E13
190	6.93E13		1.70E11	8.07E13		4.68E11	1.62E12	2.29E11	3.11E09	2.02E10	3.78E10	1.18E08	7.13E13	8.30E13
200	1.36E13		4.97E11	1.36E13		4.97E11	1.76E12	2.52E11	3.40E09	2.21E10	3.96E10	1.23E08	1.62E13	1.62E13
210	2.20E14		2.16E11	2.20E14		2.16E11	3.66E12	5.21E11	7.00E09	4.56E10	6.62E10	2.66E08	2.25E14	2.25E14
220	2.22E14		9.36E10	2.22E14		9.36E10	7.35E11	4.22E11	8.77E09	5.71E10	9.47E10	3.90E08	2.24E14	2.24E14
230	1.01E12		5.85E09	1.01E12		1.17E10	5.88E10	1.85E10	2.56E08	1.59E09	2.87E09	1.00E07	1.10E12	1.10E12
240	1.01E12		7.96E09	1.01E12		3.51E10	7.35E10	2.66E10	3.61E08	2.31E09	4.13E09	1.28E07	1.13E12	1.15E12
250	1.62E13	4.46E12	1.66E10	4.04E12		4.68E10	1.47E11	5.13E10	6.81E08	4.52E09	7.94E09	2.66E07	2.08E13	4.30E12
Totals	8.28E14	5.04E13	2.35E12	7.82E14	8.20E12	3.71E12	1.49E13	3.60E12	5.36E10	3.50E11	5.98E11	2.15E09	9.00E14	8.14E14

Table 3.21: Number of fecal coliform bacteria deposited on cropland per day

	1995	Current	Current							Totals	
Segment	**Dairy**	**Dairy**	**Biosolids**	**Deer**	**Duck**	**Goose**	**Racoon**	**Turkey**	**Dog**	**1995**	**Current**
10				6.26E09	9.57E07	6.33E08	1.07E09	3.74E06	1.81E11	1.89E11	1.89E11
20				1.63E08	2.45E06	1.56E07	3.03E07	1.06E05	2.63E08	4.74E08	4.74E08
30			2.04E08	1.70E10	2.56E08	1.68E09	3.10E09	8.78E06	2.02E11	2.24E11	2.24E11
40				5.65E09	8.21E07	5.35E08	1.04E09	3.21E06	1.48E10	2.21E10	2.21E10
50				1.55E08	2.96E06	2.32E07	5.50E07	7.71E04	0.00E00	2.36E08	2.36E08
60				1.60E09	2.22E07	1.42E08	3.14E08	1.07E06	1.65E08	2.25E09	2.25E09
70			8.16E08	2.86E09	3.78E07	2.51E08	1.96E08	1.73E06	1.15E09	5.31E09	5.31E09
80			1.37E09	3.13E09	4.19E07	2.75E08	4.84E08	1.79E06	1.37E09	6.66E09	6.66E09
90				1.07E08	1.47E06	9.78E06	1.86E07	6.38E04	0.00E00	1.37E08	1.37E08
100			1.62E09	4.35E09	5.85E07	3.82E08	6.71E08	2.29E06	3.47E09	1.06E10	1.06E10
110				1.73E09	2.31E07	1.51E08	2.71E08	1.01E06	6.28E08	2.80E09	2.80E09
120			7.80E08	1.38E09	1.85E07	1.20E08	2.26E08	8.46E05	4.34E08	2.96E09	2.96E09
130	5.04E11	5.04E11	1.16E08	6.29E09	8.41E07	5.50E08	9.18E08	3.38E06	1.01E10	5.22E11	5.22E11
140	1.72E11		1.49E09	8.28E09	1.12E08	7.30E08	1.28E09	4.20E06	1.01E10	1.92E11	2.20E10
150	8.86E09			7.14E09	9.68E07	6.29E08	1.17E09	3.83E06	3.19E09	2.11E10	1.22E10
160	1.57E11		2.08E07	4.28E09	8.87E07	5.78E08	1.05E09	3.69E06	2.69E09	1.66E11	8.71E09
170				3.71E08	4.94E06	3.22E07	6.02E07	2.05E05	2.12E08	6.80E08	6.80E08
180	1.57E12		9.23E08	1.01E10	1.34E08	8.76E08	1.51E09	5.21E06	5.23E09	1.59E12	1.88E10
190				2.58E09	3.50E07	2.27E08	4.25E08	1.33E06	2.45E09	5.71E09	5.71E09
200				6.62E08	8.91E06	5.79E07	1.04E08	3.23E05	2.33E08	1.07E09	1.07E09
210			3.12E08	8.67E09	1.16E08	7.59E08	1.10E09	4.43E06	1.85E09	1.28E10	1.28E10
220				7.23E09	1.50E08	9.79E08	1.62E09	6.68E06	4.23E09	1.42E10	1.42E10
230				1.83E09	2.54E07	1.57E08	2.84E08	9.91E05	2.02E09	4.32E09	4.32E09
240				1.29E07	1.74E05	1.11E06	1.99E06	6.19E03	1.08E06	1.72E07	1.72E07
250	6.30E11		1.18E09	5.20E08	6.90E06	4.58E07	8.05E07	2.70E05	6.28E07	6.30E11	1.90E09
Totals	3.05E12	5.04E11	8.82E09	1.02E11	1.51E09	9.85E09	1.71E10	5.93E07	4.47E11	3.62E12	1.09E12

Table 3.22: Number of fecal coliform bacteria deposited on developed land per day

Segment	Source							Totals
	Deer	Duck	Goose	Raccoon	Turkey	Septic	Dog	
10	5.96E09	9.10E07	6.02E08	1.02E09	3.56E06	1.24E10	1.72E11	1.92E11
20	1.90E08	2.85E06	1.82E07	3.53E07	1.24E05	5.99E09	3.06E08	6.54E09
30	2.10E10	3.18E08	2.09E09	3.85E09	1.09E07	7.66E10	2.50E11	3.54E11
40	7.44E08	1.08E07	7.04E07	1.37E08	4.22E05	2.10E09	1.94E09	5.01E09
50	3.09E08	5.91E06	4.62E07	1.10E08	1.54E05	0.00E00	0.00E00	4.71E08
60	8.18E07	1.13E06	7.26E06	1.60E07	5.44E04	4.65E09	8.40E06	4.76E09
70	2.19E08	2.89E06	1.92E07	1.50E07	1.33E05	1.86E10	8.83E07	1.90E10
80	2.01E08	2.70E06	1.77E07	3.12E07	1.16E05	3.23E10	8.82E07	3.27E10
90	5.63E07	7.73E05	5.15E06	9.77E06	3.36E04	0.00E00	0.00E00	7.20E07
100	7.40E08	9.96E06	6.49E07	1.14E08	3.89E05	5.02E10	5.91E08	5.17E10
110	3.16E08	4.23E06	2.77E07	4.95E07	1.84E05	3.63E10	1.15E08	3.68E10
120	8.83E07	1.18E06	7.65E06	1.44E07	5.40E04	3.00E10	2.77E07	3.01E10
130	2.30E09	3.07E07	2.01E08	3.35E08	1.24E06	3.61E11	3.68E09	3.67E11
140	8.96E09	1.21E08	7.90E08	1.38E09	4.55E06	2.66E11	1.09E10	2.88E11
150	2.69E09	3.65E07	2.37E08	4.42E08	1.44E06	7.00E10	1.20E09	7.46E10
160	4.99E09	1.03E08	6.74E08	1.22E09	4.30E06	1.99E11	3.14E09	2.09E11
170	2.73E07	3.64E05	2.37E06	4.44E06	1.51E04	3.67E10	1.56E07	3.68E10
180	1.03E09	1.38E07	8.99E07	1.55E08	5.35E05	4.06E11	5.36E08	4.07E11
190	7.24E09	9.83E07	6.40E08	1.19E09	3.73E06	7.17E10	6.89E09	8.78E10
200	3.37E09	4.53E07	2.95E08	5.29E08	1.64E06	7.84E10	1.19E09	8.38E10
210	7.12E09	9.56E07	6.23E08	9.04E08	3.63E06	1.51E11	1.52E09	1.61E11
220	6.63E09	1.38E08	8.97E08	1.49E09	6.13E06	2.29E11	3.88E09	2.42E11
230	2.70E07	3.75E05	2.32E06	4.20E06	1.47E04	6.35E09	2.99E07	6.41E09
240	2.89E07	3.92E05	2.51E06	4.48E06	1.39E04	1.05E10	2.44E06	1.05E10
250	3.93E08	5.21E06	3.46E07	6.08E07	2.04E05	5.21E10	4.74E07	5.27E10
Totals	7.47E10	1.14E09	7.46E09	1.31E10	4.36E07	2.21E12	4.58E11	2.76E12

Table 3.23: Number of fecal coliform bacteria deposited on forest per day

Segment	Source						Totals
	Deer	**Duck**	**Goose**	**Raccoon**	**Turkey**	**Muskrat**	
10	5.24E10	8.01E08	5.30E09	8.95E09	3.13E07	7.26E09	7.48E10
20	1.68E10	2.53E08	1.61E09	3.13E09	1.10E07	3.68E09	2.55E10
30	9.31E10	1.41E09	9.25E09	1.70E10	4.82E07	2.52E10	1.46E11
40	1.65E10	2.40E08	1.57E09	3.06E09	9.39E06	5.71E09	2.71E10
50	5.89E09	1.13E08	8.83E08	2.09E09	2.94E06	3.68E09	1.27E10
60	2.82E10	3.90E08	2.50E09	5.51E09	1.87E07	1.03E10	4.69E10
70	5.53E10	7.31E08	4.87E09	3.79E09	3.35E07	4.78E07	6.48E10
80	4.99E10	6.68E08	4.38E09	7.72E09	2.86E07	7.74E09	7.04E10
90	1.61E10	2.22E08	1.48E09	2.80E09	9.63E06	4.20E09	2.49E10
100	5.02E10	6.75E08	4.40E09	7.74E09	2.64E07	1.05E10	7.35E10
110	7.69E10	1.03E09	6.74E09	1.21E10	4.49E07	1.06E10	1.07E11
120	8.18E10	1.09E09	7.09E09	1.34E10	5.00E07	1.69E10	1.20E11
130	1.44E11	1.93E09	1.26E10	2.11E10	7.77E07	2.87E10	2.09E11
140	1.39E11	1.88E09	1.22E10	2.13E10	7.04E07	3.78E10	2.12E11
150	1.06E11	1.44E09	9.35E09	1.74E10	5.69E07	2.74E10	1.62E11
160	2.13E11	4.41E09	2.87E10	5.22E10	1.83E08	8.33E10	3.82E11
170	4.90E10	6.54E08	4.26E09	7.96E09	2.71E07	1.34E10	7.53E10
180	2.84E11	3.78E09	2.47E10	4.26E10	1.47E08	6.61E10	4.21E11
190	1.23E11	1.67E09	1.08E10	2.03E10	6.32E07	3.97E10	1.95E11
200	9.38E10	1.26E09	8.22E09	1.47E10	4.58E07	3.27E10	1.51E11
210	2.52E11	3.38E09	2.21E10	3.20E10	1.29E08	4.73E10	3.57E11
220	5.14E11	1.07E10	6.96E10	1.15E11	4.75E08	1.12E11	8.22E11
230	7.71E09	1.07E08	6.63E08	1.20E09	4.18E06	2.39E09	1.21E10
240	1.28E10	1.73E08	1.11E09	1.98E09	6.16E06	3.37E09	1.94E10
250	2.84E10	3.77E08	2.50E09	4.39E09	1.47E07	6.88E09	4.26E10
Totals	2.51E12	3.94E10	2.57E11	4.40E11	1.61E09	6.07E11	3.85E12

CHAPTER 4: CALIBRATION AND VERIFICATION OF THE BACTERIA MODEL

4.1 The Role of Computer Simulation Modeling in TMDLs

Computer simulation modeling provides the link between the estimated fecal coliform loads generated in the watershed and the in-stream water quality observations that led to the assessment of Goose Creek and its tributaries as impaired. The goal of modeling is to accurately represent the fate and transport of fecal coliform bacteria in the watershed; once it is established that the model can accurately represent the mechanisms and pathways by which fecal coliforms are generated and transported, the model can then be used to determine what load reductions are necessary for the impaired waterbodies to meet water quality standards and to demonstrate that those load allocations permit the waterbodies to meet standards under a variety of hydrological conditions.

4.1.1 The HSPF Model

The Hydrological Simulation Program—Fortran (HSPF) model was used to simulate the fate and transport of fecal coliform bacteria in the Goose Creek Watershed. HSPF has been used to develop TMDLs to address fecal coliform impairments in Virginia and many other states for the following reasons:

1. HSPF is a continuous simulation model. It can simulate a continuous time series of daily or hourly flows and concentrations. It is thus able to satisfy the requirement that a TMDL take into account seasonal variation and a range of hydrological conditions.
2. HSPF can represent both point and nonpoint sources. It simulates the mechanism by which runoff loads are generated by storm flow on the land surface and thereby quantifies nonpoint source loads as a function of hydrological conditions and surface loading rates.
3. HSPF can be used to assess the impact of changes in loads or loading rates. An HSPF model, once calibrated, can be used to predict the water quality response to changes in input loads. This is necessary to demonstrate the adequacy of any TMDL allocation.

A detailed description of HSPF can be found in Bicknell et al. (2000).

4.1.2 Simulation Period

HSPF requires many types of data inputs. The model is calibrated by adjusting model parameters until there is agreement between observed data and simulated values. The performance of the calibrated model is then verified by comparing simulated values with observed data that were not used to calibrate the model.

The simulation period for the fecal coliform model of the Goose Creek watershed needed to encompass the set of observations used to assess the waterbodies as impaired. As explained in Chapter 2, prior to 1998, VADEQ's water quality assessments were done on a two-year data window. In 1998, VADEQ's assessments switched to a five-year data window. As shown in Table 1.1, the impaired waterbodies in the Goose Creek watershed were placed on the 303(d) List between 1996 and 2002, suggesting a simulation period of at least 1993-2000. The period 1992 -1997 was used to calibrate the water quality model, and the period 1998 - 2001 was used to verify the calibration. As noted in the Source Assessment, livestock populations in Loudoun County changed significantly over the simulation period. The 1995 livestock population estimates were used for the calibration period, and the current livestock numbers were used for the verification period.

A longer simulation period was used to calibrate and verify the hydrology simulation. The hydrology calibration period was 1988 – 1995, and the verification period was 1996 – 2001. The longer simulation period was used to encompass a greater variety of hydrologic conditions.

4.1.3 Representation of the Watershed in the HSPF Model

As described in the Watershed Characterization chapter, the Goose Creek watershed was divided into 25 subwatersheds. Figure 4.1 shows the delineation of those subwatersheds. Only the main channel of each subwatershed was represented in HSPF as a stream reach.

Four pervious land uses and two impervious land uses were represented in each subwatershed, as shown in the Watershed Characterization chapter. Table 2.6 gives the number of acres of each type of land use in each subwatershed. Each of the four pervious land use types –forest, cropland, pasture and pervious developed land—was represented by a single parameterization in each subwatershed. The impervious land uses—barren and impervious developed land—for the most part were represented by a single parameterization. In Beaverdam Creek and the upper portions of the Goose Creek watershed (Segments 180, 210, and 220) a percentage of forested land was represented as a distinct impervious land use to take into account rock outcrops and the high percentage of the surface covered with boulders in the Blue Ridge.

4.2 Simulation of the Hydrology of the Goose Creek Watershed

HSPF is a watershed model: it simulates the hydrologic cycle, from precipitation to streamflow to evaporation, and maintains a continuous water balance for a watershed. It can route streamflow in channels through a network of river reaches and reservoirs. More details on HSPF's representation of hydrology and hydraulics can be found in Bicknell et al. (2000).

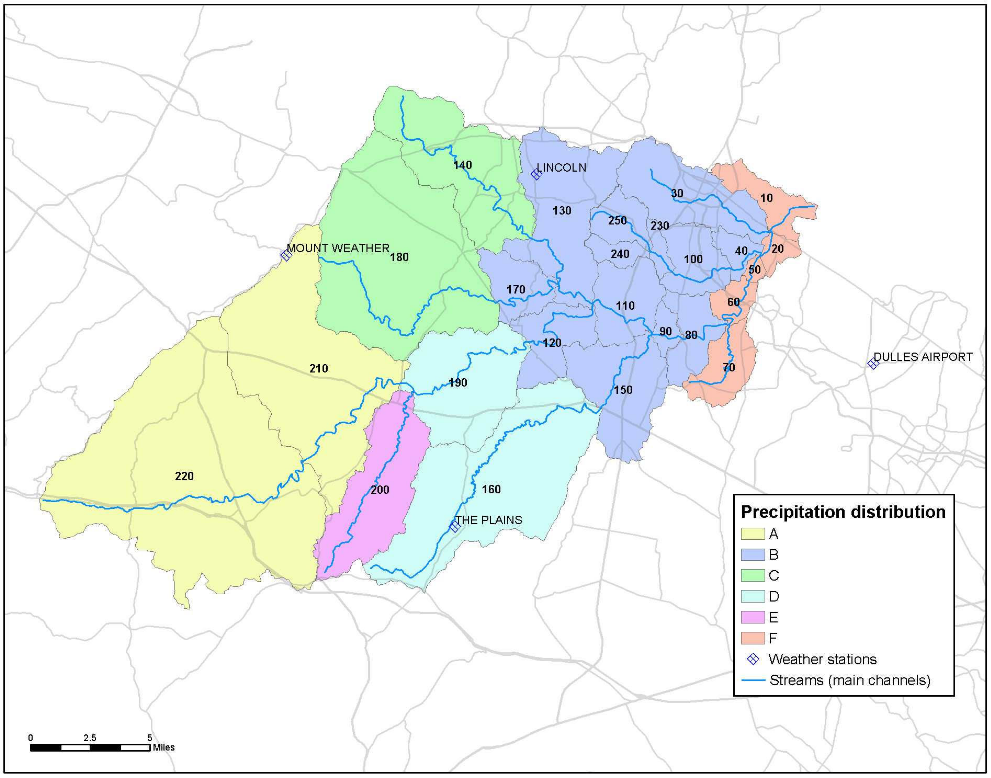
The HSPF model of the Goose Creek watershed was run on an hourly time step. The primary output from the hydrology simulation, however, is average daily flow for each stream reach.

4.2.1 Meteorological Data

HSPF requires several types of meteorological data. The two primary time series for the hydrologic simulation are hourly precipitation data and daily potential evapotranspiration. In addition, the representation of snowmelt requires hourly air temperature, wind speed, solar radiation, and dew point temperature data.

4.2.1.1. Precipitation

Daily precipitation data were available in and around the Goose Creek watershed from four stations in the National Weather Service's Cooperative Station Network: Lincoln (444909), Mt. Weather (445851), The Plains (448396), and Dulles Airport (448903). Figure 4.1 shows the location of these stations with respect to the model segments.



Group	Precipitation Station	Calibration Point
A	Mt. Weather (forest), The Plains (elsewhere)	Goose Creek Near Middleburg
B	Lincoln	Goose Creek Near Leesburg
C	Mt. Weather (forest), Lincoln (elsewhere)	Goose Creek Near Leesburg
D	The Plains	Goose Creek Near Leesburg
E	The Plains	Goose Creek Near Middleburg
F	Dulles Airport	Beaverdam Reservoir

Figure 4.1: Precipitation Stations and Calibration Points For Modeling Segments

The precipitation record from these four stations was used to drive the hydrological component of the HSPF model. Before daily precipitation data can be used in HSPF, missing observations must be filled in and the daily time series of precipitation must be "disaggregated" into an hourly time series. Hourly precipitation data were available from the following stations: The Plains, Reagan National Airport (448906), The Piedmont Research Station (446712), and Star Tannery (448046). Only the station at The Plains is located at or near the watershed. Because daily precipitation was measured at different times of the day at each of the stations, the process of filling in missing values could not be completely separated from the disaggregation of daily time series into hourly values.

Missing values in the daily precipitation time series from The Plains were filled in using data first from Mt. Weather and second, when Mt. Weather data were not available, from Reagan National Airport. There was significant disagreement between the daily and hourly precipitation records at The Plains station. The hourly record was used to generate the fraction of daily precipitation that fell each hour at The Plains. Missing hourly data were filled in from other stations in the following order: Reagan National Airport, Piedmont Research Station, and Star Tannery. If none of these stations had precipitation on a day when The Plains did, the daily precipitation at The Plains was spread evenly over the day. Table 4.1 shows the order in which stations were used for filling in missing data and for disaggregation at the Mt. Weather, Lincoln, and Dulles International Airport stations.

Table 4.1: Weather stations used to fill missing daily data and to disaggregate daily data to hourly values

Station	Coop ID	Missing Data Fill Order	Disaggregation Selection Order
The Plains	448396	Mt. Weather (445851) Reagan National (448906)	The Plains (448396) Reagan National (448906) Piedmont (446712) Star Tannery (448046)
Mt. Weather	445851	The Plains (448396) Regan National (448906)	The Plains (448396) Reagan National (448906) Piedmont (446712) Star Tannery (448046)
Lincoln	444909	The Plains (448396) Mt. Weather (445851) Dulles (448903) Reagan National (448906)	The Plains (448396) Reagan National (448906) Piedmont (446712) Star Tannery (448046)
Dulles	448903	Reagan National (448906)	Reagan National (448906) The Plains (448396) Piedmont (446712) Star Tannery (448046)

Generally, precipitation data were applied to a given modeling segment according to which station was closest to the centroid of that modeling segment. Because the Mt. Weather station sits on top of the Blue Ridge Mountains and may be subject to orographic effects, the precipitation record from that station was applied only to the forest segments in subwatersheds 140, 180, 210, and 220. Figure 4.1 shows the precipitation time series applied to each modeling segment.

4.2.1.2. Other Meteorological Data

Hourly solar radiation, air temperature, dew point, wind speed, and daily potential evapotranspiration were available for the period 1988-1997 from the Phase 4 Chesapeake Bay Program Watershed Model (CBPWSM). These meteorological inputs were calculated from data collected at the Dulles International Airport (Wang et al., 1997).

For the period 1998-2000, hourly wind speed, dew point temperature, and air temperature were obtained from the National Climatic Data Center's Surface Airways database. For 2001, hourly time series for these variables was obtained by disaggregating the daily time series available from the NCDC Summary of the Day database. Hourly solar radiation for 1998-2001 was calculated from fifteen-minute observations taken at NOAA's Integrated Surface Irradiated Study station at Sterling, VA (NOAA, 2002).

For the period 1998-2001, potential evapotranspiration was calculated in METCMP using the Hamon formula. The necessary input time series, maximum and minimum daily air temperature, were taken from the NCDC Summary of the Day database for Dulles International Airport. Monthly coefficients in the formula were calibrated to obtain agreement with monthly potential evapotranspiration used in the CBPWSM for 1997.

4.2.2 Stream Channel Characteristics

HSPF uses the "level pool" method of routing flow through channel reaches, in which the rate of flow from a reach is a single-valued function of volume. In fact, surface area and average depth are also treated as single-valued functions of volume. The relationship between volume, on the one hand, and surface area, depth, and flow, on the other, is an input to HSPF called an F-table.

The F-tables used in the simulation of Goose Creek were created using information from four different sources. F-tables for the mainstem of Goose Creek were calculated in BASINS. With the exception of the North Fork of Goose Creek, where the landowner would not permit access to the stream, ICPRB staff measured channel width, bankfull width, and depths at DEQ monitoring stations on the tributaries to Goose Creek and the mainstem at Delaplanes. This information was used with the XSECT utility (Aqua Terra, 1994) to generate F-tables for the tributaries to Goose Creek and the upper mainstem. The cross section for Beaverdam Creek was used to calculate the F-table for the North Fork of Goose Creek. Table 4.2 shows the input data used in the XSECT program. The length of the reaches, the upstream and downstream elevations, and average slope in the 100-year floodplain were calculated in GIS. F-tables for the upper portions of Sycolin Creek, Segments 230, 240, and 250, were also calculated using XSECT. Channel widths and depths, however, were taken from the USDA Flood Hazard Study (USDA, 1974).

F-tables for the City of Fairfax's water supply reservoir on Goose Creek (Segment 60) and Beaverdam Reservoir (Segment 70) were derived from information supplied by the City of Fairfax. For Beaverdam Reservoir, the relationship between storage volume, surface area, and depth at the dam are already available. RUST Engineering conducted a bathymetric survey of the water supply reservoir on Goose Creek in October 1996, just before it was dredged. The survey extended 0.92 miles upstream of the dam. The survey results were extrapolated an additional four miles upstream to capture all backwater effects from the reservoir. The result yielded a relationship between volume, average depth, and surface area for storage volumes below the top of the dam when there is no flow. Storage area in the reservoir was increased by 200,000 cubic yards during the verification period to represent the impact of dredging performed in 1997. To calculate the F-table for flows from the reservoirs when storage volume exceeded the heights of the dams, the dams were modeled as broad-crested weirs.

Table 4.2: Channel characteristics for calculating F-tables

Segment	Length (mi.)	Upstream Elevation (ft)	Downstream Elevation (ft)	Bottom Channel Width (ft)	Top Channel Width (ft)	Depth (ft)	Flood Plain Slope	Channel Manning's N	Flood Plain Manning's N
40	2.5	283	203	27	33	5	0.035	0.045	0.06
100	3	350	283	27	33	4.7	0.025	0.045	0.06
130	6.16	300	270	23	66	3.5	0.053	0.045	0.065
140	12.18	700	300	23	66	3.5	0.036	0.045	0.065
150	4.69	300	250	51	62	5.9	0.023	0.045	0.065
160	17.40	600	300	43	47	4.8	0.039	0.045	0.065
170	4.52	310	280	23	66	3.5	0.058	0.045	0.065
180	16.40	600	310	23	66	3.5	0.032	0.045	0.065
200	13.43	600	320	30	35	3	0.044	0.045	0.065
220	14.84	900	380	33.3	50	3.3	0.052	0.045	0.065
230	1.4	366	350	27	33	4.5	0.025	0.045	0.06
240	3.3	480	366	15	25	4	0.03	0.045	0.06
250	3.6	520	366	15	25	4	0.03	0.045	0.06

4.2.3 Point Source Flows

Table 4.3 presents the design flow and average daily flow for each permitted wastewater treatment plant in the watershed. For model calibration, average daily flows for each point source were calculated using Discharge Monitoring Report (DMR) information and were distributed daily for each month reported. For months with no DMR information, the average daily flow for the period of record was substituted for that month. The average daily flows for each point source were aggregated into daily time series and used to calibrate hydrology. The design flow of each point source was used in all allocation scenarios. Table 4.4 presents the average flow for domestic dischargers holding general discharge permits in the Goose Creek watershed. Because the average discharge of these sources are all below 0.0015 cfs, they were not included in the hydrology calibration.

4.2.4 Hydrology Calibration

The principal calibration of hydrological parameters occurred by comparing simulated flow from Segment 90 to the daily flow record at the USGS gage on Goose Creek near Leesburg (01644000). Two other calibration points were also used. A preliminary calibration of hydrological parameters for Segments 210 and 220 was performed by comparing simulated flows from Segment 210 with the daily flow record at the USGS gage on Goose Creek near Middleburg (01643700). Hydrological parameters for segments along the lower mainstem of Goose Creek around and below the reservoirs were determined by comparing simulated with observed volume in the Beaverdam Reservoir.

Table 4.3: Design and average daily flow for permitted point sources

VPDES	Facility	Segment	Design Flow (MGD)	Average Flow (MGD)
VA0002666	Goose Creek WTP	60		0.270
VA0022802	Purcellville STP	140	0.500	0.344
VA0024112	Foxcroft School	190	0.075	0.031
VA0024759	US FEMA – Bluemont	180	0.090	0.031
VA0024775	Middleburg WWTP	190	0.135	0.102
VA0026212	Round Hill WWTP	140	0.200	0.085
VA0027197	Notre Dame Academy	190	0.015	0.003
VA0062189	St. Louis Community	180	0.086	0.058
VA0065200	Rehau Plastics, Inc.	10	0.009	0.005
VA0080993	Goose Creek Industrial Park WWTP	40	0.010	0.008
VA0089133	Aldie WWTP	150	0.015	0.003

MGD = Million Gallons per Day
WWTP = Wastewater Treatment Plant
STP = Sewage Treatment Plant
WTP =Water Treatment Plant (not permitted to discharge fecal coliform bacteria)

Table 4.4: Average daily flow for general permits in the Goose Creek watershed

Permit No.	Facility	Segment	Average Flow (gallons/day)
VAG406015	Residence	100	800
VAG406016	Business	180	200
VAG406018	Residence	190	500
VAG406019	Residence	160	400
VAG406020	Residence	100	500
VAG406047	Residence	100	200
VAG406069	Residence	190	1000
VAG406101	Residence	100	450
VAG406113	Residence	100	600
VAG406115	Residence	180	400
VAG406116	Residence	180	800
VAG406121	Residence	100	50
VAG406135	Residence	180	580
VAG406143	Residence	180	450
VAG406146	Residence	140	500
VAG406149	Residence	180	300
VAG406170	Residence	220	700
VAG406172	Business	250	900
VAG406176	Residence	140	400
VAG406193	Residence	210	300
VAG406244	Residence	30	1000

UNT = Unnamed Tributary

All hydrology calibrations were performed using version 5 of PEST, the model-independent parameter estimation software developed by J. Doherty (Doherty, 2001). PEST determines the values of parameters that optimize a user-specified objective function. In these simulations, the objective function was the sum of the squares of the differences between daily observed and simulated values. This is equivalent to maximizing the coefficient of determination (R^2) between observed and simulated values. PEST was used to help calibrate the model, in preference to the HSPF expert system HSPEXP (USGS, 1994), because it is easier to use PEST with multiple calibration points and meteorological stations. Some minor adjustments were made to the parameters after optimization with PEST to facilitate the simulation of fecal coliform bacteria.

4.2.4.1 Hydrology Calibration at Middleburg

A preliminary calibration of hydrologic parameters for Segments 220 and 210 was made by comparing daily-simulated flows from Segment 210 with observed daily flows at the USGS gage on Goose Creek near Middleburg (01643700). The calibration period was 1988-1995. The gage was inoperative from the end of January 1997, to June 2001. Data from 1996 and January 1997 were used to verify the calibration.

The calibration was performed without simulating snowmelt. The coefficient of determination (R^2) between observed and simulated flows was 0.77. Table 4.5 shows the final parameter values. PEST was used to set the fraction of impervious forestland cover in the Blue Ridge Mountains at about 10%, which was in good agreement with the boulder cover estimated in soil surveys. The coefficient of determination between observed and simulated flows in the verification period was less than 0.5 because the simulation failed to capture the timing and magnitude of snowmelt.

This parameterization for Segments 210 and 220 was incorporated into the primary calibration of hydrologic parameters, which compared simulated daily flows to the record of observed flows at the USGS gage on Goose Creek near Leesburg (01644000). The same parameterization was also used for non-forest land uses in Segment 200, Cromwells Run.

Table 4.5 Calibrated Hydrology Parameters

Parameter	Definition	Units	Calibration Point		
			Middleburg	**Leesburg**	**Beaverdam**
INFILT	Index to infiltration capacity	in/hr	0.156-0.187	0.05-0.187	0.046-0.055
LZSN	Lower zone nominal soil moisture storage	inches	9.50	5.24	3.0
UZSN	Upper zone nominal soil moisture storage	inches	0.11-0.135	0.73-0.87	0.82—0.99
IRC	Interflow recession parameter	none	0.50	0.50	0.67
AGWRC	Base groundwater recession	none	0.91	0.89-0.91	0.906
INTFW	Interflow/surface runoff partition parameter	none	1.046	1.80-2.80	0.33803
LZETP (summer)	Lower zone ET parameter	none	0.99	0.99	0.99

The final version of the primary calibration simulated snowmelt. As part of the primary calibration, snowmelt was also simulated on Segments 210 and 220 above the USGS gage on Goose Creek near Middleburg. Figure 4.2 compares observed and simulated flow from Segment 210 in the final calibration over the period of gage record at the Middleburg gage. Figure 4.3 compares simulated and observed flows for 1992, a typical year, and Figure 4.4

shows observed and simulated flows for a storm event. Figures 4.5 and 4.6 compare the cumulative distribution of observed and simulated flows, respectively. Table 4.6 presents the simulated average annual stormflow, interflow, and baseflow for the calibration and verification periods.

Table 4.6: Simulated average annual runoff, interflow, and baseflow

Average Annual Flow	Goose Creek Near Middleburg (210)		Goose Creek Near Leesburg (90)	
	Calibration	Verification	Calibration	Verification
Runoff (in)	3.7	8.7	2.3	3.2
Interflow (in)	1.6	5.1	2.8	3.8
Baseflow (in)	9.0	20.2	8.3	9.8
Total (in)	14.3	34.0	13.3	16.6
Baseflow Index	0.63	0.59	0.62	0.59

The simulation of snowmelt increased the coefficient of determination between observed and simulated flows at that station during the calibration period to 0.79, but also increased the flow overall, so that simulated flow during the winter was 22% higher than observed. Total simulated flow remained within 10% of observed flow. R^2 for the verification period was 0.88. Tables 4.7 and 4.8 present summary statistics for the hydrology calibration and verification, respectively, at Goose Creek near Middleburg.

Low flows were oversimulated in both the calibration and verification periods, in part by design. Over the calibration period, 2% of the recorded average daily flow on Goose Creek near Middleburg was 0 cfs and almost 5% of the flows were below 1 cfs. Simulating zero and near zero flows can lead to computational difficulties when constituents like fecal coliform bacteria are simulated: simulated concentrations approach infinity as simulated volumes in stream reaches approach zero. For that reason simulated flows were calibrated to remain above about 0.001 cfs in every segment.

Table 4.7: Summary statistics for hydrology calibration at Middleburg

	Observed	Simulated	Error	Criterion
Total Volume (in)	13.3	14.3	+7	±10%
Volume Highest 10% Flows (in)	6.4	6.3	-3.0	±15%
Volume Lowest 50% Flows (in)	1.3	1.6	+20	±10%
Spring Flow Volume (in)	4.1	3.9	-4.0	±10%
Summer Flow Volume (in)	3.8	3.8	-2.0	±10%
Fall Flow Volume (in)	3.0	3.7	+22	±10%
Winter Flow Volume (in)	2.4	2.9	+22	±10%
Groundwater Recession Coefficient	0.95	0.93	-2.0	±10%
Coefficient of Determination	0.79			

Table 4.8: Summary statistics for hydrology verification at Middleburg

	Observed	Simulated	Error	Criterion
Total Volume (in)	34	37	+9.0	±10%
Volume Highest 10% Flows (in)	11	12	+13	±15%
Volume Lowest 50% Flows (in)	7.4	7.7	+3.0	±10%
Spring Flow Volume (in)	7.1	7.4	+5.0	±10%
Summer Flow Volume (in)	4.8	6.8	+42	±10%
Fall Flow Volume (in)	8.6	9.6	+11	±10%
Winter Flow Volume (in)	14	13	-3.0	±10%
Groundwater Recession Coefficient	0.96	0.93	-3.0	±10%
Coefficient of Determination	0.88			

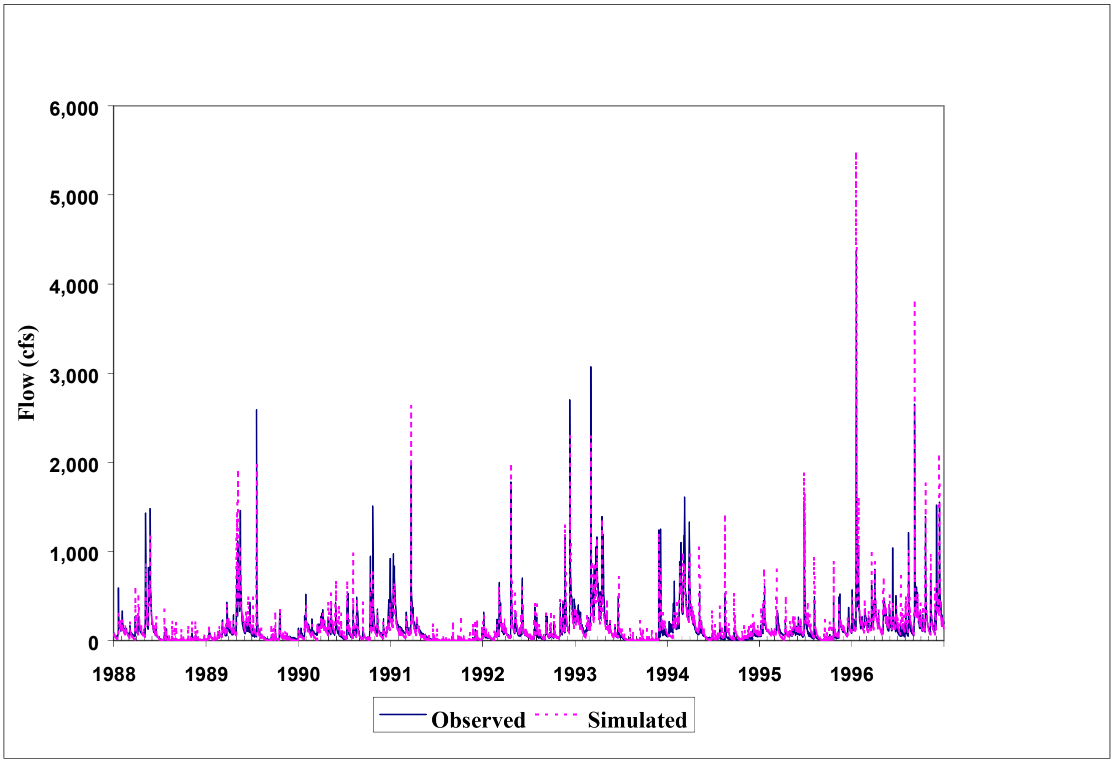


Figure 4.2: Comparison of observed and simulated streamflow at Middleburg gage for period of record (1988-1996)

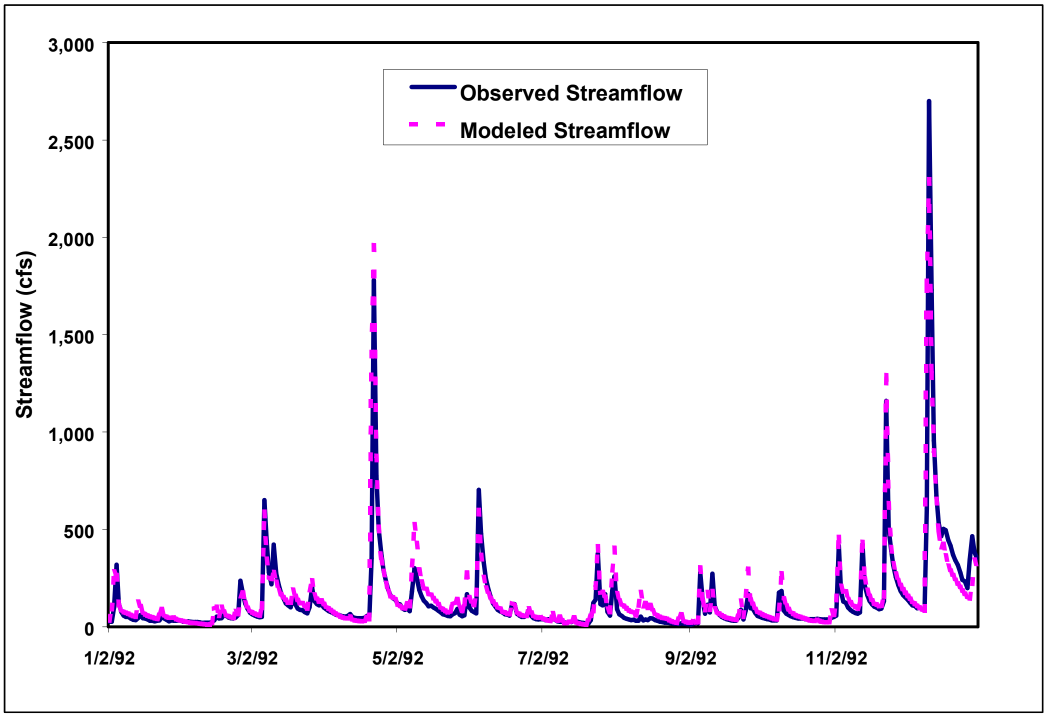


Figure 4.3: Observed and simulated streamflow at Middleburg gage for 1992

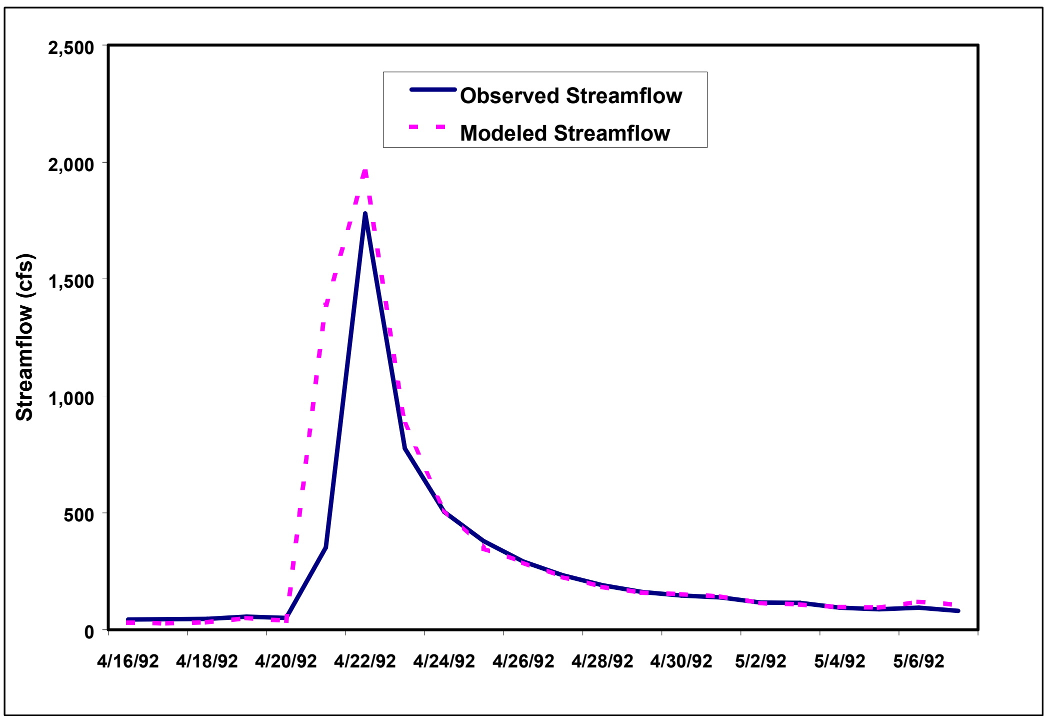


Figure 4.4: Observed and modeled streamflow at Middleburg gage for a typical storm event

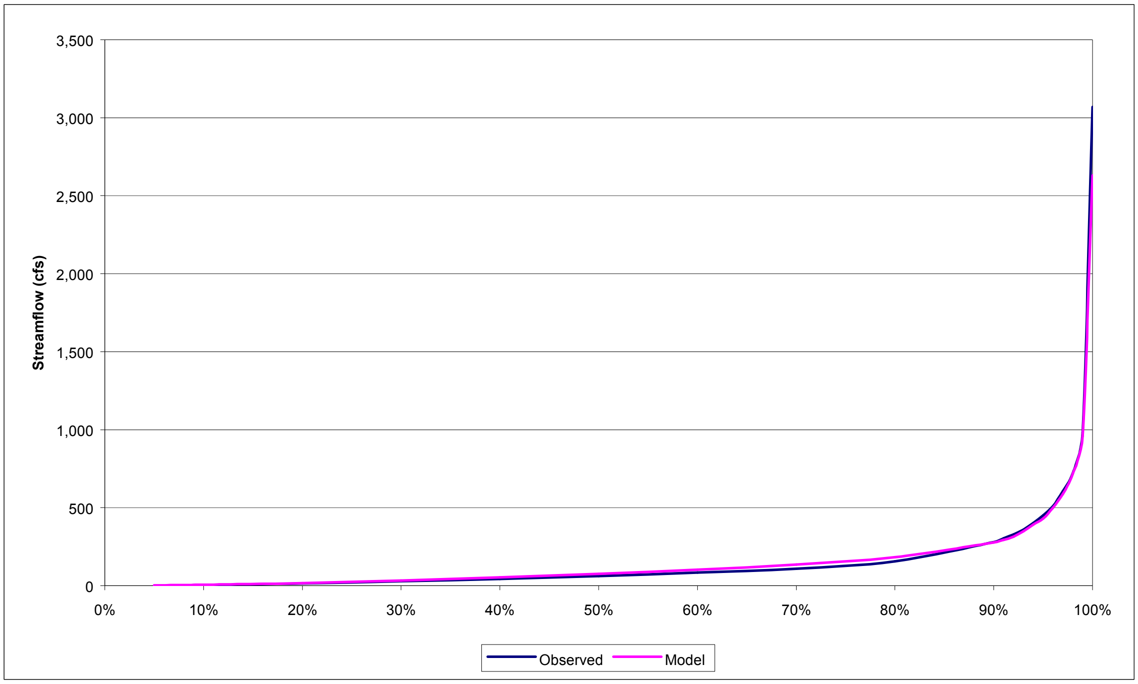


Figure 4.5: Cumulative distribution of observed and simulated flows at Goose Creek near Middleburg, calibration period (1988-1995)

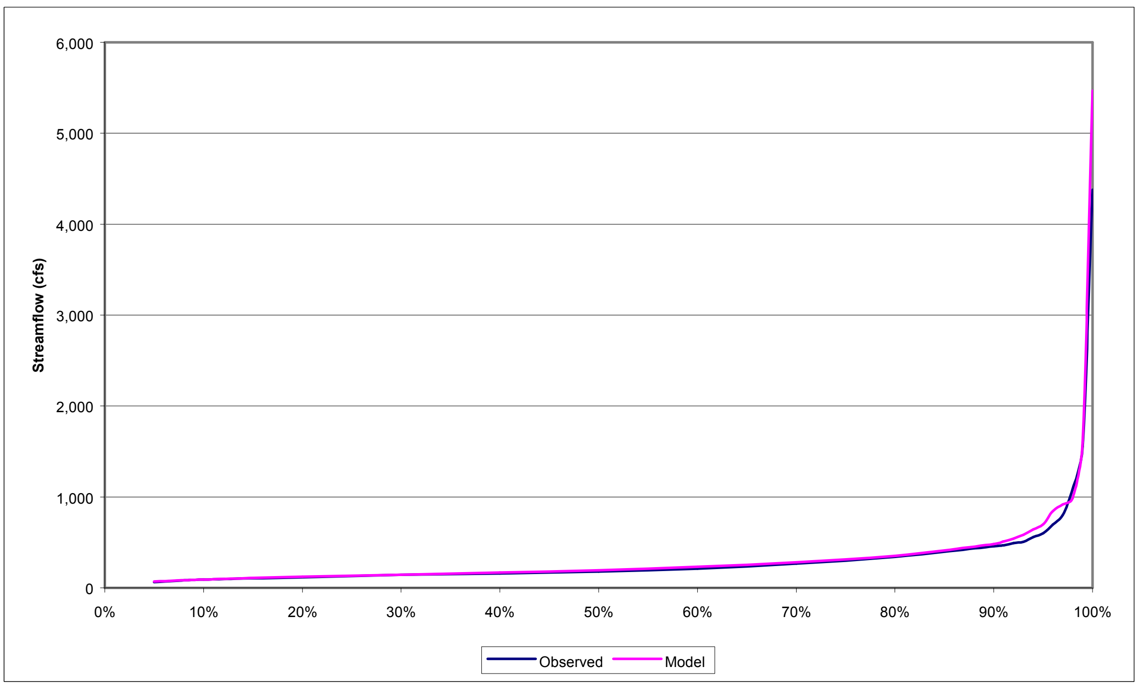


Figure 4.6: Cumulative distribution of observed and simulated flows at Goose Creek near Middleburg, verification period (1996)

4.2.4.2 Hydrology Calibration at Leesburg

The primary hydrological calibration compared simulated flows from Segment 90 with the daily flows observed at the USGS gage on Goose Creek near Leesburg (01644000). The calibration period was 1988-1995. The verification period was 1996-2001. Snowmelt was simulated. About half of the forest in Beaverdam Creek (Segment 180) is in the Blue Ridge Mountains, so 5% of the forest cover was simulated as impervious to represent boulder cover and rock outcrop.

PEST was again used to perform the calibration. Snowmelt was calibrated by adjusting the simulated elevation over the entire watershed until simulated snowmelt peaks corresponded to observed peaks. Table 4.5 shows the final hydrologic parameters, after minor adjustments were made to facilitate the simulation of fecal coliform bacteria. Figure 4.7 compares observed and simulated flows during the calibration period. Figure 4.8 shows the same comparison during the verification period. Table 4.6 presents the simulated average annual stormflow, interflow, and baseflow at the Leesburg gage for the calibration and verification periods. Figure 4.9 compares observed and simulated flows during 1990, an average flow year. Figure 4.10 shows observed and simulated flows during a typical storm event. Figures 4.11 and 4.12 compare the cumulative distribution of observed and simulated flows, respectively.

Overall, simulated flows compare quite well with the observed record. Table 4.9 compares key statistics for observed and simulated flows over the calibration period. The coefficient of determination (R^2) during the calibration period was 0.83. Generally, there is good agreement between observed and simulated flow volumes. The one exception is summer flow volume, which is oversimulated by 20%.

Table 4.10 compares key statistics for observed and simulated flows over the verification period. The correlation between observed and simulated flows remains high in the verification period; the coefficient of determination is 0.76. Although 1996 was a very wet year, most of the rest of the verification period is unusually dry, with near record-low flows. Simulated flows tend to be higher than observed during the verification period because of the oversimulation of low flow periods. The oversimulation of low flows was exacerbated by the change in the method for calculating potential evapotranspiration to simulate 1998-2001. Consumptive use of streamflow by agriculture during extremely dry weather was also not taken into account.

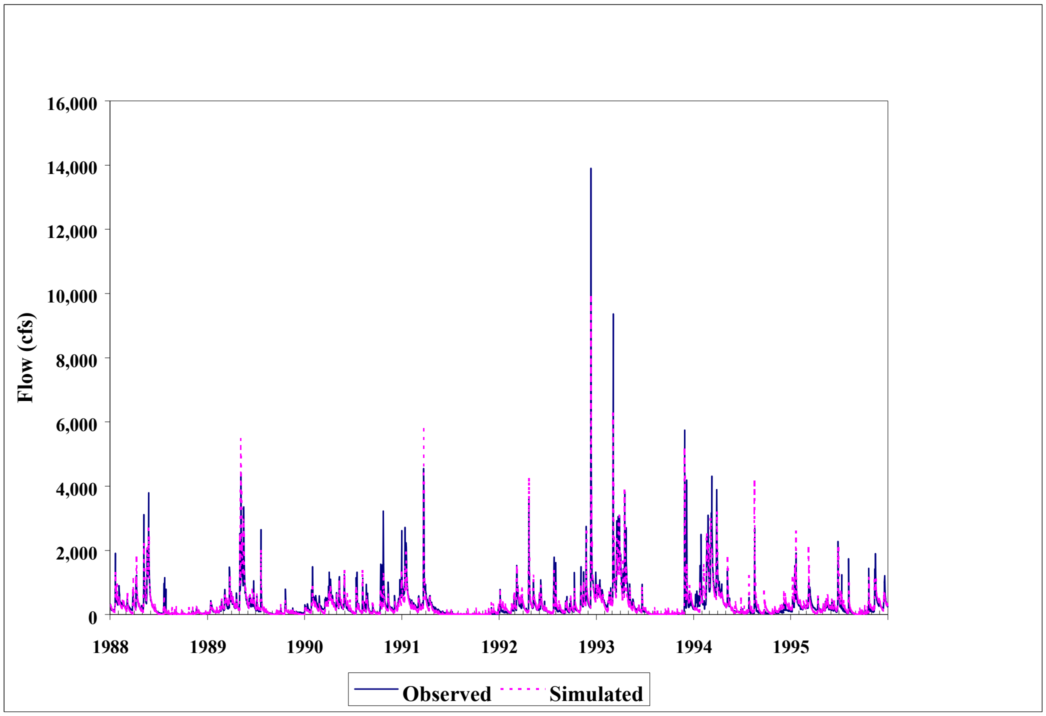


Figure 4.7: Comparison of observed and simulated streamflow at Leesburg gage for calibration period (1988-1995)

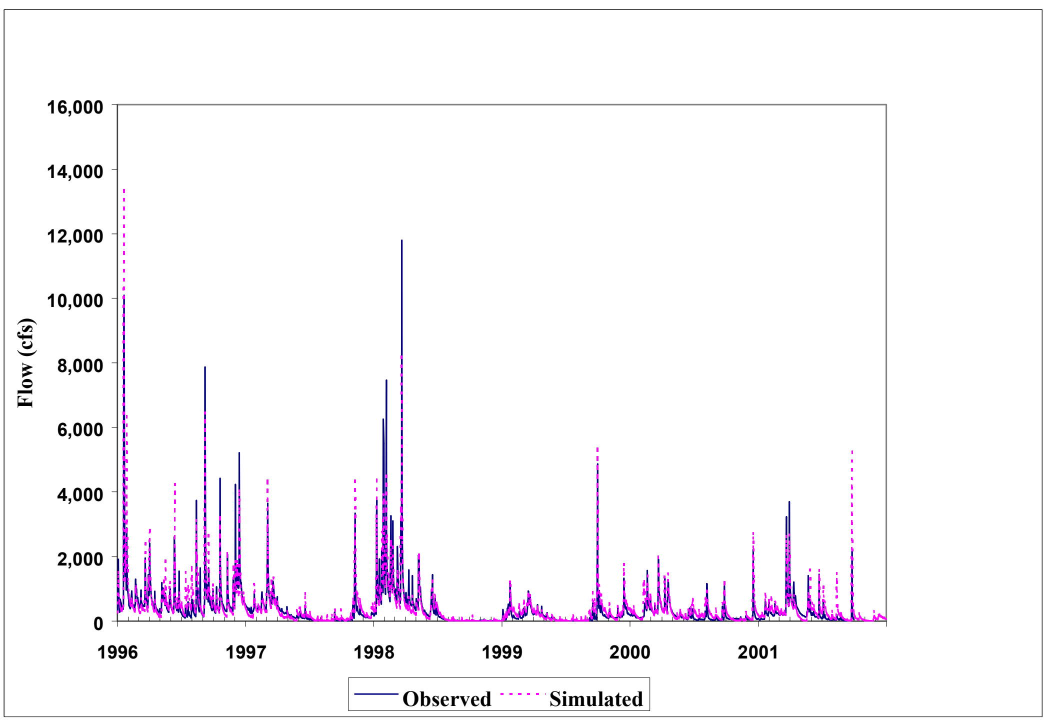


Figure 4.8: Comparison of observed and simulated streamflow at Leesburg gage for verification period (1996-2001)

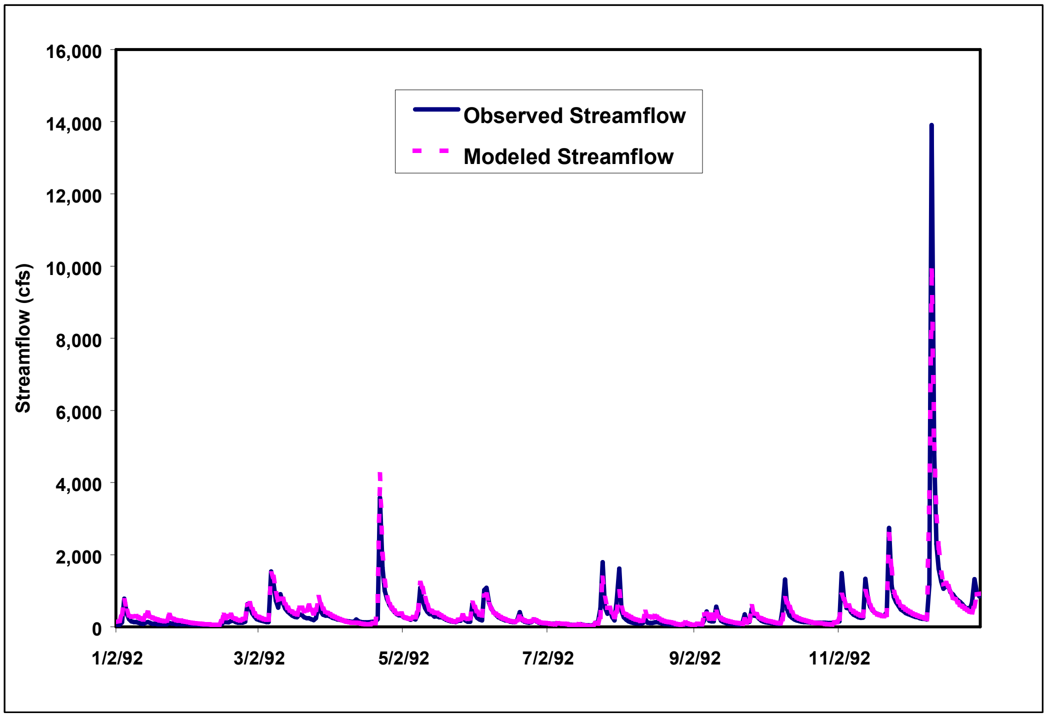


Figure 4.9: Observed and simulated streamflow at Leesburg gage for 1992

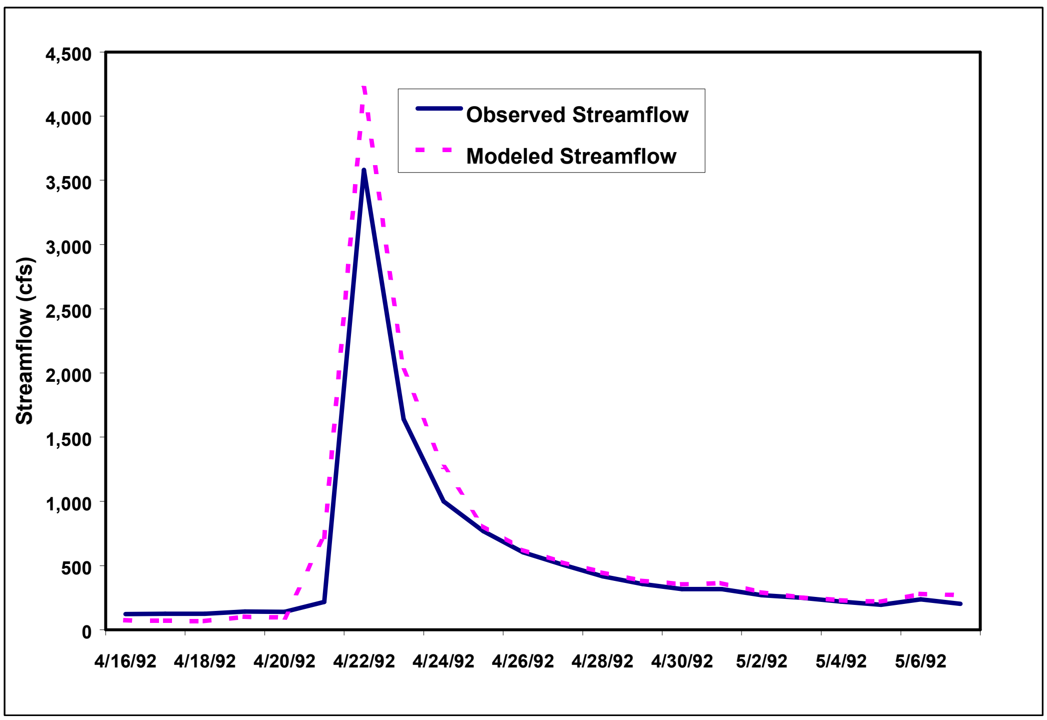


Figure 4.10: Observed and modeled streamflow at Leesburg gage for a typical storm event

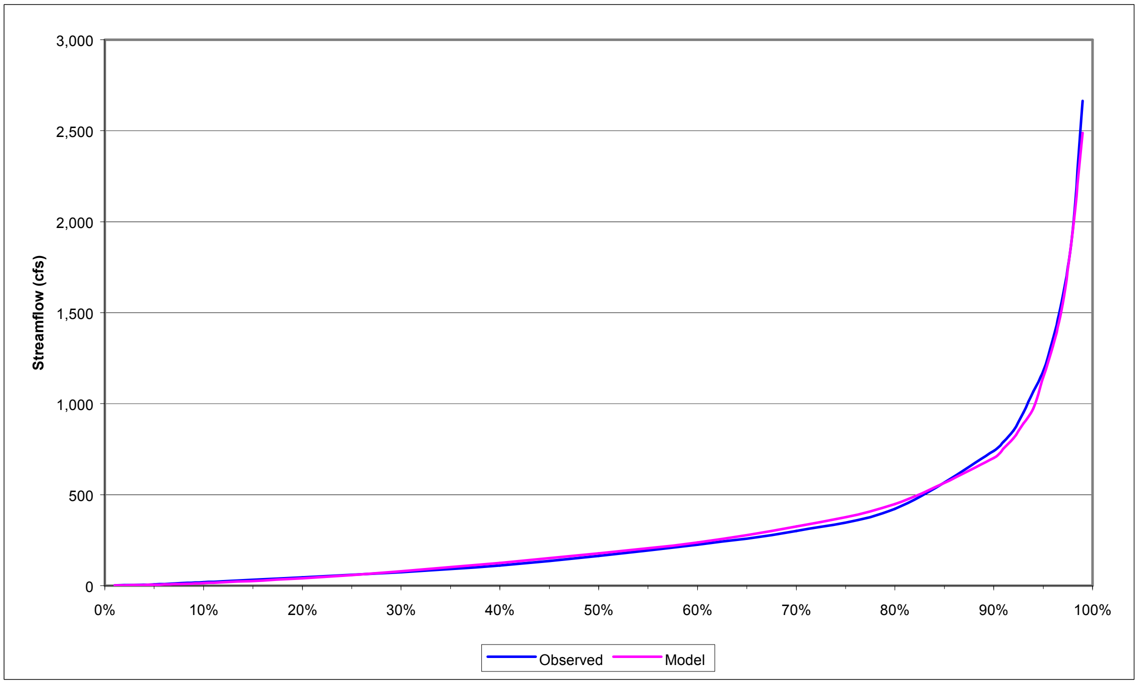


Figure 4.11: Cumulative distribution of observed and simulated flows at Goose Creek near Leesburg, calibration period (1988-1995)

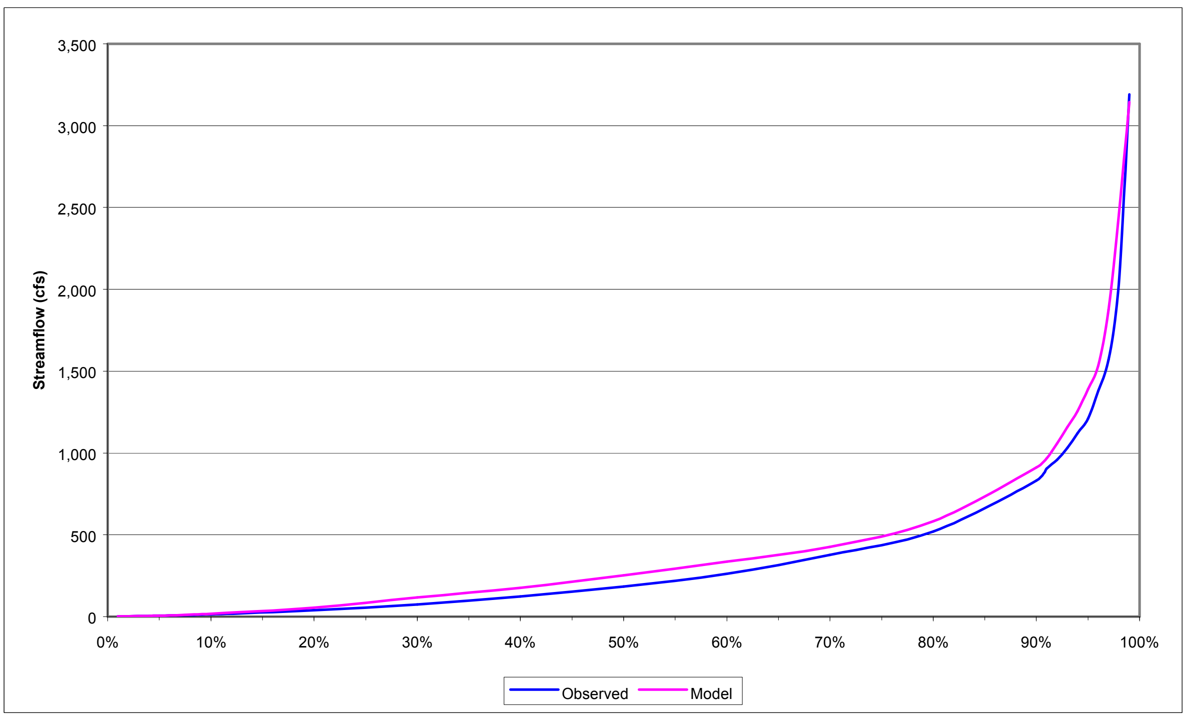


Figure 4.12: Cumulative distribution of observed and simulated flows at Goose Creek near Leesburg, verification period (1996-2001)

Table 4.9: Summary statistics for hydrology calibration at Leesburg

	Observed	Simulated	Error	Criterion
Total Volume (in)	14	13	0	±10%
Volume Highest 10% Flows (in)	6.3	6.1	-4.5	±15%
Volume Lowest 50% Flows (in)	1.3	1.4	+5.7	±10%
Spring Flow Volume (in)	6.1	5.9	-4.0	±10%
Summer Flow Volume (in)	1.7	2.0	+20	±10%
Fall Flow Volume (in)	1.4	1.5	+5.0	±10%
Winter Flow Volume (in)	4.0	3.9	-3.0	±10%
Groundwater Recession Coefficient	0.96	0.93	-2.8	±10%
Coefficient of Determination	0.83			

Table 4.10: Summary statistics for hydrology verification Leesburg

	Observed	Simulated	Error	Criterion
Total Volume (in)	11	13	+15	±10%
Volume Highest 10% Flows (in)	6.8	7.3	+7.6	±15%
Volume Lowest 50% Flows (in)	1.3	1.9	+4.4	±10%
Spring Flow Volume (in)	4.1	3.8	-7.0	±10%
Summer Flow Volume (in)	1.2	2.0	+67	±10%
Fall Flow Volume (in)	1.7	2.3	+36	±10%
Winter Flow Volume (in)	3.9	4.4	+12	±10%
Groundwater Recession Coefficient	0.96	0.92	-3.6	±10%
Coefficient of Determination	0.76			

4.2.4.3 Hydrological Calibration of the Lower Goose Creek Watershed

The simulation of the hydrology and the hydraulics of the Goose Creek watershed below the USGS gage near Leesburg is complicated by two factors: (1) The City of Fairfax operates two reservoirs, one on the mainstem of Goose Creek, for water supply; (2) the soils along the mainstem of Goose Creek, surrounding and downstream of the reservoirs, tend to have a higher clay content and lower infiltration rates than elsewhere in the watershed.

Reservoir Operation

The City of Fairfax supplied daily raw water treatment records for 1996-2001. These were used to determine average daily withdrawals from the Goose Creek Reservoir on a monthly basis. Average daily-simulated withdrawals were extrapolated back to the beginning of the simulation period.

During periods of low flow, the withdrawal rate from Goose Creek can exceed the flow. Water is sometimes released from Beaverdam Reservoir upstream of the water supply intake to supplement flow. As a rule-of-thumb, if the water level in the Goose Creek Reservoir drops three inches below the top of the dam, water is released from the Beaverdam Reservoir. The Beaverdam Reservoir can supply Goose Creek with as much as 3 million gallons per day (MGD) if the outlet valves are fully open (Boryschuk, 2001). For the simulation, it was assumed that if the volume in the Goose Creek Reservoir (Segment 60) dropped 20 acre-feet below capacity (the equivalent of three inches over the surface area of Reach 60), 3 MGD were transferred from the Beaverdam Reservoir to the Goose Creek Reservoir. Water can also be pumped from the Goose Creek Reservoir to the Beaverdam Reservoir for storage. This occurred at least once in the simulation period, in 1999. The transfer of water between the Goose Creek and Beaverdam Reservoirs was not included in the simulation.

Hydrological Calibration of Lower Goose Creek Watershed
There are no daily discharge records for flows on the mainstem of Goose Creek or its tributaries below the USGS gage on Goose Creek near Leesburg. The City of Fairfax monitored water levels in Beaverdam Reservoir between October 26, 1998 and March 22, 2000. Except for two weeks in the summer of 1999, no water was released from the reservoir to Goose Creek after December 8, 1998. This period thus provided an opportunity to calibrate the hydrologic parameters for the lower Goose Creek watershed by simulating the volume of water stored in the Beaverdam Reservoir. It proved difficult, however, to calibrate the model to capture the large increase in water levels that occurred in September 1999, because of Tropical Storm Floyd, so the calibration period was set to December 1998 to September 1999.

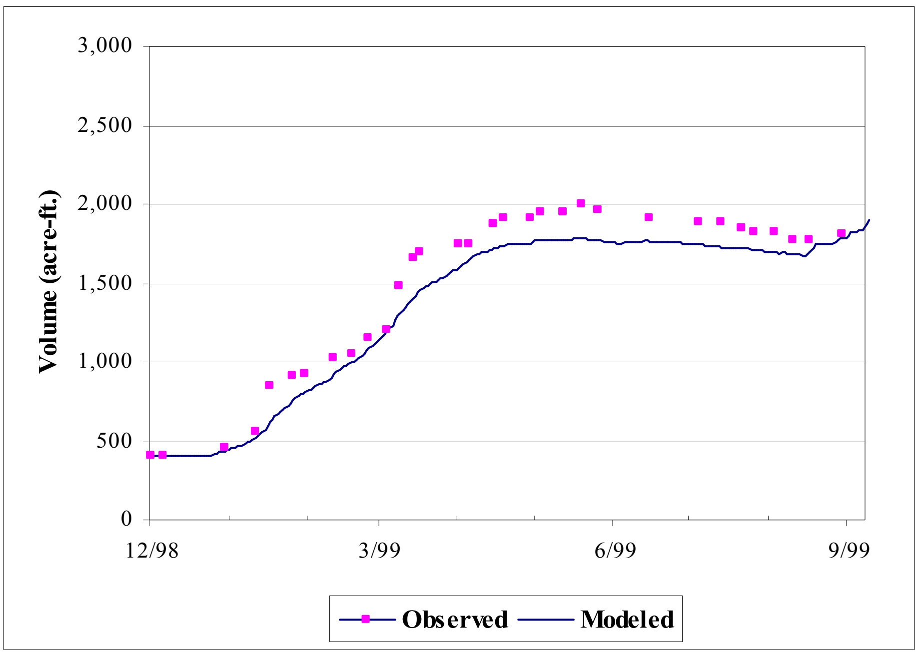


Figure 4.13: Observed and Simulated Volumes in Beaverdam Reservoir

PEST was again used to perform the calibration. Figure 4.13 compares the observed and simulated volumes in the Beaverdam Reservoir. The correlation between observed and simulated values is very good; the coefficient of determination is 0.95. Table 4.5 gives the optimum parameter values as determined by PEST. As anticipated, estimated infiltration rates are lower for the soils draining into the reservoir. These parameters were applied to Segments 10, 20, 40, 50, 60, and 70. These same segments also receive hourly precipitation derived from the record at the Dulles International Airport.

4.2.4.4 Overall Hydrology Calibration

Table 4.11 summarizes the hydrology parameters used in the simulation and the source from which they were derived. Figure 4.1 shows the source of rainfall for each segment and the calibration point at which the hydrologic parameters were determined.

Table 4.11: HSPF parameter values

Parameter	Definition	Units	Range of Values				Start	Final	Function of…
			Typical		Possible				
			Min	Max	Min	Max			
PERLND									
APWAT-PARM2									
FOREST	Fraction forest cover	none	0.00	0.5	0	0.95	0	0	Forest cover
LZSN	Lower zone nominal soil moisture storage	inches	3	8	2	15	5.0	3-9.5	Soil properties
INFILT	Index to infiltration capacity	in/hr	0.01	0.25	0.001	0.5	0.05	0.046-0.187	Soil and cover condition
LSUR	Length of overland flow	feet	200	500	100	700	300	300-500	Topography
SLSUR	Slope of overland flowplane	none	0.01	0.15	0.001	0.3		0.032-0.129	Determined by GIS
KVARY	Groundwater recession variable	1/in	0	3	0	5	0	0	Calibrate
AGWRC	Base groundwater recession	none	0.92	0.99	0.85	0.999	.95	0.890-0.986	Calibrate
BPWAT-PARM3									
PETMAX	Temp below which ET is reduced	Deg. F	35	45	32	48	40	40	Climate, vegetation
PETMIN	Temp below which ET is set to zero	Deg. F	30	35	30	40	35	35	Climate, vegetation
INFEXP	Exponent in infiltration equation	none	2	2	1	3	2	2	Soil properties
INFILD	Ratio of max/mean infiltration capacities	none	2	2	1	3	2	2	Soil properties
DEEPFR	Fraction of GW inflow to deep recharge	none	0	0.2	0	0.5	0.0	0.0	Geology
BASETP	Fraction of remain ET from baseflow	none	0	0.05	0	0.2	0.02	0.02	Riparian vegetation
AGWETP	Fraction of remain ET from active GW	none	0	0.05	0	0.2	0	0	Marsh/wetlands ET
CPWAT-PARM4									
CEPSC	Interception storage capacity	inches	0.03	0.2	0.01	0.4	0-0.1	0-0.1	Vegetation
UZSN	Upper zone nominal soil moisture storage	inches	0.10	1	0.05	2	0.1	0.9900-0.7301	Soil properties
NSUR	Manning's (roughness)	none	0.15	0.35	0.1	0.5	0.3-0.4	0.3-0.4	Land use, surface condition
INTFW	Interflow/surface runoff partition parameter	none	1	3	1	10	1.0	0.34-2.80	Soils, topography, land use
IRC	Interflow recession parameter	none	0.5	0.7	0.3	085	1.0	0.5-0.67	Soils, topography, land use
LZETP	Lower zone ET parameter	none	0.2	0.7	0.1	0.9	0.8	0.01-0.99	Vegetation
DQUAL-INPUT									
SQO	Initial storage of constituent	#/ac						2E+5-5E+9	
POTFW	Washoff potency factor	#/ton	Not simulated						
POTFS	Scour potency factor	#/ton							
ACQOP	Rate of accumulation of constituent	#/day						76E+06-86E09	Calculated From Source Assessment

Parameter	Definition	Units	Range of Values				Start	Final	Function of…
			Typical		Possible				
			Min	Max	Min	Max			
PERLND									
SQOLIM	Maximum accumulation of constituent	#						61E07-78E10	Calculated From Source Assessment
WSQOP	Wash-off rate	in/hr					1.0	0.3-2.0	Land use
IOQC	Constituent conc. In interflow	#/ft3					0	0	
AOQC	Constituent conc. In active groundwater	#/ft3					0	0	
IMPLND									
EIWAT-PARM2									
LSUR	Length of overland flow	Feet	200	500	100	700	300	300-500	Topography
SLSUR	Slope of overland flowplane	none	0.01	0.15	0.001	0.3		0.05-0.18	Topography
NSUR	Manning's (roughness)	none	0.15	0.35	0.1	0.5	0.1	0.1	Land use, surface condition
RETSC	Retention/interception storage capacity	inches	0.03	0.2	0.01	0.4	0.065	0.065	Land use, surface condition
FIWAT-PARM3									
PETMAX	Temp below which ET is reduced	deg. F	35	45	32	48	40	40	Climate, vegetation
RCHRES									
GHYDR-PARM2									
KS	Weighting factor for hydraulic routing						0.5	0.5	
HGQUAL									
FSTDEC	First order decay rate of the constituent	1/day					1.15	0.1-2.5	
THFST	Temperature correction coeff. For FSTDEC						1.05	1.05	

4.2.4.5 Sensitivity Analysis for the Hydrology Calibration

A sensitivity analysis was performed to determine the stability of the hydrology calibration with respect to key calibration parameters. The parameters shown in Table 4.12 were varied ±10% individually from their calibrated value, and the coefficient of determination of the resulting simulation was compared with the coefficient for the calibrated hydrology simulation over the period 1988-2001. Table 4.12 shows the results. In general, the calibration is relatively stable with respect to small changes in parameter values.

Table 4.12: Sensitivity analysis: variation in coefficient of determination with respect to variation in parameters for simulation period 1988-2001

Parameter	Coefficient of Determination	
	+10% change in parameter	-10% change in parameter
INFILT	0.79	0.78
LZSN	0.78	0.79
UZSN	0.79	0.79
IRC	0.78	0.79
AGWRC	0.74	0.78
INTFW	0.79	0.78
LZETP	0.79	0.78
The coefficient of determination for the combined calibration and verification periods is 0.79.		

4.3.Fecal Coliform Bacteria Load Estimates

The fecal coliform bacteria loading rates used in the model were determined from the source assessment described in Chapter 3. Fecal coliform loads can be divided into two types: loads deposited directly into stream reaches and loads applied to the land surface. The latter can be transported to surface water in runoff.

4.3.1 Point Sources and Loads Directly Deposited into Stream Reaches

The following loads are input directly into reaches as daily time series:

- Loads from wastewater treatment plants and domestic dischargers;
- Direct deposition in streams from beef and dairy cattle;
- Direct deposition in streams from wildlife;
- Loads transported in groundwater discharge originating from septic systems within 50 feet of streams.

The average daily load from each of these sources can be found in Table 3.16. Loads from septic systems and wildlife are constant. Point source loads depend on the monthly average flow from the wastewater treatment plant. Direct deposition from cattle varies monthly according to cattle population and the time spent by cattle in stream.

4.3.2 Land-Applied Loads

An average daily loading rate, in cfu/acre/day, was calculated for each land use in each subwatershed, by dividing the daily load generated on that land use in a given subwatershed by the total number of acres of that land use in the subwatershed. Table 4.13 shows the sources which contribute to the load for each land use type. Loads applied to forest and developed land was constant over the course of the simulation. Table 4.14 shows the loading rates for forest and developed land.

Table 4.13 Animal and human sources contributing to land use loads

Source	Forest	Pasture	Cropland	Developed Land
Beef Cattle		X		
Dairy Cattle		X	X	
Horse		X		
Sheep		X		
Deer	X	X	X	X
Raccoon	X	X	X	X
Muskrat	X			
Turkey	X	X	X	X
Goose	X	X	X	X
Duck	X	X	X	X
Dog		X	X	X
Septic Systems				X
Biosolids			X	

Loads applied to crop and pasture varied monthly. The monthly variation in pasture loads is due to seasonal variation in the amount of time cattle spend in pasture and to seasonal variation in the cattle population. It also depends on whether dairy manure is applied to pasture or crops. Tables 4.15 and 4.16 give the daily pasture loading rates by month for the calibration and verification periods, respectively.

Tables 4.17 and 4.18 give the loading rates by month for cropland in the calibration and verification periods. The monthly variation in crop loading rates is a function of the timing of the land application of dairy waste and of the seasonal application of biosolids. Although biosolids are applied to fields episodically, in the model they are applied at a constant daily application rate.

Table 4.14 Daily loading rates (cfu/acre/day) for forest and developed land

Segment	Forest	Developed
10	4.0E+07	9.0E+08
20	4.4E+07	1.0E+09
30	4.5E+07	4.8E+08
40	5.2E+07	2.1E+08
50	5.7E+07	9.1E+07
60	4.7E+07	1.7E+09
70	3.4E+07	2.5E+09
80	4.1E+07	4.7E+09
90	4.4E+07	5.7E+09
100	4.3E+07	2.0E+09
110	4.0E+07	3.4E+09
120	4.3E+07	1.0E+10
130	4.2E+07	2.9E+09
140	4.4E+07	9.3E+08
150	4.4E+07	8.0E+08
160	3.4E+07	6.1E+08
170	4.5E+07	3.9E+10
180	4.3E+07	8.4E+09
190	4.6E+07	3.5E+08
200	4.7E+07	7.3E+08
210	4.1E+07	4.4E+08
220	3.0E+07	6.9E+08
230	4.5E+07	6.9E+09
240	4.4E+07	1.1E+10
250	4.3E+07	3.9E+09
Total	1.08E+09	1.09E+11

Table 4.15 Daily Pasture Loading Rates By Month (cfu/acre/day) Calibration Period (1992-1997)

Segment	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
10	2.6E+09	2.6E+09	2.6E+09	3.3E+09	3.3E+09	3.7E+09	3.7E+09	3.7E+09	3.7E+09	2.6E+09	2.6E+09	2.6E+09
20	2.6E+09	2.6E+09	2.6E+09	3.3E+09	3.3E+09	3.7E+09	3.7E+09	3.7E+09	3.7E+09	2.6E+09	2.6E+09	2.6E+09
30	2.6E+09	2.6E+09	2.6E+09	3.4E+09	3.4E+09	3.7E+09	3.7E+09	3.7E+09	3.7E+09	2.6E+09	2.6E+09	2.6E+09
40	2.6E+09	2.6E+09	2.6E+09	3.4E+09	3.4E+09	3.7E+09	3.7E+09	3.7E+09	3.7E+09	2.6E+09	2.6E+09	2.6E+09
50	2.5E+09	2.5E+09	2.5E+09	3.2E+09	3.2E+09	3.6E+09	3.6E+09	3.6E+09	3.6E+09	2.5E+09	2.5E+09	2.5E+09
60	2.6E+09	2.6E+09	2.6E+09	3.3E+09	3.3E+09	3.7E+09	3.7E+09	3.7E+09	3.7E+09	2.6E+09	2.6E+09	2.6E+09
70	2.6E+09	2.6E+09	2.6E+09	3.4E+09	3.4E+09	3.7E+09	3.7E+09	3.7E+09	3.7E+09	2.6E+09	2.6E+09	2.6E+09
80	2.6E+09	2.6E+09	2.6E+09	3.4E+09	3.4E+09	3.7E+09	3.7E+09	3.7E+09	3.7E+09	2.6E+09	2.6E+09	2.6E+09
90	2.6E+09	2.6E+09	2.6E+09	3.3E+09	3.3E+09	3.7E+09	3.7E+09	3.7E+09	3.7E+09	2.6E+09	2.6E+09	2.6E+09
100	1.4E+09	1.4E+09	1.4E+09	1.8E+09	1.8E+09	1.9E+09	1.9E+09	1.9E+09	1.9E+09	1.4E+09	1.4E+09	1.4E+09
110	2.6E+09	2.6E+09	2.6E+09	3.4E+09	3.4E+09	3.7E+09	3.7E+09	3.7E+09	3.7E+09	2.6E+09	2.6E+09	2.6E+09
120	5.5E+09	5.5E+09	5.5E+09	7.1E+09	7.1E+09	7.8E+09	7.8E+09	7.8E+09	7.8E+09	5.5E+09	5.5E+09	5.5E+09
130	2.8E+09	2.8E+09	2.8E+09	3.6E+09	3.6E+09	4.0E+09	4.0E+09	4.0E+09	4.0E+09	2.8E+09	2.8E+09	2.8E+09
140	2.8E+09	2.8E+09	2.8E+09	3.6E+09	3.6E+09	4.0E+09	4.0E+09	4.0E+09	4.0E+09	2.8E+09	2.8E+09	2.8E+09
150	2.6E+09	2.6E+09	2.6E+09	3.4E+09	3.4E+09	3.7E+09	3.7E+09	3.7E+09	3.7E+09	2.6E+09	2.6E+09	2.6E+09
160	8.0E+08	8.0E+08	8.0E+08	8.0E+08	2.8E+09	2.8E+09	2.8E+09	2.8E+09	2.8E+09	2.8E+09	8.0E+08	8.0E+08
170	3.3E+09	3.3E+09	3.3E+09	4.2E+09	4.2E+09	4.6E+09	4.6E+09	4.6E+09	4.6E+09	3.3E+09	3.3E+09	3.3E+09
180	3.3E+09	3.3E+09	3.3E+09	4.2E+09	4.2E+09	4.6E+09	4.6E+09	4.6E+09	4.6E+09	3.3E+09	3.3E+09	3.3E+09
190	6.6E+09	6.6E+09	6.6E+09	8.4E+09	8.4E+09	9.3E+09	9.3E+09	9.3E+09	9.3E+09	6.6E+09	6.6E+09	6.6E+09
200	7.0E+08	7.0E+08	7.0E+08	7.0E+08	1.9E+09	1.9E+09	1.9E+09	1.9E+09	1.9E+09	1.9E+09	7.0E+08	7.0E+08
210	3.4E+09	3.4E+09	3.4E+09	3.4E+09	1.3E+10	1.3E+10	1.3E+10	1.3E+10	1.3E+10	1.3E+10	3.4E+09	3.4E+09
220	2.6E+09	2.6E+09	2.6E+09	2.6E+09	1.0E+10	1.0E+10	1.0E+10	1.0E+10	1.0E+10	1.0E+10	2.6E+09	2.6E+09
230	1.3E+09	1.3E+09	1.3E+09	1.6E+09	1.6E+09	1.8E+09	1.8E+09	1.8E+09	1.8E+09	1.3E+09	1.3E+09	1.3E+09
240	9.1E+08	9.1E+08	9.1E+08	1.1E+09	1.1E+09	1.2E+09	1.2E+09	1.2E+09	1.2E+09	9.1E+08	9.1E+08	9.1E+08
250	6.7E+09	6.7E+09	6.7E+09	8.5E+09	8.5E+09	9.5E+09	9.5E+09	9.5E+09	9.5E+09	6.7E+09	6.7E+09	6.7E+09

Table 4.16 Daily Pasture Loading Rates By Month (cfu/acre/day) Verification Period (1998-2001)

Segment	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
10	7.1E+08	7.1E+08	7.1E+08	8.4E+08	8.4E+08	9.1E+08	9.1E+08	9.1E+08	9.1E+08	7.1E+08	7.1E+08	7.1E+08
20	3.8E+07	3.8E+07	3.8E+07	3.8E+07	3.8E+07	3.8E+07	3.8E+07	3.8E+07	3.8E+07	3.8E+07	3.8E+07	3.8E+07
30	1.4E+09	1.4E+09	1.4E+09	1.7E+09	1.7E+09	1.9E+09	1.9E+09	1.9E+09	1.9E+09	1.4E+09	1.4E+09	1.4E+09
40	4.5E+07	4.5E+07	4.5E+07	4.5E+07	4.5E+07	4.5E+07	4.5E+07	4.5E+07	4.5E+07	4.5E+07	4.5E+07	4.5E+07
50	4.1E+07	4.1E+07	4.1E+07	4.1E+07	4.1E+07	4.1E+07	4.1E+07	4.1E+07	4.1E+07	4.1E+07	4.1E+07	4.1E+07
60	3.0E+08	3.0E+08	3.0E+08	3.8E+08	3.8E+08	4.1E+08	4.1E+08	4.1E+08	4.1E+08	3.0E+08	3.0E+08	3.0E+08
70	4.7E+08	4.7E+08	4.7E+08	6.0E+08	6.0E+08	6.6E+08	6.6E+08	6.6E+08	6.6E+08	4.7E+08	4.7E+08	4.7E+08
80	2.5E+09	2.5E+09	2.5E+09	3.1E+09	3.1E+09	3.4E+09	3.4E+09	3.4E+09	3.4E+09	2.5E+09	2.5E+09	2.5E+09
90	4.5E+07	4.5E+07	4.5E+07	4.5E+07	4.5E+07	4.5E+07	4.5E+07	4.5E+07	4.5E+07	4.5E+07	4.5E+07	4.5E+07
100	1.6E+09	1.6E+09	1.6E+09	2.0E+09	2.0E+09	2.2E+09	2.2E+09	2.2E+09	2.2E+09	1.6E+09	1.6E+09	1.6E+09
110	1.7E+09	1.7E+09	1.7E+09	2.2E+09	2.2E+09	2.4E+09	2.4E+09	2.4E+09	2.4E+09	1.7E+09	1.7E+09	1.7E+09
120	4.3E+09	4.3E+09	4.3E+09	5.2E+09	5.2E+09	5.6E+09	5.6E+09	5.6E+09	5.6E+09	4.3E+09	4.3E+09	4.3E+09
130	1.9E+09	1.9E+09	1.9E+09	2.4E+09	2.4E+09	2.7E+09	2.7E+09	2.7E+09	2.7E+09	1.9E+09	1.9E+09	1.9E+09
140	3.1E+09	3.1E+09	3.1E+09	4.0E+09	4.0E+09	4.4E+09	4.4E+09	4.4E+09	4.4E+09	3.1E+09	3.1E+09	3.1E+09
150	3.3E+09	3.3E+09	3.3E+09	4.3E+09	4.3E+09	4.8E+09	4.8E+09	4.8E+09	4.8E+09	3.3E+09	3.3E+09	3.3E+09
160	1.1E+09	1.1E+09	1.1E+09	1.1E+09	3.9E+09	3.9E+09	3.9E+09	3.9E+09	3.9E+09	3.9E+09	1.1E+09	1.1E+09
170	3.2E+09	3.2E+09	3.2E+09	4.1E+09	4.1E+09	4.6E+09	4.6E+09	4.6E+09	4.6E+09	3.2E+09	3.2E+09	3.2E+09
180	2.2E+09	2.2E+09	2.2E+09	2.8E+09	2.8E+09	3.2E+09	3.2E+09	3.2E+09	3.2E+09	2.2E+09	2.2E+09	2.2E+09
190	7.4E+09	7.4E+09	7.4E+09	9.5E+09	9.5E+09	1.1E+10	1.1E+10	1.1E+10	1.1E+10	7.4E+09	7.4E+09	7.4E+09
200	7.0E+08	7.0E+08	7.0E+08	7.0E+08	1.9E+09	1.9E+09	1.9E+09	1.9E+09	1.9E+09	1.9E+09	7.0E+08	7.0E+08
210	3.4E+09	3.4E+09	3.4E+09	3.4E+09	1.3E+10	1.3E+10	1.3E+10	1.3E+10	1.3E+10	1.3E+10	3.4E+09	3.4E+09
220	2.6E+09	2.6E+09	2.6E+09	2.6E+09	1.0E+10	1.0E+10	1.0E+10	1.0E+10	1.0E+10	1.0E+10	2.6E+09	2.6E+09
230	1.2E+09	1.2E+09	1.2E+09	1.5E+09	1.5E+09	1.7E+09	1.7E+09	1.7E+09	1.7E+09	1.2E+09	1.2E+09	1.2E+09
240	8.6E+08	8.6E+08	8.6E+08	1.1E+09	1.1E+09	1.2E+09	1.2E+09	1.2E+09	1.2E+09	8.6E+08	8.6E+08	8.6E+08
250	2.9E+09	2.9E+09	2.9E+09	3.4E+09	3.4E+09	3.6E+09	3.6E+09	3.6E+09	3.6E+09	2.9E+09	2.9E+09	2.9E+09

Table 4.17 Daily Cropland Loading Rates By Month (cfu/acre/day) calibration period (1992-1997)

Segment	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
10	8.4E+08	8.4E+08	8.4E+08	8.4E+08	8.4E+08	8.4E+08	8.4E+08	8.4E+08	8.4E+08	8.4E+08	8.4E+08	8.4E+08
20	8.5E+07	8.5E+07	8.5E+07	8.5E+07	8.5E+07	8.5E+07	8.5E+07	8.5E+07	8.5E+07	8.5E+07	8.5E+07	8.5E+07
30	3.8E+08	3.8E+08	3.8E+08	3.8E+08	3.8E+08	3.8E+08	3.8E+08	3.8E+08	3.8E+08	3.8E+08	3.8E+08	3.8E+08
40	1.2E+08	1.2E+08	1.2E+08	1.2E+08	1.2E+08	1.2E+08	1.2E+08	1.2E+08	1.2E+08	1.2E+08	1.2E+08	1.2E+08
50	4.1E+07	4.1E+07	4.1E+07	4.1E+07	4.1E+07	4.1E+07	4.1E+07	4.1E+07	4.1E+07	4.1E+07	4.1E+07	4.1E+07
60	4.0E+07	4.0E+07	4.0E+07	4.0E+07	4.0E+07	4.0E+07	4.0E+07	4.0E+07	4.0E+07	4.0E+07	4.0E+07	4.0E+07
70	6.3E+07	6.3E+07	6.3E+07	6.3E+07	6.3E+07	6.3E+07	6.3E+07	6.3E+07	6.3E+07	6.3E+07	6.3E+07	6.3E+07
80	7.4E+07	7.4E+07	7.4E+07	7.4E+07	7.4E+07	7.4E+07	7.4E+07	7.4E+07	7.4E+07	7.4E+07	7.4E+07	7.4E+07
90	3.6E+07	3.6E+07	3.6E+07	3.6E+07	3.6E+07	3.6E+07	3.6E+07	3.6E+07	3.6E+07	3.6E+07	3.6E+07	3.6E+07
100	1.6E+08	1.6E+08	1.6E+08	1.6E+08	1.6E+08	1.6E+08	1.6E+08	1.6E+08	1.6E+08	1.6E+08	1.6E+08	1.6E+08
110	4.7E+07	4.7E+07	4.7E+07	4.7E+07	4.7E+07	4.7E+07	4.7E+07	4.7E+07	4.7E+07	4.7E+07	4.7E+07	4.7E+07
120	7.9E+07	7.9E+07	7.9E+07	7.9E+07	7.9E+07	7.9E+07	7.9E+07	7.9E+07	7.9E+07	7.9E+07	7.9E+07	7.9E+07
130	5.8E+09	5.8E+09	3.2E+09	8.4E+07	8.4E+07	8.4E+07	8.4E+07	8.4E+07	2.4E+09	2.4E+09	3.2E+09	5.8E+09
140	1.2E+09	1.2E+09	1.6E+09	8.2E+07	8.2E+07	8.2E+07	8.2E+07	8.2E+07	5.2E+08	5.2E+08	6.6E+08	2.1E+09
150	5.0E+07	5.0E+07	2.7E+08	5.0E+07	5.0E+07	5.0E+07	5.0E+07	5.0E+07	5.0E+07	5.0E+07	5.0E+07	2.7E+08
160	1.8E+09	1.8E+09	9.5E+08	3.9E+07	3.9E+07	3.9E+07	3.9E+07	3.9E+07	7.2E+08	7.2E+08	9.5E+08	1.8E+09
170	5.4E+07	5.4E+07	5.4E+07	5.4E+07	5.4E+07	5.4E+07	5.4E+07	5.4E+07	5.4E+07	5.4E+07	5.4E+07	5.4E+07
180	1.1E+10	1.1E+10	6.1E+09	5.7E+07	5.7E+07	5.7E+07	5.7E+07	5.7E+07	4.6E+09	4.6E+09	6.1E+09	1.1E+10
190	6.5E+07	6.5E+07	6.5E+07	6.5E+07	6.5E+07	6.5E+07	6.5E+07	6.5E+07	6.5E+07	6.5E+07	6.5E+07	6.5E+07
200	4.7E+07	4.7E+07	4.7E+07	4.7E+07	4.7E+07	4.7E+07	4.7E+07	4.7E+07	4.7E+07	4.7E+07	4.7E+07	4.7E+07
210	4.4E+07	4.4E+07	4.4E+07	4.4E+07	4.4E+07	4.4E+07	4.4E+07	4.4E+07	4.4E+07	4.4E+07	4.4E+07	4.4E+07
220	3.7E+07	3.7E+07	3.7E+07	3.7E+07	3.7E+07	3.7E+07	3.7E+07	3.7E+07	3.7E+07	3.7E+07	3.7E+07	3.7E+07
230	6.8E+07	6.8E+07	6.8E+07	6.8E+07	6.8E+07	6.8E+07	6.8E+07	6.8E+07	6.8E+07	6.8E+07	6.8E+07	6.8E+07
240	3.9E+07	3.9E+07	3.9E+07	3.9E+07	3.9E+07	3.9E+07	3.9E+07	3.9E+07	3.9E+07	3.9E+07	3.9E+07	3.9E+07
250	8.6E+10	8.6E+10	4.6E+10	1.7E+08	1.7E+08	1.7E+08	1.7E+08	1.7E+08	3.5E+10	3.5E+10	4.6E+10	8.6E+10

Table 4.18 Daily Cropland Loading Rates By Month (cfu/acre/day) ,verification period (1998-2001)

Segment	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
10	8.4E+08	8.4E+08	8.4E+08	8.4E+08	8.4E+08	8.4E+08	8.4E+08	8.4E+08	8.4E+08	8.4E+08	8.4E+08	8.4E+08
20	8.5E+07	8.5E+07	8.5E+07	8.5E+07	8.5E+07	8.5E+07	8.5E+07	8.5E+07	8.5E+07	8.5E+07	8.5E+07	8.5E+07
30	3.8E+08	3.8E+08	3.8E+08	3.8E+08	3.8E+08	3.8E+08	3.8E+08	3.8E+08	3.8E+08	3.8E+08	3.8E+08	3.8E+08
40	1.2E+08	1.2E+08	1.2E+08	1.2E+08	1.2E+08	1.2E+08	1.2E+08	1.2E+08	1.2E+08	1.2E+08	1.2E+08	1.2E+08
50	4.1E+07	4.1E+07	4.1E+07	4.1E+07	4.1E+07	4.1E+07	4.1E+07	4.1E+07	4.1E+07	4.1E+07	4.1E+07	4.1E+07
60	4.0E+07	4.0E+07	4.0E+07	4.0E+07	4.0E+07	4.0E+07	4.0E+07	4.0E+07	4.0E+07	4.0E+07	4.0E+07	4.0E+07
70	4.7E+07	4.7E+07	4.7E+07	4.7E+07	4.7E+07	4.7E+07	4.7E+07	4.7E+07	4.7E+07	4.7E+07	4.7E+07	4.7E+07
80	5.1E+07	5.1E+07	5.1E+07	5.1E+07	5.1E+07	5.1E+07	5.1E+07	5.1E+07	5.1E+07	5.1E+07	5.1E+07	5.1E+07
90	3.6E+07	3.6E+07	3.6E+07	3.6E+07	3.6E+07	3.6E+07	3.6E+07	3.6E+07	3.6E+07	3.6E+07	3.6E+07	3.6E+07
100	7.0E+07	7.0E+07	7.0E+07	7.0E+07	7.0E+07	7.0E+07	7.0E+07	7.0E+07	7.0E+07	7.0E+07	7.0E+07	7.0E+07
110	4.7E+07	4.7E+07	4.7E+07	4.7E+07	4.7E+07	4.7E+07	4.7E+07	4.7E+07	4.7E+07	4.7E+07	4.7E+07	4.7E+07
120	4.9E+07	4.9E+07	4.9E+07	4.9E+07	4.9E+07	4.9E+07	4.9E+07	4.9E+07	4.9E+07	4.9E+07	4.9E+07	4.9E+07
130	5.8E+09	5.8E+09	3.2E+09	8.3E+07	8.3E+07	8.3E+07	8.3E+07	8.3E+07	2.4E+09	2.4E+09	3.2E+09	5.8E+09
140	7.3E+07	7.3E+07	7.3E+07	7.3E+07	7.3E+07	7.3E+07	7.3E+07	7.3E+07	7.3E+07	7.3E+07	7.3E+07	7.3E+07
150	5.0E+07	5.0E+07	5.0E+07	5.0E+07	5.0E+07	5.0E+07	5.0E+07	5.0E+07	5.0E+07	5.0E+07	5.0E+07	5.0E+07
160	3.8E+07	3.8E+07	3.8E+07	3.8E+07	3.8E+07	3.8E+07	3.8E+07	3.8E+07	3.8E+07	3.8E+07	3.8E+07	3.8E+07
170	5.4E+07	5.4E+07	5.4E+07	5.4E+07	5.4E+07	5.4E+07	5.4E+07	5.4E+07	5.4E+07	5.4E+07	5.4E+07	5.4E+07
180	5.2E+07	5.2E+07	5.2E+07	5.2E+07	5.2E+07	5.2E+07	5.2E+07	5.2E+07	5.2E+07	5.2E+07	5.2E+07	5.2E+07
190	6.5E+07	6.5E+07	6.5E+07	6.5E+07	6.5E+07	6.5E+07	6.5E+07	6.5E+07	6.5E+07	6.5E+07	6.5E+07	6.5E+07
200	4.7E+07	4.7E+07	4.7E+07	4.7E+07	4.7E+07	4.7E+07	4.7E+07	4.7E+07	4.7E+07	4.7E+07	4.7E+07	4.7E+07
210	4.2E+07	4.2E+07	4.2E+07	4.2E+07	4.2E+07	4.2E+07	4.2E+07	4.2E+07	4.2E+07	4.2E+07	4.2E+07	4.2E+07
220	3.7E+07	3.7E+07	3.7E+07	3.7E+07	3.7E+07	3.7E+07	3.7E+07	3.7E+07	3.7E+07	3.7E+07	3.7E+07	3.7E+07
230	6.8E+07	6.8E+07	6.8E+07	6.8E+07	6.8E+07	6.8E+07	6.8E+07	6.8E+07	6.8E+07	6.8E+07	6.8E+07	6.8E+07
240	3.9E+07	3.9E+07	3.9E+07	3.9E+07	3.9E+07	3.9E+07	3.9E+07	3.9E+07	3.9E+07	3.9E+07	3.9E+07	3.9E+07
250	5.3E+07	5.3E+07	5.3E+07	5.3E+07	5.3E+07	5.3E+07	5.3E+07	5.3E+07	5.3E+07	5.3E+07	5.3E+07	5.3E+07

4.4 Water Quality Calibration for Fecal Coliform Bacteria

The HSPF simulation of the fate and transport of fecal coliform bacteria is built on the hydrology simulation. The simulation runs on an hourly time step. The primary output of the simulation is average daily fecal coliform bacteria concentrations in the stream reaches represented in the model.

4.4.1 Representation of Fecal Coliform Bacteria in HSPF

The PQUAL module of HSPF is used to represent the build-up, die-off, and wash-off of fecal coliform bacteria from the pervious land surfaces, such as cropland, forest, and pasture. In the simple form in which it is used to represent bacteria, PQUAL is characterized by three parameters: (1) ACQOP, the daily rate, in cfu/acre, at which bacteria accumulate on the surface in scat, livestock feces, or applied manure; (2) SQOLIM, the limit, in cfu/acre of bacteria build-up on the surface, and (3) WSQOP, the rate of surface runoff (in/hr) that removes 90% of the accumulated bacteria from the surface.

ACQOP can, and does, vary monthly. Its calculation, based on animal populations and manure applications, was explained in section 4.3. SQOLIM also functions as a decay rate, on the assumption that the accumulation of bacteria on the surface will reach an asymptotic limit determined by a daily die-off rate. The soil decay rate used in previous TMDLs in Virginia is approximately 0.045/day, which leads to a SQOLIM of nine times the application rate (BST, 2000).

HSPF determines the fraction of accumulated bacteria removed from the surface at a runoff rate R (in/hr) by the formula:

$$1.0 - EXP(-2.3*R/WSQOP)$$

For the Goose Creek TMDL, WSQOP was determined by calibration.

The in-stream processes used to represent fecal coliform bacteria are also quite simple. Bacteria are represented as a dissolved substance subject to temperature-corrected, first-order decay. The decay rate of bacteria for any given time step is determined by multiplying FSTDEC, the decay rate at 20 degrees Celsius, by the factor, $THST^{T-20}$, where T is the water temperature in degrees Celsius. The decay rate, FSTDEC, was determined by calibration. The temperature correction term, THST, was set at its default value, 1.05. Table 4.11 shows the range of values used in this simulation for the parameters in the PQUAL module.

4.4.2 Goals of the Fecal Coliform Calibration

The analysis of monitoring data collected by DEQ and citizen monitoring groups revealed two trends: (1) higher fecal coliform concentrations tend to be associated with higher flows or a higher proportion of runoff in flow, and (2) fecal coliform concentrations tend to be higher in the summer than in the winter. One objective of the calibration of fecal coliform bacteria was to capture these two trends. The second objective of the calibration was to match the observed and simulated rates of violation of the current instantaneous water quality standard of 1,000 cfu/100 ml. In other words, the fraction of time the simulated concentration was above 1,000 cfu/100 ml should match the rate at which observations were above 1,000 cfu /100 ml for the simulation period from 1992-2001. The first objective provided a qualitative standard for judging the simulations of the calibration and verification periods. The second objective provided a quantitative criterion, which was met, after adjustments, over the combined simulation periods.

Table 4.19 shows the observed violations rates of the current instantaneous standard over the 1992-2001 period. It should be noted that because these violation rates are for the entire simulation period, they can differ from the violation rates calculated in the Water Quality Assessment, which uses a 5-year data window. For example, in the 2002 Assessment, Tuscarora Creek had a 9% violation rate in the 5-year data window and was therefore assessed as unimpaired. Over the1992-2001 simulation period, however, the violation rate in Tuscarora Creek was 11%.

Table 4.19: Observed and simulated exceedance rates of the 1,000 cfu/100 ml instantaneous standard

Segment	Watershed	Rate of Exceedance	
		Observed	Simulated
20	Lower Goose Creek	0.10	0.11
30	Tuscarora Creek	0.11	0.11
100	Sycolin Creek	0.2	0.2
140	North Fork Goose Creek	0.33	0.37
160	Little River	0.27	0.3
180	Beaverdam Creek	0.27	0.29
190	Middle Goose Creek	0.9	0.9
200	Cromwells Run	0.24	0.22
230	Sycolin Creek	0.4	0.36
240	South Fork Sycolin Creek	0.27	0.27
250	Sycolin Creek	0.17	0.33

4.4.3 Hydraulically Inactive Storage

The most challenging part of the calibration was to capture the fact that, except for the North Fork of Goose Creek, the highest observed concentrations tend to occur under storm flow conditions and not under low flow conditions. Simulated low flows, on the other hand, tend to produce high concentrations, because there is a smaller volume of water available to dilute the fecal coliform loads from direct deposition by cattle and wildlife and from septic systems within 50 ft of the stream. It was therefore hypothesized that the assimilative capacity of the watershed is larger than that suggested by the channel volumes calculated for the F-tables with XSECT. Three sources of additional storage were identified. First, only the main channel of Goose Creek and its major tributaries are explicitly represented in the model. Additional volume in unrepresented stream channels is available to dilute fecal coliform loads under low flow conditions and to increase residence time in the channel, thereby increasing the number of bacteria that die off in transit. Second, even when there is essentially no flow in a channel, there is still dead water that can serve as storage. Third, and most importantly, much of the flow in the watersheds in the upper portions of the mainstem of Goose Creek and its tributaries drains through farm ponds.

There are thousands of farm ponds in the Goose Creek Watershed, many dating back to the 1930's. The total surface area of these ponds was estimated using GIS representations of water features supplied by Fauquier and Loudoun Counties. Assuming that the average depth of a pond is four feet, the total storage volume of all the ponds in a segment could also be calculated. The results are shown in table 4.20. Using GIS, it was estimated that more than 30% of the flow in the upper portions of the watersheds of Goose Creek and its main tributaries is controlled by ponds.

Table 4.20: Number and size of farm ponds and calibrated hydraulically inactive storage

Segment	Number	Area (acres)	Volume (acre-ft)	Non-Hydraulic Storage (acre-ft)
10	36	12.1	48.4	0
20	8	6.8	27.2	0
30	83	30.6	122.4	9.0
40	17	4.9	19.6	0
50	11	2.2	8.8	0
60	Not Applicable			
70	Not Applicable			
80	38	16.4	65.6	0
90	11	1.8	7.2	0
100	27	19.6	78.4	5.0
110	42	30.5	122	0
120	22	21.1	84.4	0
130	93	52.1	208.4	0
140	111	198.7	794.8	12.0
150	66	66.6	266.4	0.1
160	173	145.9	583.6	15.0
170	28	10.7	42.8	0
180	248	175.5	702	30.0
190	98	70.8	283.2	31.0
200	102	78.1	312.4	1.8
210	203	168.9	675.6	75.0
220	255	187.7	750.8	75.0
230	5	1.6	6.4	0
240	10	3.2	12.8	0.2
250	23	8.7	34.8	1.00
Total	1,710	1,314.5	5,258.0	255.1

In order to represent these three sources of additional storage, a hydraulically inactive storage component was introduced as a calibration parameter to the F-tables of upland segments. Essentially, an additional volume of storage was added to each row of the F-table. This storage has no effect on the functional relationship between the volume of water stored in the channel and the flow in the channel. It represents the additional volume of water from ponds, unrepresented tributaries, and dead storage that is available in a watershed to dilute low flow loads and increase residence time. Table 4.20 gives the volume of hydraulically inactive storage added to each segment and contrasts it with estimated storage in farm ponds. The amount of inactive storage added in the calibration is never more that the amount of storage estimated to be available in farm ponds. Since not all of the land in a watershed drains into ponds, the calibrated inactive storage can be, and is, less than total farm pond volume.

4.4.4 Overall Water Quality Calibration Strategy

The simulation of the fate and transport of fecal coliform bacteria was calibrated by adjusting three parameters. The washoff rate of fecal coliform from land segments was adjusted until storm flow concentrations exceeded the range of observed concentrations. Simulated concentrations exceeded observed concentrations to take into account the upper detection limit of 8,000 cfu /100 ml for many samples and to approximate the observed trends in high flow concentrations. The washoff rate was allowed to vary from segment to segment, but the same washoff rate was used for all land uses in a given segment.

Hydraulically inactive storage was added to upstream modeling segments until the model better approximated the trend in base flow concentrations. As shown in Table 4.21, in some segments, the base temperature first-order decay rate was also adjusted from default values of 1.15 /day to better represent the baseline trend in concentrations.

After the model was calibrated to capture the observed trends in monitoring data, the verification period was simulated with the calibration parameterization to confirm the simulation. The overall simulated violation rate during the verification period was calculated and compared to the observed rate. Further adjustments were then made to the calibration parameters, if necessary, to match the observed rate. For Segments 230, 240, and 250 in Sycolin Creek, monitoring data exist only for the period 1999-2000, so these segments were calibrated for the verification period. Segment 100, downstream in Sycolin Creek, has data for both the calibration and verification periods.

4.4.5 Calibration Results

Figures 4.14 through 4.32 compare simulated and observed fecal coliform bacteria concentrations for the calibration and verification periods at each DEQ monitoring station. Table 4.19 compares observed and simulated rates of violation of the current 1,000 cfu/ 100 ml standard. Table 4.21 summarizes the parameterization of the model.

As Table 4.19 shows, there is excellent agreement between the observed and simulated violation rates. Only in Sycolin Creek is the difference between observed and simulated rates more than 10%, and there, the difference is unavoidable, due to the small number of observations and the fluctuations in observed values in the watershed. The model faithfully captures the range of the observed data; high concentrations of fecal coliform bacteria are associated with runoff events. The seasonal trend in observed bacteria concentrations is also reproduced by the model: simulated concentrations in the summer tend to be higher than in the winter.

Table 4.22 compares the geometric mean of the observed and simulated bacteria concentrations over the entire ten-year simulation period, 1992-2001. All available observed data was used to calculate the geometric mean. Observed values above or below the detection limit were assigned the detection limit as their value. The simulated daily average fecal coliform concentration was used in calculating the simulated geometric mean. Overall, there is good agreement between the overall observed and simulated geometric means, considering the variability and range of both the observed and simulated fecal coliform concentrations.

Table 4.21: Calibration parameters for the HSPF fecal coliform model

Segment	WSQOP (in)	FSTDEC (/d)
10	0.50	1.15
20	0.50	0.10
30	0.50	1.15
40	0.50	1.15
50	0.50	0.10
60	0.50	0.10
70	0.50	0.10
80	0.50	1.15
90	0.50	1.15
100	0.50	1.85
110	0.50	1.15
120	0.50	1.15
130	1.0	1.15
140	2.0	1.15
150	0.50	1.15
160	0.50	1.15
170	1.0	1.15
180	1.0	1.15
190	1.5	2.50
200	0.23	1.15
210	1.5	2.50
220	1.5	2.50
230	0.30	1.15
240	0.40	1.15
250	1.5	1.15

Table 4.22: Observed and Simulated Geometric Mean Fecal Coliform Concentration Over the Simulation Period (1992-2001)

Segment	Station ID	Watershed	Geometric Mean (cfu/100 mL)	
			Observed	Modeled
20	1AGOO002.38	Lower Goose Creek	198.28	376.49
30	1ATUS000.37	Tuscarora Creek	215.02	234.15
100	1ASYC002.03	Sycolin Creek	261.20	293.07
140	1ANOG005.69	North Fork Goose Creek	371.84	636.81
160	1ALIV004.78	Little River	523.50	560.61
180	1ABEC004.76	Beaverdam Creek	345.87	515.28
190	1AGOO022.44	Middle Goose Creek	168.01	349.95
200	1ACRM001.20	Cromwells Run	344.09	348.59
230	1ASYC004.93	Sycolin Creek	689.98	624.01
240	1ASFS000.28	South Fork Sycolin Creek	461.69	440.05
250	1ASYC007.43	Sycolin Creek	233.24	617.46

4.4.6 Sensitivity Analysis

A sensitivity analysis was performed to determine how sensitive the calibration is to changes in the first-order decay rate, washoff rate, and hydraulically inactive storage. Each of these key calibration parameters were varied individually by ±20%. Table 4.23 shows the resulting change in the violation rate. The violation rate is not very sensitive to changes in the washoff rate, but can change as much as 25% with a 20% change in the first-order decay rate or hydraulically inactive storage.

Table 4.23: Sensitivity analysis: change in violation rate from 20% change in calibration parameter values

Segment	WSQOP		FSTDEC		VOLUME	
	+20%	-20%	+20%	-20%	+20%	-20%
20	-0.01	+0.01	-0.03	+0.06	-0.01	0
30	0	+0.01	-0.01	+0.02	-0.01	+0.02
100	-0.01	0	-0.05	+0.05	-0.04	+0.02
140	-0.01	+0.01	-0.04	+0.04	-0.02	+0.02
160	-0.01	+0.01	-0.02	+0.02	-0.01	+0.01
180	0	+0.01	-0.05	+0.08	-0.02	+0.04
190	0	0	-0.03	+0.05	-0.03	+0.03
200	-0.01	0	-0.01	+0.01	-0.01	0
230	-0.01	+0.01	-0.02	+0.02	-0.02	+0.01
240	0	+0.01	-0.01	+0.02	-0.01	+0.02
250	0	+0.01	-0.01	+0.04	-0.02	+0.02

4.4.7 Average Daily Loads By Source

Table 4.24 gives the average annual fecal coliform loads to the stream from point sources, nonpoint sources, and direct deposition. Table 4.25 gives the percent contribution to the total edge-of-stream load from each source. Over 95% of the load comes from pasture runoff or direct deposition by cattle. In the upper segments of Goose Creek in Fauquier County, the load from direct deposition by cattle is greater than the load from pasture. In the North Fork of Goose Creek and the uppermost segment of Sycolin Creek, the loads from direct deposition by cattle equal to the loads from pasture. In most watersheds pasture runoff is the dominant source of fecal coliform bacteria, accounting for two-thirds to three-quarters of the load.

Table 4.24: Average Daily Loads By Source (cfu/day)

Segment	Direct Sources				Runoff Loads				Direct	Runoff	Total
	Point Sources	Septic	Wildlife	Cattle	Forest	Crop	Pasture	Developed			
10	3.70E+06		9.95E+08	3.74E+10	1.43E+10	4.79E+10	1.02E+11	3.95E+10	3.84E+10	2.04E+11	2.42E+11
20			4.09E+08	2.09E+10	4.86E+09	1.2E+08	3.18E+09	1.35E+09	2.13E+10	9.50E+09	3.08E+10
30	7.57E+05		3.14E+09	2.37E+11	9.39E+09	3.13E+10	6.18E+11	3.72E+10	2.40E+11	6.96E+11	9.36E+11
40	5.71E+06		5.99E+08	2.80E+10	5.48E+09	5.53E+09	5.37E+09	1.09E+09	2.86E+10	1.75E+10	4.61E+10
50			2.64E+08	2.38E+09	2.46E+09	60197349	4E+08	2.17E+08	2.65E+09	3.14E+09	5.78E+09
60			8.61E+08	3.06E+10	9.03E+09	5.7E+08	3.81E+10	9.84E+08	3.15E+10	4.86E+10	8.01E+10
70			8.21E+08	9.55E+10	1.20E+10	1.15E+09	1.75E+11	3.81E+09	9.63E+10	1.92E+11	2.88E+11
80			1.24E+09	1.66E+11	3.86E+09	7.64E+08	6.19E+11	3.40E+09	1.67E+11	6.27E+11	7.94E+11
90			4.49E+08	2.83E+10	1.36E+09	18986530	2.55E+09	1.18E+09	2.88E+10	5.11E+09	3.39E+10
100	1.97E+06	1.95E+03	1.40E+09	9.94E+10	3.06E+09	1.04E+09	3.13E+11	3.79E+09	1.01E+11	3.21E+11	4.22E+11
110		1.95E+03	1.73E+09	1.97E+11	5.83E+09	3.85E+08	5.45E+11	3.86E+09	1.98E+11	5.55E+11	7.54E+11
120			1.93E+09	3.45E+11	6.81E+09	3.23E+08	1.14E+12	3.18E+09	3.47E+11	1.15E+12	1.50E+12
130		5.83E+03	4.23E+09	7.40E+11	7.62E+09	5.34E+10	1.29E+12	1.74E+10	7.44E+11	1.37E+12	2.11E+12
140	3.25E+08	9.75E+03	5.12E+09	1.26E+12	6.47E+08	1.42E+09	1.69E+12	1.41E+10	1.26E+12	1.70E+12	2.97E+12
150	2.46E+06		3.32E+09	6.37E+11	8.40E+09	1.65E+09	2.08E+12	7.55E+09	6.40E+11	2.10E+12	2.74E+12
160	3.03E+05	6.57E+03	8.74E+09	1.23E+12	2.20E+10	1.36E+09	3.18E+12	1.84E+10	1.24E+12	3.22E+12	4.46E+12
170			1.48E+09	2.48E+11	4.02E+09	68999785	6.46E+11	2.76E+09	2.50E+11	6.52E+11	9.02E+11
180	4.62E+07	1.76E+04	9.71E+09	2.11E+12	1.41E+10	1.79E+09	3.79E+12	2.18E+10	2.12E+12	3.83E+12	5.95E+12
190	1.04E+08	1.95E+03	4.68E+09	1.82E+12	4.65E+09	5.18E+08	4.21E+12	5.57E+09	1.82E+12	4.22E+12	6.05E+12
200		3.46E+03	4.14E+09	3.35E+11	1.22E+10	1.81E+08	9.77E+11	8.58E+09	3.39E+11	9.98E+11	1.34E+12
210	2.37E+07	3.90E+03	8.05E+09	5.42E+12	9.68E+09	8.37E+08	4.3E+12	3.86E+09	5.43E+12	4.31E+12	9.74E+12
220	5.30E+05	9.76E+03	1.47E+10	5.46E+12	2.35E+10	9.95E+08	4.46E+12	9.27E+09	5.48E+12	4.50E+12	9.97E+12
230			3.16E+08	2.48E+10	9.57E+08	7.13E+08	1.12E+11	8.09E+08	2.52E+10	1.15E+11	1.40E+11
240			4.47E+08	2.48E+10	1.35E+09	2565037	1.03E+11	1.19E+09	2.53E+10	1.06E+11	1.31E+11
250	6.81E+05		9.18E+08	3.62E+11	1.36E+09	76637895	3.28E+11	3.05E+09	3.63E+11	3.32E+11	6.95E+11
Total	5.15E+08	6.27E+04	7.97E+10	2.10E+13	1.89E+11	1.52E+11	3.07E+13	2.14E+11	2.10E+13	3.13E+13	5.23E+13

Table 4.25: Percent of Total Average Daily Edge-of-Stream Load By Source

Subwatershed	Direct Sources				Runoff Loads					
	Point Sources	Septic	Wildlife	Cattle	Forest	Crop	Pasture	Developed	Direct	Runoff
10	0.002%		0.41%	15.4%	5.9%	19.8%	42.2%	16.3%	15.8%	84.2%
20			1.33%	67.8%	15.8%	0.4%	10.3%	4.4%	69.1%	30.9%
30	0.000%		0.34%	25.3%	1.0%	3.3%	66.0%	4.0%	25.7%	74.3%
40	0.012%		1.30%	60.8%	11.9%	12.0%	11.7%	2.4%	62.1%	37.9%
50			4.57%	41.2%	42.5%	1.0%	6.9%	3.8%	45.8%	54.2%
60			1.07%	38.2%	11.3%	0.7%	47.5%	1.2%	39.3%	60.7%
70			0.28%	33.1%	4.2%	0.4%	60.7%	1.3%	33.4%	66.6%
80			0.16%	20.9%	0.5%	0.1%	77.9%	0.4%	21.1%	78.9%
90			1.33%	83.6%	4.0%	0.1%	7.5%	3.5%	84.9%	15.1%
100	0.000%	0.000%	0.33%	23.6%	0.7%	0.2%	74.2%	0.9%	23.9%	76.1%
110		0.000%	0.23%	26.1%	0.8%	0.1%	72.3%	0.5%	26.3%	73.7%
120			0.13%	23.0%	0.5%	0.0%	76.2%	0.2%	23.1%	76.9%
130		0.000%	0.20%	35.0%	0.4%	2.5%	61.1%	0.8%	35.2%	64.8%
140	0.011%	0.000%	0.17%	42.4%	0.0%	0.0%	56.9%	0.5%	42.6%	57.4%
150	0.000%	0.000%	0.12%	23.3%	0.3%	0.1%	76.0%	0.3%	23.4%	76.6%
160		0.000%	0.20%	27.6%	0.5%	0.0%	71.2%	0.4%	27.8%	72.2%
170			0.16%	27.5%	0.4%	0.0%	71.6%	0.3%	27.7%	72.3%
180	0.001%	0.000%	0.16%	35.5%	0.2%	0.0%	63.7%	0.4%	35.6%	64.4%
190	0.002%	0.000%	0.08%	30.1%	0.1%	0.0%	69.7%	0.1%	30.1%	69.9%
200		0.000%	0.31%	25.1%	0.9%	0.0%	73.0%	0.6%	25.4%	74.6%
210	0.000%	0.000%	0.08%	55.6%	0.1%	0.0%	44.1%	0.0%	55.7%	44.3%
220	0.000%	0.000%	0.15%	54.8%	0.2%	0.0%	44.7%	0.1%	54.9%	45.1%
230			0.23%	17.8%	0.7%	0.5%	80.2%	0.6%	18.0%	82.0%
240			0.34%	18.9%	1.0%	0.0%	78.8%	0.9%	19.3%	80.7%
250	0.000%		0.13%	52.1%	0.2%	0.0%	47.1%	0.4%	52.2%	47.8%
Total	0.001%	0.000%	0.15%	40.1%	0.4%	0.3%	58.7%	0.4%	40.2%	59.8%

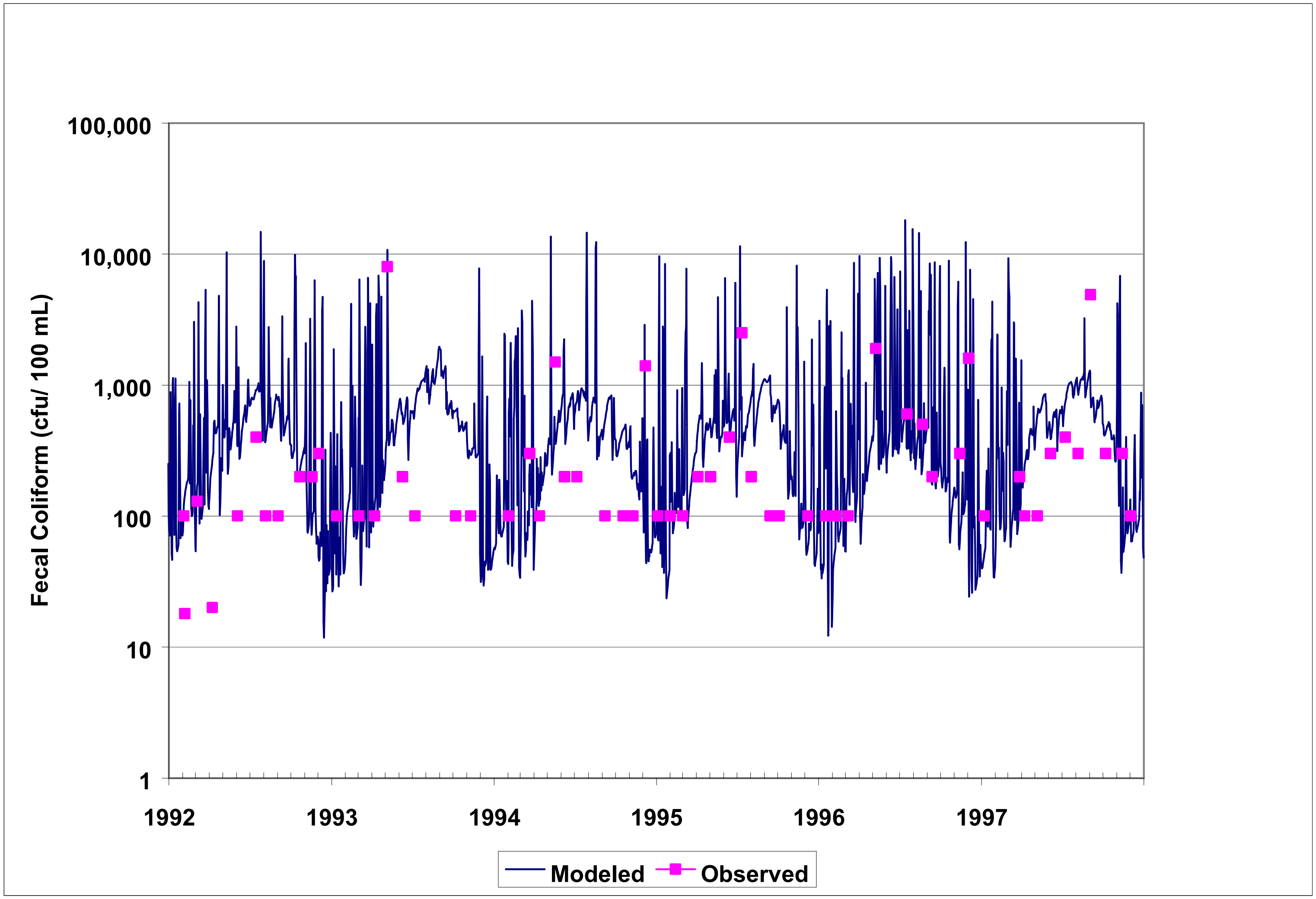


Figure 4.14: Simulated and observed fecal coliform concentrations at Lower Goose Creek for calibration period

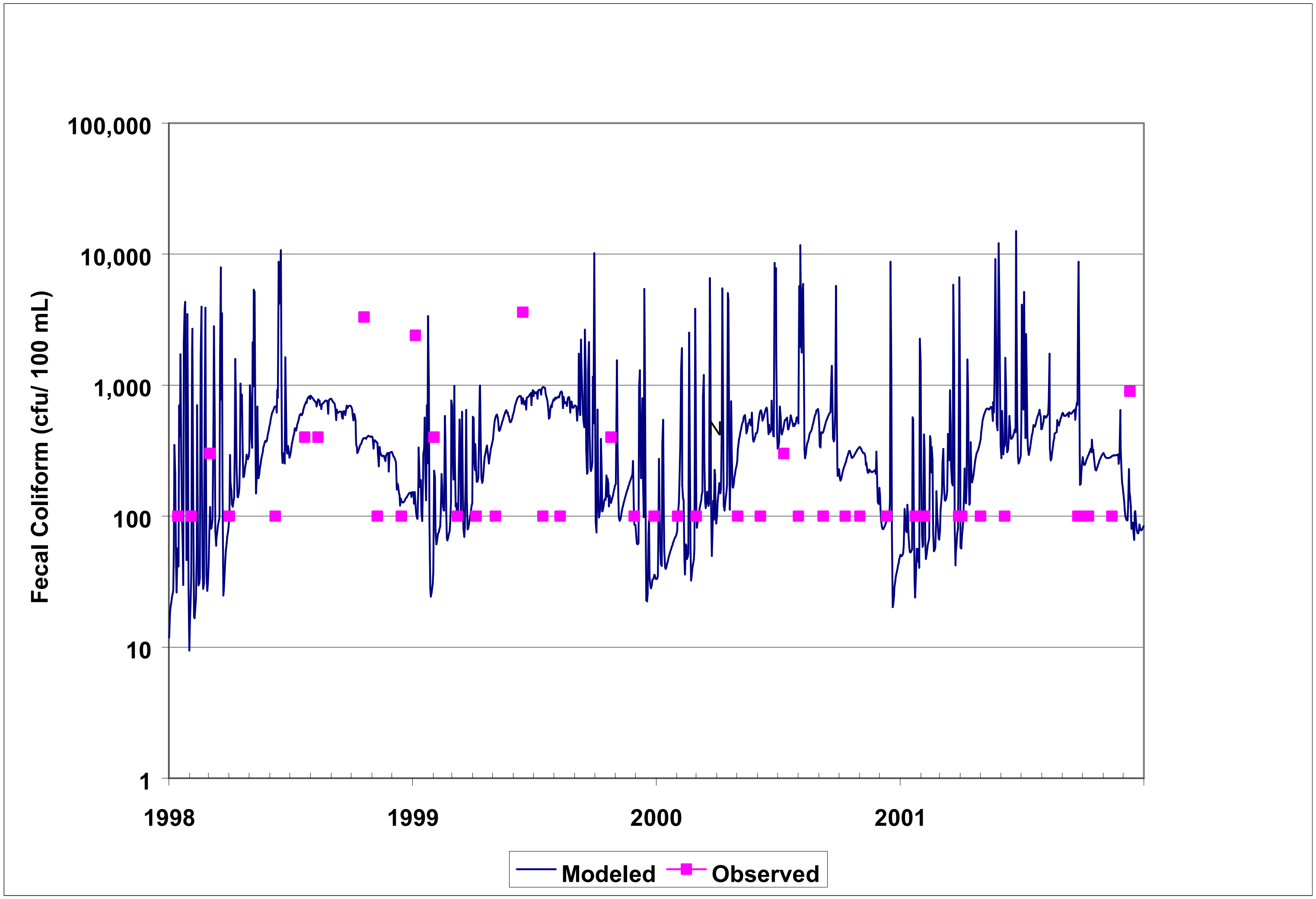


Figure 4.15: Simulated and observed fecal coliform concentrations at Lower Goose Creek for verification period

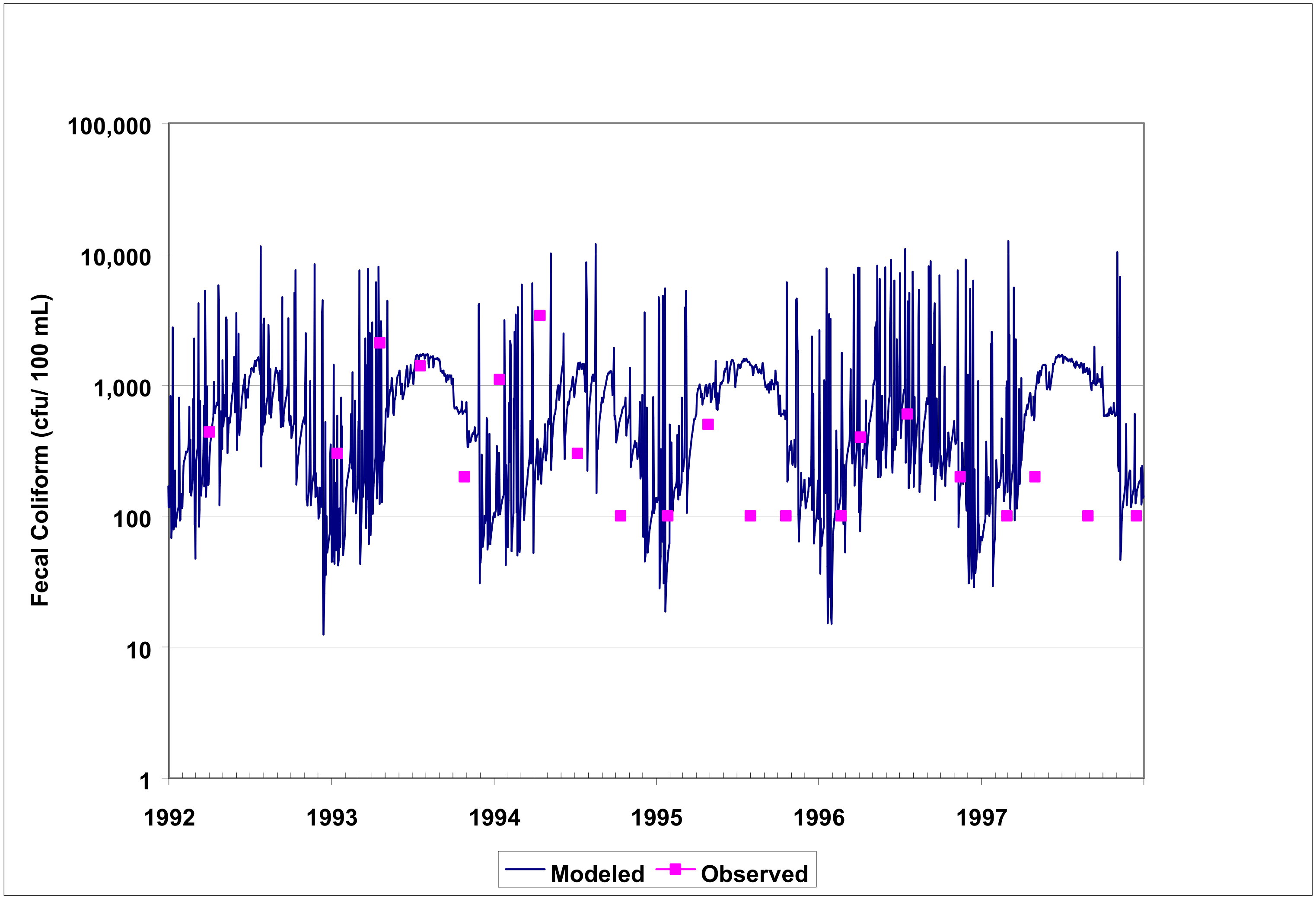


Figure 4.16: Simulated and observed fecal coliform concentrations at Sycolin Creek for calibration period

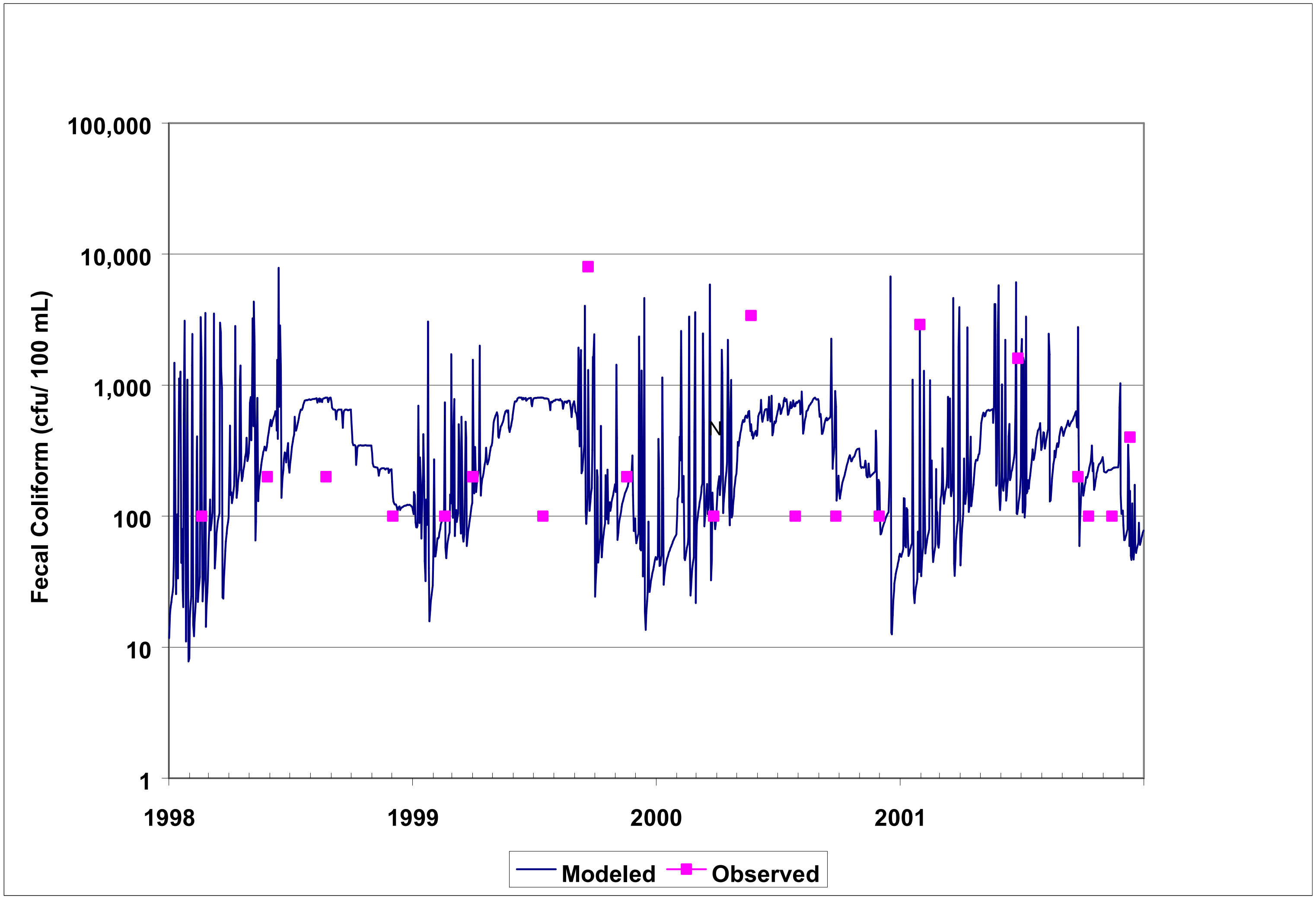


Figure 4.17: Simulated and observed fecal coliform concentrations at Sycolin Creek for verification period

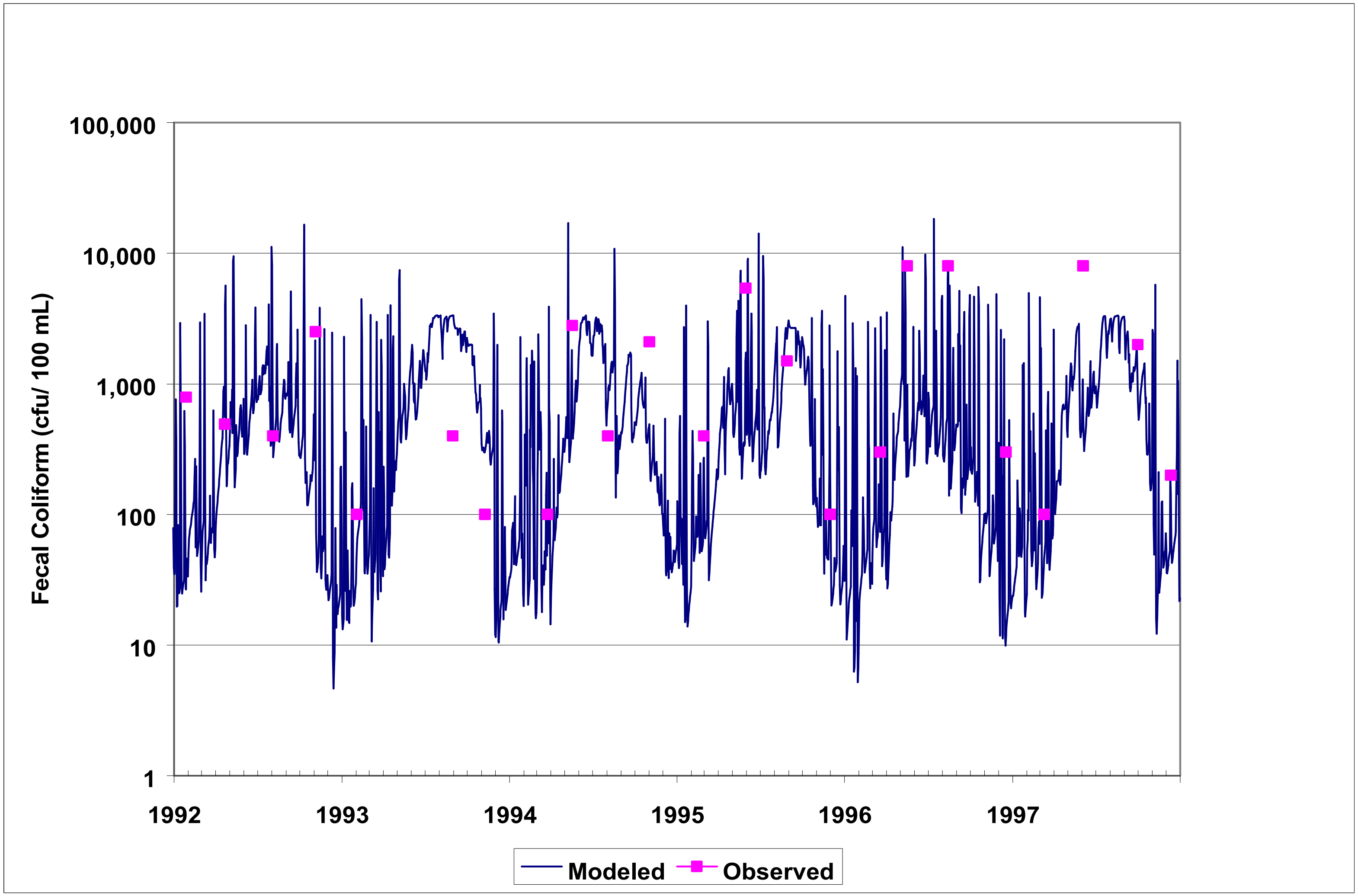


Figure 4.18: Simulated and observed fecal coliform concentrations at Little River for calibration period

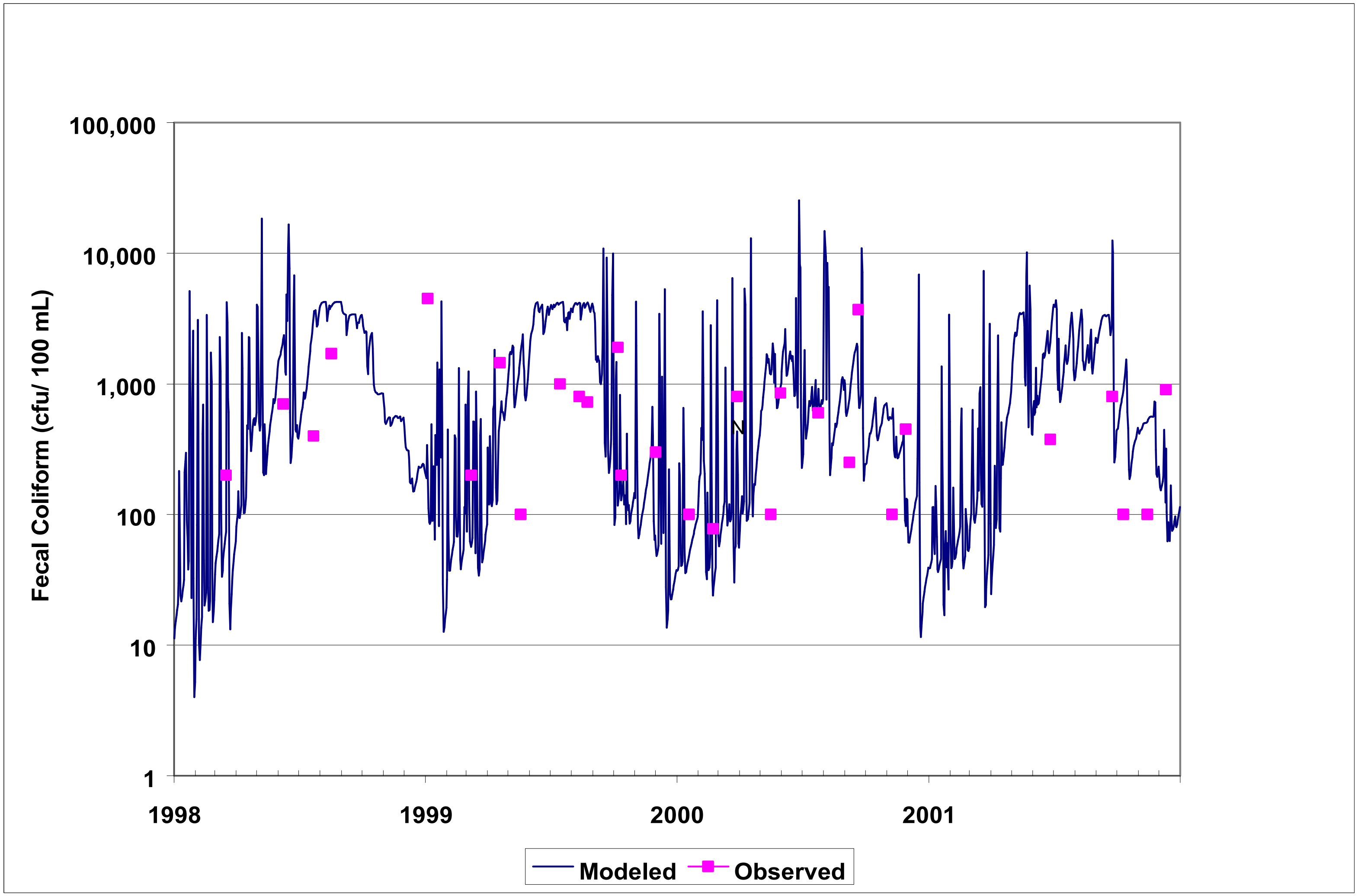


Figure 4.19: Simulated and observed fecal coliform concentrations at Little River for verification period

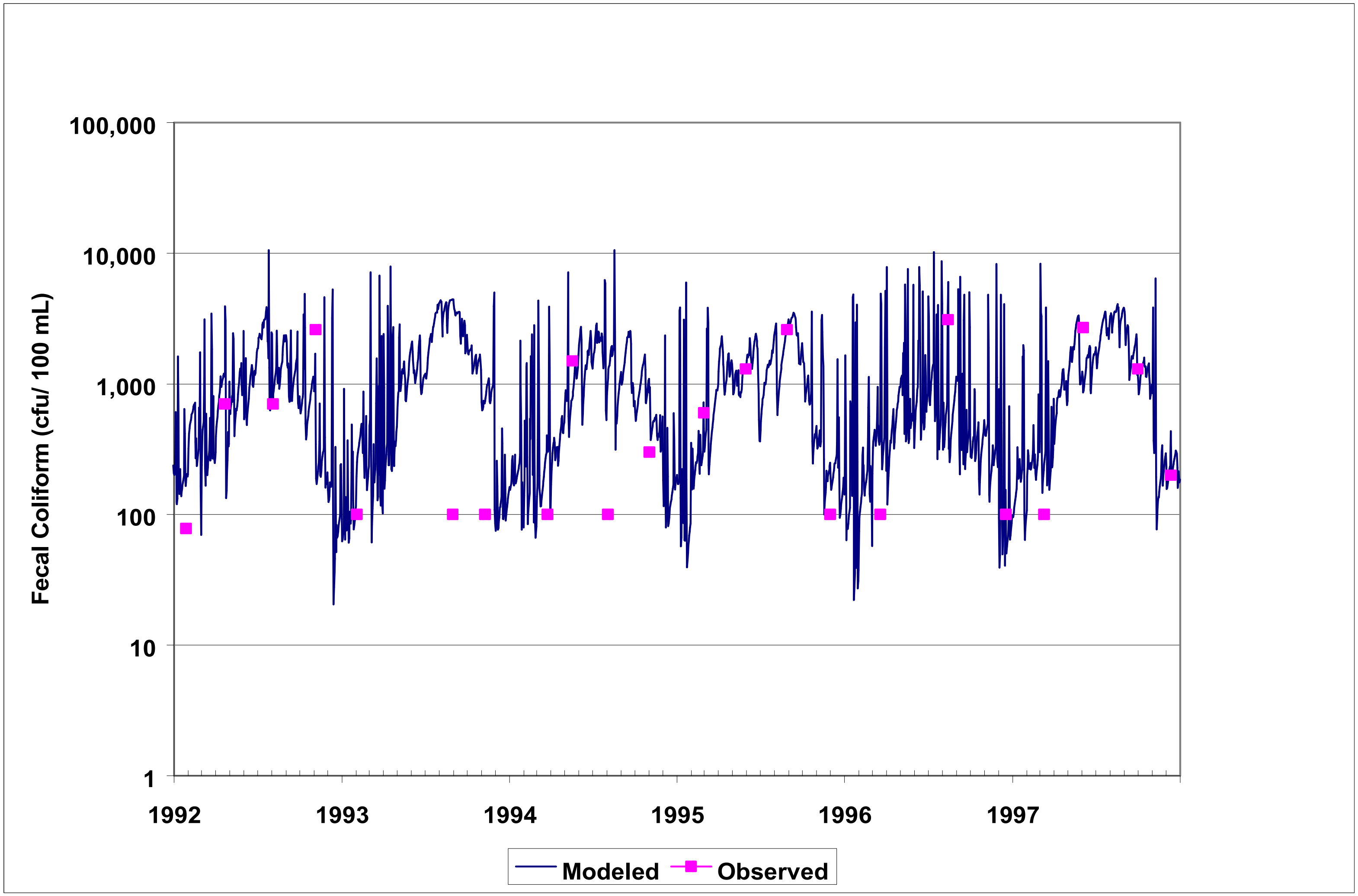


Figure 4.20: Simulated and observed fecal coliform concentrations at North Folk Goose Creek for calibration period

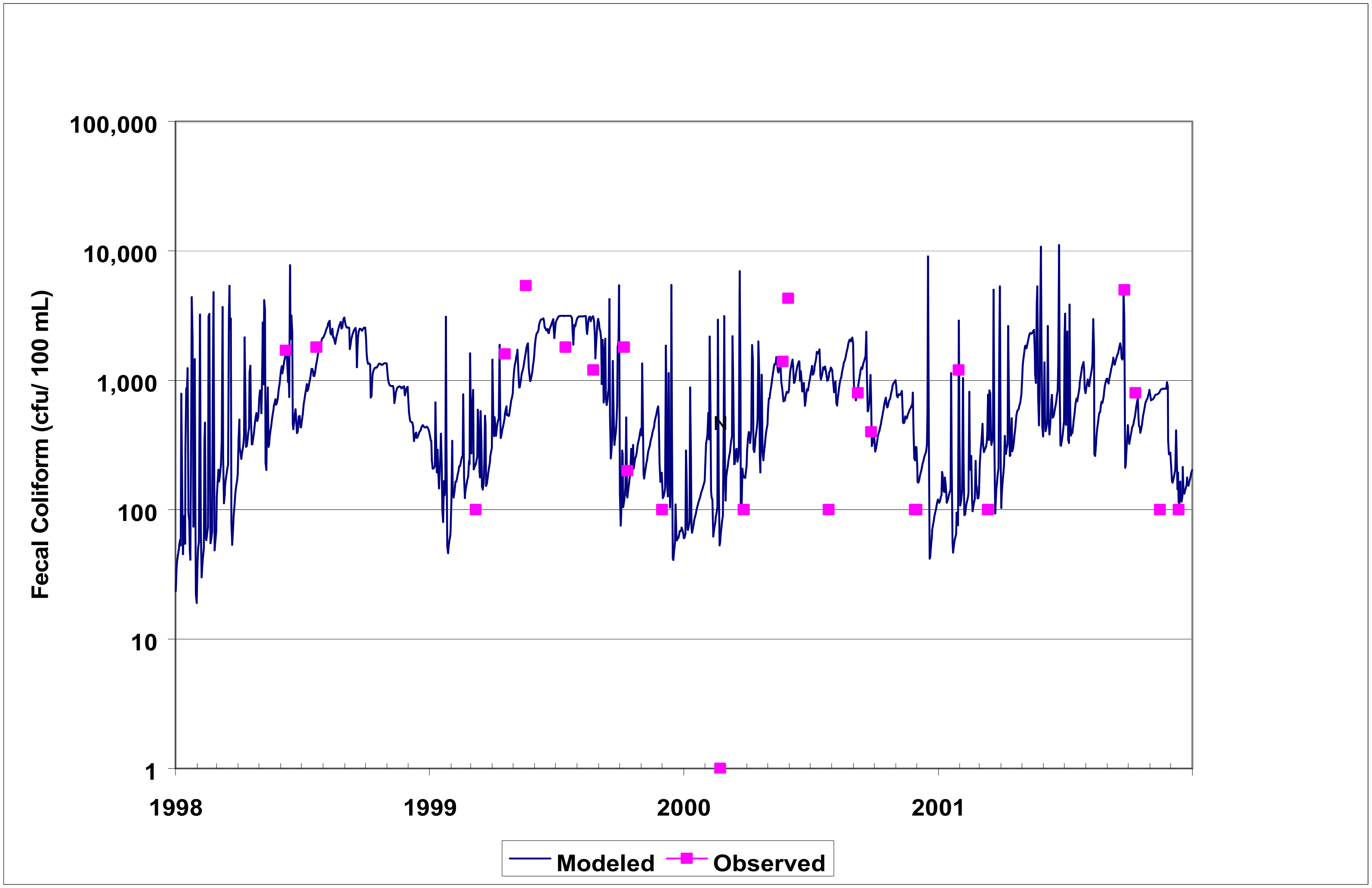


Figure 4.21: Simulated and observed fecal coliform concentrations at North Fork Goose Creek for verification period

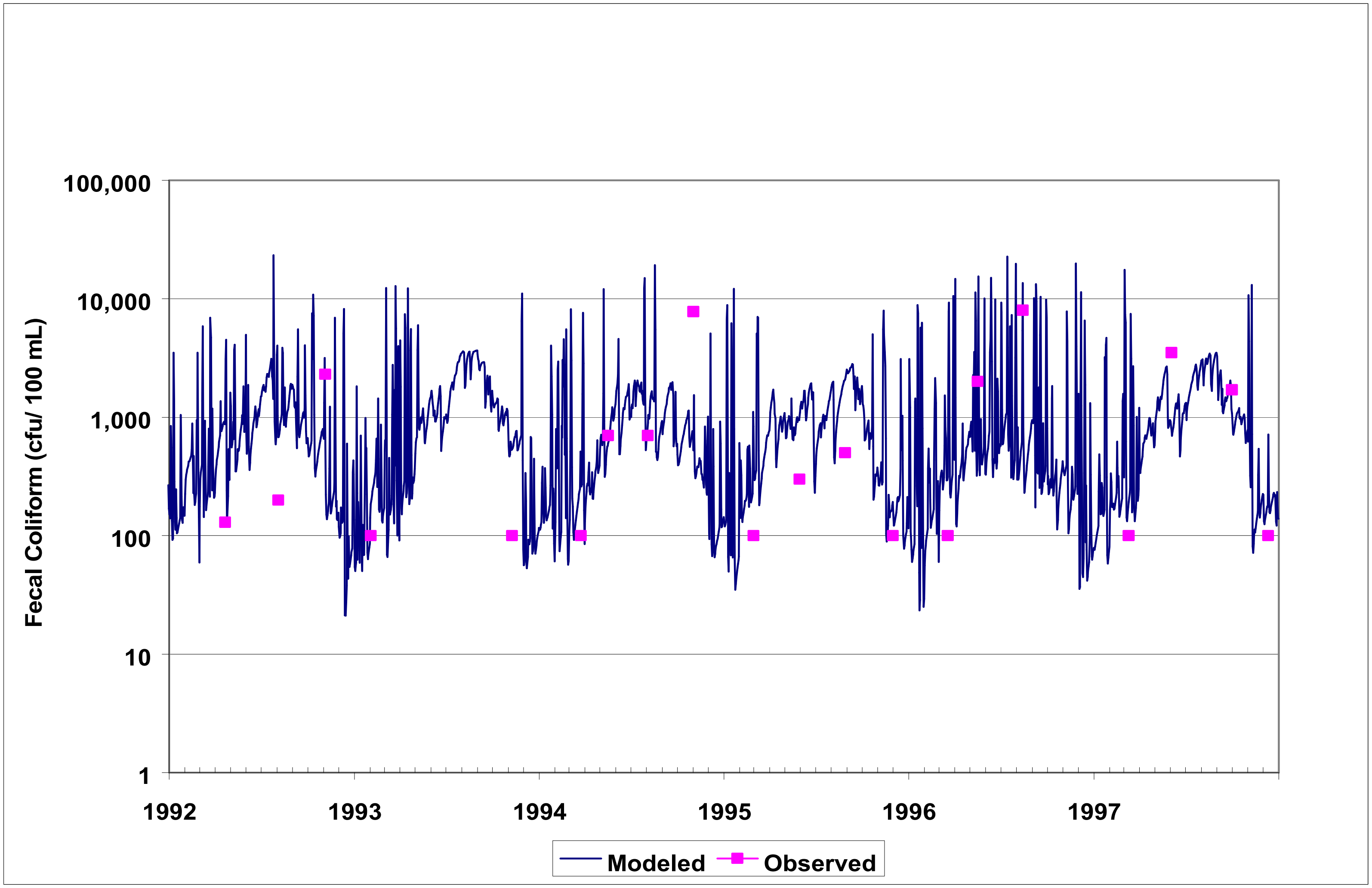


Figure 4.22: Simulated and observed fecal coliform concentrations at Beaverdam Creek for calibration period

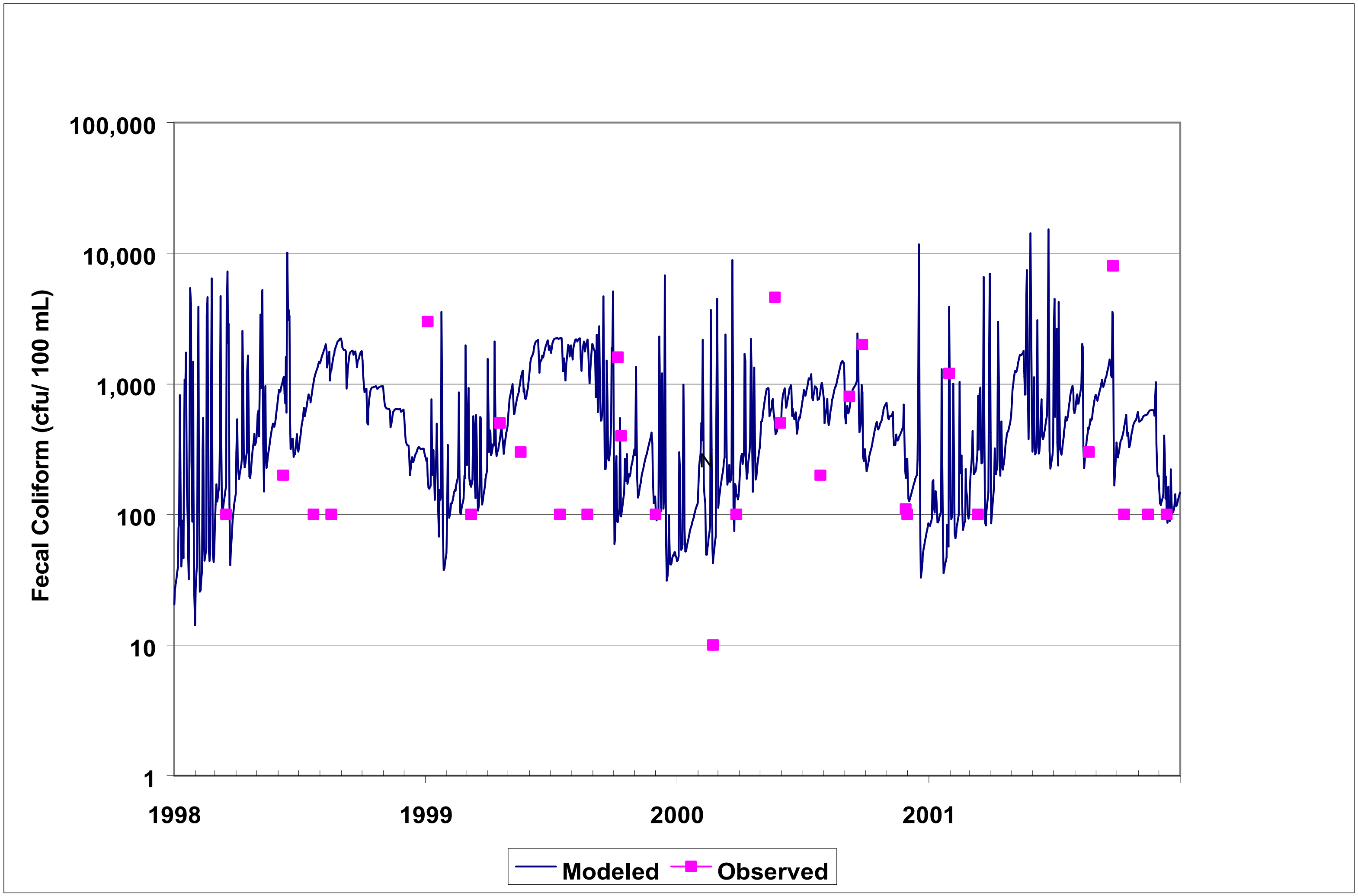


Figure 4.23: Simulated and observed fecal coliform concentrations at Beaverdam Creek for verification period

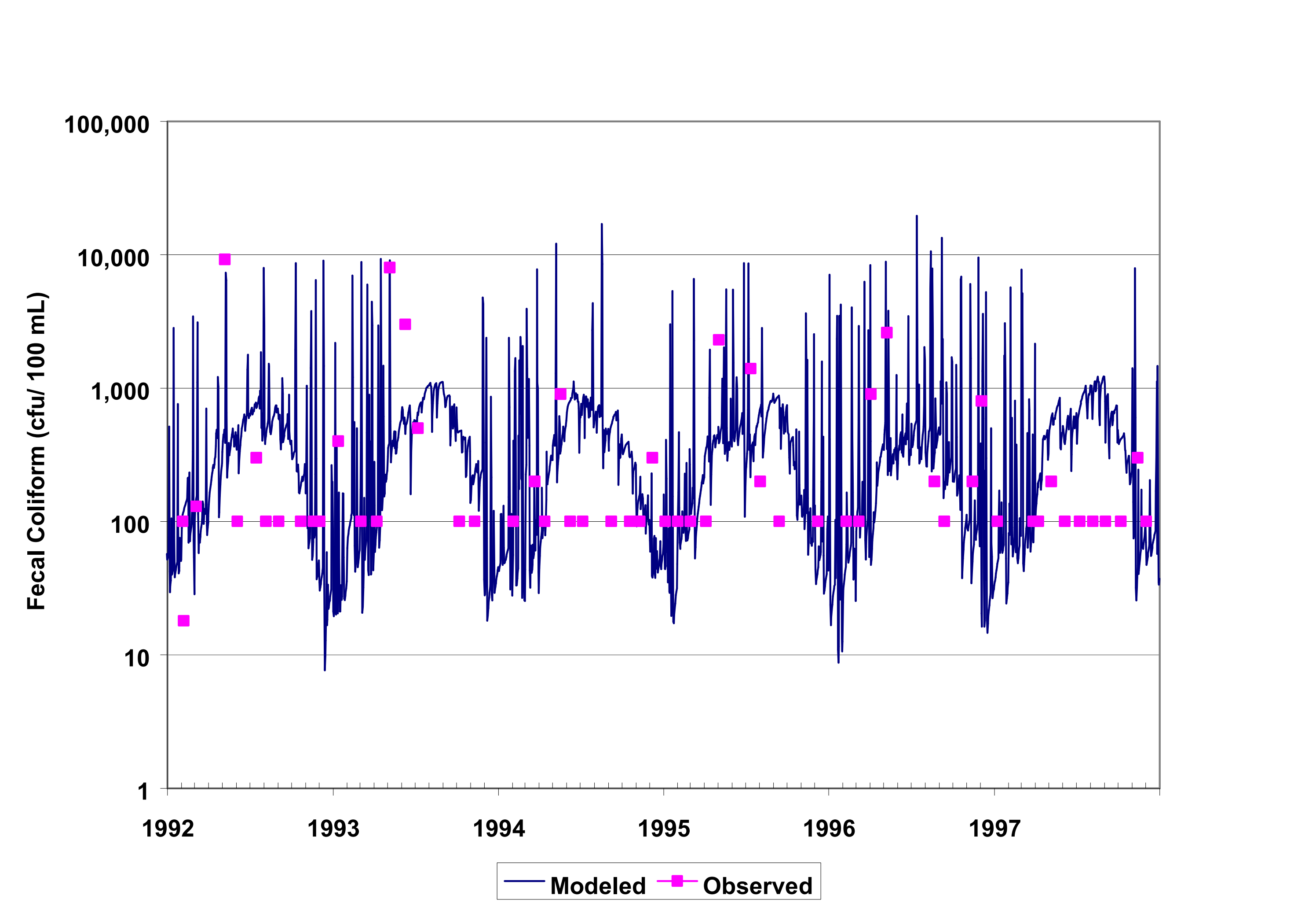


Figure 4.24: Simulated and observed fecal coliform concentrations at Goose Creek for calibration period

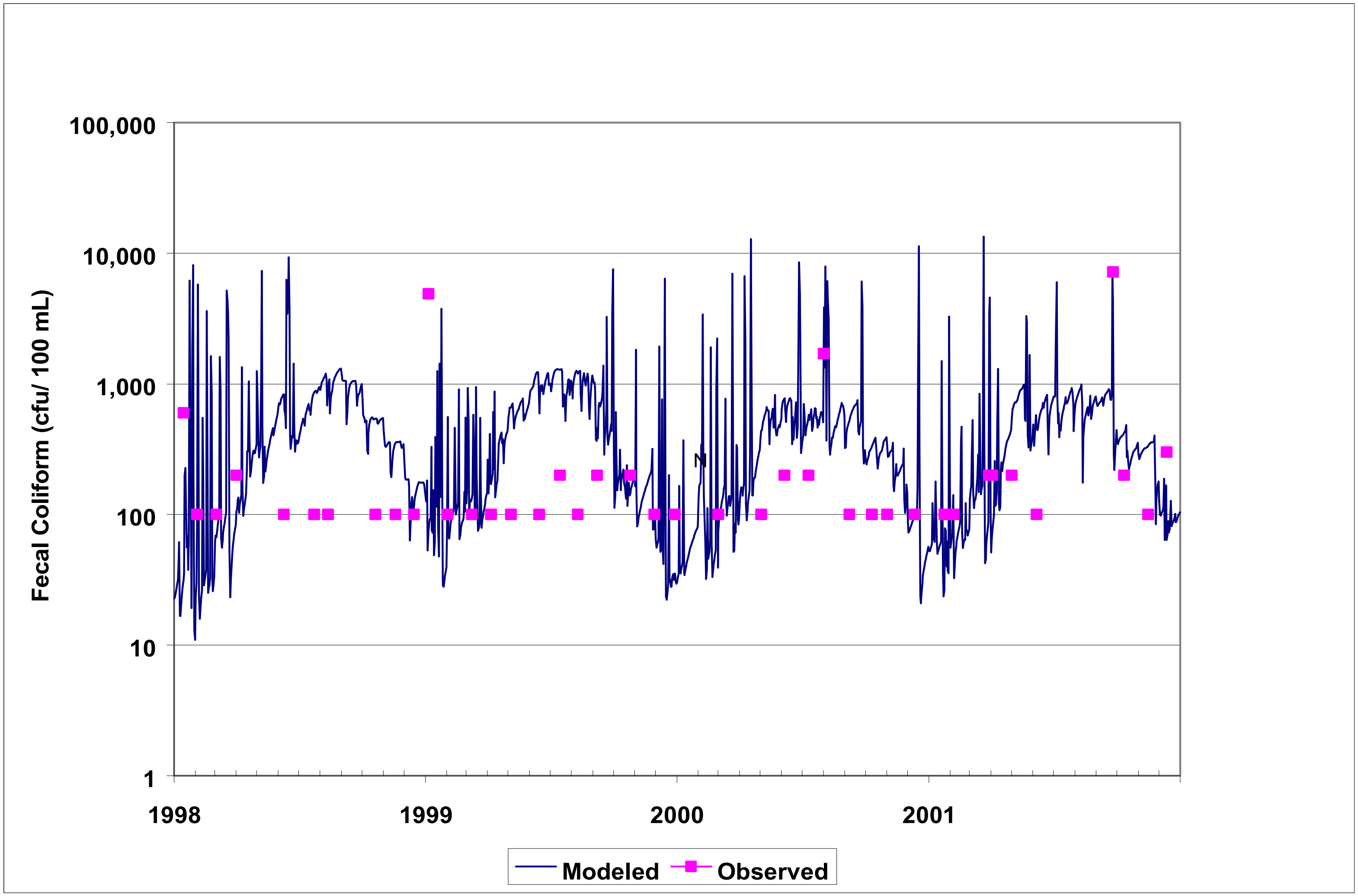


Figure 4.25 Simulated and observed fecal coliform concentrations at Goose Creek for verification period

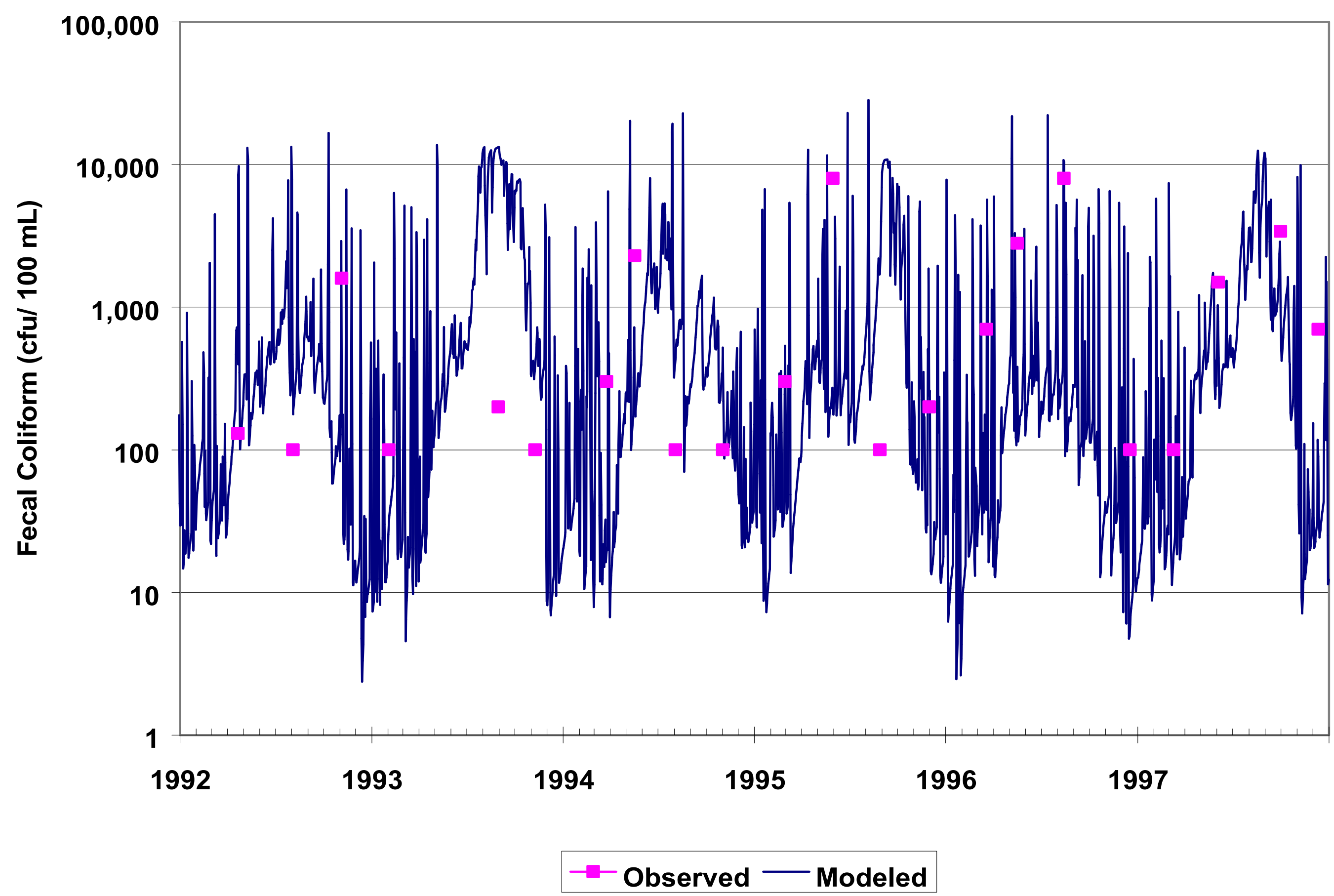


Figure 4.26: Simulated and observed fecal coliform concentrations at Cromwells Run for calibration period

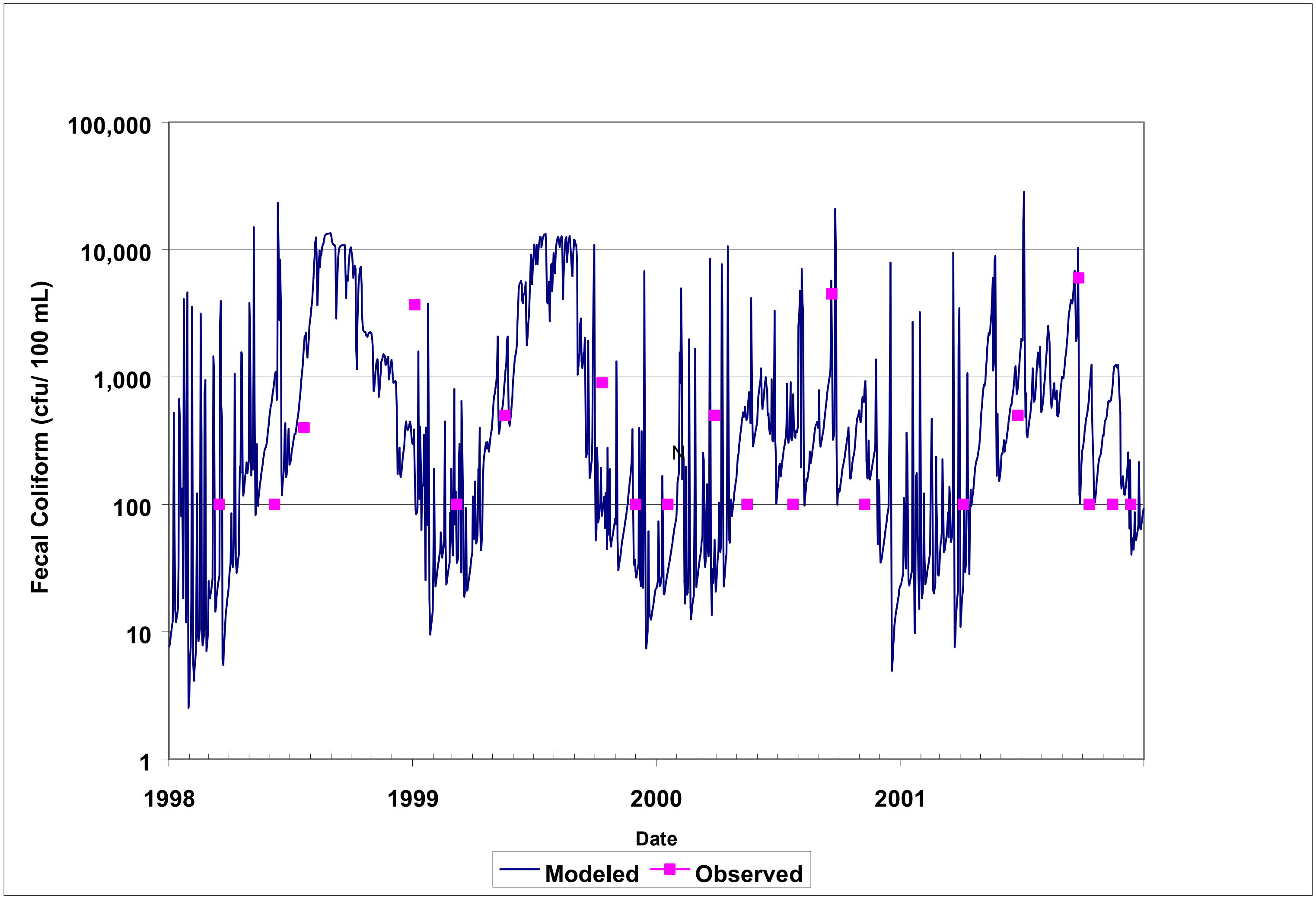


Figure 4.27: Simulated and observed fecal coliform concentrations at Cromwells Run for verification period

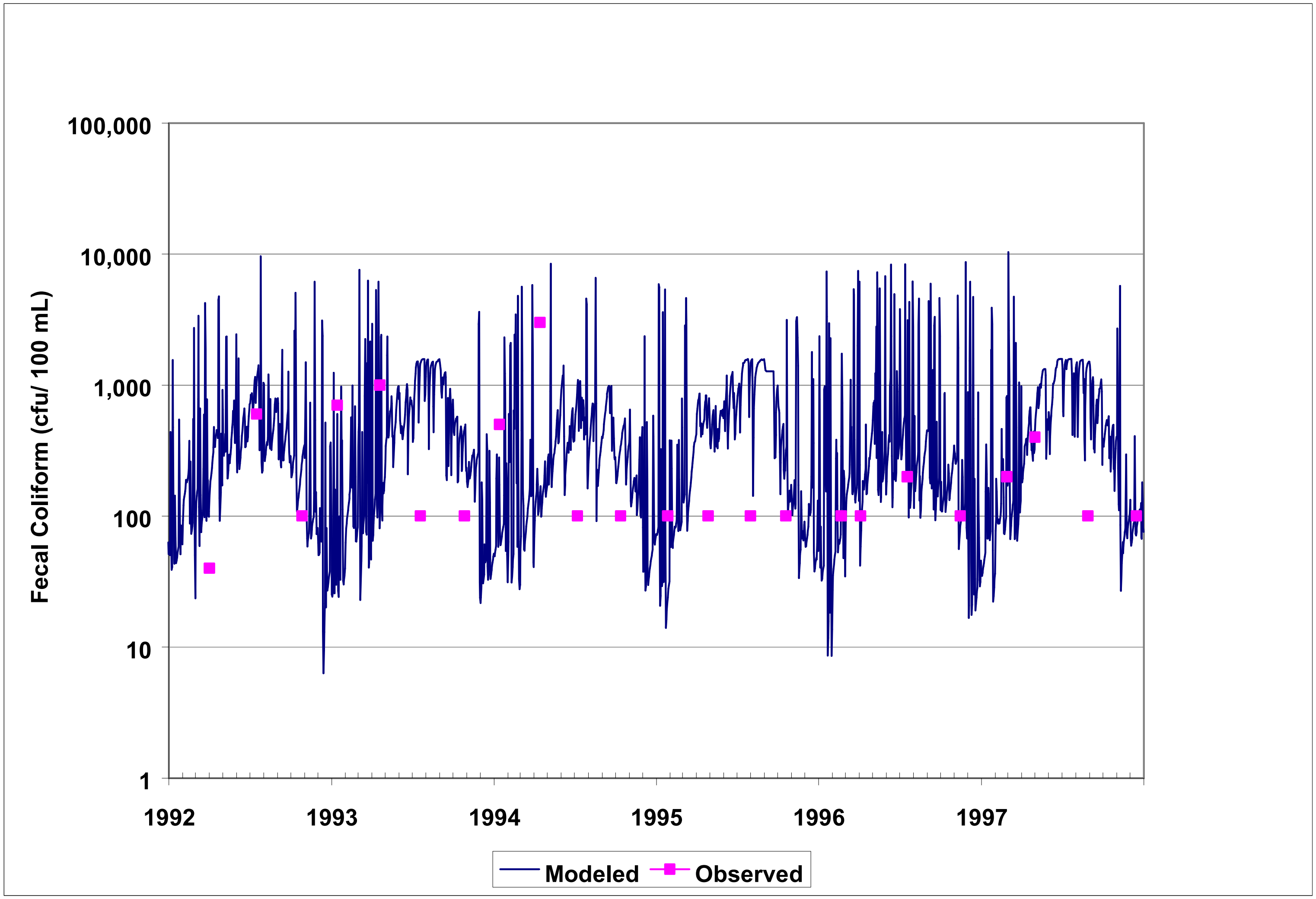


Figure 4.28: Simulated and observed fecal coliform concentrations at Tuscarora Creek for calibration period

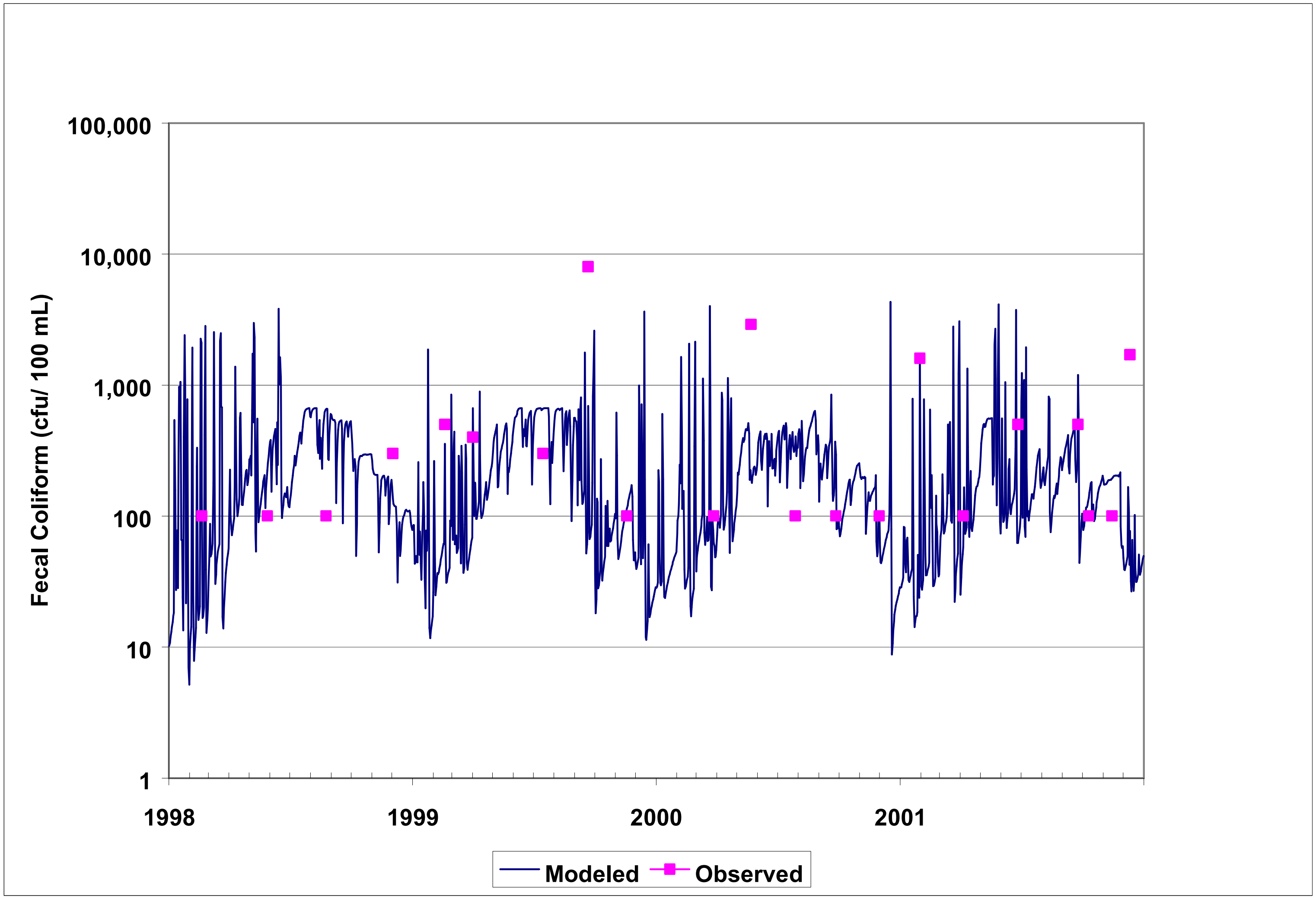


Figure 4.29: Simulated and observed fecal coliform concentrations at Tuscarora Creek for verification period

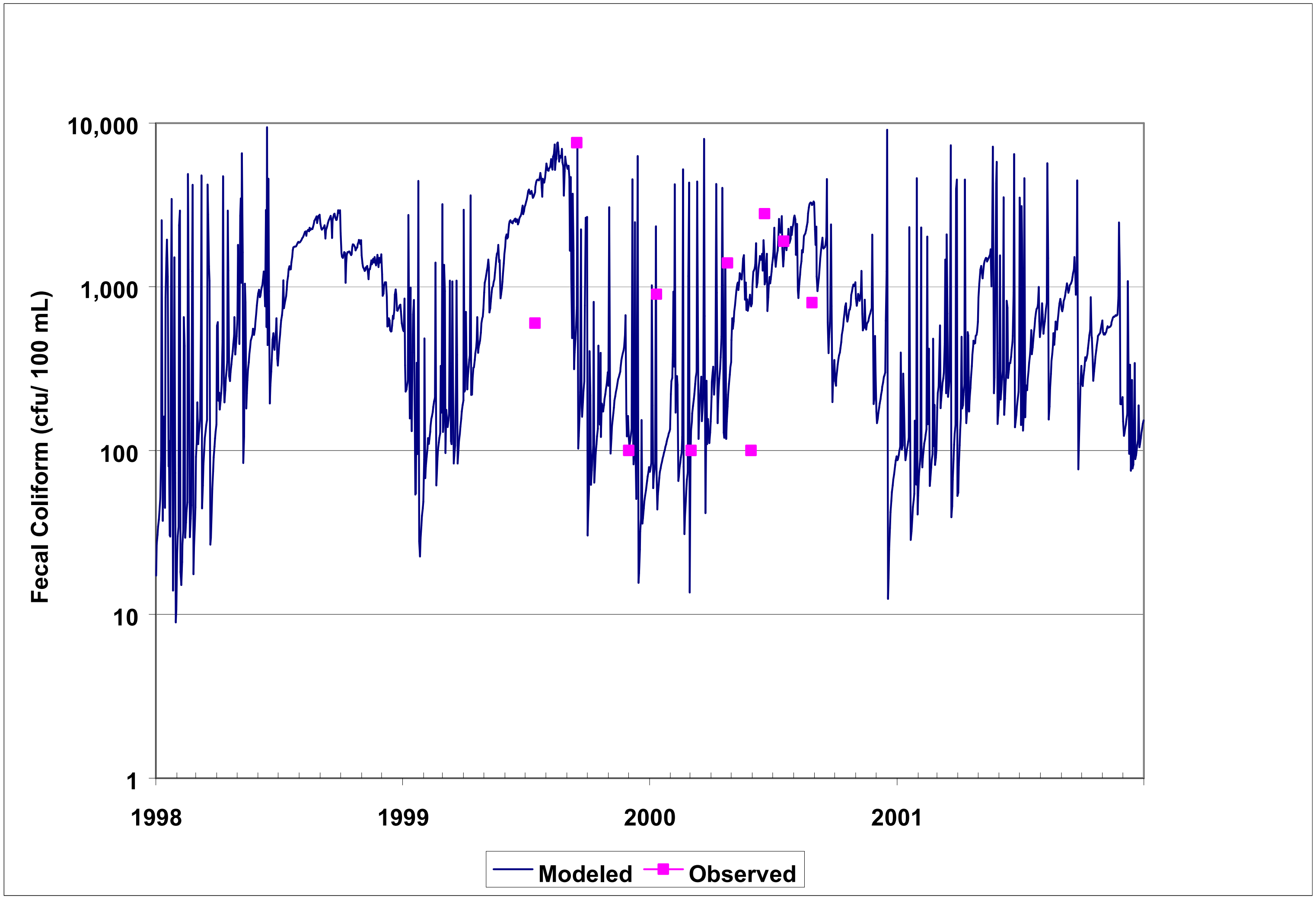


Figure 4.30: Simulated and observed fecal coliform concentrations at Upper Sycolin Creek for verification period

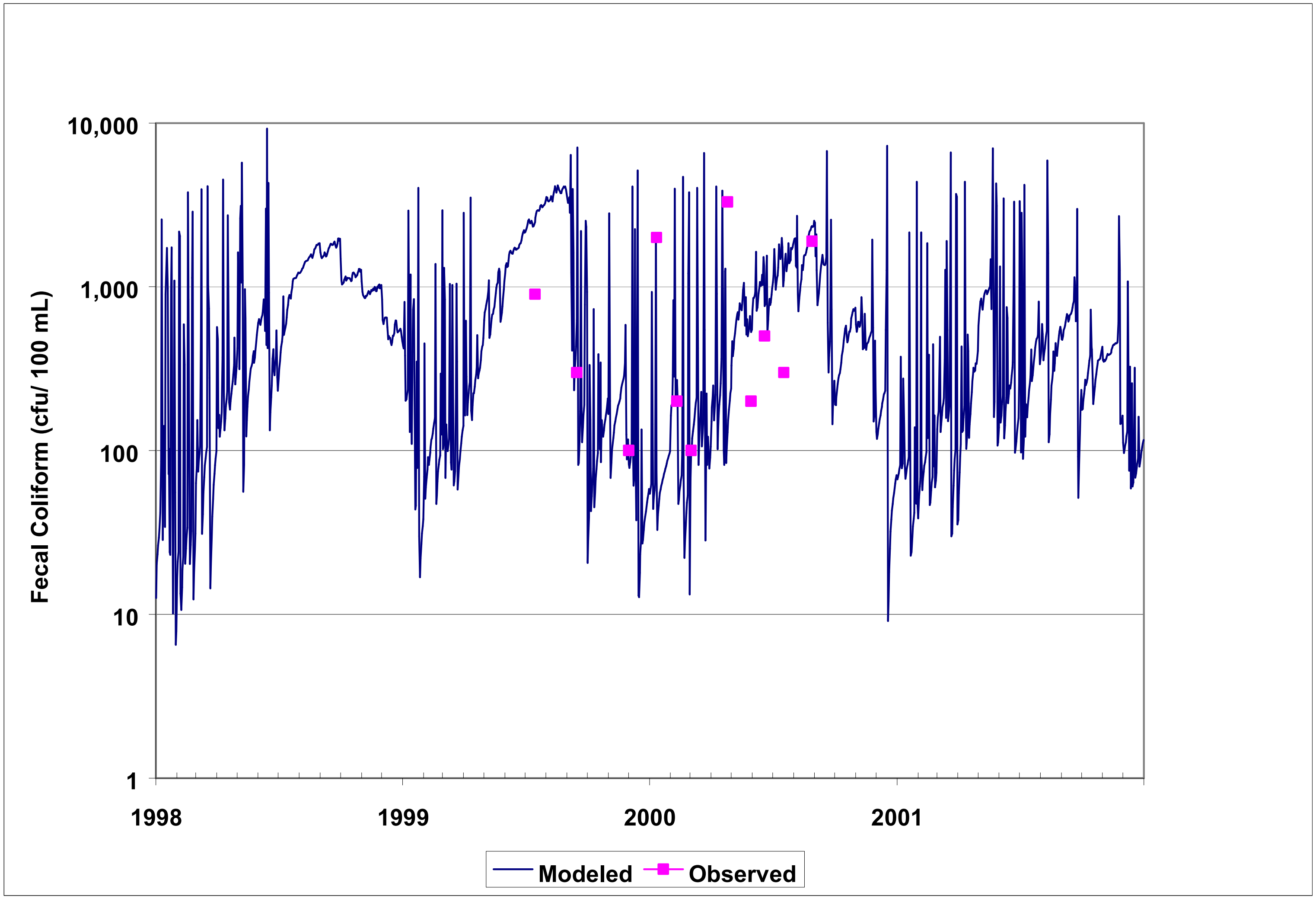


Figure 4.31: Simulated and observed fecal coliform concentrations at South Fork Sycolin Creek for verification period

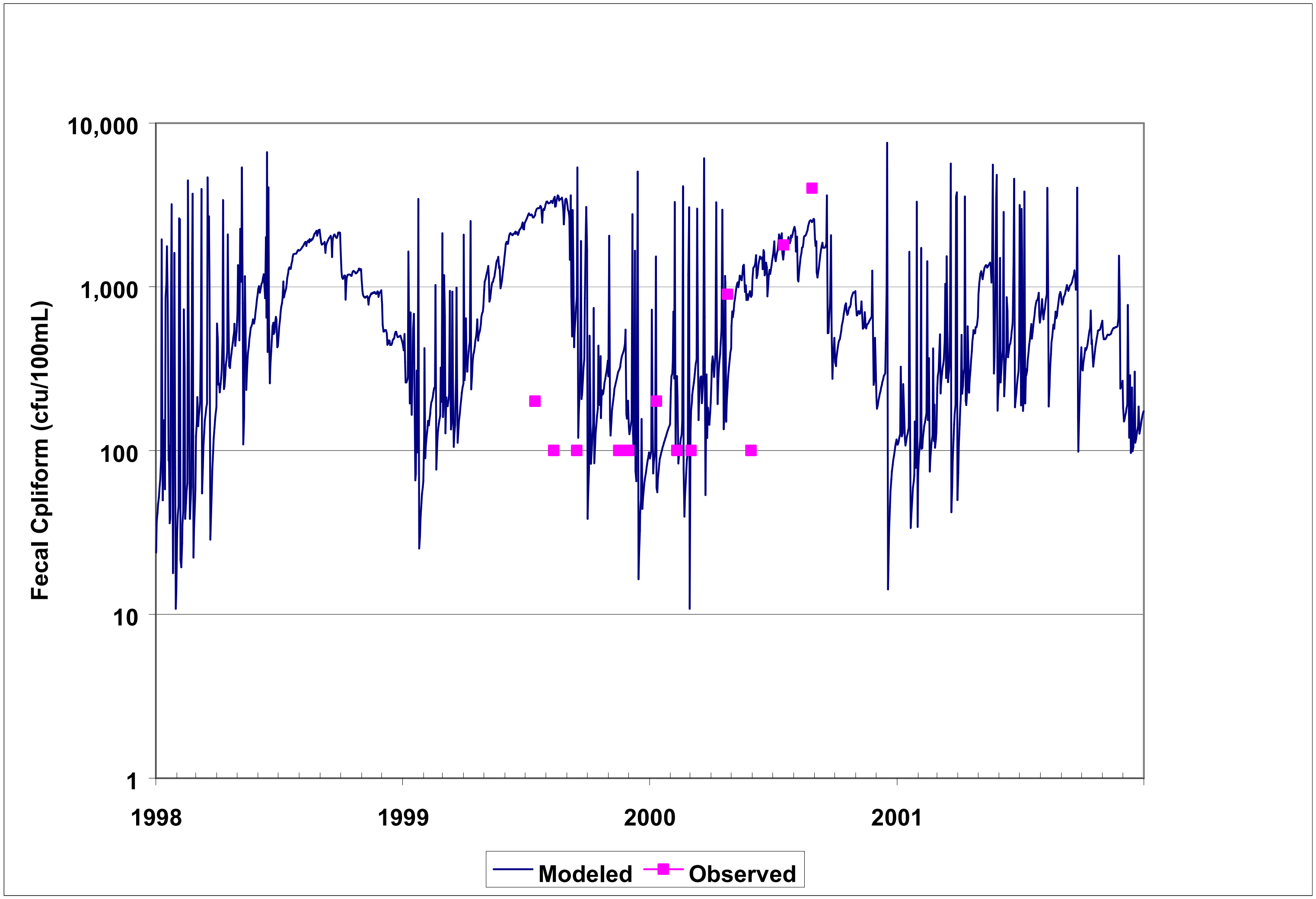


Figure 4.32: Simulated and observed fecal coliform concentrations at North Fork Sycolin Creek for verification period

CHAPTER 5: LOAD ALLOCATIONS

5.1 Background

Total maximum daily loads (TMDLs) are designed with the intention of allocating allowable loads among different pollutant sources so that appropriate control actions can be taken to achieve water quality standards (USEPA, 1991). The main objective of the Goose Creek TMDLs was to determine the reductions in bacteria loads that would be necessary to meet Virginia water quality standards. Both the fecal coliform standard and the *E. coli* standard must be met.

The new fecal coliform standard calls for the geometric mean of all samples taken in a calendar month to not exceed 200 cfu/100 ml, and for no more than 10% of the samples taken in a calendar month to be more than 400 cfu/ 100 ml. Under the new *E. coli* standard, the geometric mean of all samples taken within a calendar month must not exceed 126 cfu/ 100 ml and no single sample can be higher than 235 cfu /100 ml.

The TMDLs for the Goose Creek watershed consider all potential sources of bacteria. The incorporation of the different sources into the TMDLs is defined in the following equation:

$$TMDL = WLA + LA + MOS$$

Where:	WLA	=	wasteload allocation (point source contributions)
	LA	=	load allocation (non-point source contributions)
	MOS	=	margin of safety

5.1.1 Margin of Safety

A margin of safety (MOS) is included to account for any uncertainty in TMDL development. According to EPA guidance on the TMDL process, the MOS can be either implicit or explicit. When conservative assumptions are used or when conservative factors are used in the calculations, the MOS is considered implicit. When a percentage of the load is factored into the TMDL calculation as a MOS, then the MOS is considered explicit.

An implicit MOS is used in these TMDLs, based on the following conservative assumptions made in model calibration and in the simulation of the allocation scenarios:

- A ten-year simulation period, encompassing a wide range of hydrological conditions, was used in allocation scenarios; and
- Design flow and maximum permitted concentrations are used for all point sources in allocation scenarios.

5.1.2 Wasteload Allocation

All VPDES permitted point source dischargers of bacteria were considered in the model. For the purposes of allocation, the wasteload allocation for each permitted facility was set equivalent to the design flow rate multiplied by the 200 cfu/ 100 mL permit limit for fecal coliform bacteria. Table 5.1 lists the permitted point sources, their design flows, and the resultant wasteload allocations. Domestic dischargers with individual permits were assigned a wasteload allocation of 7.57E+06 cfu/day, based on a design flow of 1000 gal/day and a permit limit of 200 cfu / 100 ml. Table 5.2 lists the domestic discharges holding general permits, their permitted flows, and the resultant wasteload allocations. Table 5.3 summarizes wasteloads in the Goose Creek watershed by permit type. No reductions were required on any permitted source because they contribute only a small fraction of the total daily load and meet water quality standards on discharge.

Table 5.1: Design flow, permitted outflow concentrations, and wasteload allocations of fecal coliform bacteria for permitted point sources

VPDES	Facility	Segment	Design Flow (MGD)	Permitted Concentration (cfu/100 mL)	WLA (cfu/day)
VA0022802	Purcellville STP	140	0.500	200	3.79E+09
VA0024112	Foxcroft School	190	0.075	200	5.68E+08
VA0024759	US FEMA – Bluemont	210	0.090	200	6.81E+08
VA0024775	Middleburg WWTP	190	0.135	200	1.02E+09
VA0026212	Round Hill WWTP	140	0.200	200	1.51E+09
VA0027197	Notre Dame Academy	190	0.015	200	1.14E+08
VA0062189	St. Louis Community	180	0.086	200	6.51E+08
VA0065200	Rehau Plastics, Inc.	10	0.009	200	6.81E+07
VA0080993	Goose Creek Industrial Park WWTP	40	0.010	200	7.57E+07
VA0089133	Aldie WWTP	150	0.015	200	1.14E+08
Total			1.135	200	8.59E+09

MGD = Million Gallons per Day

5.1.3 Load Allocation

The load allocation portion of the Goose Creek TMDL is attributed solely to non-point sources of bacteria such as direct deposition by cattle and wildlife and runoff from agricultural, forest, and residential lands. Reductions in the current bacteria loads will be required from some combination of these sources to meet the designated TMDL.

5.2 Baseline Loads and Selection of Sources for Load Allocation Reductions

Baseline loads are the loads in terms of which TMDL reductions are measured. They are composed of (1) the current maximum permitted loads from point sources and (2) existing loads from nonpoint sources. Baseline loads are identical with loads from the verification scenario except for the following minor changes:

- Point sources are assumed to discharge at their permit limits of 200 cfu/100 ml and design flows. Although this represents an over ten-fold increase in point source loads over what was used in the calibration and verification scenarios, the relative contribution of point sources to bacteria loads remains small.

- Biosolids applications are reduced by 90% to represent the impact of the Loudoun County biosolids regulations implemented in 1999.
- Loads from failing septic systems in surveyed communities are eliminated, since all problems in surveyed areas have been eliminated or are in the process of being eliminated (Yates, 2002).

Table 5.2: Design flow, permitted outflow concentrations, and wasteload allocations of fecal coliform bacteria for permitted domestic dischargers

Permit No.	Facility	Segment	Permitted Flow (gallons/day)	Permitted Concentration (cfu/ 100 mL)	WLA (cfu/day)
VAG406015	Residence	100	1000	200	7.57E06
VAG406016	Business	180	1000	200	7.57E06
VAG406018	Residence	190	1000	200	7.57E06
VAG406019	Residence	160	1000	200	7.57E06
VAG406020	Residence	100	1000	200	7.57E06
VAG406047	Residence	100	1000	200	7.57E06
VAG406069	Residence	190	1000	200	7.57E06
VAG406101	Residence	100	1000	200	7.57E06
VAG406113	Residence	100	1000	200	7.57E06
VAG406115	Residence	180	1000	200	7.57E06
VAG406116	Residence	180	1000	200	7.57E06
VAG406121	Residence	100	1000	200	7.57E06
VAG406135	Residence	180	1000	200	7.57E06
VAG406143	Residence	180	1000	200	7.57E06
VAG406146	Residence	140	1000	200	7.57E06
VAG406149	Residence	180	1000	200	7.57E06
VAG406170	Residence	220	1000	200	7.57E06
VAG406172	Business	250	1000	200	7.57E06
VAG406176	Residence	140	1000	200	7.57E06
VAG406193	Residence	210	1000	200	7.57E06
VAG406244	Residence	30	1000	200	7.57E06
		Total	21,000	200	1.59E+08

Table 5.3 Summary of wasteloads in the Goose Creek watershed by permit type

Permit Type	Design Flow (MGD)	Permitted Concentration (cfu/100 mL)	WLA (cfu/day)
Individual Permits (WWTPs)	1.135	200	8.59E+09
General Permits (domestic dischargers)	0.021	200	1.59E+08
Watershed Total	1.156	200	8.75E+09

Table 5.4 Average daily baseline loads

Segment	Direct Loads				Runoff Loads				Direct	Runoff	Total
	Point Sources	Septic	Wildlife	Cattle	Forest	Crop	Pasture	Developed			
10	6.81E+07		9.95E+08	9.94E+09	1.43E+10	4.79E+10	1.02E+11	3.95E+10	1.09E+10	2.04E+11	2.15E+11
20			4.09E+08		4.86E+09	1.20E+08	3.18E+09	1.35E+09	4.09E+08	9.50E+09	9.91E+09
30	7.57E+06		3.14E+09	1.24E+11	9.39E+09	3.13E+10	6.18E+11	3.72E+10	1.27E+11	6.96E+11	8.23E+11
40	7.57E+07		5.99E+08		5.48E+09	5.53E+09	5.37E+09	1.09E+09	5.99E+08	1.75E+10	1.81E+10
50			2.64E+08		2.46E+09	6.02E+07	4.00E+08	2.17E+08	2.64E+08	3.14E+09	3.40E+09
60			8.61E+08	4.97E+09	9.03E+09	5.70E+08	3.81E+10	9.84E+08	5.83E+09	4.86E+10	5.45E+10
70			8.21E+08	2.48E+10	1.20E+10	1.15E+09	1.75E+11	3.81E+09	2.57E+10	1.92E+11	2.18E+11
80			1.24E+09	1.49E+11	3.86E+09	7.64E+08	6.19E+11	3.40E+09	1.50E+11	6.27E+11	7.78E+11
90			4.49E+08		1.36E+09	1.90E+07	2.55E+09	1.18E+09	4.49E+08	5.11E+09	5.56E+09
100	4.54E+07	1.95E+03	1.40E+09	9.94E+10	3.06E+09	1.04E+09	3.13E+11	3.79E+09	1.01E+11	3.21E+11	4.22E+11
110		1.95E+03	1.73E+09	1.49E+11	5.83E+09	3.85E+08	5.45E+11	3.86E+09	1.51E+11	5.55E+11	7.06E+11
120			1.93E+09	2.48E+11	6.81E+09	3.23E+08	1.14E+12	3.18E+09	2.50E+11	1.15E+12	1.40E+12
130		5.83E+03	4.23E+09	6.05E+11	7.62E+09	5.34E+10	1.29E+12	1.74E+10	6.09E+11	1.37E+12	1.98E+12
140	5.31E+09	9.75E+03	5.12E+09	9.94E+11	6.47E+08	1.42E+09	1.69E+12	1.41E+10	1.00E+12	1.70E+12	2.71E+12
150	1.14E+08		3.32E+09	5.96E+11	8.40E+09	1.65E+09	2.08E+12	7.55E+09	5.99E+11	2.10E+12	2.70E+12
160	7.57E+06	6.57E+03	8.74E+09	1.38E+12	2.20E+10	1.36E+09	3.18E+12	1.84E+10	1.39E+12	3.22E+12	4.61E+12
170			1.48E+09	2.48E+11	4.02E+09	6.90E+07	6.46E+11	2.76E+09	2.50E+11	6.52E+11	9.02E+11
180	6.97E+08	1.76E+04	9.71E+09	1.49E+12	1.41E+10	1.79E+09	3.79E+12	2.18E+10	1.50E+12	3.83E+12	5.33E+12
190	1.72E+09	1.95E+03	4.68E+09	1.98E+12	4.65E+09	5.18E+08	4.21E+12	5.57E+09	1.99E+12	4.22E+12	6.21E+12
200		3.46E+03	4.14E+09	3.35E+11	1.22E+10	1.81E+08	9.77E+11	8.58E+09	3.39E+11	9.98E+11	1.34E+12
210	6.98E+08	3.90E+03	8.05E+09	5.42E+12	9.68E+09	8.37E+08	4.30E+12	3.86E+09	5.43E+12	4.31E+12	9.74E+12
220	7.57E+06	9.76E+03	1.47E+10	5.46E+12	2.35E+10	9.95E+08	4.46E+12	9.27E+09	5.48E+12	4.50E+12	9.98E+12
230			3.16E+08	2.48E+10	9.57E+08	7.13E+08	1.12E+11	8.09E+08	2.52E+10	1.15E+11	1.40E+11
240			4.47E+08	2.48E+10	1.35E+09	2.57E+06	1.03E+11	1.19E+09	2.53E+10	1.06E+11	1.31E+11
250	7.57E+06		9.18E+08	9.94E+10	1.36E+09	7.66E+07	3.28E+11	3.05E+09	1.00E+11	3.32E+11	4.33E+11
Total	8.75E+09	6.27E+04	7.97E+10	1.95E+13	1.89E+11	1.52E+11	3.07E+13	2.14E+11	1.96E+13	3.13E+13	5.08E+13

For the purpose of allocating loads, bacteria sources were divided into six groups: direct deposition from cattle, direct deposition from wildlife, failing septic systems, and runoff from pasture, cropland, and developed land. This breakdown reflects the available range of potential control measures. Table 5.4 gives the baseline loads from these sources.

5.3 Load Allocation Scenarios

Ten potential load allocation scenarios were developed. For the sake of equity and because of the uncertainty in the magnitude of loads from failing septic systems, the same level of load reduction was always applied to failing septic systems and to cattle in stream. In any case, the fact that the discharge of untreated waste to state waters is illegal in Virginia is sufficient grounds for requiring the elimination of failing septic systems.

The same level of load reduction was always applied to crop and developed land, except in Segment 130, where dairy cattle waste is applied to cropland. The percent reduction applied to pasture was applied to cropland in this segment. Thus the load allocation scenarios are defined by four levels of load reduction applied to the six sources. Table 5.5 identifies the load reductions made for each scenario.

Table 5.5: Allocation scenario descriptions*

Scenario	Percent Reduction in Bacteria Loads from Existing Conditions					
	Cattle In-stream	Wildlife In-stream	Pasture	Cropland	Residential Land	Failing Septic Systems
1	100%[A]	NR	100%[A]	100%[A]	100%[A]	100%
2	100%	NR	100%[A]	100%[A]	100%[A]	100%
3	100%	NR	NR	NR	NR	100%
4	NR	NR	100%	NR	NR	NR
5	95%	NR	75%	NR	NR	90%
6	100%	NR	50%	NR	NR	100%
7	100%	NR	95%	NR	NR	100%
8	100%	NR	98%	NR	NR	100%
9	100%	10%	75%	75%	75%	100%
10	100%	50%	75%	75%	75%	100%

* Allocations applied to all segments where not otherwise noted
[A] Allocations applied to Segment 200 and all Segments below 190 (1AGOO22.4)

The simulation period used for the load allocation scenarios was 1992-2001. *E. coli* bacteria concentrations were not simulated directly but were calculated from simulated fecal coliform concentrations using a regression equation developed by VADEQ. The regression equation was developed based on a comparison of simultaneous fecal coliform and *E. coli* observations across Virginia. The equation is:

$$\text{Log}_2(EC) = -0.0172 + 0.91905 * \text{Log}_2(FC)$$

Where: EC = *E. coli* concentration (cfu/ 100 ml)
FC = fecal coliform concentration (cfu/ 100 ml)

Geometric means for each calendar month for both simulated fecal coliform concentrations and *E. coli* concentrations were calculated for each scenario. Scenarios were tested to see if (1) the geometric mean of fecal coliform concentrations exceeded 200 cfu/ 100 ml, (2) more than 10% of the fecal coliform concentrations exceeded 400 cfu/100 ml in a calendar month, (3) the geometric mean of *E. coli* concentrations exceeded 126 cfu /100 ml, and (4) any *E. coli* concentrations exceeded 235 cfu/100 ml. Table 5.6 shows the violation rate of each of these four conditions for each allocation scenario.

5.3.1 Analysis of the Results of the Allocation Scenarios

These scenarios demonstrate the answer to two sets of questions at the core of the load allocations for the impairments in the Goose Creek watershed. First, the calibration and verification scenarios demonstrate that the primary sources of fecal coliform loads are direct deposition of bacteria by cattle in stream and the transport of bacteria in runoff from pasture. Is controlling both these sources necessary to meet water quality standards? Is controlling these sources alone sufficient to meet those standards?

Second, fecal coliform loads to the impaired section of the mainstem of Goose Creek are potentially delivered from the whole upstream watershed. This includes the section upstream of DEQ monitoring station 1AGOO0022.44 at the outlet of Segment 190, which, on the basis of current standards, has not been listed as impaired, except for Cromwells Run. Do load allocations need to be made upstream of Segment 190?

The first two allocation scenarios address this last question. They demonstrate that even if all loads in runoff and all in-stream loads except wildlife and point sources are eliminated downstream of Segment 190, water quality standards will not be met in the lower mainstem of Goose Creek. Under the first scenario, no load reductions are made upstream of Segment 190 except in Cromwells Run. Under the second scenario, direct deposition from cattle and loads from failing septic systems are reduced 100%. Neither scenario meets the new fecal coliform standard or the new *E. coli* standard. Fecal coliform concentrations during storm events are high enough that the simulated monthly geometric mean is above 200 cfu/ 100 ml. If water quality standards are to be met in the mainstem of lower Goose Creek, load reductions will have to be made throughout the watershed.

The third scenario calls for a 100% reduction in direct deposition from cattle and loads from failing septic systems. Reductions from these sources are not sufficient to meet water quality standards in any of the impaired waterbodies. The fourth scenario calls for a 100% reduction in loads from pasture runoff. This, too, is not sufficient to meet water quality standards anywhere in the watershed. Reductions in both direct deposition by cattle and loads from pasture runoff are necessary.

Table 5.6 Violation Rates for fecal coliform standard and E. coli standard

Scenario	Segment	Watershed	Fecal Coliform Standard		*E. Coli* Standard	
			Geometric Mean[1]	Monthly[1]	Geometric Mean[1]	Instantaneous[2]
1	20	Lower Goose Creek	15.8%	15.0%	17.5%	5.6%
	140	N. Fork Goose Creek	0%	0%	0%	0%
	160	Little River	0%	0%	0%	0%
	180	Beaverdam Creek	0%	0%	0%	0%
	200	Cromwells Run	0%	0%	0%	0%
	230	Sycolin Creek	0%	0%	0%	0%
	240	S. Fork Sycolin Creek	0%	0%	0%	0%
	250	Sycolin Creek	0%	0%	0%	0%
2	20	Lower Goose Creek	0%	14.2%	0%	5.2%
	140	N. Fork Goose Creek	0%	0%	0%	0%
	160	Little River	0%	0%	0%	0%
	180	Beaverdam Creek	0%	0%	0%	0%
	200	Cromwells Run	0%	0%	0%	0%
	230	Sycolin Creek	0%	0%	0%	0%
	240	S. Fork Sycolin Creek	0%	0%	0%	0%
	250	Sycolin Creek	0%	0%	0%	0%
3	20	Lower Goose Creek	0%	44.2%	0%	11.6%
	140	N. Fork Goose Creek	0%	33.3%	0%	9.0%
	160	Little River	0.8%	49.2%	0.8%	13.1%
	180	Beaverdam Creek	0%	37.5%	0%	10.5%
	200	Cromwells Run	0%	29.2%	0%	7.9%
	230	Sycolin Creek	0%	30.0%	0%	9.0%
	240	S. Fork Sycolin Creek	0%	37.5%	0%	10.9%
	250	Sycolin Creek	0%	30.0%	0%	9.0%
4	20	Lower Goose Creek	50.8%	40.0%	50.8%	27.2%
	140	N. Fork Goose Creek	64.2%	61.7%	65.8%	50.2%
	160	Little River	55.0%	56.7%	55.0%	43.5%
	180	Beaverdam Creek	59.2%	55.0%	59.2%	40.7%
	200	Cromwells Run	49.2%	45.8%	49.2%	31.7%
	230	Sycolin Creek	60.8%	58.3%	60.8%	47.2%
	240	S. Fork Sycolin Creek	49.2%	46.7%	49.2%	35.7%
	250	Sycolin Creek	60.8%	58.3%	60.8%	47.2%
5	20	Lower Goose Creek	0%	37.5%	1.7%	10.0%
	140	N. Fork Goose Creek	1.7%	29.2%	2.5%	8.0%
	160	Little River	14.2%	43.3%	15.0%	11.5%
	180	Beaverdam Creek	0%	32.5%	0.8%	9.1%
	200	Cromwells Run	10.8%	35.0%	11.7%	12.9%
	230	Sycolin Creek	0.8%	27.5%	0.8%	8.2%
	240	S. Fork Sycolin Creek	5.0%	33.3%	5.0%	9.6%
	250	Sycolin Creek	0.8%	27.5%	0.8%	8.2%

			Fecal Coliform Standard		*E. Coli* Standard	
Scenario	Segment	Watershed	Geometric Mean[1]	Monthly[1]	Geometric Mean[1]	Instantaneous[2]
6	20	Lower Goose Creek	0%	27.5%	0%	8.1%
	140	N. Fork Goose Creek	0%	21.7%	0%	6.4%
	160	Little River	0%	31.7%	0%	8.7%
	180	Beaverdam Creek	0%	25.0%	0%	7.3%
	200	Cromwells Run	0%	17.5%	0%	5.9%
	230	Sycolin Creek	0%	23.3%	0%	6.4%
	240	S. Fork Sycolin Creek	0%	25.8%	0%	7.6%
	250	Sycolin Creek	0%	23.3%	0%	6.4%
7	20	Lower Goose Creek	0%	0%	0%	1.0%
	140	N. Fork Goose Creek	0%	0%	0%	0.4%
	160	Little River	0%	0.8%	0%	1.4%
	180	Beaverdam Creek	0%	0%	0%	0.7%
	200	Cromwells Run	0%	0%	0%	1.1%
	230	Sycolin Creek	0%	0%	0%	0.1%
	240	S. Fork Sycolin Creek	0%	0%	0%	0.2%
	250	Sycolin Creek	0%	0%	0%	0.1%
8	20	Lower Goose Creek	0%	0%	0%	0%
	140	N. Fork Goose Creek	0%	0%	0%	0%
	160	Little River	0%	0%	0%	0%
	180	Beaverdam Creek	0%	0%	0%	0%
	200	Cromwells Run	0%	0%	0%	0%
	230	Sycolin Creek	0%	0%	0%	0%
	240	S. Fork Sycolin Creek	0%	0%	0%	0%
	250	Sycolin Creek	0%	0%	0%	0%
9	20	Lower Goose Creek	0%	16.7%	0%	5.5%
	140	N. Fork Goose Creek	0%	15.0%	0%	4.7%
	160	Little River	0%	20.0%	0%	6.1%
	180	Beaverdam Creek	0%	19.2%	0%	5.4%
	200	Cromwells Run	0%	4.2%	0%	4.1%
	230	Sycolin Creek	0%	11.7%	0%	4.6%
	240	S. Fork Sycolin Creek	0%	12.5%	0%	4.9%
	250	Sycolin Creek	0%	11.7%	0%	4.6%
10	20	Lower Goose Creek	0%	16.7%	0%	5.5%
	140	N. Fork Goose Creek	0%	15.0%	0%	4.7%
	160	Little River	0%	20.0%	0%	6.1%
	180	Beaverdam Creek	0%	19.2%	0%	5.4%
	200	Cromwells Run	0%	4.2%	0%	4.1%
	230	Sycolin Creek	0%	11.7%	0%	4.5%
	240	S. Fork Sycolin Creek	0%	12.5%	0%	4.9%
	250	Sycolin Creek	0%	11.7%	0%	4.5%

1 Calculated on monthly basis; 2 Calculated on a daily basis.

The fifth, sixth, and seventh scenarios examine what level of reductions in loads from cattle in stream and pasture runoff are necessary to meet water quality standards. Scenario 5 calls for a 95% reduction in direct deposition by cattle and a 25% reduction in loads from pasture runoff, Scenario 6 calls for a 100% reduction in direct deposition by cattle and 50% reduction in loads from pasture runoff, and Scenario 7 call for a 100% reduction in direct deposition by cattle and a 95% reduction in loads from pasture runoff. None of these scenarios meets the instantaneous *E. coli* standard. Scenario 7 meets the new fecal coliform standard in all impaired waterbodies except Little River. To meet the instantaneous *E. coli* standard, direct deposition by cattle must be reduced 100% and pasture loads must be reduced 99 % in Little River and Cromwells Run and 98% everywhere else, as shown by Scenario 8 in Table 5.6.

Scenarios 9 and 10 examine whether there is a trade-off that would meet water quality standards between reductions in pasture loads and reductions in direct deposition from wildlife and loads in runoff from cropland and developed land. Direct deposition from cattle is reduced 100%. Reductions in loads in runoff from pasture are held at 75%. Reductions in loads in runoff from cropland and developed land are also set at 75%. In Scenario 9 reductions in direct deposition from wildlife are set at 10%, and in Scenario 10 direct deposition from wildlife is reduced 50%. Neither scenario meets the new fecal coliform standard or the *E. coli* standard. The reductions simulated in Scenario 8 are both necessary and sufficient to meet the new water quality standards.

5.4 Summary of TMDL Allocations For Goose Creek

The load allocation that meets both fecal coliform standards and *E. coli* standards in the impaired tributaries and the lower mainstem of Goose Creek calls for the following reductions:

- 99% reduction in loads from pasture runoff in Little River and Cromwells Run
- 98% reduction in loads from pasture runoff elsewhere in the watershed,
- 100% reduction in direct deposition from cattle in streams, and
- 100% reduction in loads from failing septic systems.

The deep reductions in these loads are necessary to meet the instantaneous single sample *E. coli* standard and the limitation on violations in a single month of the instantaneous fecal coliform standard. Explicit reductions in wildlife loads are not necessary to meet water quality standards.

The proposed TMDL allocations were tested by simulating fecal coliform and *E. coli* concentrations under the load allocation over a ten-year period. The ten-year simulation period spans a variety of seasonal variation and flow conditions, and no violations of water quality standards were simulated.

Tables 5.7.1.1 through 5.7.7.4 show, for each impaired segment (1) the Total Maximum Daily Load, Wasteload Allocation, and Load Allocation; (2) the Wasteload Allocation assigned to individual permitted sources; (3) the existing loads from nonpoint source categories, their Load Allocations, and the percent reduction in load from each category under the TMDL; and (4) the Wasteload allocation, in terms of *E. coli* bacteria, assigned to individual permitted sources. Nonpoint source loads, both under existing conditions and under the TMDL load allocation, represent loads delivered to surface water (edge-of-stream loads).

Figures 5.1 through 5.16 show the simulated fecal coliform and *E. coli* concentrations under the TMDLs and their calendar-month geometric means. These figures also illustrate the fact that the reductions called for in the TMDLs are driven by the need to meet the instantaneous E. coli standard, not the geometric mean standards or the monthly instantaneous fecal coliform standard.

Under the TMDL allocations, over the course of the ten-year simulation only two storm events produce daily average *E. coli* concentrations larger than 90% of the instantaneous *E. coli* standard: a June 26, 2000 thunderstorm which impacts Little River and Cromwells Run, and a June 23, 2001 thunderstorm which impacts the *E. coli* concentration in the lower Goose Creek but in no other impairment. Otherwise the simulated *E. coli* concentrations are well below the standard everywhere else in the watershed over the ten-year simulation. The simulated E. *coli* concentrations in the North Fork of Goose Creek and the Sycolin Creek watershed are particularly low because the load allocation for these watersheds were not determined by the need to meet water quality standards locally but to meet the *E. coli* standard in the lower Goose Creek

The simulated daily fecal coliform concentrations are also overall quite low throughout the watershed over the course of the ten-year simulation. Because impaired segments meet the instantaneous fecal coliform standard with a 95% reduction in the load from pasture runoff, the additional 80-90% reduction necessary to meet the instantaneous *E. coli* standard drives the fecal concentrations well below the standard. In no calendar month are 10% of the simulated daily concentrations above 200 cfu / 100 mL in any impaired segment.

The figures also show that under the TMDL allocations, the calendar month geometric means of both the fecal coliform concentrations and *E. coli* concentrations are well below the limits set by the standards. In the bacteria simulation, as in the monitoring data, high bacteria concentrations are associated with storm flow. The highest bacteria concentrations therefore occur episodically. The geometric mean of bacteria concentrations tends to discount outlying high concentrations and follows the trend of the concentrations during base flow. Since base flow concentrations tend to be lower than the episodic storm flow concentrations, the geometric mean standards for bacteria are more easily met. In fact, wet years, like 1996, can have lower geometric mean concentrations than drier years like 1997, because in wet years higher base flows dilute low-flow loads and lower the geometric mean concentrations overall.

Table 5.7.1.1 Elements of the TMDL for Cromwells Run (Segment 200)

Waterbody (Waterbody ID)	Parameter	TMDL (cfu/yr)	WLA (cfu/yr)	LA[1] (cfu/yr)	MOS (cfu/yr)
Cromwells Run (CRM01A00)	Fecal Coliform	9.80E+12	0	9.80E+12	Implicit

[1] Edge-of-stream load.

Table 5.7.1.2 Load Allocation[1] for Cromwells Run (Segment 200)

Land Use	Existing Load (cfu/yr)	Allocated Load (cfu/yr)	Percent Reduction
Forest	4.45E+12	4.45E+12	0%
Cropland	6.61E+10	6.61E+10	0%
Pasture	3.57E+14	3.57E+12	99%
Developed Land (without failing septic systems)	2.02E+11	2.02E+11	0%
Failing Septic Systems	2.93E+12	0	100%
Straight Pipes/Septic Systems Within 50 Ft of Surface Water	1.26E+06	0	100%
Direct Deposition from Cattle	1.22E+14	0	100%
Direct Deposition from Wildlife	1.51E+12	1.51E+12	0%
Total Load Allocation	4.88E+14	9.80E+12	98%

[1] Edge-of-stream load.

Table 5.7.2.1 Elements of the TMDL for North Fork of Goose Creek (Segment 140)

Waterbody (Waterbody ID)	Parameter	TMDL (cfu/yr)	WLA (cfu/yr)	LA[1] (cfu/yr)	MOS (cfu/yr)
North Fork of Goose Creek (NOG01A00)	Fecal Coliform	1.73E+13	1.94E+12	1.54E+13	Implicit

[1] Edge-of-stream load.

Table 5.7.2.2 Fecal Coliform Wasteload Allocation for North Fork of Goose Creek (Segment 140)

Permit Number	Facility	Existing Load (cfu/ yr)	Allocated Load (cfu/yr)
VA0022802	Purcellville STP	1.38E+12	1.38E+12
VA0026212	Round Hill WWTP	5.51E+11	5.51E+11
VAG406146	Residence	2.76E+09	2.76E+09
VAG406176	Residence	2.76E+09	2.76E+09
Total Wasteload Allocation		1.94E+12	1.94E+12

Table 5.7.2.3 Load Allocation[1] for North Fork of Goose Creek (Segment 140)

Land Use	Existing Load (cfu/yr)	Allocated Load (cfu/yr)	Percent Reduction
Forest	2.36E+11	2.36E+11	0%
Cropland	5.18E+11	5.18E+11	0%
Pasture	6.17E+14	1.23E+13	98%
Developed Land (without failing septic systems)	3.93E+11	3.93E+11	0%
Failing Septic Systems	4.75E+12	0	100%
Straight Pipes/Septic Systems Within 50 Ft of Surface Water	3.56E+06	0	100%
Direct Deposition from Cattle	3.63E+14	0	100%
Direct Deposition from Wildlife	1.87E+12	1.87E+12	0%
Total Load Allocation	9.89E+14	1.54E+13	98%

[1] Edge-of-stream load.

Table 5.7.2.4 *E. coli* Wasteload Allocation for North Fork of Goose Creek (Segment 140)

Permit Number	Facility	Existing Load (cfu/ yr)	Allocated Load (cfu/yr)
VA0022802	Purcellville STP	8.70E+11	8.70E+11
VA0026212	Round Hill WWTP	3.48E+11	3.48E+11
VAG406146	Residence	1.74E+09	1.74E+09
VAG406176	Residence	1.74E+09	1.74E+09
Total Wasteload Allocation		1.22E+12	1.22E+12

Table 5.7.3.1 Elements of the TMDL for Beaverdam Creek (Segment 180)

Waterbody (Waterbody ID)	Parameter	TMDL (cfu/yr)	WLA (cfu/yr)	LA[1] (cfu/yr)	MOS (cfu/yr)
Beaverdam Creek (BEC01A00)	Fecal Coliform	3.73E+13	2.54E+11	3.70E+13	Implicit

[1] Edge-of-stream load.

Table 5.7.3.2 Fecal Coliform Wasteload Allocation for Beaverdam Creek (Segment 180)

Permit Number	Facility	Existing Load (cfu/ yr)	Allocated Load (cfu/yr)
VA0062189	St. Louis	2.38E+11	2.38E+11
VAG406016	Business	2.76E+09	2.76E+09
VAG406115	Residence	2.76E+09	2.76E+09
VAG406116	Residence	2.76E+09	2.76E+09
VAG406135	Residence	2.76E+09	2.76E+09
VAG406143	Residence	2.76E+09	2.76E+09
VAG406149	Residence	2.76E+09	2.76E+09
Total Wasteload Allocation		2.54E+11	2.54E+11

Table 5.7.3.3 Load Allocation[1] for Beaverdam Creek (Segment 180)

Land Use	Existing Load (cfu/yr)	Allocated Load (cfu/yr)	Percent Reduction
Forest	5.15E+12	5.15E+12	0%
Cropland	6.53E+11	6.53E+11	0%
Pasture	1.38E+15	2.77E+13	98%
Developed Land (without failing septic systems)	1.96E+10	1.96E+10	0%
Failing Septic Systems	7.94E+12	0	100%
Straight Pipes/Septic Systems Within 50 Ft of Surface Water	6.42E+06	0	100%
Direct Deposition from Cattle	5.44E+14	0	100%
Direct Deposition from Wildlife	3.54E+12	3.54E+12	0%
Total Load Allocation	1.94E+15	3.70E+13	98%

[1] Edge-of-stream load.

Table 5.7.3.4 *E. coli* Wasteload Allocation for Beaverdam Creek (Segment 180)

Permit Number	Facility	Existing Load (cfu/ yr)	Allocated Load (cfu/yr)
VA0062189	St. Louis	1.50E+11	1.50E+11
VAG406016	Business	1.74E+09	1.74E+09
VAG406115	Residence	1.74E+09	1.74E+09
VAG406116	Residence	1.74E+09	1.74E+09
VAG406135	Residence	1.74E+09	1.74E+09
VAG406143	Residence	1.74E+09	1.74E+09
VAG406149	Residence	1.74E+09	1.74E+09
Total Wasteload Allocation		1.60E+11	1.60E+11

Table 5.7.4.1 Elements of the TMDL for Little River (Segment 160)

Waterbody (Waterbody ID)	Parameter	TMDL (cfu/yr)	WLA (cfu/yr)	LA[1] (cfu/yr)	MOS (cfu/yr)
Little River (LIV01A00)	Fecal Coliform	2.36E+13	2.76E+09	2.36E+13	Implicit

[1] Edge-of-stream load.

Table 5.7.4.2 Fecal Coliform Wasteload Allocation for Little River (Segment 160)

Permit Number	Facility	Existing Load (cfu/ yr)	Allocated Load (cfu/yr)
VAG406019	Residence	2.76E+09	2.76E+09
Total Wasteload Allocation		2.76E+09	2.76E+09

Table 5.7.4.3 Load Allocation[1] for Little River (Segment 160)

Land Use	Existing Load (cfu/yr)	Allocated Load (cfu/yr)	Percent Reduction
Forest	8.03E+12	8.03E+12	0%
Cropland	4.96E+11	4.96E+11	0%
Pasture	1.16E+15	1.16E+13	99%
Developed Land (without failing septic systems)	3.21E+11	3.21E+11	0%
Failing Septic Systems	6.39E+12	0	100%
Straight Pipes/Septic Systems Within 50 Ft of Surface Water	2.40E+06	0	100%
Direct Deposition from Cattle	5.04E+14	0	100%
Direct Deposition from Wildlife	3.19E+12	3.19E+12	0%
Total Load Allocation	1.68E+15	2.36E+13	99%

[1] Edge-of-stream load.

Table 5.7.4.4 *E. coli* Wasteload Allocation for Little River (Segment 160)

Permit Number	Facility	Existing Load (cfu/ yr)	Allocated Load (cfu/yr)
VAG406019	Residence	1.74E+09	1.74E+09
Total Wasteload Allocation		1.74E+09	1.74E+09

Table 5.7.5.1 Elements of the TMDL for Sycolin Creek (Segments 230,240,250)

Waterbody (Waterbody ID)	Parameter	TMDL (cfu/yr)	WLA (cfu/yr)	LA[1] (cfu/yr)	MOS (cfu/yr)
Sycolin Creek (SYC02A02)	Fecal Coliform	6.23E+12	2.76E+09	6.22E+12	Implicit

[1] Edge-of-stream load.

Table 5.7.5.2 Fecal Coliform Wasteload Allocation for Sycolin Creek (Segments 230,240,250)

Permit Number	Facility	Existing Load (cfu/ yr)	Allocated Load (cfu/yr)
VAG406172	Business	2.76E+09	2.76E+09
Total Wasteload Allocation		2.76E+09	2.76E+09

Table 5.7.5.3 Load Allocation[1] for Sycolin Creek (Segments 230,240,250)

Land Use	Existing Load (cfu/yr)	Allocated Load (cfu/yr)	Percent Reduction
Forest	1.34E+12	1.34E+12	0%
Cropland	2.89E+11	2.89E+11	0%
Pasture	1.98E+14	3.96E+12	98%
Developed Land (without failing septic systems)	1.75E+10	1.75E+10	0%
Failing Septic Systems	1.83E+12	0	100%
Straight Pipes/Septic Systems Within 50 Ft of Surface Water	0	0	100%
Direct Deposition from Cattle	5.44E+13	0	100%
Direct Deposition from Wildlife	6.14E+11	6.14E+11	0%
Total Load Allocation	2.56E+14	6.22E+12	98%

[1] Edge-of-stream load.

Table 5.7.5.4 *E. coli* Wasteload Allocation for Sycolin Creek (Segments 230,240,250)

Permit Number	Facility	Existing Load (cfu/ yr)	Allocated Load (cfu/yr)
VAG406172	Business	1.74E+09	1.74E+09
Total Wasteload Allocation		1.74E+09	1.74E+09

Table 5.7.6.1 Elements of the TMDL for South Fork Sycolin Creek (Segment 240)

Waterbody (Waterbody ID)	Parameter	TMDL (cfu/yr)	WLA (cfu/yr)	LA[1] (cfu/yr)	MOS (cfu/yr)
South Fork Sycolin Creek (SFS01A02)	Fecal Coliform	1.41E+12	0	1.41E+12	Implicit

[1] Edge-of-stream load.

Table 5.7.6.2 Load Allocation[1] for South Fork Sycolin Creek (Segment 240)

Land Use	Existing Load (cfu/yr)	Allocated Load (cfu/yr)	Percent Reduction
Forest	4.93E+11	4.93E+11	0%
Cropland	9.38E+08	9.38E+08	0%
Pasture	3.76E+13	7.52E+11	98%
Developed Land (without failing septic systems)	0	0	0%
Failing Septic Systems	4.34E+11	0	100%
Straight Pipes/Septic Systems Within 50 Ft of Surface Water	0	0	100%
Direct Deposition from Cattle	9.05E+12	0	100%
Direct Deposition from Wildlife	1.63E+11	1.63E+11	0%
Total Load Allocation	4.77E+13	1.41E+12	97%

[1] Edge-of-stream load.

Table 5.7.7.1 Elements of the TMDL for Goose Creek (Segments 20-250)

Waterbody (Waterbody ID)	Parameter	TMDL (cfu/yr)	WLA (cfu/yr)	LA[1] (cfu/yr)	MOS (cfu/yr)
Goose Creek (GOO01A00)	Fecal Coliform	3.67E+14	3.17E+12	3.63E+14	Implicit

[1] Edge-of-stream load.

Table 5.7.7.2 Fecal Coliform Wasteload Allocation for Goose Creek (Segments 20-250)

Permit Number	Facility	Existing Load (cfu/ yr)	Allocated Load (cfu/yr)
VA0022802	Purcellville	1.38E+12	1.38E+12
VA0024112	Foxcroft	2.07E+11	2.07E+11
VA0024759	US FEMA	2.49E+11	2.49E+11
VA0024775	Middleburg	3.72E+11	3.72E+11
VA0026212	Round Hill	5.51E+11	5.51E+11
VA0027197	Notre Dame	4.16E+10	4.16E+10
VA0062189	St. Louis	2.38E+11	2.38E+11
VA0080993	Goose Creek	2.76E+10	2.76E+10
VA0089133	Aldie WWTP	4.16E+10	4.16E+10
VAG406015	Residence	2.76E+09	2.76E+09
VAG406016	Business	2.76E+09	2.76E+09
VAG406018	Residence	2.76E+09	2.76E+09
VAG406019	Residence	2.76E+09	2.76E+09
VAG406020	Residence	2.76E+09	2.76E+09
VAG406047	Residence	2.76E+09	2.76E+09
VAG406069	Residence	2.76E+09	2.76E+09
VAG406101	Residence	2.76E+09	2.76E+09
VAG406113	Residence	2.76E+09	2.76E+09
VAG406115	Residence	2.76E+09	2.76E+09
VAG406116	Residence	2.76E+09	2.76E+09
VAG406121	Residence	2.76E+09	2.76E+09
VAG406135	Residence	2.76E+09	2.76E+09
VAG406143	Residence	2.76E+09	2.76E+09
VAG406146	Residence	2.76E+09	2.76E+09
VAG406149	Residence	2.76E+09	2.76E+09
VAG406170	Residence	2.76E+09	2.76E+09
VAG406172	Business	2.76E+09	2.76E+09
VAG406176	Residence	2.76E+09	2.76E+09
VAG406193	Residence	2.76E+09	2.76E+09
VAG406244	Residence	2.76E+09	2.76E+09
Total Wasteload Allocation		3.17E+12	3.17E+12

Table 5.7.7.3 Load Allocation[1] for Goose Creek (Segments 20-250)

Land Use	Existing Load (cfu/yr)	Allocated Load (cfu/yr)	Percent Reduction
Forest	6.37E+13	6.37E+13	0%
Cropland	3.81E+13	3.81E+13	0%
Pasture	1.12E+16	2.24E+14	98%
Developed Land (without failing septic systems)	9.25E+12	9.25E+12	0%
Failing Septic Systems	5.44E+13	0	100%
Straight Pipes/Septic Systems Within 50 Ft of Surface Water	2.29E+07	0	100%
Direct Deposition from Cattle	7.10E+15	0	100%
Direct Deposition from Wildlife	2.87E+13	2.87E+13	0%
Total Load Allocation	1.85E+16	3.63E+14	98%

[1] Edge-of-stream load.

Table 5.7.7.4 *E. coli* Wasteload Allocation for Goose Creek (Segments 20-250)

Permit Number	Facility	Existing Load (cfu/ yr)	Allocated Load (cfu/yr)
VA0022802	Purcellville	8.70E+11	8.70E+11
VA0024112	Foxcroft	1.31E+11	1.31E+11
VA0024759	US FEMA	1.57E+11	1.57E+11
VA0024775	Middleburg	2.35E+11	2.35E+11
VA0026212	Round Hill	3.48E+11	3.48E+11
VA0027197	Notre Dame	2.61E+10	2.61E+10
VA0062189	St. Louis	1.50E+11	1.50E+11
VA0080993	Goose Creek	1.74E+10	1.74E+10
VA0089133	Aldie WWTP	2.61E+10	2.61E+10
VAG406015	Residence	1.74E+09	1.74E+09
VAG406016	Business	1.74E+09	1.74E+09
VAG406018	Residence	1.74E+09	1.74E+09
VAG406019	Residence	1.74E+09	1.74E+09
VAG406020	Residence	1.74E+09	1.74E+09
VAG406047	Residence	1.74E+09	1.74E+09
VAG406069	Residence	1.74E+09	1.74E+09
VAG406101	Residence	1.74E+09	1.74E+09
VAG406113	Residence	1.74E+09	1.74E+09
VAG406115	Residence	1.74E+09	1.74E+09
VAG406116	Residence	1.74E+09	1.74E+09
VAG406121	Residence	1.74E+09	1.74E+09
VAG406135	Residence	1.74E+09	1.74E+09
VAG406143	Residence	1.74E+09	1.74E+09
VAG406146	Residence	1.74E+09	1.74E+09
VAG406149	Residence	1.74E+09	1.74E+09
VAG406170	Residence	1.74E+09	1.74E+09
VAG406172	Business	1.74E+09	1.74E+09
VAG406176	Residence	1.74E+09	1.74E+09
VAG406193	Residence	1.74E+09	1.74E+09
VAG406244	Residence	1.74E+09	1.74E+09
Total Wasteload Allocation		2.00E+12	2.00E+12

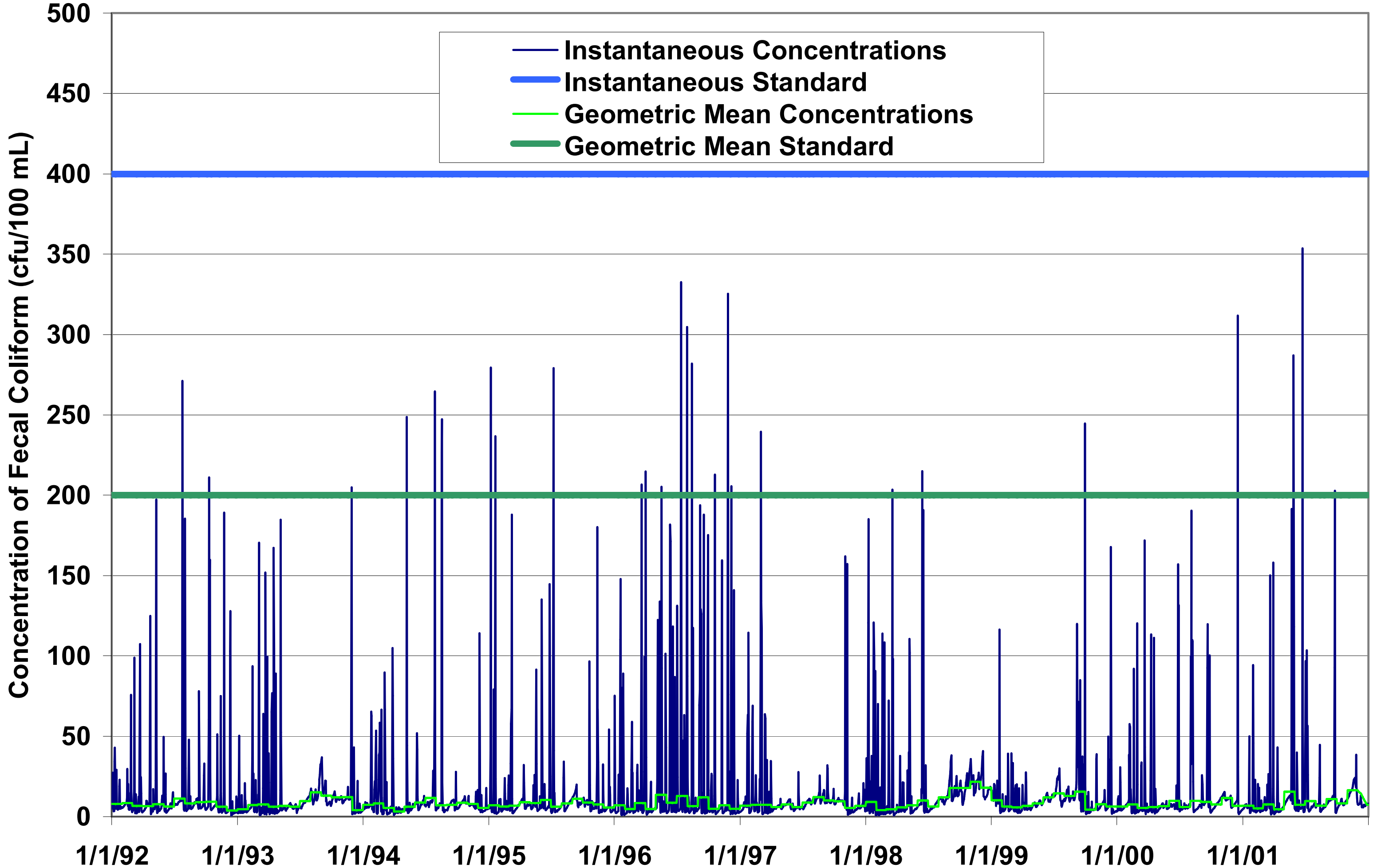


Figure 5.1: Simulated instantaneous and geometric mean fecal coliform concentrations (cfu/100 mL) at Lower Goose Creek (1AGOO002.38) for the TMDL Scenario

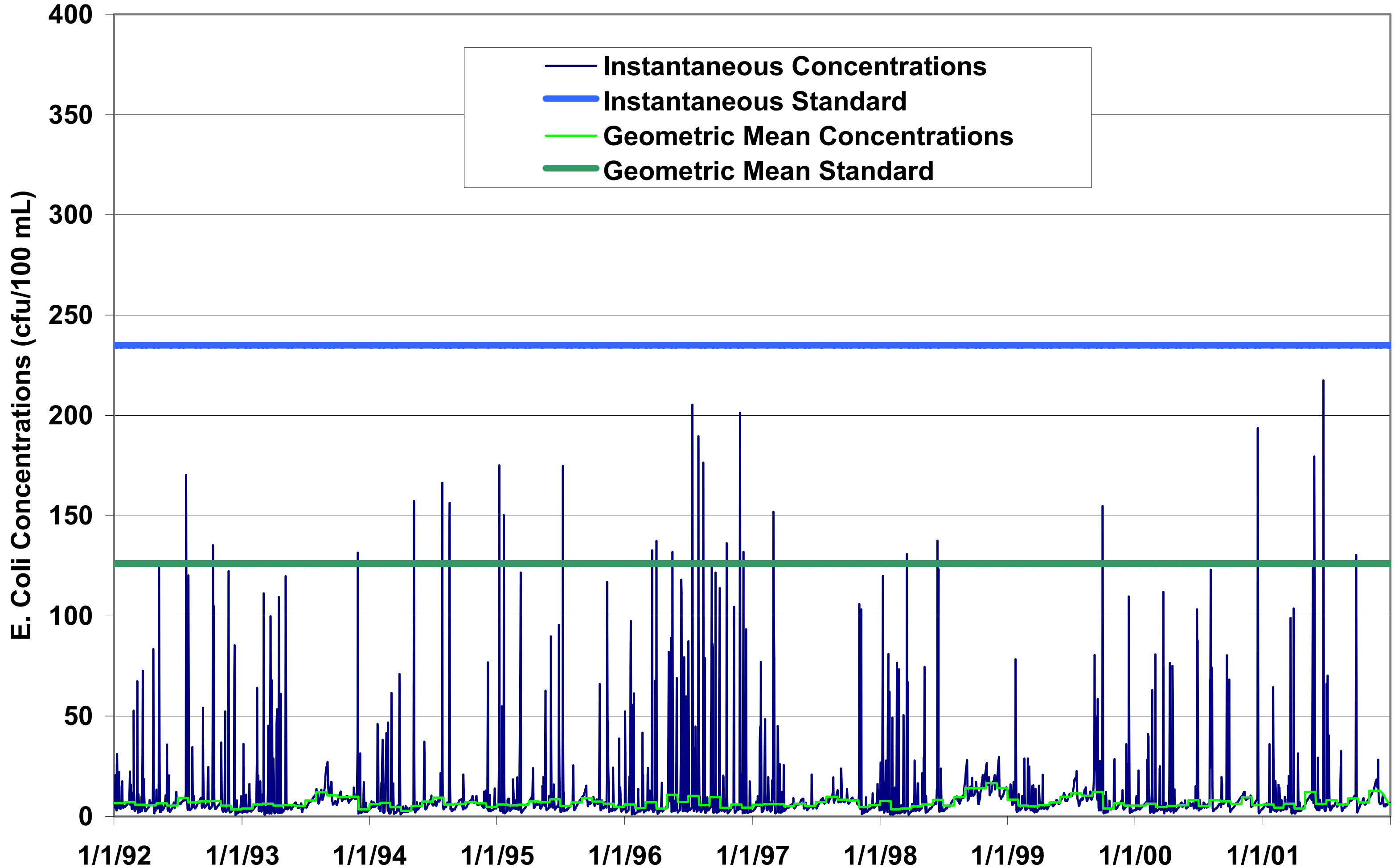


Figure 5.2: Simulated instantaneous and geometric mean *E. coli* concentrations (cfu/100 mL) at Lower Goose Creek (1AGOO002.38) for the TMDL Scenario

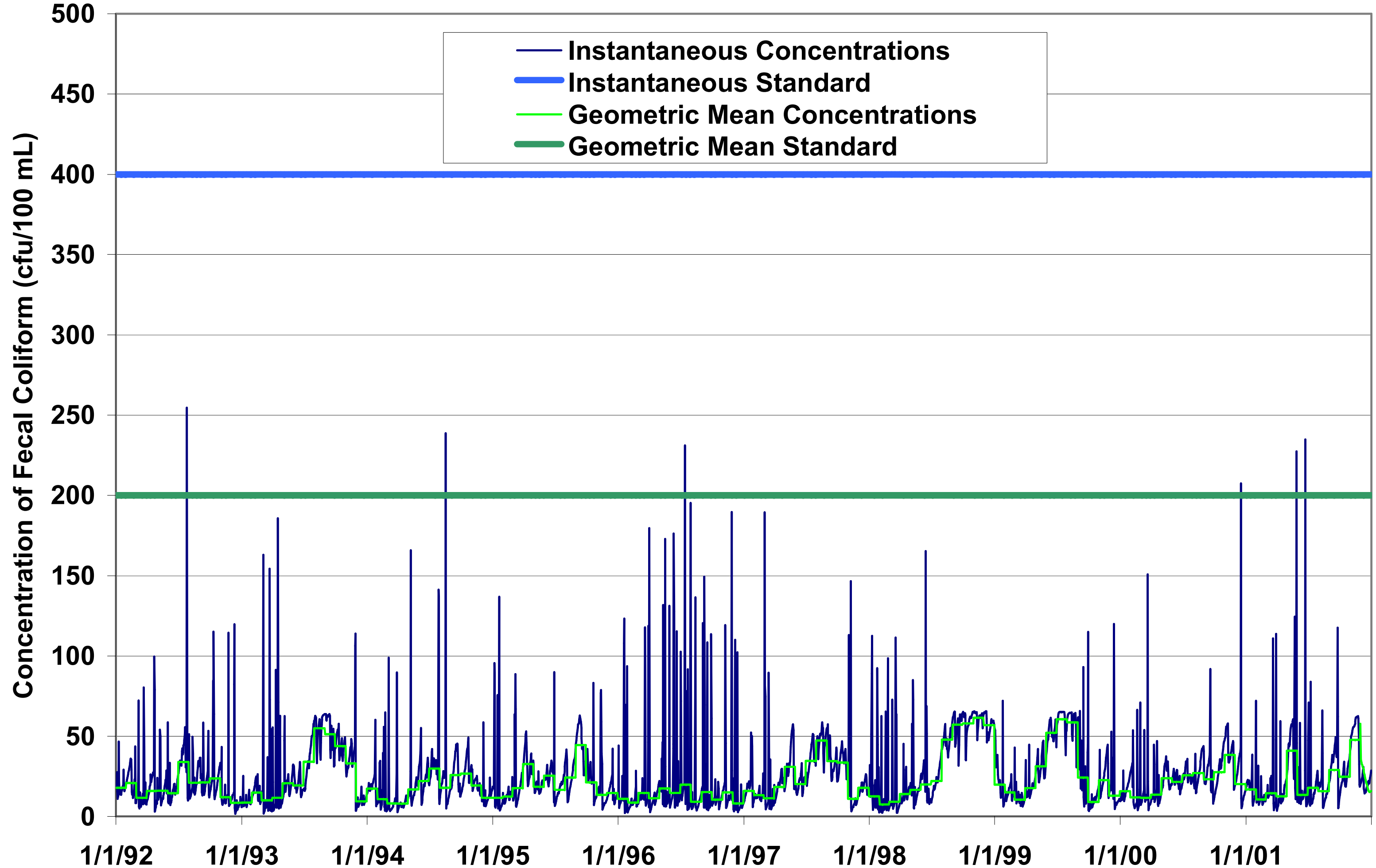


Figure 5.3 : Simulated instantaneous and geometric mean fecal coliform concentrations (cfu/100 mL) at North Fork Goose Creek (1ANOG005.69) for the TMDL Scenario

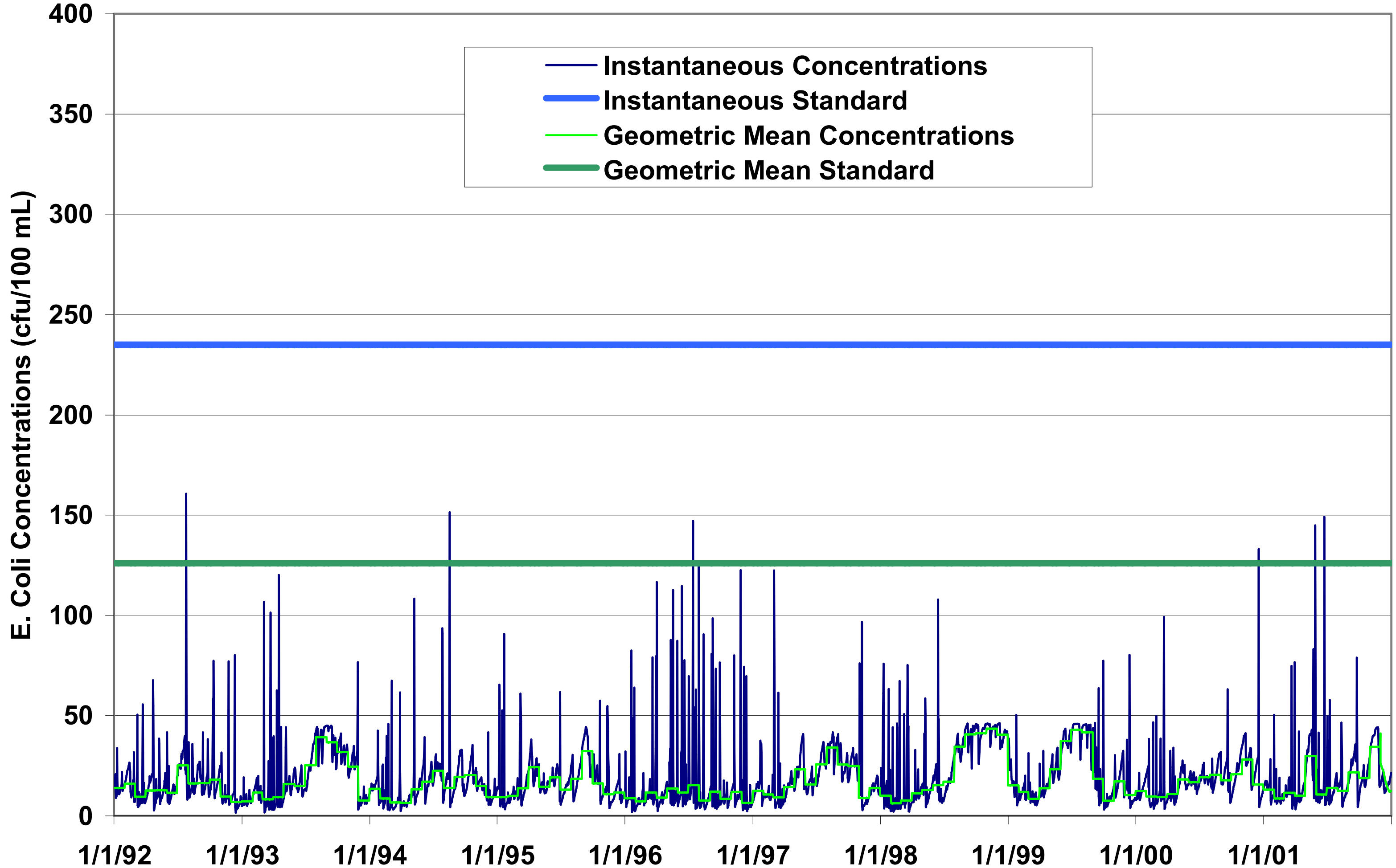


Figure 5.4: Simulated instantaneous and geometric mean *E. coli* concentrations (cfu/100 mL) at North Fork Goose Creek (1ANOG005.69) for the TMDL Scenario

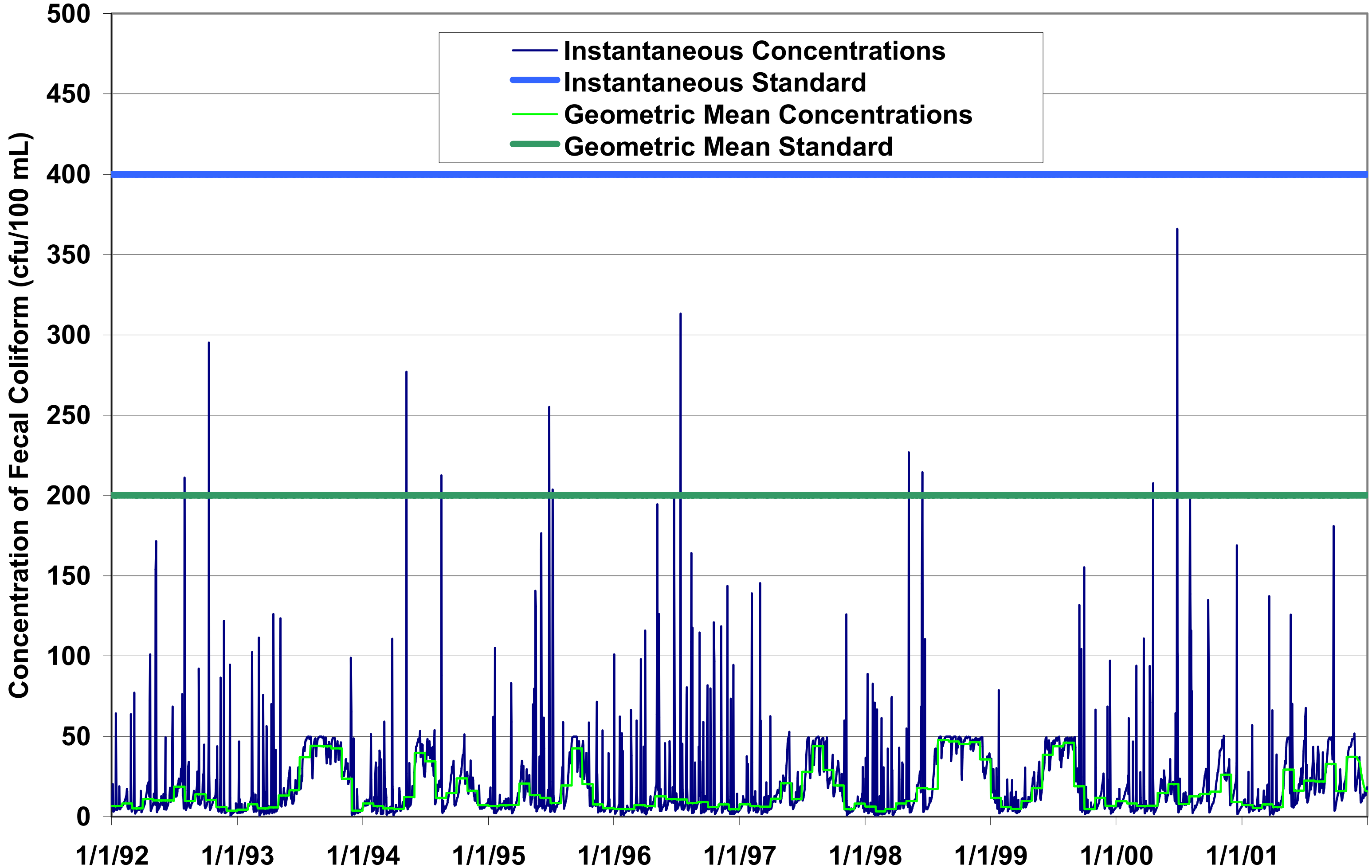


Figure 5.5: Simulated instantaneous and geometric mean fecal coliform concentrations (cfu/100 mL) at Little River (1ALIV004.78) for the TMDL Scenario

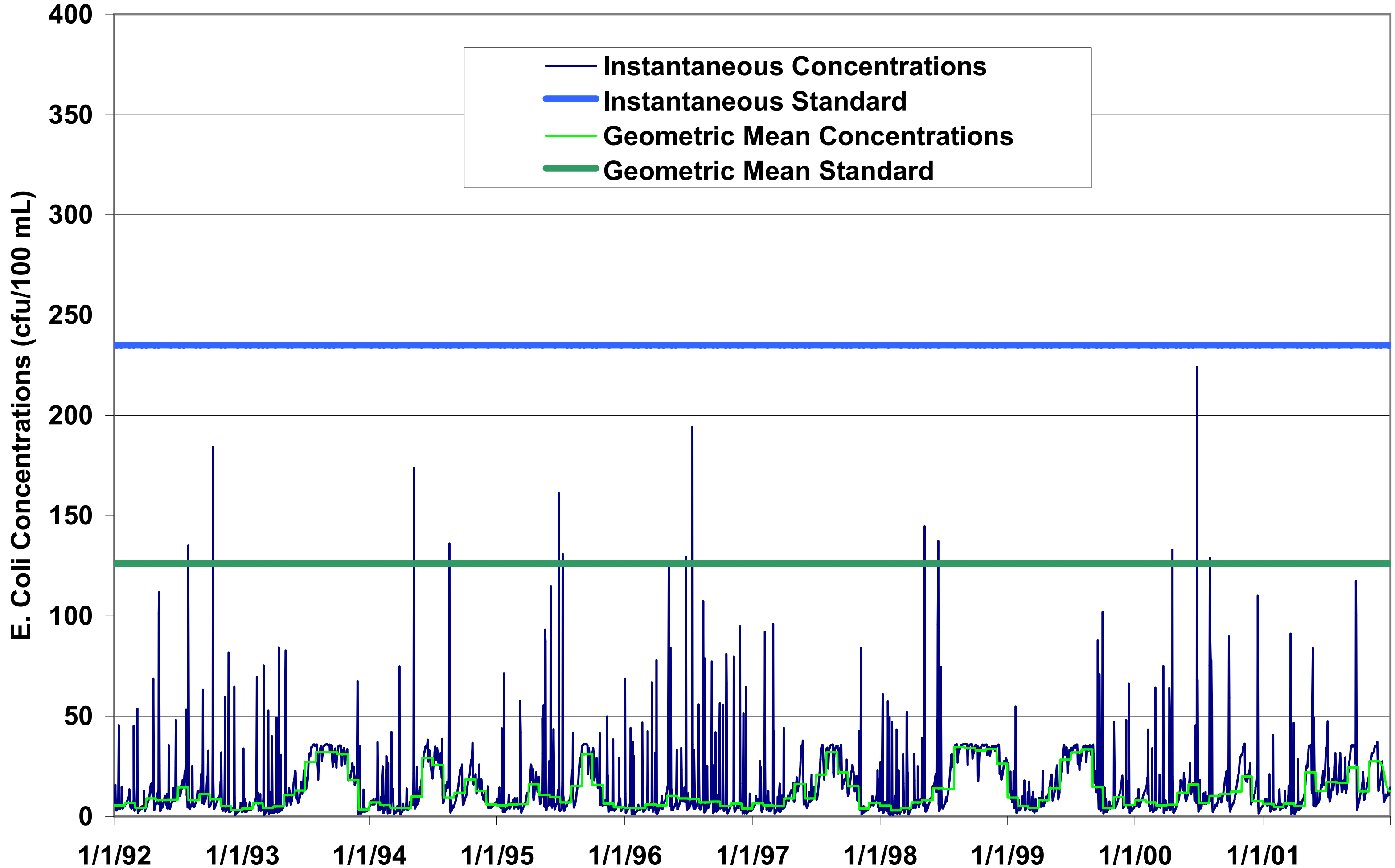


Figure 5.6: Simulated instantaneous and geometric mean *E. coli* concentrations (cfu/100 mL) at Little River (1ALIV004.78) for the TMDL Scenario

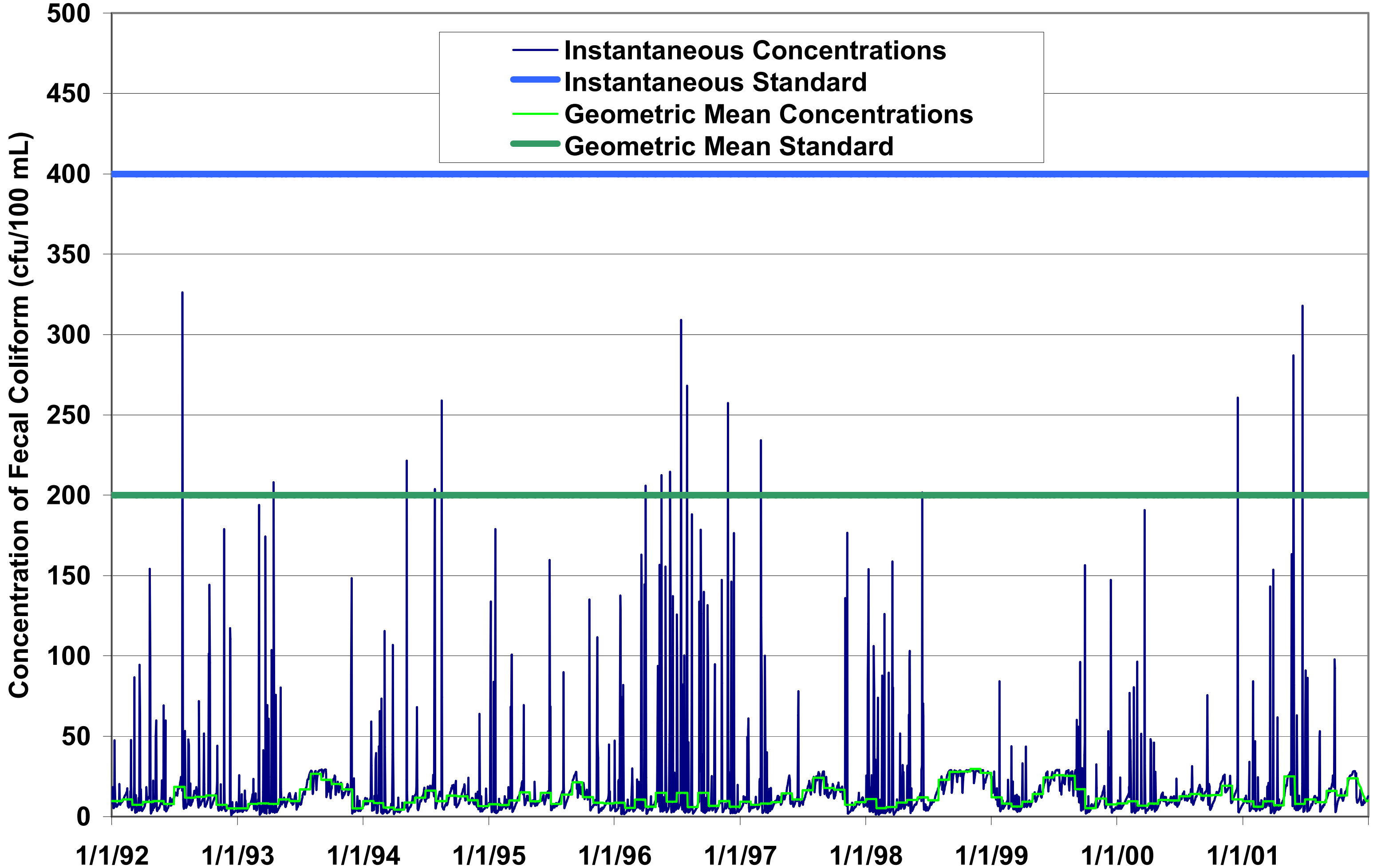


Figure 5.7: Simulated instantaneous and geometric mean fecal coliform concentrations (cfu/100 mL) at Beaverdam Creek (1ABEC004.76) for the TMDL Scenario

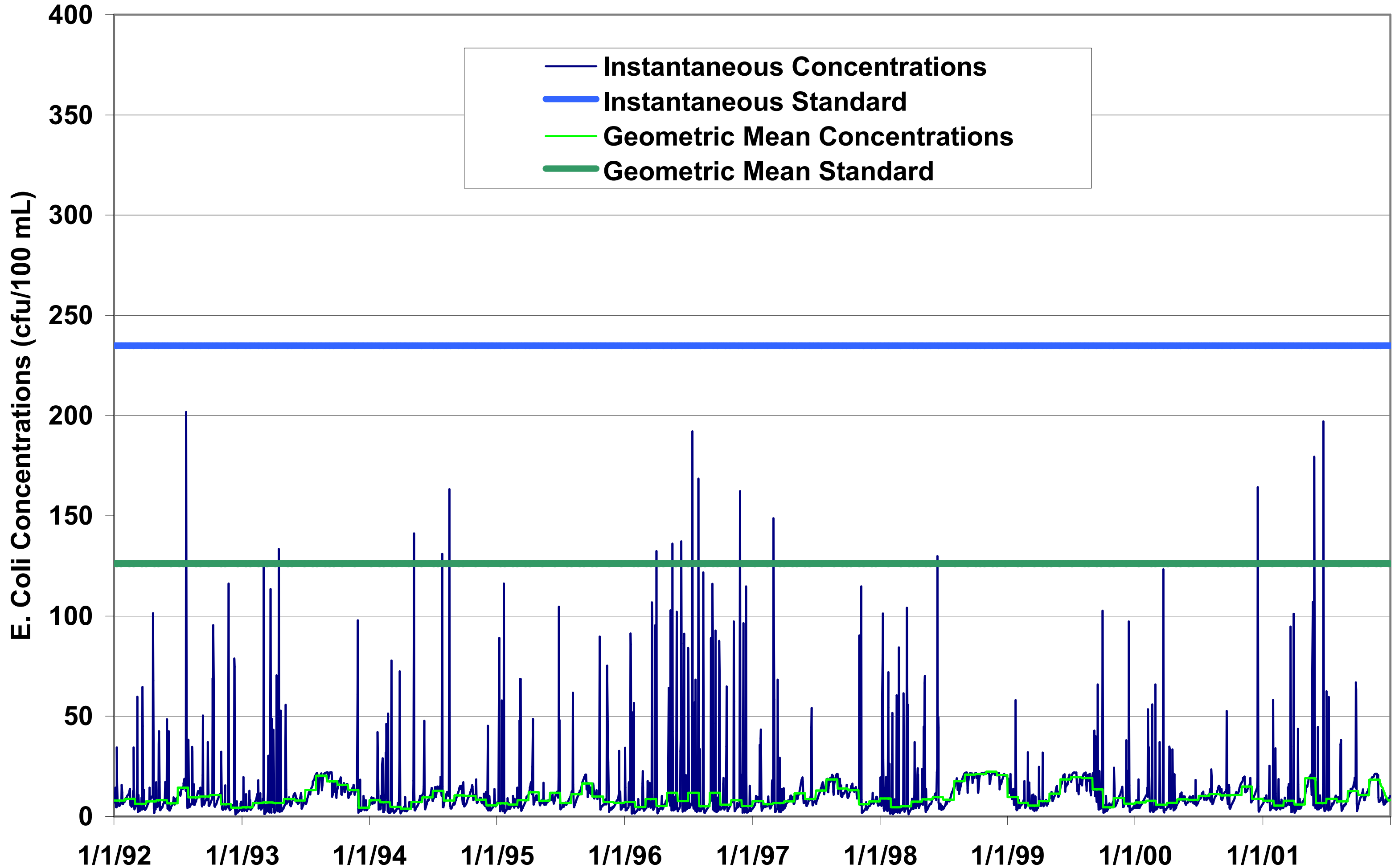


Figure 5.8: Simulated instantaneous and geometric mean *E. coli* concentrations (cfu/100 mL) at Beaverdam Creek (1ABEC004.76) for the TMDL Scenario

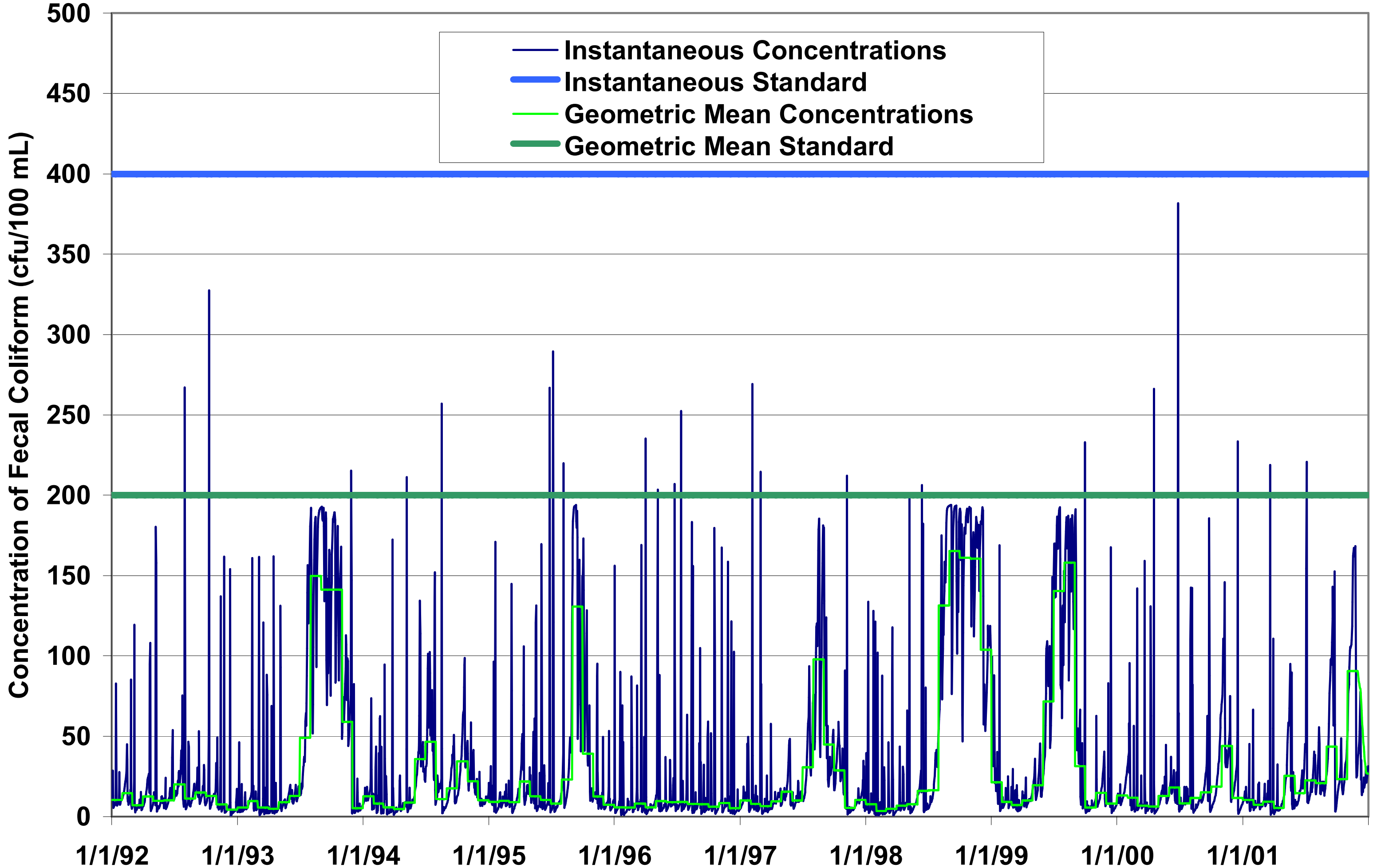


Figure 5.9: Simulated instantaneous and geometric mean fecal coliform concentrations (cfu/100 mL) at Cromwells Run (1ACRM001.20) for the TMDL Scenario

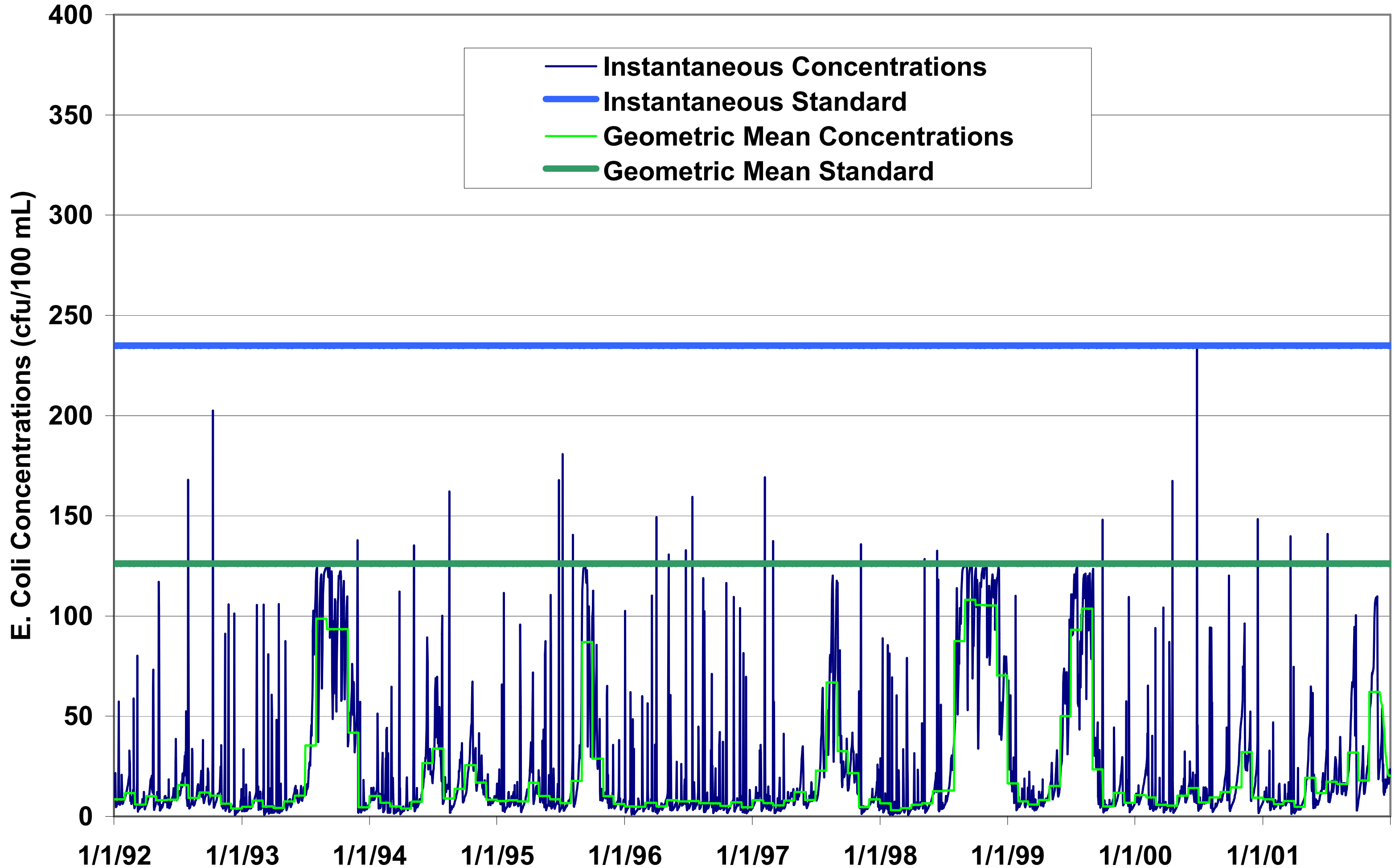


Figure 5.10: Simulated instantaneous and geometric mean *E. coli* concentrations (cfu/100 mL) at Cromwells Run (1ACRM001.20) for the TMDL Scenario

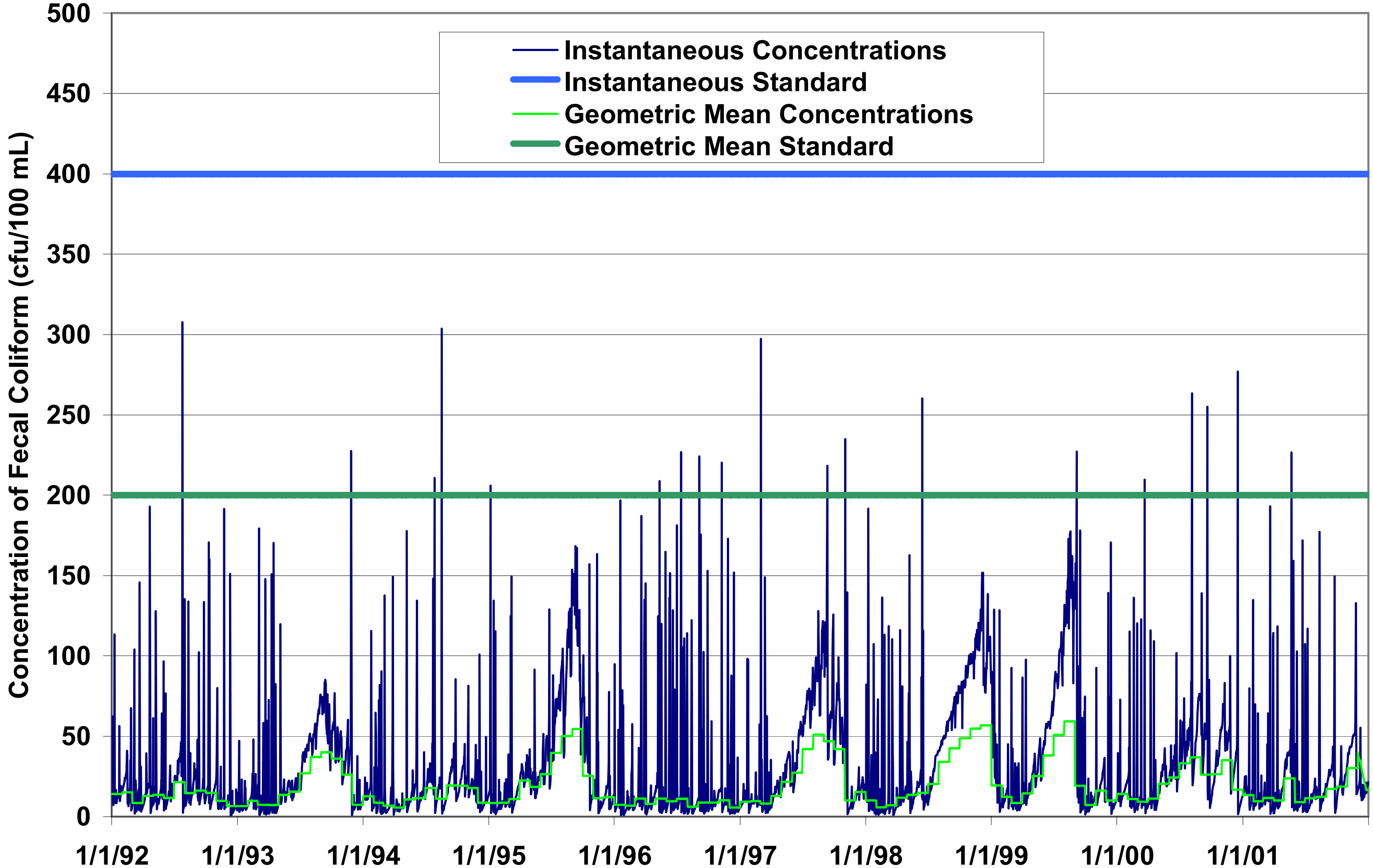


Figure 5.11: Simulated instantaneous and geometric mean fecal coliform concentrations (cfu/100 mL) at Middle Sycolin Creek (1ASYC004.93) for the TMDL Scenario

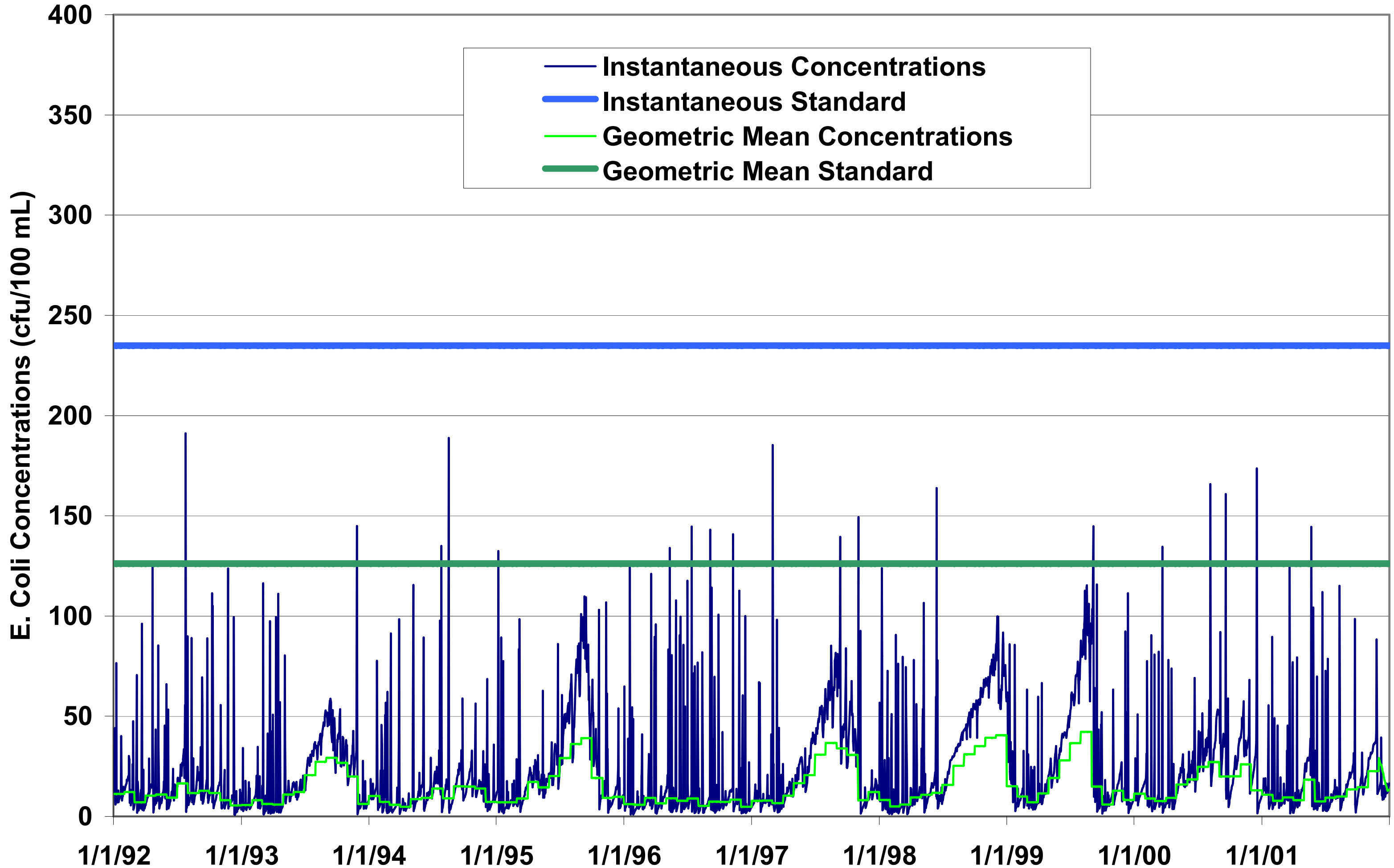


Figure 5.12: Simulated instantaneous and geometric mean *E. coli* concentrations (cfu/100 mL) Middle Sycolin Creek (1ASYC004.93) for the TMDL Scenario

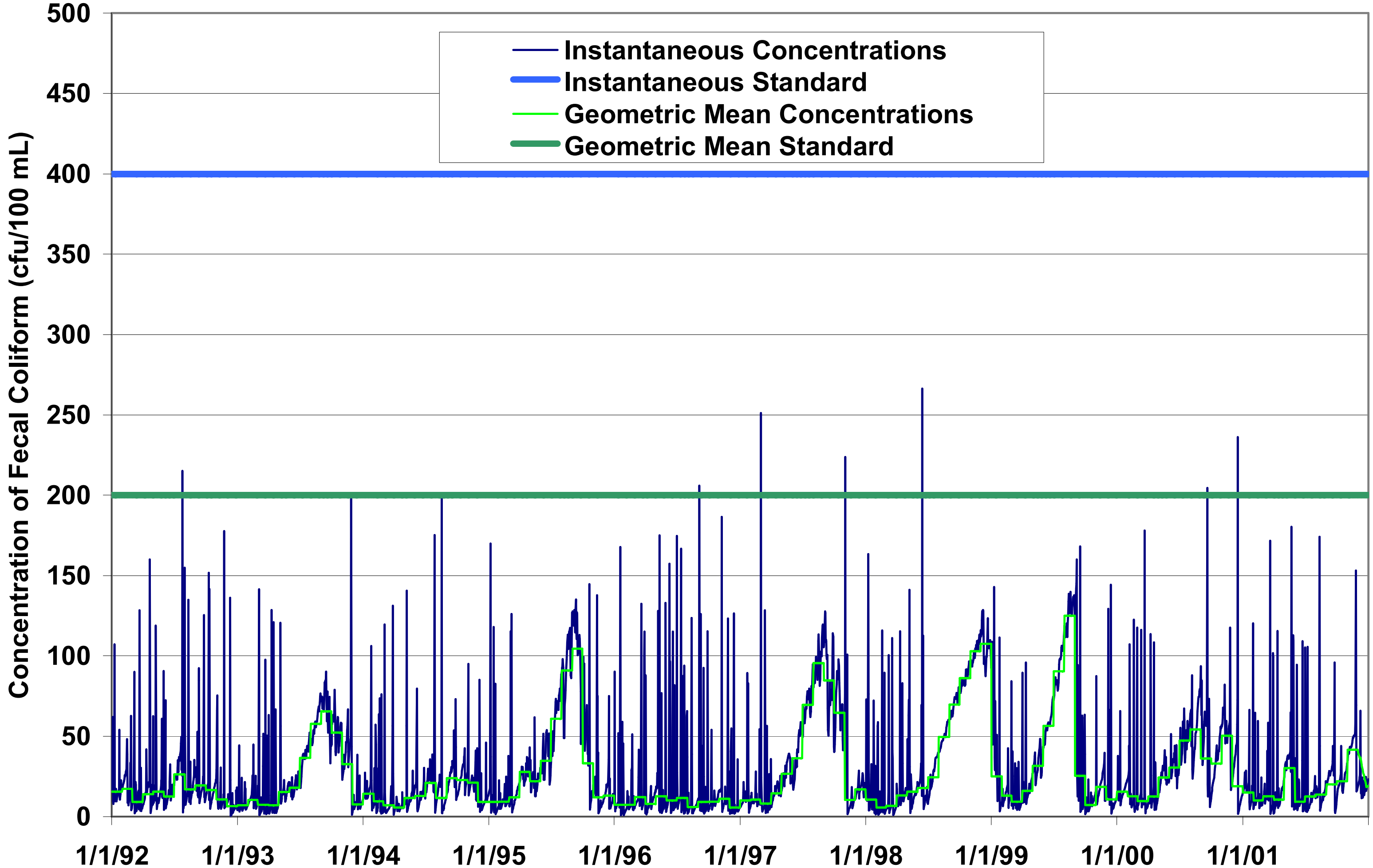


Figure 5.13: Simulated instantaneous and geometric mean fecal coliform concentrations (cfu/100 mL) at South Fork Sycolin Creek (1ASFS000.28) for the TMDL Scenario

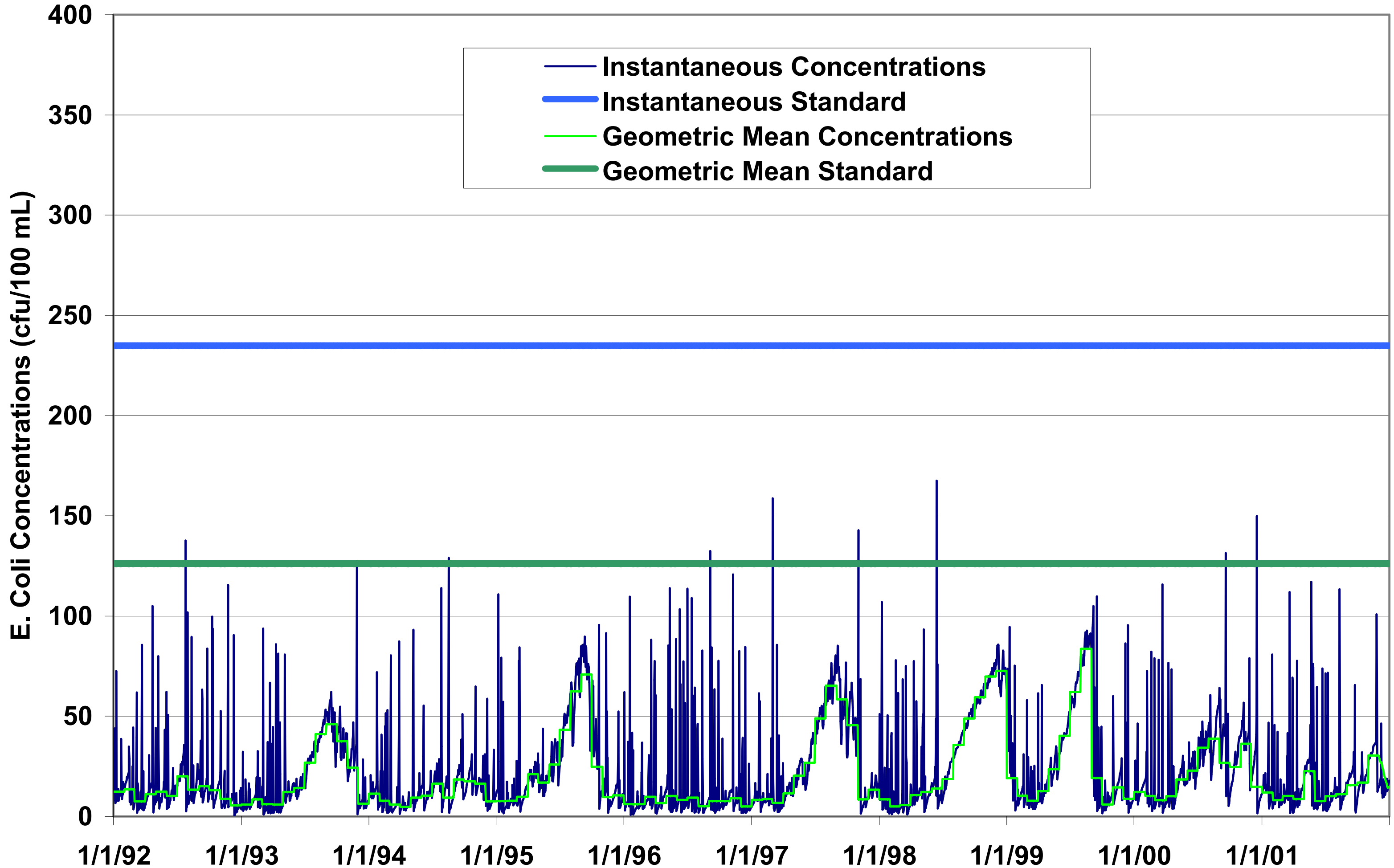


Figure 5.14: Simulated instantaneous and geometric mean *E. coli* concentrations (cfu/100 mL) at South Fork Sycolin Creek (1ASFS000.28) for the TMDL Scenario

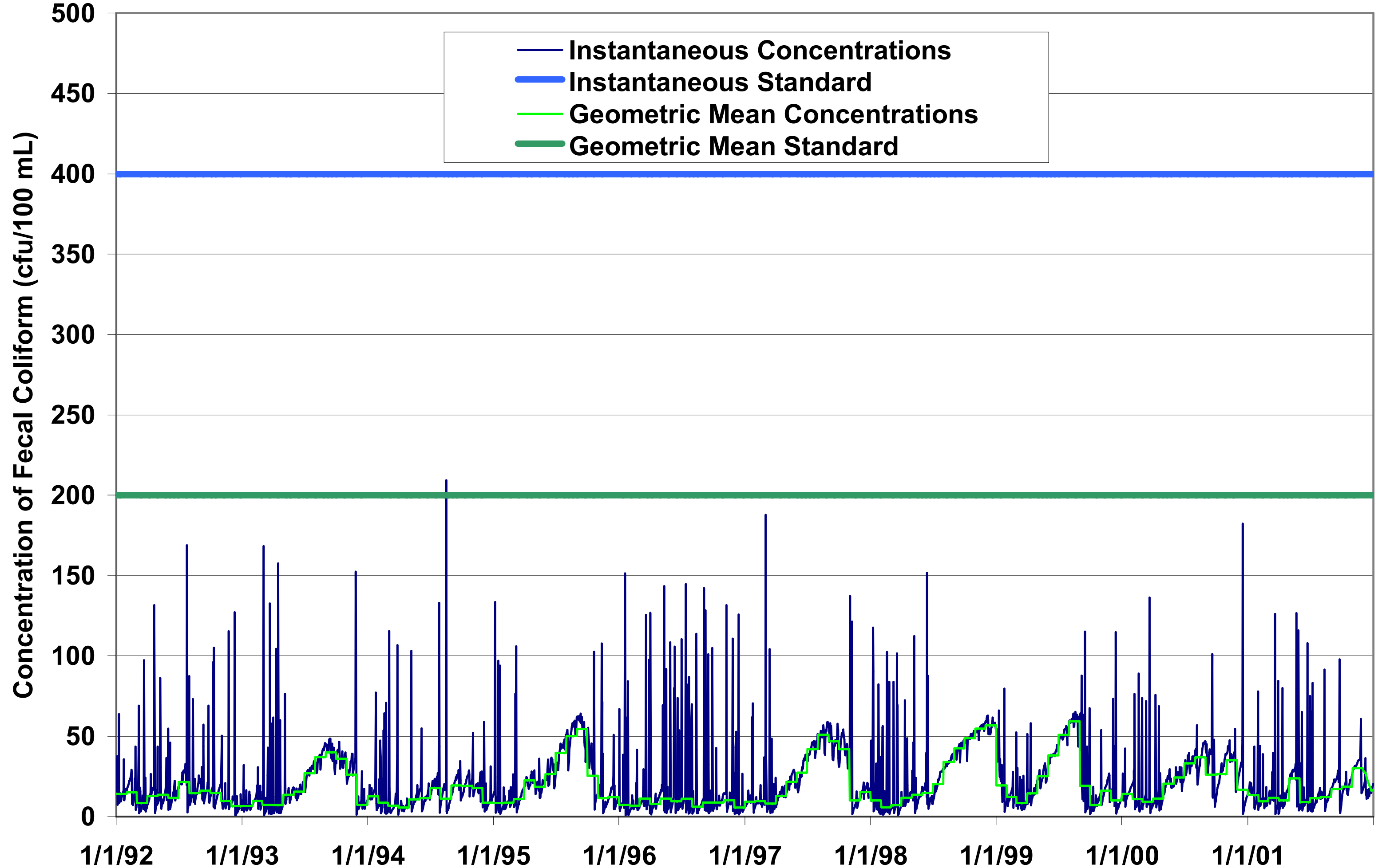


Figure 5.15: Simulated instantaneous and geometric mean fecal coliform concentrations (cfu/100 mL) at North Fork Sycolin Creek (1ASYC007.43) for the TMDL Scenario

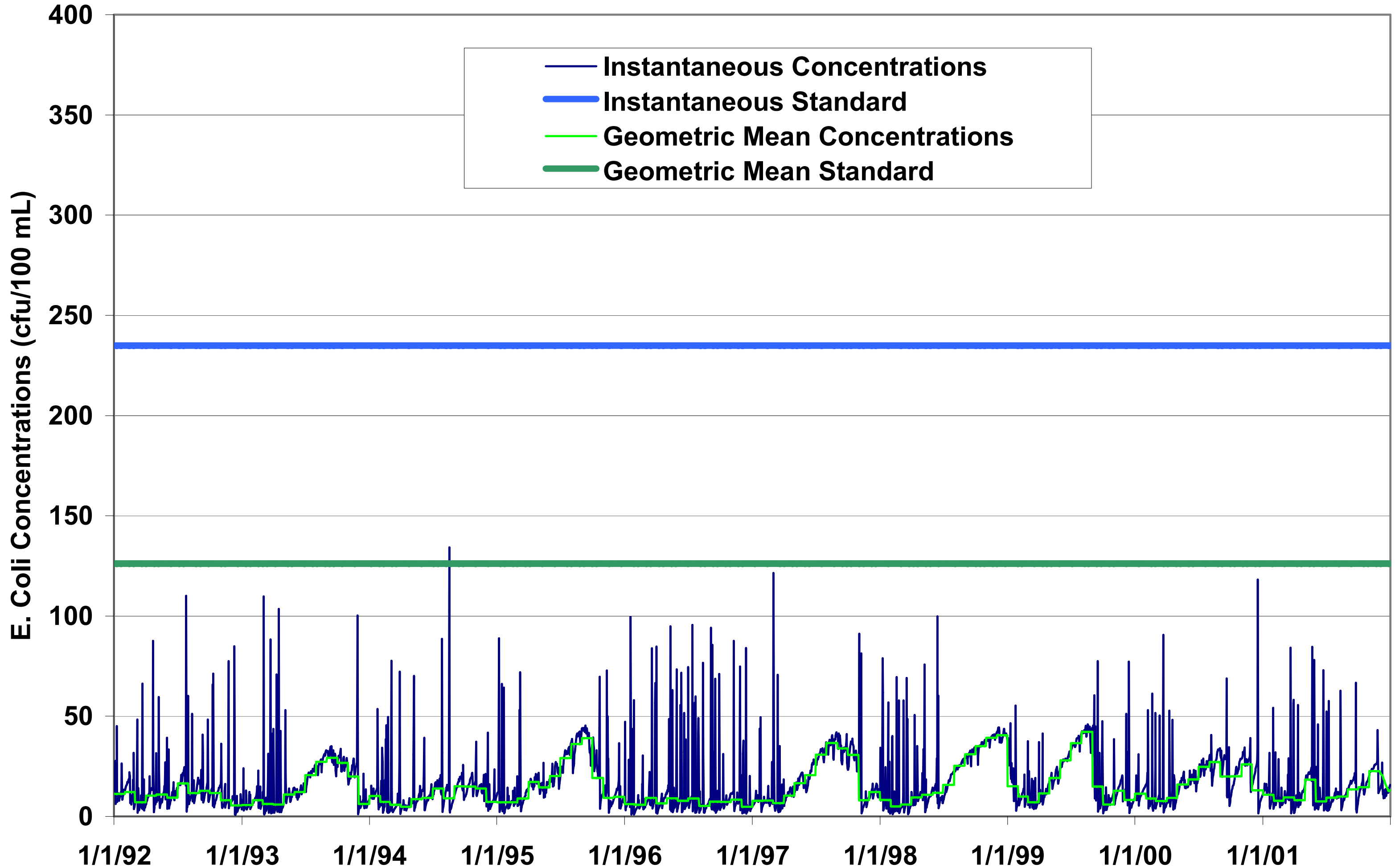


Figure 5.16: Simulated instantaneous and geometric mean *E. coli* concentrations (cfu/100 mL) at North Fork Sycolin Creek (1ASYC007.43) for the TMDL Scenario

CHAPTER 6: IMPLEMENTATION

The goal of the TMDL program is to establish a three-step path that will lead to attainment of water quality standards in the Goose Creek watershed. The first step in the process was to develop TMDLs that will result in meeting water quality standards. This report represents the culmination of that effort. The second step is to develop a TMDL implementation plan. The final step is to implement the TMDL, monitor water quality, and determine if water quality standards are being attained.

6.1 The Implementation Process

Upon EPA approval of the TMDLs, VADEQ intends to incorporate them into the appropriate Water Quality Management Plan (WQMP), in accordance with the CWA's Section 303(e). VADEQ submitted a Continuous Planning Process to EPA that commits to regularly updating the WQMPs. Thus, the WQMPs will become the repository for all TMDLs and TMDL implementation plans developed within a river basin.

Section 303(d) of the Clean Water Act (CWA) and current EPA regulations do not require the development of implementation strategies. However, including implementation plans as a TMDL requirement has been discussed for future federal regulations. Additionally, Virginia's 1997 Water Quality Monitoring, Information and Restoration Act (WQ MIRA) directs VADEQ in section 62.1-44.19.7 to "develop and implement a plan to achieve fully supporting status for impaired waters". The WQ MIRA also establishes that the implementation plan shall include the date of expected achievement of water quality objectives, measurable goals, corrective actions necessary and the associated cost, benefits and environmental impact of addressing the impairments. EPA outlines the minimum elements of an approvable implementation plan in its 1999 "Guidance for Water Quality-Based Decisions: The TMDL Process" (USEPA, 1999). The listed elements include implementation actions/management measures, time line, legal or regulatory controls, time required to attain water quality standards, monitoring plan and milestones for attaining water quality standards. Watershed stakeholders will have opportunities to provide input and to participate in the development of the implementation plan, which will also be supported by regional and local offices of VADEQ, VADCR, and other cooperating agencies. A guidance document will also be available from DEQ and DCR to help citizens understand and participate in the TMDL implementation process.

6.2 Staged Implementation

In general, the Commonwealth intends for the required reductions to be implemented in an iterative process that first addresses those sources with the largest impact on water quality. For example, the most promising management practice in agricultural areas of the watershed is livestock exclusion from streams. This has been shown to be very effective in lowering bacteria concentrations in streams, both from the cattle deposits themselves and from additional buffering in the riparian zone. Additionally, reducing the human bacteria loading from failing septic systems should be a primary focus because of its health implications. This component could be implemented through education on septic pump-outs as well as a septic system inspection and management program.

Implementation of this TMDL will also contribute to on-going water quality improvement efforts aimed at restoring water quality in the Chesapeake Bay. Several BMPs known to be effective in controlling bacteria have also been identified for implementation as part of the 2001 Interim Nutrient Cap Strategy for the Shenandoah/Potomac basin. For example, management of on-site waste management systems, management of livestock and manure, and pet waste management are among the components of the strategy described under nonpoint source implementation mechanisms. (2001Draft Interim Nutrient Cap Strategy for the Shenandoah/Potomac River Basins)

Implementation of the TMDLs for Goose Creek and its tributaries will occur in stages. The benefits of phased implementation are:

1. As stream monitoring continues, water quality improvements can be recorded as they are achieved;
2. It provides a measure of quality control, given the uncertainties inherent in computer simulation modeling;
3. It provides a mechanism for developing public support;
4. It helps ensure that the most cost effective practices are implemented first; and
5. It allows for the evaluation of the adequacy of the TMDL in achieving water quality standards.

The goal of the Phase I Implementation Scenario is to limit the frequency of violations of the instantaneous standard for *E. coli* to less than 10%. The Phase I Scenario selected calls for a 100% reduction of direct deposition by cattle in the stream, 100% reduction of loads from failing septic systems, and a 50% reduction in loads from pasture runoff. Table 6.1 shows the percent violations of the fecal coliform and *E. coli* standards under this scenario. No violations of the geometric mean for either the fecal coliform or the *E. coli* standards are simulated, and the simulated violation rate of the *E. coli* instantaneous standard is below 10% for all impairments. The number of months in which the instantaneous fecal coliform standard is violated more than 10% of the time is 33% or less for all impairments; the percent of the time over the course of the simulation that the simulated fecal coliform concentration is above 400 cfu/ 100 ml, without regard to calendar month, is less than 10% in every impaired segment. Tables 6.2.1.1 through 6.2.7.2 show, for each impairment, (1) the Wasteload Allocation and Load Allocation for the Phase I Allocation Scenario, and (2) the existing load, the allocated load, and the percent reduction in load under the Phase I Scenario for categories of nonpoint source loads. All nonpoint source loads represent the load delivered to surface water (the edge-of-stream load). Since the Phase I Scenario does not call for reductions in wasteloads, a breakdown of the wasteload allocation by individual permits is not necessary. Figures 6.1 through 6.16 show the simulated fecal coliform and *E. coli* concentrations under the Phase I Allocation Scenario and their calendar-month geometric means.

Table 6.1 Percent simulated violations of fecal coliform and *E. coli* standards under the Phase I Implementation Scenario

Segment	Watershed	Fecal Coliform Standard			*E. coli* Standard	
		Geometric Mean[1]	Monthly[1]	Greater Than 400 cfu/ 100 mL[2]	Geometric Mean[1]	Instantaneous[2]
20	Lower Goose Creek	0%	27.5%	8.0%	0%	8.1%
140	North Fork Goose Creek	0%	21.7%	6.4%	0%	6.4%
160	Little River	0%	31.7%	8.3%	0%	8.7%
180	Beaverdam Creek	0%	25.0%	7.3%	0%	7.3%
200	Cromwells Run	0%	17.5%	5.9%	0%	5.9%
230	Sycolin Creek	0%	23.3%	6.4%	0%	6.4%
240	S. Fork Sycolin Creek	0%	25.8%	7.6%	0%	7.6%
250	Sycolin Creek	0%	23.3%	6.4%	0%	6.4%

1 Calculated on monthly basis; 2 Calculated on a daily basis.

6.3 Follow-up Monitoring

VADEQ will continue to monitor Goose Creek and its tributaries in accordance with its ambient monitoring program. VADEQ and VADCR will continue to use data from these monitoring stations for evaluating reductions in fecal coliform bacteria counts and the effectiveness of the TMDL in attainment of water quality standards. Intensive sampling, as was conducted under the special study to support development of these TMDLs, will be suspended until an implementation plan has been developed and implementation measures have begun in the watershed. Ambient sampling will continue every other month at five trend stations in the Goose Creek watershed: 1AGOO044.36, 1AGOO030.75, 1ANOG005.69, 1ABEC004.76, and 1AGOO011.23. Ambient sampling includes field parameters, bacteria, nutrients and solids. Bacteria sampling will include both fecal coliform and *E. coli*, although sampling for fecal coliform bacteria will be phased out after twelve *E coli* samples have been taken to

6.4 Potential Funding Sources

One potential source of funding for TMDL implementation is Section 319 of the CWA. In response to the federal Clean Water Action Plan, Virginia developed a Unified Watershed Assessment that identifies watershed priorities. Watershed restoration activities, such as TMDL implementation, within these priority watersheds are eligible for Section 319 funding. Increases in Section 319 funding in future years will be targeted toward TMDL implementation and watershed restoration. Additional funding sources for implementation include the USDA Conservation Reserve Enhancement Program (CREP), the Virginia state revolving loan program, and the Virginia Water Quality Improvement Fund.

6.5 Current Efforts to Control Bacteria

Watershed stakeholders will have opportunities to provide input and to participate in the development of the implementation plan, with support from regional and local offices of VADEQ, VADCR, and other participating agencies. Many efforts are planned or are underway that will help reduce fecal coliform and *E. coli* loads to Goose Creek and its tributaries. The list of these activities includes:

1. Streambank fencing is being implemented at an accelerating rate since 1999 under the Virginia Agricultural Best Management Practices Cost Share and Tax Credit Program;
2. The Loudoun County Health Department has secured a $50,000 grant from VADCR to provide a 50% match to homeowners to fund repairs or replacements of failing septic systems;
3. As a follow-up to the Source Water Assessment for the City of Fairfax's water supply intake on Goose Creek, the City of Fairfax and the Loudoun County Sanitation Authority are preparing a implementation plan to protect source water in the Goose Creek and Beaverdam Reservoirs; and
4. The Piedmont Environmental Council and the Goose Creek Association have commissioned a study to identify which subwatersheds are most impaired and to develop a strategy for watershed protection.

Table 6.2.1.1 Elements of Phase I Allocation for Cromwells Run (Segment 200)

Waterbody (Waterbody ID)	Parameter	Phase I (cfu/yr)	WLA (cfu/yr)	LA[1] (cfu/yr)	MOS (cfu/yr)
Cromwells Run (CRM01A00)	Fecal Coliform	1.85E+14	0	1.85E+14	Implicit

[1] Edge-of-stream load.

Table 6.2.1.2 Phase I Load Allocation[1] for Cromwells Run(Segment 200)

Land Use	Existing Load (cfu/yr)	Allocated Load (cfu/yr)	Percent Reduction
Forest	4.45E+12	4.45E+12	0%
Cropland	6.61E+10	6.61E+10	0%
Pasture	3.57E+14	1.78E+14	50%
Developed Land (without failing septic systems)	2.02E+11	2.02E+11	0%
Failing Septic Systems	2.93E+12	0	100%
Straight Pipes/Septic Systems Within 50 Ft of Surface Water	1.26E+06	0	100%
Direct Deposition from Cattle	1.22E+14	0	100%
Direct Deposition from Wildlife	1.51E+12	1.51E+12	0%
Total Load Allocation	4.88E+14	1.85E+14	62%

[1] Edge-of-stream load.

Table 6.2.2.1 Elements of Phase I Allocation for North Fork of Goose Creek (Segment 140)

Waterbody (Waterbody ID)	Parameter	PHASE I (cfu/yr)	WLA (cfu/yr)	LA[1] (cfu/yr)	MOS (cfu/yr)
North Fork of Goose Creek (NOG01A00)	Fecal Coliform	3.13E+14	1.94E+12	3.11E+14	Implicit

[1] Edge-of-stream load.

Table 6.2.2.2 Phase I Load Allocation for North Fork of Goose Creek (Segment 140)

Land Use	Existing Load (cfu/yr)	Allocated Load (cfu/yr)	Percent Reduction
Forest	2.36E+11	2.36E+11	0%
Cropland	5.18E+11	5.18E+11	0%
Pasture	6.17E+14	3.08E+14	50%
Developed Land (without failing septic systems)	3.93E+11	3.93E+11	0%
Failing Septic Systems	4.75E+12	0	100%
Straight Pipes/Septic Systems Within 50 Ft of Surface Water	3.56E+06	0	100%
Direct Deposition from Cattle	3.63E+14	0	100%
Direct Deposition from Wildlife	1.87E+12	1.87E+12	0%
Total Load Allocation	9.89E+14	3.11E+14	69%

[1] Edge-of-stream load.

Table 6.2.3.1 Elements of Phase I Allocation for Beaverdam Creek (Segment 180)

Waterbody (Waterbody ID)	Parameter	PHASE I (cfu/yr)	WLA (cfu/yr)	LA[1] (cfu/yr)	MOS (cfu/yr)
Beaverdam Creek BEC01A00	Fecal Coliform	7.01E+14	2.54E+11	7.01E+14	Implicit

[1] Edge-of-stream load.

Table 6.2.3.2 Phase I Load Allocation[1] for Beaverdam Creek (Segment 180)

Land Use	Existing Load (cfu/yr)	Allocated Load (cfu/yr)	Percent Reduction
Forest	5.15E+12	5.15E+12	0%
Cropland	6.53E+11	6.53E+11	0%
Pasture	1.38E+15	6.92E+14	50%
Developed Land (without failing septic systems)	1.96E+10	1.96E+10	0%
Failing Septic Systems	7.94E+12	0	100%
Straight Pipes/Septic Systems Within 50 Ft of Surface Water	6.42E+06	0	100%
Direct Deposition from Cattle	5.44E+14	0	100%
Direct Deposition from Wildlife	3.54E+12	3.54E+12	0%
Total Load Allocation	1.94E+15	7.01E+14	64%

[1] Edge-of-stream load.

Table 6.2.4.1 Elements of Phase I Allocation for Little River (Segment 160)

Waterbody (Waterbody ID)	Parameter	PHASE I (cfu/yr)	WLA (cfu/yr)	LA[1] (cfu/yr)	MOS (cfu/yr)
Little River (LIV01A00)	Fecal Coliform	5.92E+14	2.76E+09	5.92E+14	Implicit

[1] Edge-of-stream load.

Table 6.2.4.2 Phase I Load Allocation[1] for Little River (Segment 160)

Land Use	Existing Load (cfu/yr)	Allocated Load (cfu/yr)	Percent Reduction
Forest	8.03E+12	8.03E+12	0%
Cropland	4.96E+11	4.96E+11	0%
Pasture	1.16E+15	5.80E+14	50%
Developed Land (without failing septic systems)	3.21E+11	3.21E+11	0%
Failing Septic Systems	6.39E+12	0	100%
Straight Pipes/Septic Systems Within 50 Ft of Surface Water	2.40E+06	0	100%
Direct Deposition from Cattle	5.04E+14	0	100%
Direct Deposition from Wildlife	3.19E+12	3.19E+12	0%
Total Load Allocation	1.68E+15	5.92E+14	65%

[1] Edge-of-stream load.

Table 6.2.5.1 Elements of Phase I Allocation for Sycolin Creek (Segments 230,240,250)

Waterbody (Waterbody ID)	Parameter	PHASE I (cfu/yr)	WLA (cfu/yr)	LA[1] (cfu/yr)	MOS (cfu/yr)
Sycolin Creek (SYC02A02)	Fecal Coliform	1.01E+14	2.76E+09	1.01E+14	Implicit

[1] Edge-of-stream load.

Table 6.2.5.2 Phase I Load Allocation[1] for Sycolin Creek (Segments 230,240,250)

Land Use	Existing Load (cfu/yr)	Allocated Load (cfu/yr)	Percent Reduction
Forest	1.34E+12	1.34E+12	0%
Cropland	2.89E+11	2.89E+11	0%
Pasture	1.98E+14	9.91E+13	50%
Developed Land (without failing septic systems)	1.75E+10	1.75E+10	0%
Failing Septic Systems	1.83E+12	0	100%
Straight Pipes/Septic Systems Within 50 Ft of Surface Water	0	0	100%
Direct Deposition from Cattle	5.44E+13	0	100%
Direct Deposition from Wildlife	6.14E+11	6.14E+11	0%
Total Load Allocation	2.56E+14	1.01E+14	61%

[1] Edge-of-stream load.

Table 6.2.6.1 Elements of Phase I Allocation for South Fork Sycolin Creek (Segment 240)

Waterbody (Waterbody ID)	Parameter	PHASE I (cfu/yr)	WLA (cfu/yr)	LA[1] (cfu/yr)	MOS (cfu/yr)
South Fork Sycolin Creek (SFS01A02)	Fecal Coliform	1.95E+13	0	1.95E+13	Implicit

[1] Edge-of-stream load.

Table 6.2.6.2 Phase I Load Allocation[1] for South Fork Sycolin Creek (Segment 240)

Land Use	Existing Load (cfu/yr)	Allocated Load (cfu/yr)	Percent Reduction
Forest	4.93E+11	4.93E+11	0%
Cropland	9.38E+08	9.38E+08	0%
Pasture	3.76E+13	1.88E+13	50%
Developed Land (without failing septic systems)	0	0	0%
Failing Septic Systems	4.34E+11	0	100%
Straight Pipes/Septic Systems Within 50 Ft of Surface Water	0	0	100%
Direct Deposition from Cattle	9.05E+12	0	100%
Direct Deposition from Wildlife	1.63E+11	1.63E+11	0%
Total Load Allocation	4.77E+13	1.95E+13	59%

[1] Edge-of-stream load.

Table 6.2.7.1 Elements of Phase I Allocation for Goose Creek (Segments 20-250)

Waterbody (Waterbody ID)	Parameter	PHASE I (cfu/yr)	WLA (cfu/yr)	LA[1] (cfu/yr)	MOS (cfu/yr)
Goose Creek (GOO01A00)	Fecal Coliform	5.73E+15	3.17E+12	5.73E+15	Implicit

[1] Edge-of-stream load.

Table 6.2.7.2 Phase I Load Allocation[1] for Goose Creek (Segments 20-250)

Land Use	Existing Load (cfu/yr)	Allocated Load (cfu/yr)	Percent Reduction
Forest	6.37E+13	6.37E+13	0%
Cropland	3.81E+13	3.81E+13	0%
Pasture	1.12E+16	5.59E+15	50%
Developed Land (without failing septic systems)	9.25E+12	9.25E+12	0%
Failing Septic Systems	5.44E+13	0	100%
Straight Pipes/Septic Systems Within 50 Ft of Surface Water	2.29E+07	0	100%
Direct Deposition from Cattle	7.10E+15	0	100%
Direct Deposition from Wildlife	2.87E+13	2.87E+13	0%
Total Load Allocation	1.85E+16	5.73E+15	69%

[1] Edge-of-stream load.

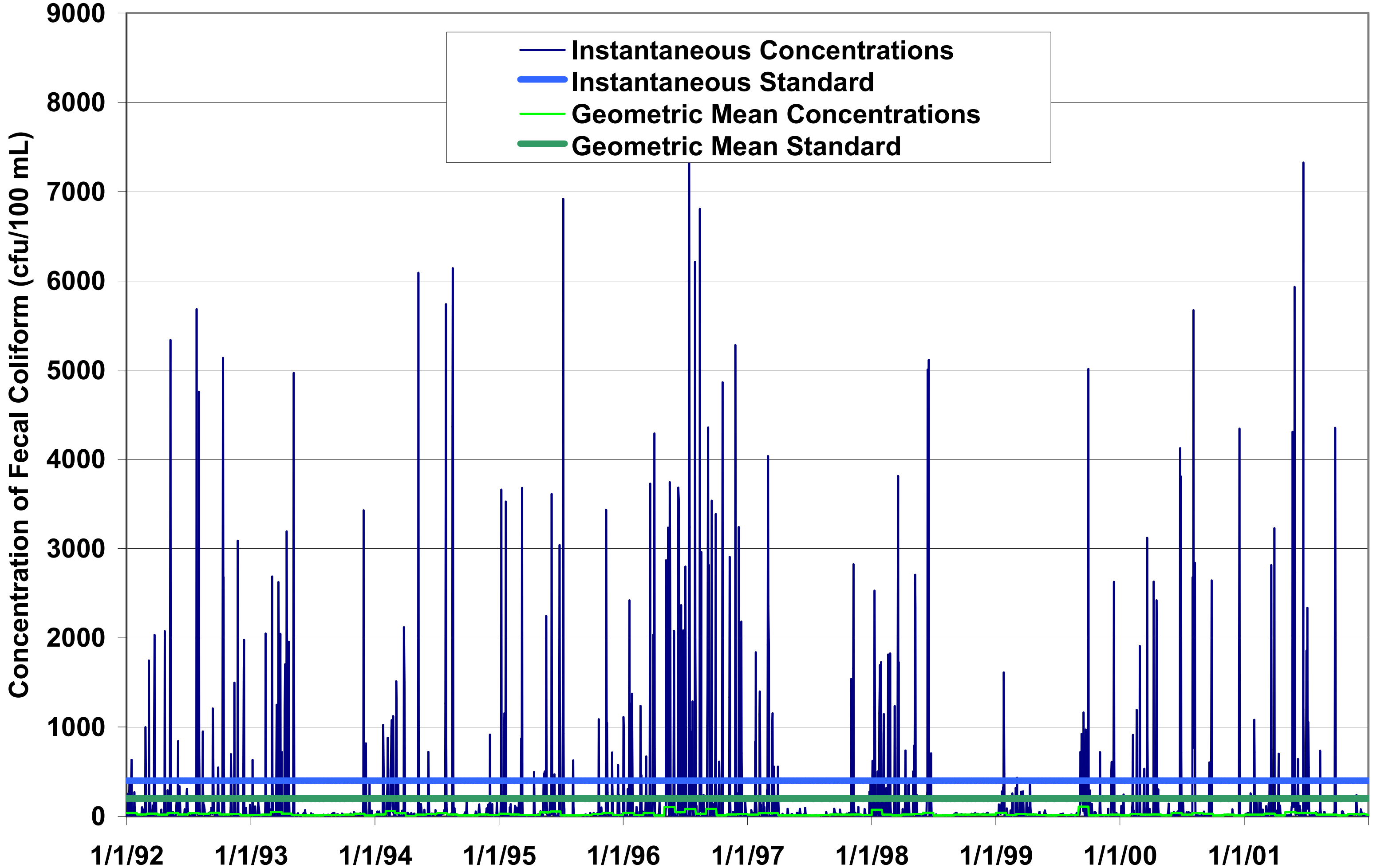


Figure 6.1: Simulated instantaneous and geometric mean fecal coliform concentrations (cfu/100 mL) at Lower Goose Creek (1AGOO002.38) for Phase I Allocation Scenario

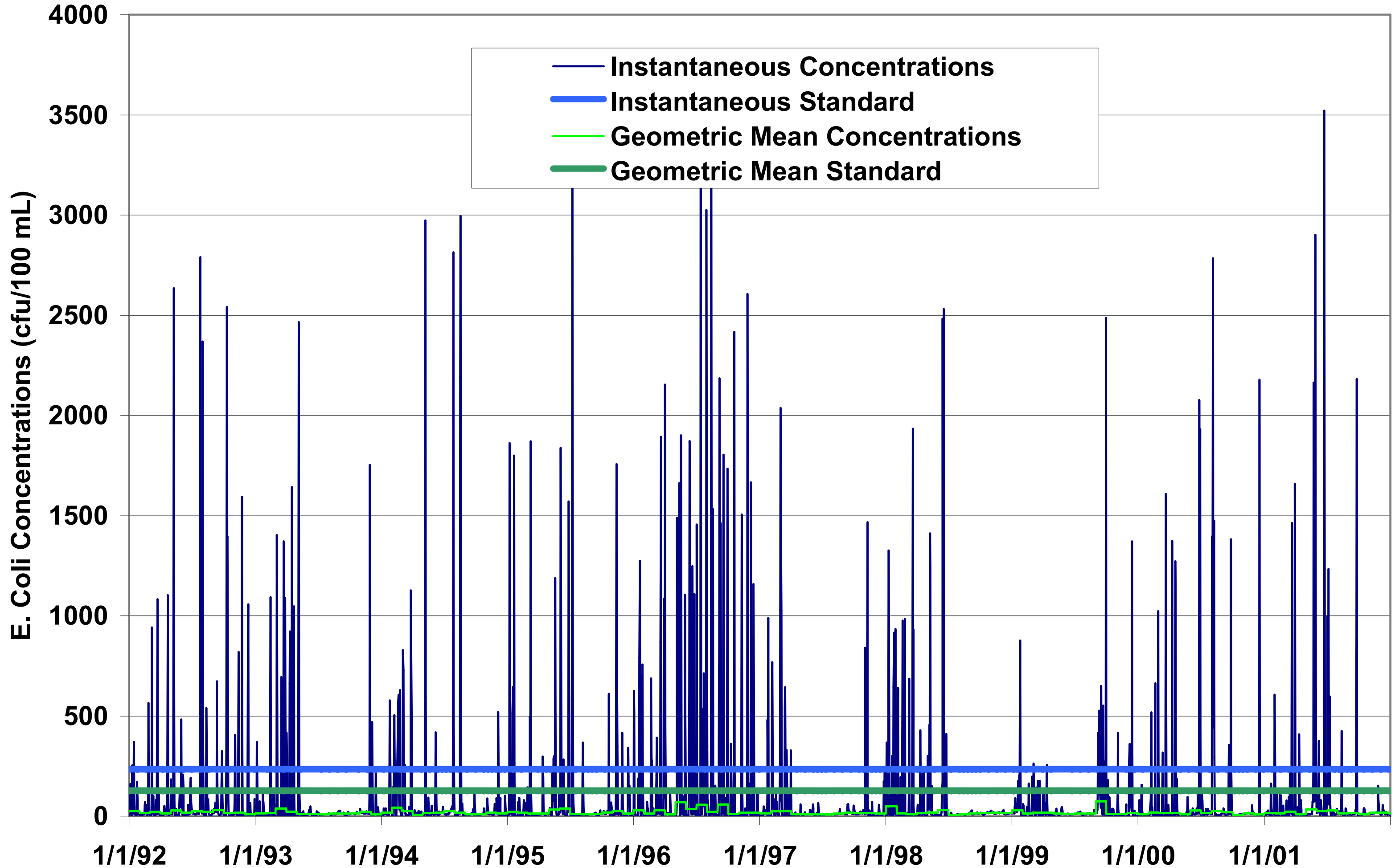


Figure 6.2: Simulated instantaneous and geometric mean *E. coli* concentrations (cfu/100 mL) at Lower Goose Creek (1AGOO002.38) for Phase I Allocation Scenario

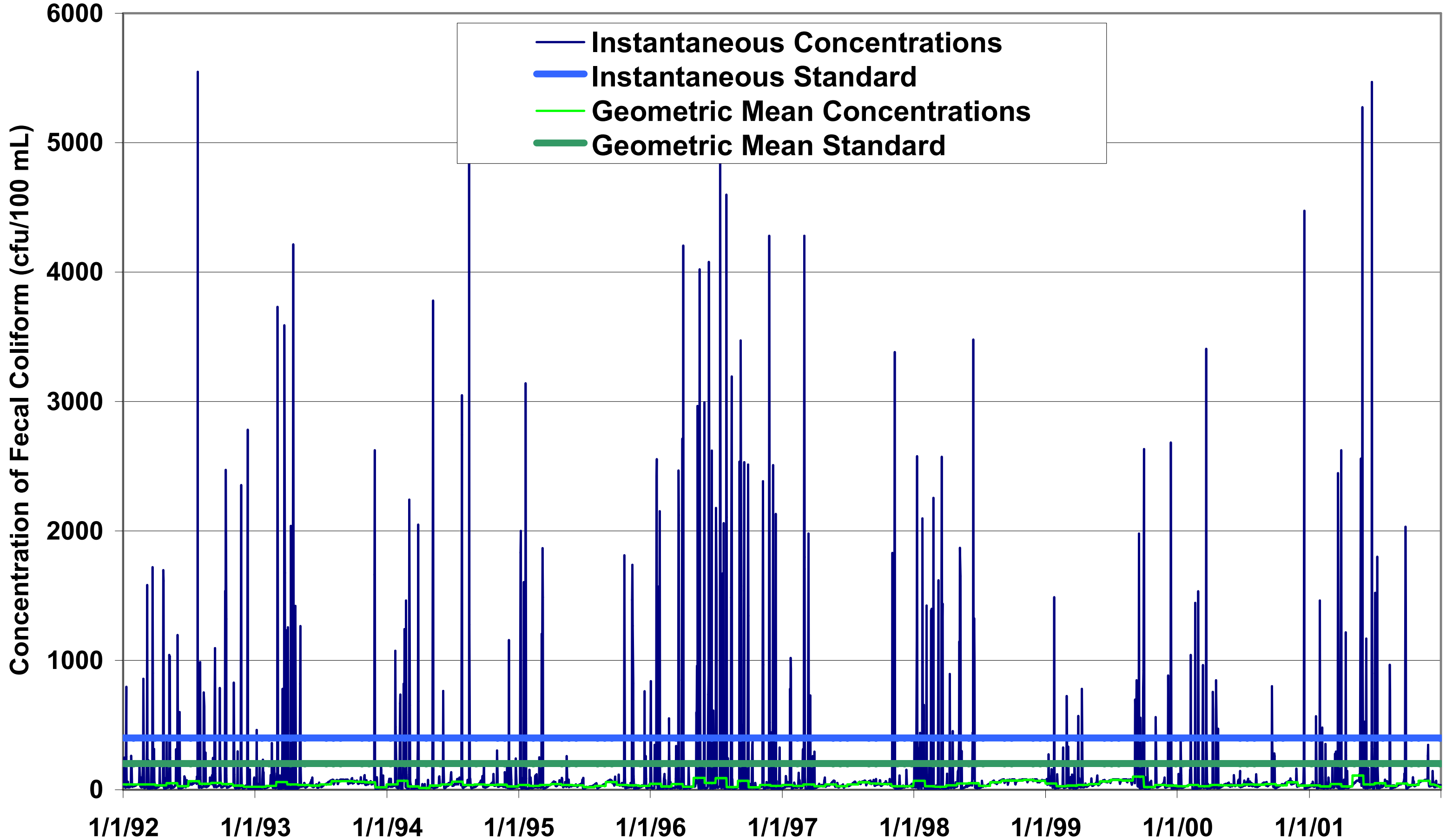


Figure 6.3: Simulated instantaneous and geometric mean fecal coliform concentrations (cfu/100 mL) at North Fork Goose Creek (1ANOG005.69) for Phase I Allocation Scenario

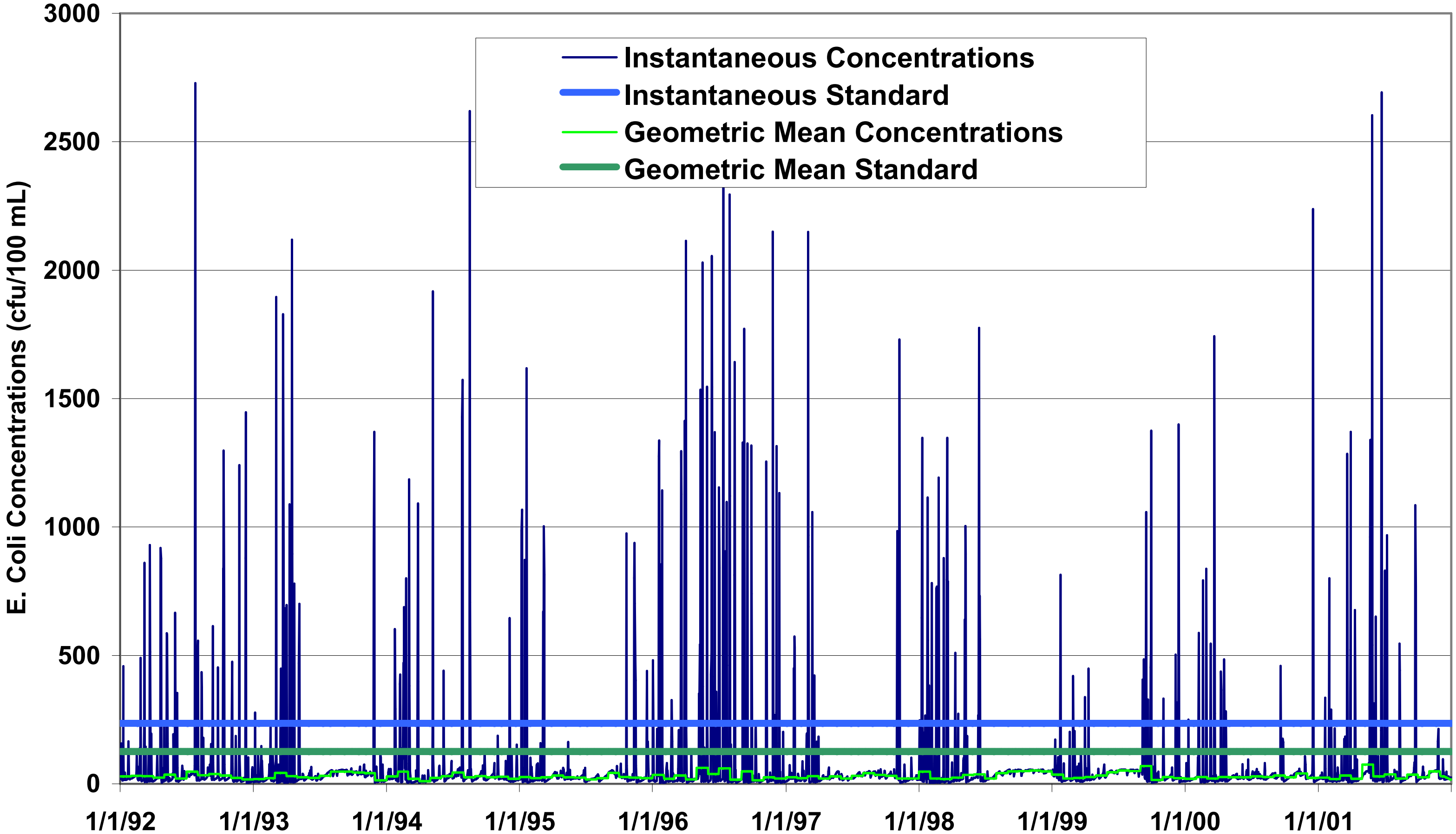


Figure 6.4: Simulated instantaneous and geometric mean *E. coli* concentrations (cfu/100 mL) at North Fork Goose Creek (1ANOG005.69) for Phase I Allocation Scenario

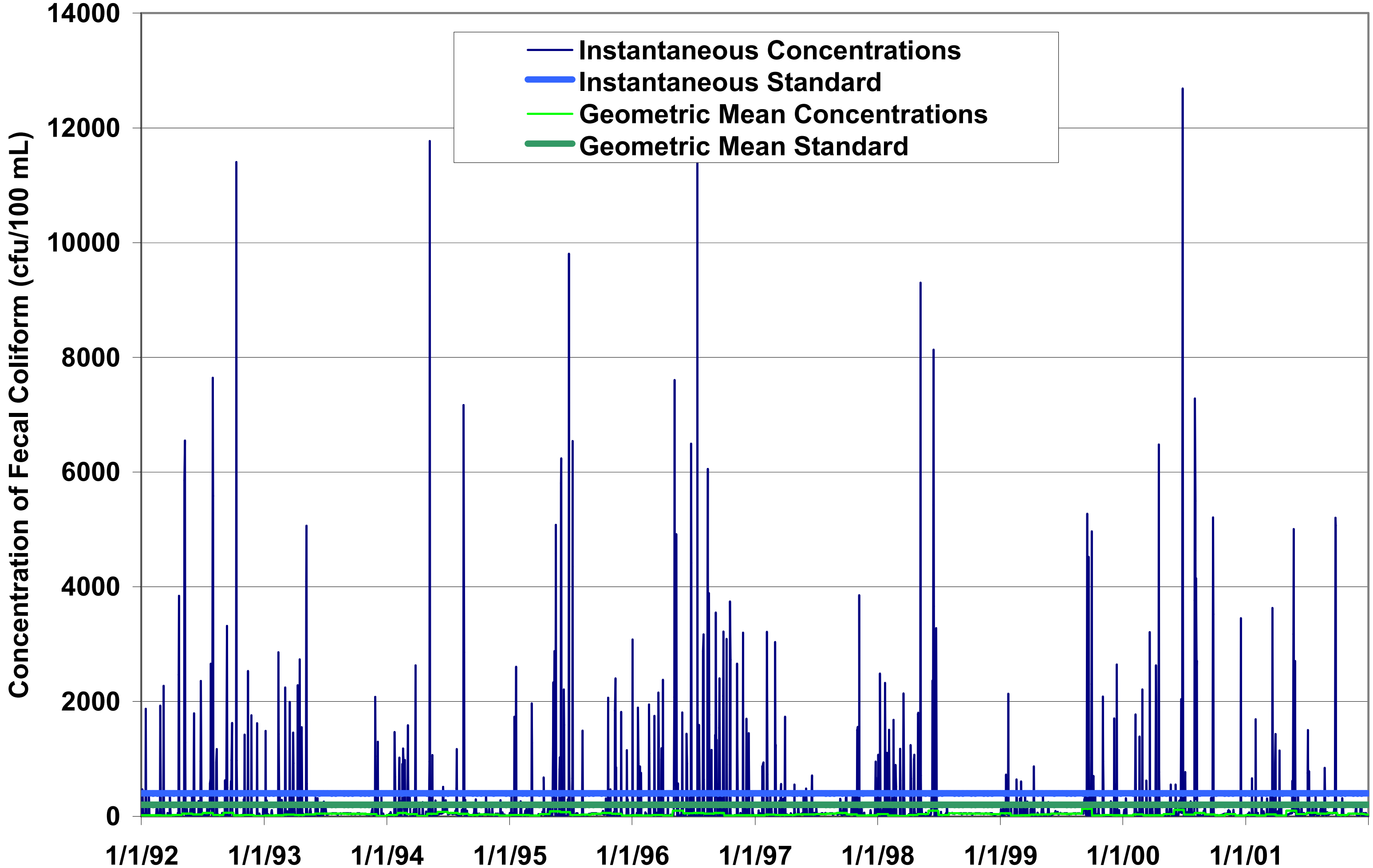


Figure 6.5: Simulated instantaneous and geometric mean fecal coliform concentrations (cfu/100 mL) at Little River (1ALIV004.78) for Phase I Allocation Scenario

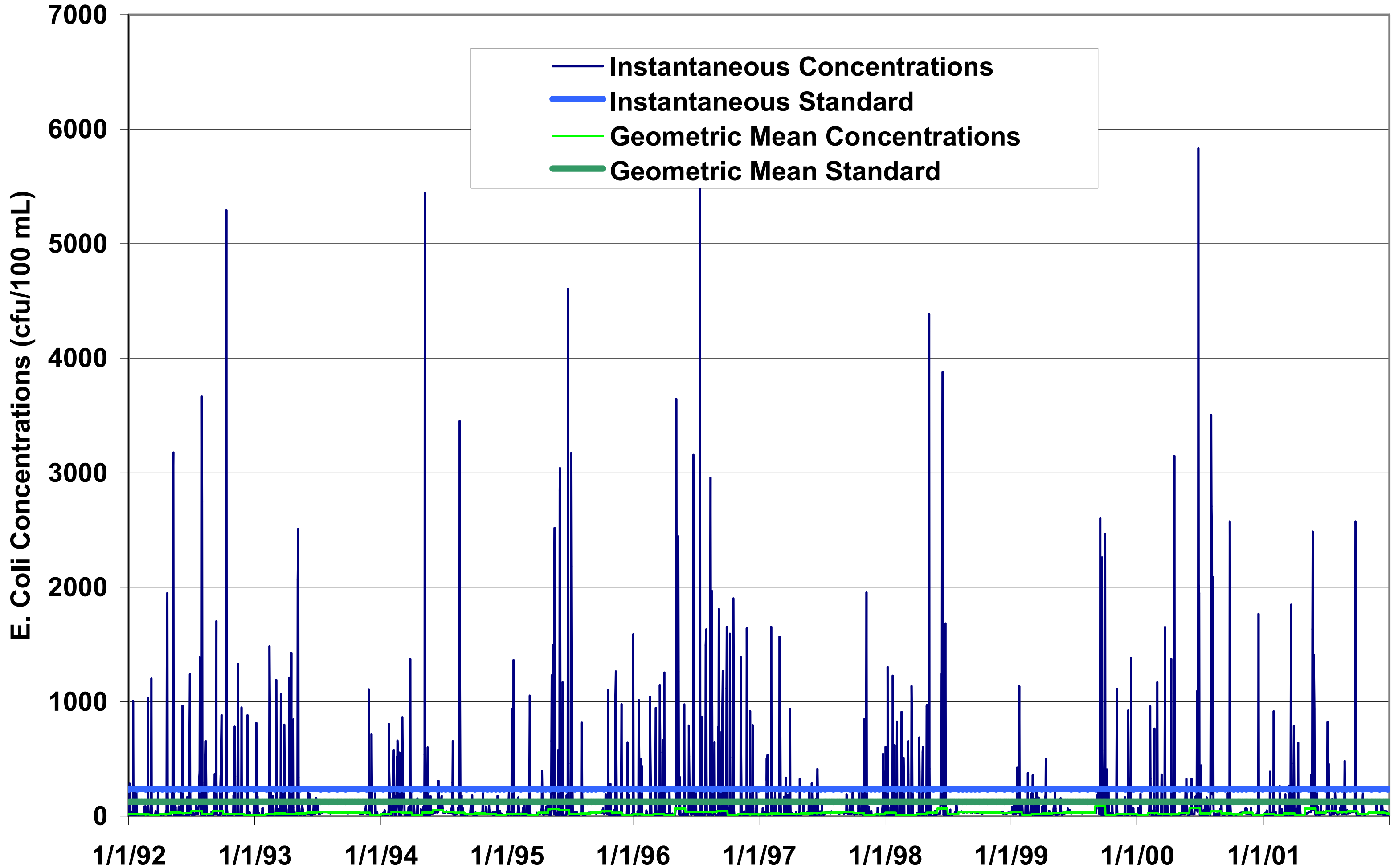


Figure 6.6: Simulated instantaneous and geometric mean *E. coli* concentrations (cfu/100 mL) at Little River (1ALIV004.78) for Phase I Allocation Scenario

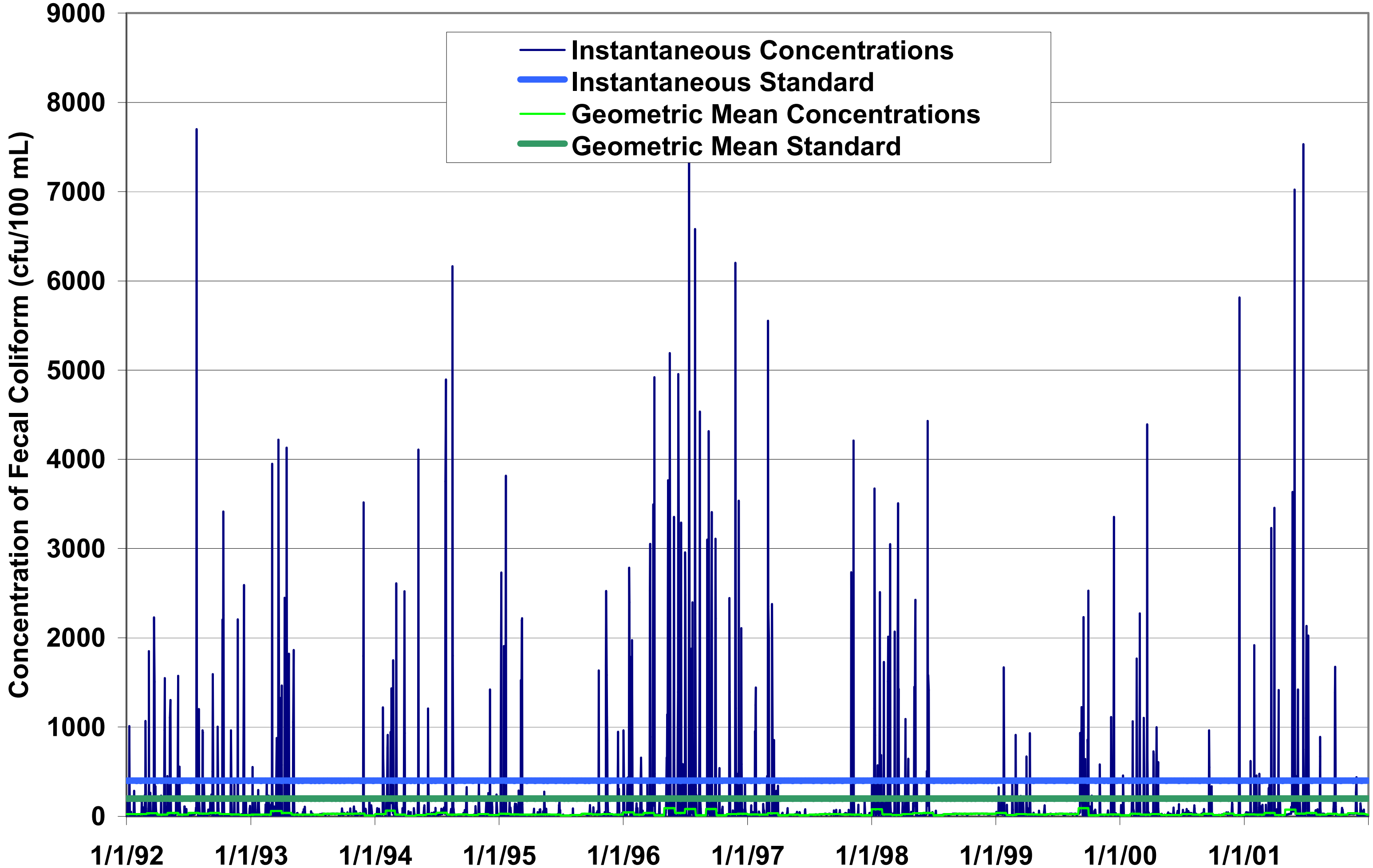


Figure 6.7: Simulated instantaneous and geometric mean fecal coliform concentrations (cfu/100 mL) at Beaverdam Creek (1ABEC004.76) for Phase I Allocation Scenario

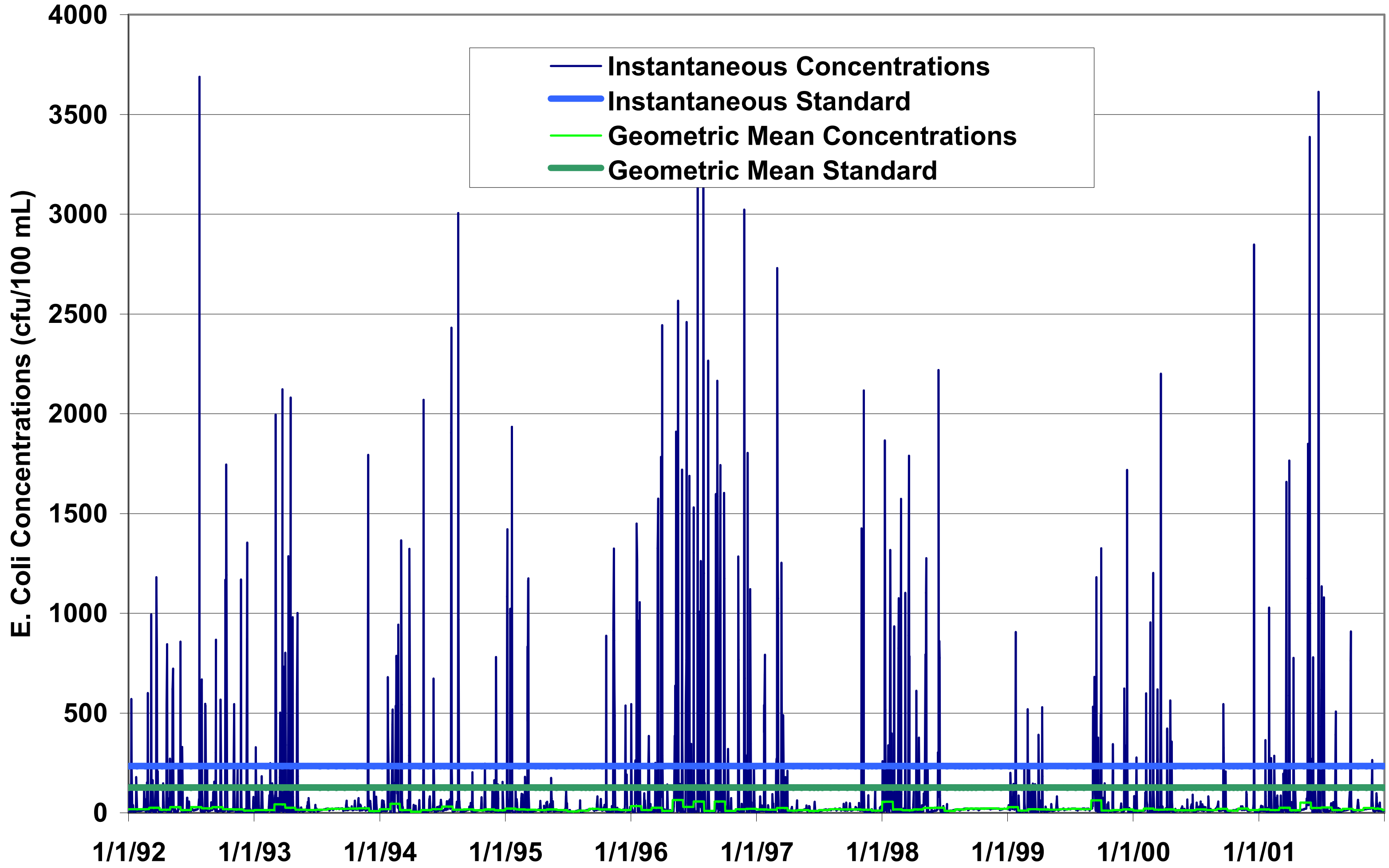


Figure 6.8: Simulated instantaneous and geometric mean *E. coli* concentrations (cfu/100 mL) at Beaverdam Creek (1ABEC004.76) for Phase I Allocation Scenario

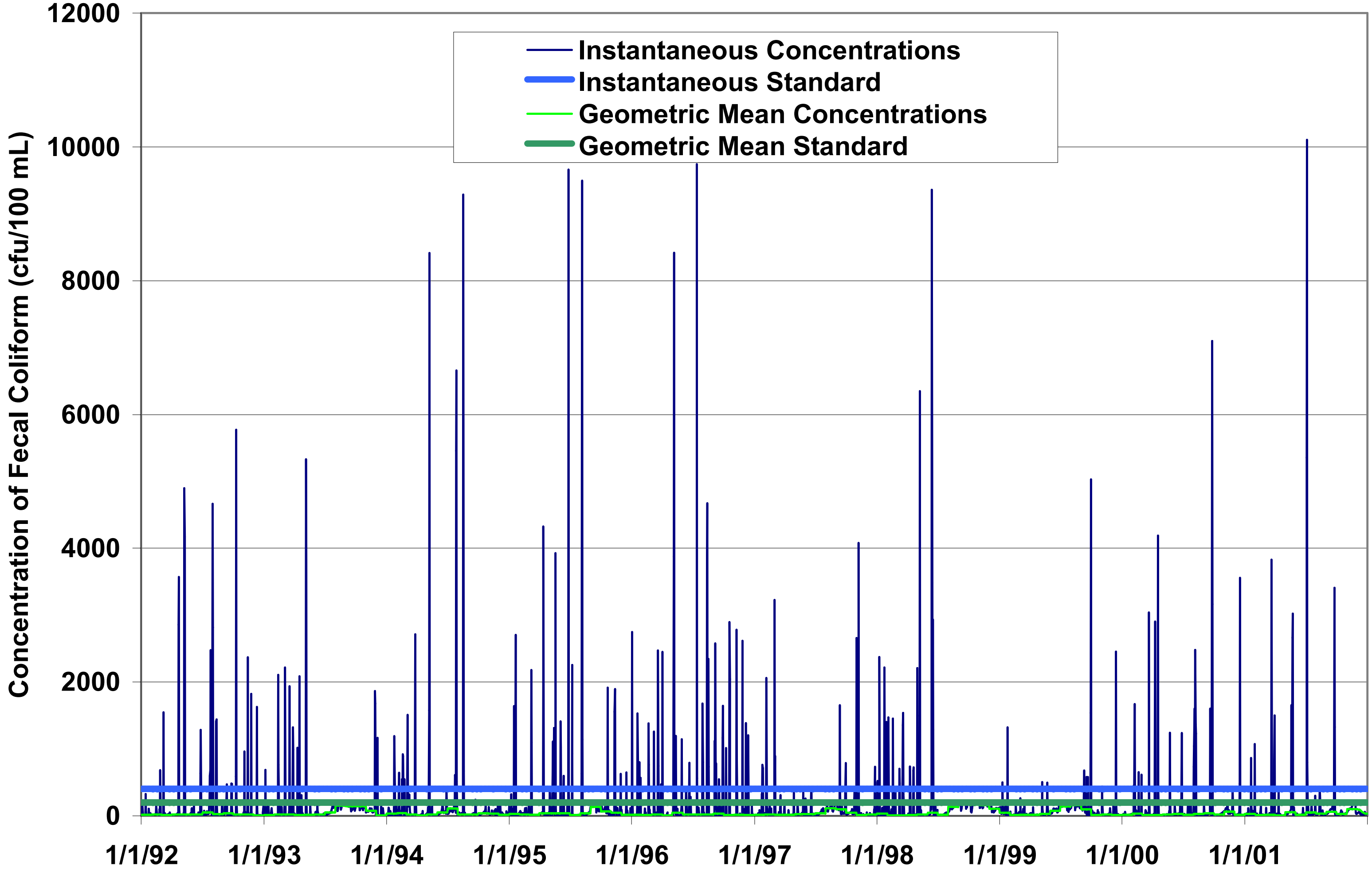


Figure 6.9: Simulated instantaneous and geometric mean fecal coliform concentrations (cfu/100 mL) at Cromwells Run (1ACRM001.20) for Phase I Allocation Scenario

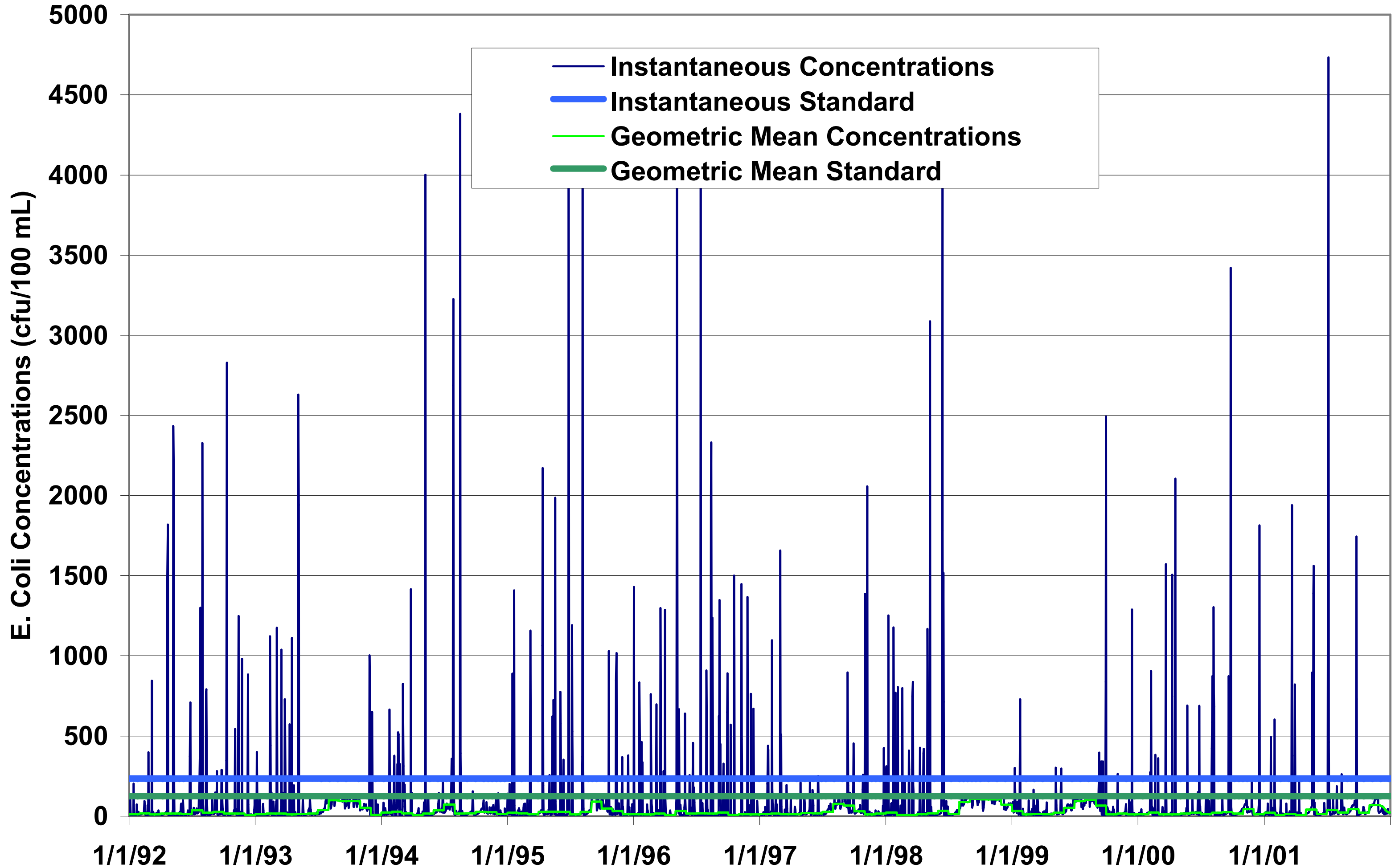


Figure 6.10: Simulated instantaneous and geometric mean *E. coli* concentrations (cfu/100 mL) at Cromwells Run (1ACRM001.20) for Phase I Allocation Scenario

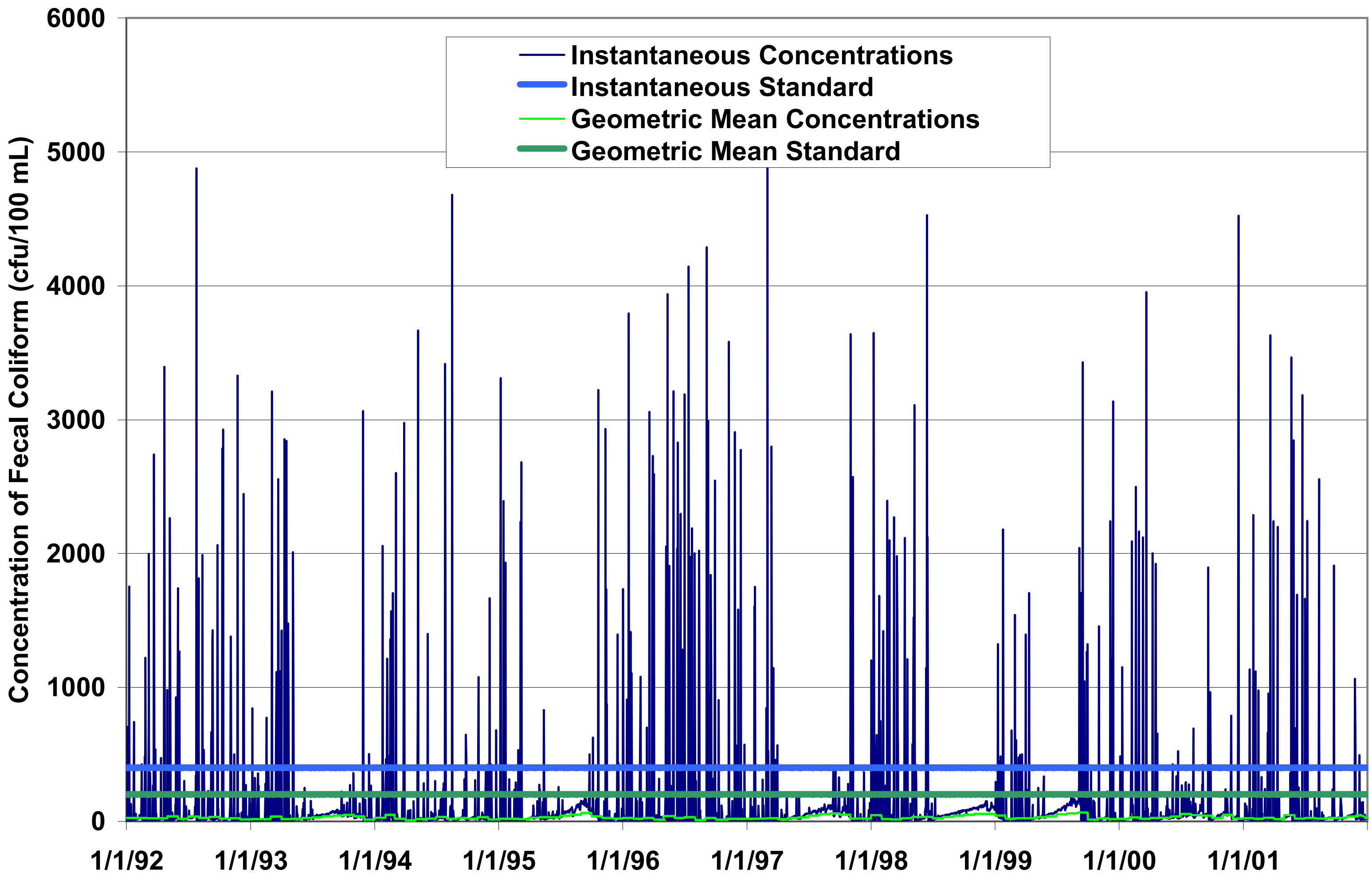


Figure 6.11: Simulated instantaneous and geometric mean fecal coliform concentrations (cfu/100 mL) at Middle Sycolin Creek (1ASYC004.93) for Phase I Allocation Scenario

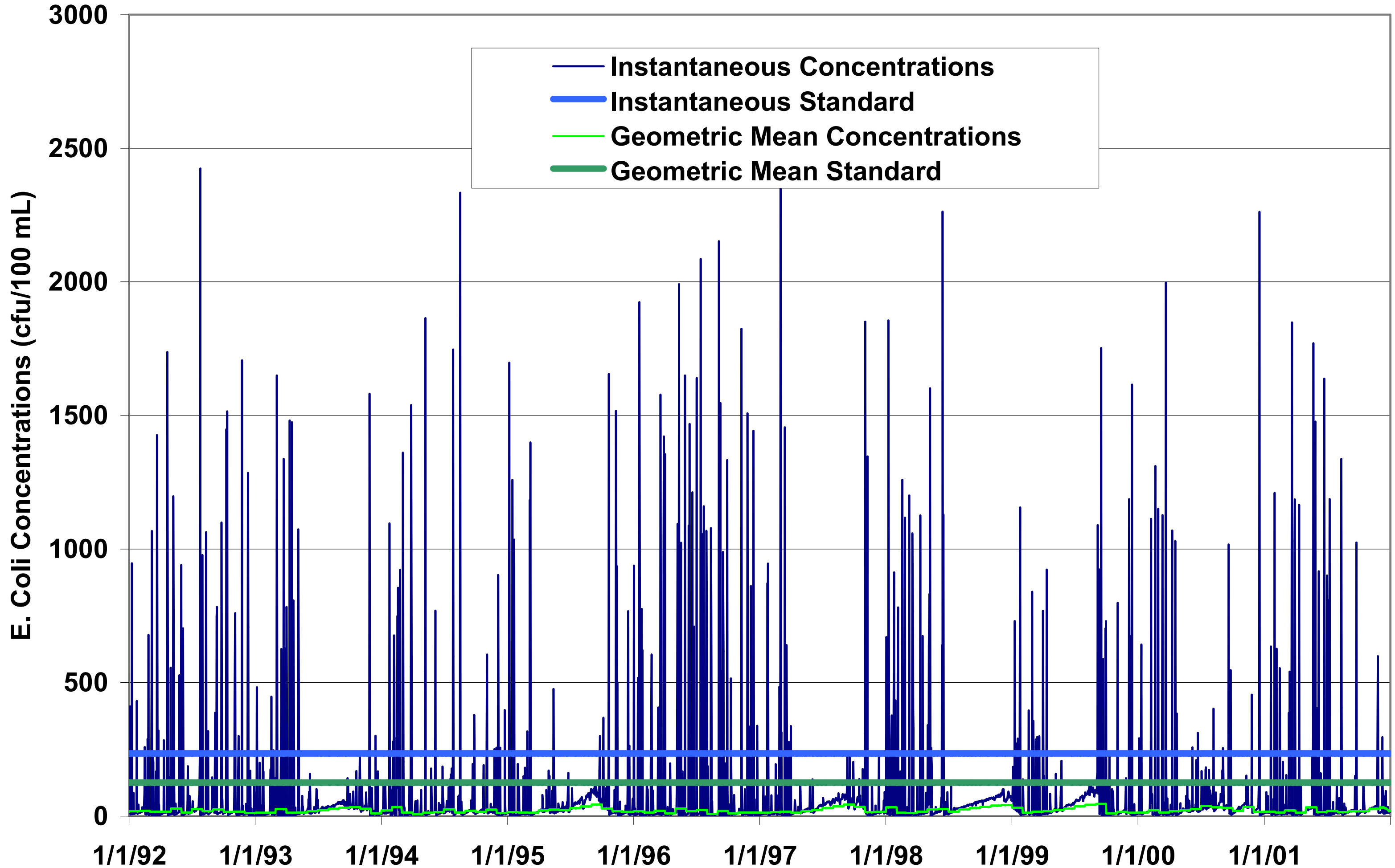


Figure 6.12: Simulated instantaneous and geometric mean *E. coli* concentrations (cfu/100 mL) Middle Sycolin Creek (1ASYC004.93) for Phase I Allocation Scenario

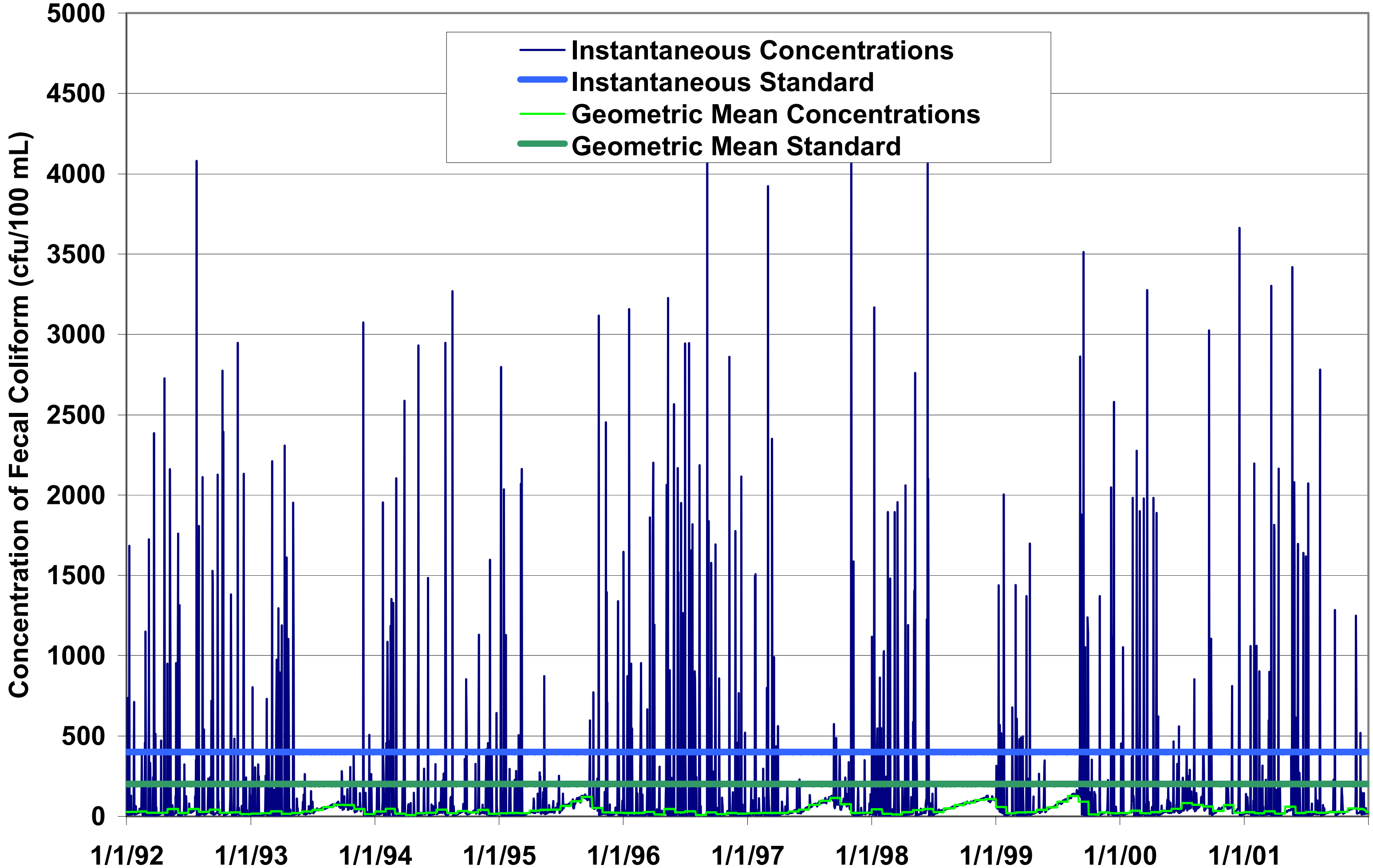


Figure 6.13: Simulated instantaneous and geometric mean fecal coliform concentrations (cfu/100 mL) at South Fork Sycolin Creek (1ASFS000.28) for Phase I Allocation Scenario

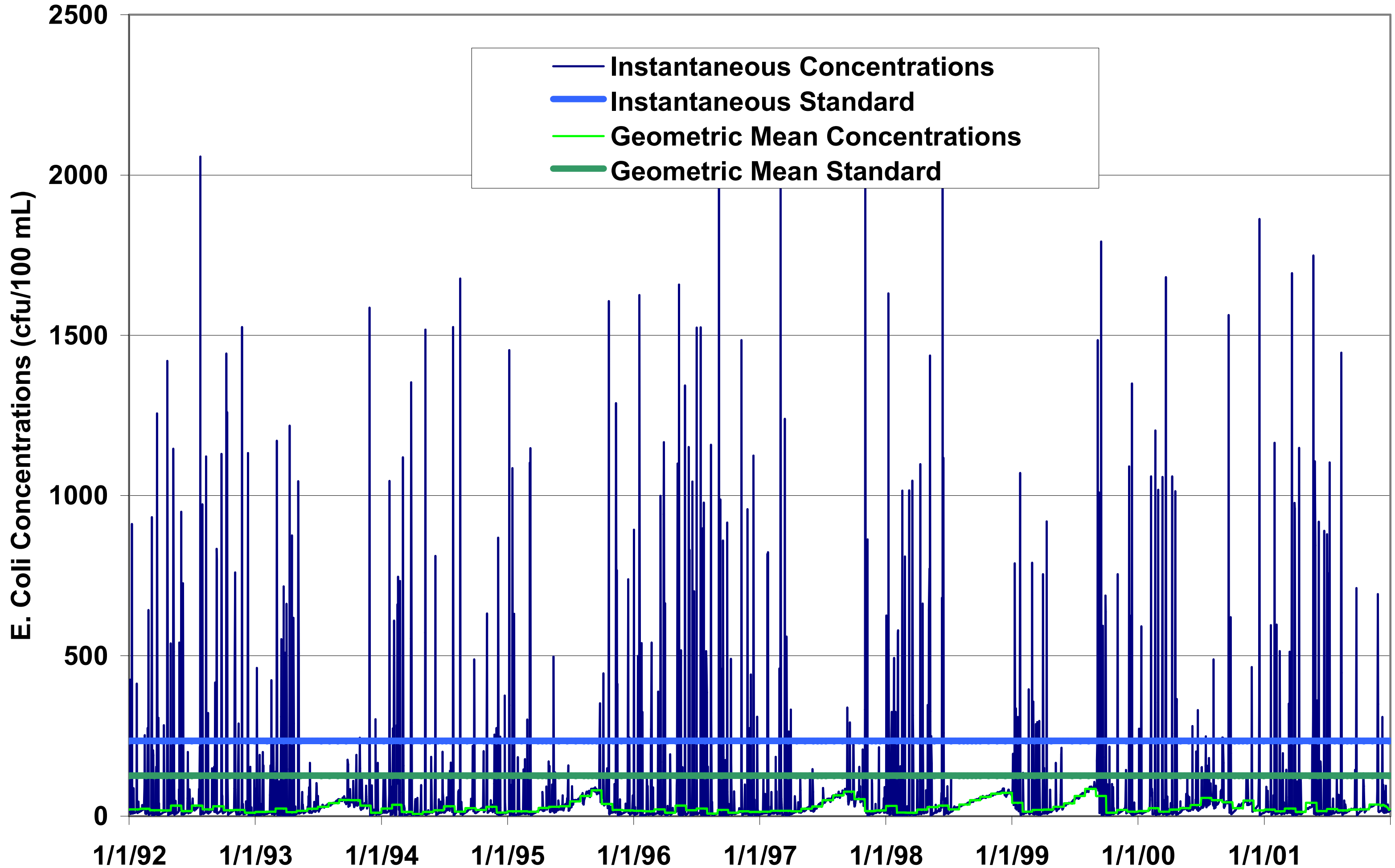


Figure 6.14: Simulated instantaneous and geometric mean *E. coli* concentrations (cfu/100 mL) at South Fork Sycolin Creek (1ASFS000.28) for Phase I Allocation Scenario

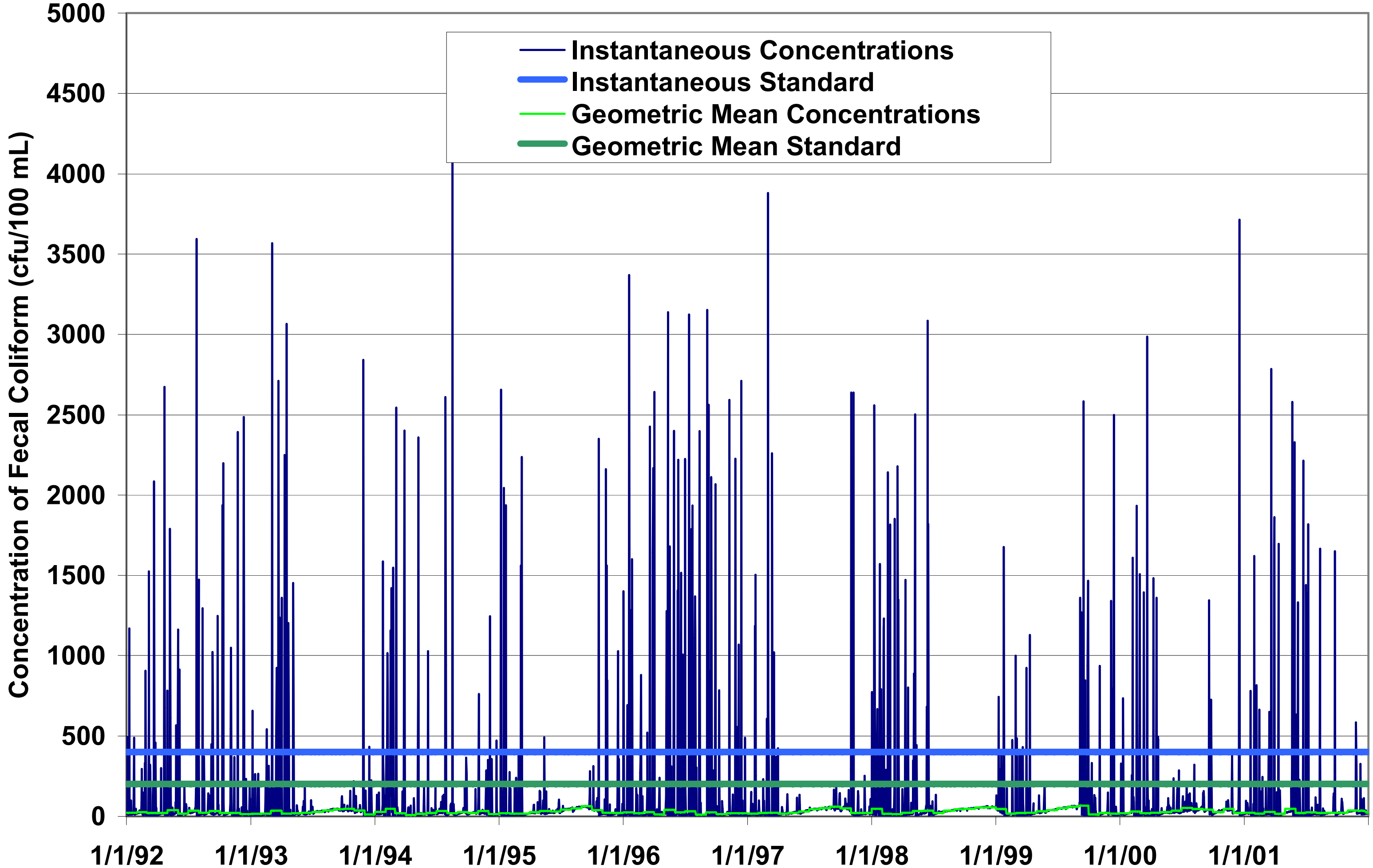


Figure 6.15: Simulated instantaneous and geometric mean fecal coliform concentrations (cfu/100 mL) at North Fork Sycolin Creek (1ASYC007.43) for Phase I Allocation Scenario

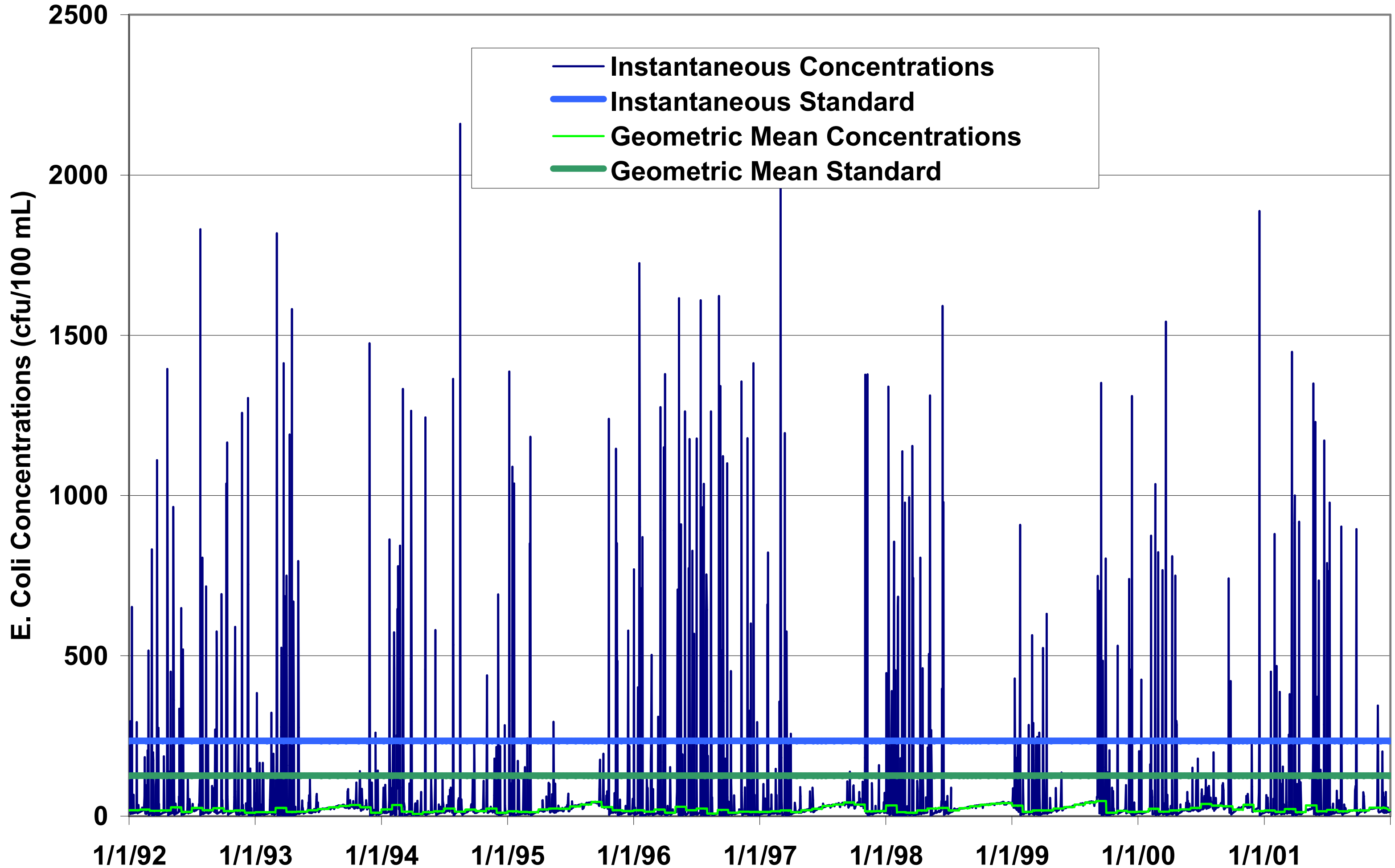


Figure 6.16: Simulated instantaneous and geometric mean E. coli concentrations (cfu/100 mL) at North Fork Sycolin Creek (1ASYC007.43) for Phase I Allocation Scenario

CHAPTER 7: PUBLIC PARTICIPATION

The development of the Goose Creek TMDLs relied on participation from the general public and various stakeholder groups. A series of public meetings were held to present the results of the TMDLs and to solicit comments and suggestions. The first public meeting was held in Leesburg on October 17, 2001. Copies of the presentation materials were available for public distribution. The meeting was public noticed in the Virginia Register and advertised in the Fauquier Times Democrat, Fauquier Citizen, Loudoun Times Mirror, Leesburg Today and Fairfax Connection newspapers. There was a 30 day-public comment period and no written comments were received.

The second and third public meetings were held within a week of each other in different parts of the watershed in order to encourage broader public participation. The second public meeting was held in Leesburg on November 14, 2002, while the third public meeting was held in Marshall on November 20, 2002. Both meetings covered the same material. Copies of the presentation were available at both meetings for public distribution. The meetings were public noticed in the Virginia Register and advertised in the Fauquier Times Democrat, Loudoun Times Mirror and Fairfax Connection newspapers. There was a 30-day public comment period and __ written comments were received. Table 7.1 details the specifics of the three public meetings.

Table 7.1: Public participation in the Goose Creek TMDLs

Date	Location	Address	City	Attendance
10/17/01	First Floor Board Room Loudoun Co. Gov't Center	1 Harrison Street, SE	Leesburg, VA	9
11/14/02	Lovettsville Room Loudoun Co. Gov't Center	1 Harrison Street, SE	Leesburg, VA	TBD
11/20/02	Marshall Community Center	4133 Rectortown Rd.	Marshall, VA	TBD

In addition to keeping the public apprised of progress in the development of the Goose Creek TMDLs, a Technical Advisory Committee (TAC) was also established to help advise the TMDL developers. The TAC membership included representatives from VADGIF, VADCR and VADEQ, Loudoun and Fauquier Counties, Fairfax City, and several citizen groups. The Goose Creek TAC met on the following dates: August 9, 2001, December 5, 2001, June 5, 2002 and October 8, 2002. TAC meetings were used as a forum to review data and assumptions used in the modeling, and to provide local city and county government agencies an opportunity to raise concerns about the implications of the TMDL for their jurisdictions.

Frequent meetings were also held with the Loudoun and John Marshall Soil and Water Conservation Districts (SWCDs) to gather information on agricultural practices and trends in the watershed. The input of the SWCDs was invaluable to the assessment of sources in, and the accurate representation of, the watershed and their participation was greatly appreciated.

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APPENDIX A: OBSERVED FECAL COLIFORM BACTERIA CONCENTRATIONS IN THE GOOSE CREEK WATERSHED

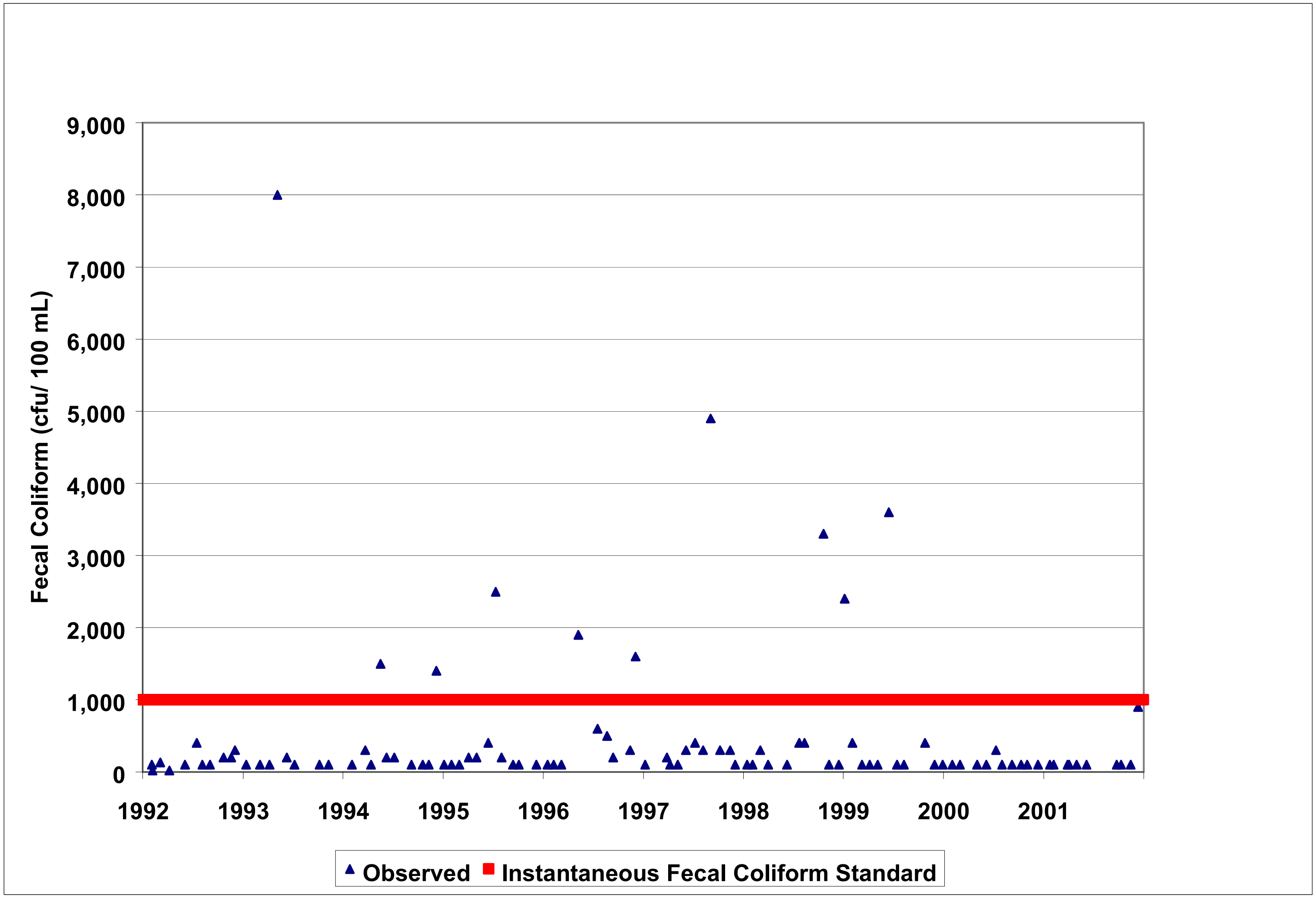

Figure A.1 Observed fecal coliform concentrations at Lower Goose Creek (1AGOO002_38)

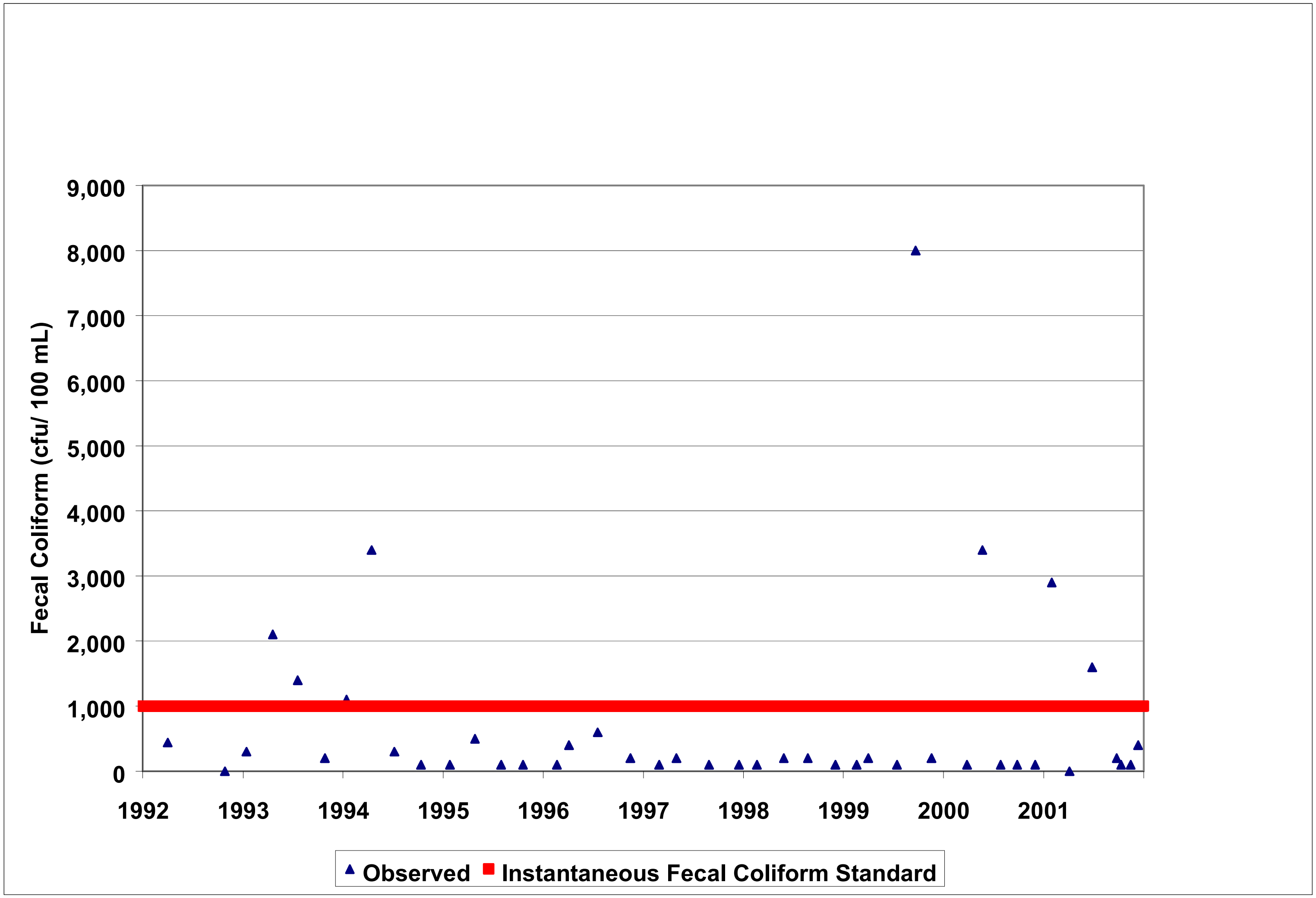

Figure A.2 Observed fecal coliform concentrations at Sycolin Creek (1ASYC002)

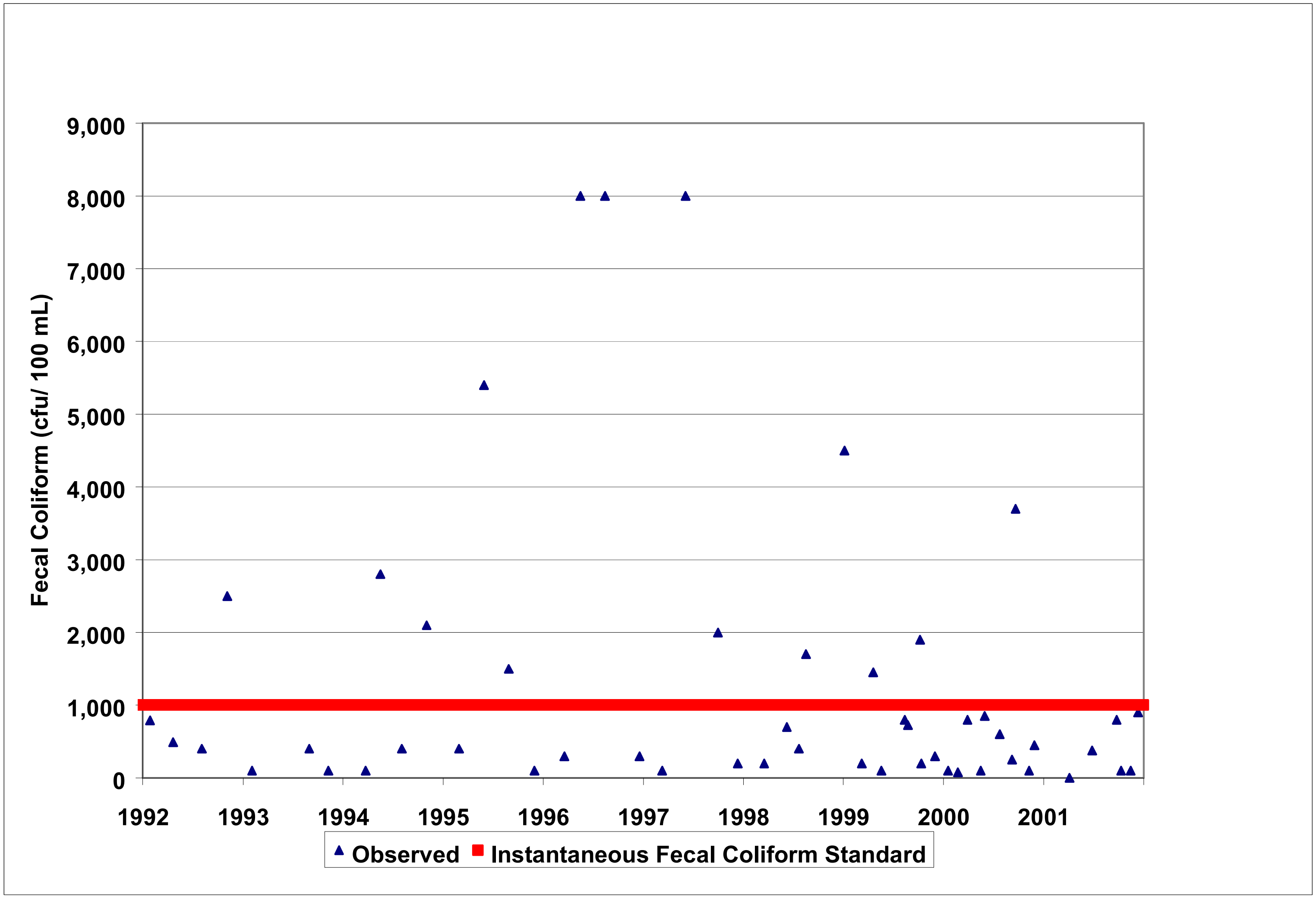

Figure A.3 Observed fecal coliform concentrations at Little River (1ALIV004_78)

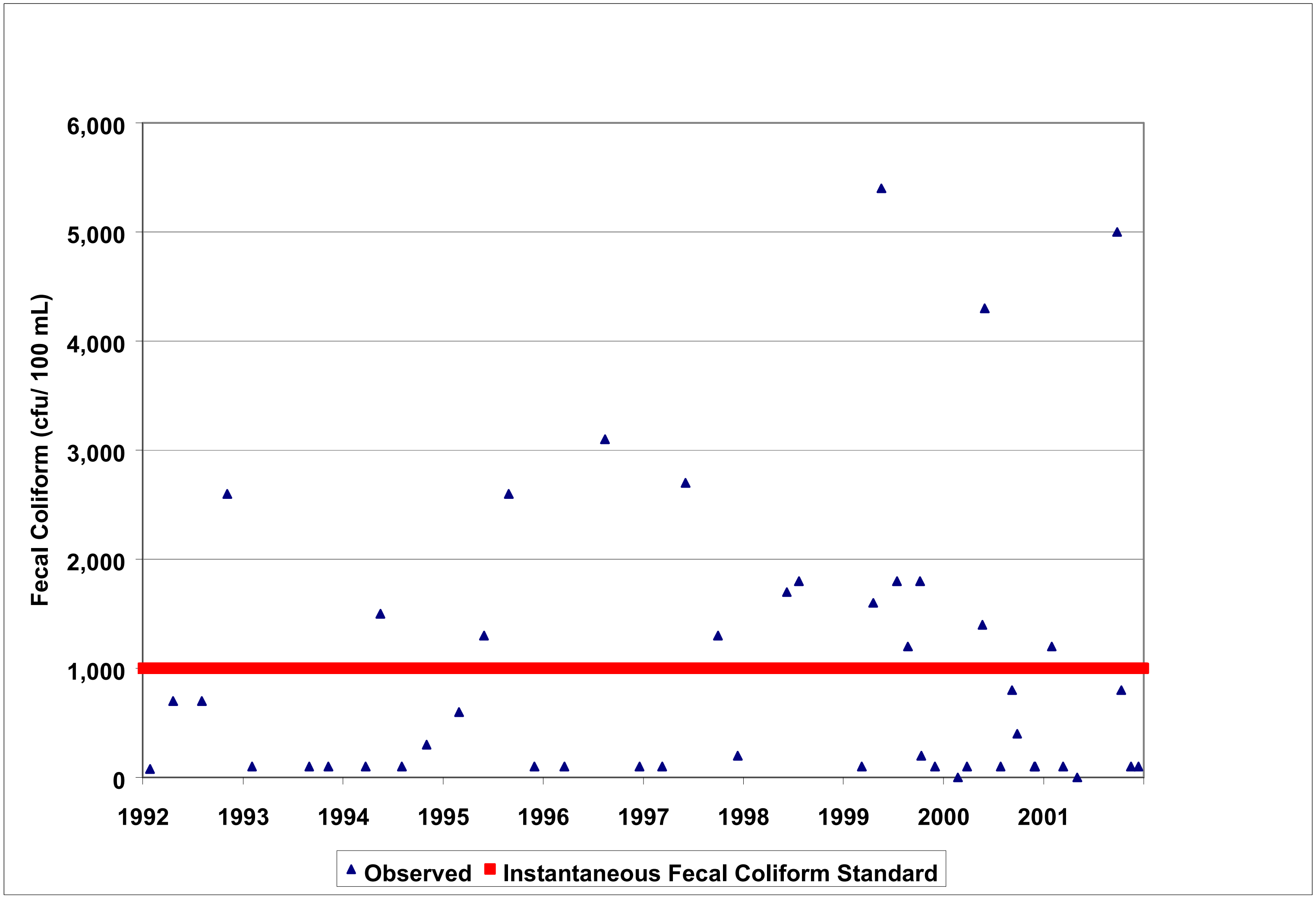

Figure A.4 Observed fecal coliform concentrations at North Folk Goose Creek (1ANOG005_69)

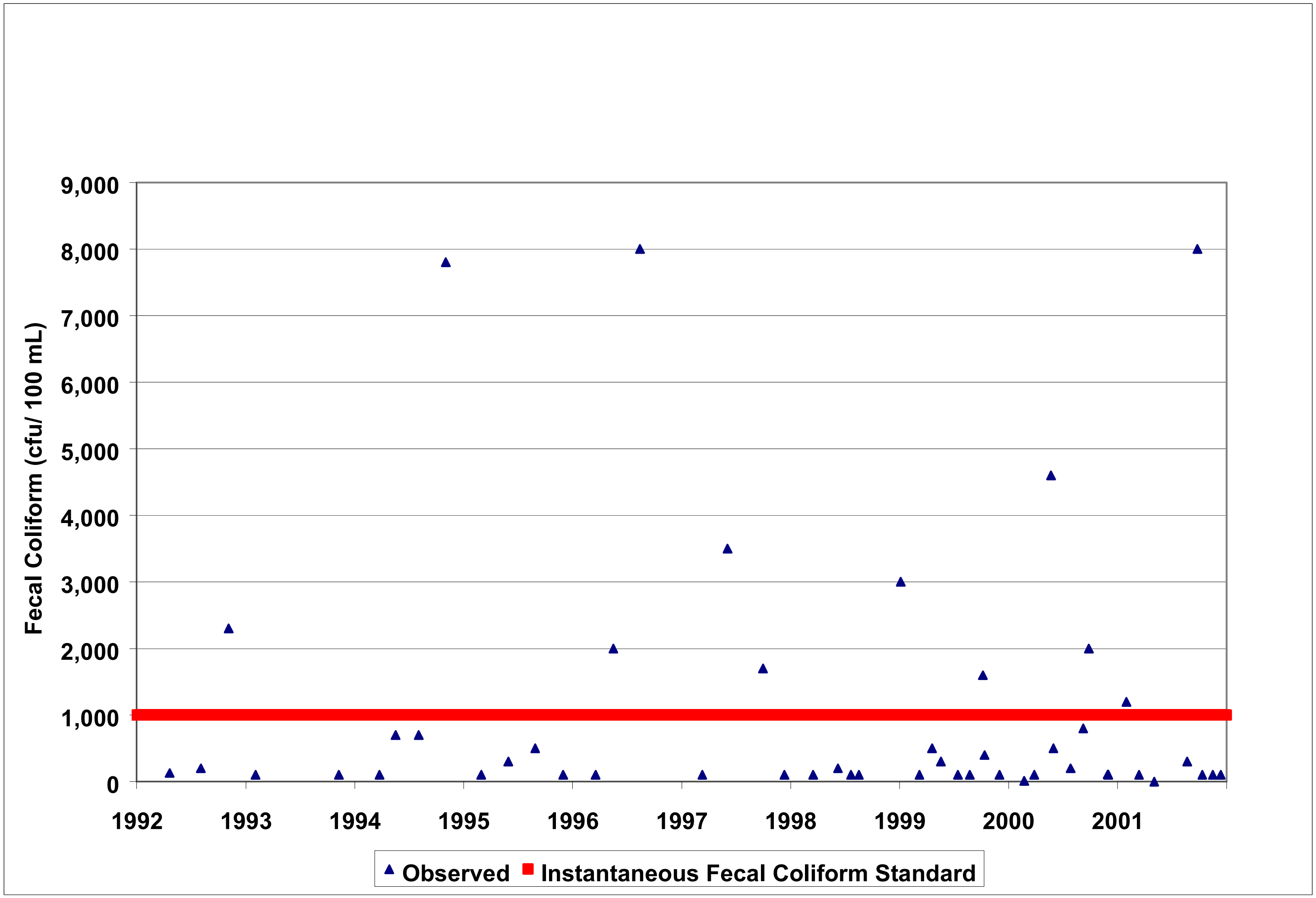

Figure A.5 Observed fecal coliform concentrations at Beaverdam Creek (1ABEC004_76,BC731)

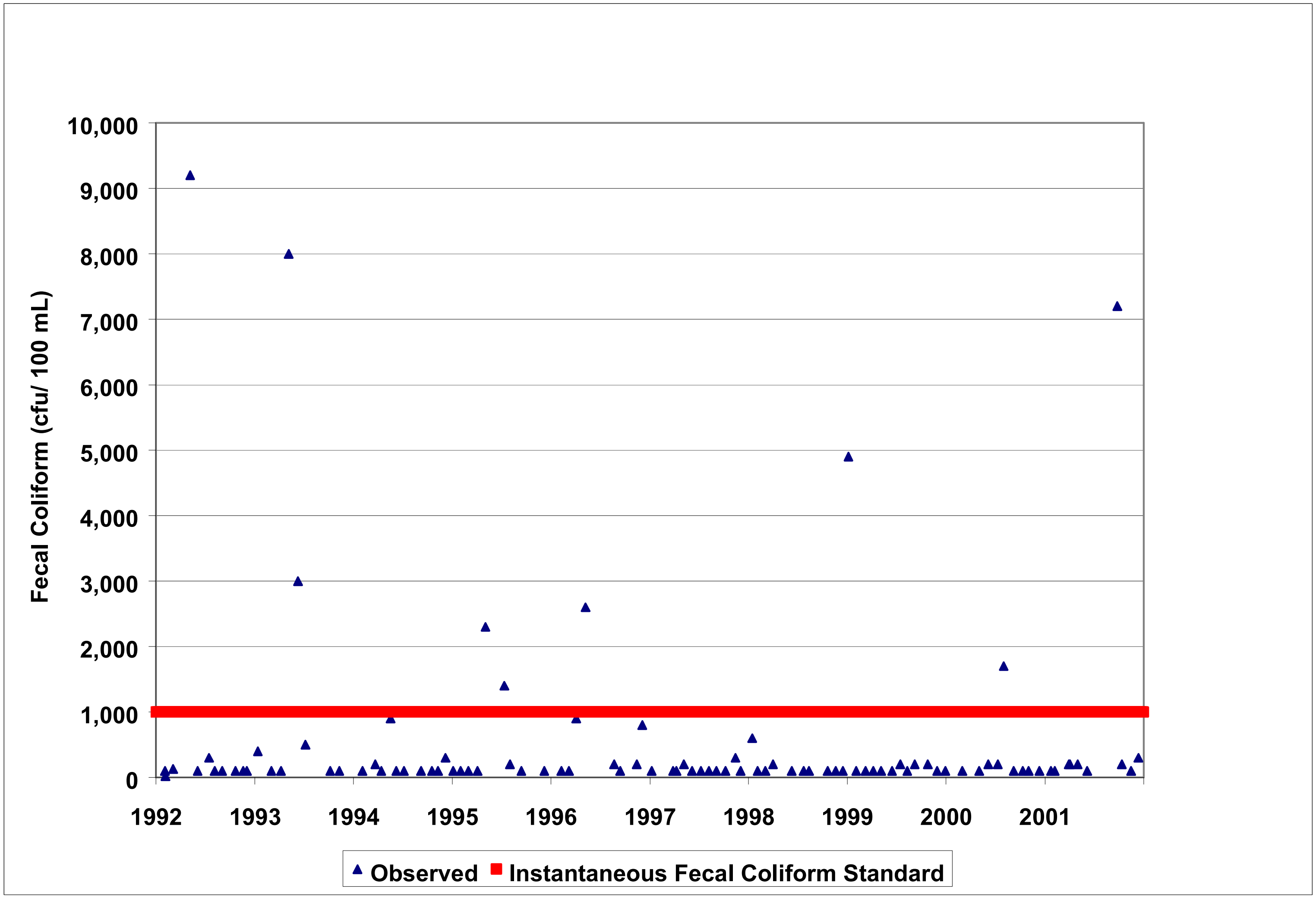

Figure A.6 Observed fecal coliform concentrations at Goose Creek (1AGOO002_44)

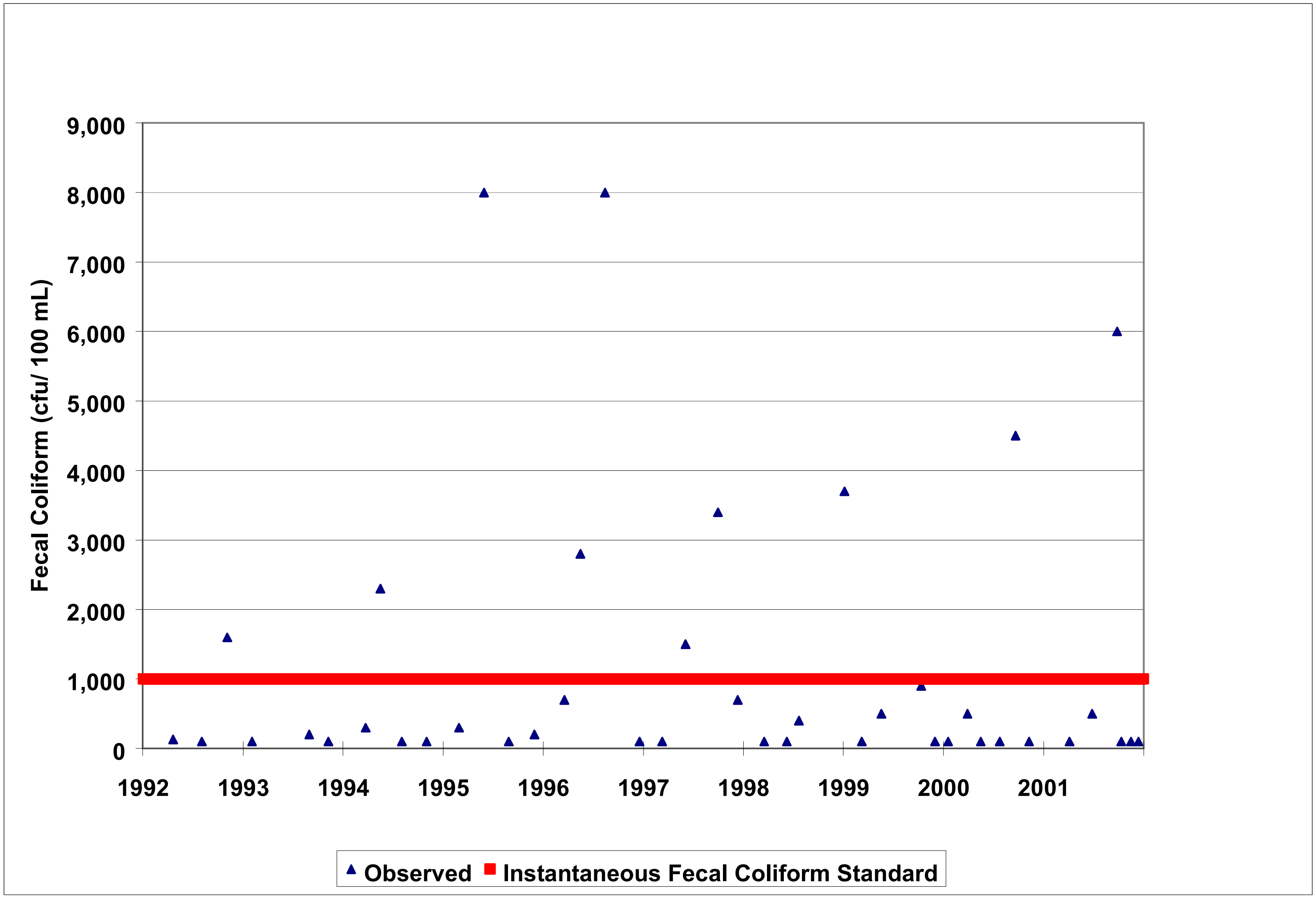

Figure A.7 Observed fecal coliform concentrations at Cromwells Run (1ACRM001_20)

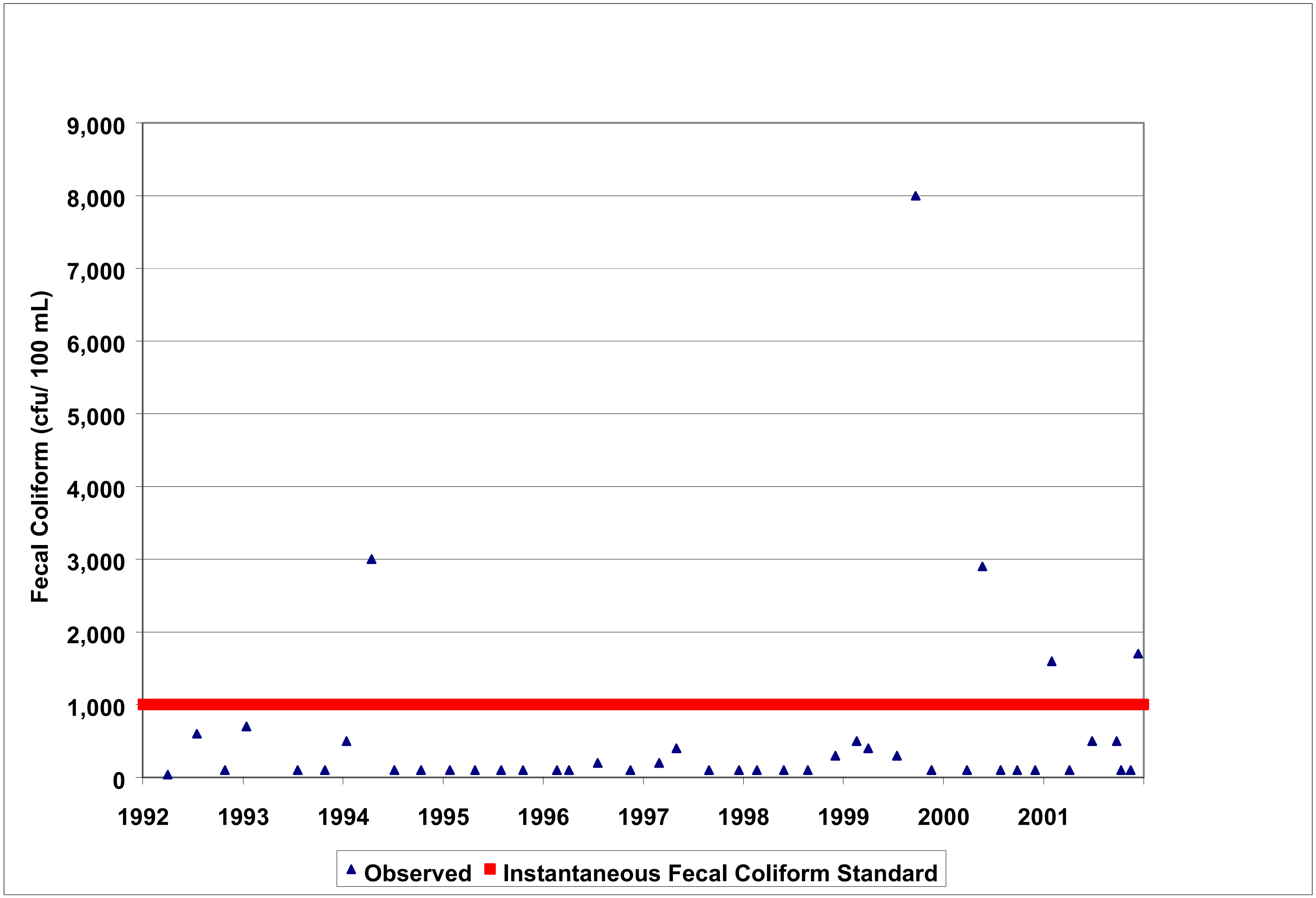

Figure A.8 Observed fecal coliform concentrations at Tuscarora Creek (1ATUS000_37)

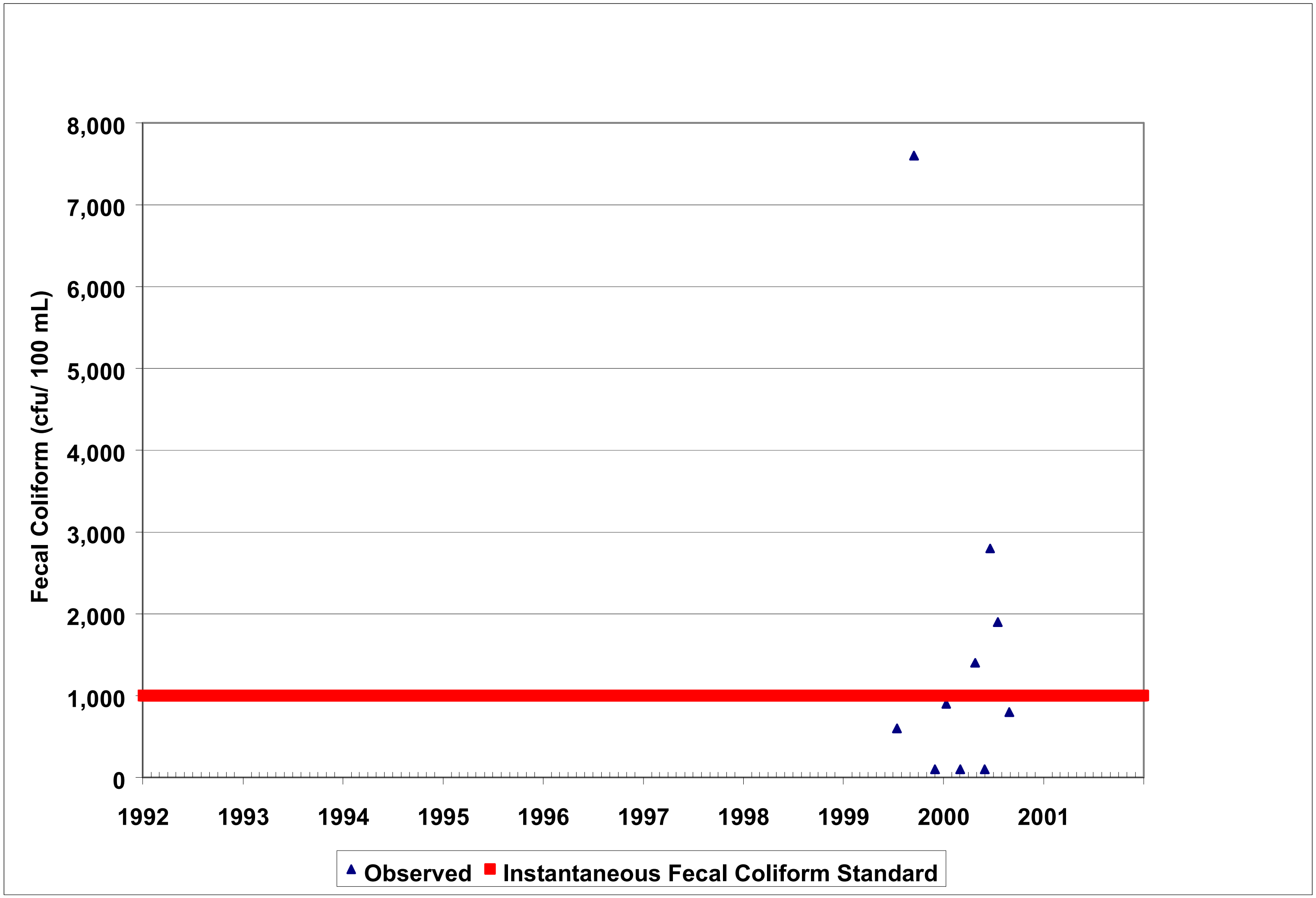

Figure A.9 Observed fecal coliform concentrations at Upper Sycolin Creek (1ASYC004)

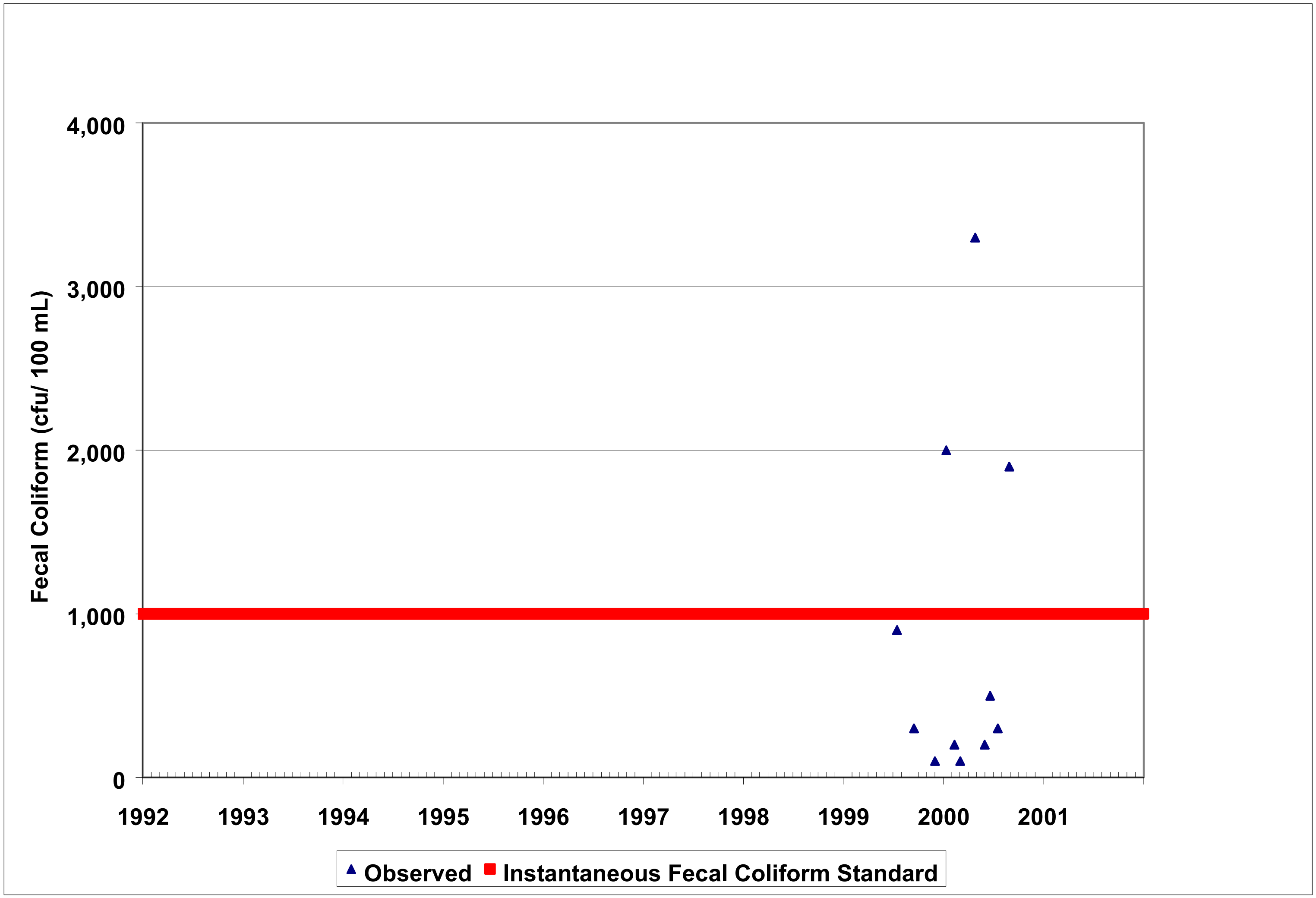

Figure A.10 Observed fecal coliform concentrations at South Folk Sycolin Creek (1ASFS000)

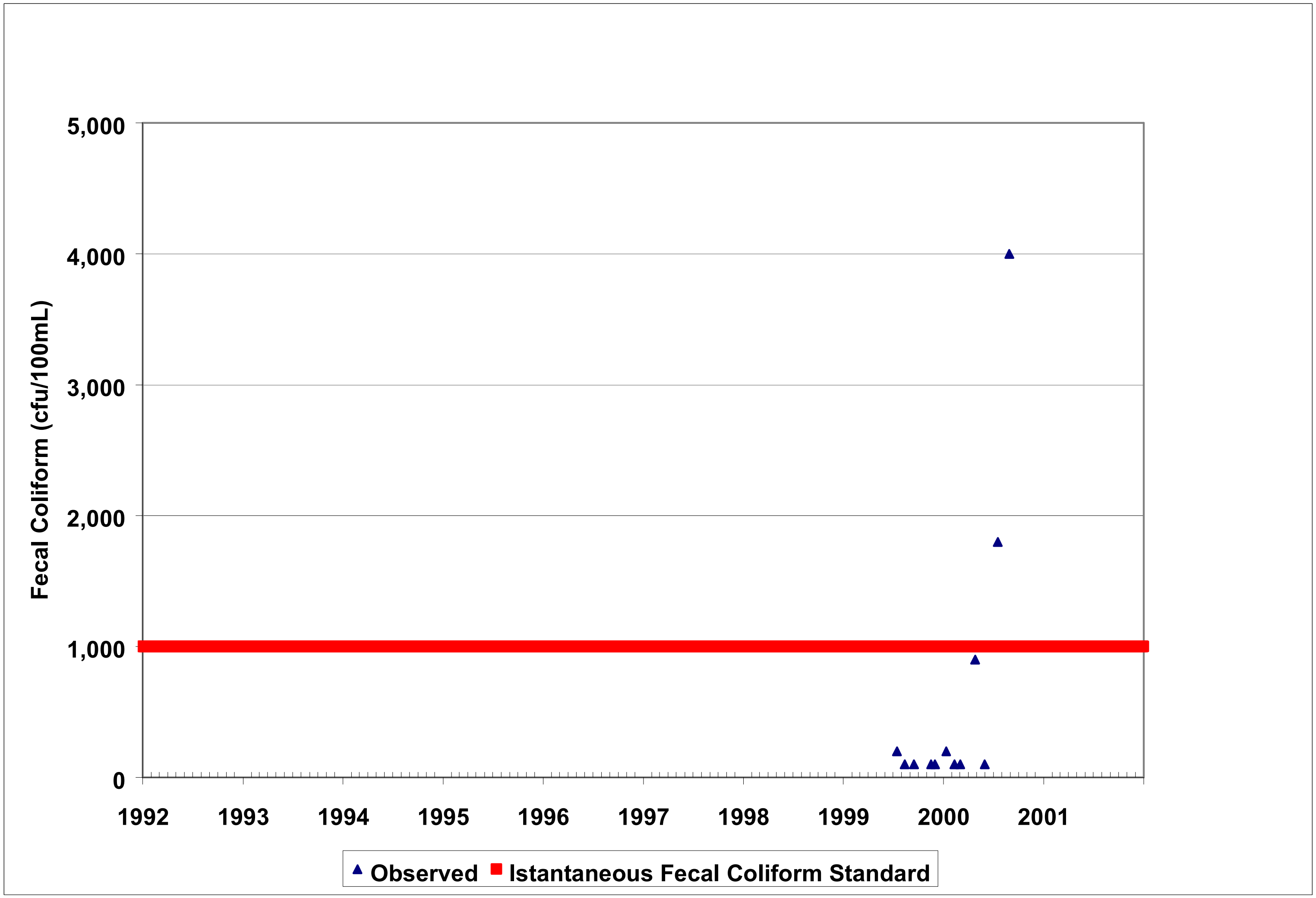

Figure A.11 Observed fecal coliform concentrations at North Folk Sycolin Creek (1ASYC007)

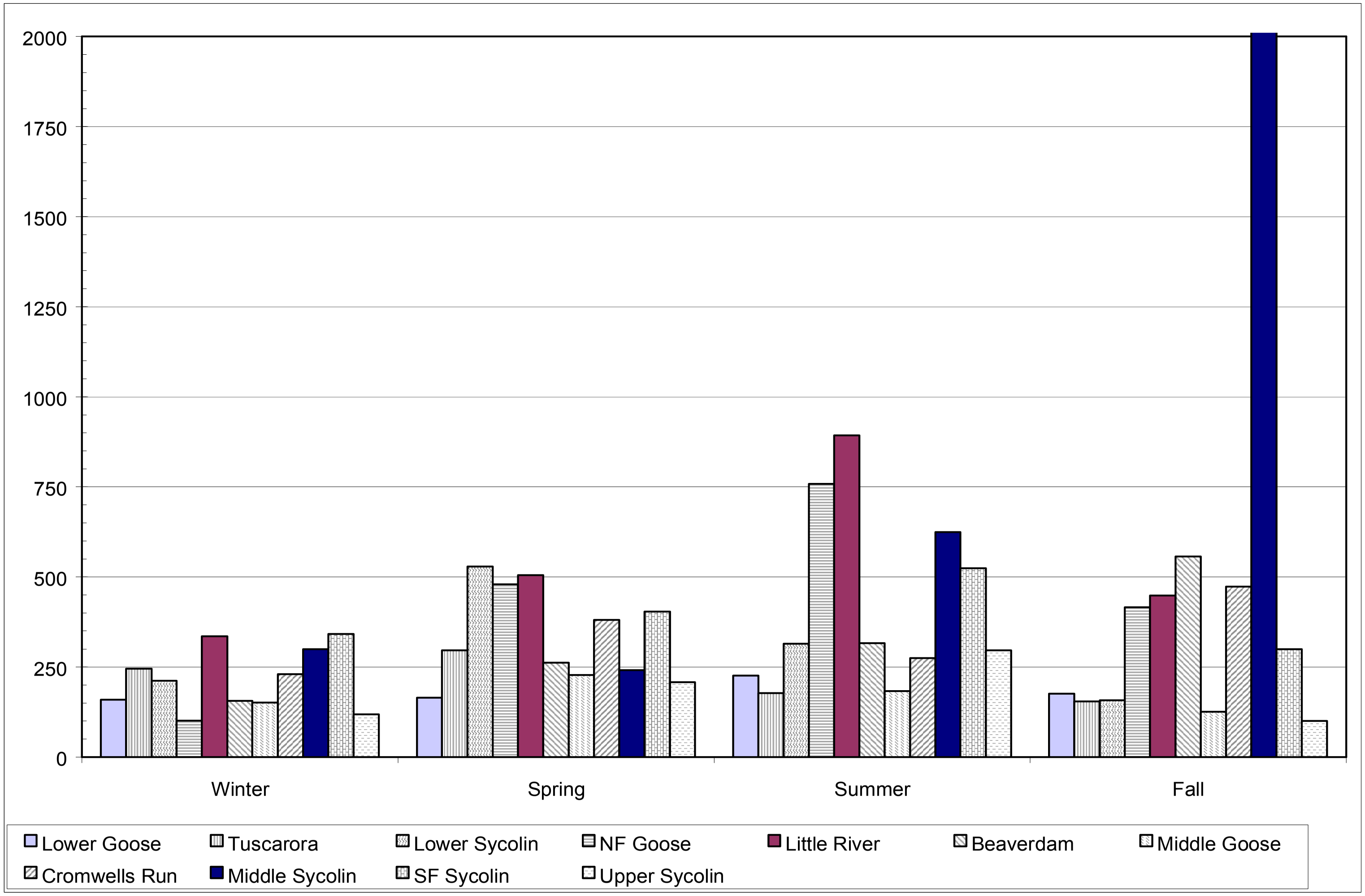

Figure A.12 Seasonal Geometric Means at VADEQ monitoring stations
(Seasons were defined as follows: Winter: December, January, February; Spring: March, April, May; Summer: June, July, August; Fall: September, October, November. The geometric mean was calculated from all available data for the season. Fall geometric mean for Middle Sycolin represents a single value.)

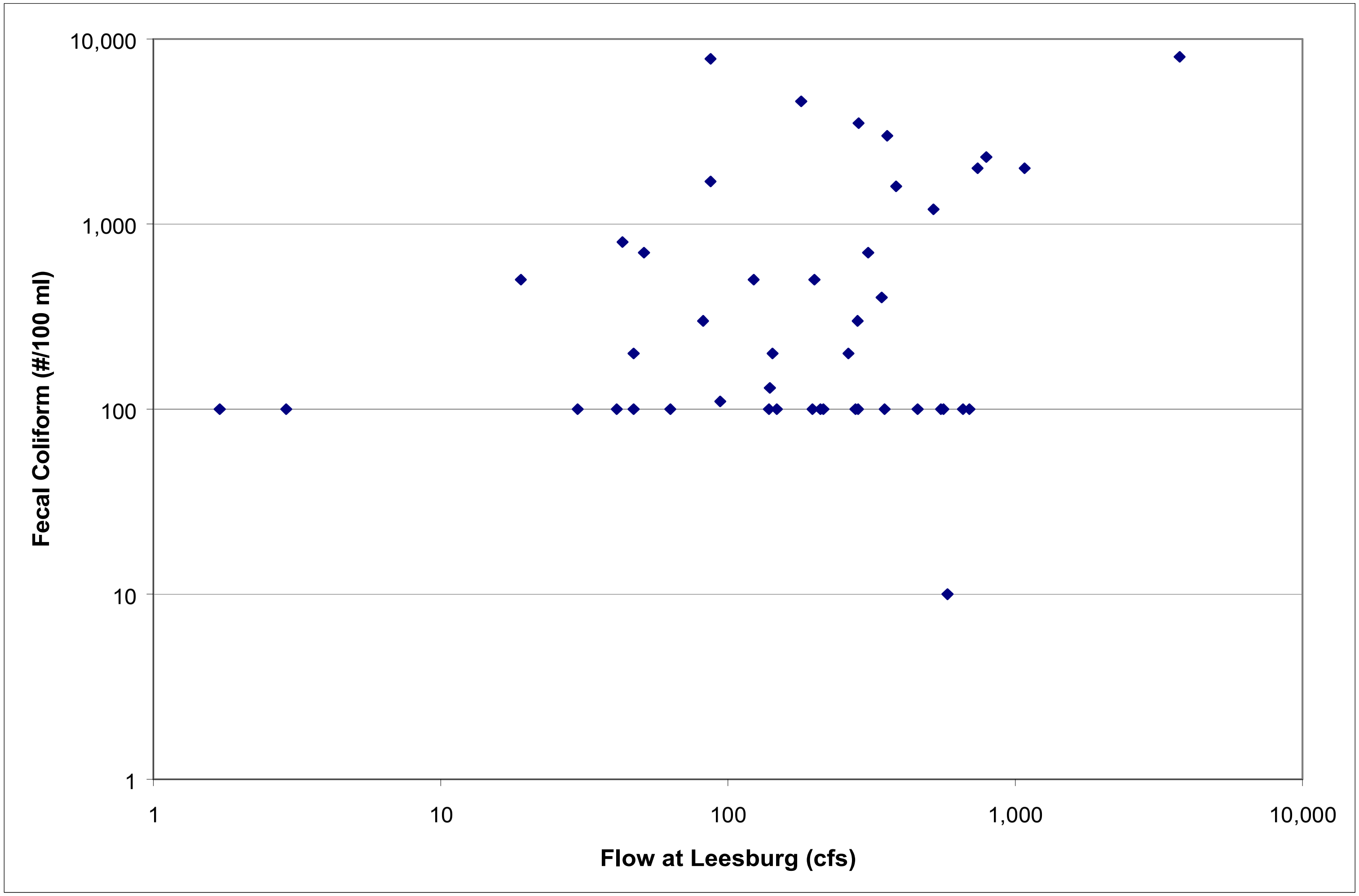

Figure A.13 Observed fecal coliform concentrations at Beaverdam Creek (1ABEC004_76, BC731) versus flow at Leesburg

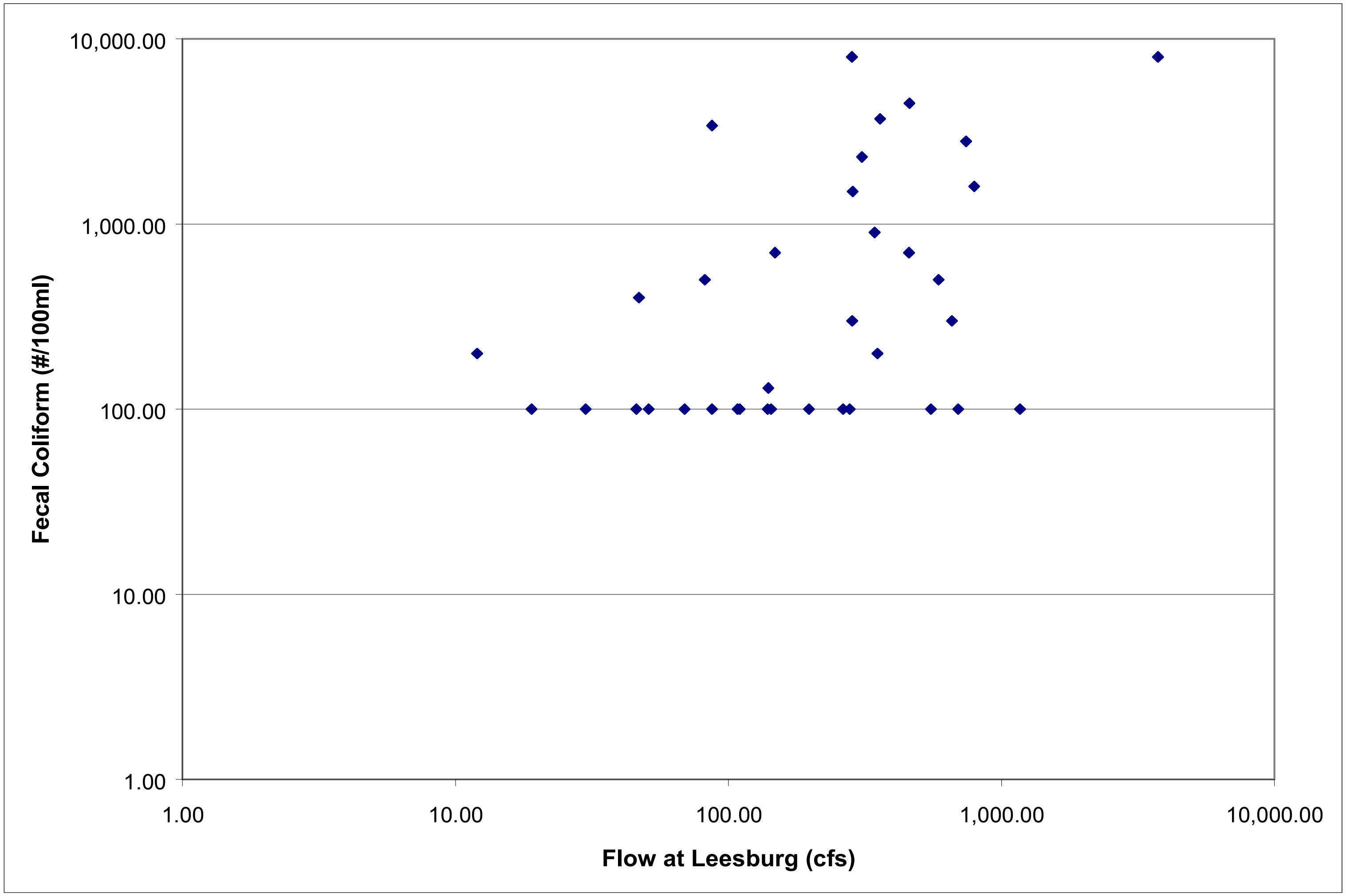

Figure A.14 Observed fecal coliform concentrations at Cromwells Run (1ACRM001_20) versus flow at Leesburg

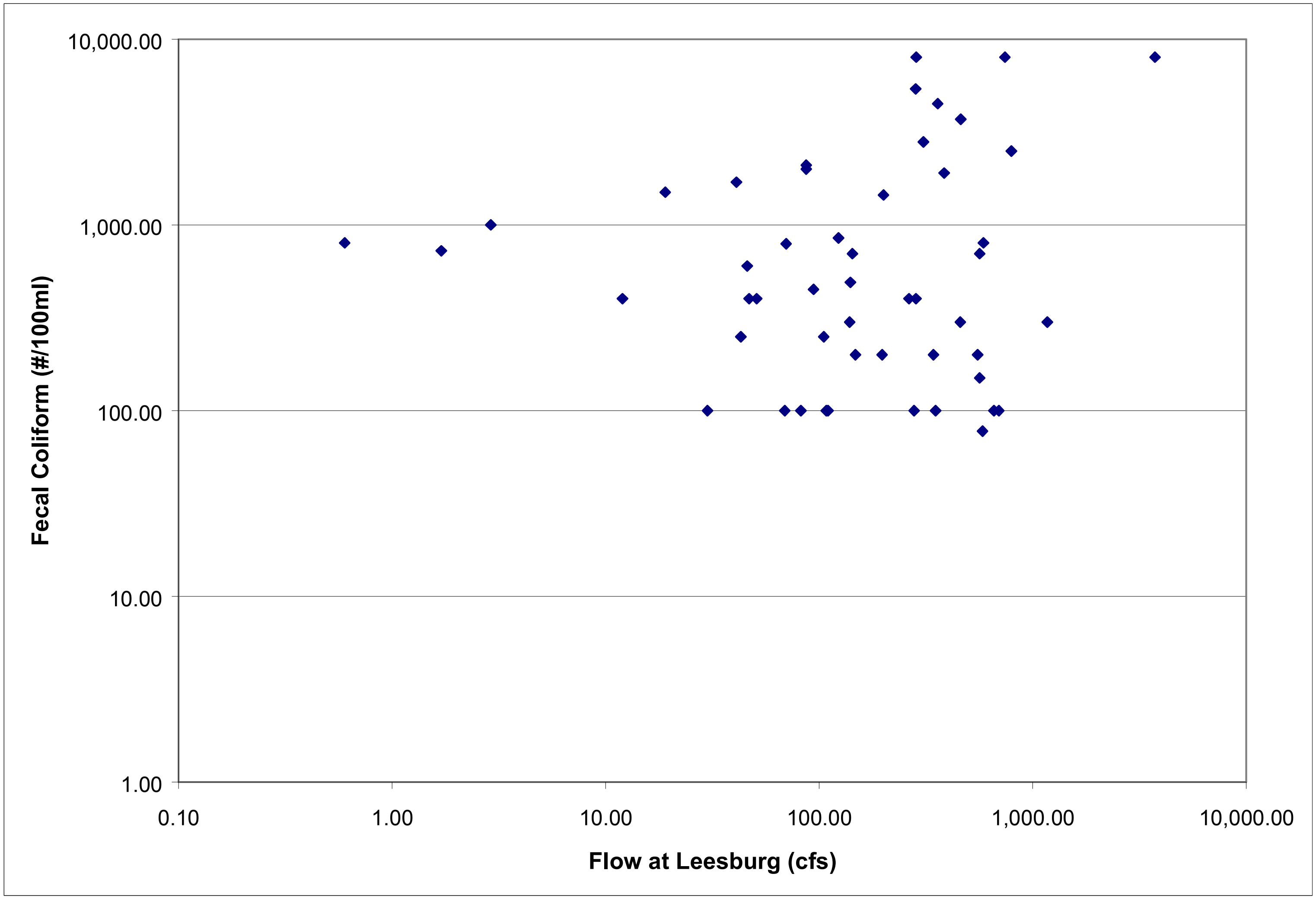

Figure A.15 Observed fecal coliform concentrations at Little River (1ALIV004_78) versus flow at Leesburg

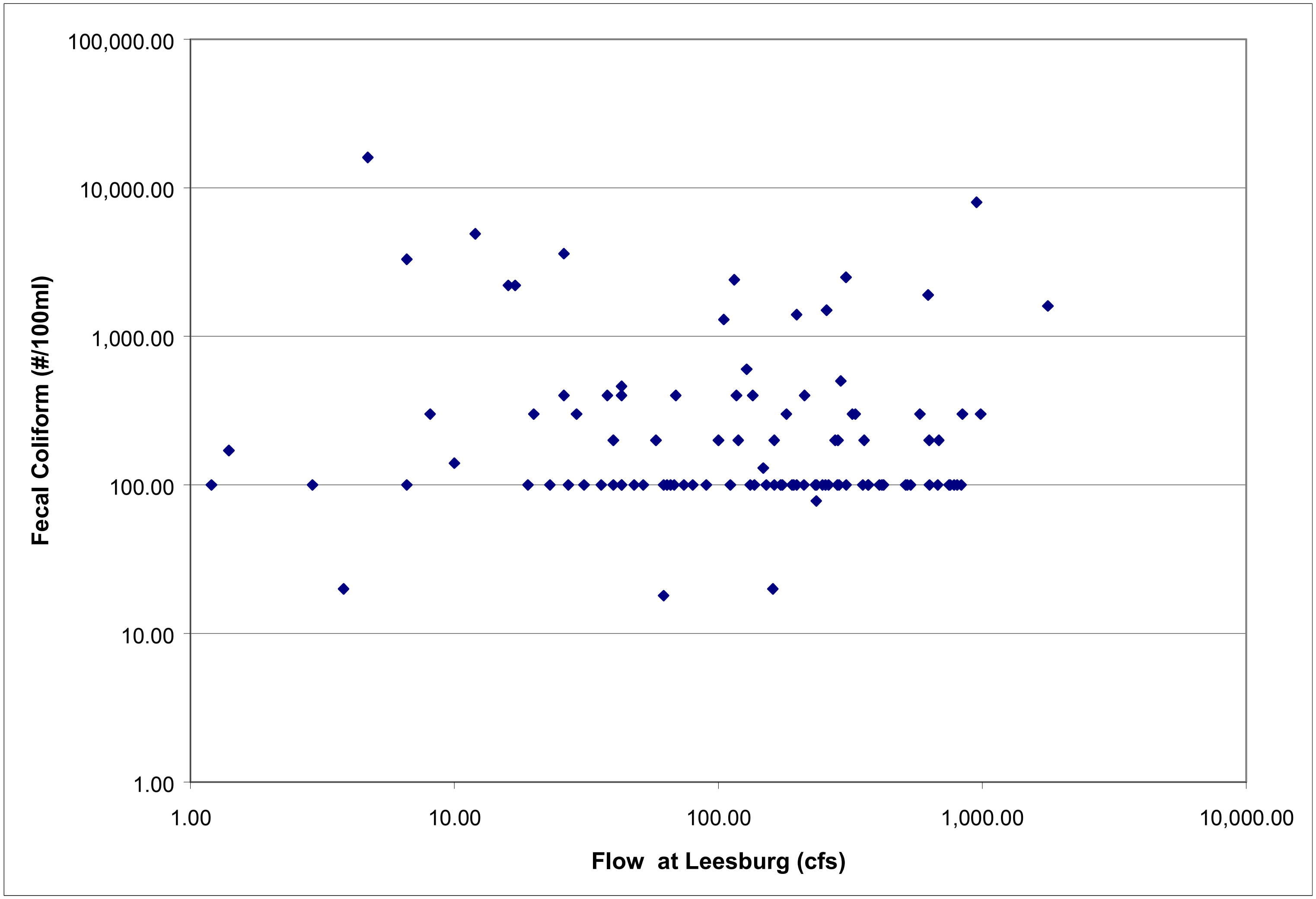

Figure A.16 Observed fecal coliform concentrations at Lower Goose Creek (1AGOO002_38) versus flow at Leesburg

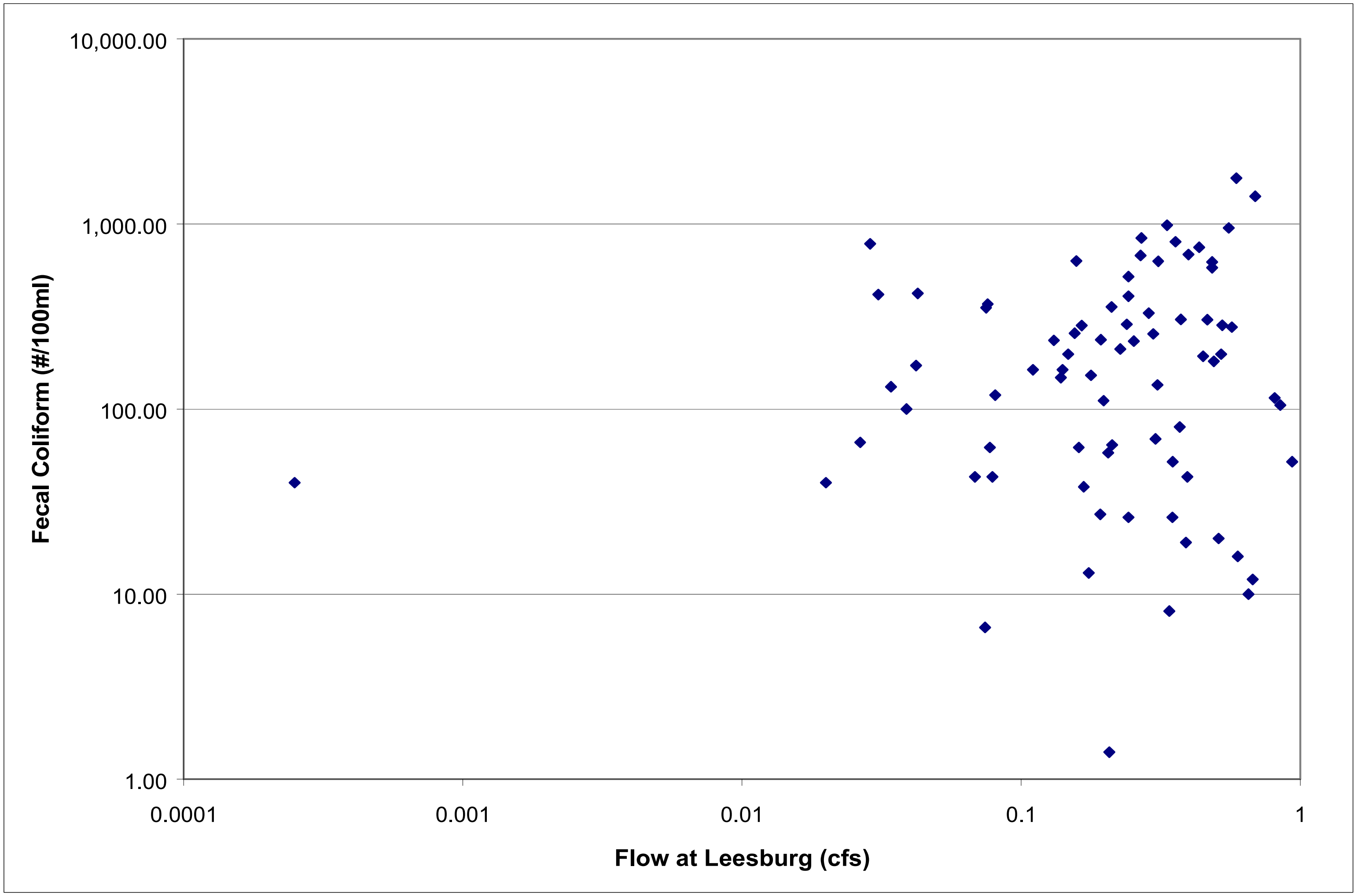

Figure A.17 Observed fecal coliform concentrations at Middle Goose Creek(1AGOO022_44) versus flow at Leesburg

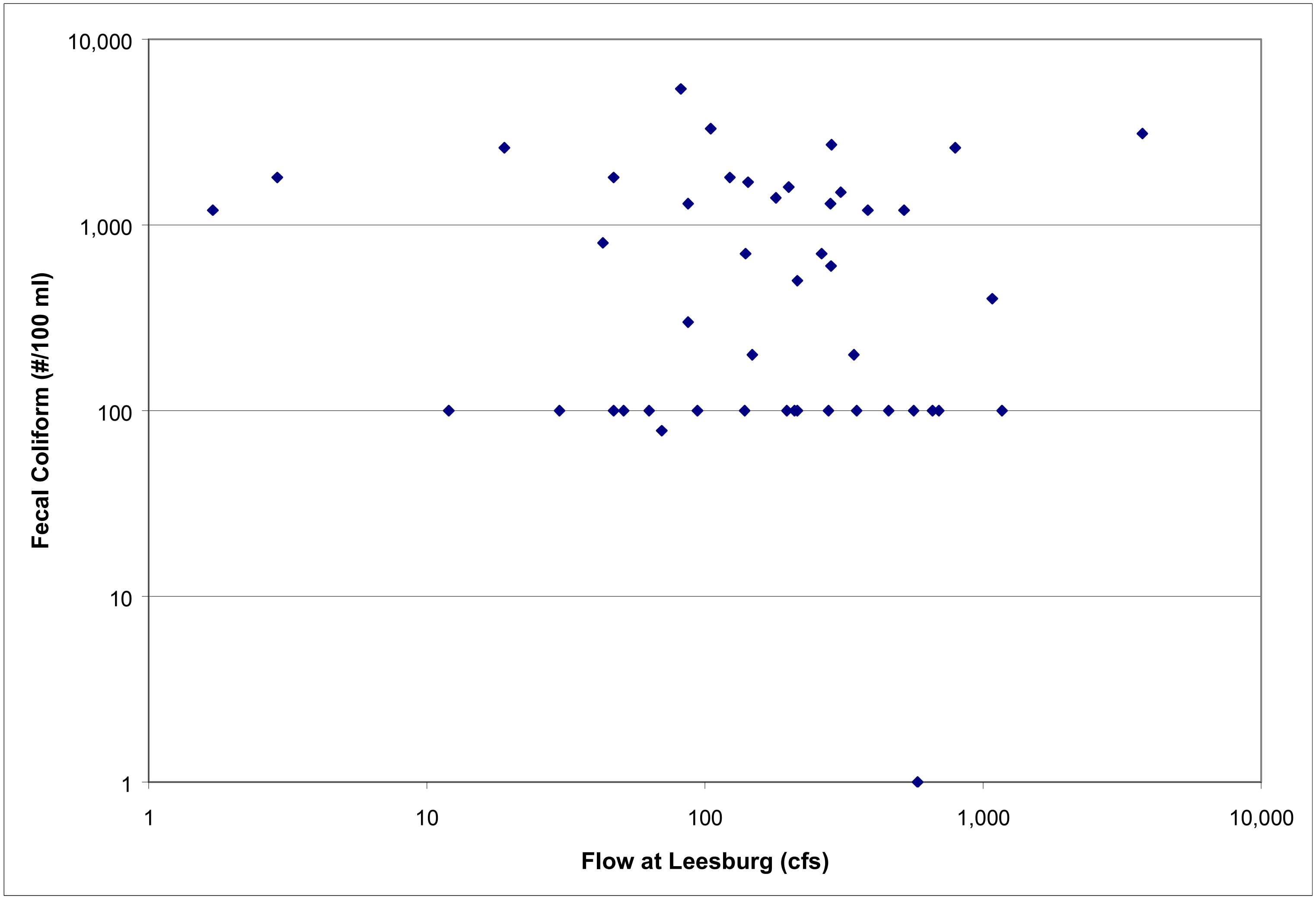

Figure A.18 Observed fecal coliform concentrations at North Folk Goose Creek (1ANOG005_69) versus flow at Leesburg

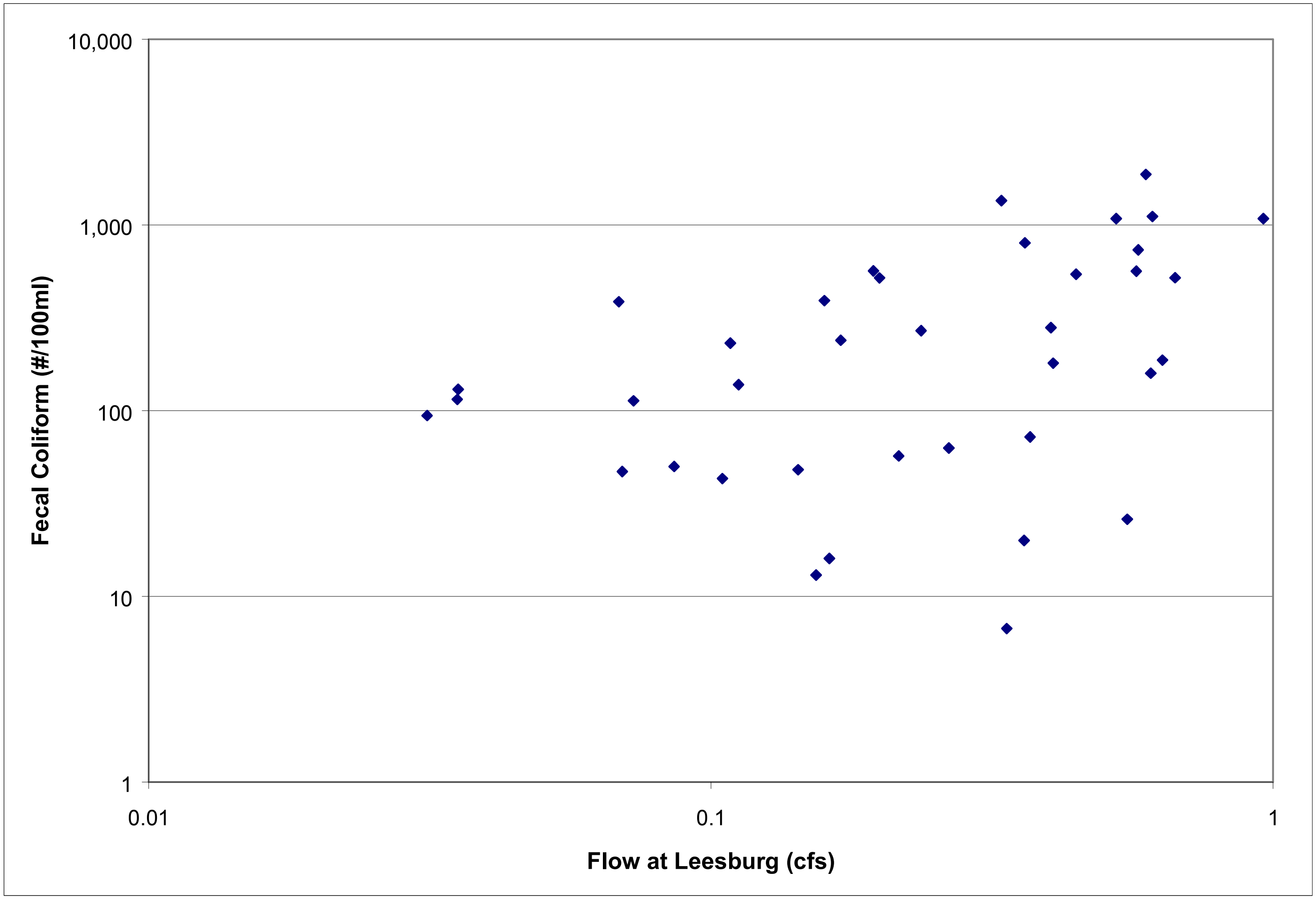

Figure A.19 Observed fecal coliform concentrations at Tuscarora Creek (1ATUS000_37) versus flow at Leesburg

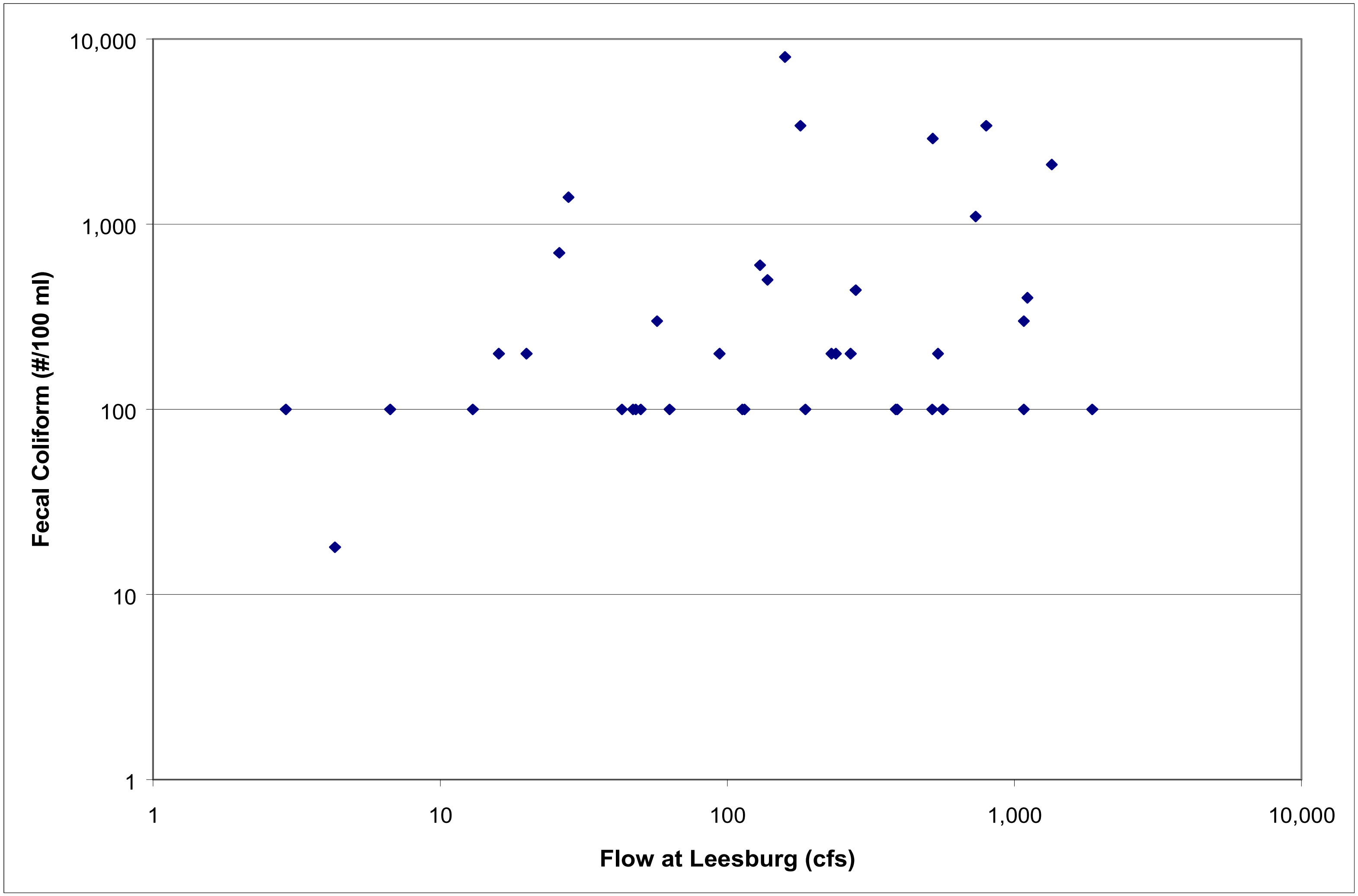

Figure A20 Observed fecal coliform concentrations at Sycolin Creek (1ASYC002) versus flow at Leesburg

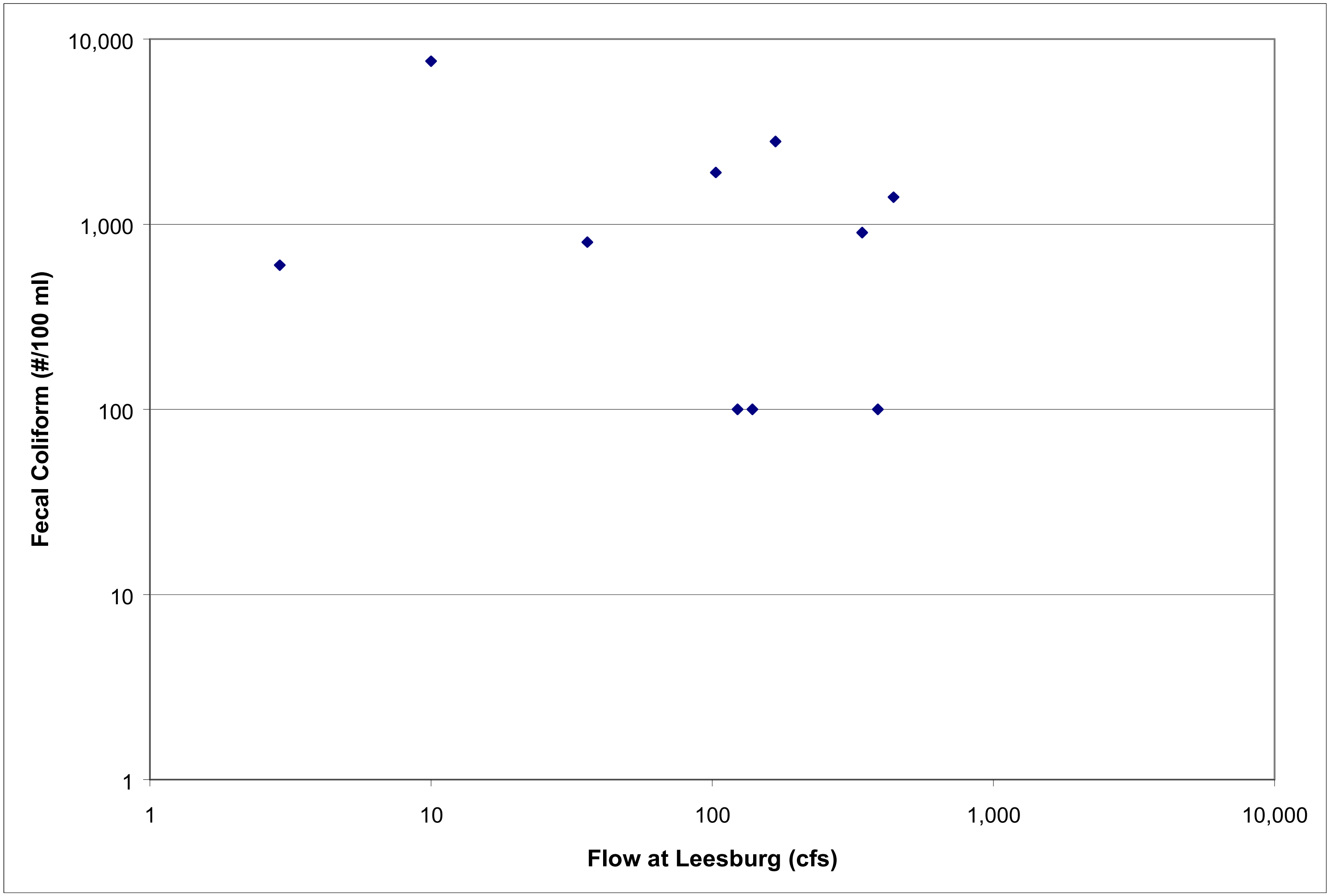

Figure A.21 Observed fecal coliform concentrations at Upper Sycolin Creek (1ASYC004) versus flow at Leesburg

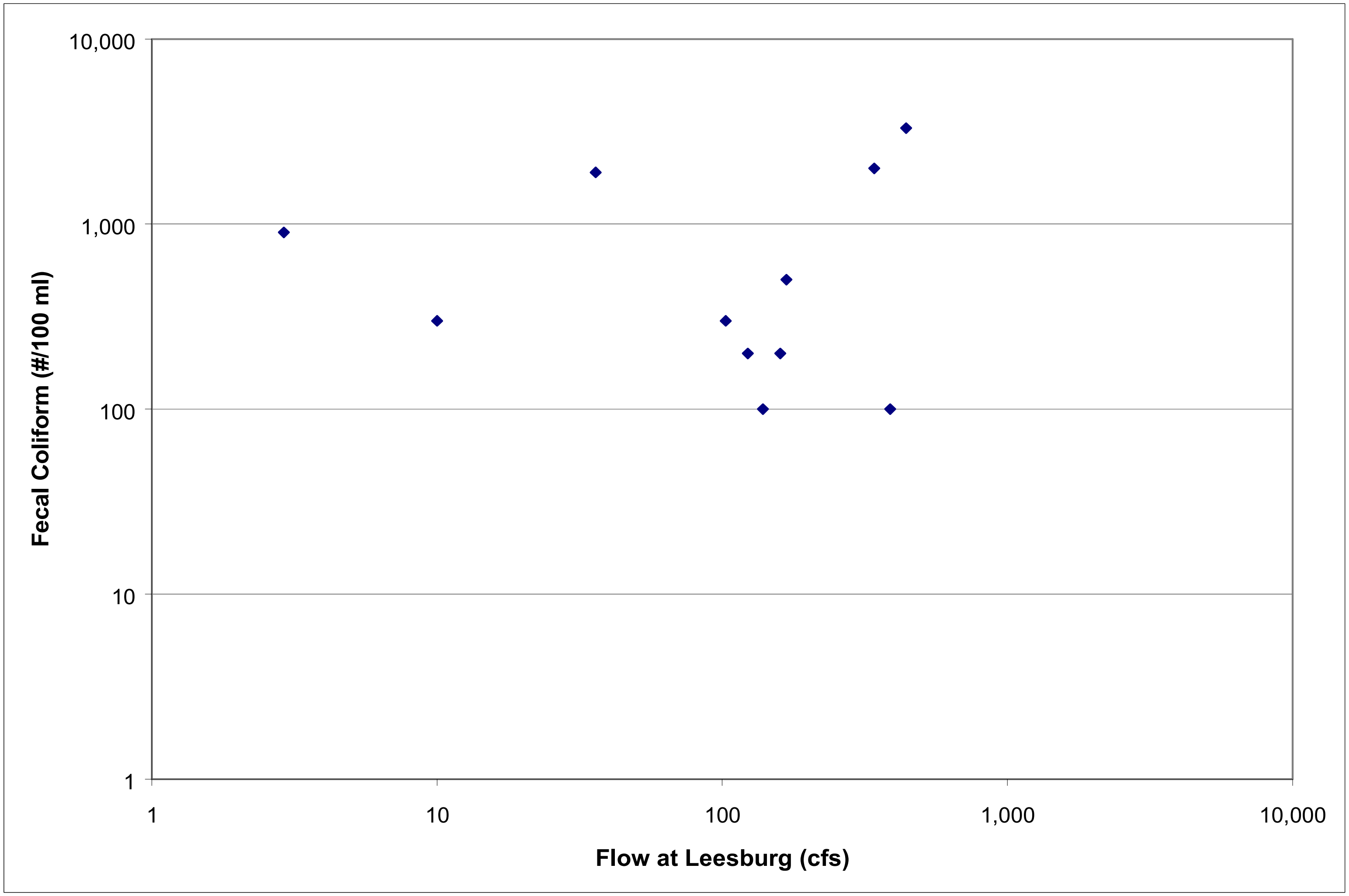

Figure A.22 Observed fecal coliform concentrations at South Folk Sycolin Creek (1ASFS000) versus flow at Leesburg

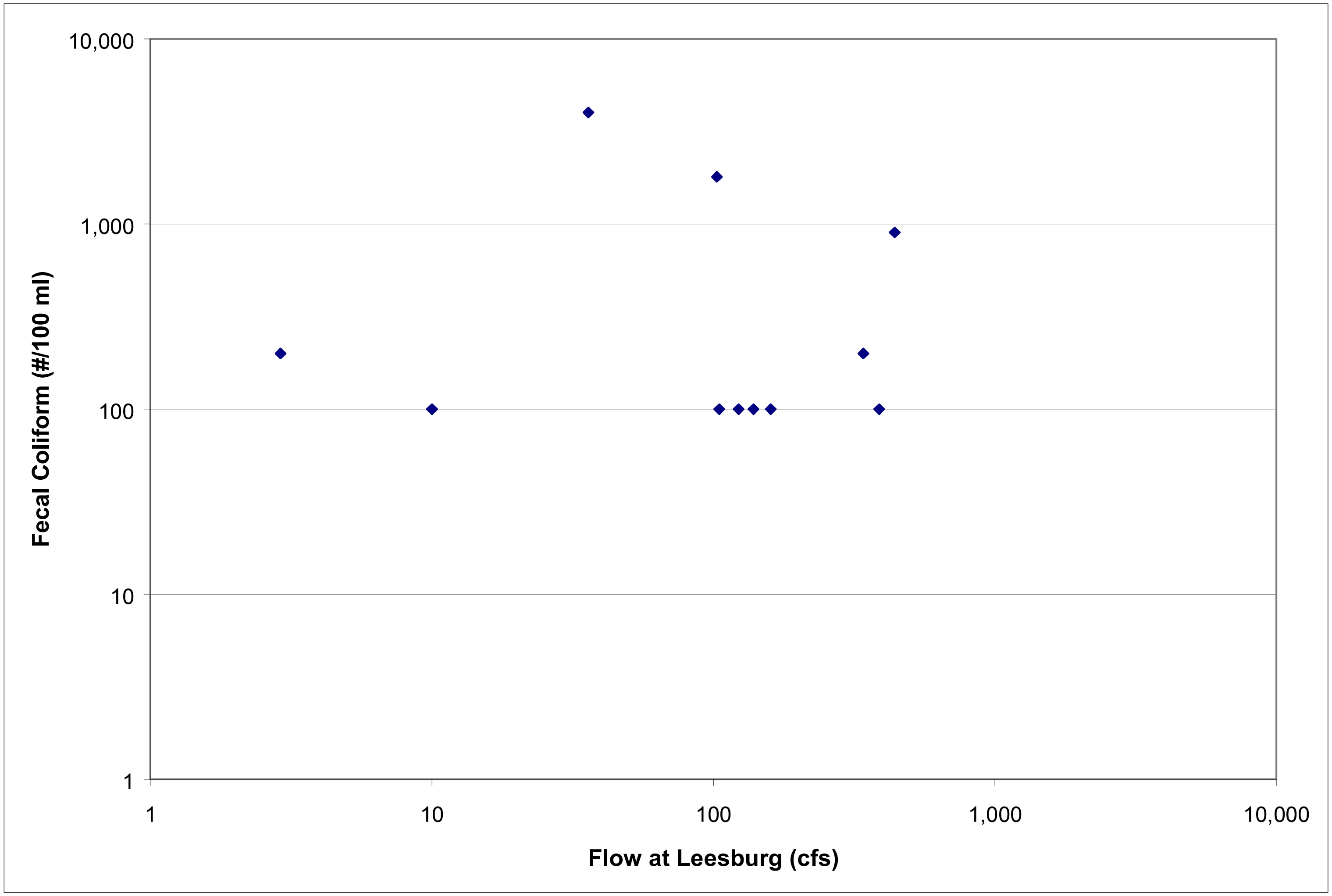

Figure A.23 Observed fecal coliform concentrations at North Folk Sycolin Creek (1ASYC007) versus flow at Leesburg

APPENDIX B: USE OF ANTIBIOTIC RESISTANCE ANALYSIS (ARA) TO IDENTIFY NONPOINT SOURCES OF FECAL CONTAMINATION IN THE GOOSE CREEK WATERSHED

Use of Antibiotic Resistance Analysis (ARA) to Identify Nonpoint Sources of Fecal Contamination in the Goose Creek Watershed

Final Report presented to the Interstate Commission on the Potomac River Basin

Bruce A. Wiggins*

August 31, 2002

The antibiotic resistance analysis (ARA) method of determining the sources of fecal contamination in natural waterways was applied to the Goose Creek watershed. ARA involves isolation of indicator bacteria (enterococci) from different known fecal samples, as well as from unknown water samples. Source identification is accomplished by using the statistical method of discriminant analysis to classify each isolate extracted from water by comparing its antibiotic resistance patterns with the resistance patterns of isolates taken from known fecal samples. The potential sources of fecal contamination in Goose Creek that were tested were beef cattle, dogs, horses, humans, geese, and deer. Eleven stations in the Goose Creek watershed were sampled monthly from September 2001 through July 2002. The samples were processed using ARA, and fecal coliform counts were measured to evaluate the quantity of fecal material in the water. The results indicate that several sources, including beef cattle, deer, and human contribute to the fecal pollution in Goose Creek. Bacteria from beef cattle and deer sources make up the majority of the fecal coliforms found in Goose Creek.

Introduction

Fecal contamination in natural waterways can lead to several problems, including an increased incidence of pathogens (3). Additionally, the increased levels of phosphorous and nitrogen in natural waterways due to fecal pollution can lead to algal blooms that, when degraded, result in deoxygenation of waterways (1). This situation is currently leading to a deterioration of the aquatic environment in the Chesapeake Bay. Fecal contamination in waterways has consistently been demonstrated by the presence of indicator organisms such as fecal coliforms or enterococci (3). However, differentiation of the sources of fecal contamination in waters receiving mixed agricultural and human waste is more difficult. Knowledge of the source of fecal contamination is important because humans are more susceptible to infections by pathogens found in human feces (3). Once the source is identified, steps can be taken to control the influx of fecal pollution.

Several approaches have been developed for the source identification of fecal contamination. The ratio of fecal coliforms to fecal streptococci, and the presence of certain bacteriophages as source indicators have been used (4). Another method involves DNA "fingerprinting" of fecal coliforms using pulsed field gel electrophoresis (PFGE) analysis to differentiate between the variations in restriction fragments of bacteria that are found in the feces of different hosts (2). Ribotyping uses the slight differences in ribosomal RNA in *E. coli* isolated from the feces of different hosts to identify the source of fecal pollution (2).

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Antibiotic resistant bacteria can develop in animals and humans as a result of treatment with antibiotics. Our laboratory has developed antibiotic resistance analysis (ARA), which uses enterococci as an indicator organism in identification of sources of fecal contamination (4). Enterococci are a group of gram-positive, catalase-negative cocci that hydrolyze esculin, and are capable of growing at 6.5% NaCl and at 45°C. Enterococci are used because they survive well in natural waters and can be isolated from all potential sources of fecal pollution (4, 5). In this approach, enterococci are isolated from known fecal sources, and grown on plates containing various concentrations of 11 different antibiotics. The resulting antibiotic resistance patterns of each isolate are then analyzed using discriminant analysis, a multivariate statistical method. The results are pooled to form a "known library" of antibiotic resistance patterns from different fecal sources. Resistance patterns of isolates from natural waterways are then compared with this known library to determine the source(s) of fecal pollution in that waterway (4, 5).

In this report, ARA and fecal coliform counts were used to draw conclusions about the source(s) of fecal contamination in the Goose Creek watershed. Goose Creek and its tributaries are located in Loudon and Fauquier Counties, Virginia, and is highly polluted with fecal matter. Goose Creek flows into the Potomac River , which flows into the Chesapeake Bay. The possible sources of fecal contamination in the Goose Creek watershed have been identified as beef cattle, failing septic systems, dogs, horses, geese, and deer. Eleven monthly sets of samples were analyzed during the course of the project.

Materials and Methods

Sample Collection

Stream samples were collected by Lynn Meadows from the DEQ-NVRO and shipped by overnight delivery to the laboratory. Known samples were collected by C. J. Mitchem from Engineering Concepts, Inc. Known samples were collected in sterile whirl-pack bags, and stream samples were collected in sterile 500-ml bottles. The numbers and sources of the known samples are shown in Table 1. Eleven sites were sampled in the Goose Creek watershed during each sampling event (Table 2). Stream (unknown) samples were received as shown in Table 3. A total of 115 stream samples were collected. The goal was to test 46 isolates from each sample, resulting in a precision of approximately 2%. Because of low counts, fewer isolates were analyzed for some samples.

Isolation of enterococci

Varying amounts of fecal samples (0.1 – 0.5 g) were suspended in 50 ml of saline buffer. The sample was mixed vigorously before filtering through 0.45-µm pore-size filters. Varying volumes of unknown water samples were filtered using the same filters. The filters were placed in 50 mm petri dishes containing 5 ml of m-Enterococcus agar. The petri dishes were incubated at 37°C for 48 hours. After incubation, isolated colonies were selected (48 for unknown samples, and 12-24 for known samples) and transferred to 96-microwell plates containing 0.2 ml of Enterococcosel broth. The microwell plates were incubated at 37°C for 48 hours. Esculin-negative isolates were not analyzed.

Counting of Fecal Indicator Organisms

Fecal coliform (FC) counts were performed by filtering various volumes of all unknown stream samples, and of the suspended fecal samples (as described above). The filters were then placed in 50 mm petri-dishes containing 5 ml of m-FC agar. The petri dishes were incubated in a water bath at 44.5°C for 18 – 24 hours. After incubation, the number of blue colonies were enumerated and recorded. In the tables, the values in the "average" rows are geometric means.

Enteroccocci counts were performed by filtering various volumes of all unknown stream samples, and of the suspended fecal samples (as described above). The filters were then placed in 50 mm petri-dishes containing 5 ml of mEnterococcus agar. The petri dishes were incubated at 37°C for 48 hours. After incubation, the number of red colonies were enumerated and recorded. In the tables, the values in the "average" rows are geometric means.

Antibiotics

Isolates from the 96-microwell plate were transferred to antibiotic-containing Trypticase Soy agar (TSA) plates using a sterile 48-prong replica-plater. Various concentrations of 11 antibiotics were used (37 concentrations total) (6). The isolates were also replica-plated to two TSA plates that did not contain antibiotics as a control. All TSA plates were incubated at 37°C for 24-48 hours. After incubation, the growth of each isolate on each concentration of each antibiotic was determined, and the resulting antibiotic resistance patterns were combined to form a library of known sources. For known samples, isolates with identical resistance patterns were discarded. Only unique isolates were used in the known library (Table 1).

Statistical Analysis

The results from resistance testing were entered into the SAS statistical program where they were analyzed using the DISCRIM procedure, which produces a classification table. The average rate of correct classification (ARCC) is the average rate that known isolates are correctly classified, and was used to measure the reliability of the known library. To cross-validate the known library, jackknife analyses were performed by removing all of the isolates from each sample, and classifying them using the resulting library. This simulates how well the library can classify "new" isolates, and is an estimation of the representativeness of the library. If a library is representative of a watershed, then isolates from new samples should be classified as well (on average) as the isolates of that type that are in the library.

The Minimum Detectable Percentage (MDP) for each source type was determined by averaging the percentages of other source types that were misclassified as that type. This value is the minimum percentage for each particular source that can be detected in a stream sample.

Additional Libraries

In addition to the known isolates from the Goose Creek watershed, isolates from 5 other Virginia watersheds were used to create a larger, merged library. The watersheds used were: Blacks Run, Holmans Creek, Long Glade Creek, Moores Creek, and Thumb Run.

Results

Library Construction

A library of the isolates obtained from the six types of known sources was constructed. As shown in Table 1, this Goose Creek library consisted of 468 unique isolates. Discriminant analysis was performed on this library at three levels of classification: two-way (human vs. animal), three-way (human vs. domestic vs. wild) and six-way (all six sources). For the two-way analyses, beef, deer, dog, goose, and horse isolates were pooled together as animal. For the three-way analyses, beef, dog, and horse isolates were pooled together as domestic, and deer and goose isolates were pooled together as wild.

When a two-way analysis was performed on the Goose Creek library, 84% of the animal isolates and 73% of the human isolates were correctly classified, resulting in an average rate of correct classification (ARCC) of 78% (random classification would be 50%) (Table 4). However, jackknife analysis of this library resulted in an ARCC of just 62%, which is not greatly higher than the 50% level of random classification. This suggests that the Goose Creek library is not a representative library, probably because of its small size. A three-way analysis of the library resulted in an ARCC of 65% (random classification would be 33%) (Table 5). Again, however, jackknife cross-validation resulted in an ARCC of only 49%. Similarly, the six-way classification showed an ARCC of 55% (random classification would be 17%) (Table 6), but the jackknife analysis was just 31%.

The low ARCCs resulting from jackknife analysis suggests that the library collected for this project is not representative of the isolates in the watershed, i.e., it does not contain enough different patterns, and thus it will not do well in classifying new isolates. To avoid this problem, the isolates from the Goose Creek library were combined with a much larger library comprised of 4,609 isolates from the same types of sources collected in other watersheds in Virginia. Although larger libraries generally have slightly lower ARCCs, they are much more representative, and thus the confidence in the results is higher. When a two-way analysis was performed on this merged Virginia library, the ARCC was 76% (Table 7). The jackknife ARCC was 74%, showing that this library is very good at classifying new patterns. The ARCC for the three-way analysis was 61% (Table 8), and the jackknife ARCC was slightly lower at 56%. The six-way analysis showed an ARCC of just 47% (Table 9), and the jackknife ARCC was 38%. Because the merged library showed lower reductions in ARCC when cross-validated with jackknife analysis, this library was used to classify the unknown isolates from the Goose Creek watershed.

Based on the merged library, the Minimum Detectable Percentage (MDP) values were calculated. These values were approximately 25% with the two-way analysis (Table 7). This means that if the percentage of, for example, animal isolates in a sample exceeds 25%, we can be confident that these are actually animal isolates, and not human isolates that have been misclassified. With the three-way analysis, the MDPs were approximately 20% (Table 8), and ranged from 9% to 13% for the six-way analysis (Table 9).

Levels of Indicator Organisms

Fecal coliform levels were generally low in most samples. Only 9 of the 115 samples had FC levels above the standard of 1000 FC/100 ml (Table 10). The geometric mean of the FC counts over the 11 months exceeded 200 FC/100 ml at stations 1, 2, 6 and 10. Some sampling days showed much higher geometric means than others. Eight of the twenty-one sampling days had geometric means greater than 200 FC/100 ml (Table 14). These means ranged from 13,133 FC/100 ml on September 25th to as low as 12 FC/100 ml on February 7th. Enterococci counts were similar to FC counts in the water samples. The correlation between the logs of the indicator counts was 80%.

Fecal coliform and enterococci counts were also measured in the known fecal samples. Counts ranged from 5×10^3 to 1×10^6 cells/g (Table 1). Generally, animal sources had somewhat higher levels of enterococci, with the exception of beef cattle. Human septic samples, which had higher FC than ENT counts, had much lower total counts, but this was because the fecal material was diluted in water.

Two-way Classification of Unknown Isolates: Human vs. Animal

Using the merged library, the 115 stream samples were classified. The results are shown in Tables 11 (listed by sample site) and 15 (listed by collection date). Both human and animal sources were identified in the stream. There was variation from station to station, and from day to day, but some clear trends are evident:

1. On average, all sampling stations are polluted by animals. Animal sources were above the MDP and were the major source at all 11 sites and on all but one sampling day. Animal sources were present at levels above the MDP for every individual sample.

2. Human pollution is present as well. Ten of eleven stations had average values that were higher than the MDP. There were 69 of the 115 samples with human values greater than the MDP, and 15 samples showed human as the major source. Human was the dominant source on just one of the sampling days.

Three-way Classification of Unknown Isolates: Human vs. Domestic vs. Wild

The results of the three-way analysis are shown in Tables 12 (listed by sample site) and 16 (listed by collection date). All three sources were identified in the stream. Again, some clear trends are evident:

1. Pollution from human sources was detected at all sampling stations. On average, human isolates were above the MDP at 10 of 11 stations. The percentage of human isolates was above the MDP in 71 of the 115 samples, and human was the major source in 26 samples. On average, human was the dominant source on 4 sampling days, 3 of which occurred in late September and early October.

2. Pollution from domestic sources is present as well. On average, domestic sources were dominant at 7 of the 11 stations. Domestic sources were not detected in just 8 samples, and were the major source in 56 of the 115 samples. Domestic sources were the dominant source on 13 of the 21 sampling days.

3. On average, pollution from wild sources was above the MDP at all sampling stations, and was the major source at 4 stations. The percentage of wild isolates was above the MDP in 103 of the 115 samples, and wild was the major source in 39 samples. Wild sources were the dominant source on just 4 of the sampling days.

Six-way Classification of Unknown Isolates: Beef vs. Deer vs. Dog vs. Goose vs. Horse vs. Human

To determine which animal sources are contributing to the pollution in Goose Creek, six-way analyses were performed. The results of these analysis are shown in Tables 13 (listed by sample site) and 17 (listed by collection date). A summary of this analysis is shown in Table 18. All six sources were identified in the stream. Again, some clear trends are evident:

1. Beef and deer sources were the most common. On average, beef isolates were dominant at 5 sites, deer isolates were dominant at 6 sites. Beef was the dominant source in 45 samples, and deer was dominant in 42 samples. The percentage of beef isolates was above the MDP in all but 26 samples, and deer isolates were found above the MDP in all but 22 samples. There was no real temporal variation in these two sources, although samples during the winter months (October through January) tended to have deer as the dominant source, while summer samples (May, June, and July) had beef as the dominant source, although there were exceptions during these times.

2. Human isolates, while not dominant at any site, were detected on average at levels above the MDP at all 11 sites. Human was the dominant source in 24 of the 115 samples, and was above the MDP in 85 of the samples. Human was the dominant source in both September samplings.

3. Goose isolates were found at levels above the MDP at 9 of 11 sites, but most of the averages were very close to the detection limit of 9%. Goose was found at percentages above the MDP in 51 of the 115 samples, ands was the dominant source in 5 samples. Three of these samples were collected on March 26th.

4. Horse isolates were detected at levels above the MDP in 38 samples, and was the dominant source in 6 samples. Two of these were collected on May 9th.

5. Dog isolates were detected only at low levels. Only 6 samples had percentages of dog isolates above the MDP, and was the dominant source in one of these.

Conclusions

These results show that both humans and animals are major sources of pollution in the Goose Creek watershed. Almost every site had average percentages of both animal and human sources that were at or above the minimum detectable level. Of the animal sources, the dominant sources are beef cattle and deer. Horse and goose sources were present at smaller levels, and dog was not a significant source of fecal pollution.

There was very little variation in the source types, either temporally or by site. All sites generally were polluted by beef, deer, and human, and the proportions only shifted slightly during the year, with deer being slightly higher in the winter, and beef slightly higher in the summer. On the two days with very high indicator counts, there was no pattern in the sources: on September 25th the dominant source was human and on March 21st the dominant source was beef.

Limitations of this study. The water samples analyzed in this study were collected over an eleven-month period. There may be year-to-year variation in the numbers and proportions of sources that were not included in the time frame of this study. Additionally, keep in mind that all BST methods, including ARA, are still being developed, and there are no "standard methods" yet for any method. There are many variables that determine the sources of fecal bacteria in water, and many of them are poorly understood.

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Table 1. Numbers of known fecal samples and isolates used in this study, and approximate averages of the numbers of indicator organisms in each source.

Source	No. of Samples	Total No. of Isolates	No. of Unique Isolates	Ave. No. of FC	Ave. No. of ENT
Beef Cattle	10	110	76	1.70E+04	5.70E+03
Deer	11	126	87	5.50E+05	8.60E+05
Dog	15	161	84	6.50E+04	1.10E+06
Goose	10	116	66	5.10E+03	4.80E+04
Horse	10	107	64	7.60E+03	1.10E+04
Human	11	115	91	1.50E+02	6.00E+01
Totals	67	735	468	--	--

Table 2. Location and description of sampling sites in the Goose Creek watershed.

Site	DEQ Number	Description
1	1aCRM001.20	Cromwells Run
2	1aNOG005.69	North Fork of Goose Creek
3	1aBEC004.76	Beaverdam Creek
4	1aSYC002.03	Sycoline Creek
5	1aLIV004.78	Little River
6	1aGOO044.36	Goose Creek
7	1aGOO022.44	Goose Creek
8	1aGOO0002.38	Goose Creek
9	1aGOO011.23	Goose Creek, USGS gauge
10	1aLIV001.70	Little River
11	1aTUS000.37	Tuscarora Creek

Table 3. Dates of sampling the sites in the Goose Creek watershed. All samples were analyzed on the day after they were collected. Set 1: sites # 4, 5, 8, 9, 10, and 11. Set 2: sites #1, 2, 3, 6, and 7. NS = no samples received.

Month	Date Set 1 Collected	Date Set 2 Collected
September 2001	9/24	9/25
October 2001	10/10	10/13
November 2001	11/14	11/15
December 2001	NS	12/12
January 2002	1/23	1/24
February 2002	2/6	2/7
March 2002	3/26	3/21
April 2002	4/11	4/10
May 2002	5/8	5/9
June 2002	6/4	6/5
July 2002	7/1	7/2

Table 4. Classification of 468 isolates of enterococci from known animal and human sources in the Goose Creek watershed. Correctly-classified isolates are shown in bold. The ARCC for this analysis is 78%.

	Number (and Percent) of Isolates Classified As:	
SOURCE	ANIMAL	HUMAN
ANIMAL (n = 377)	**316 (84)**	61 (16)
HUMAN (n = 91)	25 (27)	**66 (73)**
MDP	27	16

Table 5. Classification of 468 isolates of enterococci from known human, domestic, and wild sources in the Goose Creek watershed. Correctly-classified isolates are shown in bold. The ARCC for this analysis is 65%.

	Number (and Percent) of Isolates Classified As:		
SOURCE	HUMAN	DOMESTIC	WILD
HUMAN (n = 91)	**61 (67)**	23 (25)	7 (8)
DOMESTIC (n = 224)	39 (18)	**133 (59)**	52 (23)
WILD (n = 153)	16 (11)	34 (22)	**103 (67)**
MDP	15	24	16

Table 6. Classification of 468 isolates of enterococci from known beef, deer, dog, goose, horse, and human sources in the Goose Creek watershed. Correctly-classified isolates are shown in bold. The ARCC for this analysis is 55%.

	Number (and Percent) of Isolates Classified As:					
SOURCE	BEEF	DEER	DOG	GOOSE	HORSE	HUMAN
BEEF (n = 76)	**51 (67)**	4 (6)	1 (1)	9 (12)	10 (13)	1 (1)
DEER (n = 87)	19 (22)	**39 (45)**	2 (2)	13 (15)	10 (11)	4 (5)
DOG (n=84)	4 (5)	1 (1)	**64 (76)**	4 (5)	5 (6)	6 (7)
GOOSE (n=66)	8 (12)	7 (10)	4 (6)	**38 (59)**	7 (10)	2 (3)
HORSE (n=64)	16 (25)	10 (16)	1 (1)	16 (25)	**17 (27)**	4 (6)
HUMAN (n=91)	12 (13)	5 (6)	14 (15)	3 (3)	4 (5)	**53 (58)**
MDP	15	8	5	12	9	4

Table 7. Classification of 4,609 isolates of enterococci from known animal and human sources from several Virginia watersheds, including Goose Creek. Correctly-classified isolates are shown in bold. The ARCC for this analysis is 76%.

	Number (and Percent) of Isolates Classified As:	
SOURCE	ANIMAL	HUMAN
ANIMAL (n = 2,639)	**2,012 (76)**	627 (24)
HUMAN (n = 1,970)	496 (25)	**1,474 (75)**
MDP	25	24

Table 8. Classification of 4,609 isolates of enterococci from known human, domestic, and wild sources from several Virginia watersheds, including Goose Creek. Correctly-classified isolates are shown in bold. The ARCC for this analysis is 61%.

	Number (and Percent) of Isolates Classified As:		
SOURCE	HUMAN	DOMESTIC	WILD
HUMAN (n = 1,970)	**1,345 (68)**	321 (16)	304 (16)
DOMESTIC (n = 2,024)	379 (19)	**1,197 (59)**	448 (22)
WILD (n = 615)	115 (19)	153 (25)	**347 (56)**
MDP	19	20	19

Table 9. Classification of 4,609 isolates of enterococci from known beef, deer, dog, goose, horse, and human sources from several Virginia watersheds, including Goose Creek. Correctly-classified isolates are shown in bold. The ARCC for this analysis is 47%.

	Number (and Percent) of Isolates Classified As:					
SOURCE	BEEF	DEER	DOG	GOOSE	HORSE	HUMAN
BEEF (n = 1,308)	**491 (38)**	194 (15)	165 (13)	108 (8)	226 (17)	124 (9)
DEER (n = 189)	31 (16)	**89 (47)**	3 (2)	4 (2)	45 (24)	17 (9)
DOG (n=376)	8 (2)	12 (3)	**224 (60)**	48 (13)	22 (6)	62 (16)
GOOSE (n=426)	38 (9)	76 (18)	27 (6)	**176 (41)**	58 (14)	51 (12)
HORSE (n=340)	66 (19)	70 (21)	16 (5)	30 (9)	**137 (40)**	21 (6)
HUMAN (n=1,970)	157 (8)	122 (6)	330 (17)	239 (12)	63 (3)	**1,059 (54)**
MDP	11	13	9	9	13	10

Table 18. The sources of fecal contamination found in Goose Creek watershed. B = beef, D = deer, C = dog (canine), G = goose, E = horse (equine), H = human. "X" = above MDP. "**X**" = dominant source. "-" = not sampled.

Month	Site 1						Site 2						Site 3						Site 4						Site 5						Site 6					
	B	D	C	G	E	H	B	D	C	G	E	H	B	D	C	G	E	H	B	D	C	G	E	H	B	D	C	G	E	H	B	D	C	G	E	H
Sep-01		X			X	**X**		X			X	**X**		X			X	**X**	X	**X**				X		X			X	**X**					X	**X**
Oct-01		**X**			X	X	**X**						**X**	X		X		X		X				**X**	X	**X**		X		X	X	**X**				X
Nov-01	X	**X**			X	X	X	**X**						**X**			X		**X**	X					X	**X**				X		**X**		X		X
Dec-01		**X**		X			X	**X**		X			**X**	X		X			-	-	-	-	-	-	-	-	-	-	-	-	X	**X**		X		X
Jan-02	**X**	X				X	X	X			**X**		X	**X**				X		X				**X**	X	**X**				X		**X**			X	X
Feb-02	X	**X**		X		X	**X**	X			X	X	**X**	X					X	**X**				X	X	**X**					**X**	X		X		X
Mar-02	**X**	X		X		X	X		X			**X**	**X**	X		X		X	X	X		**X**		X	**X**			**X**		X	**X**	X		X		X
Apr-02		**X**		X		X	**X**	X				X	X	**X**						**X**		X	X	X	X	**X**		X		X		**X**	X	X		X
May-02				X	X	**X**	X			X	**X**	X		X			**X**	X	X	X			**X**		**X**	X			X	X				X	X	**X**
Jun-02	X			**X**	X	X	**X**	X		X	X	X	**X**	X		X	X	X	**X**	X				X		**X**		X	X	**X**	X	X		X	**X**	X
Jul-02	**X**			X		X	**X**	X					**X**	X			X			X			**X**	X	X			X		**X**	**X**			X		X

Month	Site 7						Site 8						Site 9						Site 10						Site 11					
	B	D	C	G	E	H	B	D	C	G	E	H	B	D	C	G	E	H	B	D	C	G	E	H	B	D	C	G	E	H
Sep-01		X			X	**X**		**X**			X	**X**	X	**X**				**X**	X	X				**X**		X		X	X	**X**
Oct-01	X	**X**			X		X	**X**			X		X	X				**X**	**X**	X					X	**X**				**X**
Nov-01	X	**X**		X		X		**X**				X	X	**X**					X	**X**				X		**X**				X
Dec-01	X	**X**		X			-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Jan-02		**X**				X	**X**	X				X	X	**X**					**X**			X		X	X	**X**		X		**X**
Feb-02	**X**	X					**X**	X	X		X		**X**	X				X		**X**	X	X			X	**X**		X	X	X
Mar-02	**X**		X	X		X	X			X		**X**	**X**			**X**		**X**	**X**							**X**				X
Apr-02	X	**X**	**X**	X	X	X	X					**X**	**X**			X			**X**	X		X		X	X	**X**		X		X
May-02	**X**			X	X	X	**X**	X		X			**X**	X		X	X	X	X	X		**X**	X		**X**	X			X	
Jun-02	X	X				**X**	**X**	X		X		X	**X**					X	**X**			X		X	**X**	X				
Jul-02	**X**	X		X		X	**X**	X				X	**X**	X		X		X	**X**	X					**X**				X	X