# Development of Stormwater Control Measure (SCM) Performance Curves for Forest, Meadow, and Lawn Vegetated Buffers in Maine

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# 1 INTRODUCTION

The Stormwater Management Rules (Chapter 500) established by the State of Maine Department of Environmental Protection (Maine DEP) outline the stormwater standards for activities licensed under the State's Stormwater Management Law and Site Location of Development Law. Maine DEP is in the process of updating Chapter 500 and closely related regulations to mandate Low Impact Development (LID) practices and to address climate adaptation and resiliency. The agency also aims to streamline these rules to enhance the day-to-day implementation of the State's stormwater regulatory program.

Vegetated buffers are one of the stormwater control measures (SCMs) currently permitted under Chapter 500. These buffers typically consist of natural, undisturbed strips of forest or meadow that capture runoff from developed areas. As stormwater flows through these buffers, it undergoes various treatment processes, including infiltration, evapotranspiration, particulate entrapment, and nutrient uptake by plants. Because vegetated buffers can enhance the infiltration of stormwater, they also promote groundwater recharge. Even when implemented at a single site, groundwater recharge can provide effective hydraulic protection for streams at the watershed level. A key element of the proposed revisions to Chapter 500 is the establishment of a standard for groundwater recharge (or infiltration), which will require regulated activities to manage stormwater volume specifically in impaired urban watersheds and areas vulnerable to urbanization.

Furthermore, the proposed strategy specifies nitrogen and phosphorus removal requirements for activities in coastal watersheds and sensitive regions. Vegetated buffers are particularly effective at removing phosphorus and nitrogen when properly designed and maintained. Their pollutant removal efficiency depends on several factors, including flow path length, slope, soil structure, vegetation type, and water distribution. Proper flow distribution is crucial, as concentrated runoff can bypass the buffer's treatment capacity. Typically used for small impervious areas like those in residential or small commercial developments, buffer strips require minimal maintenance, enhance aesthetics, and are tailored through specific design criteria depending on site conditions. While vegetated buffers can offer these benefits, more information about their performance is necessary for effective planning and crediting of these SCMs.

The implementation of the proposed Chapter 500 framework will require stormwater control measure (SCM) sizing tools to meet the standards for stormwater volume, nitrogen, and phosphorus reduction. One such tool is the performance curve, which illustrates the minimum sizes of SCMs needed to achieve specific pollutant removal targets. These performance curves are developed based on advanced continuous stormwater modeling and monitoring data, providing a reliable estimate of an SCM's long-term cumulative performance under a variety of conditions. Currently, performance curves are utilized in both the Massachusetts and New Hampshire Municipal Separate Storm Sewer System (MS4) permitting processes administered by the U.S. Environmental Protection Agency (EPA) Region 1 and are easy to understand and use.

This technical report details the development of long-term cumulative performance curves relevant for planning and crediting vegetated forests, meadows, and lawn buffers within the State of Maine. The project team consisted of Khalid Alvi and Ben Bowes (Paradigm Environmental), Jeff Dennis and Kerem Gungor (Maine DEP), and Mark Voorhees (University of New Hampshire Stormwater Center). Using EPA Region 1's Opti-Tool, the project team focused on creating cumulative performance curves for runoff volume, Total Phosphorus (TP), and Total Nitrogen (TN). Additionally, the project team created cumulative performance curves for Total Suspended Solids (TSS), Total Zinc (Zn), and Bacteria (E. coli). These were based on the Hydrologic Response Unit (HRU) influent timeseries of hourly runoff and stormwater quality, derived from 28 years of climatic data collected at the Portland Jetport (January 1997 – December 2024). The results include sets of performance curves categorized by vegetated buffer types—forest, meadow, and lawn—based on Hydrologic Soil Group (HSG) and the ratio of impervious cover drainage area (IC) to pervious cover buffer area (PC). These performance curves may serve as components of the proposed Chapter 500 rules for the planning and crediting of these SCMs. The report presents findings intended to support decision-making by Maine DEP staff and is not meant as guidance for compliance with Chapter 500.

# 2 LITERATURE REVIEW

The project team conducted a literature review on vegetated buffers, with a particular focus on forest and meadow buffers in urban watersheds. The data of interest included specific details about the buffers, such as their dimensions, types of vegetation, sources of runoff, treated impervious surfaces, soil infiltration properties, as well as the volume of water and pollutant reductions achieved. While there is a substantial amount of literature addressing the treatment of agricultural runoff using vegetated buffers, there is less research specifically examining the effectiveness of forest or meadow buffers for managing runoff from urban impervious surfaces. Additionally, no studies specifically focused on Maine were found. The most relevant literature reviewed is listed in Table 2-1.

**Table 2-1. Vegetated buffer, literature reviewed**

| First Author | Date | Title | Citation |
|---|---|---|---|
| Cole | 2020 | Managing riparian buffer strips to optimize ecosystem services: A review | (Cole *et al.*, 2020) |
| Dunn | 2022 | Impacts of different vegetation in riparian buffer strips on runoff and sediment loss | (Dunn *et al.*, 2022) |
| García-Serrana | 2017 | Analysis of Infiltration and Overland Flow over Sloped Surfaces: Application to Roadside Swales | (García-Serrana, 2017) |
| | 2016 | Enhancement and Application of the Minnesota Dry Swale Calculator | (García-Serrana *et al.*, 2016) |
| | 2017 | Infiltration capacity of roadside filter strips with non-uniform overland flow | (García-Serrana, Gulliver, *et al.*, 2017a) |
| | 2017 | Non-uniform overland flow-infiltration model for roadside swales | (García-Serrana, Gulliver, *et al.*, 2017b) |
| | 2018 | Calculator to Estimate Annual Infiltration Performance of Roadside Swales | (García-Serrana *et al.*, 2018) |
| | 2017 | Infiltration Flux for Parallel Strip Water Sources | (García-Serrana, Nieber, *et al.*, 2017) |
| Nsenga kumwimba | 2024 | Nutrient and sediment retention by riparian vegetated buffer strips: Impacts of buffer length, vegetation type, and season | (Nsenga kumwimba *et al.*, 2024) |
| Winston | 2009 | Field Evaluation of Level Spreader-Vegetative Filter Strip Systems for Improvement of Urban Hydrology and Water Quality | (Winston, 2009) |

Through the literature review, the project team determined that the Winston study, conducted in North Carolina, was the most applicable for comparison with vegetated buffers in Maine. This study established and evaluated grass (essentially lawn) and grass/forest combination buffers draining a site consisting of parking and access pavement, a building, and landscaped area at an emergency response facility (called the Louisburg site). Runoff was collected and delivered (in one case split) via level lip spreaders to two separate buffers: a 25 ft grass buffer and a 50 ft buffer the upgradient half of which was grass and the downgradient half forest. The buffers were evaluated for runoff retention, peak flow reduction and lag, pollutant removal (nitrogen and phosphorus species) and temperature control from March 2008 to March 2009. The following points summarize the relevant configuration details and findings from this study:

- **Buffer topography:** The contour data for the Louisburg site indicates that runoff from the level lip spreader is directed into a narrow swale located on the northern side of the buffer by the time it reaches the forest. This observation is confirmed by an evaluation of the effective buffer area, which shows that almost all runoff at this point follows a channel rather than being dispersed across the buffer area.
- **Very high contributing watershed to buffer area:** The ratio of contributing watershed area to buffer area and contributing IC area to buffer area for the Louisburg site are shown in Table 2-2. At least for the 50 ft buffer, the ratio is greatly underestimated because the "effective buffer area" (the area to which the level spreader drained) is much less than the area used to calculate the ratio. Rather than 13:1, this ratio is probably greater than 20:1. These ratios are so high that any expectation of significant pollutant removal or runoff retention, at least for larger storm events, would be unwarranted. Despite this, the overall TP load reduction in these mostly grass/lawn buffers for the successfully measured storms was close to 50%. It is surprising that even for relatively large storms, there was significant volume reduction in these buffers.

Table 2-2. Louisburg site contributing area to buffer ratios

| Buffer Length (ft) | Watershed: Buffer Area Ratio | IC: Buffer Area Ratio |
|---|---|---|
| 25 | 45:1 | 30:1 |
| 50 | 20:1 | 13:1 |

- **Vegetation characteristics**: Virtually no description of the vegetation or the maintenance thereof (e.g., mowing height and frequency) was given for the buffer areas. The few photos provided suggest the grass buffer is maintained as a lawn, not a meadow, and, though it is unclear in the photos, the forest at the Louisburg site is thin at best. While the height of the vegetation in the grass area appears closer to a lawn than a meadow, the soil may not be compacted, as many lawns are, so its infiltration capacity may not be compromised, as the measured minimum surface infiltration rate was 1.5 in/hr.
- **TP treatment**: The graphs of the TP concentration and TP load curves for the Louisburg site yield some interesting information. Outlet TP concentration varies dramatically with inlet TP concentration, being sometimes lower and sometimes higher. However, the TP load at the outflow is lower in all but three of the 22 measured storms, and sometimes much lower. Note that the July 18th storm had extremely high inflow concentration due to testing of fire extinguishers in the parking lot, so that storm has been removed from the following evaluation. Also, the April 29th storm was removed from the evaluation of the 50 ft buffer due to erosive failure of the swale in the forest portion of the buffer. Evaluation of the reported TP load data in *Table F-18* (Winston, 2009; Appendix F) yields the load reduction values shown in Table 2-3. The April 29th storm that was removed from the analysis for the 50 ft buffer appears to have performed somewhat better than the partially wooded 50 ft buffer, but the difference is limited by the fact that, based on the contours provided, the slope in the buffer diverted much of the discharge from the level spreader away from much of the grassed buffer and the runoff was channelized in a narrow swale by the time it reached the forested portion of the buffer. While the flow path within the buffer was twice as long, the effective buffer area is likely similar and the effect of any forest cover is greatly diminished, so these results cannot be used to evaluate the relative effectiveness of a grass to a forest buffer because the effective forest area was so limited.

Table 2-3. Louisburg site TP load reduction percentages from the measured storm events (Table F-18 in Winston (2009))

| Buffer Length (ft) | Total Mass Load Reduction (%) | Mean Load Reduction (%) |
|---|---|---|
| 25 | 49%* | 41%* |
| 50 | 54%** | 54%** |

*: 20 storm events

**: 19 storm events

- **Pollutant reduction mechanisms**: The TP concentration data presented in Figure 5-40 of the Winston study shows minimal variation between the inlet and outlet for both buffers, while the TP load demonstrates significant variation. This suggests that the majority of TP load reduction in the buffers is likely due to runoff volume reduction through infiltration and evapotranspiration processes rather than filtration or adsorption of phosphorus, which are more dominant processes in forest soils. This finding is not surprising, especially considering that the grass buffer, based on the limited photos provided, resembles a lawn rather than a meadow.
- **Runoff volume reduction**: Both buffers resulted in very impressive runoff volume reduction as shown in Table 2-4. The 25-foot grass buffer performed slightly better than the 50-foot hybrid grass/forest buffer, although the difference was not significant. This outcome is likely due to the fact that the concentration of flow in the 50-foot buffer caused its effective buffer area to be no larger than that of the 25-foot buffer; most, if not all, of the flow was channeled through the forest section of the buffer. Additionally, these data may underestimate the actual reduction in runoff volume from the contributing watershed, as they do not account for the contribution of direct precipitation onto the buffer.

Table 2-4. Louisburg site runoff volume reduction percentages. Note that the mean reduction is calculated from storm events with more than 0.1 inches of precipitation

| Buffer Length (ft) | Total Reduction (%) | Mean Reduction (%) |
|---|---|---|
| 25 | 50% | 73% |
| 50 | 48% | 70% |

- **Soil characteristics**: While the soil series in the area are mapped as Wedowee Sandy Loam (from the USDA soil series maps), it is likely that the actual soils on site do not fit the typical textural profile for a Wedowee Sandy Loam which would have limited infiltration capacity. The arithmetic average of saturated hydraulic conductivity values measured for the top 12 inches of the soil profile (from 6 sample sites and discarding two outlier measurements) was 2.6 cm/hr. This, along with the hydrologic performance of the buffers, the soil particle size distribution measured in the buffer soils, and the infiltration rate tests, suggests a HSG A type soil.

The Winston study offers a useful data point for comparing the performance of lawn buffers in the Opti-Tool; however, the literature review did not uncover any suitable data—such as time series on flow and pollutants—that would allow for the typical calibration and validation of forest or meadow buffers. This represents a significant data gap that would benefit from further monitoring and research, particularly in the New England region.

# 3 OPTI-TOOL MODELING APPROACH

The Opti-Tool (Stormwater Management Optimization Tool) is a spreadsheet-based optimization tool developed by EPA Region 1 that provides users with modeling tools to quantify the benefits and costs of potential BMP options and facilitate the decision-making process for stormwater management(U.S. EPA, 2025a). The Opti-Tool provides a spreadsheet-based interface for running the EPA's SUSTAIN (System for Urban Stormwater Treatment and Analysis Integration) model to estimate BMP performance and retrieve optimization results to provide cost-effective BMP sizing strategies. These planning- and implementation-level analysis tools help planners determine the best mix of BMPs to provide the greatest benefit for achieving water resources goals while balancing costs. The Opti-Tool also supports the creation of SCM performance curves, which can be used for design and crediting of SCMs by stormwater managers. Performance curves are currently used in both the Massachusetts (U.S. EPA, 2016) and New Hampshire (U.S. EPA, 2017) Municipal Separate Storm Sewer System (MS4) permitting processes and can also be developed for region-specific SCMs, like the vegetated buffers in Maine, as well as new and innovative stormwater management devices (U.S. EPA, 2024).

Configuring the vegetated buffers in the Opti-Tool for this project required several inputs and processes, including:

1. Creation of regionally calibrated Hydrologic Response Unit (HRU) time series of runoff volume and stormwater quality using the Opti-Tool SWMM model and local meteorological data.
2. Configuration of the buffers in Opti-Tool using the IC Disconnection-type BMP based on relevant literature and best professional judgement.

After configuration, Performance Curves were created (Section 4). Due to the data limitations described in Section 2, standard calibration of the buffers to specific observations was not feasible; therefore, validation of the buffers' performance in the Opti-Tool was assessed based on summarized relevant literature and best professional judgement (Section 5).

## 3.1 HRU Loading Rate and Time Series Development

HRUs are used by the Opti-Tool to characterize flow and pollutant loading from a drainage area of a given stormwater control measure (SCM; often referred to as a Best Management Practice [BMP]). The EPA's Opti-Tool software package includes a set of unique HRUs that were developed for the EPA Region 1 (New England) area based on land use, land cover, and soil characteristics. Each HRU represents areas of similar physical characteristics attributable to core hydrologic and pollutant processes identified through GIS overlays. The HRUs represent the primary building blocks for developing the rainfall-runoff response timeseries and characterizing the unique landscape features in a drainage area. The Opti-Tool HRUs were generated with the EPA SWMM model available as part of the Opti-Tool software package, which has been regionally calibrated based on the best available information on New England-region stormwater runoff nutrient quality, including build-up/wash-off processes. The regional calibration process is described in the technical memos available with the Opti-Tool software package (U.S. EPA, 2025b; U.S. EPA and Paradigm Environmental, 2019). The related memos are provided on Maine DEP website in addition to this technical memo.

In order to characterize unattenuated stormwater flow and load from the Opti-Tool HRUs that are representative of conditions in Maine, flow and pollutant load export rates were generated using the Opti-Tool SWMM model and local meteorological data for: i) Total Phosphorus (TP), ii) Total Nitrogen (TN), iii) Total Suspended Solids (TSS), iv) Zinc (Zn), and v) *E. coli* (most probable number [mpn]). Meteorological data include hourly precipitation and daily minimum/ maximum temperature collected from the National Oceanic and Atmospheric Administration (NOAA) station located at the Portland Jetport (WBAN-14764) for the most recent 28 years (January 1, 1997 to December 31, 2024). These climate data were reviewed for completeness and screened for data gaps using annual summary statistics, seasonal summary statistics, and time series plots. The quality flagging provided with the data was also reviewed. After filling in any gaps, the data were translated to the required input format for the SWMM model.

No significant data gaps (missing records) were found during the data review; daily temperature had no missing records, while precipitation had 6,526 hours (2.7% of the period of record) flagged as missing. The longest consecutive period of missing precipitation data was 6 hours. Missing hours were first filled with the mean hourly value for the given month from the entire period of record. For any given day, filled values were then adjusted so that the difference between the observed daily value (if available) and the hourly total was zero, with the difference evenly distributed among that day's missing values. For example, if the difference between a day's hourly total and the daily value is 0.2 inches and there are two missing hours, each missing hour would be filled with a value of 0.1 inches. The precipitation data are summarized in Figure 3-1, Figure 3-3, and Table 3-1; temperature data, which drive evapotranspiration simulation, are summarized in Figure 3-3.

The results of the SWMM model simulation include 28 years of hourly surface runoff and pollutant loading time series. These time series are summarized as annual average rates in Table 3-2 and used as inputs to the Opti-Tool BMP simulation module.

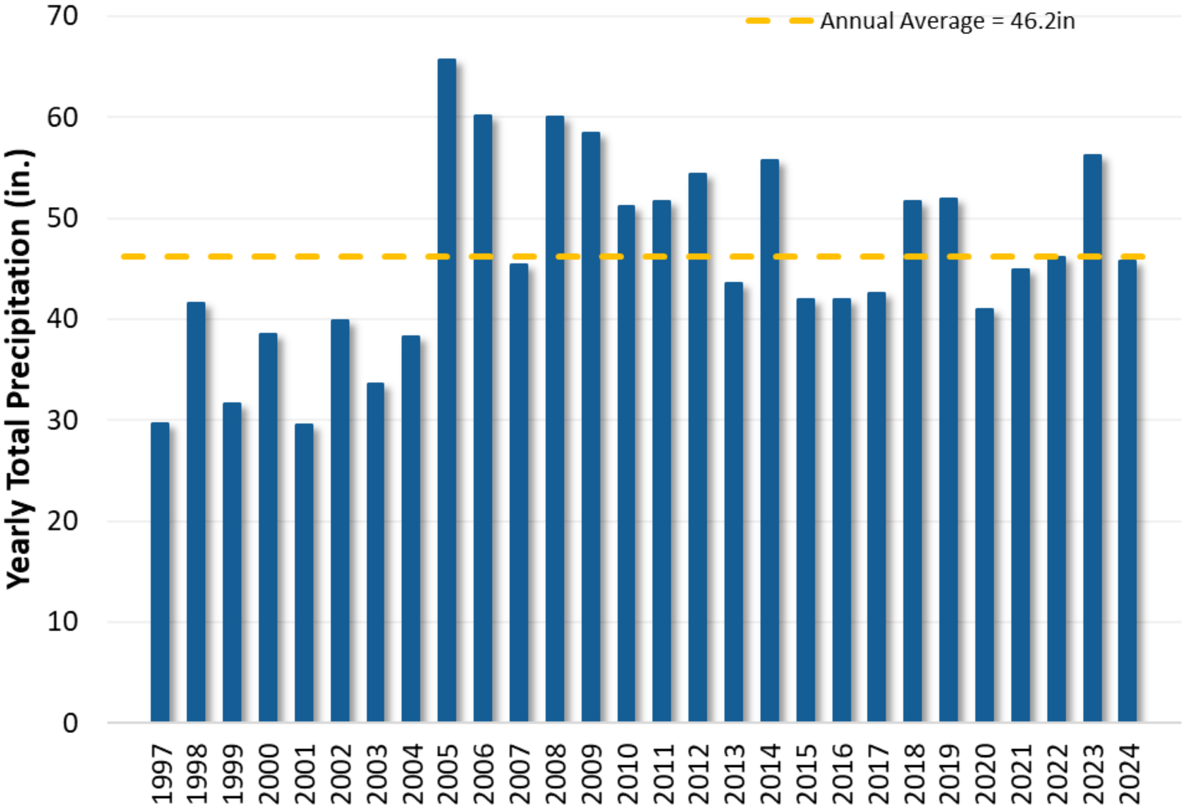


Figure 3-1. Total yearly precipitation at the Portland Jetport.

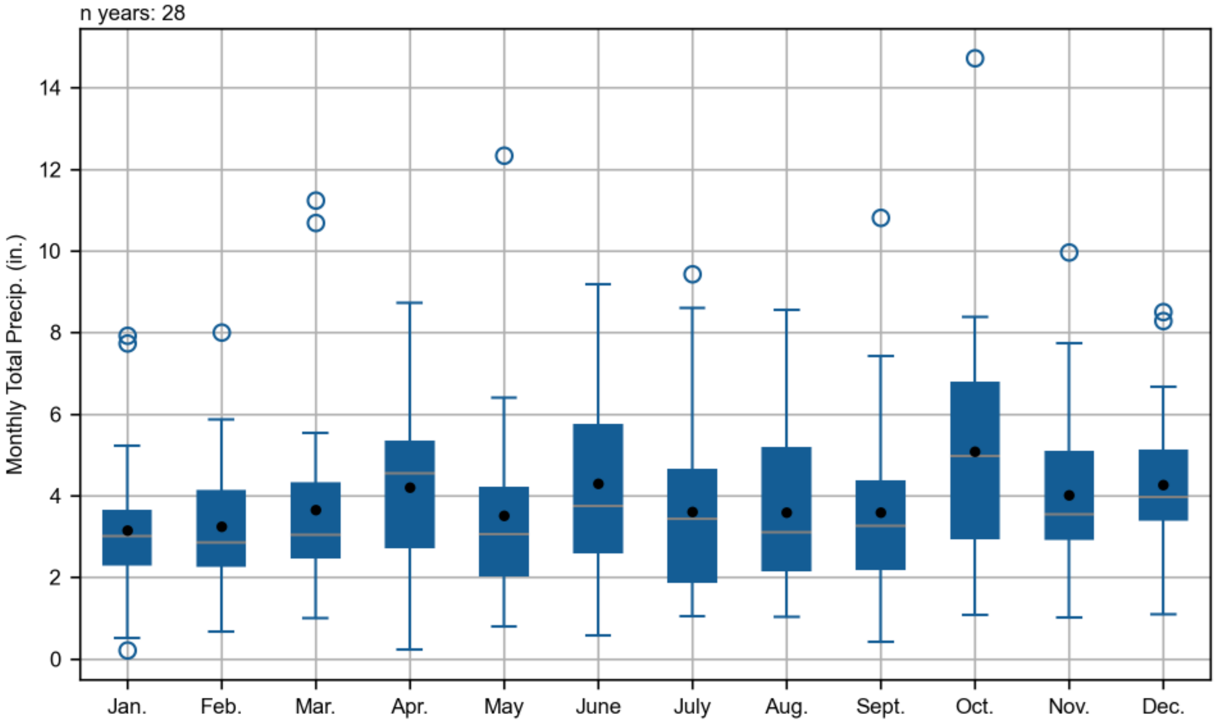


Figure 3-2. Distribution of total monthly precipitation (January 1, 1997 to December 31, 2024) at the Portland Jetport.

Table 3-1. Summary of precipitation statistics at the Portland Jetport

| PORTLAND JETPORT, ME US | | | | | | | |
|---|---|---|---|---|---|---|---|
| Year | Rainfall (in.) | Percentile<br>10th %<br>Average<br>90th % | Difference From Average (in.) | Number of Rain Days per Year: | | | |
| | | | | >= 0.1" | >= 0.5" | >= 1.0" | >=1.5" |
| 1997 | 29.64 | 7% | -16.56 | 71 | 20 | 5 | 1 |
| 1998 | 41.55 | 31% | -4.65 | 72 | 28 | 11 | 5 |
| 1999 | 31.62 | 10% | -14.58 | 62 | 16 | 7 | 3 |
| 2000 | 38.53 | 21% | -7.67 | 76 | 24 | 10 | 2 |
| 2001 | 29.56 | 3% | -16.64 | 57 | 14 | 5 | 3 |
| 2002 | 39.93 | 24% | -6.27 | 78 | 31 | 8 | 1 |
| 2003 | 33.66 | 14% | -12.54 | 70 | 24 | 6 | 1 |
| 2004 | 38.34 | 17% | -7.86 | 72 | 20 | 13 | 3 |
| 2005 | 65.74 | 97% | 19.54 | 92 | 40 | 19 | 10 |
| 2006 | 60.13 | 93% | 13.93 | 90 | 41 | 15 | 9 |
| 2007 | 45.47 | 52% | -0.73 | 75 | 31 | 10 | 5 |
| 2008 | 60.00 | 90% | 13.80 | 93 | 34 | 18 | 10 |
| 2009 | 58.42 | 86% | 12.22 | 81 | 33 | 19 | 12 |
| 2010 | 51.21 | 62% | 5.01 | 70 | 25 | 16 | 9 |
| 2011 | 51.67 | 69% | 5.47 | 91 | 33 | 14 | 4 |
| 2012 | 54.39 | 76% | 8.19 | 81 | 35 | 12 | 7 |
| 2013 | 43.62 | 45% | -2.58 | 80 | 31 | 11 | 5 |
| 2014 | 55.80 | 79% | 9.60 | 87 | 36 | 13 | 5 |
| 2015 | 41.94 | 34% | -4.26 | 74 | 25 | 9 | 3 |
| 2016 | 42.00 | 38% | -4.20 | 72 | 26 | 8 | 5 |
| 2017 | 42.62 | 41% | -3.58 | 77 | 31 | 10 | 4 |
| 2018 | 51.67 | 66% | 5.47 | 86 | 42 | 13 | 6 |
| 2019 | 51.99 | 72% | 5.79 | 89 | 39 | 11 | 5 |
| 2020 | 40.93 | 28% | -5.27 | 70 | 26 | 13 | 4 |
| 2021 | 44.89 | 48% | -1.31 | 82 | 32 | 12 | 4 |
| 2022 | 46.15 | 59% | -0.05 | 70 | 29 | 16 | 5 |
| 2023 | 56.23 | 83% | 10.03 | 85 | 39 | 17 | 8 |
| 2024 | 45.79 | 55% | -0.40 | 82 | 27 | 13 | 6 |
| **Average** | **46.2** | -- | -- | **78** | **30** | **12** | **5** |

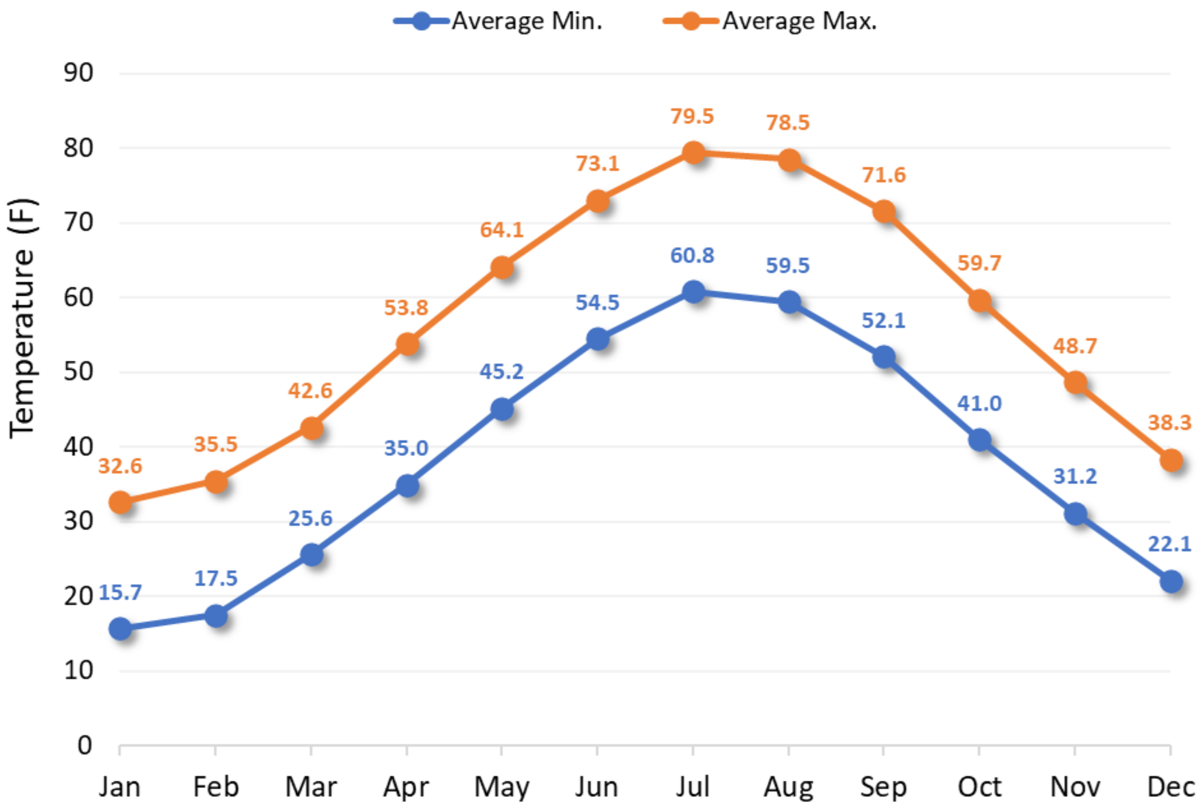


**Figure 3-3. Average daily minimum and maximum temperature by month at the Portland Jetport.**

Table 3-2. Annual average (January 1, 1997 to December 31, 2024) unit area stormwater loading rates

| SWMM HRU[4] | Land Use/Land Cover | HSG[1] | Flow (MG/ac/year) | TP (lb/ac/year) | TN (lb/ac/year) | Zn (lb/ac/year) | TSS (lb/ac/year) | *E. coli* (mpn[3]/ac/year) |
|---|---|---|---|---|---|---|---|---|
| Pervious_A | Pervious | A | 0.02 | 0.04 | 0.37 | 0.01 | 9.51 | 1.11E+11 |
| Pervious_B | | B | 0.10 | 0.17 | 1.70 | 0.03 | 44.27 | 3.80E+11 |
| Pervious_C | | C | 0.20 | 0.28 | 3.15 | 0.06 | 80.11 | 7.67E+11 |
| Pervious_D | | D | 0.35 | 0.46 | 4.59 | 0.09 | 117.51 | 1.22E+12 |
| Forest_A | Forest[2] | A | 0.02 | 0.01 | 0.18 | 0.01 | 9.51 | 1.11E+10 |
| Forest_B | | B | 0.10 | 0.02 | 0.82 | 0.07 | 44.27 | 3.80E+10 |
| Forest_C | | C | 0.20 | 0.04 | 1.56 | 0.13 | 80.11 | 7.67E+10 |
| Forest_D | | D | 0.35 | 0.07 | 2.36 | 0.18 | 117.51 | 1.22E+11 |
| Agriculture_A | Agriculture | A | 0.02 | 0.14 | 0.84 | 0.01 | 9.51 | 4.40E+09 |
| Agriculture_B | | B | 0.10 | 0.67 | 3.84 | 0.03 | 44.27 | 1.51E+10 |
| Agriculture_C | | C | 0.20 | 1.08 | 7.06 | 0.06 | 80.11 | 3.04E+10 |
| Agriculture_D | | D | 0.35 | 1.75 | 10.07 | 0.09 | 117.51 | 4.84E+10 |
| Commercial_I | Commercial | Impervious | 1.17 | 1.81 | 15.43 | 1.44 | 394.92 | 9.52E+09 |
| HigDensityRes_I | High Density Residential | Impervious | 1.17 | 2.39 | 14.43 | 0.74 | 459.34 | 1.94E+12 |
| MedDensityRes_I | Med. Density Residential | Impervious | 1.17 | 1.97 | 14.43 | 0.74 | 459.34 | 1.94E+12 |
| LowDensityRes_I | Low Density Residential | Impervious | 1.17 | 1.51 | 14.43 | 0.74 | 459.34 | 1.94E+12 |
| Highway_I | Highway | Impervious | 1.17 | 1.40 | 10.45 | 1.84 | 1,548.86 | 2.27E+07 |
| Forest_I | Forest | Impervious | 1.17 | 1.51 | 11.62 | 0.74 | 677.64 | 2.86E+11 |
| OpenSpace_I | OpenSpace | Impervious | 1.17 | 1.51 | 11.62 | 1.04 | 677.64 | 2.86E+12 |
| Agriculture_I | Agriculture | Impervious | 1.17 | 1.51 | 11.62 | 0.74 | 677.64 | 1.13E+11 |

1. Hydrologic Soil Group
2. Forest TP export rates were adjusted from the default Opti-Tool values to represent conditions in Maine based on studies from the Hubbard Brook watershed (Hubbard Brook Research Foundation)
3. Most probable number
4. Hydrologic Response Unit.

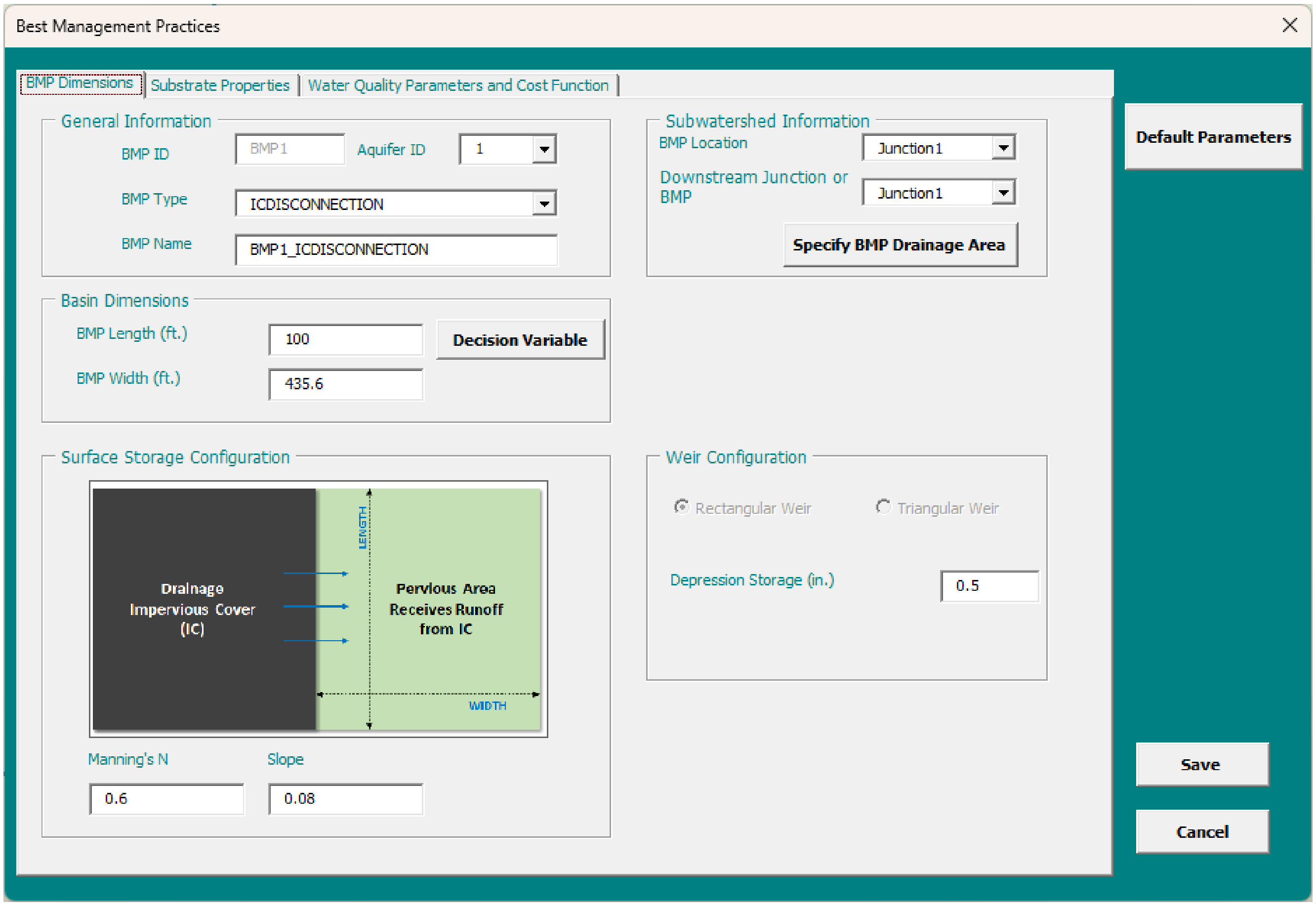
## 3.2 Buffer Configuration

The Opti-Tool "IC Disconnection" type BMP was adapted for simulating vegetated buffers. The IC Disconnection BMP routes runoff as sheet flow from the specified drainage area—1 acre of commercial impervious HRU in this case—onto the pervious area as shown in Figure 3-4. Depending on the buffer type, the pervious receiving area was set to either the "Forest" or "Pervious" HRU by hydrologic soil group to represent the forest and meadow buffers, respectively. Because there is no "Meadow" type HRU in the Opti-Tool by default and there was insufficient observed data available to develop that HRU, the more generic "Pervious" HRU, which typically represents lawns, was used; however, the Manning's n and depression storage values were adjusted to be more representative of meadows based on sensitivity analysis and best professional judgment, as described in Section 3.3.

Two simulation runs are conducted in Opti-Tool to assess the reductions in runoff volume and pollutant load achieved through buffers. In the first simulation run, the HRU time series from the impervious drainage area and the HRU time series from the buffer pervious area (such as a forest) are routed to the same junction in parallel. It is important to note that HRU time series are unit-area-based rainfall runoff response time series generated using the regionally calibrated SWMM model. Instead of simulating rainfall, Opti-Tool uses the runoff and pollutant load HRU time series as inputs for the BMP simulation.

In the second simulation run, the HRU time series from the impervious drainage area is routed to the IC Disconnection BMP (i.e., the buffer area), which then drains into a junction. Opti-Tool employs nonlinear reservoir routing algorithms adapted from the SWMM model to route the surface runoff from the impervious area to the buffer pervious area. The reductions in flow and pollutant load are determined by calculating the differences between the results of these two simulation runs.

Additional details on BMP simulation processes are available in the SUSTAIN reports, available as part of the SUSTAIN software package (U. S. EPA, 2014).



BMP ID: BMP1

Aquifer ID: 1

BMP Type: ICDISCONNECTION

BMP Name: BMP1_ICDISCONNECTION

BMP Location: Junction1

Downstream Junction or BMP: Junction1

BMP Length (ft.): 100

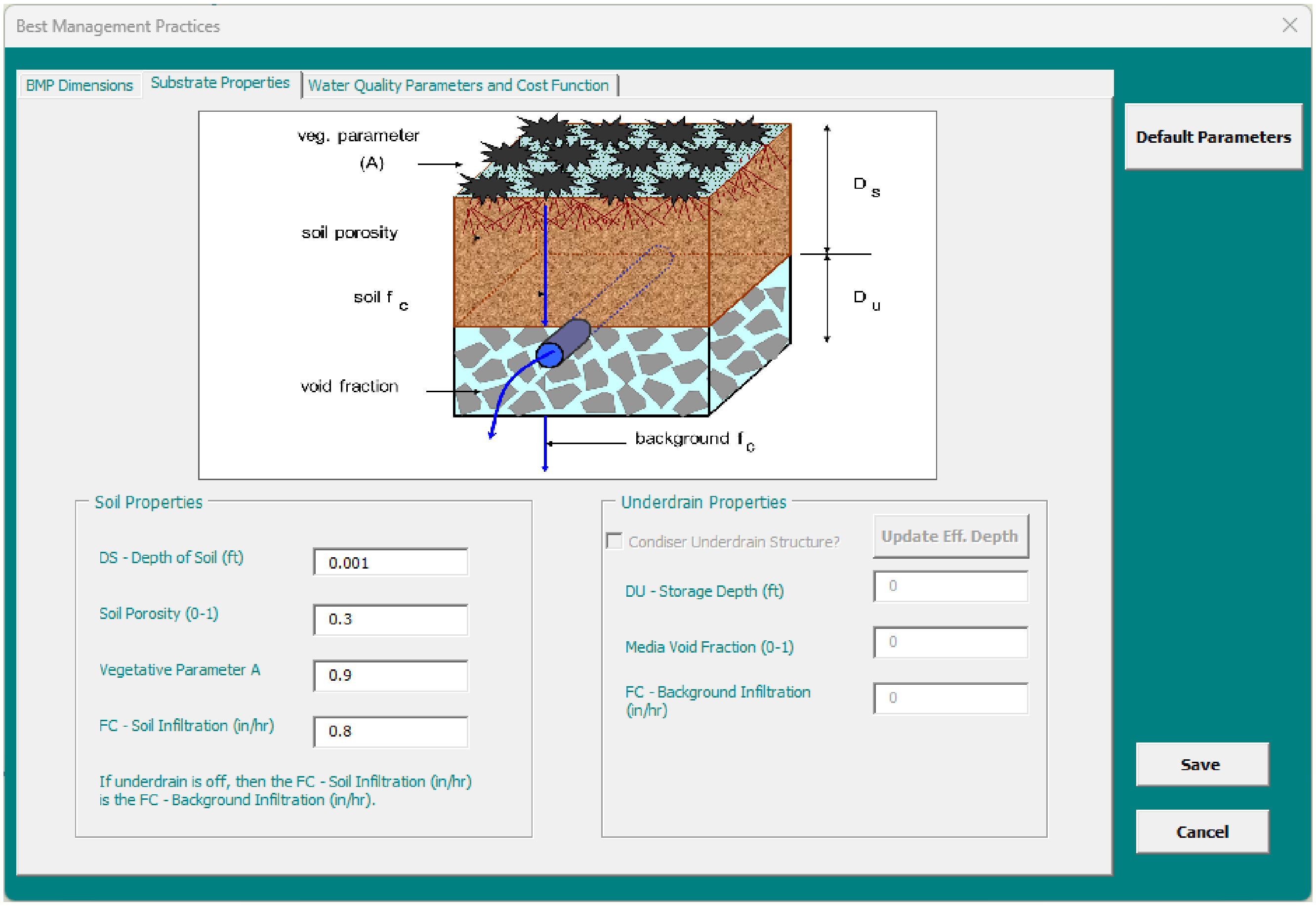
BMP Width (ft.): 435.6

Depression Storage (in.): 0.5

Manning's N: 0.6

Slope: 0.08

Figure 3-4. Opti-Tool IC Disconnection schematic and details as configured for the vegetated buffers.



Soil Properties

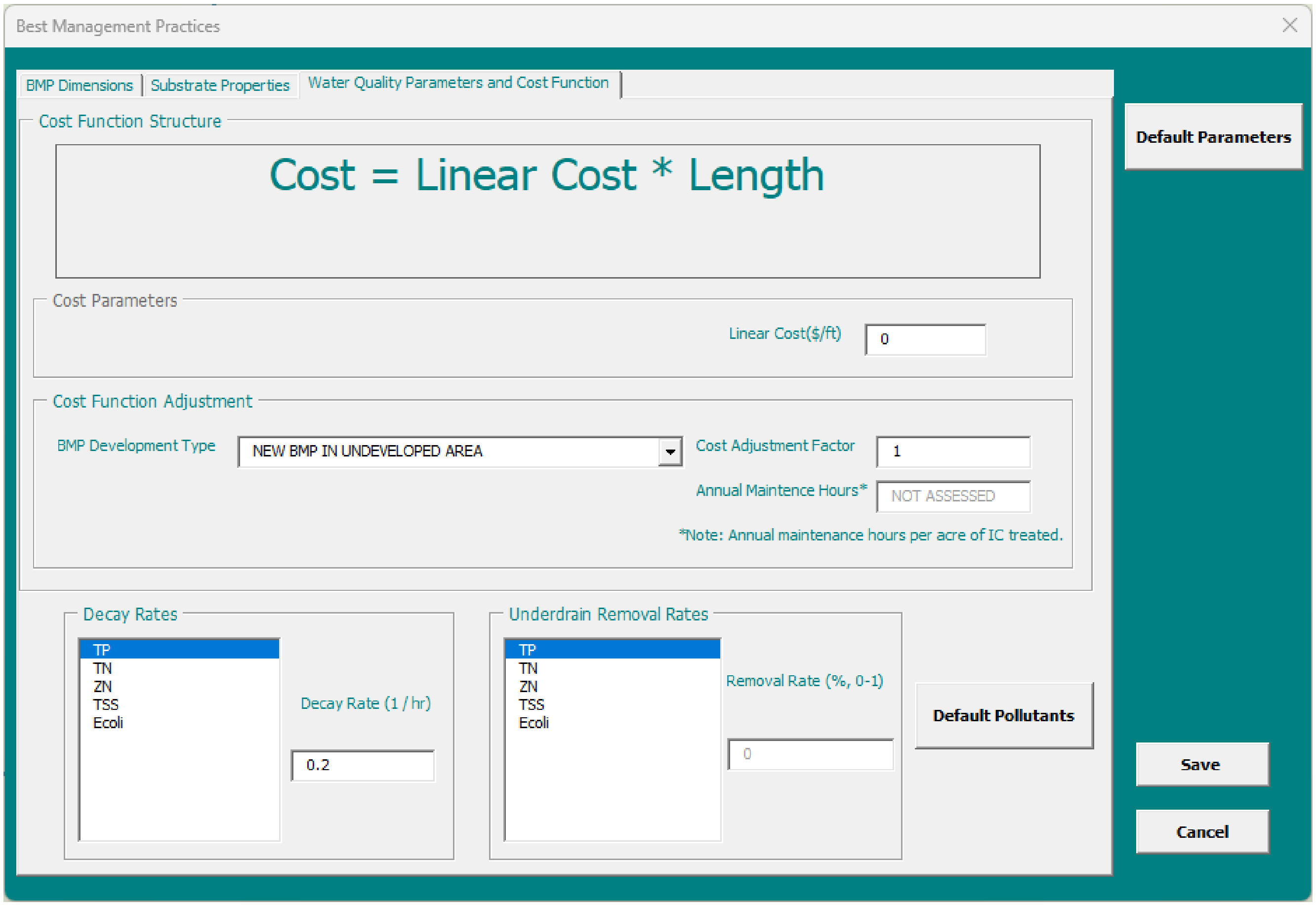
DS - Depth of Soil (ft): 0.001
Soil Porosity (0-1): 0.3
Vegetative Parameter A: 0.9
FC - Soil Infiltration (in/hr): 0.8

If underdrain is off, then the FC - Soil Infiltration (in/hr) is the FC - Background Infiltration (in/hr).

Underdrain Properties

☐ Condiser Underdrain Structure?
DU - Storage Depth (ft): 0
Media Void Fraction (0-1): 0
FC - Background Infiltration (in/hr): 0

Figure 3-5. Opti-Tool IC Disconnection substrate properties as configured for the vegetated buffers. Because no underdrain is simulated, the Soil Infiltration rate is a key parameter for the pervious buffer area.



Cost = Linear Cost * Length

Linear Cost($/ft): 0

BMP Development Type: NEW BMP IN UNDEVELOPED AREA

Cost Adjustment Factor: 1

Annual Maintence Hours*: NOT ASSESSED

*Note: Annual maintenance hours per acre of IC treated.

Decay Rates: TP, TN, ZN, TSS, Ecoli

Decay Rate (1 / hr): 0.2

Underdrain Removal Rates: TP, TN, ZN, TSS, Ecoli

Removal Rate (%, 0-1): 0

Figure 3-6. Opti-Tool IC Disconnection water quality properties as configured for the vegetated buffers. Decay rates are the default values for IC Disconnection BMP in Opti-Tool, as shown in this window.

## 3.3 Sensitivity Analysis

The project team carried out a sensitivity analysis on selected parameters to evaluate their impact on flow and pollutant reductions and to choose conditions representative of vegetated buffers in Maine based on the team's experience. The parameters evaluated for the pervious buffer area are listed in *Chapter 5* as influencing the effectiveness of vegetated buffers (MEDEP, 2016):

- **Slope**: *Chapter 5* specifies that buffer slopes must be less than 15% and divides requirements for certain buffer types into two slope groups: 0-8% and 9-15%. Initial tests showed very limited sensitivity to slope in these groups; therefore, the project team determined to use 8% as a representative average value.
- **IC to PC ratio**: the IC:PC ratio controls the amount of runoff delivered from an impervious area to a buffer for treatment.
- **Manning's n**: the roughness coefficient in the equations for simulating sheet flow which represents sources of friction. TR-55 provides typical Manning's n values (NRCS, 1986). The duff layer within a forest buffer and tall stands of grasses in a meadow buffer impact this value.
- **Depression storage**: represents the micro-topography irregularities within a buffer that provide small areas where runoff can pool, infiltrate, and evaporate.

- **Infiltration rates by HSG**: infiltration is a key process in runoff treatment by vegetated buffers that can vary based on soil characteristics. Representative infiltration rates for HSGs were taken from the long memo on the proposed Chapter 500 language (Dennis *et al.*, 2025).

The results of the sensitivity analysis for soils with an infiltration rate of 0.5 in/hr and IC:PC ratios of 1:1, 4:1, and 8:1 are shown in Table 3-3, Table 3-4, and Table 3-5, respectively. Similar tables are shown for soils with a lower infiltration rate of 0.05 in/hr and IC:PC ratios of 1:4, 1:1, and 4:1 in Table 3-6, Table 3-7, and Table 3-8, respectively. Focusing on TP, these results illustrate the connections between the relative amount of managed runoff (IC:PC ratio), the roughness of the buffer surface (Manning's n), and the micro-topography (depression storage). As the relative amount of managed runoff increases, the impact of depression storage becomes greater. For example, with an infiltration rate of 0.5 in/hr, Manning's n of 0.5, and IC:PC of 1:1 (Table 3-3), the difference between the TP load reductions for 0.1 in and 1.0 in of depression storage is 0.9% (98.7% and 99.6%, respectively). With an IC:PC ratio of 4:1, this difference increases to 6.3% (90.0% and 96.3%, respectively) and with an IC:PC ratio of 8:1, the difference increases to 12.2% (73.9% and 86.1%, respectively).

For any given IC:PC ratio and depression storage, Manning's n was less sensitive than depression storage and ranged within a few percentage points. For example, with an infiltration rate of 0.05 in/hr, depression storage of 0.5 in, and an IC:PC ratio of 1:1 (Table 3-7), TP reductions ranged from 81.4%, 82.3%, and 83.3% for Manning's n values of 0.1, 0.5, and 1, respectively.

Based on the results of the sensitivity analysis, literature values, and the project team's experience and knowledge of local conditions, a set of parameters for each buffer type (i.e., forest, meadow, and lawn) was selected for performance curve development (Table 3-9).

Table 3-3. Flow and pollutant reductions from sensitivity testing with a soil infiltration rate of 0.5 in/hr and an IC:PC ratio of 1:1

| IC:PC = 1:1; Infiltration Rate = 0.5 in/hr; Slope = 8% | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Manning's n | 0.1 | | | 0.5 | | | 1 | | |
| Depression Storage (in) | 0.1 | 0.5 | 1 | 0.1 | 0.5 | 1 | 0.1 | 0.5 | 1 |
| Runoff Volume Reduction | 96.6% | 98.0% | 98.7% | 97.0% | 98.2% | 98.8% | 97.3% | 98.3% | 98.8% |
| TP Load Reduction | 98.5% | 99.1% | 99.5% | 98.7% | 99.2% | 99.6% | 98.9% | 99.3% | 99.6% |
| TN Load Reduction | 98.7% | 99.3% | 99.6% | 98.9% | 99.4% | 99.6% | 99.0% | 99.4% | 99.7% |
| ZN Load Reduction | 95.7% | 98.6% | 99.5% | 96.7% | 98.9% | 99.6% | 97.3% | 99.0% | 99.6% |
| TSS Load Reduction | 95.1% | 98.2% | 99.2% | 96.2% | 98.5% | 99.3% | 96.8% | 98.7% | 99.4% |
| E. coli Load Reduction | 81.5% | 91.5% | 97.1% | 84.5% | 92.9% | 97.7% | 86.5% | 93.8% | 98.1% |

Table 3-4. Flow and pollutant reductions from sensitivity testing with a soil infiltration rate of 0.5 in/hr and an IC:PC ratio of 4:1

| IC:PC = 4:1; Infiltration Rate = 0.5 in/hr; Slope = 8% | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Manning's n | 0.1 | | | 0.5 | | | 1 | | |
| Depression Storage (in) | 0.1 | 0.5 | 1 | 0.1 | 0.5 | 1 | 0.1 | 0.5 | 1 |
| Runoff Volume Reduction | 78.5% | 83.9% | 87.8% | 79.9% | 84.7% | 88.4% | 80.9% | 85.4% | 88.8% |
| TP Load Reduction | 88.5% | 93.2% | 96.0% | 90.0% | 93.9% | 96.3% | 91.0% | 94.5% | 96.5% |
| TN Load Reduction | 87.5% | 92.4% | 95.4% | 89.0% | 93.2% | 95.7% | 90.1% | 93.7% | 96.0% |
| ZN Load Reduction | 61.6% | 72.0% | 81.2% | 65.3% | 74.5% | 82.2% | 68.0% | 76.3% | 83.2% |
| TSS Load Reduction | 61.5% | 71.8% | 81.0% | 65.2% | 74.3% | 82.1% | 67.8% | 76.1% | 83.1% |
| E. coli Load Reduction | 71.0% | 78.8% | 83.5% | 73.8% | 80.1% | 84.0% | 75.6% | 81.0% | 84.5% |

### Table 3-5. Flow and pollutant reductions from sensitivity testing with a soil infiltration rate of 0.5 in/hr and an IC:PC ratio of 8:1

| IC:PC = 8:1; Infiltration Rate = 0.5 in/hr; Slope = 8% | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Manning's n | 0.1 | | | 0.5 | | | 1 | | |
| Depression Storage (in) | 0.1 | 0.5 | 1 | 0.1 | 0.5 | 1 | 0.1 | 0.5 | 1 |
| Runoff Volume Reduction | 58.8% | 64.7% | 69.8% | 60.3% | 65.8% | 70.6% | 61.5% | 66.7% | 71.3% |
| TP Load Reduction | 71.4% | 79.0% | 85.3% | 73.9% | 80.7% | 86.1% | 75.8% | 81.9% | 86.7% |
| TN Load Reduction | 70.1% | 77.7% | 84.0% | 72.6% | 79.4% | 84.8% | 74.4% | 80.6% | 85.5% |
| ZN Load Reduction | 38.5% | 47.0% | 57.1% | 42.3% | 50.0% | 58.7% | 45.0% | 52.4% | 60.1% |
| TSS Load Reduction | 38.5% | 46.9% | 57.0% | 42.2% | 50.0% | 58.6% | 45.0% | 52.3% | 60.0% |
| E. coli Load Reduction | 51.5% | 61.6% | 70.8% | 55.2% | 64.0% | 71.9% | 57.7% | 65.8% | 72.9% |

### Table 3-6. Flow and pollutant reductions from sensitivity testing with a soil infiltration rate of 0.05 in/hr and an IC:PC ratio of 1:4

| IC:PC = 1:4; Infiltration Rate = 0.05 in/hr; Slope = 8% | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Manning's n | 0.1 | | | 0.5 | | | 1 | | |
| Depression Storage (in) | 0.1 | 0.5 | 1 | 0.1 | 0.5 | 1 | 0.1 | 0.5 | 1 |
| Runoff Volume Reduction | 57.5% | 74.5% | 85.1% | 59.1% | 75.3% | 85.5% | 60.5% | 76.0% | 85.9% |
| TP Load Reduction | 63.1% | 79.0% | 89.5% | 66.0% | 80.5% | 90.4% | 68.4% | 81.9% | 91.1% |
| TN Load Reduction | 71.3% | 84.5% | 92.2% | 73.6% | 85.5% | 92.8% | 75.5% | 86.5% | 93.3% |
| ZN Load Reduction | 55.7% | 76.3% | 88.7% | 59.5% | 78.2% | 89.7% | 62.6% | 79.9% | 90.5% |
| TSS Load Reduction | 48.0% | 70.9% | 85.7% | 52.3% | 73.1% | 87.0% | 55.7% | 75.1% | 88.0% |
| E. coli Load Reduction | 42.2% | 77.5% | 92.5% | 46.4% | 79.6% | 93.1% | 50.3% | 81.3% | 93.6% |

### Table 3-7. Flow and pollutant reductions from sensitivity testing with a soil infiltration rate of 0.05 in/hr and an IC:PC ratio of 1:1

| IC:PC = 1:1; Infiltration Rate = 0.05 in/hr; Slope = 8% | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Manning's n | 0.1 | | | 0.5 | | | 1 | | |
| Depression Storage (in) | 0.1 | 0.5 | 1 | 0.1 | 0.5 | 1 | 0.1 | 0.5 | 1 |
| Runoff Volume Reduction | 49.8% | 65.7% | 76.3% | 51.5% | 66.5% | 76.8% | 52.8% | 67.2% | 77.3% |
| TP Load Reduction | 66.6% | 81.4% | 88.2% | 69.7% | 82.3% | 88.9% | 71.9% | 83.3% | 89.5% |
| TN Load Reduction | 69.5% | 84.3% | 90.6% | 72.4% | 85.1% | 91.1% | 74.5% | 86.0% | 91.6% |
| ZN Load Reduction | 41.2% | 64.7% | 78.2% | 46.2% | 66.6% | 79.6% | 49.9% | 68.6% | 80.8% |
| TSS Load Reduction | 38.3% | 61.2% | 75.2% | 43.3% | 63.1% | 76.6% | 47.0% | 65.2% | 78.0% |
| E. coli Load Reduction | 26.2% | 47.5% | 70.6% | 29.6% | 49.6% | 72.6% | 32.1% | 52.4% | 74.2% |

### Table 3-8. Flow and pollutant reductions from sensitivity testing with a soil infiltration rate of 0.05 in/hr and an IC:PC ratio of 4:1

| IC:PC = 4:1; Infiltration Rate = 0.05 in/hr; Slope = 8% | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Manning's n | 0.1 | | | 0.5 | | | 1 | | |
| Depression Storage (in) | 0.1 | 0.5 | 1 | 0.1 | 0.5 | 1 | 0.1 | 0.5 | 1 |
| Runoff Volume Reduction | 22.9% | 35.3% | 45.9% | 24.2% | 36.1% | 46.5% | 25.3% | 36.9% | 47.1% |
| TP Load Reduction | 37.1% | 58.8% | 72.1% | 41.5% | 60.7% | 73.2% | 45.0% | 62.6% | 74.4% |
| TN Load Reduction | 36.8% | 58.5% | 71.7% | 41.2% | 60.3% | 72.8% | 44.7% | 62.2% | 74.0% |
| ZN Load Reduction | 16.2% | 32.6% | 45.5% | 20.9% | 35.0% | 47.0% | 24.7% | 37.3% | 48.8% |
| TSS Load Reduction | 15.9% | 32.0% | 44.8% | 20.5% | 34.4% | 46.2% | 24.3% | 36.7% | 48.0% |
| E. coli Load Reduction | 12.1% | 24.0% | 34.5% | 14.6% | 24.7% | 34.1% | 16.9% | 26.0% | 34.8% |

**Table 3-9. Selected parameter values for the development of performance curves**

| Buffer Type | Slope (%) | Manning's n | Depression Storage (in.) | Infiltration Rate (in/hr) | | | |
|---|---|---|---|---|---|---|---|
| | | | | HSG-A | HSG-B | HSG-C | HSG-D |
| Forest | 8% | 0.6 | 0.5 | 0.8 | 0.4 | 0.2 | 0.1 |
| Meadow | | 0.24 | 0.25 | | | | |
| Lawn | | 0.06 | 0.1 | | | | |

# 4 CUMULATIVE PERFORMANCE CURVES

An Opti-Tool performance curve shows the long-term percentage reduction in flow or pollutant load from an SCM for a range of SCM sizes. In the case of these vegetated buffers, the sizing variable is the ratio of impervious to pervious cover (IC:PC) from 1:1 to 8:1 in IC increments of 0.5. To create performance curves for a specific buffer type, the long-term flow and pollutant loads (i.e., TP, TN, Zn, TSS, and E. coli) from the corresponding Opti-Tool HRU time series by HSG over 28 years (as discussed in Section 3.1) were used with the appropriate area for the IC:PC ratio. It should be noted that, while Zn, TSS, and E. coli are included in the performance curves, they are intended to provide background information as only nutrients and runoff were the focus of buffer configuration. Impervious cover was represented using the Impervious Commercial HRU, forest buffers used the Forest HRU by HSG, and meadow and lawn buffers used the Pervious HRU by HSG. Meadow and lawn buffers had different physical parameters selected based on the sensitivity analysis, as shown in Table 3-9. As an example, the 1:1 IC:PC forest buffer on HSG-A was simulated using 1 acre of Impervious Commercial HRU generating sheet flow onto 1 acre of HSG-A Forest HRU (see Figure 3-4).

Because these performance curves are based on long-term continuous simulation, they represent cumulative reductions over a wide range of storm and antecedent moisture conditions. As shown in Table 3-1, nearly two-thirds (62%) of days with rainfall are for small events with depths < 0.5 in. Many of these smaller events may achieve 100% runoff reduction and therefore completely capture the first flush of pollutants from IC. As such, these curves provide a more realistic picture of long-term SCM performance, assuming proper maintenance, for planning and crediting purposes, as opposed to performance based on a single storm event or synthetic design storm, because of the repeated build up, wash-off, and capture of pollutants from small events which form the majority of rainfall events.

## 4.1 Forest Buffers

The long-term cumulative performance curves for forest buffers by pollutant are shown in Figure 4-1 to Figure 4-6 for Flow (Runoff Volume), TP, TN, Zn, TSS, and *E.coli*, respectively.

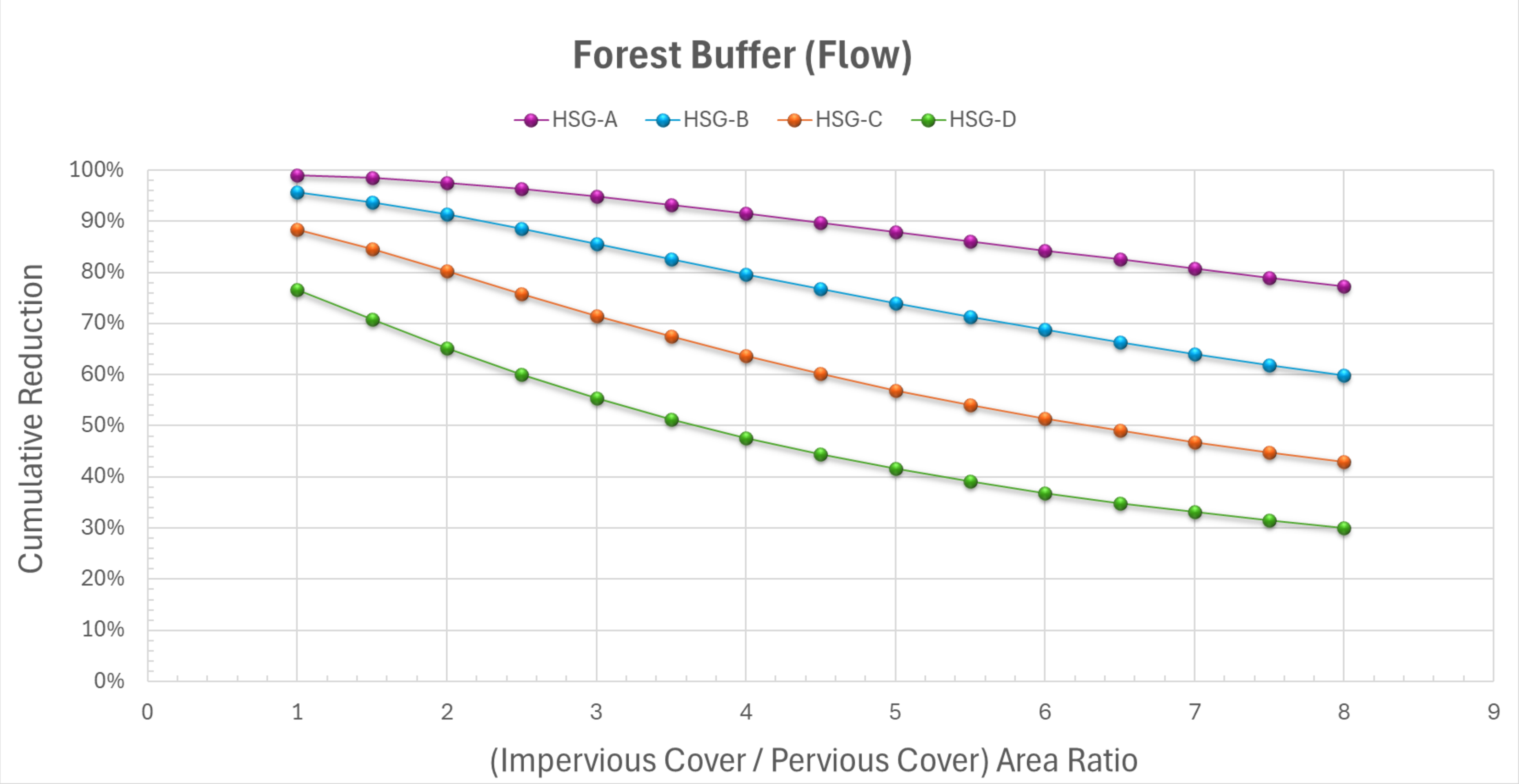


**Figure 4-1. Performance curve for cumulative reduction in flow for forest buffers by hydrologic soil group (HSG).**

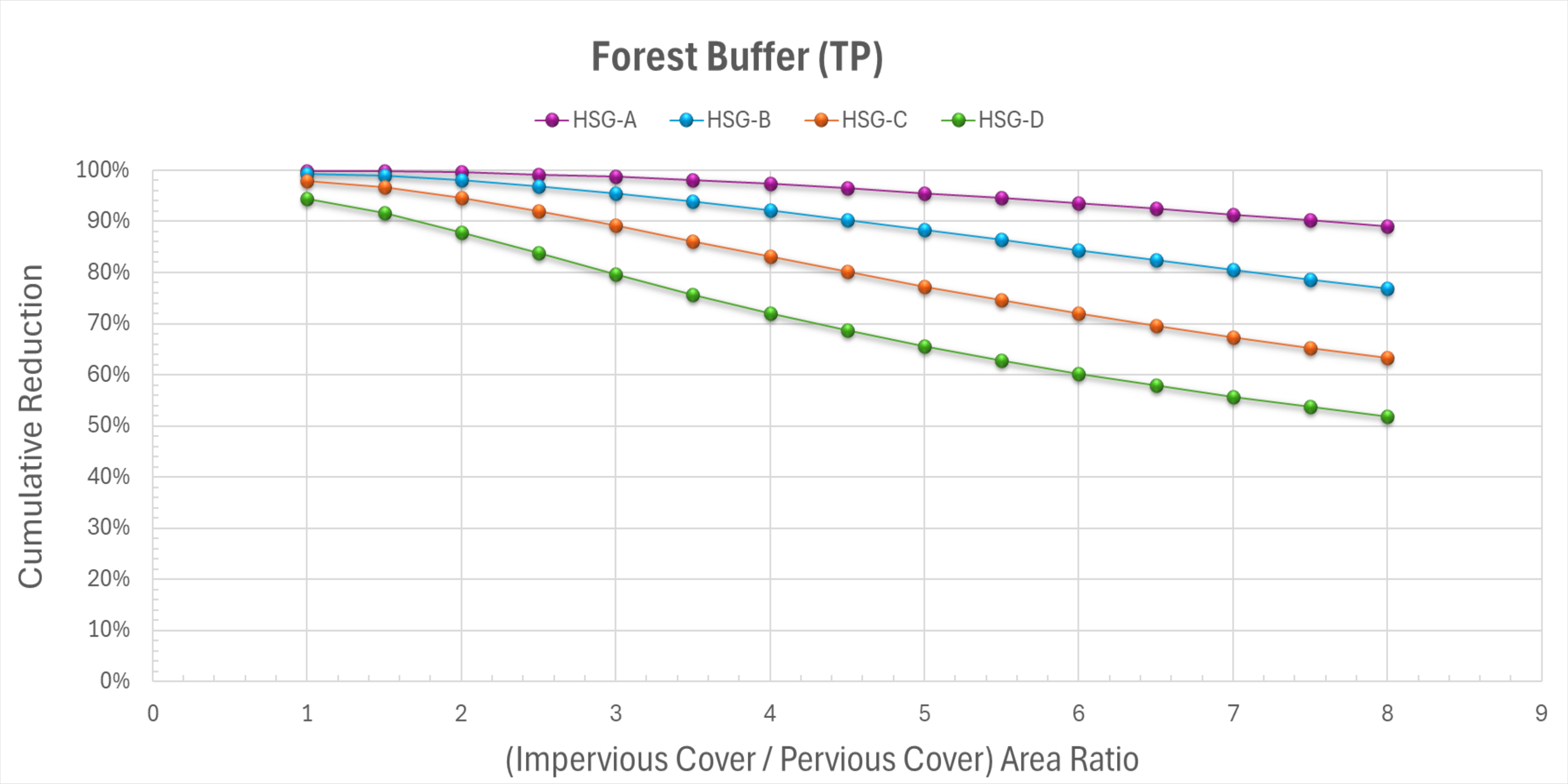


**Figure 4-2. Performance curve for cumulative reduction in TP load for forest buffers by hydrologic soil group (HSG).**

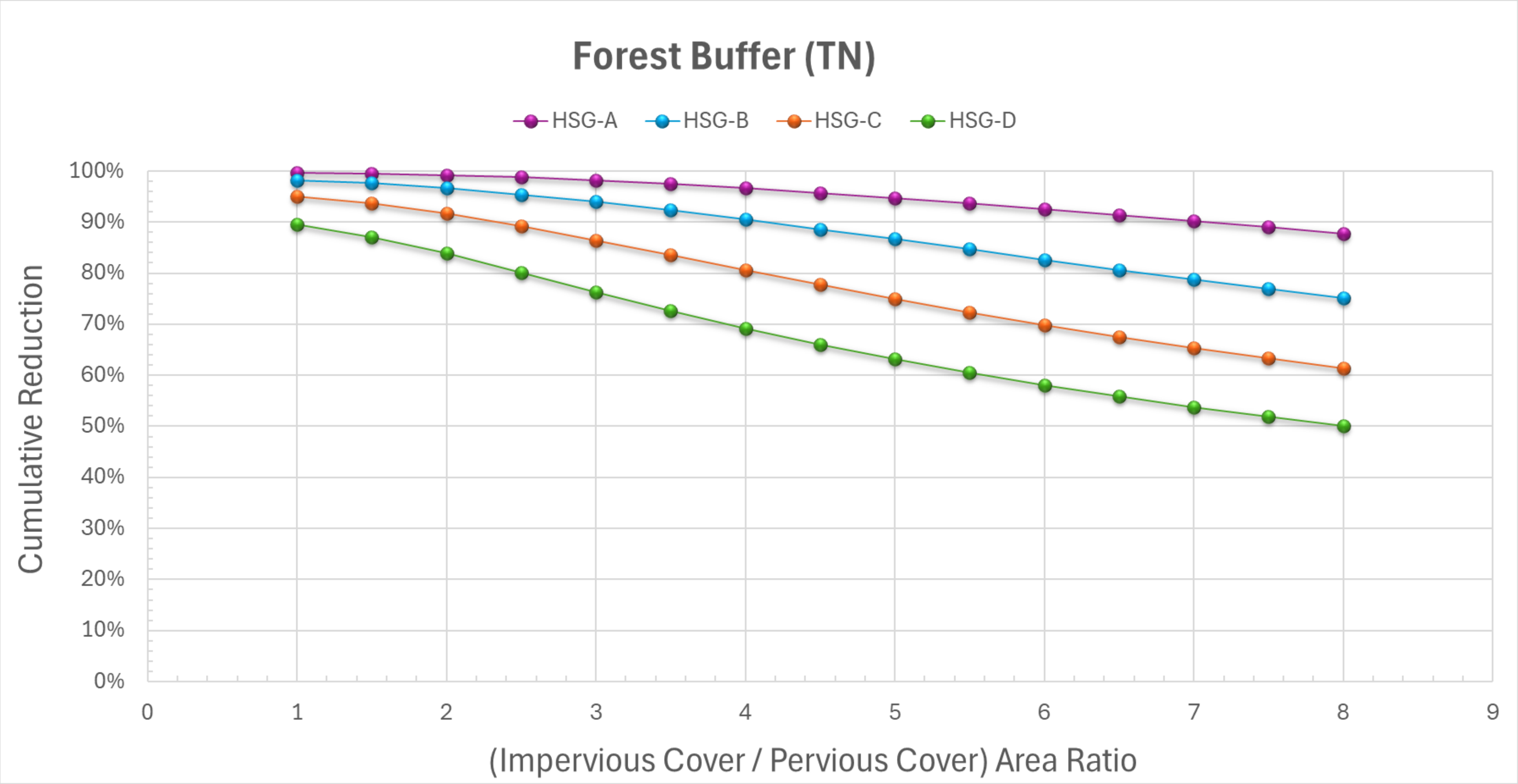


**Figure 4-3. Performance curve for cumulative reduction in TN load for forest buffers by hydrologic soil group (HSG).**

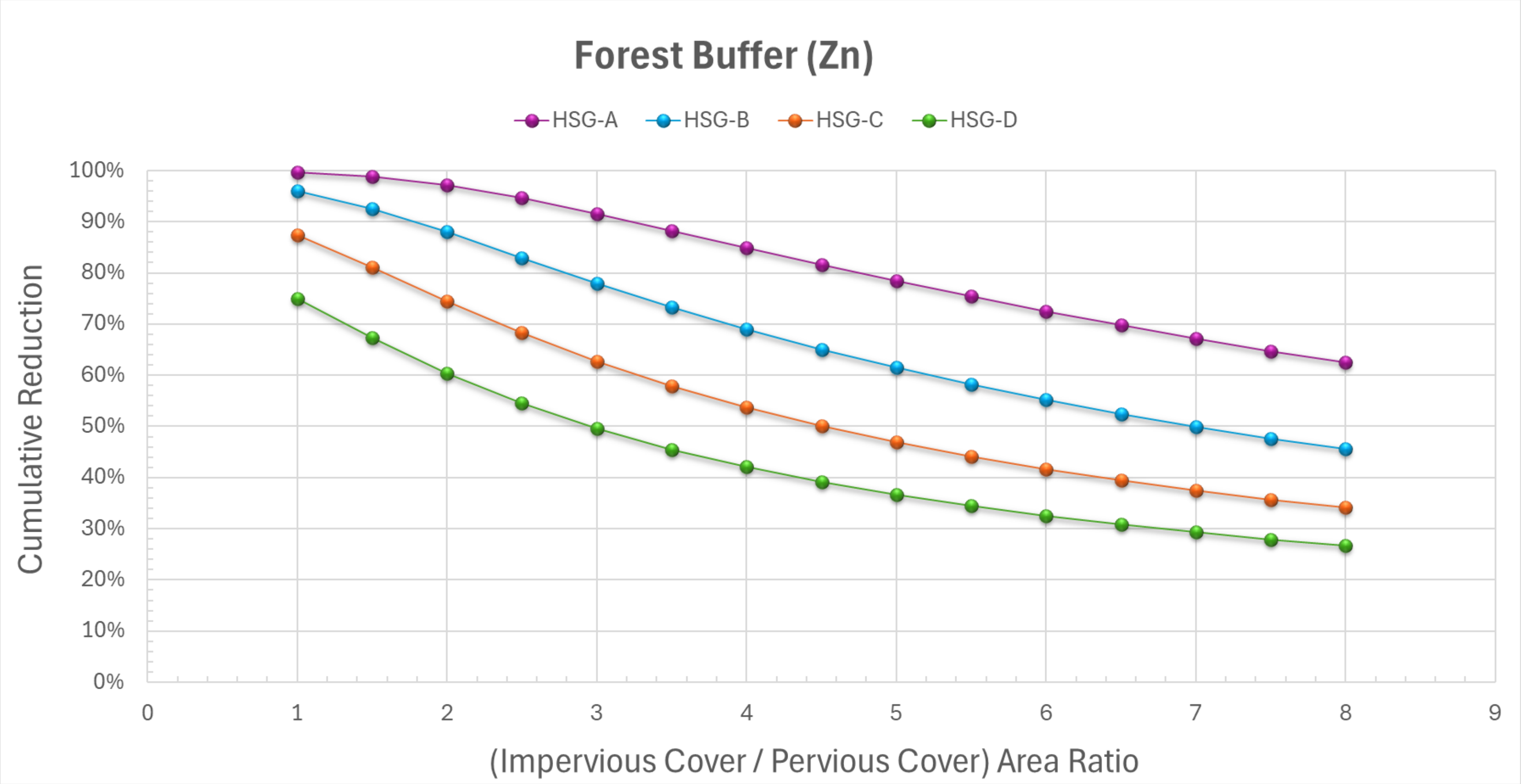


**Figure 4-4. Performance curve for cumulative reduction in Zn load for forest buffers by hydrologic soil group (HSG).**

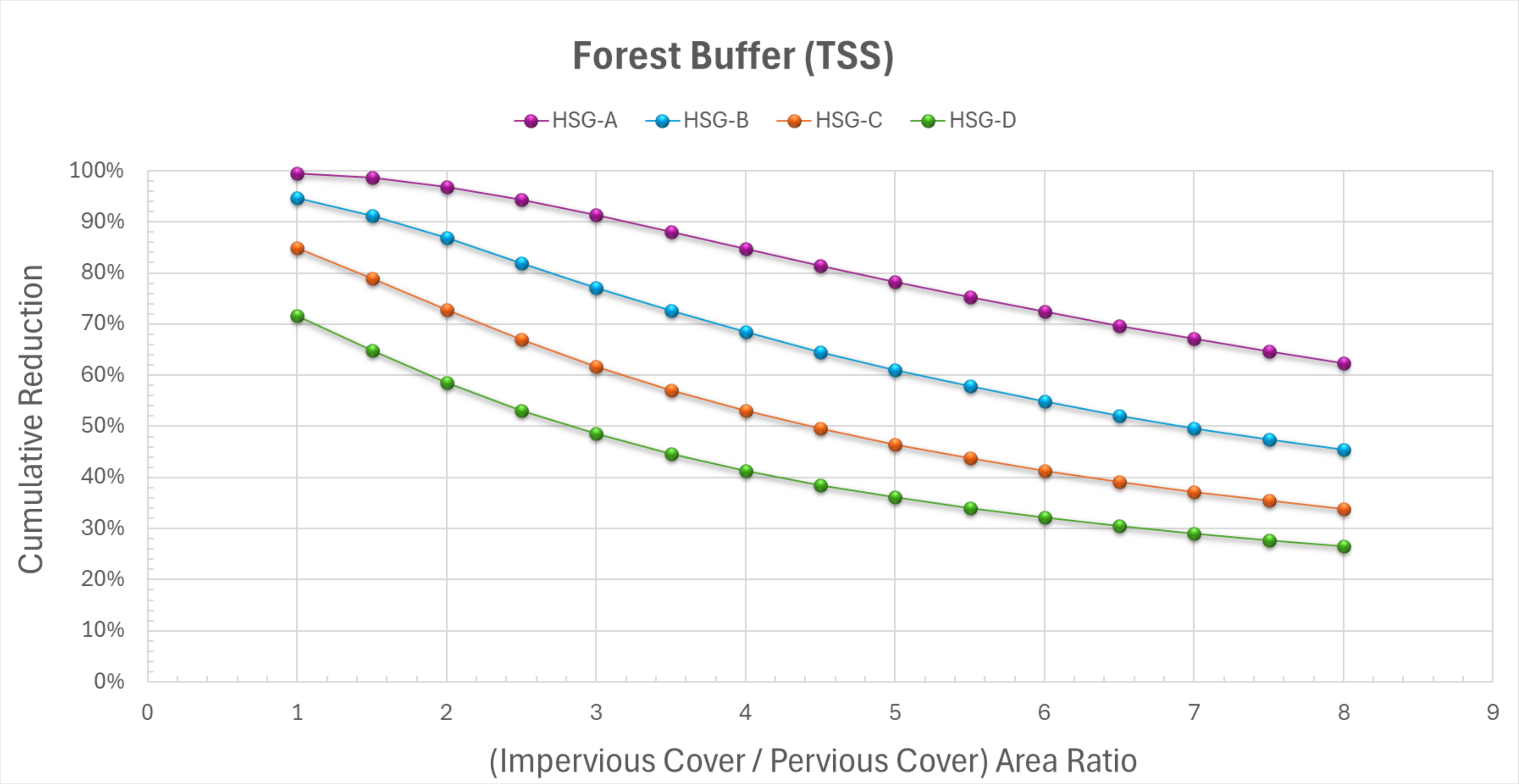


Figure 4-5. Performance curve for cumulative reduction in TSS load for forest buffers by hydrologic soil group (HSG).

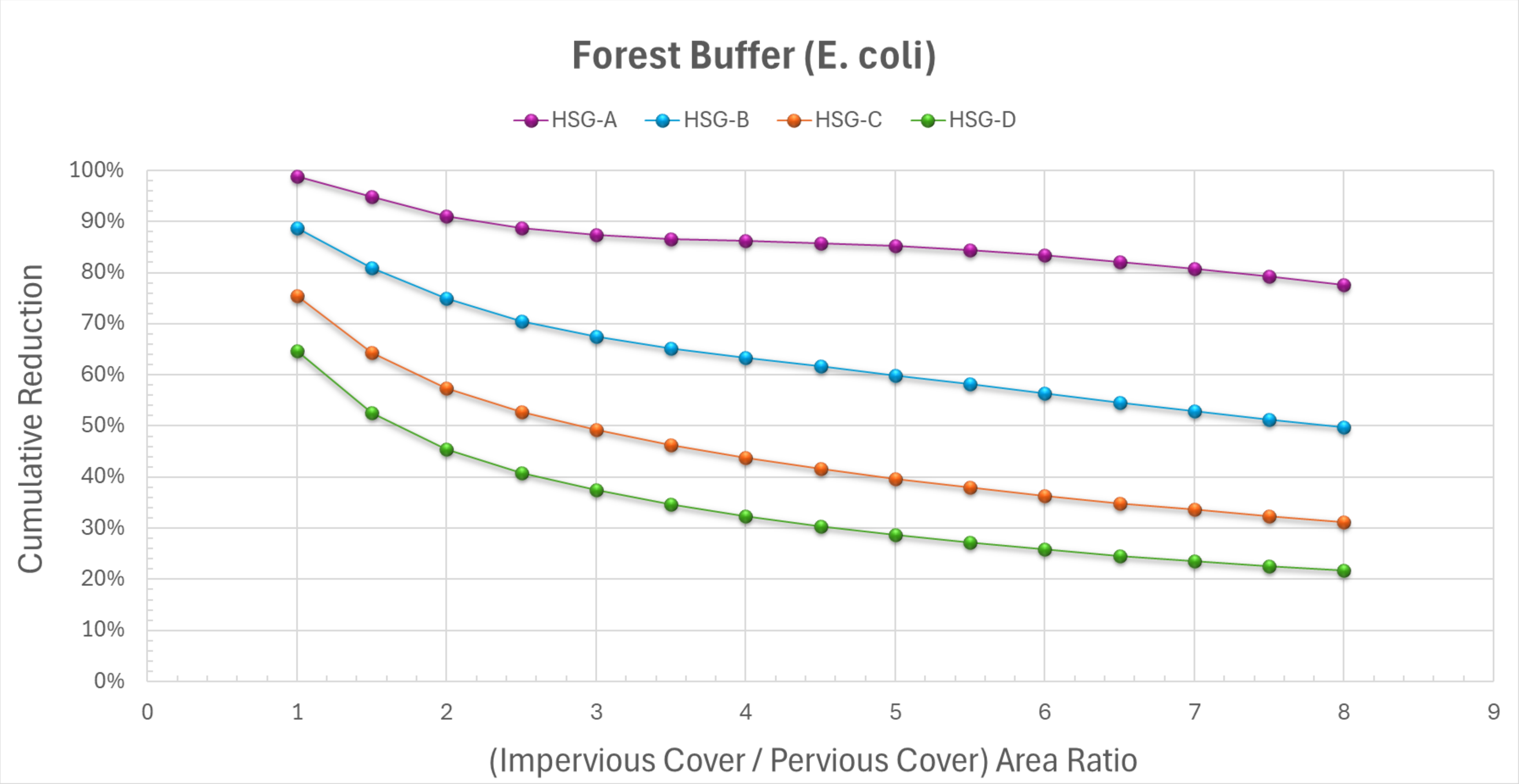


**Figure 4-6. Performance curve for cumulative reduction in *E. coli* load for forest buffers by hydrologic soil group (HSG).**

## 4.2 Meadow Buffers

The long-term cumulative performance curves for meadow buffers by pollutant are shown in Figure 4-7 to Figure 4-12 for Flow (Runoff Volume), TP, TN, Zn, TSS, and *E.coli*, respectively.

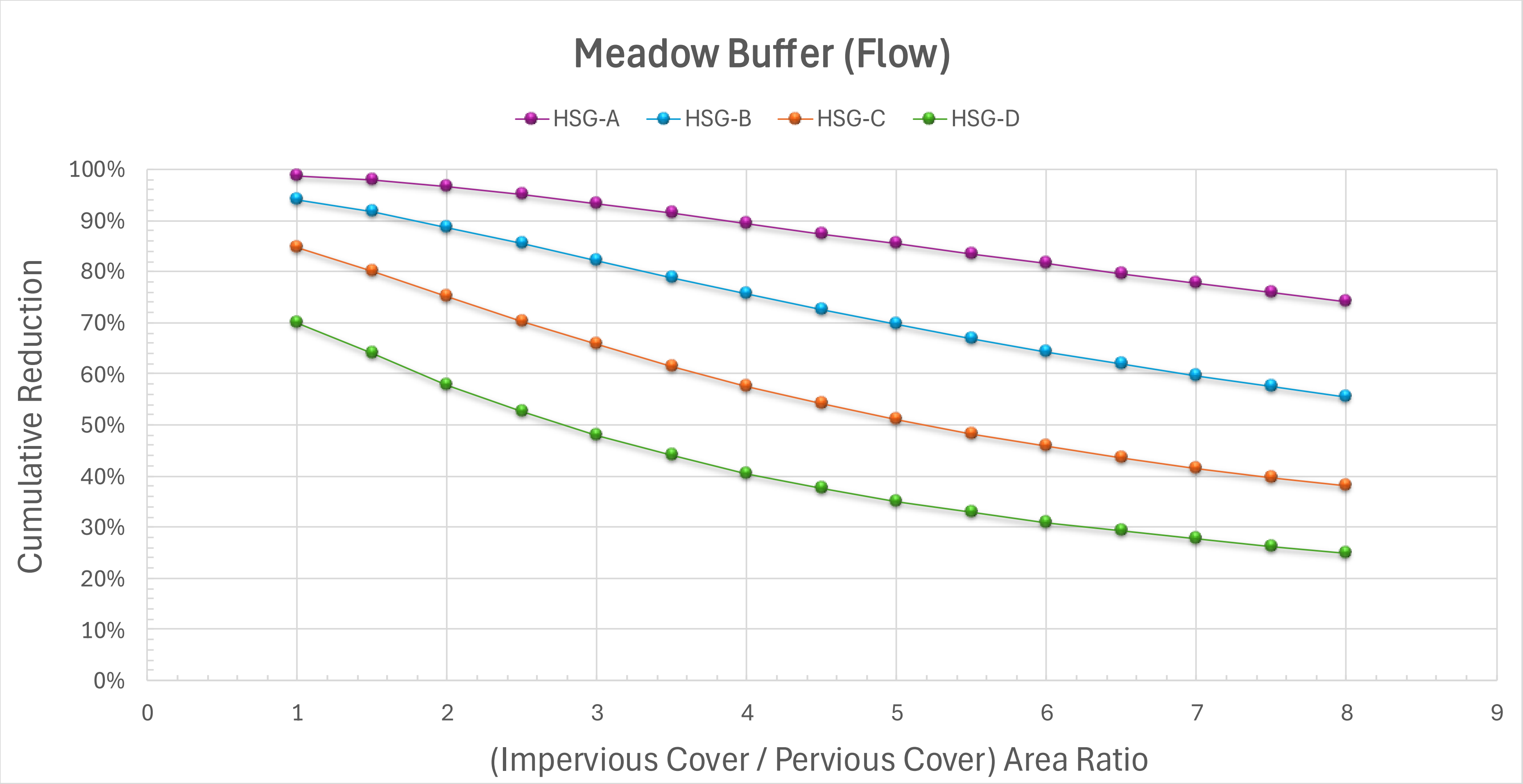


**Figure 4-7. Performance curve for cumulative reduction in flow for meadow buffers by hydrologic soil group (HSG).**

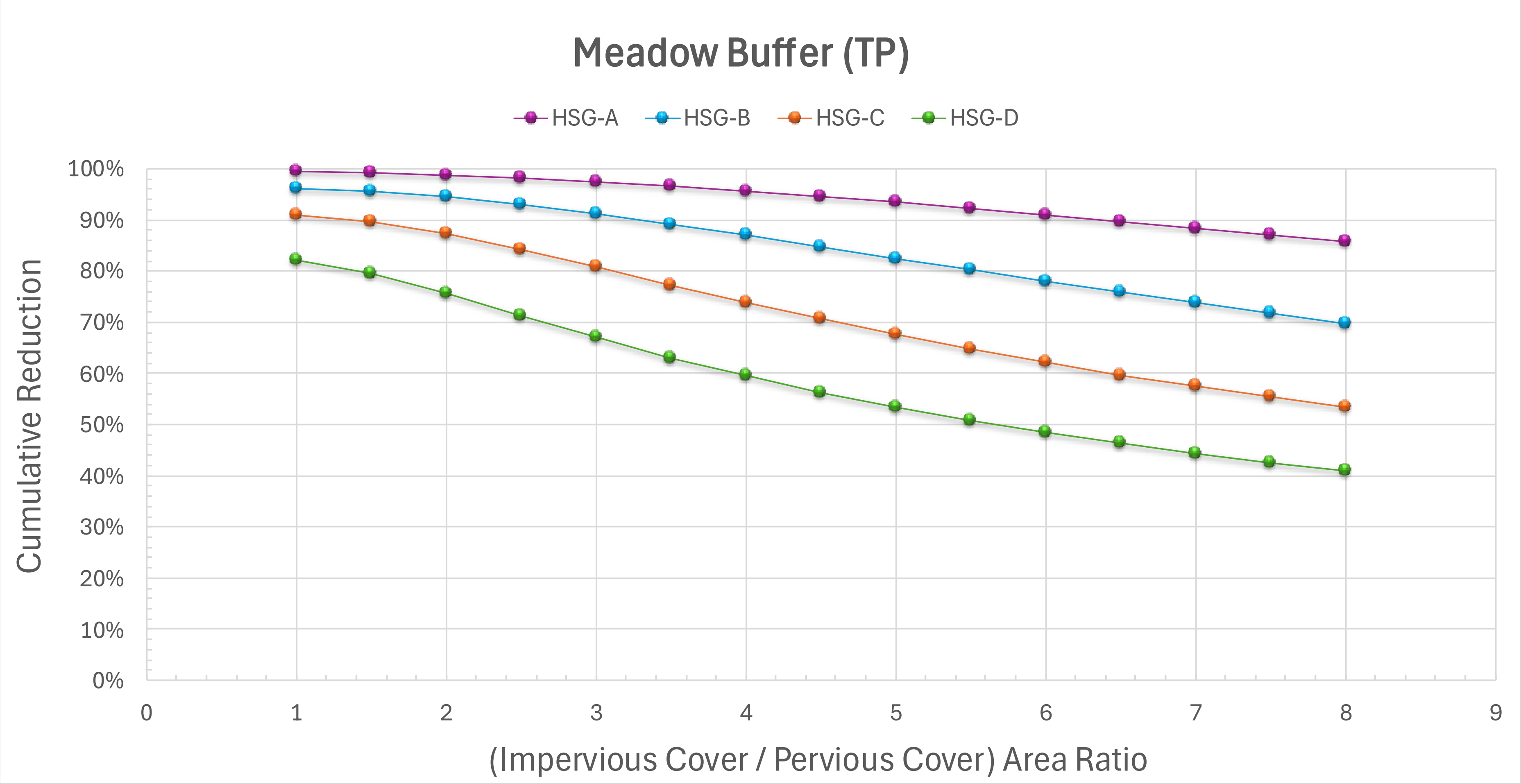


**Figure 4-8. Performance curve for cumulative reduction in TP load for meadow buffers by hydrologic soil group (HSG).**

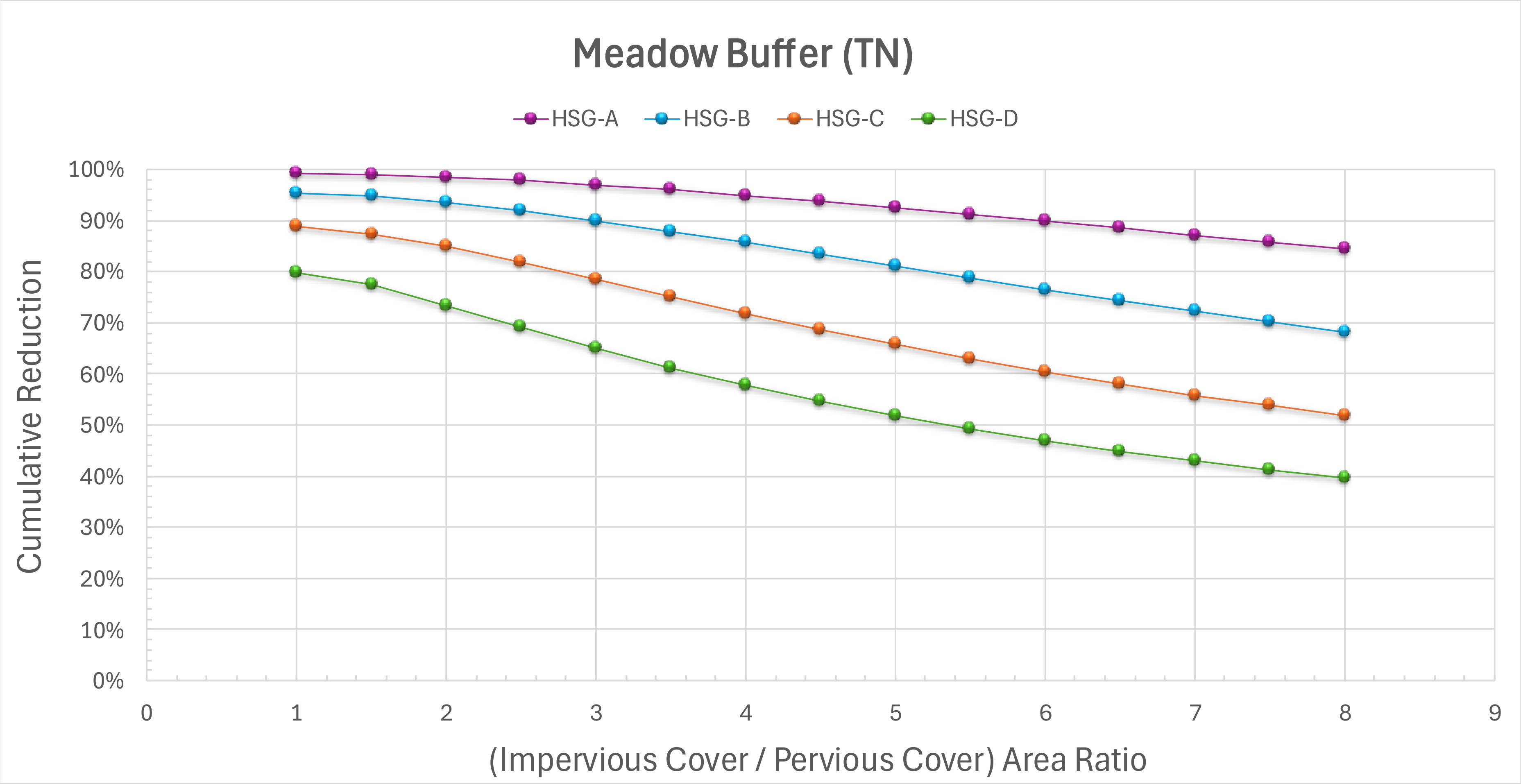


**Figure 4-9. Performance curve for cumulative reduction in TN load for meadow buffers by hydrologic soil group (HSG).**

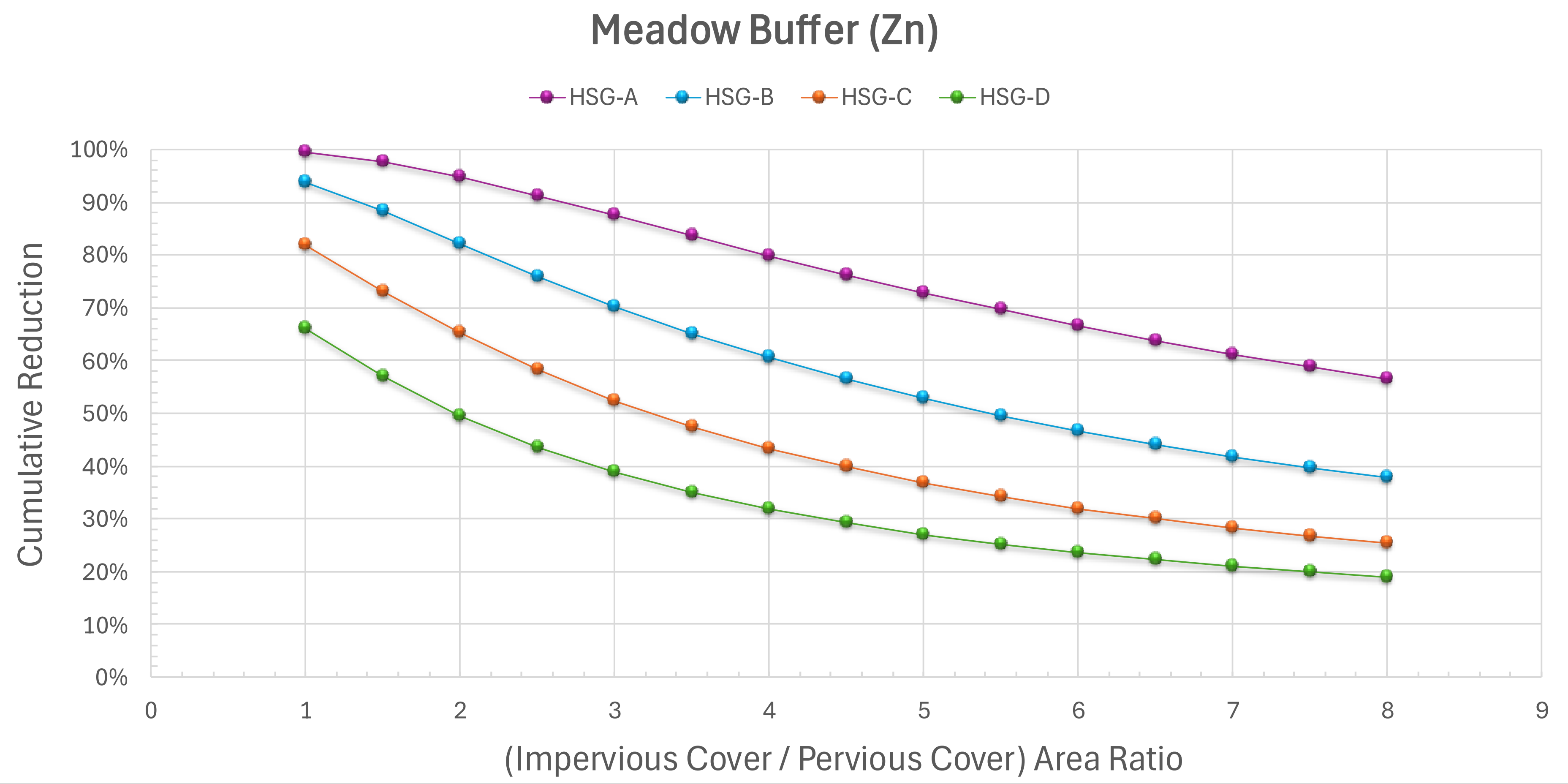


**Figure 4-10. Performance curve for cumulative reduction in Zn load for meadow buffers by hydrologic soil group (HSG).**

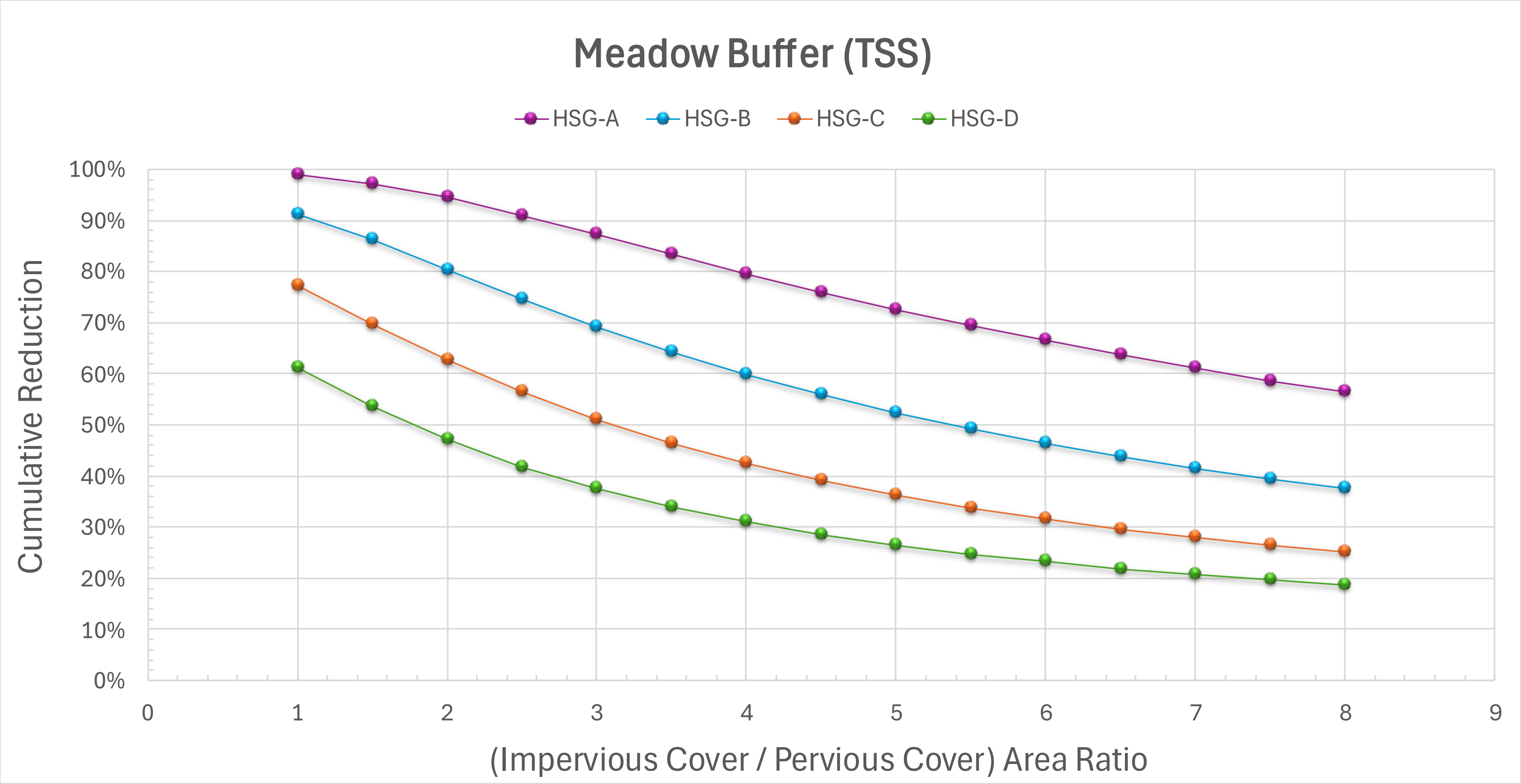


**Figure 4-11. Performance curve for cumulative reduction in TSS load for meadow buffers by hydrologic soil group (HSG).**

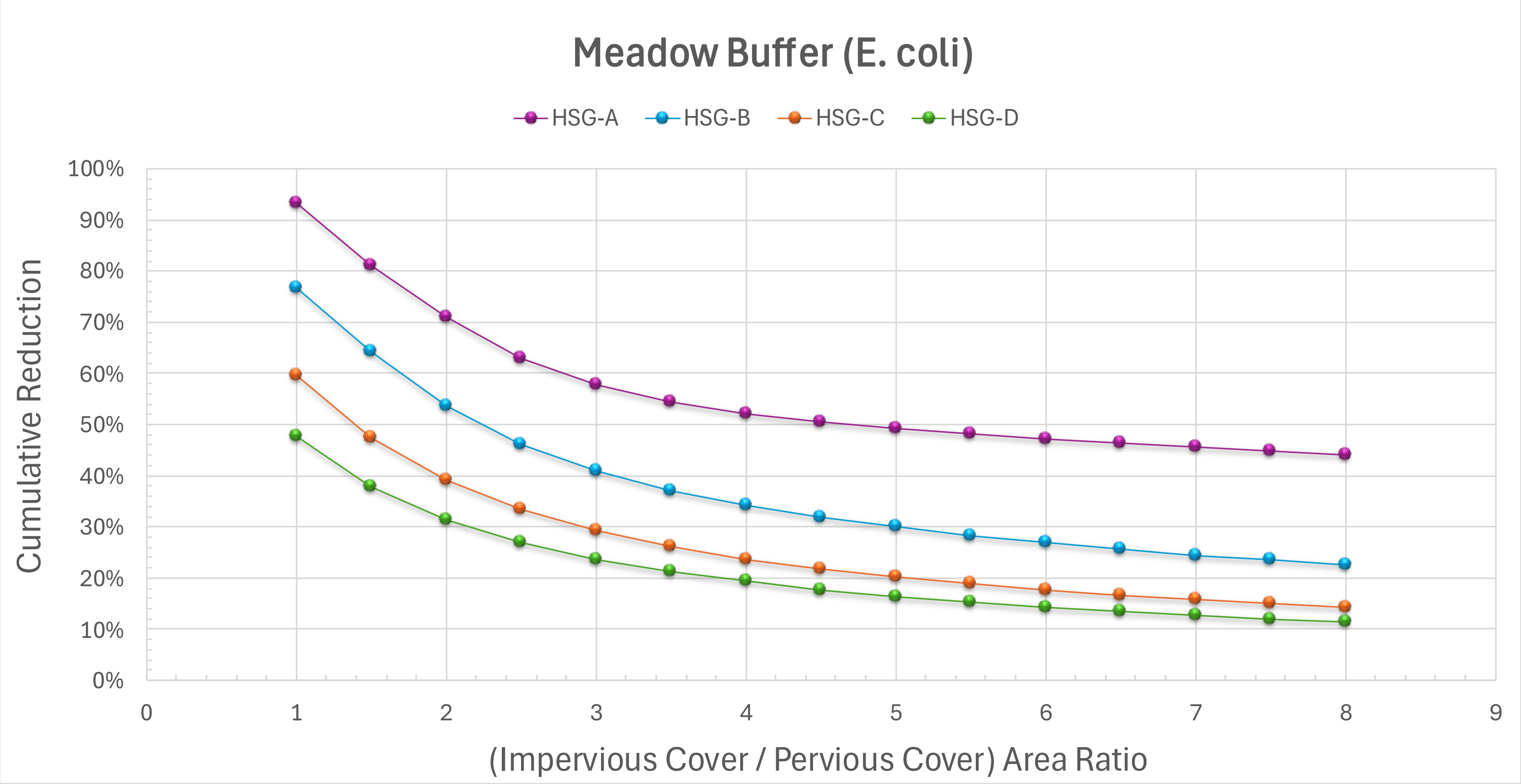


**Figure 4-12. Performance curve for cumulative reduction in *E. coli* load for meadow buffers by hydrologic soil group (HSG).**

## 4.3 Lawn Buffers

Lawn buffers are intended to represent short, managed grass, as opposed to tall, more natural meadows. These are envisioned as uncompacted grass cover on an undisturbed soil profile with very high or high infiltration capacity, as opposed to typical lawns, for example on engineered fill as common in residential developments. The long-term cumulative performance curves for lawn buffers by pollutant are shown in Figure 4-13 to Figure 4-18 for Flow (Runoff Volume), TP, TN, Zn, TSS, and *E.coli*, respectively. Flow reduction curves were developed for HSGs A to D; even the lower infiltration rate HSGs (i.e., C and D) can provide substantial benefits in terms of volume reduction. It should be noted however, that the project team limited the pollutant reduction curves to only HSG A and B for lawn buffers considering the potential pollutant load export rates of HSG C and D lawn.

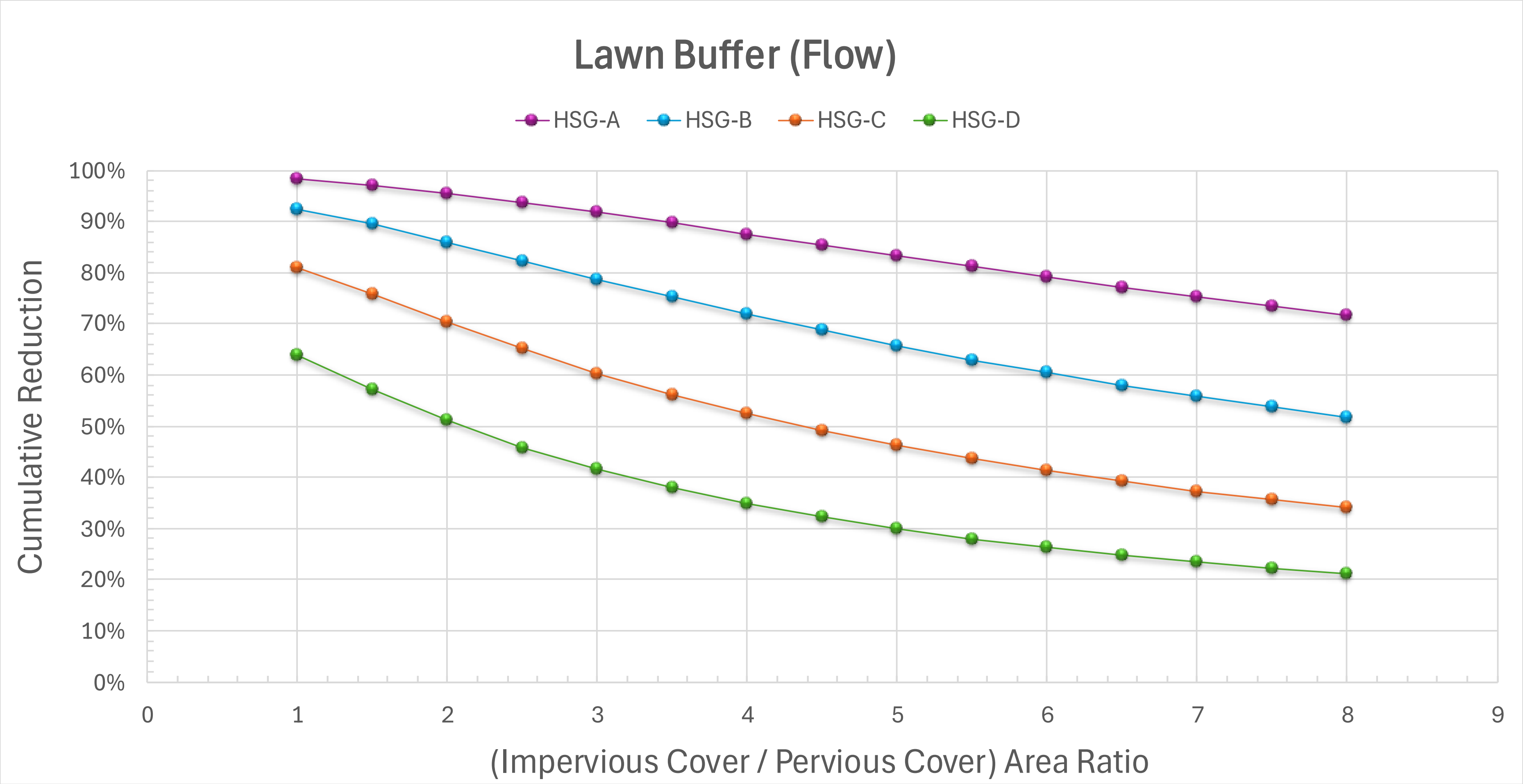


Figure 4-13. Performance curve for cumulative reduction in flow for lawn buffers by hydrologic soil group (HSG).

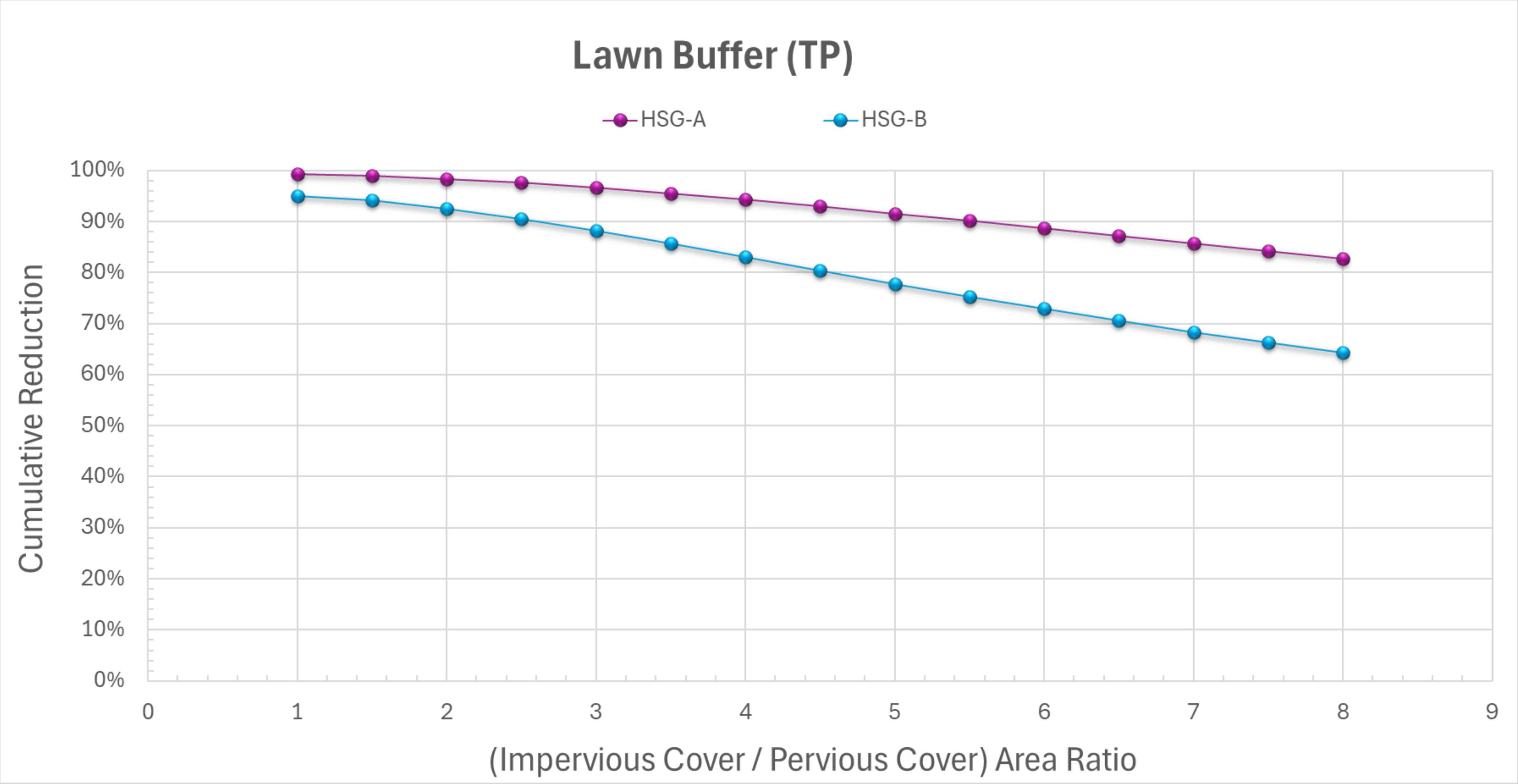


**Figure 4-14. Performance curve for cumulative reduction in TP load for lawn buffers by hydrologic soil group (HSG).**

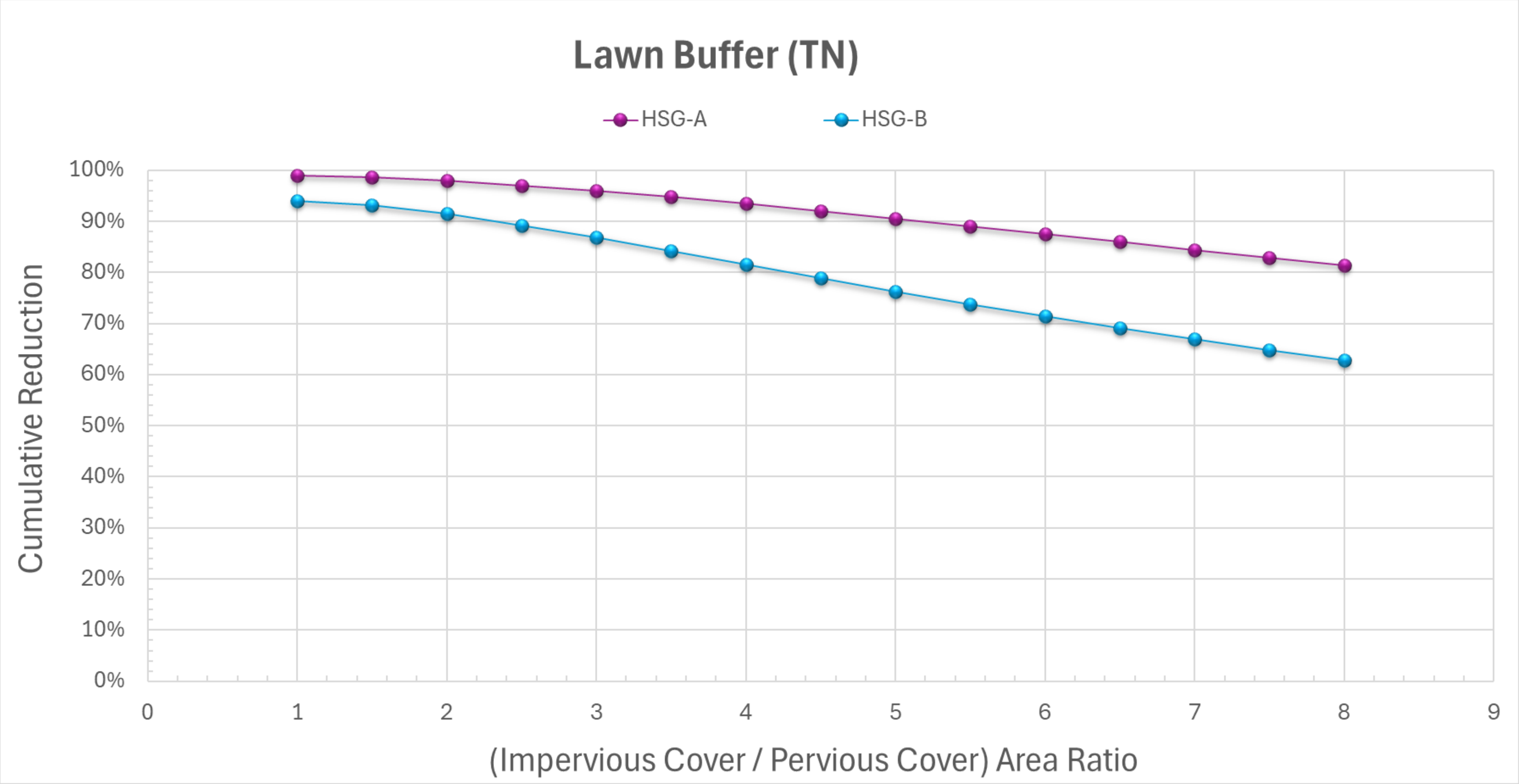


Figure 4-15. Performance curve for cumulative reduction in TN load for lawn buffers by hydrologic soil group (HSG).

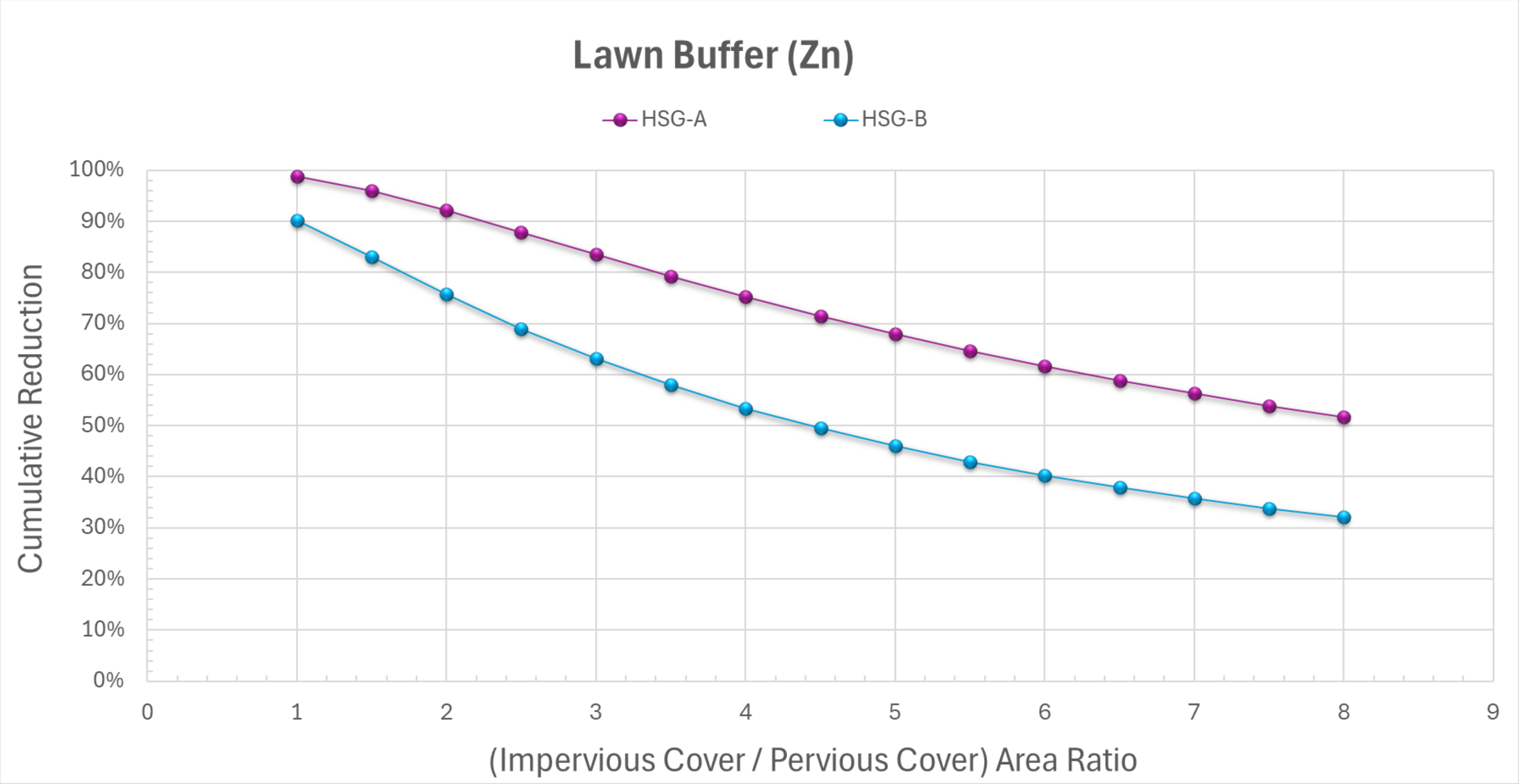


Figure 4-16. Performance curve for cumulative reduction in Zn load for lawn buffers by hydrologic soil group (HSG).

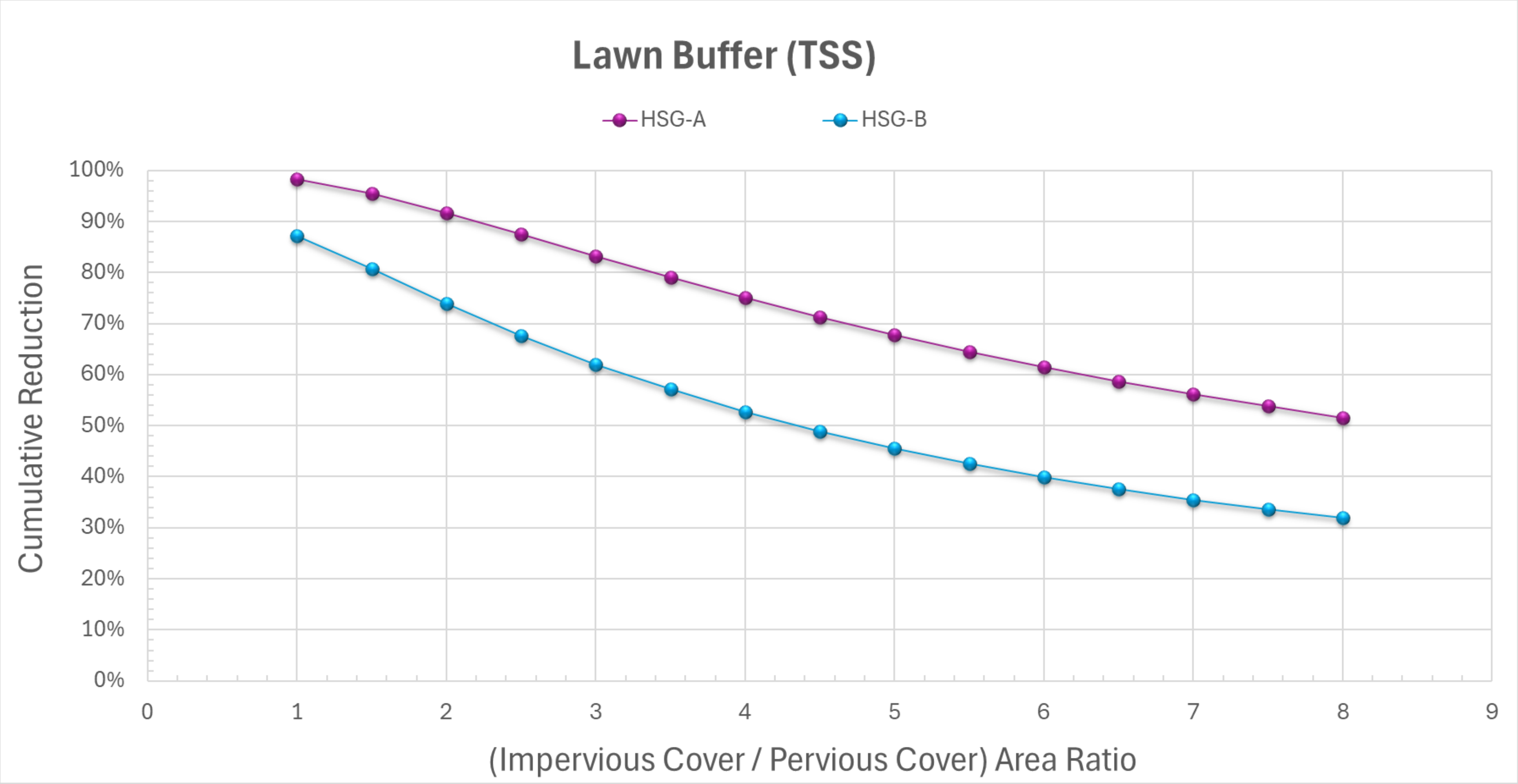


Figure 4-17. Performance curve for cumulative reduction in TSS load for lawn buffers by hydrologic soil group (HSG).

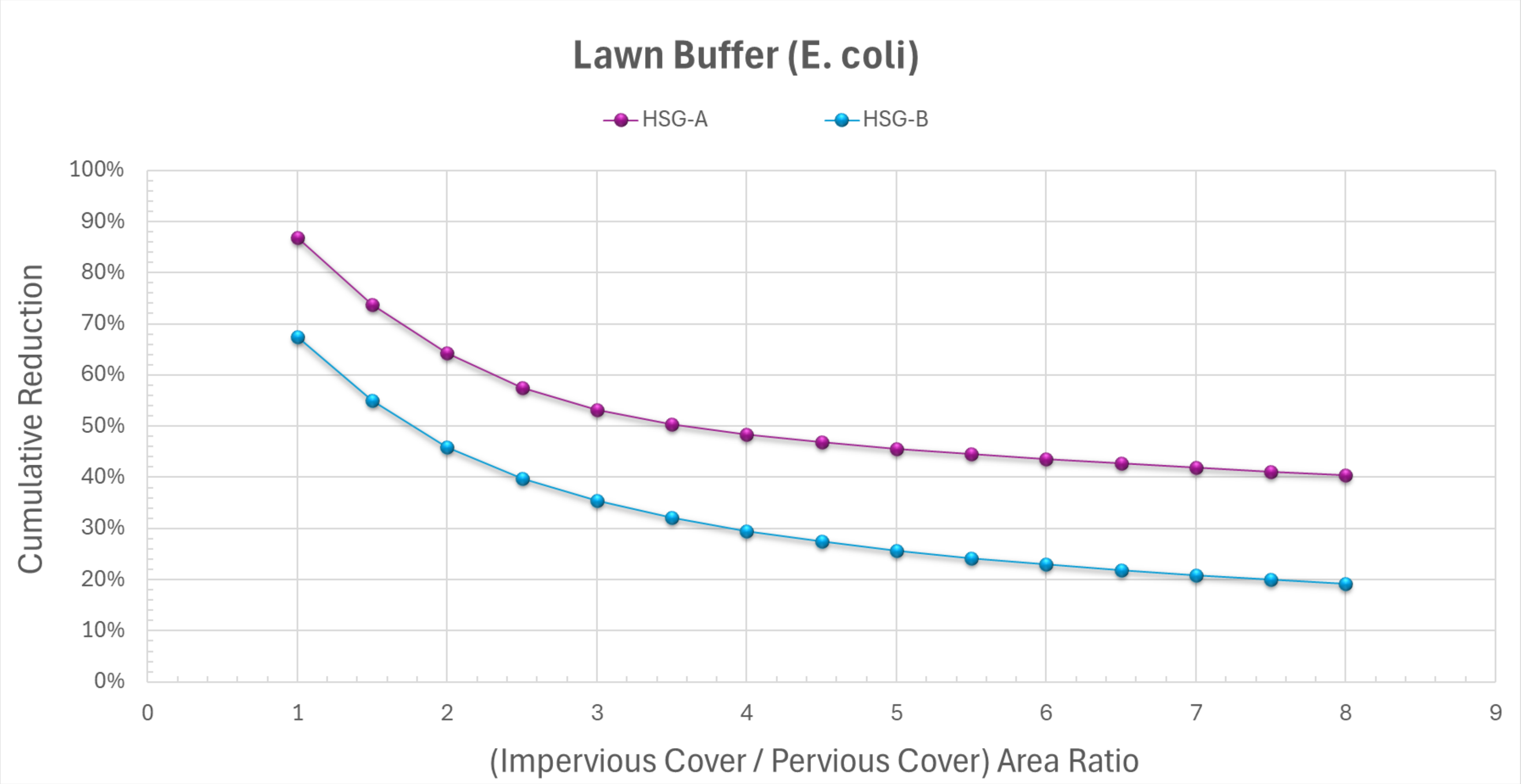


Figure 4-18. Performance curve for cumulative reduction in *E. coli* load for lawn buffers by hydrologic soil group (HSG).

# 5 BUFFER PERFORMANCE VALIDATION

A validation of the buffer performance was carried out using the available information from Winston (2009) as discussed in Section 2. Specifically, the most direct comparison possible was for the lawn type buffer with an IC:PC ratio of 30:1 and HSG-A. The Winston study also referenced a contemporary study by Line and Hunt (2009); fewer details were available regarding the conditions in this study, but it provides another point of comparison. The Opti-Tool lawn performance curves are provided in Section 4.3; note that the performance curves do not extend to the large 30:1 ratio, so an additional Opti-Tool run was carried out for this validation.

The focus of the validation was on TP (Table 5-1). Over the long-term continuous Opti-Tool simulation, the TP load reduction is 43.5%; this is comparable to both the Winston and Line and Hunt studies. The Opti-Tool flow reduction was 34%, which is smaller than the results reported by Winston (2009) and Line and Hunt (2009). The total flow volume reduction reported by these two studies is very close (50 and 49%) so are their TP load reductions (49 and 48%). Given the differences and assumptions for each study, the reduction results provides a weight-of-evidence that the physical processes controlling buffer performance are well captured by the Opti-Tool as represented in the long-term cumulative performance curves.

**Table 5-1. Comparison of lawn buffer performance for an IC:PC ratio of 30:1**

| Study | IC:PC | Meteorology | Reduction (%) | | |
|---|---|---|---|---|---|
| | | | Flow Volume | TP Load | TN Load |
| Winston, 2009<br>(Louisburg site, 25ft buffer) | 30:1 | 21 storm events ranging from 0.2 in – 2.0 in | 50%* | **49%**** | 53%*** |
| Line and Hunt, 2009<br>(bermuda grass) | Unknown | 14 storm events (Winston, 2009; Table 2-4) | 49%<br>(Winston, 2009; Table 2-6) | **48%**<br>(Winston, 2009; Table 2-6) | Not Calculated |
| Opti-Tool | 30:1 | Continuous simulation of 28 years based on data from the Portland Jetport | 34% | **43.5%** | 42.4% |

*: Total reduction percentage for the entire monitoring period (see Table D-5 in Winston (2009)). The sampling period was approximately one year (354 days).
**: One event excluded due to contamination (see Section 6.2 and Table F-18 in Winston (2009). The sampling period was 10 months (318 days).
***: One event excluded due to contamination (see Section 6.2 and Table F-18 in Winston (2009). The sampling period was 11 months (339 days).

# 6 LIMITATIONS

While the performance curves presented in this report are a robust and regionally adopted tool within EPA Region 1, there are limitations and assumptions in their development that should be noted. These include:

- No observed performance data for forest or meadow buffers as implemented in the State of Maine were found. This prevented a standard calibration of the Opti-Tool buffer configuration; however, because the simulations are based on physical processes, the project team was able to use their local knowledge and expertise to develop representative buffer configurations. The buffer configurations were validated and agreed well with the available relevant literature.

- Processes related to snow hydrology were not explicitly simulated. All precipitation used in the HRU time series development was modeled as rainfall. This preserves total precipitation volumes but does have some impact on the timing of runoff. There could potentially be impacts on buffer performance from frozen ground and snowpack at seasonal or event scales, especially from flattening of meadow buffers, as was noted in Nsenga kumwimba et al. (2024). Snow hydrology should be incorporated if the focus of buffer evaluation is on seasonal or event performance; however, the intent of performance curves for planning and crediting purposes is long-term cumulative SCM performance.
- The Opti-Tool vegetated buffer configuration is based on the "IC Disconnection" type BMP. This assumes that buffers, when built, are adequately configured to spread runoff as sheet flow across the buffer. In the absence of a level spreader or equivalent flow dispersion mechanism, runoff may concentrate, resulting in channelized flow and significantly reduced treatment performance.
- The Opti-Tool models the buffer as a rectangular control volume with flow uniformly distributed across its width (perpendicular to the primary flow direction), ensuring adequate hydraulic residence time for treatment processes. Performance curves are parameterized based on the surface area ratio between the impervious cover (IC) and the buffer pervious cover (PC). For a given area ratio, hydraulic and pollutant removal performance remains consistent regardless of variations in the buffer's aspect ratio (i.e., length-to-width configuration).

# 7 SUMMARY

This technical report describes the development of long-term cumulative performance curves using the EPA Region 1 Opti-Tool that are applicable for planning and crediting of vegetated forest, meadow, and lawn (i.e., uncompacted grass cover on an undisturbed soil profile) buffers within the State of Maine. The performance curves were developed based on 28 years of climatic data from the Portland Jetport (Jan 1997 – Dec 2024) and illustrate the effectiveness of these SCMs for runoff and pollutant treatment. Because the performance curves represent cumulative reductions over a wide range of storm and antecedent moisture conditions, they are highly effective and provide a more realistic picture of long-term SCM performance, assuming proper maintenance, as opposed to performance based on a single storm event or synthetic design storm. Many events may achieve 100% runoff reduction and therefore completely capture the first flush of pollutants from IC, with an appropriate IC:PC ratio, because the majority of daily rainfall depths (62% on average) are for small events with depths < 0.5 in.

Implementation of the proposed Chapter 500 framework requires SCM sizing tools to be used for meeting the stormwater volume, nitrogen, and phosphorus reduction standards. The curves presented in this memo are a planning tool intended to represent typical conditions; additional information is required to apply these curves at the site-scale. For example, a single HSG can encompass a range of infiltration values in different locations and should be measured and understood for a specific site to appropriately apply the performance curves. These curves are an easily understandable method for the sizing of vegetated buffers, illustrate their effectiveness, and complement other SCM curves in use throughout the New England region.

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# 9 APPENDIX

Table 9-1. Annual average flow volume reductions for buffer performance curves by buffer type, hydrologic soil group (HSG), and ratio of impervious cover (IC) to pervious cover (PC)

| Average Annual Flow Volume Reduction (%) | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| IC:PC | Forest | | | | Meadow | | | | Lawn | | | |
| | HSG-A | HSG-B | HSG-C | HSG-D | HSG-A | HSG-B | HSG-C | HSG-D | HSG-A | HSG-B | HSG-C | HSG-D |
| 1 | 99% | 96% | 88% | 77% | 99% | 94% | 85% | 70% | 98% | 92% | 81% | 64% |
| 1.5 | 98% | 94% | 84% | 71% | 98% | 92% | 80% | 64% | 97% | 89% | 76% | 57% |
| 2 | 97% | 91% | 80% | 65% | 97% | 89% | 75% | 58% | 96% | 86% | 70% | 51% |
| 2.5 | 96% | 89% | 76% | 60% | 95% | 85% | 70% | 52% | 94% | 82% | 65% | 46% |
| 3 | 95% | 86% | 72% | 55% | 93% | 82% | 66% | 48% | 92% | 79% | 60% | 41% |
| 3.5 | 93% | 83% | 67% | 51% | 91% | 79% | 61% | 44% | 90% | 75% | 56% | 38% |
| 4 | 91% | 80% | 64% | 48% | 89% | 76% | 58% | 41% | 88% | 72% | 52% | 35% |
| 4.5 | 90% | 77% | 60% | 44% | 87% | 73% | 54% | 38% | 85% | 69% | 49% | 32% |
| 5 | 88% | 74% | 57% | 42% | 85% | 70% | 51% | 35% | 83% | 66% | 46% | 30% |
| 5.5 | 86% | 71% | 54% | 39% | 83% | 67% | 48% | 33% | 81% | 63% | 44% | 28% |
| 6 | 84% | 69% | 51% | 37% | 82% | 64% | 46% | 31% | 79% | 60% | 41% | 26% |
| 6.5 | 82% | 66% | 49% | 35% | 80% | 62% | 44% | 29% | 77% | 58% | 39% | 25% |
| 7 | 81% | 64% | 47% | 33% | 78% | 60% | 42% | 28% | 75% | 56% | 37% | 23% |
| 7.5 | 79% | 62% | 45% | 32% | 76% | 57% | 40% | 26% | 73% | 54% | 36% | 22% |
| 8 | 77% | 60% | 43% | 30% | 74% | 55% | 38% | 25% | 72% | 52% | 34% | 21% |

Table 9-2. Annual average TP load reductions for buffer performance curves by buffer type, hydrologic soil group (HSG), and ratio of impervious cover (IC) to pervious cover (PC)

| Average Annual TP Load Reduction (%) | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| IC:PC | Forest | | | | Meadow | | | | Lawn | |
| | HSG-A | HSG-B | HSG-C | HSG-D | HSG-A | HSG-B | HSG-C | HSG-D | HSG-A | HSG-B |
| 1 | 100% | 99% | 98% | 94% | 99% | 96% | 91% | 82% | 99% | 95% |
| 1.5 | 100% | 99% | 97% | 92% | 99% | 96% | 90% | 80% | 99% | 94% |
| 2 | 100% | 98% | 95% | 88% | 99% | 95% | 87% | 76% | 98% | 93% |
| 2.5 | 99% | 97% | 92% | 84% | 98% | 93% | 84% | 71% | 98% | 90% |
| 3 | 99% | 96% | 89% | 80% | 98% | 91% | 81% | 67% | 97% | 88% |
| 3.5 | 98% | 94% | 86% | 76% | 97% | 89% | 77% | 63% | 95% | 86% |
| 4 | 97% | 92% | 83% | 72% | 96% | 87% | 74% | 60% | 94% | 83% |
| 4.5 | 96% | 90% | 80% | 69% | 95% | 85% | 71% | 56% | 93% | 80% |
| 5 | 96% | 88% | 77% | 66% | 93% | 82% | 68% | 53% | 92% | 78% |
| 5.5 | 95% | 86% | 75% | 63% | 92% | 80% | 65% | 51% | 90% | 75% |
| 6 | 94% | 84% | 72% | 60% | 91% | 78% | 62% | 48% | 89% | 73% |
| 6.5 | 92% | 82% | 70% | 58% | 90% | 76% | 60% | 46% | 87% | 71% |
| 7 | 91% | 81% | 67% | 56% | 88% | 74% | 57% | 44% | 86% | 68% |
| 7.5 | 90% | 79% | 65% | 54% | 87% | 72% | 55% | 43% | 84% | 66% |
| 8 | 89% | 77% | 63% | 52% | 86% | 70% | 53% | 41% | 83% | 64% |

### Table 9-3. Annual average TN load reductions for buffer performance curves by buffer type, hydrologic soil group (HSG), and ratio of impervious cover (IC) to pervious cover (PC)

| Average Annual TN Load Reduction (%) | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| IC:PC | Forest | | | | Meadow | | | | Lawn | |
| | HSG-A | HSG-B | HSG-C | HSG-D | HSG-A | HSG-B | HSG-C | HSG-D | HSG-A | HSG-B |
| 1 | 100% | 98% | 95% | 90% | 99% | 95% | 89% | 80% | 99% | 94% |
| 1.5 | 100% | 98% | 94% | 87% | 99% | 95% | 87% | 77% | 99% | 93% |
| 2 | 99% | 97% | 92% | 84% | 98% | 94% | 85% | 73% | 98% | 91% |
| 2.5 | 99% | 95% | 89% | 80% | 98% | 92% | 82% | 69% | 97% | 89% |
| 3 | 98% | 94% | 86% | 76% | 97% | 90% | 79% | 65% | 96% | 87% |
| 3.5 | 97% | 92% | 84% | 73% | 96% | 88% | 75% | 61% | 95% | 84% |
| 4 | 97% | 90% | 81% | 69% | 95% | 86% | 72% | 58% | 93% | 82% |
| 4.5 | 96% | 89% | 78% | 66% | 94% | 83% | 69% | 55% | 92% | 79% |
| 5 | 95% | 87% | 75% | 63% | 93% | 81% | 66% | 52% | 91% | 76% |
| 5.5 | 94% | 85% | 72% | 60% | 91% | 79% | 63% | 49% | 89% | 74% |
| 6 | 93% | 83% | 70% | 58% | 90% | 76% | 60% | 47% | 87% | 71% |
| 6.5 | 91% | 81% | 68% | 56% | 89% | 74% | 58% | 45% | 86% | 69% |
| 7 | 90% | 79% | 65% | 54% | 87% | 72% | 56% | 43% | 84% | 67% |
| 7.5 | 89% | 77% | 63% | 52% | 86% | 70% | 54% | 41% | 83% | 65% |
| 8 | 88% | 75% | 61% | 50% | 84% | 68% | 52% | 40% | 81% | 63% |

### Table 9-4. Annual average Zn load reductions for buffer performance curves by buffer type, hydrologic soil group (HSG), and ratio of impervious cover (IC) to pervious cover (PC)

| Average Annual Zn Load Reduction (%) | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| IC:PC | Forest | | | | Meadow | | | | Lawn | |
| | HSG-A | HSG-B | HSG-C | HSG-D | HSG-A | HSG-B | HSG-C | HSG-D | HSG-A | HSG-B |
| 1 | 100% | 96% | 87% | 75% | 99% | 94% | 82% | 66% | 99% | 90% |
| 1.5 | 99% | 92% | 81% | 67% | 98% | 88% | 73% | 57% | 96% | 83% |
| 2 | 97% | 88% | 74% | 60% | 95% | 82% | 65% | 50% | 92% | 76% |
| 2.5 | 95% | 83% | 68% | 55% | 91% | 76% | 58% | 43% | 88% | 69% |
| 3 | 92% | 78% | 63% | 50% | 88% | 70% | 52% | 39% | 83% | 63% |
| 3.5 | 88% | 73% | 58% | 46% | 84% | 65% | 47% | 35% | 79% | 58% |
| 4 | 85% | 69% | 54% | 42% | 80% | 61% | 43% | 32% | 75% | 53% |
| 4.5 | 82% | 65% | 50% | 39% | 76% | 56% | 40% | 29% | 71% | 49% |
| 5 | 78% | 62% | 47% | 37% | 73% | 53% | 37% | 27% | 68% | 46% |
| 5.5 | 75% | 58% | 44% | 34% | 70% | 50% | 34% | 25% | 65% | 43% |
| 6 | 73% | 55% | 42% | 33% | 67% | 47% | 32% | 24% | 62% | 40% |
| 6.5 | 70% | 52% | 39% | 31% | 64% | 44% | 30% | 22% | 59% | 38% |
| 7 | 67% | 50% | 38% | 29% | 61% | 42% | 28% | 21% | 56% | 36% |
| 7.5 | 65% | 48% | 36% | 28% | 59% | 40% | 27% | 20% | 54% | 34% |
| 8 | 62% | 46% | 34% | 27% | 56% | 38% | 25% | 19% | 52% | 32% |

### Table 9-5. Annual average TSS load reductions for buffer performance curves by buffer type, hydrologic soil group (HSG), and ratio of impervious cover (IC) to pervious cover (PC)

| Average Annual TSS Load Reduction (%) | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| IC:PC | Forest | | | | Meadow | | | | Lawn | |
| | HSG-A | HSG-B | HSG-C | HSG-D | HSG-A | HSG-B | HSG-C | HSG-D | HSG-A | HSG-B |
| 1 | 99% | 95% | 85% | 72% | 99% | 91% | 77% | 61% | 98% | 87% |
| 1.5 | 99% | 91% | 79% | 65% | 97% | 86% | 70% | 54% | 95% | 81% |
| 2 | 97% | 87% | 73% | 59% | 94% | 80% | 63% | 47% | 92% | 74% |
| 2.5 | 94% | 82% | 67% | 53% | 91% | 75% | 56% | 42% | 87% | 68% |
| 3 | 91% | 77% | 62% | 49% | 87% | 69% | 51% | 37% | 83% | 62% |
| 3.5 | 88% | 73% | 57% | 45% | 83% | 64% | 46% | 34% | 79% | 57% |
| 4 | 85% | 68% | 53% | 41% | 80% | 60% | 42% | 31% | 75% | 53% |
| 4.5 | 81% | 65% | 50% | 39% | 76% | 56% | 39% | 29% | 71% | 49% |
| 5 | 78% | 61% | 46% | 36% | 73% | 52% | 36% | 26% | 68% | 46% |
| 5.5 | 75% | 58% | 44% | 34% | 69% | 49% | 34% | 25% | 65% | 43% |
| 6 | 72% | 55% | 41% | 32% | 66% | 46% | 32% | 23% | 62% | 40% |
| 6.5 | 70% | 52% | 39% | 30% | 64% | 44% | 30% | 22% | 59% | 38% |
| 7 | 67% | 50% | 37% | 29% | 61% | 41% | 28% | 21% | 56% | 35% |
| 7.5 | 65% | 47% | 35% | 28% | 59% | 39% | 27% | 20% | 54% | 34% |
| 8 | 62% | 45% | 34% | 26% | 56% | 38% | 25% | 19% | 52% | 32% |

### Table 9-6. Annual average *E. coli* load reductions for buffer performance curves by buffer type, hydrologic soil group (HSG), and ratio of impervious cover (IC) to pervious cover (PC)

| Average Annual *E. coli* Load Reduction (%) | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| IC:PC | Forest | | | | Meadow | | | | Lawn | |
| | HSG-A | HSG-B | HSG-C | HSG-D | HSG-A | HSG-B | HSG-C | HSG-D | HSG-A | HSG-B |
| 1 | 99% | 89% | 75% | 65% | 93% | 77% | 60% | 48% | 87% | 67% |
| 1.5 | 95% | 81% | 64% | 53% | 81% | 64% | 47% | 38% | 74% | 55% |
| 2 | 91% | 75% | 57% | 45% | 71% | 54% | 39% | 31% | 64% | 46% |
| 2.5 | 89% | 70% | 53% | 41% | 63% | 46% | 33% | 27% | 57% | 40% |
| 3 | 87% | 67% | 49% | 37% | 58% | 41% | 29% | 24% | 53% | 35% |
| 3.5 | 87% | 65% | 46% | 35% | 54% | 37% | 26% | 21% | 50% | 32% |
| 4 | 86% | 63% | 44% | 32% | 52% | 34% | 24% | 19% | 48% | 30% |
| 4.5 | 86% | 62% | 42% | 30% | 50% | 32% | 22% | 18% | 47% | 27% |
| 5 | 85% | 60% | 40% | 29% | 49% | 30% | 20% | 16% | 46% | 26% |
| 5.5 | 84% | 58% | 38% | 27% | 48% | 28% | 19% | 15% | 45% | 24% |
| 6 | 83% | 56% | 36% | 26% | 47% | 27% | 18% | 14% | 44% | 23% |
| 6.5 | 82% | 55% | 35% | 25% | 46% | 26% | 17% | 13% | 43% | 22% |
| 7 | 81% | 53% | 34% | 24% | 46% | 24% | 16% | 13% | 42% | 21% |
| 7.5 | 79% | 51% | 32% | 23% | 45% | 23% | 15% | 12% | 41% | 20% |
| 8 | 78% | 50% | 31% | 22% | 44% | 23% | 14% | 11% | 40% | 19% |