6. Pollutant Load Reduction and Allocation

This chapter discusses the pollutant load reductions required to meet the TMDL requirements for the streams in the Neshanic River Watershed. A TMDL is a calculation of the maximum amount of a pollutant that a waterbody can receive and still meet water quality standards, and an allocation of that amount to the pollutant's sources. The development of TMDLs is required by EPA for all impaired streams. A TMDL for fecal coliform was adopted for the Neshanic River by NJDEP in 2003. It requires 87 percent reduction in fecal coliform from medium/high density residential, low density/rural residential, commercial, industrial, mixed urban/other urban, forest and agricultural lands (NJDEP, 2003). A total nutrient TMDL for the Raritan Basin that contains the Neshanic River Watershed was developed and is still under review by NJDEP. The adopted fecal coliform TMDL and the nutrient TMDL under development are all based on the water quality monitoring data at the USGS Reaville Gage Station, and therefore cover only the upper portion of the Neshanic River Watershed restoration planning area. Therefore, the project team developed its own pollutant load reductions to meet the TMDL requirement in the Neshanic River Watershed.

6.1. Load Reduction Targets

6.1.1. Load Duration Curve Method

A TMDL is the sum of the allowable loads of a single pollutant from all contributing point and nonpoint sources. Calculation of a TMDL must include a margin of safety (MOS) to ensure that a waterbody can be used for its designated use and account for seasonable variation in water quality. A TMDL has been defined by the following simple equation:

$$TMDL = LC = WLA + LA + MOS + RC \tag{6.1}$$

where: LC = loading capacity; WLA = wasteload allocation for point sources; LA = load allocation for nonpoint sources; MOS = margin of safety; and RC = reserve capacity.

Rearranging Equation 6.1, a Modified Loading Capacity (LC') is defined as:

$$LC' = LC - MOS - RC = WLA + LA \tag{6.2}$$

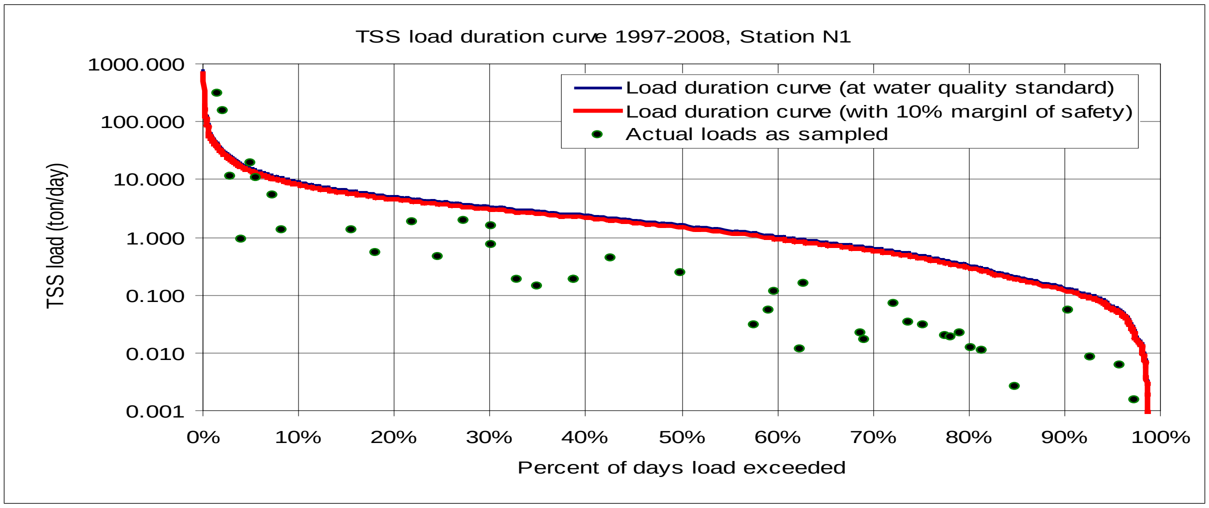
LC' equals the TMDL allocated among all point and nonpoint sources taking into consideration both RC and MOS. LC' is often expressed as an average daily load based upon average long-term flow conditions and represents the long-term average TMDL. The latter have been dubbed as “bare bones” TMDLs due to the simplicity of the calculation. While these TMDLs satisfy the requirements of the Clean Water Act, they have contributed little to any watershed/waterbody assessment and restoration plans. These types of TMDLs do little to characterize the problems the TMDLs are intended to address and to identify and implement appropriate solutions (Rahl, 2002).

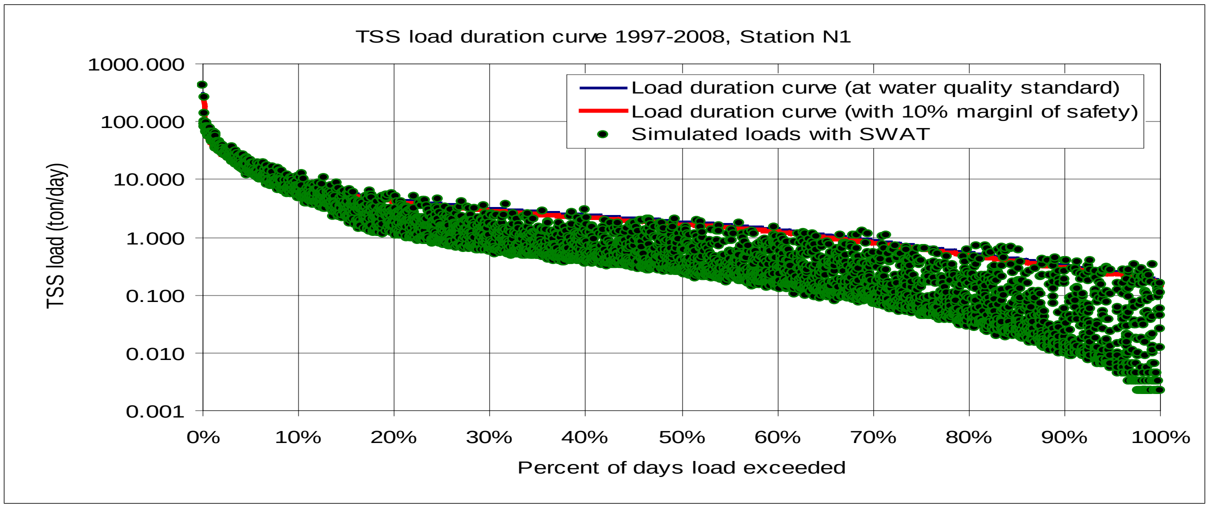
For TMDLs to be beneficial in the assessment and implementation process, they should reflect water quality for a range of flow conditions rather than for a single flow condition, such as average daily flow. This project uses a more robust load duration curve method for setting TMDL targets required by USEPA (2007). A load duration curve is a graph representing the percentage of time during which the value of a given parameter (e.g., flow or load) is equaled or exceeded. The load duration curve method is a useful tool for characterizing the pollutant problems over the entire flow regime (USEPA, 2007). The steps in developing a load duration curve are briefly described. The first step is to develop a flow duration curve using available daily streamflow data at the watershed outlet. A flow duration curve relates flow values to the percent of time those values have been met or exceeded. The second step is to develop a load duration curve by multiplying the ranked streamflow data by the water quality standard for the pollutant of concern and a unit conversion factor. The results are then multiplied by 0.9 to take into consideration the 10 percent MOS. The third step is to compare the measured or simulated water quality data to the desired pollutant loads by plotting the water quality data on the load duration curve developed in the second step. In order to do so, the water quality data measured in terms of concentration has to be converted into daily loads using the pollutant concentration and streamflow. Points above the pollutant load curve represent exceedance of the water quality standards and the associated allowable loadings. The "less than 10 percent" exceedance threshold is commonly used when defining the TMDL reduction targets. The fourth step is to assess the load reduction target if the frequency of exceedance is greater than 10 percent. Several load reduction rates can be applied to the calculated daily pollutant load from the measured or simulated water quality data to evaluate the resulting frequency of exceedance as in the third step. The largest reduction rate that achieves less than 10 percent frequency of exceedance is the TMDL load reduction target.

6.1.2. Load Reduction Targets

The load reduction target for the Neshanic River Watershed is defined as the total pollutant load reductions that are required to satisfy the water quality standards for the non-trout FW2 streams in the watershed as defined by NJDEP. A 10 percent MOS and less than 10 percent frequency of exceedance were adopted to determine the pollutant load reduction targets. Three sets of load duration curves were developed in the watershed for the time period 1997- 2008. Each set contains five load duration curves for five pollutants (i.e., TSS, TN, TP, fecal coliform and *E. coli*). The first set of load duration curves was based on observed streamflow and water quality data at the USGS Reaville Gage Station (i.e., N1 monitoring station in the watershed), whose drainage areas only contain the upper portion of the watershed. The second set of load duration curves was based on streamflow and water quality simulations obtained with the SWAT model at N1 station. Since there are no observed streamflow and water quality data at the watershed outlet, the third set of load duration curves was only based on the SWAT-simulated streamflow and water quality during the same period.

Figure 6.1 shows the load duration curves for TSS based on observed streamflow and TSS data at the N1 station (upper graph) and SWAT-simulated results at the N1 station (middle graph) and at the watershed outlet (lower graph). The observed TSS sampling results are distributed within the broad range simulated by SWAT. Given 10 percent of MOS, the frequencies of exceedance for TSS are about 7 and 8 percent based on the observed data and the SWAT-simulated results, respectively. Since the frequencies of exceedance are below 10 percent of the threshold, TSS contamination at the N1 station is not considered to be a water quality issue. However, the frequency of exceedance at the watershed outlet based on the SWAT-simulated results is about 12 percent. In order to reduce the frequency of exceedance to 10 percent or below, a 9 percent reduction in TSS concentration at the watershed outlet is required. Load duration curves for TN, TP, fecal coliform and *E. coli*. are shown in Figure 6.2, Figure 6.3, Figure 6.4 and Figure 6.5, respectively.





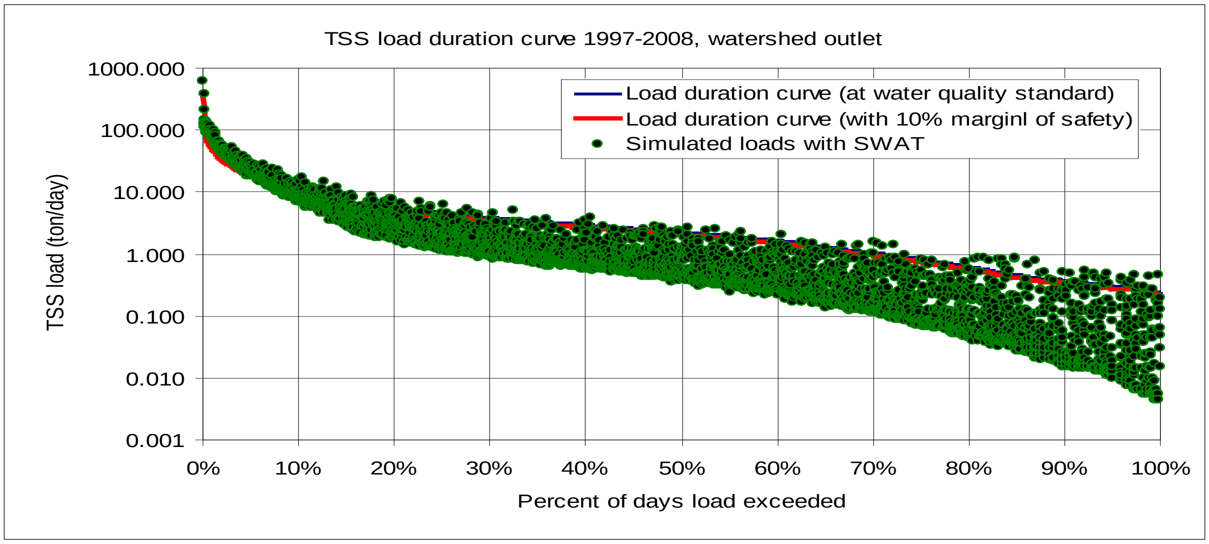
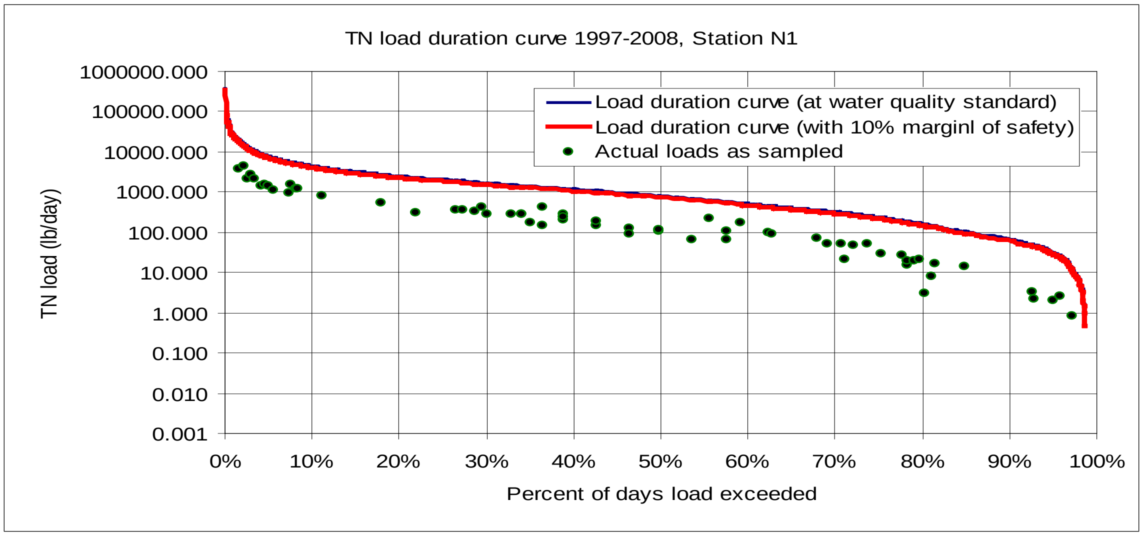
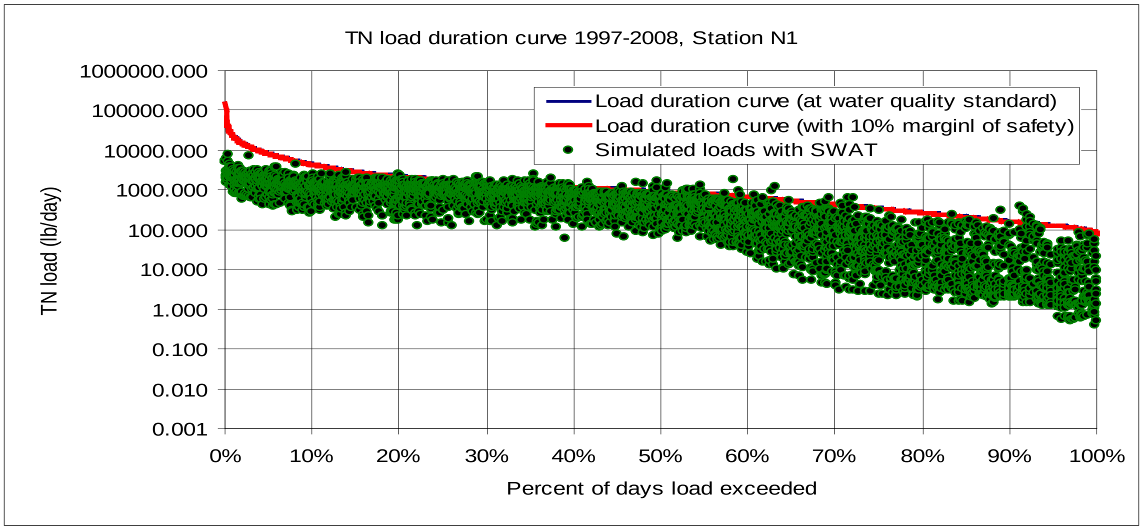


Figure 6.1: Load duration curves for TSS





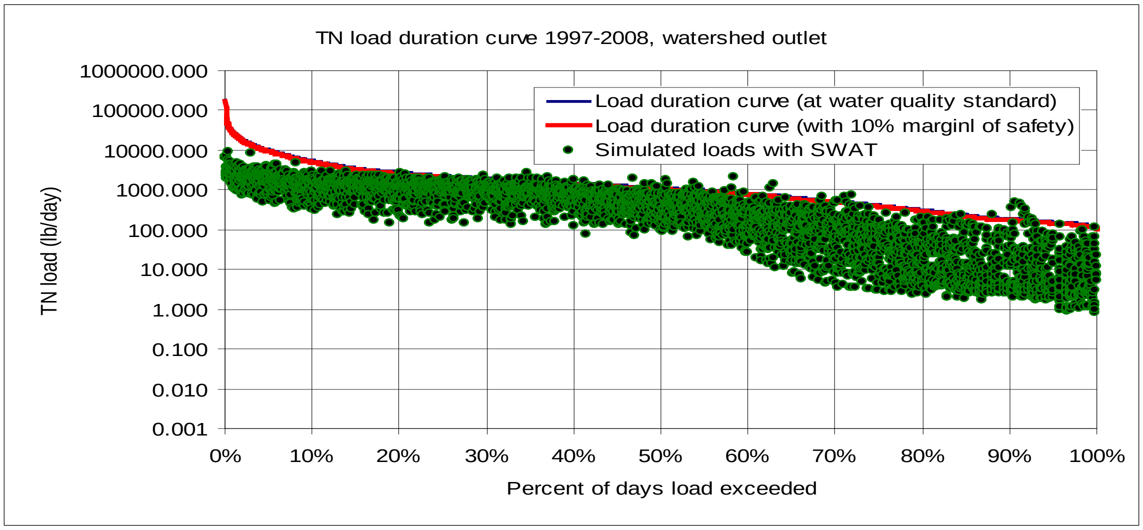


Figure 6.2: Load duration curves for TN

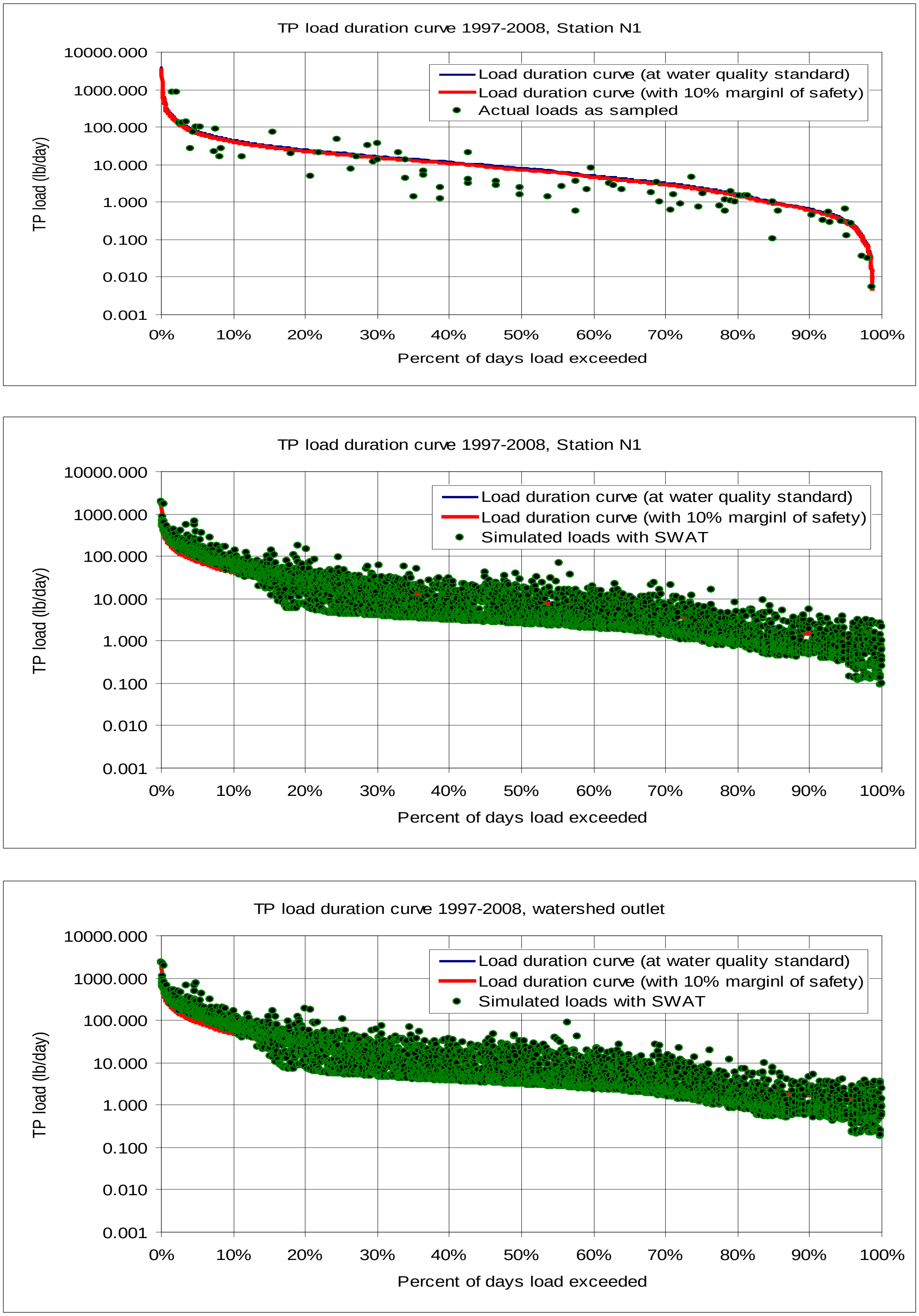


Figure 6.3: Load duration curves for TP

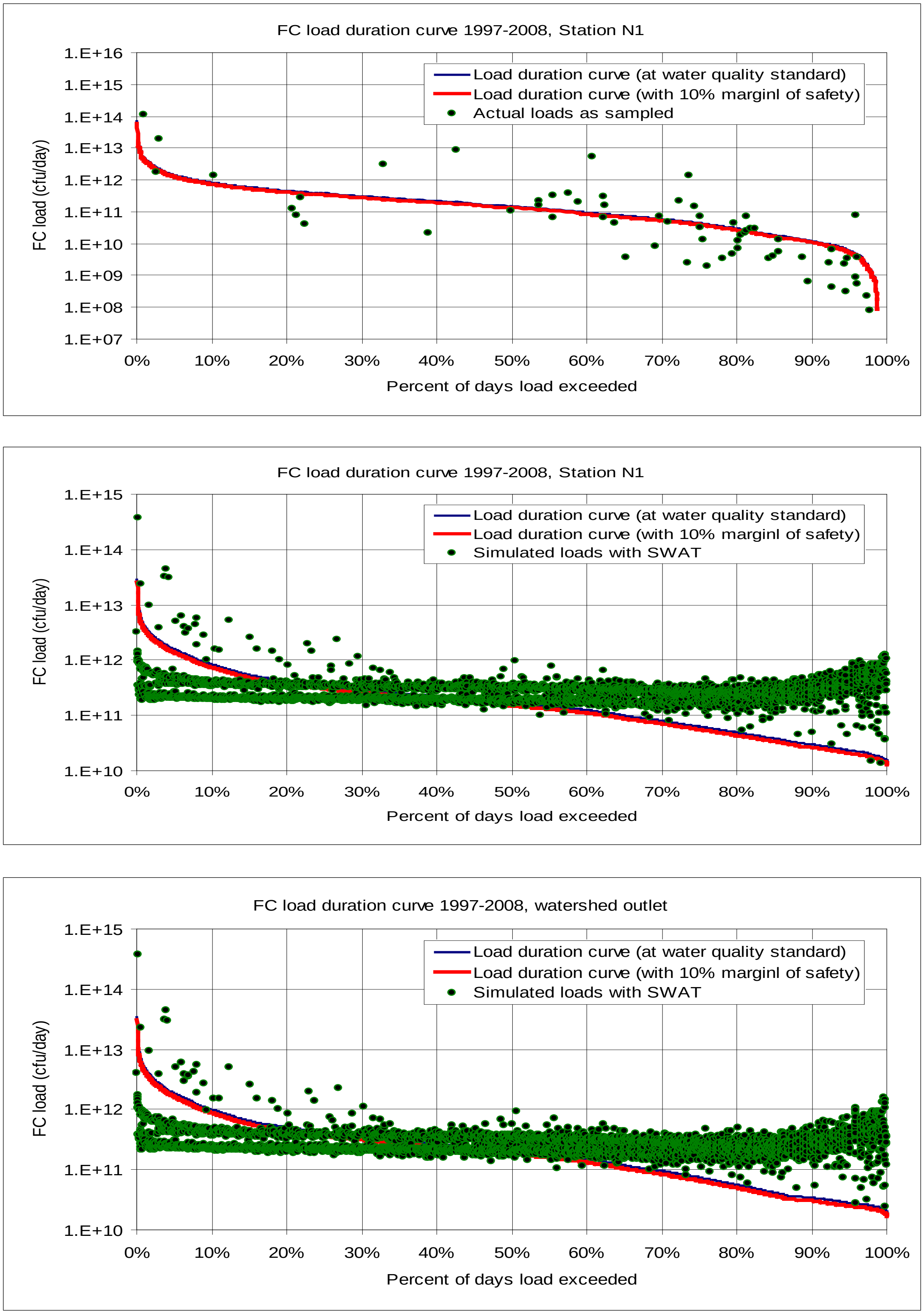


Figure 6.4: Load duration curves for fecal coliform

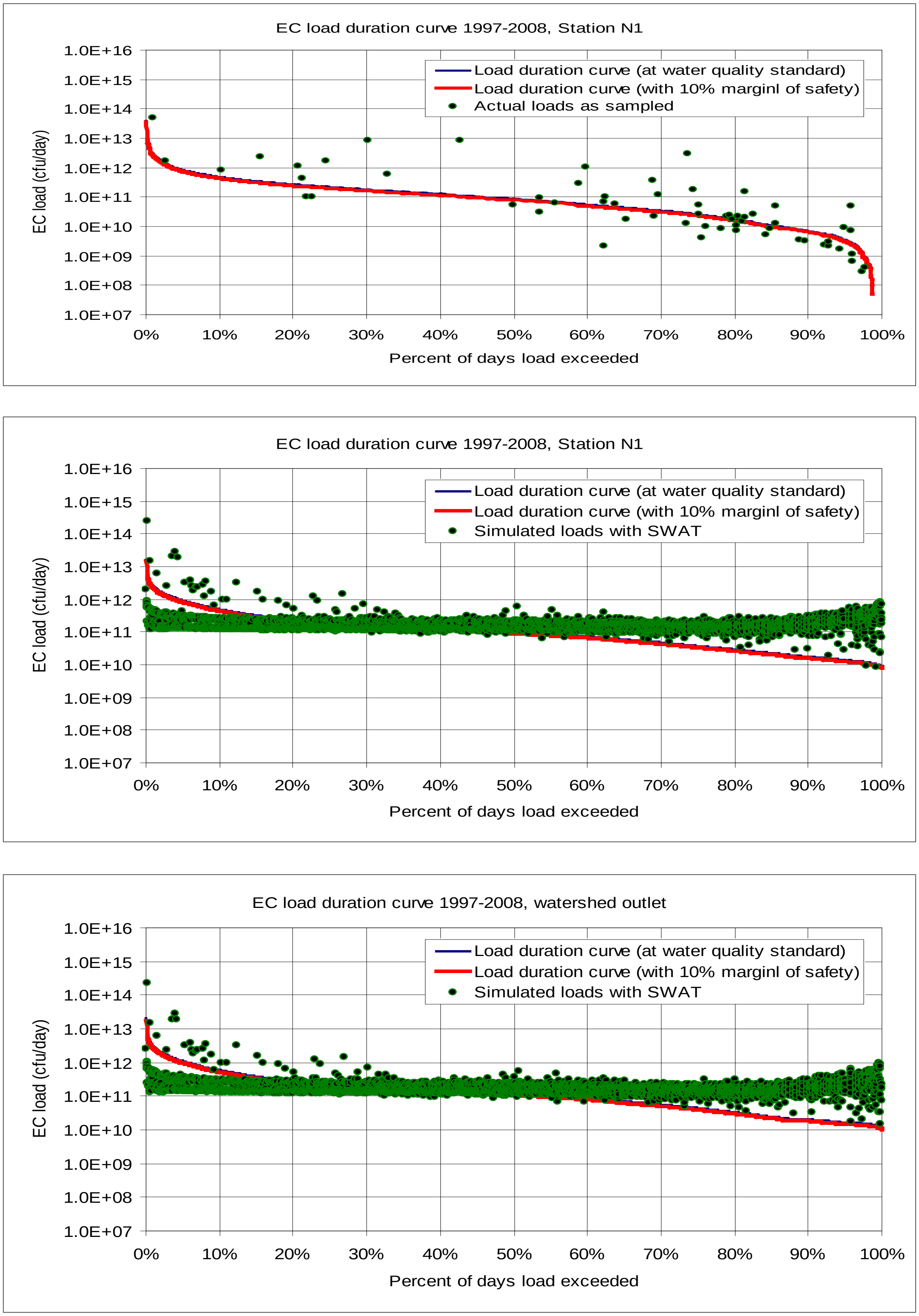


Figure 6.5: Load duration curves for *E. coli*

These load duration curves demonstrate interesting differences in the relationship between the pollutant and streamflow. For the load duration curves for TSS, TN and TP based on observed data at the N1 Station, there is a positive relationship between pollutant load and streamflow (i.e., a high pollutant load is associated with a high streamflow). Such a relationship implies that water pollution from TSS, TN and TP is dominated by nonpoint sources in the watershed. The positive relationships between fecal coliform and streamflow and *E. coli* concentrations and streamflow in the respective load duration curves based on observations at the N1 Station are not as obvious as for TSS, TN and TP. Many observed loads during medium and low streamflow are just as high as those during high streamflow. This phenomenon indicates that pathogenic contamination may be attributed to weather-independent and persistent sources, such as manure deposited by livestock into the streams and effluent from failing OSDS located near streams. Similar trends were observed for the load duration curves based on the SWAT simulations for both the N1 Station and watershed outlet. There is a flat band of simulated pollutant loads in the load duration curves for fecal coliform and *E. coli*, which results from the simplifying assumption that the effluent from failing OSDS into streams remains constant throughout the year and livestock manure deposited into streams remains constant during the grazing period.

The frequencies of exceedance of water quality standards and load reduction targets for the five pollutants of concern at the N1 station and watershed outlet are summarized in Table 6.1. Based on the observed streamflow and water quality data at the N1 Station, the frequencies of exceedance for TSS, TN, TP, fecal coliform and *E. coli* are about 7, 0, 30, 38 and 59 percent, respectively. While TSS and TN satisfy the threshold of “less than 10 percent” frequency of exceedance, the load reduction targets of 48, 90 and 91 percent for TP, fecal coliform and *E. coli*, respectively, are required to achieve the specified TMDL goals including MOS and the threshold for the frequency of exceedance at the N1 Station. The SWAT simulated results at the N1 Station show the frequencies of exceedance to be about 8, 2, 38, 61 and 63 percent for TSS, TN, TP, fecal coliform and *E. coli*, respectively. There is no load reduction requirement for TSS and TN, but there are load reductions of 48, 90 and 91 percent for TP, fecal coliform and *E. coli* relative to the respective TMDL goals. At the watershed outlet, the SWAT-simulated results indicate that the frequencies of exceedance for TSS, TN, TP, fecal coliform and *E. coli* are about 12, 1, 38, 61 and 63 percent, respectively. Load reduction targets need to be 9 percent for TSS, 49 percent for TP, 89 percent for fecal coliform and 89 percent for *E. coli* in order to meet the TMDL goals at the watershed outlet.

Table 6.1: Frequency of exceedance and load reduction target for the pollutants of concern in the Neshanic River Watershed

Pollutant of Concern	Frequency of Exceedance (percent)			Load Reduction Target (percent)		
	Observed Data at N1 Station	SWAT-Simulated Results		Observed Data at N1 Station	SWAT-Simulated Results	
		N1	Outlet		N1	Outlet
TSS	7.32	8.30	12.25	0	0	9
TN	0	2.03	1.76	0	0	0
TP	30.49	38.49	37.96	48	48	49
Fecal Coliform	37.50	61.15	60.96	90	90	89
E. coli	59.02	63.91	63.38	91	91	89

6.2. **BMP Assessment of Pollutant Load Reduction**

The previous section discusses the pollutant load reduction target required to achieve water quality standards in the watershed. This section uses the SWAT modeling results to evaluate the potential for achieving the pollutant load reduction targets with BMPs.

Table 6.2: Definition of BMPs

Number	BMP	Description
S0	Baseline	Modest N and P commercial fertilizer applications and reduced tillage for agricultural lands. Cattle and horse manures are applied to 11 percent of corn lands at standard rates. Minimum (chisel/disk plows) for crops in a corn-soybean-rye rotation; 6-year rotation moldboard/disk/hallow plows for hay and pasture. Orchards, forests, and wetlands are modeled using their default SWAT schedules.
S1	Reduce manure application	Reduce application rates of cattle and horse manures to corn from 45 Mg/ha to 11.6 Mg/ha.
S2	Grazing management	Increase the minimal grass biomass of pasture lands from 200 kg/ha to 700 kg/ha to reduce soil erosion caused by over grazing.
S3	Nitrogen commercial fertilizer management	Reduce N commercial fertilizer application rates by 25 percent for all agricultural lands and urban lawns.
S4	Phosphorus commercial fertilizer management I	Reduce P commercial fertilizer application rates by 25 percent for all agricultural lands and urban lawns.
S5	Phosphorus commercial fertilizer management II	Reduce P commercial fertilizer application rates by 25 percent for all agricultural lands and 100 percent for urban lawns.
S6	No tillage	Change minimum and conventional tillage to no-till practices for all row crops (corn-soybean-rye rotation).
S7	Cover crop	Plant winter rye following crop harvest and kill winter rye by crop planting for corn-soybean rotation.
S8	Filter strips	Apply 5-m (15-ft) edge-of-field filter strips to all agricultural lands.
S9	Fencing	Construct fences for all pasture lands within 100 meters of a stream to control livestock access to streams.
S10	Eliminate failing OSDSs	Improve the maintenance of OSDSs and increase the reliability. Assume 0 percent failure rate after improvement.
S11	Channel protection	Increase vegetative cover of channel banks or use riprap to stabilize banks.
S12	Combo 1	Combination of BMPs S1, S2, S3, S4, S7, S9, S10
S13	Combo 2	Combination of BMPs S1, S2, S3, S4, S8, S9, S10
S14	Combo 3	Combination of BMPs S1, S2, S3, S4, S7, S8, S9, S10
S15	Combo 4	Combination of BMPs S1, S2, S3, S4, S7, S8, S9, S10, S11
S16	Combo 5	Combination of BMPs S7, S8
S17	Combo 6	Combination of BMPs S4, S7, S8
S18	Combo 7	Combination of BMPs S1, S9
S19	Combo 8	Combination of BMPs S1, S8, S9
S20	Combo 9	Combination of BMPs S1, S8, S9, S10

Table 6.2 presents the pollutant load reductions and frequency of daily load exceedance for five pollutants with the alternative BMPs simulated with the SWAT model. BMP 0 (S0) is the baseline, representing the current condition. Each of BMPs 1-11 represents a single BMP. BMPs 12-20 are various combinations of single BMPs represented by BMPs 1-11. The combination BMPs consider the aggregated effects of the single BMPs for certain water pollutants. For example, the combination BMPs S16 and S17 were designed to evaluate the aggregated effects of selected BMPs on TP load reduction. The combination BMPs S18, S19 and S20 were designed to evaluate the aggregated effects of selected BMPs on pathogen load reduction. The combination BMPs S12, S13, S14 and S15 were designed to evaluate the aggregated effects of all BMPs on load reductions for all pollutants. Table 6.3 presents the effects of the alternative BMPs on the pollutant load reduction and the frequency of daily load exceedance for five pollutants of concern in the Neshanic River Watershed. The BMPs that achieve the pollutant load reduction targets are also highlighted in the table. The bold numbers indicate that the specific BMP scenario attains the water quality standard for the specific pollutant.

No tillage (S6), cover crop (S7), filter strips (S8) and channel protection (S11) are effective BMPs for sediment removal; they lead to average annual sediment load reductions of about 10, 15, 17 and 60 percent, respectively, compared to the baseline. Reducing channel erosion has a large impact on TSS loads. For appropriate application of BMPs in the watershed, a target daily load exceedance frequency of less than 10 percent can be achieved. In other words, each of these four BMPs and any combination BMP that contains at least one of the four BMPs has the potential to achieve the required 9 percent of TSS load reduction.

TN is not a water quality concern in the watershed even under the baseline. The SWAT modeling assessment indicates that reducing manure application (S1), nitrogen fertilizer management (S3), cover crop (S7) and filter strips (S8) are effective measures for TN reduction that achieve TN load reduction rates of more than 10 percent.

Reducing manure application (S1), phosphorus fertilizer management I and II (S4 and S5), cover crop (S7) and filter strips (S8) are more effective than other BMPs, achieving average annual TP load reductions of about 4, 15, 26, 16 and 38 percent, respectively. The frequency of daily TP load exceedance of the filter strip BMP (S8) cannot be accurately assessed because of a limitation of the SWAT model. The frequency of exceedance for several single BMPs is more than the 10 percent. However, by themselves, none of the single BMPs can achieve the required 49 percent of annual TP load reduction. Several BMPs must be implemented together to achieve the required TP load reduction target. As shown in Table 6.3, the combination BMPs S14 and S15 can achieve the desired TP load reduction rates with frequencies of exceedance less than 23 percent. The reason why their frequencies of exceedance cannot be precisely assessed is because both combination BMPs contain the filter strip BMP. Considering the effectiveness of conservation buffers in TP removal demonstrated by numerous empirical studies, we can reasonably assume the frequency of exceedance required by TMDLs can be achieved as well under both scenarios.

As shown in Table 6.3, although most load reductions are positive, there are negative load reductions for some BMPs. Negative reductions imply that the corresponding pollutant loads increase because of the aggregated impacts of complicated overland and instream biological processes. One example of this is BMP S5 (no phosphorus in lawn fertilizer application) for which a 100 percent reduction in P application reduces lawn growth causing N intake to fall and TN loads in streams to increase.

Table 6.3: Pollutant load reduction and the frequency of daily load exceedance for five pollutants with alternative BMPs in the Neshanic River Watershed

	Pollutant Load Reduction (percent)					Frequency of Exceedance (percent)				
	TSS	TN	TP	Fecal	*E. coli*	TSS	TN	TP	Fecal	*E. coli*
S0	na*	na	na	na	na	12.25	1.76	37.96	60.96	63.38
S1	0.05	25.65	4.40	23.23	23.17	12.21	0.34	36.46	60.57	63.08
S2	2.75	0.83	1.53	0.12	0.12	11.36	1.78	37.58	60.94	63.40
S3	-0.72	11.10	-3.89	0.39	0.39	12.25	1.00	38.60	60.99	63.56
S4	0	-0.17	15.36	0	0	12.25	1.76	33.45	60.96	63.38
S5	-1.57	-44.66	25.97	0.31	0.31	12.55	13.00	28.04	60.89	63.40
S6	**9.80**	2.46	-5.89	-7.90	-7.88	**9.51**	1.21	43.44	59.84	62.15
S7	**15.21**	23.03	15.77	1.04	1.04	**7.76**	0.62	30.80	62.79	65.16
S8**	**17.28**	46.21	37.72	11.91	11.88	**<12.25**	<1.62	<37.96	<60.96	<63.38
S9	0	0.04	0.21	19.30	19.22	12.25	1.76	37.37	51.22	54.96
S10	0	0.29	1.64	46.92	47.09	12.25	1.76	35.75	32.56	34.20
S11	**59.60**	-1.65	0.85	4.05	4.05	**2.30**	1.78	37.76	59.73	61.76
S12	**23.99**	55.40	32.72	**90.20**	**90.23**	**5.86**	0	22.56	**0.18**	**0.23**
S13**	**25.03**	61.93	46.29	**93.82**	**93.84**	**<10.75**	<0.07	<29.93	**<0.25**	**<0.27**
S14**	**31.90**	68.76	**51.46**	**94.05**	**94.07**	**<5.86**	0	**<22.56**	**<0.18**	**<0.23**
S15**	**83.04**	68.39	**51.86**	**94.45**	**94.47**	**<1.12**	0	**<22.36**	**<0.16**	**<0.21**
S16**	**24.48**	55.37	41.86	12.95	12.92	**<7.76**	<0.55	<30.80	<62.79	<65.16
S17**	**24.49**	55.35	**51.07**	12.95	12.92	**<7.76**	<0.55	**<26.17**	<62.79	<65.16
S18	0.05	25.70	4.62	42.53	42.39	12.21	0.34	36.09	50.67	54.48
S19**	**17.32**	55.69	37.53	45.56	45.41	**<12.21**	<0.34	<36.09	<50.67	<54.48
S20**	**24.27**	56.04	39.16	**92.49**	**92.51**	**<11.43**	<0.34	<34.43	**<0.25**	**<0.27**

Note: * Not applicable;
** Indicates that exact frequency of daily load exceedance cannot be determined.

Single BMPs, including reducing manure application (S1), filter strips (S8), fencing (S9), eliminating failing OSDSs (S10) and channel protection (S11), reduce fecal coliform by about 23, 12, 19, 47 and 4 percent, and E. coli by about 23, 12, 19, 46 and 4 percent, respectively. These reductions are less than the required load reduction targets of 89 percent for fecal coliform and 89 percent for *E. coli*. The frequencies of daily load exceedance of these single BMPs are more than 30 percent, which is higher than the 10 percent frequency of exceedance required by the TMDLs. The bacteria load reduction targets and frequency of daily load exceedance can be achieved by using a combination of several effective BMPs. Combination BMP S20, which involves reducing manure application, filter strips, fencing and eliminating septic failure, reduces the average annual load for fecal coliform by 92 percent and *E. coli by* 93 percent. With additional BMPs, including grazing management, nitrogen and phosphorus fertilizer applications, cover crop and channel protection, the combination BMP S15 reduces pathogenic load by almost 94 percent. Both S15 and S20 achieve frequencies of daily load exceedance for fecal coliform and *E. coli* of less than 10 percent.

The BMP analyses indicate it is possible to achieve the pollutant load reduction targets required to satisfy water quality standards for the Neshanic River Watershed. The BMPs evaluated here include only BMPs that can be easily assessed using the SWAT model. There are many other BMPs that can be implemented to achieve the required pollutant load reductions in the watershed as discussed in Chapter 7. Examples of such BMPs include rain gardens, detention basin retrofitting and ditch and swale retrofitting. Because these BMPs involve site-specific engineering structures, their water quality impacts cannot be simulated using the SWAT model and therefore they are excluded from the BMP analysis. As indicated in the literature, BMPs involving site-specific engineering structures are generally very effective in achieving load reductions in sediment, nutrients and pathogens. For that reason, those BMPs provide alternative ways to achieve pollutant load reductions in the watershed.