Lake Champlain BMP Scenario Tool

Requirements and Design

April 2015

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Background

The Scenario Tool uses the calibrated Lake Champlain Basin SWAT watershed model results and the calibrated Lake Champlain BATHTUB model results in combination with BMP efficiencies to evaluate whether various load reduction scenarios have reasonable potential to meet TMDL loading targets for Lake Champlain.

Purpose

- To identify a phosphorus reduction scenario that meets the TMDL targets (primary)
- To evaluate possible alternative scenarios (secondary)
- To enable EPA and key state agency stakeholders to work together in identifying potentially successful BMP scenarios for presentation to the larger stakeholder community

Users

- EPA
- Vermont agencies (e.g., VT DEC, VAAFM)
- Potentially, New York State agencies, as the availability of data on the New York portion of the basin allows

Loading Sources

The tool allows users to evaluate the effects of best management practices (BMPs) on loads from multiple sources, including:

- Agricultural lands
- Urban/developed lands
- Back roads
- Streambank loading

Effects from alternative discharge scenarios from wastewater treatment plants can also be evaluated.

BMPs

The tool allows users to evaluate phosphorus reductions from the BMPs listed in Table 1. BMP definitions/explanations are included in the Calculation of Reductions section below.

Table 1. Scenario Tool BMPs

BMP	Source	Source of Reduction
Cover crops	Agriculture	Efficiency (SWAT model)
Changes in crop rotation	Agriculture	
Alternative manure incorporation (injection)	Agriculture	
Conservation tillage	Agriculture	
Reduced P manure	Agriculture	
Grassed waterways	Agriculture	
Grassed riparian buffers	Agriculture	
Fencing/livestock exclusion	Agriculture	Efficiency (SWAT model)
Barnyard runoff management (CWD and HUA)	Agriculture	Efficiency (literature)
Crop to hay	Agriculture	Efficiency (SWAT model)
Field ditch buffer	Agriculture	Efficiency (literature)
Infiltration basins & unlined bioretention systems	Urban	Efficiency (BMP performance curves)
Infiltration trenches	Urban	
Biofiltration (lined bioretention systems – no infiltration)	Urban	
Gravel wetlands	Urban	
Extended detention (extended dry detentions)	Urban	Vermont Stormwater Management Manual
Wet ponds	Urban	Efficiency (Chesapeake Bay Data)
Ban on P fertilizer use on turf	Urban	Efficiency (Appendix A and USEPA, 2014b)
Street sweeping (various methods and frequencies)	Urban	Efficiency (recent studies)
More frequent catch basin cleaning	Urban	Efficiency (Chesapeake Bay Data)
Leaf litter collection	Urban	Efficiency (literature)
Impervious area disconnection	Urban	Efficiency (Tetra Tech, 2012)
Impervious area removal	Urban	Efficiency (Tetra Tech, 2012)
Roadside erosion control	Back roads	Efficiency (Wemple 2013)
Suite of practices geared at restoration of eroding reaches to stable channel evolution stage	Streambank erosion	VT stream reach analysis [a]
Forest logging BMPs	Forest	Efficiency [b]

a. Efficiency determined through TMDL reach analysis based on SWAT model results and comparison of loads from stable and unstable reaches, as described in the Calculation of Reductions section below.
b. See the Calculation of Reductions section for a discussion of how forest BMPs (such as erosion and sedimentation control at logging road stream crossings) are handled in this analysis.

Software

Microsoft (MS) Excel Visual Basic for Application (VBA) is used for processing and the interface.

Interface

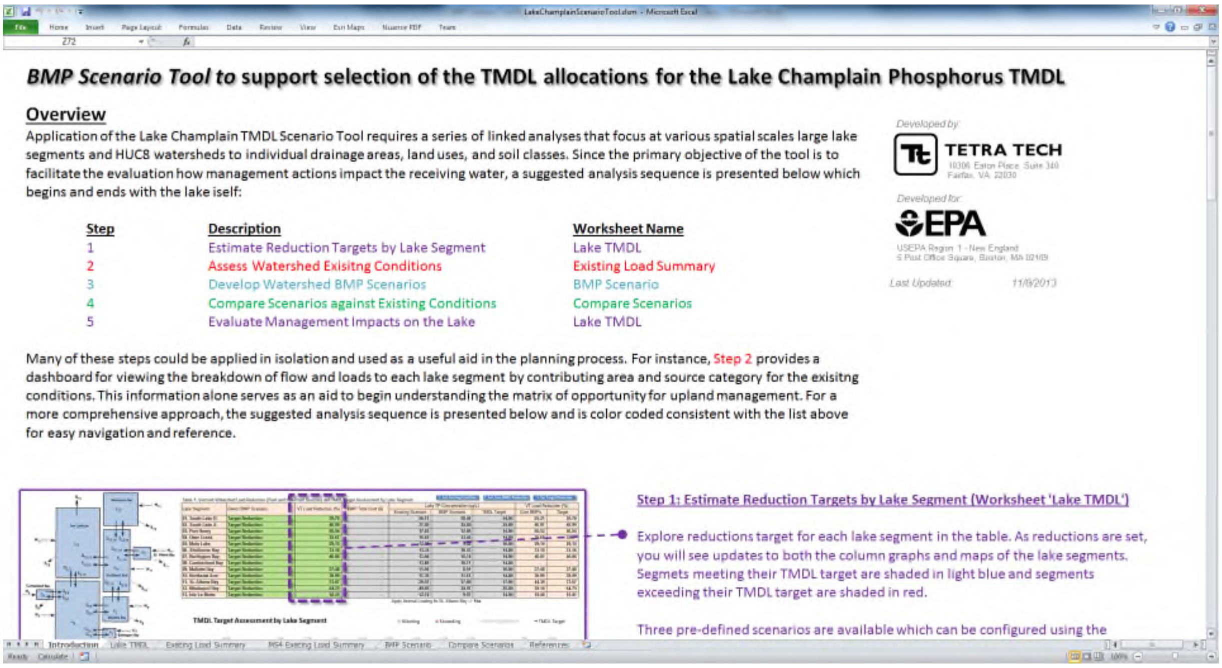
The user environment is an MS Excel spreadsheet with multiple tabs containing introductory information, user instructions, data references for BMP efficiencies and definitions, and so forth, and a Scenario tab from which users can target specific basins and BMPs for evaluation and comparison.

Tabs

Multiple tabs are used to provide background and user instructions, reference information and functionality (i.e., to evaluate reductions from various BMP implementation schemes). Hidden tabs hold the information used by the tool to perform calculations and include tabs for lookup tables, baseline data and saved scenarios. The visible tabs are the following:

Introduction Tab

This tab includes basic instructions for the user and lays out the conceptual steps to follow to develop BMP scenarios that meet the TMDL target at the selected lake segment. It gives an overview of the Scenario Tool and explains logical steps for using the tool.



Lake TMDL Tab

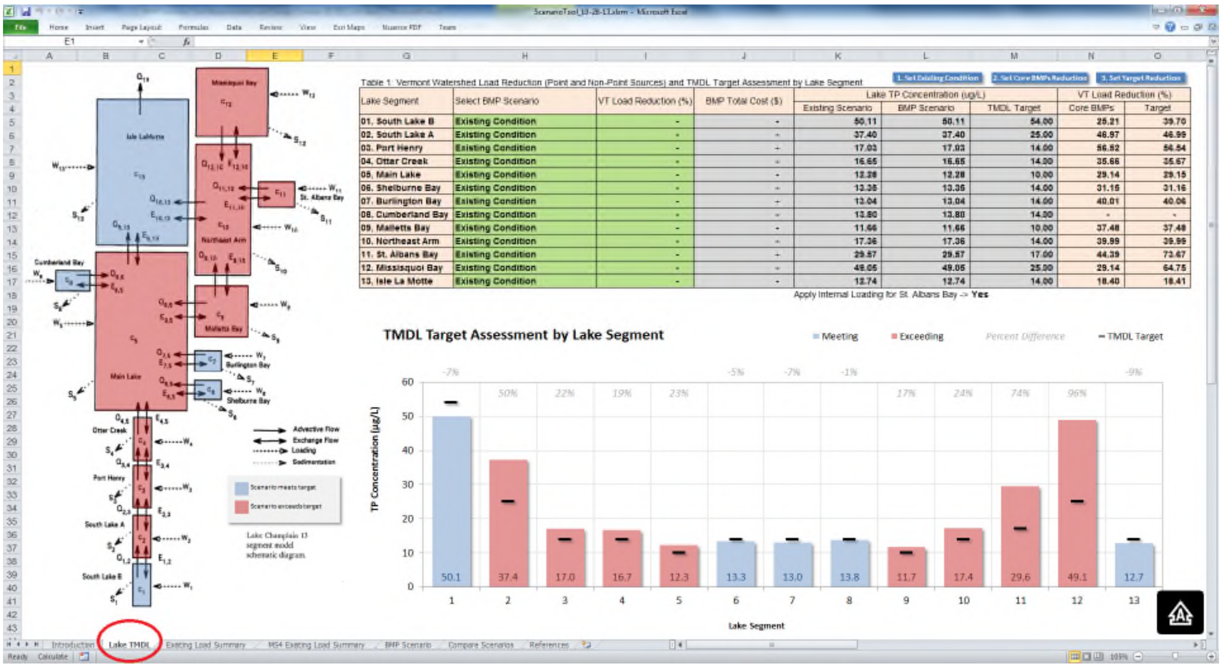
The purpose of this tab is to illustrate whether BMP scenarios meet lake criteria. Information on this tab is based primarily on results from the revised calibrated BATHTUB model[1] (Tetra Tech 2014a). It also uses the functionality of MS Excel Solver to facilitate identification of various optimized reduction

[1] Using results from the DFS BATHTUB mass balance spreadsheet model that corresponds to the calibrated BATHTUB model.

combinations from major sources contributing to the selected lake segment. Annual loads are by Water Year.

Key features include:

- Spatial schematic and bar chart showing the relationship between the lake segments and their loads and highlighting the segments for the given BMP scenario that meet or exceed the target criteria
- User-developed list of BMP scenarios for each lake segment to select and evaluate against the target criteria
- Options for accounting for future growth and a margin of safety in the total loading capacity allocation for each lake segment
- Options for defining the constraints (minimum and maximum) on allowable load reductions for each major source category (i.e., cropland, pastureland, farmstead, forest, backroad, developed, and streambank erosion)



Existing Load Summary Tab

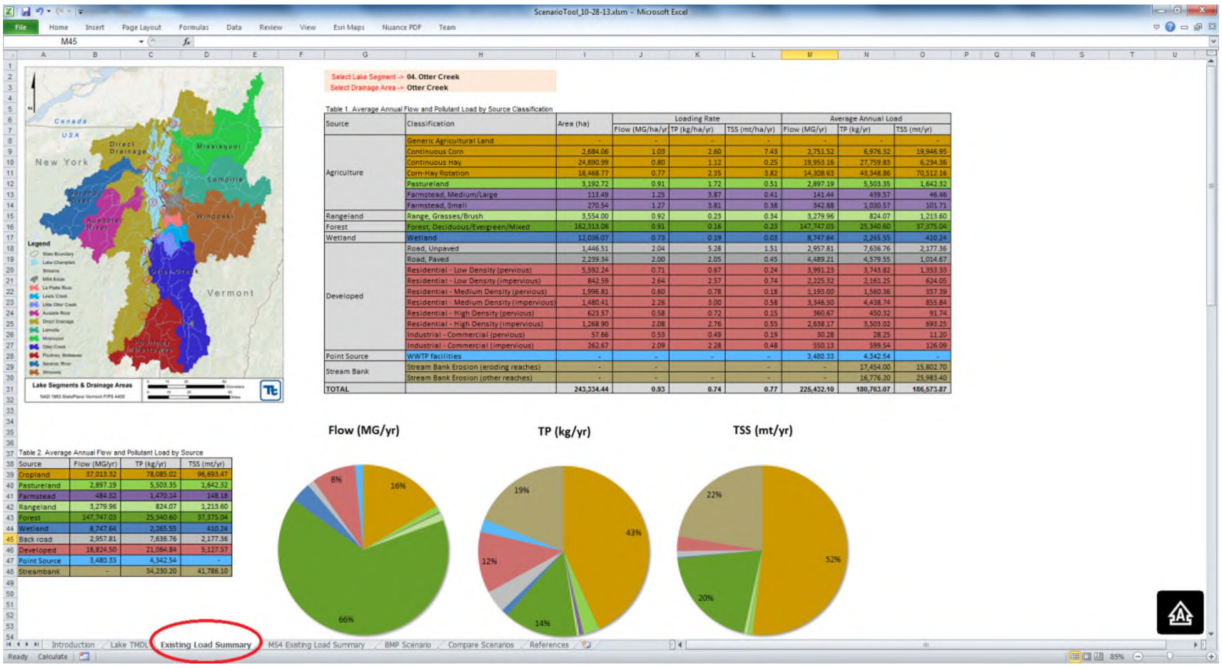
The information on this tab serves two purposes: (1) to summarize the SWAT existing loading predicted for the Lake Champlain Basin (Vermont side) and (2) to support and facilitate users' strategic manipulation of BMPs in a target basin.

Key features include:

- Map of the basin and major tributaries
- Tabular and graphic data summarizing basin characteristics such as
  - Existing land use area distribution by soil and slope type
  - Existing average annual load summary by land use classification
  - Unit area loading rates and statistics by major land uses

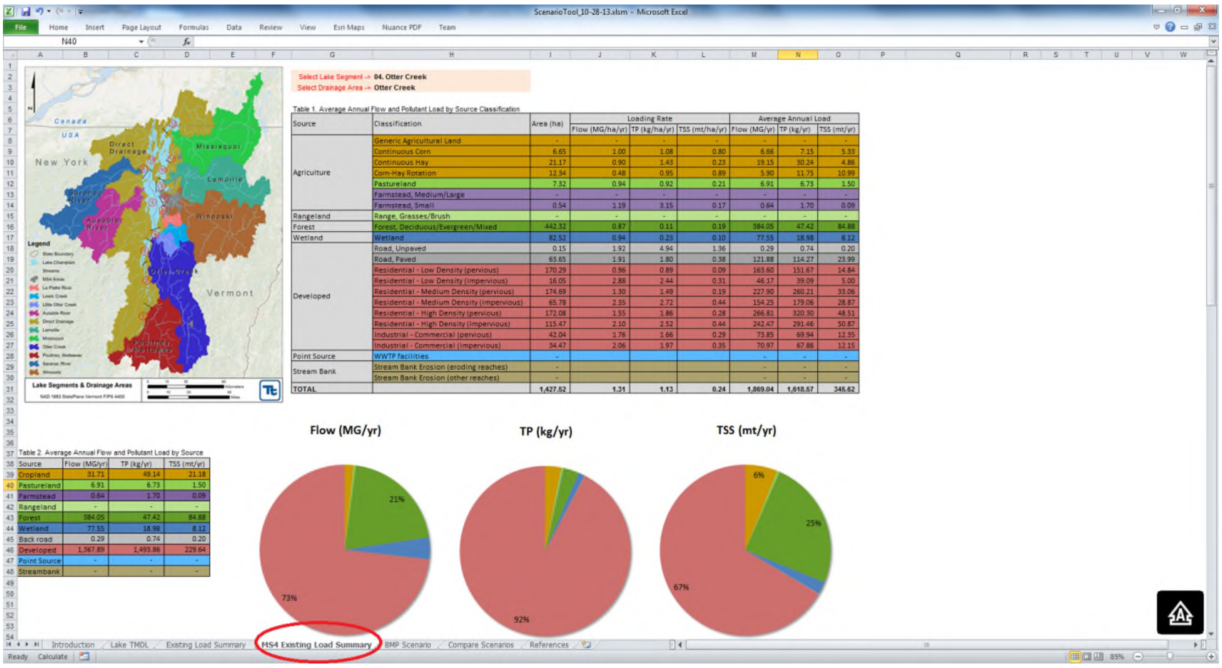
Data from the Existing Load Summary tab is useful to guide the user during the BMP manipulation process. For example, before applying a structural practice that relies on infiltration, the user might first determine the prevalence of A and B soils in the drainage area before specifying an application coverage area. Annual loads are by Water Year to correspond to BATHTUB loads.

Note that the Burlington Bay Segment includes two drainage areas available for selection: Burlington Bay Direct Drainage and Burlington Bay CSO. The annual load for the Burlington CSO discharge is presented when the 'Burlington Bay CSO' is selected.



🗀 MS4 Existing Load Summary Tab

This tab summarizes the SWAT existing loading predicted for the municipal separate storm sewer (MS4) areas on the Vermont side that drain to the selected lake segment. The key features are the same as those of the Existing Load Summary tab. For Burlington Bay, two segments are available, 'Burlington Bay Direct Drainage' and 'Burlington Bay CSO'; thus the loads and their contributing drainage areas are summarized separately.

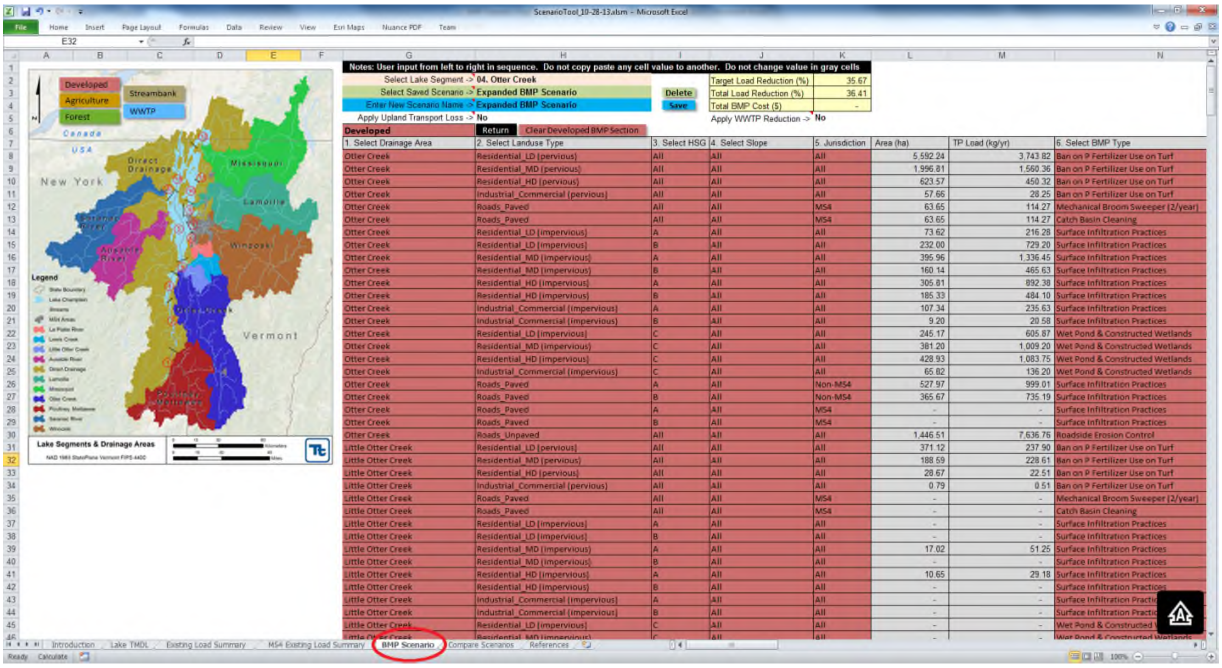


BMP Scenario Tab

This tab allows the user to select a target lake segment and create a BMP implementation scenario for evaluation. For certain BMPs, the user may select levels of control to apply; for example, for urban structural practices the user can select treatment runoff depth, ranging from 0.25 to 2 inches. For the Burlington Bay Segment, this tab allows for specifying BMPs on the CSO drainage areas separately from the non-CSO drainage area.

Key features include the ability to:

- Select target lake segment
- Select land uses/sources to address in contributing basin(s)
- Specify percentage of land use to address (MS4 and/or non-MS4 areas)
- Select from the prepopulated list of BMPs
- Apply various levels of control (particularly for stormwater, e.g., 0.25-inch, 0.5-inch runoff depth)
- Load an existing scenario from the scenario list to begin with or edit an existing scenario
- Save new scenarios and/or delete existing scenarios
- Calculate and present the total load reduction as a result of selected BMP types and levels of application; also presents the percentage total load reduced at the lake for allocation analysis.



Compare Scenarios

This tab displays graphical summaries of up to two scenarios and compares them to the baseline scenario.

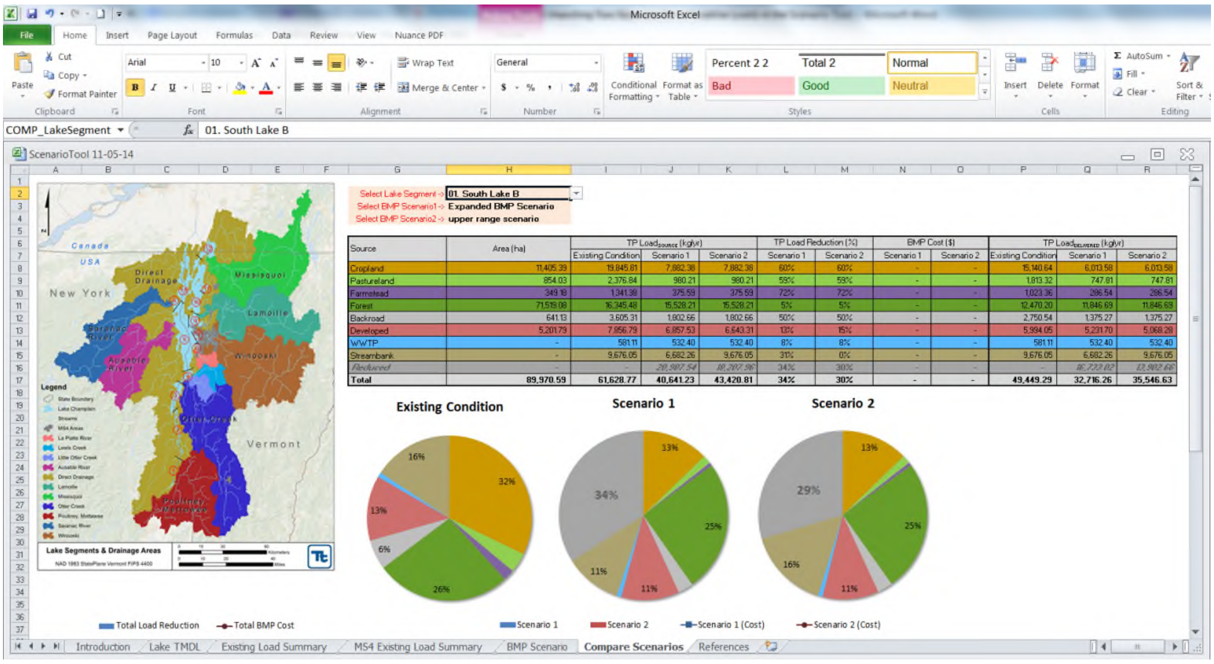
Key features include:

- Selection of target lake segment from the prepopulated list of lake segments
- Selection of up to two scenarios from the user-defined BMP scenarios for the selected lake segment
- Comparison of selected scenarios against the existing loads and load reduction due to BMPs in tabular and graphical (pie chart and bar chart) format
- Presents percent load reduction results of the BMP scenarios at the lake "DELIVERED" and at the source "SOURCE".

How the Scenario Tool Accounts for the SWAT and BATHTUB Models' Different Baseline Loads

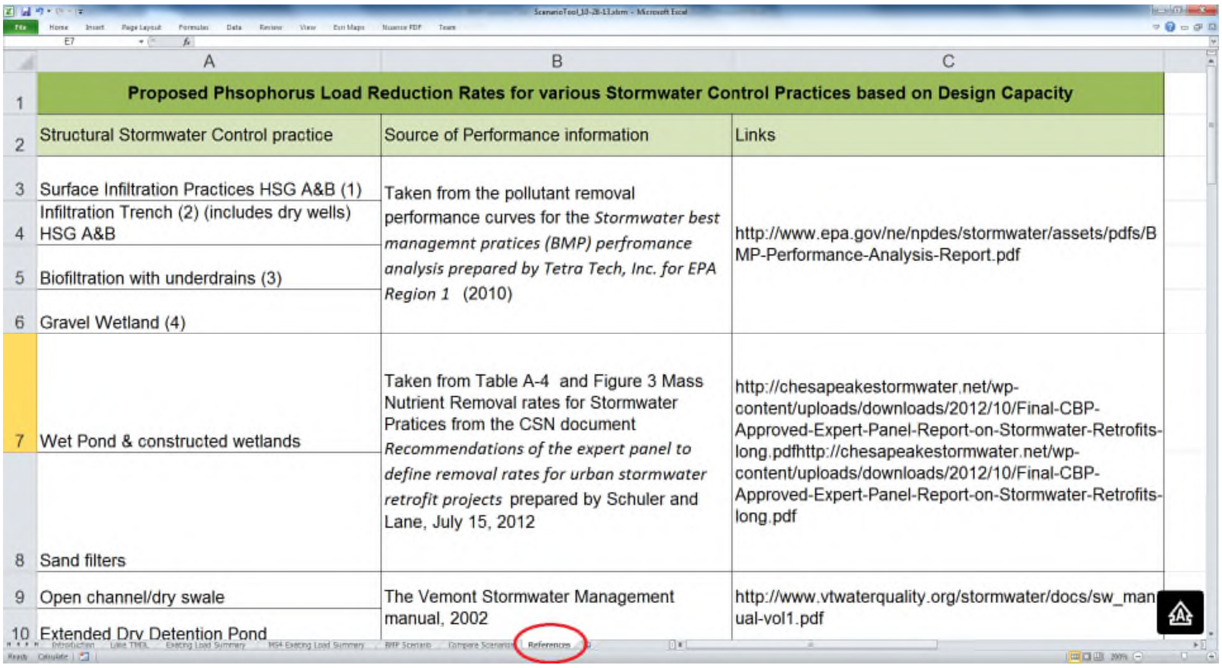
The modeling to support the Lake Champlain TMDL involved two separate applications: 1) Bathtub for the lake modeling and 2) SWAT for the watershed/source load modeling. Although both models were subjected to calibration processes in which input parameters were adjusted to match monitoring data, baseline loads for the two models are different.

The Scenario Tool applies BMP efficiencies to SWAT generated loading. It then calculates a percent reduction to the total SWAT load and applies the same percentage reduction to the Bathtub baseline input load at the lake.



References Tab

This tab includes a list of BMP definitions, efficiencies, and links to or descriptions of the sources from which efficiency data have been compiled.



	A	B	C
1	**Proposed Phosphorus Load Reduction Rates for various Stormwater Control Practices based on Design Capacity**		
2	Structural Stormwater Control practice	Source of Performance information	Links
3	Surface Infiltration Practices HSG A&B (1)	Taken from the pollutant removal performance curves for the *Stormwater best managemnt pratices (BMP) perfromance analysis prepared by Tetra Tech, Inc. for EPA Region 1* (2010)	http://www.epa.gov/ne/npdes/stormwater/assets/pdfs/BMP-Performance-Analysis-Report.pdf
4	Infiltration Trench (2) (includes dry wells) HSG A&B		
5	Biofiltration with underdrains (3)		
6	Gravel Wetland (4)		
7	Wet Pond & constructed wetlands	Taken from Table A-4 and Figure 3 Mass Nutrient Removal rates for Stormwater Pratices from the CSN document *Recommendations of the expert panel to define removal rates for urban stormwater retrofit projects* prepared by Schuler and Lane, July 15, 2012	http://chesapeakestormwater.net/wp-content/uploads/downloads/2012/10/Final-CBP-Approved-Expert-Panel-Report-on-Stormwater-Retrofits-long.pdfhttp://chesapeakestormwater.net/wp-content/uploads/downloads/2012/10/Final-CBP-Approved-Expert-Panel-Report-on-Stormwater-Retrofits-long.pdf
8	Sand filters		
9	Open channel/dry swale	The Vemont Stormwater Management manual, 2002	http://www.vtwaterquality.org/stormwater/docs/sw_manual-vol1.pdf
10	Extended Dry Detention Pond		

Scale

From the targeted lake segment, users may specify application of BMPs in the contributing drainages, at the 8-digit Hydrologic Unit Code (HUC8) level, for any directly draining basins and for the smaller watersheds of LaPlatte, Little Otter and Lewis creeks. The tool also allows applying BMPs on MS4 areas within the selected lake segment. The MS4 areas are lumped under HUC8 watersheds or direct drainage areas to a given lake segment. Users may also manipulate discharge characteristics (within a predefined set of discharge levels) for specific wastewater treatment facilities within the selected area.

Functionality

Application of the Lake Champlain Scenario Tool requires a series of linked analyses that focus at various spatial scales from large lake segments and HUC8 watersheds to individual drainage areas, land uses and soil classes.

Suggested Analysis Sequence

The primary objective of the tool is to facilitate evaluating management action impacts on various segments of Lake Champlain. A suggested analysis sequence begins and ends with the lake itself; it is presented in Table 2.

Table 2. Suggested Analysis Sequence

Step	Description	Worksheet Name
1	Estimate reduction targets by lake segment	Lake TMDL
2	Assess watershed existing conditions	Existing Load Summary
3	Develop watershed BMP scenarios	BMP Scenario
4	Compare scenarios against existing conditions	Compare Scenarios
5	Evaluate management impacts on the lake	Lake TMDL

Many of these steps could be applied in isolation and used as a useful aid in the planning process. For instance, Step 2 provides a dashboard for viewing the breakdown of flow and loads to each lake segment by contributing area and source category for the existing conditions. This information alone serves as an aid to begin understanding the matrix of opportunity for upland management. For a more comprehensive approach, the suggested analysis sequence is described below.

Step 1: Estimate reduction targets by Lake Segment (Worksheet "Lake TMDL")

Explore reduction targets for each lake segment in the table. As reductions are set, you will see updates to both the column graphs and maps of the lake segments. Segments meeting their TMDL target are shaded in light blue, and segments exceeding their TMDL target are shaded in red.

Two predefined scenarios, which can be configured using the buttons on the interface, are available: (1) the Existing Condition and (2) a placeholder Target Reduction scenario.

An optional optimization tool is also provided. It allows you to minimize the reduction required in each lake segment in order to meet the TMDL target. These scenarios can be accessed by scrolling to the right and using the command button for (4) Maximum Reduction or (5) Run Solver for Selected Lake Segment.

Step 2: Assess watershed existing conditions (Worksheet "Existing Load Summary")

Each lake segment identified for reduction in Step 1 receives flow, total phosphorus and total suspended sediment from a number of upland drainage areas. This dashboard presents upland sources by drainage area.

Use the "Existing Load Summary" worksheet to analyze the lake segments identified during Step 1 and develop an understanding of the pollutant source categories in each drainage area. Selecting different combinations of lake segment and contributing area will update both the table and the pie charts.

Take note of the magnitude of different source categories with respect to the overall load reduction required to achieve the TMDL target in the lake. Understanding this information allows you to begin to define the set of feasible opportunities for evaluating a suite of management practices.

Step 3: Develop BMP scenarios (Worksheet "BMP Scenario")

With the knowledge from Step 2 of where opportunities likely exist for applying upland BMPs, use the "BMP Scenario" worksheet to build management scenarios to evaluate against the watershed and lake existing conditions.

Name and save a new management scenario, and then select the lake segment of interest. For each source category, BMPs can be implemented to specific combinations of drainage area, land use, soil class and slope. Click in the highlighted cells and use the drop-down lists to make selections. Continue scrolling to the right and select the BMP type and percent of contributing area managed. Note that grey cells are populated automatically by the tool.

Scroll to the right across this worksheet to apply BMPs to different source categories.

Step 4: Compare scenarios against existing conditions (Worksheet "Compare Scenarios")

After developing management scenarios in Step 3, compare the effects of up to two scenarios on loadings to the watersheds by source category. Management scenarios are presented alongside the Existing Condition scenario as a benchmark.

Step 5: Evaluate management impacts on the lake (Worksheet "Lake TMDL")

Finally, after developing and comparing management scenarios for the watershed, you can revisit the "Lake TMDL" worksheet to evaluate the receiving water impacts of different scenarios. Initially the selected BMP scenario should be Existing Condition for all 13 lake segments.

Selectively change the BMP scenario segment by segment to one of the scenarios you developed in Step 3. As before, the lake map and column graph will update with each scenario selection. Segments meeting their TMDL target are shaded in light blue, and segments exceeding their TMDL target are shaded in red.

The goal of this exercise is to identify a combination of BMP scenarios that will meet the TMDL target in all lake segments. To achieve the TMDL, it might be necessary to revisit Step 3 and add or revise one of your scenarios.

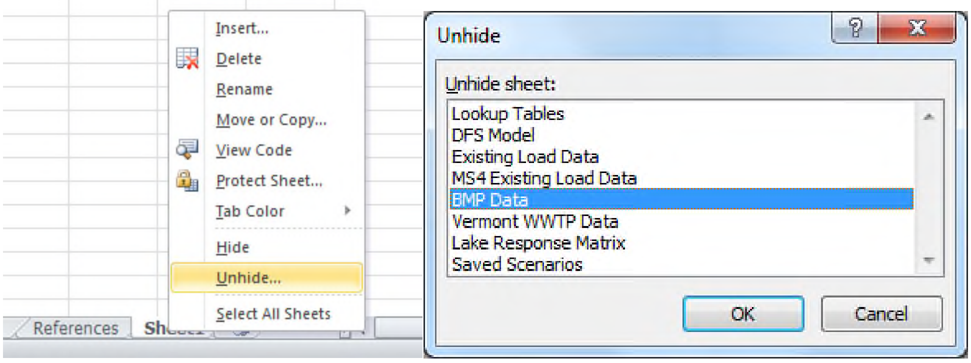
Adding Future BMPs

Placeholders for future BMPs have been included for all categories. Urban BMPs that EPA has identified for further consideration include the following:

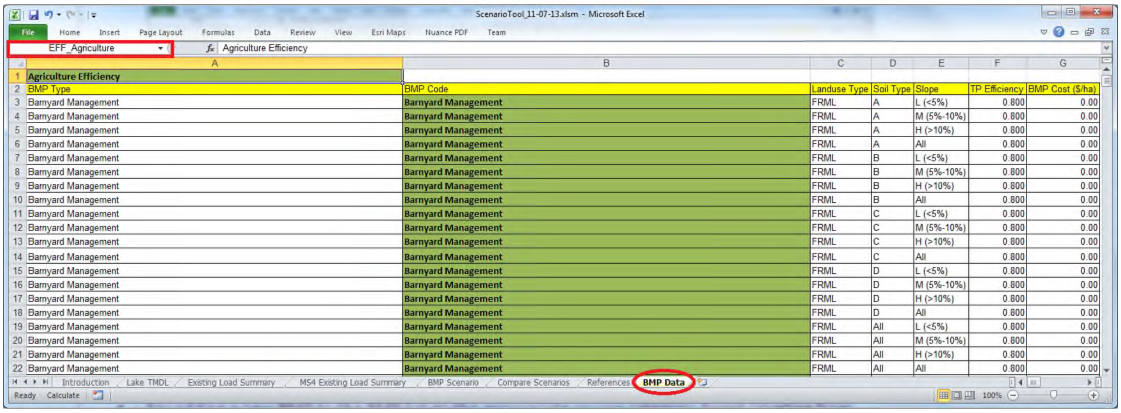
- Rooftop disconnection with storage
- Rooftop disconnection, routed to pervious areas
- Establishment of tree canopy in impervious areas

To incorporate these into the tool, the target source loads and reduction efficiencies must be identified. The new BMP types and efficiencies need to be added to the "BMP Data" worksheet, which is hidden by default. Follow these steps to add new BMP types:

- Click the right mouse button on any tab (worksheet) and select the Unhide option. This action reveals a list of hidden worksheets. Select the "BMP Data" worksheet to reveal it.



- To add a new BMP, select the appropriate source category—agriculture (*EFF_Agriculture*), forest (*EFF_Forest*), developed (*EFF_Developed*) or streambank erosion (*EFF_Streambank*)—in the name box (top left corner) under the "BMP Data" worksheet. Add the number of rows as desired at the end of the target source category. Type in the new BMP type, land use type to be applied, soil type, slope type, efficiency number and cost information. Note that there must be a blank row at the start of each new source category to keep the categories separate.

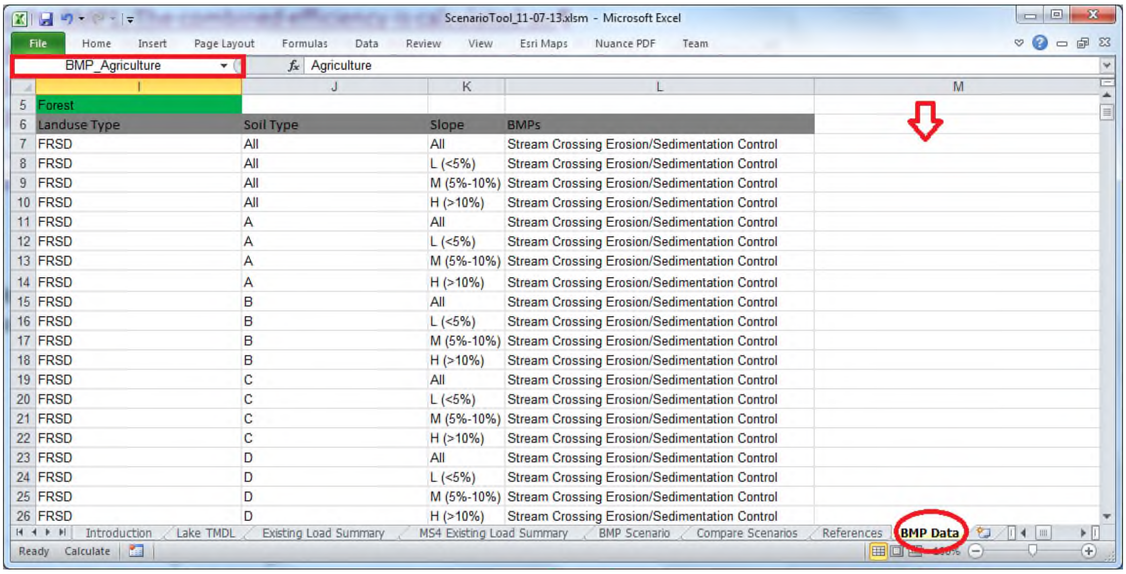


	A	B	C	D	E	F	G
1	Agriculture Efficiency						
2	BMP Type	BMP Code	Landuse Type	Soil Type	Slope	TP Efficiency	BMP Cost ($/ha)
3	Barnyard Management	Barnyard Management	FRML	A	L (<5%)	0.800	0.00
4	Barnyard Management	Barnyard Management	FRML	A	M (5%-10%)	0.800	0.00
5	Barnyard Management	Barnyard Management	FRML	A	H (>10%)	0.800	0.00
6	Barnyard Management	Barnyard Management	FRML	A	All	0.800	0.00
7	Barnyard Management	Barnyard Management	FRML	B	L (<5%)	0.800	0.00
8	Barnyard Management	Barnyard Management	FRML	B	M (5%-10%)	0.800	0.00
9	Barnyard Management	Barnyard Management	FRML	B	H (>10%)	0.800	0.00
10	Barnyard Management	Barnyard Management	FRML	B	All	0.800	0.00
11	Barnyard Management	Barnyard Management	FRML	C	L (<5%)	0.800	0.00
12	Barnyard Management	Barnyard Management	FRML	C	M (5%-10%)	0.800	0.00
13	Barnyard Management	Barnyard Management	FRML	C	H (>10%)	0.800	0.00
14	Barnyard Management	Barnyard Management	FRML	C	All	0.800	0.00
15	Barnyard Management	Barnyard Management	FRML	D	L (<5%)	0.800	0.00
16	Barnyard Management	Barnyard Management	FRML	D	M (5%-10%)	0.800	0.00
17	Barnyard Management	Barnyard Management	FRML	D	H (>10%)	0.800	0.00
18	Barnyard Management	Barnyard Management	FRML	D	All	0.800	0.00
19	Barnyard Management	Barnyard Management	FRML	All	L (<5%)	0.800	0.00
20	Barnyard Management	Barnyard Management	FRML	All	M (5%-10%)	0.800	0.00
21	Barnyard Management	Barnyard Management	FRML	All	H (>10%)	0.800	0.00
22	Barnyard Management	Barnyard Management	FRML	All	All	0.800	0.00

- If multiple BMP practices are applied to the same source (land use, soil and slope), calculate the combined efficiency and enter that number under the efficiency number. For example, the "Reduced P Manure - Grassed Waterways" combination will require treating the practices as a series—applying reduced phosphorus manure (BMP1) first and then applying grassed waterways (BMP2) to the remaining load from BMP1. The combined efficiency is calculated as:

*Combined efficiency (%) = BMP1_efficiency + (100 - BMP1_efficiency) * BMP2_efficiency*

- To add a new BMP to the BMP list, select the appropriate source category—agriculture (*BMP_Agriculture*), forest (*BMP_Forest*) or developed (*BMP_Developed*)—in the name box (top left corner) under the "BMP Data" worksheet. Add the new BMP type at the end of the BMP list for the given land use, soil and slope combination under the target source category.



Costs

The costs of BMP implementation can be evaluated with the tool. For urban structural BMPs, cost estimates will be based on unit volume costs. For non-structural BMPs, cost estimates will be based on area treated. The current tool has a placeholder for the BMP cost, which can be added later.

Calculation of Reductions

The tool calculates reductions to source loads in a manner that is specific to each source loading category. Generally, efficiencies derived from the literature and from other locally relevant studies are applied to existing condition loads generated by SWAT. For most agricultural BMPs, efficiencies are derived from SWAT modeling. For wastewater treatment plants (WWTPs), load reductions are based on the results of load calculations performed for the treatment plants at various levels of discharge.

Developed Lands

Existing condition loads for pervious and impervious urban lands are from the calibrated SWAT model and are presented as loads and unit area export rates (e.g., annual load kg/ha/year). Structural and non-structural practices are included. GIS-derived urban land uses are listed in Table 3 along with the corresponding modeled land use category. These are the “developed” land use categories. Table 4 illustrates the hydrologic respone unit (HRU) combinations to which urban BMPs can be applied.

The tool allows the user to select a target HRU in an MS4 area and apply BMPs to a fraction of those areas. The unit area loading rate for the selected HRU is the same for MS4 or non-MS4 areas. In SWAT an HRU does not have a specific geographic location. As a result, associating HRUs with MS4 areas is an approximate analysis. The area of MS4 HRUs was determined using a GIS procedure in which the MS4 boundaries were intersected with the SWAT sub-basins and the land use dataset. Land use areas within each SWAT sub-basin and MS4 area designation were determined. The fraction of the HRU area by land use occupied by MS4 areas within a sub-basin was then determined and designated as the respective MS4 area. MS4 polygons and entities were provided by the Vermont Department of Environmental Conservation (VT DEC).

Table 3. Developed Land Categories

Land Use	GIS Source	Representative SWAT Class
Developed, Open Space - areas with a mixture of some constructed materials, but mostly vegetation in the form of lawn grasses. Impervious surfaces account for less than 20% of total cover. These areas most commonly include large-lot, single-family housing units, parks, golf courses, and vegetation planted in developed settings for recreation, erosion control or aesthetic purposes.	**NLCD 2006**	Residential - Low Density
Developed, Low Intensity - areas with a mixture of constructed materials and vegetation. Impervious surfaces account for 20% to 49% of total cover. These areas most commonly include single-family housing units.	**NLCD 2006**	Residential - Medium Density
Developed, Medium Intensity - areas with a mixture of constructed materials and vegetation. Impervious surfaces account for 50% to 79% of the total cover.	**NLCD 2006**	Residential - High Density

Land Use	GIS Source	Representative SWAT Class
These areas most commonly include single-family housing units.		
Developed High Intensity - highly developed areas where people reside or work in high numbers. Examples include apartment complexes, row houses and commercial/ industrial. Impervious surfaces account for 80% to 100% of the total cover.	**NLCD 2006**	Industrial – Commercial
Paved Roads	**VT E911**	Paved Roads

Table 4. Developed Land BMP and HRU Combinations

BMP Treatment	Land Use					Slopes			Soils			
	LDR	MDR	HDR	COMM/IND	Paved Road	<5	5–10	>10	A	B	C	D
Infiltration basins & unlined bioretention systems	•	•	•	•	•	•	•		•	•		
Infiltration trenches	•	•	•	•	•	•	•		•	•		
Biofiltration (lined bioretention systems – no infiltration)	•	•	•	•	•	•	•		•	•	•	•
Gravel wetlands	•	•		•	•	•	•	•	•	•	•	•
Extended detention (extended dry detentions)	•	•	•	•	•	•	•		•	•	•	•
Wet ponds & constructed wetlands	•	•	•	•	•	•	•		•	•	•	•
Ban on P fertilizer use on turf	•	•	•	•		•	•	•	•	•	•	•
Street sweeping					•	•	•	•	•	•	•	•
More frequent catch basin cleaning					•	•	•	•	•	•	•	•
Leaf litter collection					•	•	•	•	•	•	•	•
Impervious area disconnection	•	•	•	•	•	•	•	•	•	•	•	•
Impervious area removal	•	•	•	•	•	•	•	•	•	•	•	•

Developed Land BMPs

Structural Practices

Expected reductions for structural practices are based on efficiencies presented in EPA's BMP performance curves (USEPA 2010) for structural BMPs, or as noted. The performance curves were developed using multiyear effectiveness data for practices monitored by the University of New Hampshire's Stormwater Center in Durham, New Hampshire.

P Fertilizer Turf Ban

Refer to Appendix A for details on P fertilizer ban reduction calculations.

Impervious Area Disconnection

Refer to Appendix B for details on reduction calculations.

Impervious Area Removal

Refer to Appendix C for details on reduction calculations.

Street Sweeping

Areas to which street sweeping can be applied are based on a GIS exercise that calculated the area of paved roads within urban area boundaries (i.e., areas where street sweeping is expected to occur). Table 5 shows the results of the GIS tabulation and the fraction of urban roads within each lake segment drainage area to which the street sweeping BMP can be applied.

Table 5. Fraction of Urban Roads Subject to Street Sweeping BMP by Lake Segment Drainage Area

Lake Segment	Drainage Area	Fraction of Urban Road
01. South Lake B	Poultney River	0.558
01. South Lake B	Mettawee River	0.558
01. South Lake B	South Lake B Direct Drainage	0.294
02. South Lake A	South Lake A Direct Drainage	0.551
03. Port Henry	Port Henry Direct Drainage	0.119
04. Otter Creek	Otter Creek	0.543
04. Otter Creek	Little Otter Creek	0.344
04. Otter Creek	Lewis Creek	0.344
05. Main Lake	Winooski River	0.609
05. Main Lake	Main Lake Direct Drainage	0.408
06. Shelburne Bay	LaPlatte River	0.659
07. Burlington Bay	Burlington Bay Direct Drainage	0.985
08. Cumberland Bay	Saranac River	N/A
08. Cumberland Bay	Cumberland Bay Direct Drainage	N/A
09. Malletts Bay	Lamoille River	0.537
09. Malletts Bay	Malletts Bay Direct Drainage	0.716
10. Northeast Arm	Northeast Arm Direct Drainage	0.554
11. St. Albans Bay	St. Albans Bay Direct Drainage	0.781
12. Missisquoi Bay	Mississquoi River	0.520
12. Missisquoi Bay	Mississquoi Bay Direct Drainage	0.580
13. Isle La Motte	Isle La Motte Direct Drainage	0.556

Data Required

Data	Source
Pervious and impervious HRU loading rates by HUC12	SWAT model
Crosswalk BMP performance curve LUs and HRUs	Match appropriate loading rates from the modeled HRUs and BMP performance curves (i.e., performance curve “commercial” land use might not necessarily be analogous to Champlain HRU “non-residential”).

Data	Source
BMP performance curve efficiencies	*Stormwater Best Management Practices (BMP) Performance Analysis* (USEPA 2010)
Wet ponds	Efficiencies (Chesapeake Bay Program – CSN 2011)
Non-structural BMP efficiencies	Turf P fertilizer ban—Appendix A and USEPA (2014b) Street sweeping (various types)—USEPA (2014a) More frequent catch basin cleaning—USEPA (2104a) Leaf litter collection—USEPA (2014a)
Spatial information to match MS4 areas with entities	VT DEC

Developed Land BMP Efficiencies

Table 6. Developed Non-structural BMP Efficiencies

BMP Type		BMP Code	TP Efficiency
Street sweeping	Twice yearly (spring and late fall) using mechanical broom sweeper	Mechanical Broom (2/year)	0.01
	Monthly using mechanical broom sweeper	Mechanical Broom (monthly)	0.03
	Monthly using high-efficiency regenerative air-vacuum	Regenerative Air-Vacuum (monthly)	0.08
Catch basin cleaning, maintaining minimum of 50% sump storage capacity		Catch Basin Cleaning	0.02
Weekly street leaf litter and organic debris collection, September through November		Leaf Litter Collection Program	0.05

Table 7. Developed Non-structural BMP Efficiencies (Impervious Area Removal/Disconnection)

Non-structural BMP Type	BMP Code	BMP Cost ($/ha)	Land Use Type	Soil Type	TP Efficiency
Impervious area disconnection	IAD-MDR-A	10,000	MDR	A	0.48
Impervious area disconnection	IAD-MDR-B	10,000	MDR	B	0.27
Impervious area disconnection	IAD-HDR-A	10,000	HDR	A	0.30
Impervious area disconnection	IAD-HDR-B	10,000	HDR	B	0.14
Impervious area disconnection	IAD-I&C-A	10,000	I&C	A	0.30
Impervious area disconnection	IAD-I&C-B	10,000	I&C	B	0.14
Impervious area removal	IAR-MDR	20,000	MDR	n/a	0.89
Impervious area removal	IAR-HDR	20,000	HDR	n/a	0.89
Impervious area removal	IAR-I&C	20,000	I&C	n/a	0.89

Table 8. Developed Non-structural BMP Efficiencies (P Fertilizer Ban)

Non-structural BMP Type	BMP Code	Land Use Type	Soil Type	Total Turf Area (%)	Fertilized Turf Area (%)	Phosphorus Yield Fertilized (kg/ha/yr)	TP Efficiency
Ban on P fertilizer use on turf	**Ban-on-P-LDR**	LDR	All	0.32	0.37	0.86	0.50
Ban on P fertilizer use on turf	**Ban-on-P-MDR**	MDR	All	0.51	0.37	0.86	0.50
Ban on P fertilizer use on turf	**Ban-on-P-HDR**	HDR	All	0.28	0.37	0.86	0.50
Ban on P fertilizer use on turf	**Ban-on-P-I&C**	I&C	All	0.28	0.37	0.86	0.50

Table 9. Developed Structural BMP Efficiencies

Structural BMP Type	BMP Code	Soil Type				Runoff Depth from Contributing Impervious Area (inches)				
		A	**B**	**C**	**D**	**0.25**	**0.50**	**0.90**	**1.50**	**2.00**
Surface infiltration practices	Surface Infiltration	yes	yes	n/a	n/a	0.54	0.77	0.92	0.98	0.99
Infiltration trench (includes dry wells)	Infiltration Trench	yes	yes	n/a	n/a	0.51	0.77	0.93	0.98	0.99
Biofiltration with underdrains	Bio-filtration	yes	yes	yes	yes	0.38	0.59	0.74	0.84	0.89
Gravel wetland	Gravel Wetland	yes	yes	yes	yes	0.30	0.46	0.59	0.65	0.66
Wet pond & constructed wetlands	Wet Pond	yes	yes	yes	yes	n/a	0.42	0.50	0.56	0.65
Extended dry detention pond	Ext-Dry Detention Pond	yes	yes	yes	yes	n/a	n/a	0.19	n/a	n/a

Agriculture

Reductions due to agricultural BMPs are calculated based on model results and literature-based efficiency values. In some cases, modeled efficiencies were adjusted based on recommendations of the TMDL workgroup and a review of available literature values.

Agriculture BMPs

Descriptions of the agricultural BMPs included in the Scenario Tool are provided in Table 10, along with their abbreviations in the Tool and notes on how the efficiencies were derived. When "SWAT" is indicated as the source of the efficiency estimate, it means that the reduction efficiency was derived from loading rates predicted by the calibrated SWAT model. For these BMPs, a baseline condition was run along with multiple scenarios representing implementation of the specified BMP. The BMP scenario runs generated a prediction of the relative change in loads in comparison to the baseline. These relative changes provided the basis for the efficiency estimates in these cases. Because the Champlain Basin SWAT model was developed separately for each HUC8 basin, the agricultural baseline and BMP runs were run for each basin and the resulting efficiency used in the Scenario Tool is the average efficiency among all the basins. However, the average efficiencies do vary by land cover, soil type and slope, as depicted in Table D-1 in Appendix D. For the BMPs where efficiencies were derived from literature values (or any source other than the SWAT runs), an explanation is provided in Table 10 or in separate text below the table, as noted.

Table 10. Agriculture BMP Definitions and Efficiency Derivations

BMP	Definition and Derivation of Efficiency
Cover crop (CC)	Establishing a seasonal cover on annual cropland for soil erosion reduction and conservation purposes. Seasonal cover consists of a crop of winter rye or other herbaceous plants seeded at a minimum rate of 100 lb/ac or at the highest recommended rate to provide effective soil coverage. Planting dates are addressed in the modeling assumptions. Reduction efficiency based on recommendations of TMDL workgroup members and literature values (Meals 2011).
Change in crop rotation (CR)	Introducing feasible changes in crop rotation. Currently, standard rotations consist of corn (2 years)/hay (4 years) and corn (1 year)/soybean (1 year). Example changes in crop rotation could be to change the corn-hay rotation to corn (2 years) followed by hay (6 years). Reduction efficiency derived from SWAT model runs.
Manure injection (MI)	Applying liquid manure below the soil surface. Reduction efficiency derived from SWAT model runs.
Conservation tillage (CT)	Any tillage and planting system that leaves a minimum of 30% of the soil surface covered with plant residue after the tillage or planting operation (e.g., reduced till, no-till). For silage corn, this could involve required application of a cover crop or use of zip-till, zone-till or minimum tillage equipment. Reduction efficiency based on recommendations of TMDL workgroup members and literature values (Meals 2011).
Reduced P manure (PMan)	A 20% reduction of the total P content applied to fields, through either manure or fertilizer. This can be accomplished by reducing the amount of manure/fertilizer applied or by altering livestock feed formulation or treating manure prior to application, although specifying the “how” is not necessary at this time. Reduction efficiency derived from SWAT model runs.
Grassed waterways (GWW)	Stabilizing areas prone to field gully erosion by establishing grass-lined swales. Reduction efficiency based on recommendations of TMDL workgroup members and literature values (Meals 2011).
Riparian buffer (RB)	Areas of grasses or shrubs (which may include trees) located adjacent to ponds, lakes and streams that filter out pollutants from runoff. Reduction efficiency: see text below.
Permanent cropland to hay conversion (Crop to Hay)	Permanent conversion of cropland use to hay. Reduction efficiency derived from SWAT model runs.
Field ditch buffer (DB)	Grassed strips along the drainage ditches that filter out pollutants from the adjacent land runoff. Reduction efficiency: see text below.
Fencing	Exclusion of livestock from waterways and streambanks by installing fence. Reduction efficiency: see text below.
Barnyard runoff management	Exclusion of clean water runoff from the barnyard and heavy-use area, and management of the remaining runoff in a way that minimizes its pollution. Reduction efficiency: see text below.

Fencing

The Scenario Tool applies a 55 percent reduction to loads from grazing livestock due to fencing, based on model results. The total manure generated by grazing livestock has been partitioned by SWAT as direct land application (on pasture) and as a point source to the stream. Total loads are based on animal population data from the Agriculture Census (dairy cattle, non-dairy and horses) and estimates of animals in large and medium operations. (For more details please refer to *SWAT Model Calibration Report* (Tetra Tech 2013b).) Approximately 95 percent of the load is applied by the model to the pastureland and 5 percent applied directly to streams as point sources to simulate livestock depositing directly in streams. To develop the estimated efficiency for fencing, the 5 percent of the load directly deposited in streams was removed and applied to pastureland (i.e., 100 percent of the load from grazing livestock was applied to pastureland). The model was rerun and the efficiency calculated for all the basins. The Scenario Tool uses the average efficiency (55 percent) from all the basins. This efficiency is also consistent with the findings of studies designed to measure the effectiveness of livestock exclusion, both within the Lake Champlain Basin (Meals 2000) and elsewhere (Line et al. 2000; Jones and Knowlton 1999). In the Scenario Tool, the effect of the fencing practice can be simulated in combination with the riparian buffer practice (41 percent efficiency; see below), yielding a combined efficiency of 78 percent.

Barnyard Runoff Management

The reduction efficiency attributed to barnyard runoff management is specific to the way this practice is implemented in Vermont. In Vermont, either the barnyard or farmstead runoff is diverted to a manure storage facility or the barnyard is covered. Therefore, the scenario tool uses an 80 percent efficiency factor for this practice, per the recommendation of the Vermont Natural Resources Conservation Service (NRCS) office (Potter 2013).

Riparian Buffers

A 41 percent reduction efficiency was selected for riparian buffers, using the effectiveness/buffer width table in SWAT. A 25-foot buffer results in a 67 percent reduction efficiency, and a 10-foot buffer results in a 51 percent reduction efficiency. TMDL workgroup members estimated that 10-foot buffers might already be in place along about half of the waterways in agricultural areas in Vermont, but 25-foot buffers are much less common. Information from the Missisquoi Area-Wide Plan (USDA-NRCS 2008) suggests that 25-foot buffers (or larger) are present along only approximately 10 to 20 percent of the waterways in agricultural areas. To estimate the average efficiency of establishing 25-foot buffers both where there are no buffers at present and where there are already 10-foot buffers, the average of 67 percent and 15 percent (the additional reduction efficiency gained when a 10-foot buffer is expanded to a 25-foot buffer), or 41 percent, was used to simulate the overall reduction efficiency for 25-foot riparian buffers implemented in the Vermont portion of the Lake Champlain Basin. Note that the SWAT riparian buffer width efficiency table is based on the effectiveness of filter strips, which may be composed of grass only. Because riparian buffers may also contain shrubs and trees, the effectiveness value should be viewed as somewhat conservative. Gitau et al. (2005) report a slightly higher average efficiency for forested riparian buffers than for filter strips.

Field Ditch Buffers

A 10-foot width was assumed for this practice, and the 51 percent reduction efficiency was obtained from the SWAT riparian buffer table referenced above. A 25-foot width was also provided as an option, and the 67% reduction efficiency was obtained from the SWAT riparian buffer table.

Combined BMP Efficiencies

To avoid a situation where the effects of multiple BMPs are simulated unrealistically, it was necessary to identify appropriate groupings or scenarios of BMPs that realistically can be applied together. The land use categories are defined in Table 11; the BMP groupings are shown in Table 12.

Table 11. Agricultural Land Use Categories for BMP Application

Land Use Category	Definition
PAST	Pasture
CRNC	Continuous corn – Non-clay
CRCL	Continuous corn – Clay
CHNC	Corn-hay rotation – Non-clay
CHCL	Corn-hay rotation – Clay
HAY	Continuous hay

Table 12. Agricultural BMP and HRU Combinations

BMP Treatment	Land Use						Slopes			Soils			
	PAST	CRNC	CRCL	CHNC	CHCL	HAY	<5	5–10	>10	A	B	C	D
CC[a]		•	•	•	•		•	•	•	•	•	•	•
CR		•	•	•	•		•	•	•	•	•	•	•
CT[a]		•	•	•	•		•	•	•	•	•	•	•
PMan		•	•	•	•	•	•	•	•	•	•	•	•
GWW		•	•	•	•	•	•	•	•	•	•	•	•
RB		•	•	•	•	•	•	•	•	•	•	•	•
CC[a]+CR		•	•	•	•		•	•	•	•	•	•	•
CC+MI		•	•	•	•		•	•	•	•	•	•	•
CR+CT		•	•	•	•		•	•	•	•	•	•	•
CR+MI				•	•		•	•	•	•	•	•	•
CT+MI		•					•	•	•	•	•	•	•
MI+PMan		•	•	•	•	•	•	•	•	•	•	•	•
PMan+GWW		•	•	•	•	•	•	•	•	•	•	•	•
CC+CR+MI				•	•		•	•	•	•	•	•	•
CC+CR+PMan				•	•		•	•	•	•	•	•	•
CR+CT+MI				•			•	•	•	•	•	•	•
CR+MI+PMan				•	•		•	•	•	•	•	•	•
CC+ CR+MI+PMan				•	•		•	•	•	•	•	•	•
CR-MI-PMan-GWW				•	•		•	•	•	•	•	•	•
CR-MI-PMan-RB				•	•		•	•	•	•	•	•	•
PMan-RB				•	•		•	•	•	•	•	•	•
CC-GWW		•	•	•	•		•	•	•	•	•	•	•
MI-PMan-GWW		•	•	•	•	•	•	•	•	•	•	•	•
MI-PMan-RB				•	•		•	•	•	•	•	•	•
CC-CT-MI		•	•	•	•		•	•	•	•	•	•	•
GWW-RB		•	•	•	•	•	•	•	•	•	•	•	•
CC-CT-MI-RB		•	•	•	•		•	•	•	•	•	•	•
CC-CT-MI-GWW		•	•	•	•		•	•	•	•	•	•	•
CC-CT-MI-GWW-RB		•	•	•	•		•	•	•	•	•	•	•
Fencing	•						•	•	•	•	•	•	•
Fencing+RB	•						•	•	•	•	•	•	•
DB		•	•	•	•	•	•	•	•	•	•	•	•
CR-GWW-DB-RB			•		•		•	•	•				•
CC-CT-GWW-DB-RB		•	•	•	•		•	•	•	•	•	•	•
Crop to Hay		•	•	•	•			•	•	•	•	•	•

[a] Applies to corn part only in the corn-hay rotation.

Data Required

Data	Source
Calibrated modeled loads and export rates	SWAT model
BMP groupings	Table 12
SWAT BMP results	SWAT model runs
Fencing efficiencies	SWAT model results simulating removal of direct deposits
Barnyard management BMP efficiencies	80 percent

Agriculture BMP Efficiencies

Refer to Appendix D.

Streambank Erosion

SWAT provides streambed and streambank erosion loading estimates for each modeled reach. In a selected HUC8, the Scenario Tool predicts load reductions for eroding reaches. Eroding reaches were determined by distributing the HUC8 total channel load modeled by SWAT among the HUC12 reaches on the basis of their "erosion susceptibility ratings." (Refer to *SWAT Model Calibration Report* (Tetra Tech 2013b) for a description of that process.) The HUC12 reaches exceeding the 25th percentile load are considered the eroding reaches.[2] Reductions are applied to the SWAT-predicted loads for those eroding reaches. The baseline load is the sum of all HUC12 streambank erosion loads. The reduced load is the sum of the streambank loads of the eroding reaches multiplied by an efficiency factor plus the baseline loads from the non-eroding reaches. The efficiency factor is based on a separate analysis that compared SWAT-modeled loads from eroding reaches to loads from more stable reaches, as explained in the paragraphs that follow.

Streambank Erosion BMPs

The erosion control "practice" in this TMDL context is not actually a BMP in the conventional sense. Given that channel erosion control projects (such as bank stabilization) in one part of a stream system can have destabilizing effects on other parts of the system, the goal in this case was to estimate the phosphorus reduction associated with bringing an entire stream reach to a more stable geomorphic condition. Following years of detailed geomorphic assessments, VT DEC has classified a large subset of Vermont streams according to channel evolution model (CEM) stages I through V. Streams in CEM stages I and V are typically fairly stable systems close to equilibrium conditions; stage II and III streams are generally unstable and eroding; and stage IV streams are usually in between stable and unstable conditions.

As the term *channel evolution* implies, stream systems naturally evolve over time from one stage to another, starting with stage I (stable) and progressing through the unstable stages (II and III) and eventually back to the more stable stage (V). Then the cycle begins again. However, human development in a watershed can significantly affect the timing of this evolution and the severity of erosion during the unstable stages. For example, encroachments into stream floodplains (such as houses or roads) can speed up the transition from stage I to II and can dramatically increase erosion during stages II and III. Likewise, actions like preventing floodplain encroachment, reestablishing stream access to floodplains, and properly sizing stream culverts can reduce the severity of erosion (and flooding) for reaches at stage II or III and can speed up the evolution to stage IV and ultimately to stages V and I. The erosion control practice simulated for TMDL purposes represents the transition from the phosphorus loading levels associated with the less stable stages II and III to the more stable stages I and V. The TMDL does not assume or prescribe a set method for achieving this transition. The appropriate actions will be determined at the implementation stage based on the unique characteristics of each reach.

[2] The Scenario Tool allows for evaluating load reductions applied to reaches exceeding the 25th, 50th and 75th percentile loads.

Data Required

Data	Source
Erosion Susceptibility Rating for VT reaches	Results from Erosion Susceptibility Rating Analysis
HUC8 bed and bank loads	SWAT model
Channel evolution stage data	Phase II data and spatial coverage from VT DEC
BMP reduction efficiencies	Difference in median loads between stable and unstable reaches

Streambank Erosion BMP Efficiency

The efficiency factor used in the Scenario Tool is based on the results of a separate analysis that compared SWAT-modeled loads from eroding reaches to loads from more stable reaches as follows. Available channel evolution stage classifications for the HUC12 basins in the Vermont portion of the basin were compared to the HUC12 channel loads generated by SWAT. (Note that channel evolution stage classification data were not available for all SWAT-modeled HUC12s.) This was accomplished by intersecting the VT DEC CEM GIS layer with the SWAT model HUC12 sub-basins. The Vermont geomorphic assessment process typically results in the identification of multiple small reaches at different CEM stages within each larger HUC-12. Because SWAT estimates phosphorus loads by HUC-12 reach, it was necessary to aggregate the CEM data up to the HUC-12 reach scale. To do this, the total length associated with each CEM stage in a HUC12 was calculated and the HUC12 was assigned the stage with the greatest length. For example, if a HUC12 contained 10 reaches at various CEM stages and stage III was dominant (based on total length), then the HUC12 was designated as stage III. The process of assigning a HUC12 to a particular dominant CEM stage reduced the total number of Lake Champlain basin reaches with CEM stage data from 1,528 to 105. The reduction efficiency was calculated by computing the difference between median loads from HUC12 stream reaches in stages II and III to those in stages I and V. The aggregation process resulted in no HUC12 reaches designated as stage V because stage V was not dominant in any of the few HUC12 reaches containing stage V segments. Therefore, the reduction efficiency ultimately was calculated based on the comparison of "unstable" stage II and III reaches (combined) with "stable" stage I reaches (Figure 1). Stage IV reaches were not used in this analysis because such reaches are at an "in between" stage of stability.

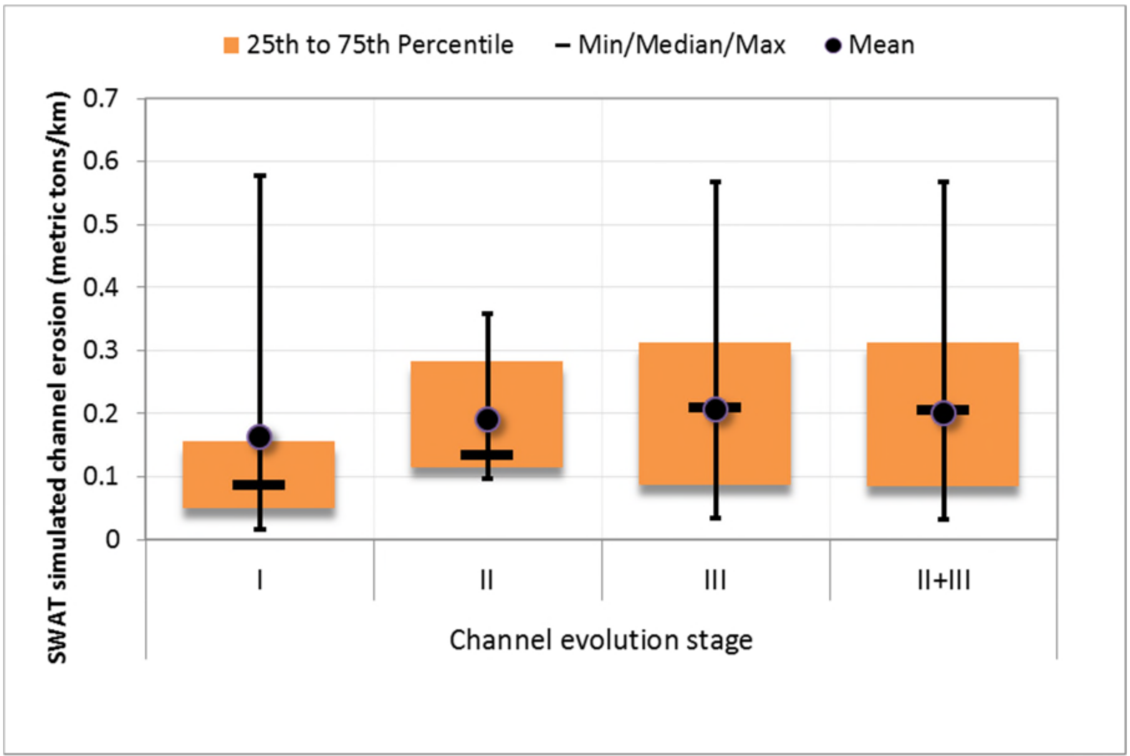


Figure 1. Phosphorus loading by CEM stage.

The reduction efficiency calculated using this approach was 55 percent. This percentage was derived from a weighted average of the reductions calculated for stage II and stage III (Table 13), and it takes into account that a much higher number of HUC12 segments are at stage III than at stage II (49 versus 11).

Table 13. Phosphorus reduction efficiency based on comparison of loading rates from reaches at CEM stages II and III with the loading rate from reaches at CEM stage I

CEM Stage	Reduction Efficiency
II	36%
III	59%
II + III	55%

Because data were not available for the entire basin, CEM stage was designated for only 105 of the 187 HUC12 sub-basins in the Vermont portion of the Lake Champlain basin. To estimate the potential phosphorus reduction associated with applying the 55 percent efficiency factor more broadly, there was a need for a way to identify the larger group of highly eroding HUC12 reaches throughout the basin that are likely dominated by CEM stages II and III even though actual CEM data are lacking. An analysis of all HUC12 loads (distributed into four quartile groups) compared with loads from HUC12s having an assigned CEM stage found that the three quartiles above the 25th percentile loading group were dominated by reaches at stages III and II (see Table 14). Based on this alignment, stream reaches in HUC12 sub-basins in the phosphorus loading groups above the 25th percentile are assumed to be predominantly at CEM stages III and II. Accordingly, the Scenario Tool was configured to allow application of the stream channel erosion control "practice" to reaches above the 25th percentile (loading rates) throughout the Vermont portion of the basin.

Table 14. Number and Percentage of CEM Stage Reaches (aggregated up to the HUC12 scale) in Each HUC12 Phosphorus Loading Rate Quartile Group

CEM Stage	# Reaches in Loading Rate Quartile				% Reaches in Loading Rate Quartile			
	< 25th	25th–50th	50th–75th	> 75th	< 25th	25th–50th	50th–75th	> 75th
I	12	8	6	4	44%	31%	22%	15%
II	6	1	7	3	22%	4%	26%	11%
III	7	15	11	16	26%	58%	41%	59%
IV	2	2	3	4	7%	8%	11%	15%

Notes:
II, IIb, IIc and IId have been lumped into CEM stage II.
Refer to above text for context.

Lastly, because SWAT generates channel loads in the form of sediment rather than phosphorus, an additional step in this process was to convert the channel sediment to a phosphorus load based on sediment phosphorus concentration data available for the Lake Champlain Basin (Ross and Ishee 2011).

This reduction efficiency factor provides a way to estimate the total load that may ultimately be reduced (in part through natural stream evolution) primarily at the HUC8, large-basin scale. At the implementation stage, the HUC12s above the 25th loading percentile may certainly be looked at to identify enhancement opportunities, but EPA recognizes that most implementation work would be driven by actual field assessments (as is the case for the other phosphorus source categories as well).

Unpaved Roads

Existing loads/loading rates are from the calibrated SWAT HRUs representing back roads. A 50 percent reduction efficiency is used.

Table 15. Unpaved Road BMP and HRU Combinations

BMP Treatment	Land Use	Slopes		Soils			
	Unpaved Road	<5	≥5	A	B	C	D
Back roads and roadside erosion control	•	•	•	•	•	•	•

Data Required

Data	Source
Loads/export rates for Unpaved HRUs	SWAT, with P concentration data and grade adjustments derived from the 2013 Wemple Lake Champlain back roads study.
Back roads and roadside erosion control efficiency	50% is being used as a placeholder efficiency until information becomes available from a University of Vermont/Lake Champlain Basin Program study currently under way.

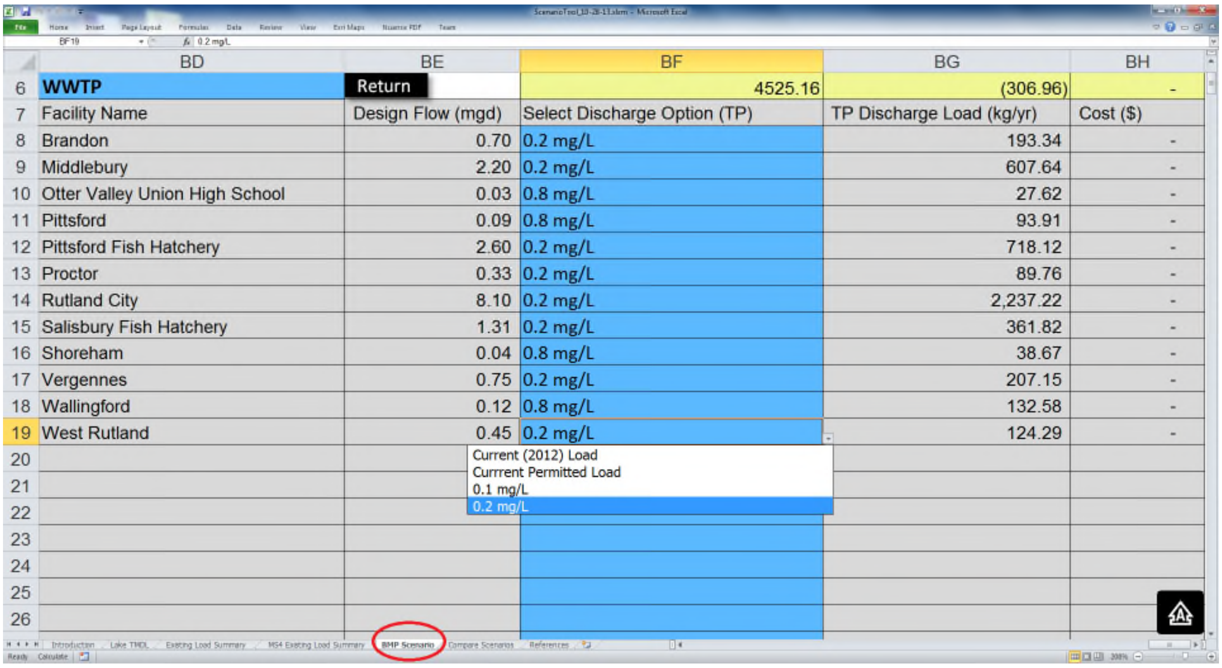
WWTP

Existing loads from wastewater treatment plants have been calculated based on representative discharge characteristics for 2012. Reductions are based on calculations of facility loads at various discharge levels. Table 16 illustrates discharge scenarios included in the Scenario Tool.

The tool allows users to select scenarios based on *flow category* (e.g., to evaluate loading by assigning the same discharge characteristics to groups of facilities based on permitted flows) as well as *specific facilities*.

Table 16. WWTP Facility Scenarios

Facility Flow Category	Currently Permitted Loads	2012 Loads	0.8 mg/L	0.2 mg/L	0.1 mg/L
			Design Flow		
< 0.2 mgd	•	•	•		
≥ 0.2 mgd	•	•		•	•



BD	BE	BF	BG	BH
WWTP	Return	4525.16	(306.96)	-
Facility Name	Design Flow (mgd)	Select Discharge Option (TP)	TP Discharge Load (kg/yr)	Cost ($)
Brandon	0.70	0.2 mg/L	193.34	-
Middlebury	2.20	0.2 mg/L	607.64	-
Otter Valley Union High School	0.03	0.8 mg/L	27.62	-
Pittsford	0.09	0.8 mg/L	93.91	-
Pittsford Fish Hatchery	2.60	0.2 mg/L	718.12	-
Proctor	0.33	0.2 mg/L	89.76	-
Rutland City	8.10	0.2 mg/L	2,237.22	-
Salisbury Fish Hatchery	1.31	0.2 mg/L	361.82	-
Shoreham	0.04	0.8 mg/L	38.67	-
Vergennes	0.75	0.2 mg/L	207.15	-
Wallingford	0.12	0.8 mg/L	132.58	-
West Rutland	0.45	0.2 mg/L	124.29	-

Figure 2. Example scenario screen for WWTPs

Data Required

Data	Source
Existing facility loads	Calculated
Discharge scenario loads	Calculated

Forest

SWAT was not configured to approximate loading from logging activities or logging roads. However, if deemed necessary moving forward, options for estimating potential reductions associated with certain forest management BMPs may be further investigated. The existing loads and export rates would be from the calibrated SWAT forest category HRUs representing deciduous, conifer and mixed forest.

Assuming information on the extent, area and length of logging roads is available by HUC8, one approach would be to calculate the phosphorus load for logging roads based on length of road, literature value loading rates and percent road connectivity to waterways. Estimates of the extent of current forest BMP implementation and opportunities for additional BMPs would then be needed. Lastly, reduction efficiencies, to the extent available, would be applied to the appropriate portion of the current load. One of the challenges associated with this approach is that very limited data exist on the logging road network in each watershed, the opportunities for additional BMPs (e.g., the number of stream crossings that are inadequately protected in each watershed), and, perhaps most important, the effectiveness (in terms of phosphorus reduction) of forestry BMPs.

Nevertheless, in an initial effort to include some representation of the potential benefits of increased implementation of forest management practices, the Scenario Tool includes an option to select a 5 percent reduction from each forest category. In the absence of more data, this reduction level is considered a very conservative estimate of the potential effects of additional implementation of key practices such as erosion and sedimentation control at logging road water crossings. This reduction efficiency may be refined in the near future if more information becomes available, as discussed above. **Update following the outside technical review**: A more detailed analysis of loads and potential phosphorus reductions from forest lands was subsequently conducted by EPA and is expected to be included in an appendix to the TMDL document.

Data Required

Data	Source
Loads/export rates	SWAT
Export rate and efficiency	Stakeholders/literature

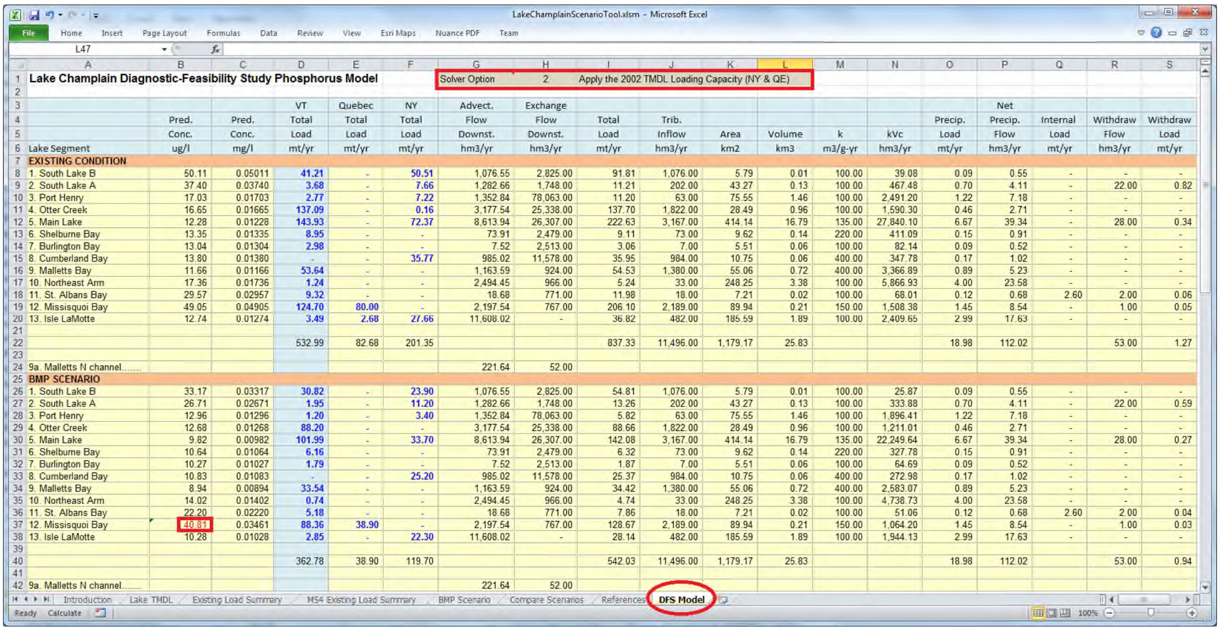
Linkage to Lake Conditions

The results of any given load reduction scenario can be evaluated against resulting in-lake concentrations to determine whether the scenario can meet water quality standards. For the Vermont load reduction evaluation, loads from New York are set to the 2002 loading capacity.

A mass balance spreadsheet version of the revised calibrated BATHTUB model was implemented in the Scenario Tool to show predicted effects on the lake water quality from changes in incoming loads. Use of the spreadsheet model allows for identifying relative changes in lake segments in response to incoming load changes without having to rerun BATHTUB. The spreadsheet model was first created to provide a spreadsheet version of the original 2002 BATHTUB model, and it has been updated to reflect the 2012 recalibrated BATHTUB model's inputs, exchange flow rates and sedimentation terms. The spreadsheet model is implemented in the Scenario Tool under a worksheet named "DFS Model" (Figure 3), which is hidden by default so that users cannot inadvertently make changes to the cells. Calculations are performed on the DFS Model tab; results are presented on the Lake TMDL tab. The tool uses the spreadsheet model's predictions for all lake segments except for Missisquoi Bay. The recently completed Phosphorus Mass Balance model for Missisquoi Bay (LimnoTech 2012) was integrated into the Scenario Tool, and results from that model, instead of the revised BATHTUB model, are used to predict water quality in the Missisquoi Bay segment. Using the results from this separate modeling effort allows EPA to account for the internal loading known to occur within the Missisquoi Bay and to factor its effects into lake segment water quality predictions under various load reduction scenarios and time horizons.

Figure 6-5 from the final model report (LimnoTech 2012) is the basis of the Missisquoi Bay calculations that are used to replace the revised BATHTUB predictions (

Figure 4). The figure shows predicted summer concentrations of total phosphorus in the Missisquoi Bay for 30 years following varying load reductions—0, 25, 50 and 75 percent. To incorporate these predictions into the Scenario Tool, the linear slopes and intercepts were estimated graphically from the dotted lines and were used to estimate the P concentrations versus year for the various percent load reductions. A regression relationship was developed on final P concentration (after the various time intervals) versus percent reduction for 30 years after 2010 (Figure 5). The slope and intercept of the regression are used in the DFS Model tab in place of the BATHTUB predictions for the Missisquoi Bay segment to predict future concentrations as a function of any percent load reduction.



Lake Champlain Diagnostic-Feasibility Study Phosphorus Model — Solver Option: 2 — Apply the 2002 TMDL Loading Capacity (NY & QE)

Lake Segment	Pred. Conc. ug/l	Pred. Conc. mg/l	VT Total Load mt/yr	Quebec Total Load mt/yr	NY Total Load mt/yr	Advect. Flow Downst. hm3/yr	Exchange Flow Downst. hm3/yr	Total Load mt/yr	Trib. Inflow hm3/yr	Area km2	Volume km3	k m3/g-yr	kVc hm3/yr	Precip. Load mt/yr	Net Precip. Flow hm3/yr	Internal Load mt/yr	Withdraw Flow hm3/yr	Withdraw Load mt/yr
EXISTING CONDITION																		
1. South Lake B	50.11	0.05011	41.21	-	50.51	1,076.55	2,825.00	91.81	1,076.00	5.79	0.01	100.00	39.08	0.09	0.55	-	-	-
2. South Lake A	37.40	0.03740	3.68	-	7.66	1,282.66	1,748.00	11.21	202.00	43.27	0.13	100.00	467.48	0.70	4.11	-	22.00	0.82
3. Port Henry	17.03	0.01703	2.77	-	7.22	1,352.84	78,063.00	11.20	63.00	75.55	1.46	100.00	2,491.20	1.22	7.18	-	-	-
4. Otter Creek	16.65	0.01665	137.09	-	0.16	3,177.54	25,338.00	137.70	1,822.00	28.49	0.96	100.00	1,590.30	0.46	2.71	-	-	-
5. Main Lake	12.28	0.01228	143.93	-	72.37	8,613.94	26,307.00	222.63	3,167.00	414.14	16.79	135.00	27,840.10	6.67	39.34	-	28.00	0.34
6. Shelburne Bay	13.35	0.01335	8.95	-	-	73.91	2,479.00	9.11	73.00	9.62	0.14	220.00	411.09	0.15	0.91	-	-	-
7. Burlington Bay	13.04	0.01304	2.98	-	-	7.52	2,513.00	3.06	7.00	5.51	0.06	100.00	82.14	0.09	0.52	-	-	-
8. Cumberland Bay	13.80	0.01380	-	-	35.77	985.02	11,578.00	35.95	984.00	10.75	0.06	400.00	347.78	0.17	1.02	-	-	-
9. Malletts Bay	11.66	0.01166	53.64	-	-	1,163.59	924.00	54.53	1,380.00	55.06	0.72	400.00	3,366.89	0.89	5.23	-	-	-
10. Northeast Arm	17.36	0.01736	1.24	-	-	2,494.45	966.00	5.24	33.00	248.25	3.38	100.00	5,866.93	4.00	23.58	-	-	-
11. St. Albans Bay	29.57	0.02957	9.32	-	-	18.68	771.00	11.98	18.00	7.21	0.02	100.00	68.01	0.12	0.68	2.60	2.00	0.06
12. Missisquoi Bay	49.05	0.04905	124.70	80.00	-	2,197.54	767.00	206.10	2,189.00	89.94	0.21	150.00	1,508.38	1.45	8.54	-	1.00	0.05
13. Isle LaMotte	12.74	0.01274	3.49	2.68	27.66	11,608.02	-	36.82	482.00	185.59	1.89	100.00	2,409.65	2.99	17.63	-	-	-
			532.99	82.68	201.35			837.33	11,496.00	1,179.17	25.83			18.98	112.02		53.00	1.27
9a. Malletts N channel.......						221.64	52.00											
BMP SCENARIO																		
1. South Lake B	33.17	0.03317	30.82	-	23.90	1,076.55	2,825.00	54.81	1,076.00	5.79	0.01	100.00	25.87	0.09	0.55	-	-	-
2. South Lake A	26.71	0.02671	1.95	-	11.20	1,282.66	1,748.00	13.26	202.00	43.27	0.13	100.00	333.88	0.70	4.11	-	22.00	0.59
3. Port Henry	12.96	0.01296	1.20	-	3.40	1,352.84	78,063.00	5.82	63.00	75.55	1.46	100.00	1,896.41	1.22	7.18	-	-	-
4. Otter Creek	12.68	0.01268	88.20	-	-	3,177.54	25,338.00	88.66	1,822.00	28.49	0.96	100.00	1,211.01	0.46	2.71	-	-	-
5. Main Lake	9.82	0.00982	101.99	-	33.70	8,613.94	26,307.00	142.08	3,167.00	414.14	16.79	135.00	22,249.64	6.67	39.34	-	28.00	0.27
6. Shelburne Bay	10.64	0.01064	6.16	-	-	73.91	2,479.00	6.32	73.00	9.62	0.14	220.00	327.78	0.15	0.91	-	-	-
7. Burlington Bay	10.27	0.01027	1.79	-	-	7.52	2,513.00	1.87	7.00	5.51	0.06	100.00	64.69	0.09	0.52	-	-	-
8. Cumberland Bay	10.83	0.01083	-	-	25.20	985.02	11,578.00	25.37	984.00	10.75	0.06	400.00	272.98	0.17	1.02	-	-	-
9. Malletts Bay	8.94	0.00894	33.54	-	-	1,163.59	924.00	34.42	1,380.00	55.06	0.72	400.00	2,583.07	0.89	5.23	-	-	-
10. Northeast Arm	14.02	0.01402	0.74	-	-	2,494.45	966.00	4.74	33.00	248.25	3.38	100.00	4,738.73	4.00	23.58	-	-	-
11. St. Albans Bay	22.20	0.02220	5.18	-	-	18.68	771.00	7.86	18.00	7.21	0.02	100.00	51.06	0.12	0.68	2.60	2.00	0.04
12. Missisquoi Bay	40.81	0.03461	88.36	38.90	-	2,197.54	767.00	128.67	2,189.00	89.94	0.21	150.00	1,064.20	1.45	8.54	-	1.00	0.03
13. Isle LaMotte	10.28	0.01028	2.85	-	22.30	11,608.02	-	28.14	482.00	185.59	1.89	100.00	1,944.13	2.99	17.63	-	-	-
			362.78	38.90	119.70			542.03	11,496.00	1,179.17	25.83			18.98	112.02		53.00	0.94
9a. Malletts N channel.......						221.64	52.00											

Figure 3. Lake Champlain DFS Model tab.

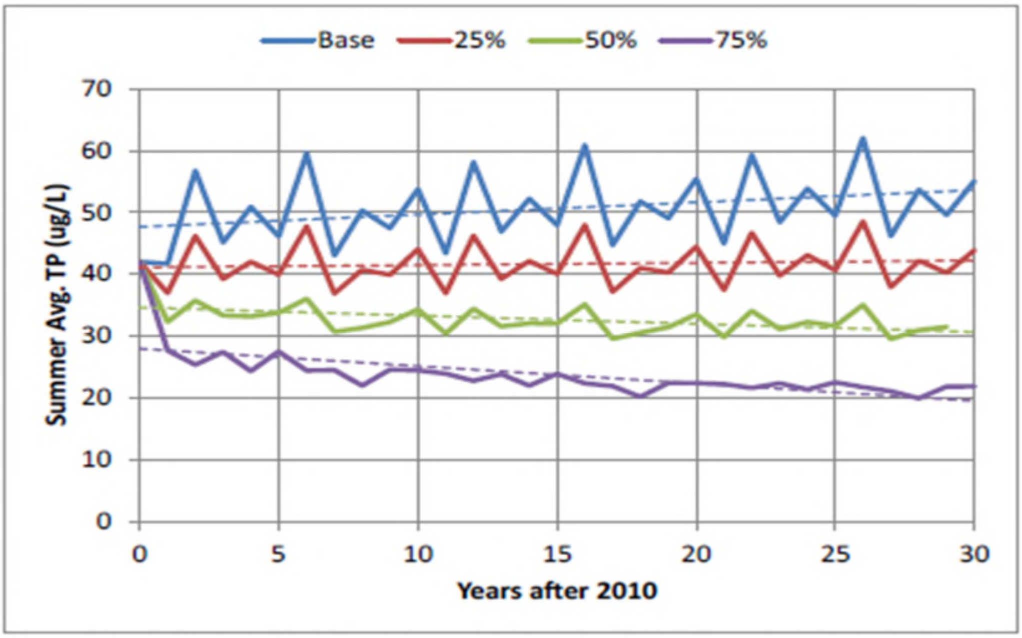


Figure 6-5. Bay-wide June-Sept TP concentration for 30 years after 2010.

Figure 4. Missisquoi Bay P Mass Balance Model report Figure 6-5, showing predicted summer TP concentrations for 30 years after 2010 (LimnoTech 2012).

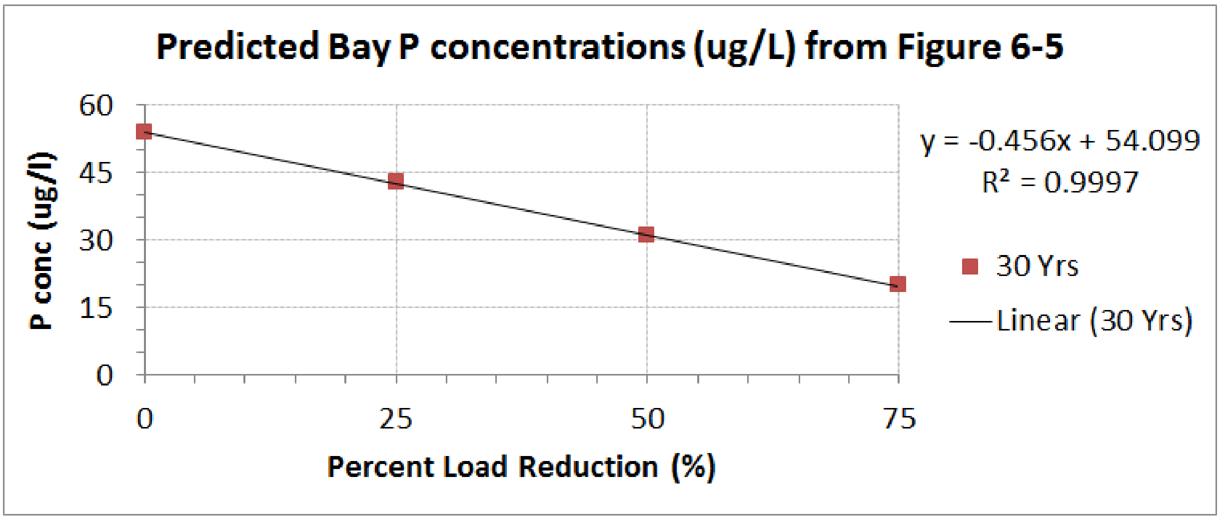


Figure 5. Regression results for P concentration 30 years after load reductions are implemented.

Data Required

Data	Source
Spreadsheet Mass Balance Model	VT DEC
Missisquoi Bay	Missisquoi Bay P mass balance model results
Results from load scenarios	Tool

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Appendix A: Calculating Phosphorus Reductions Resulting from a P Fertilizer Ban

Prepared by EPA Region 1 – November 2013 Draft

Background

A ban on phosphorus-containing fertilizer is included as one of the best management practices (BMPs) in the Scenario Tool to reduce phosphorus loads from developed land to meet TMDL loading targets for Lake Champlain. Phosphorus in fertilizers applied to turf (e.g., landscaped areas or lawns) is a potential source of phosphorus to receiving waters in urban/suburban areas. Because phosphorus-containing fertilizer is generally not needed to promote healthy turf growth in most lawns, a number of states, including Vermont and New York, have recently enacted legislation to ban phosphorus in most commercial and retail fertilizer sales.

Several key factors impact the phosphorus load reductions expected from such a ban, including amount of turf in the watershed, fertilizer application rate, runoff potential from turf and nutrient concentrations in fertilized and unfertilized runoff. Quantifying these key factors without site-specific data is a challenging endeavor. To that end, EPA has developed an approach to estimate the phosphorus load reduction from a fertilizer ban in the Scenario Tool, as described below, for situations where site-specific data are not readily available.

Methodology:

Turf Analysis in Developed Land Uses

Turf is not typically available as a separate land use category, and estimates of the amount of turf in developed areas can vary. Therefore, the first step was to conduct a GIS-based analysis to develop estimates of turf cover for four urban developed land use categories in the Lake Champlain Basin. NLCD (2006) land use data were obtained from Tetra Tech for all developed land (pervious and impervious), as described in Table A-1. Aerial images of the Lake Champlain watershed in 2011 were obtained from the U.S. Department of Agriculture (USDA).

Table A-1. Developed classes in the land use raster and the representative SWAT class

NLCD 2006	Representative SWAT class
Developed, Open Space - areas with a mixture of some constructed materials, but mostly vegetation in the form of lawn grasses. Impervious surfaces account for less than 20 of total cover. These areas most commonly include large-lot, single-family housing units, parks, golf courses, and vegetation planted in developed settings for recreation, erosion control or aesthetic purposes.	Residential - Low Density
Developed, Low Intensity - areas with a mixture of constructed materials and vegetation. Impervious surfaces account for 20% to 49% of total cover. These areas most commonly include single-family housing units.	Residential - Medium Density
Developed, Medium Intensity - areas with a mixture of constructed materials and vegetation. Impervious surfaces account for 50% to 79% of the total cover. These areas most commonly include single-family housing units.	Residential - High Density
Developed High Intensity - highly developed areas where people reside or work in high numbers. Examples include apartment complexes, row houses and commercial/industrial. Impervious surfaces account for 80% to 100% of the total cover.	Commercial/Industrial

Study Area

Urban developed land constitutes only about 5 percent of the total land area on the Vermont side of the Lake Champlain watershed. The study areas for this analysis focused on the Chittenden County area, which contains a large portion of the developed land.

GIS Analysis

Using the four developed land use categories described above along with the aerial images obtained from USDA, estimates of turf were derived through a GIS analysis. The general steps in the analysis are detailed below:

1. The developed land use raster was converted into polygons to represent each of the four categories:
    - Residential – low density
    - Residential – medium density
    - Residential – high density
    - Commercial/Industrial.

2. The polygons were numbered, and a random number generator was used to select 15–20 polygons from each land use category.

3. Within each polygon in each land use category, all areas of turf were digitized based on the aerial photos (airports ignored). Forest area was not considered turf.

4. For each polygon, the areas of turf digitized were summed.

5. The percentage of each polygon that is covered by turf was calculated by dividing the sum of turf in the polygon by the total area of the polygon.

6. The turf values for each polygon were compiled, and the mean, standard deviation and standard error were calculated for each developed land use category.

Results from this analysis are presented in Table A-2; these results apply to total urban developed land, both impervious and pervious. However, because the Scenario Tool will use the pervious area of the watershed for calculations, the results were translated to reflect pervious area only (Table A-3).

Table A-2. Turf Cover Estimates from GIS Analysis

Land Use	95 CI	Mean Turf	95 CI
Low Density Residential	23	**29**	35
Medium Density Residential	16	**22**	29
High Density Residential	5	**12**	18
Commercial/Industrial	1	**5**	8

Table A-3. Turf Cover Estimates for Developed Area in the Lake Champlain Basin

Land Use	Mean Turf (of total developed area)	Mean Turf (of pervious portion of developed area)
Low Density Residential	29	32
Medium Density Residential	22	51
High Density Residential	12	28
Commercial/Industrial	5	28

Turf Fertilizer Application

An important component of urban fertilizer management is understanding what percent of turf is fertilized in a given year. The Lake Champlain Committee has conducted two surveys to assess citizen awareness of stormwater pollution in Chittenden County. Questions in the survey addressed lawn care and management, with results providing an estimate of the percentage of turf fertilized for the Lake Champlain watershed. Relevant results related to fertilizer use from the two surveys are presented in Table 4. The average of the two survey results, 37, was used to estimate the percentage of turf fertilized in the basin. Notably, according to the results of these surveys, Chittenden County residents were less likely to use lawn fertilizer than respondents in three surveys used for comparison from Wathcom County, Washington; San Mateo County, California; and the Chesapeake Bay Program (The Lake Champlain Committee, 2004). According to surveys conducted by Swann (1999), 50 percent of homeowners in the Chesapeake Bay watershed report that they fertilize their yard, with an average of two applications per year (CSN 2011).

Table A-4. Lake Champlain Committee Survey Results on Lawn Care Management

Question 8: Did you or anyone in your household use any other fertilizers in your yard?		
Response	**2003**	**2007**
Yes	40.40	33.40
No	58.00	64.30
Don't Know	1.60	2.30
Total	*100.0 (245)*	*100.0 (311)*
Note: Chi^2 test indicates **no** significant difference between 2003 and 2007 (significance value = .225).		

Nutrient Concentrations from Fertilized Turf

Source assessment work conducted as part of the Chesapeake Bay Program indicated that runoff from fertilized turf had higher concentrations than that from non-fertilized turf and recommended that turf cover be split into these two categories when modeling local nutrient loads (CSN 2011). Table 5 presents the estimates of nutrient concentrations from lawn areas that are residential (fertilizer status unknown), fertilized, and non-fertilized. EPA's analysis of stormwater quality data, considered representative of the New England region, indicates that the magnitude of pervious runoff total phosphorus concentrations from residential areas is around 0.3 mg/L (USEPA, 2014), consistent with the work from the Chesapeake Bay.

For the Lake Champlain urban fertilizer calculations, EPA recommends using the fertilized and non-fertilized concentrations from Table A-5.

Table A-5. Reported Nutrient Concentrations for Runoff from Pervious Residential Areas

	Total Phosphorous (mg/L)	Total Nitrogen (mg/L)
Residential (overall)	0.3	2
Fertilized	0.4	2.5
Non-fertilized	0.2	1.5

Estimated Runoff Potential

The SWAT watershed model, set up and calibrated for the Lake Champlain Basin by Tetra Tech, was used to estimate runoff from each developed pervious land use by soil category. Each soil category has varying runoff potential; for that reason, a weighted average runoff (in million gallons per hectare per year) was calculated for each land use category and used in phosphorus load calculations (Table A-6).

Table A-6. Model Results for Runoff Potential

Landuse	HSG Soil Category	Runoff (MG/ha/yr)	Area (ha)
Low Density Residential	**A**	0.011	7,284
Low Density Residential	**B**	0.385	2,291
Low Density Residential	**C**	0.746	12,193
Low Density Residential	**D**	0.852	7,921
Weighted Average Runoff/Total Area		***0.57***	***29,689***

Landuse	HSG Soil Category	Runoff (MG/ha/yr)	Area (ha)
Medium Density Residential	**A**	0.013	2,753
Medium Density Residential	**B**	0.364	1,462
Medium Density Residential	**C**	0.64	2,226
Medium Density Residential	**D**	0.778	1,433
Weighted Average Runoff/Total Area		***0.39***	***7,874***
High Density Residential	**A**	0.02	1,951
High Density Residential	**B**	0.303	443
High Density Residential	**C**	0.615	964
High Density Residential	**D**	0.741	961
Weighted Average Runoff/Total Area		***0.34***	***4,319***
Commercial/Industrial	**A**	0.027	156
Commercial/Industrial	**B**	0.266	58
Commercial/Industrial	**C**	0.593	68
Commercial/Industrial	**D**	0.761	69j
Weighted Average Runoff/Total Area		***0.32***	***351***

Fertilizer Calculations in Scenario Tool

As described in the Scenario Tool guidance, users may specify application of BMPs at the HUC8 level as well as for certain smaller watersheds. In this case, given that the P fertilizer ban applies basinwide, users will likely apply this practice to all watersheds to estimate the resulting phosphorus load reduction. Data for the calculations will come from both the SWAT model and default values determined through the analysis explained above.

After the user selects the watersheds, the tool will be populated by information from the SWAT model; these parameters are indicated in Table 8 with "SWAT Model" in the source column. The user then has the opportunity to refine the phosphorus load reduction estimates by adjusting three key parameters used in the fertilizer management calculation:

- Percent turf
- Percent turf fertilized
- Compliance rate with phosphorus fertilizer ban

Default values for these parameters are provided in the Scenario Tool based on the analysis conducted above; if more accurate data are available, it is recommended that the user use that information. A summary of assumptions is provided in Table A-7. An example calculation is provided in Table A-8 for a watershed of 8,000 hectares of low density residential area to demonstrate how the tool will calculate the phosphorus load reductions.

Table A-7. Summary of Assumptions in Phosphorus Load Reduction Calculations

Parameter	Default Value	Units
Fertilized area total phosphorus concentration	0.4	mg/L
Non-fertilized area total phosphorus concentration	0.2	mg/L

Table A-8. Default Parameters for Phosphorous Load Reduction Calculations

Parameter	Default Value	Units
Percent turf for residential low density (RLD)	32	%
Percent turf for residential medium density (RMD)	51	%
Percent turf for residential high density (RHD)	28	%
Percent turf for commercial/ industrial	28	%
Percent fertilized turf	37	%
Compliance rate	100	%

Table A-9. Example Phosphorus Load Reduction Calculation

Parameter	Example	Units	Source
Land Use	RLD		SWAT Model
Total Pervious Developed Area	8,000	ha	SWAT Model
Percent Turf	32		Default/User Defined
Total Turf Area	2,560	ha	Calculated by tool
Percent Fertilized Turf	37		Default/User Defined
Fertilized Turf Area	947	ha	Calculated by tool
Phosphorus Yield: Fertilized	0.86	kg/ha/yr	*Use SWAT weighted runoff x 0.4 mg/L
Phosphorus Load: Fertilized Turf Area	814	kg/yr	Calculated by tool
Phosphorus Yield: Not Fertilized	0.43	kg/ha/yr	*Use SWAT weighted runoff x 0.2 mg/L
Phosphorus Load: Not Fertilized Turf Area	694	kg/yr	Calculated by tool
Phosphorus Load: Total Turf Area	1,508	kg/yr	Calculated by tool
Compliance Rate	100	%	Default/User Defined
Phosphorus Load: Total Turf Area Not Fertilized	1,101	kg/yr	Calculated by tool
Phosphorus Load: Net Reduction	**407**	**kg/yr**	**Calculated by tool**

References:

CSN (Chesapeake Stormwater Network). 2011. *Nutrient Accounting Methods to Document Local Stormwater Load Reductions in the Chesapeake Bay Watershed, Version 1.0.* Review draft. Technical Bulletin No. 9. August 2011.

The Lake Champlain Committee. 2004. *Final 319 Grant Project Report to VTDEC: A Survey of Citizen Awareness of Stormwater Pollution Issues in Chittenden County*. April.

USEPA (U.S Environmental Protection Agency). 2014b. Calculation of Phosphorus Reduction Credit for Lawn Areas Using Phosphorus-Free Fertilizers. Memorandum to the Permit File for Draft Small Massachusetts MS4 General Permit. USEPA, Region I, Boston MA. August 25.

Appendix B: Impervious Area Disconnection Credits for Scenario Tool

The credits were derived from Cumulative Performance Curves for Three Non-Structural BMPs, prepared by Tetra Tech, Inc., and summarized in a memorandum dated December 31, 2012.

Summary: The phosphorus reduction credits would be applicable to three developed land use categories: medium density residential (MDR), high density residential (HDR) and commercial/industrial(C/I). Credits will be calculated using impervious areas for two soil conditions: (1) hydrologic soil group (HSG) A and (2) HSG B.

Scenario Tool

Impervious Area Disconnection				
Parameter	**Example**		**Units**	**Source**
Land Use	LU	MDR		Scenario Tool
Total Impervious Area for Disconnection by Land Use and HSG	$TIAD_{MDR-A}$	1	ha	Derived from SWAT model
Impervious Area (IA) to Pervious Area (PA) for selecting Performance	$IA:PA_{MDR}$	4		Default/user-defined
Percent Phosphorus Load Reduction	$PPLR_{MDR-A}$	48		Default/user-defined
Average Annual Impervious Area Phosphorus Loading Rate	$IAPLR_{MDR}$	1.5	kg/ha/yr	Derived from SWAT model
Total Load from Impervious Area Disconnected	$PLIAD_{MDR-A}$	1.5	kg/yr	Calculated (TIAD x IAPLR)
Net Reduction	NR_{MDR-A}	0.72	kg/yr	Calculated (PLRAT x PPLR)
Unit Cost for IA Disconnection	$UCIAD_{MDR}$	10,000	$/ha	Default/user-Defined

Total Cost for IA Disconnection	$TCIAD_{MDR-A}$	10,000	$	Calculated (UCIAD x TIAD)
Unit Phosphorus Cost	UPC_{MDR-A}	13,889	$/kg-P	Calculated (TCRS/PLRAT)

Default Input Parameters for Scenario Tool for Hydrologic Soil Group A		**Land Use Category**		
Parameter	**Parameter**	**MDR**	**HDR**	**I&C**
Impervious Area (IA) to Pervious Area (PA) for selecting Performance	$IA:PA_{LU}$	4	8	8
Percent Phosphorus Load Reduction	$PPLR_{LU}$	48	30	30
Unit Cost IA Disconnection	$UCRD_{LU}$	$10,000/ha	$10,000/ha	$10,000/ha

Default Input Parameters for Scenario Tool for Hydrologic Soil Groups B		**Land Use Category**		
Parameter	**Parameter**	**MDR**	**HDR**	**I&C**
Impervious Area (IA) to Pervious Area (PA) for Selecting Performance	$IA:PA_{LU}$	4	8	8
Percent Phosphorus Load Reduction	$PPLR_{LU}$	27	14	14
Unit Cost IA Disconnection	$UCRD_{LU}$	$10,000/ha	$10,000/ha	$10,000/ha

References:

Tetra Tech. 2012. Cumulative Performance Curves for Three Non-Structural BMPs. Draft. Memorandum to M. Voorhees, EPA Region 1, from Tetra Tech, Inc. December 31.

Appendix C: Impervious Area Removal Credits for Scenario Tool

The credits were derived from Cumulative Performance Curves for Three Non-Structural BMPs prepared by Tetra Tech, Inc., and summarized in a memorandum dated December 31, 2012.

Summary: The phosphorus reduction credits would be applicable to three developed land use categories: medium density residential (MDR), high density residential (HDR) and commercial/industrial (C/I). One P load reduction credit is proposed for impervious area on HSGs A, B, C and D; it would require restoration of the hydrological function of the restored permeable surface.

Scenario Tool

Impervious Area Removal				
Parameter	**Example**		**Units**	**Source**
Land Use	LU	MDR		Scenario Tool
Total Impervious Area for Removal by Land Use and HSG	$TIAR_{MDR-A}$	1	ha	Derived from SWAT model
Percent Phosphorus Load Reduction	$PPLR_{MDR-A}$	89		Default/user-defined
Average Annual Impervious Area Phosphorus Loading Rate	$IAPLR_{MDR}$	1.5	kg/ha/yr	Derived from SWAT model
Total Load from Impervious Area Removed	$PLIAR_{MDR-A}$	1.5	kg/yr	Calculated (TIAR x IAPLR)
Net Reduction	NR_{MDR-A}	1.34	kg/yr	Calculated (PLIAR x PPLR)
Unit Cost for IA Removal	$UCIAR_{MDR}$	20,000	$/ha	Default/user-defined
Total Cost for IA Removal	$TCIAR_{MDR-A}$	20,000	$	Calculated (UCIAR x TIAR)
Unit Phosphorus Cost	UPC_{MDR-A}	14,925	$/kg-P	Calculated (TCIAR/NR)

Default Input Parameters for Scenario Tool for Hydrologic Soil Group A, B, C and D		**Land Use Category**		
Parameter	**Parameter**	**MDR**	**HDR**	**I&C**
Percent Phosphorus Load Reduction	$PPLR_{LU}$	89	89	89
Unit Cost IA Removal	$UCRD_{LU}$	$20,000/ha	$20,000/ha	$20,000/ha

References:

Tetra Tech. 2012. Cumulative Performance Curves for Three Non-Structural BMPs. Draft. Memorandum to M. Voorhees, EPA Region 1, from Tetra Tech, Inc. December 31.

Appendix D: Agricultural BMP Efficiencies

Table D-1. SWAT-Calculated Agricultural BMP Efficiencies

LAND USE	SLOPE	SOIL	CC	CR	CT	PMan	GWW	RB	PMan-RB	PMan-GWW	GWW-RB	CR-CT	CR-MI-PMan	CR-MI-PMan-RB	CR-MI-PMan-GWW	CC-GWW	CC-CR	CC-CR-PMan	CC-CT-MI	CC-CT-MI-RB	CC-CT-MI-GWW	CC-CT-MI-GWW-RB	Crop-to-Hay
CHCL	**0-5**	**D**	0.30	0.26	0.50	0.04	0.30	0.41	0.43	0.33	0.59	0.63	0.28	0.58	0.50	0.51	0.48	0.50	0.65	0.79	0.76	0.86	0.70
CHCL	**5-10**	**D**	0.30	0.28	0.50	0.03	0.25	0.41	0.43	0.27	0.56	0.64	0.30	0.59	0.48	0.48	0.50	0.51	0.65	0.79	0.74	0.85	0.80
CHCL	**≥10**	**D**	0.25	0.28	0.50	0.03	0.20	0.41	0.43	0.23	0.53	0.64	0.30	0.59	0.44	0.40	0.46	0.48	0.63	0.78	0.70	0.82	0.80
CHNC	**0-5**	**A**	0.30	0.26	0.10	0.05	0.50	0.41	0.44	0.53	0.71	0.33	0.29	0.58	0.64	0.65	0.48	0.51	0.37	0.63	0.69	0.81	N/A
CHNC	**5-10**	**A**	0.30	0.28	0.15	0.04	0.40	0.41	0.44	0.43	0.65	0.38	0.30	0.59	0.58	0.58	0.49	0.52	0.41	0.65	0.64	0.79	0.80
CHNC	**≥10**	**A**	0.25	0.27	0.20	0.04	0.30	0.41	0.44	0.33	0.59	0.41	0.29	0.58	0.51	0.48	0.45	0.47	0.40	0.65	0.58	0.75	0.80
CHNC	**0-5**	**B**	0.30	0.23	0.15	0.03	0.50	0.41	0.43	0.52	0.71	0.35	0.25	0.56	0.63	0.65	0.46	0.48	0.41	0.65	0.70	0.82	N/AN/A
CHNC	**5-10**	**B**	0.30	0.26	0.20	0.03	0.40	0.41	0.43	0.42	0.65	0.41	0.28	0.58	0.57	0.58	0.48	0.50	0.44	0.67	0.66	0.80	0.80
CHNC	**≥10**	**B**	0.25	0.25	0.25	0.03	0.30	0.41	0.43	0.32	0.59	0.44	0.28	0.57	0.49	0.48	0.44	0.46	0.44	0.67	0.61	0.77	0.80
CHNC	**0-5**	**C**	0.30	0.19	0.20	0.03	0.35	0.41	0.43	0.37	0.62	0.36	0.22	0.54	0.49	0.55	0.44	0.46	0.44	0.67	0.64	0.79	N/AN/A
CHNC	**5-10**	**C**	0.30	0.26	0.25	0.03	0.30	0.41	0.43	0.32	0.59	0.44	0.28	0.57	0.49	0.51	0.48	0.50	0.48	0.69	0.63	0.78	0.80
CHNC	**≥10**	**C**	0.25	0.25	0.30	0.03	0.25	0.41	0.43	0.27	0.56	0.47	0.27	0.57	0.45	0.44	0.44	0.45	0.48	0.69	0.61	0.77	0.80
CRCL	**0-5**	**D**	0.30	0.25	0.50	0.06	0.30	0.41	N/A	0.34	0.59	0.63	N/A	N/A	N/A	N/A	0.48	N/A	0.65	0.79	0.76	0.86	0.70
CRCL	**5-10**	**D**	0.30	0.25	0.50	0.05	0.25	0.41	N/A	0.29	0.56	0.63	N/A	N/A	N/A	N/A	0.48	N/A	0.65	0.79	0.74	0.85	0.80
CRCL	**≥10**	**D**	0.25	0.25	0.50	0.04	0.20	0.41	N/A	0.23	0.53	0.63	N/A	N/A	N/A	N/A	0.44	N/A	0.63	0.78	0.70	0.82	0.80
CRNC	**0-5**	**A**	0.30	0.25	0.10	0.18	0.50	0.41	N/A	0.59	0.71	0.33	N/A	N/A	N/A	N/A	0.48	N/A	0.37	0.63	0.69	0.81	N/A
CRNC	**5-10**	**A**	0.30	0.25	0.15	0.12	0.40	0.41	N/A	0.47	0.65	0.36	N/A	N/A	N/A	N/A	0.48	N/A	0.41	0.65	0.64	0.79	0.80
CRNC	**≥10**	**A**	0.25	0.25	0.20	0.11	0.30	0.41	N/A	0.37	0.59	0.40	N/A	N/A	N/A	N/A	0.44	N/A	0.40	0.65	0.58	0.75	0.80
CRNC	**0-5**	**B**	0.30	0.25	0.15	0.09	0.50	0.41	N/A	0.55	0.71	0.36	N/A	N/A	N/A	N/A	0.48	N/A	0.41	0.65	0.70	0.82	N/A
CRNC	**5-10**	**B**	0.30	0.25	0.20	0.08	0.40	0.41	N/A	0.45	0.65	0.40	N/A	N/A	N/A	N/A	0.48	N/A	0.44	0.67	0.66	0.80	0.80
CRNC	**≥10**	**B**	0.25	0.25	0.25	0.09	0.30	0.41	N/A	0.37	0.59	0.44	N/A	N/A	N/A	N/A	0.44	N/A	0.44	0.67	0.61	0.77	0.80

LAND USE	SLOPE	SOIL	CC	CR	CT	PMan	GWW	RB	PMan-RB	PMan-GWW	GWW-RB	CR-CT	CR-MI-PMan	CR-MI-PMan-RB	CR-MI-PMan-GWW	CC-GWW	CC-CR	CC-CR-PMan	CC-CT-MI	CC-CT-MI-RB	CC-CT-MI-GWW	CC-CT-MI-GWW-RB	Crop-to-Hay
CRNC	**0-5**	**C**	0.30	0.25	0.20	0.09	0.35	0.41	N/A	0.41	0.62	0.40	N/A	N/A	N/A	N/A	0.48	N/A	0.44	0.67	0.64	0.79	N/A
CRNC	**5-10**	**C**	0.30	0.25	0.25	0.08	0.30	0.41	N/A	0.36	0.59	0.44	N/A	N/A	N/A	N/A	0.48	N/A	0.48	0.69	0.63	0.78	0.80
CRNC	**≥10**	**C**	0.25	0.25	0.30	0.09	0.25	0.41	N/A	0.32	0.56	0.48	N/A	N/A	N/A	N/A	0.44	N/A	0.48	0.69	0.61	0.77	0.80
HAY	**5-10**	**A**	N/A	N/A	N/A	0.01	0.38	0.41	N/A	0.39	0.64	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
HAY	**≥10**	**A**	N/A	N/A	N/A	0.00	0.54	0.41	N/A	0.55	0.73	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
HAY	**0-5**	**B**	N/A	N/A	N/A	0.03	0.48	0.41	N/A	0.50	0.69	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
HAY	**5-10**	**B**	N/A	N/A	N/A	0.03	0.56	0.41	N/A	0.57	0.74	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
HAY	**≥10**	**B**	N/A	N/A	N/A	0.03	0.68	0.41	N/A	0.69	0.81	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
HAY	**0-5**	**C**	N/A	N/A	N/A	0.02	0.47	0.41	N/A	0.48	0.69	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
HAY	**5-10**	**C**	N/A	N/A	N/A	0.02	0.54	0.41	N/A	0.55	0.73	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
HAY	**≥10**	**C**	N/A	N/A	N/A	0.02	0.64	0.41	N/A	0.65	0.79	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
HAY	**0-5**	**D**	N/A	N/A	N/A	0.02	0.38	0.41	N/A	0.39	0.63	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
HAY	**5-10**	**D**	N/A	N/A	N/A	0.01	0.40	0.41	N/A	0.41	0.65	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
HAY	**≥10**	**D**	N/A	N/A	N/A	0.01	0.48	0.41	N/A	0.49	0.69	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A

Table D-1. CONTINUED

LAND USE	SLOPE	SOIL	DB	CR-GWW-DB-RB	CC-CT-GWW-DB-RB
CHCL	**0-5**	**D**	0.51	0.85	0.93
CHCL	**5-10**	**D**	0.51	0.84	0.92
CHCL	**≥10**	**D**	0.51	0.83	0.91

LAND USE	SLOPE	SOIL	DB	CR-GWW-DB-RB	CC-CT-GWW-DB-RB
CHNC	**0-5**	**A**	0.51	N/A	0.91
CHNC	**5-10**	**A**	0.51	N/A	0.90
CHNC	**≥10**	**A**	0.51	N/A	0.88
CHNC	**0-5**	**B**	0.51	N/A	0.91
CHNC	**5-10**	**B**	0.51	N/A	0.90
CHNC	**≥10**	**B**	0.51	N/A	0.89
CHNC	**0-5**	**C**	0.51	N/A	0.89
CHNC	**5-10**	**C**	0.51	N/A	0.89
CHNC	**≥10**	**C**	0.51	N/A	0.89
CRCL	**0-5**	**D**	0.51	0.85	0.93
CRCL	**5-10**	**D**	0.51	0.84	0.92
CRCL	**≥10**	**D**	0.51	0.83	0.91
CRNC	**0-5**	**A**	0.51	N/A	0.91
CRNC	**5-10**	**A**	0.51	N/A	0.90
CRNC	**≥10**	**A**	0.51	N/A	0.88
CRNC	**0-5**	**B**	0.51	N/A	0.91
CRNC	**5-10**	**B**	0.51	N/A	0.90
CRNC	**≥10**	**B**	0.51	N/A	0.89
CRNC	**0-5**	**C**	0.51	N/A	0.89
CRNC	**5-10**	**C**	0.51	N/A	0.89
CRNC	**≥10**	**C**	0.51	N/A	0.89
HAY	**5-10**	**A**	0.51	N/A	N/A
HAY	**≥10**	**A**	0.51	N/A	N/A
HAY	**0-5**	**B**	0.51	N/A	N/A

LAND USE	SLOPE	SOIL	DB	CR-GWW-DB-RB	CC-CT-GWW-DB-RB
HAY	**5-10**	**B**	0.51	N/A	N/A
HAY	**≥10**	**B**	0.51	N/A	N/A
HAY	**0-5**	**C**	0.51	N/A	N/A
HAY	**5-10**	**C**	0.51	N/A	N/A
HAY	**≥10**	**C**	0.51	N/A	N/A
HAY	**0-5**	**D**	0.51	N/A	N/A
HAY	**5-10**	**D**	0.51	N/A	N/A
HAY	**≥10**	**D**	0.51	N/A	N/A

Table D-1. continued

LAND USE	SLOPE	SOIL	Fencing	Fencing+RB
PASTURE	all	all	0.55	0.735